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An intelligent electrocardiogram tutoring package EKGCHALLENGER

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Abstract

Title of thesis : *An Intelligent Electrocardiogram Tutoring Package - EKGCHALLENGER*

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Master of Science in Electrical Engineering, 1989

Thesis Advisor : *Dr. Stanley Reisman, Professor and Associate Chairman, Electrical Engineering Department*

This thesis presents the development and implementation of an intelligent electrocardiogram tutoring package, namely, EKGCHALLENGER which is meant for use in medical schools to teach medical students a method of diagnosing electrocardiograms.

EKGCHALLENGER is an IBM - PC based, user friendly package. It works in two basic modes. The first is a *tutorial* mode wherein the user is taught the step-by-step diagnosis of electrocardiograms (EKGs) which are presented in order of increasing difficulty. The second is the *challenger* mode wherein the user is asked to diagnose EKGs which are randomly chosen from an EKG database. The diagnosis of the user is compared with that of an expert system, (which is a section of this package) so that a score can be awarded to the user as a measure of his competence in diagnosing cardiac arrhythmias.

The expert system is written in Prolog. It is a rule-based system and has, at present, the capability of diagnosing 43 kinds of cardiac arrhythmias using a *depth-first* mode of search. The 43 arrhythmias detected by the system include the cardiac arrhythmias encountered under emergency conditions.

This expert system can also be used as a stand-alone unit either as a learning tool which a student can use to practice diagnosing EKGs, or as a preliminary diagnostic tool by non-trained individuals who are assisting patients entering the emergency medical system.

An Intelligent Electrocardiogram Tutoring Package EKGCHALLENGER

By

Santosh K. Ananthraman

Thesis Submitted to the Faculty of the Graduate School of the New Jersey Institute of Technology in partial fulfillment of the requirements for the degree of Master of Science in Electrical Engineering

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Approval Sheet

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An Intelligent Electrocardiogram Tutoring Package - EKGCHALLENGER

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1. "*The EKG CHALLENGER Revisited*", IEEE Engineering in Medicine and Biology Society, Co-authored with S.S. Reisman & K.J. Friedman, Spring 1989.*(pending)*

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Tac ca samsmrutya - samsmrutya,

rupam atyadbhutam Hareh,

vismayo me mahan rajan,

hrsyama ca punah - punah.

— Again and again does that most wondrous form of The Lord arise in my mind, generating great astonishment and endless joy.

The above is an invocation in praise of The Lord who provided me with the strength and the will power to make this endeavor a successful one.

I am deeply indebted to my advisor, Dr. Stanley Reisman for all the inspiration and tireless help. He was very patient with me and was always there in the time of need to help me out of my predicaments.

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Last, but not the least, thanks are due to my roomies – 'Doc' Prasad, Suddu and Surya who were behind me with constant encouragement and ocassional ideas.

The use of words like 'man', 'he', 'him' and 'his' are used in the general sense of the word denoting mankind in general and do not refer specifically to the male kind.

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1. Introduction

1.1 An Introduction to Artificial Intelligence

According to the most common definition, artificial intelligence, or AI as it is popularly known, is the art of making computers do smart things. Some of the more technical definitions are as follows :

As a branch of software engineering, AI is merely a collection of programming techniques that makes a computer do certain tricks : communicate with the user in a pseudo natural language, behave like a pseudo expert trouble shooting in highly specialized domains, and so on. From the programming point of view, the AI style of programming differs from the conventional style, in that, the programmer, instead of telling the computer what to do in every conceivable situation, tells it only what it needs to 'know'- i.e certain facts , skills and rules of the thumb that the system can apply to the changing situations that it encounters as it goes along. The point here is that the machine can now perform flexibly and sensibly instead of rigidly and mechanically [1].

According to Roger Schank, (one of the gurus of AI) AI is a part of the grand attempt to understand thinking [1].

Artificial Intelligence is the study of mental facilities through the use of computational models [2].

Artificial Intelligence is the study of how to make computers do things at which, at the moment, people do better [3].

From the philosophical point of view, AI is the study of knowledge;

what knowledge is and how it can be represented usefully, in a computer [1].

Every theory, in the scientific world, has to have a real world application in order to be considered useful. This holds for artificial intelligence too. Given below, are some of the areas in which the theoretical knowledge of AI is being applied in current day research.

1.1.1) *Computer Aided Instruction* : Intelligent computer aided instruction (CAI) programs which diagnose each student's level of understanding and thus, adjust themselves to react to each student individually according to his ability, have been created and marketed successfully [2].

1.1.2) *Expert Systems* : This is one of the most popular and acclaimed areas of AI, as far as applications are concerned. An expert system can solve problems that are typically domain specific and highly specialized, which ordinarily would require the attention of a human who happens to be an expert in that field [4]. Areas of application range from medicine to geology to configuring VAX computer systems.

1.1.3) *Natural Language Processing* : This is a highly venturesome area, which aims to get the computer to understand and communicate in the natural language (like English) of its users. Although there are programs that can understand stories and draw conclusions out of them, the trouble lies in getting the computer to be able to recognize the contextual use of words. For example, it must be able to distinguish between the contextual use of the word 'dined' in [3] :

1. I dined with a friend.
2. I dined with a fork.

1.1.4) *Computer Vision* : This again is a fledgeling area with a lot of potential. A good example of its success and prospects is a vehicle built at Carnegie Mellon University that propels itself by using a self-correcting visual guidance and navigation system [1].

1.1.5) *Robotics* : This is a well known 'sister area' of AI which has gained publicity from both fictional (science fiction) and non fictional (industrial) applications. Current real world applications include Flexible Manufacturing Systems in automotive industries and also in hazardous areas like nuclear power plants [1].

One underlying principle is what is known as the 'Superhuman Human Fallacy' [8]. This is best explained with the help of an example. Let us assume that there are two people A and B talking to each other. A says to B, "You say that your computer is intelligent; can it compose the sonatas of Beethoven or write works similar to the works of Shakespeare ?". To this, B calmly retorts, "Can you ?".

The basic thing to be understood here is that, contrary to the popular misconception, AI aims at making the computer resemble an ordinary human being like any of us and not a superhuman.

1.2 Why an AI Language Was Chosen for This Application

This thesis describes the construction and implementation of an intelligent electrocardiogram tutorial package called the EKGCHALLENGER. The backbone of such a package is a system that verifies the student's diagnosis of

electrocardiograms. Thus, AI techniques were employed and an expert system was created for this purpose. This section justifies the choice of an AI language over that of a conventional language for the creation of the expert system.

Almost all of the conventional languages like BASIC, PASCAL, FORTRAN and C are termed, 'procedural' languages. These languages are very far from the natural languages that we use in day-to-day life. It has been proven without doubt that the human mind definitely does not think (under natural circumstances) like a procedure in Pascal; it can never be as systematic as that. Were this the case, we would not have to make a special effort to write programs but could key them in directly.

In contrast, AI programming languages are a lot closer to natural languages and the way we think. Such languages are called declarative languages. Some of the commonly used AI languages are LISP (List Processing), Prolog (Programming in Logic), and Smalltalk. Thus in a language like Prolog, you can declare, or describe to the computer, the logical relationships (in the form of facts and rules) which define the problem and leave the rest to Prolog; to extract the result by a process of 'unification' [5] and 'backward chaining' [5].

One other major advantage is the compactness of code that is achieved by using a declarative language like Prolog. A few pages of code written in a procedural language like Pascal can often be reduced to a few lines of Prolog code. This can be best understood with an example.

An Example [4] :

Consider the task of searching through a maze which is as defined in the

Consider the task of searching through a maze which is as defined in the figure given below :

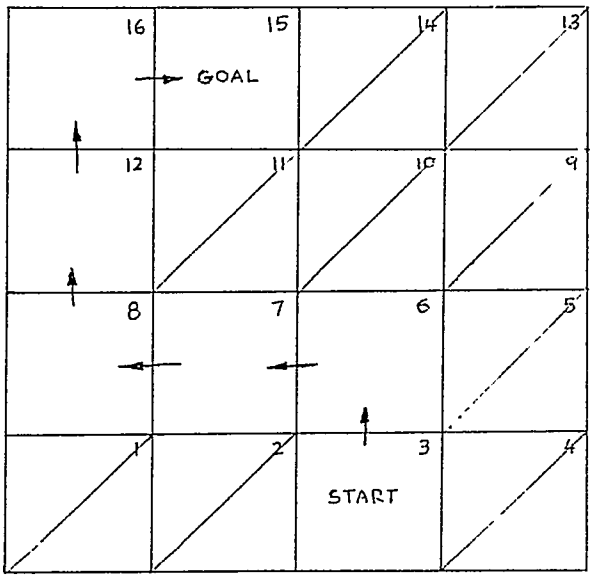


FIG. (1) : A MAZE

In the maze, each location, which represents a possible move , has a unique number in the upper right corner. The locations which are valid moves are shown as empty boxes and the invalid ones with boxes that are crossed out. Assuming that our starting point is location 3 and our goal is location 15, we can see that there exists the following path from the starting point to the goal :

$$3 \rightarrow 6 \rightarrow 7 \rightarrow 8 \rightarrow 12 \rightarrow 16 \rightarrow 15$$

To write a solution to the maze in a procedural language like Pascal, we would have to write instructions for all the necessary steps. For example, we must write instructions to determine if a move is valid or invalid and also

```
**********************************************************************
program maze (input, output);
    type
    path-array = array[1..6, 1..2] of integer;
    const
    max-path = 6;
    path : path-array = ((3,6),(6,7),(7,8),(8,12),(12,16),(16,15));
    var
    goal, start : integer;
procedure search (start, goal : integer);
[This procedure searches through the maze. ]
    var
    found : boolean;
    i : integer;
    begin
    found := false;
    i := 0;
    repeat
    i := i + 1;
    if start = path[i,1] then begin
    found := true;
    writeln('Move from ', path[i,1], 'to', path[i,2]);
    end;
    until (found) or (i = max-path);
    if found then begin
    if path[i,2] neq goal then
    search(path[i,2],goal) else
    writeln('Solution found. ');
    end
```

```
    else writeln('No solution for the maze.');
    end;
    begin
[main program]
    writeln('Please input start of maze ');
    read(start);
    writeln('Please input the end of maze ');
    read(goal);
    search(start,goal);
    end.
```

****

In this procedural approach one must define both the data structures and the algorithm needed to solve the problem. With our problem, it is necessary to define a data structure to store the important information concerning the paths that are available for travel. A discussion of the program follows :

'Path-array' is a 6 X 2 array of integers that specifies the valid moves within the maze. For example, (3,6) would indicate that a valid move could be made within the maze from location 3 to location 6. A constant 'max-path' also has to be specified in the beginning of the program to indicate the exact number of valid moves within the maze. The procedure 'search' searches through the maze using recursion. The user is asked to input the starting location and the ending location (i.e, the goal). These parameters are passed on to the procedure 'search' that looks for the solution by checking each element of the path array and updating its current path. Finally, an appropriate message is printed out, i.e solution found/not found.

At this point, the disadvantages of this implementation become clear. If

one were to increase the dimensions of the maze, one would also have to change the data structure by changing 'max-path' and the 'path-array'. Even the procedure 'search' would have to be modified to incorporate the change in the data structure.

At this point, let us look at an equivalent Prolog program :

```
************************************************************
predicates
    find-goal(integer,integer)
    path(integer)
    clauses
    find-goal(Start,End) :-
    path(Start,End), write("Goal is",End),nl.
    find-goal(Start,End) :-
    path(Start,G), !,
    write("Move from",Start,"To",G), nl,
    find-goal(G,End).
[Fact Database ]
    path(3,6).
    path(6,7).
    path(7,8).
    path(8,12).
    path(12,16).
    path(16,15).
************************************************************
```

Notice the obvious shortening of code size because of the use of Prolog. A brief discussion of the program follows :

First, the known facts are defined in the Fact Database. In this case, they

are clauses of the form 'path(12,16)' which means that there is a valid path from location 12 to location 16. The main body of the program is in the form of 'if-then' rules. An example of an 'if-then' rule follows :

```
grandpa(X,Z) :-
        male(X),
        parent(X,Y),
        parent(Y,Z).
```

The above stated rule has the form :

(conclusion) if [(A) and (B) and (C)] are satisfied.

That is, X is the grandfather of Z if X is a male, X is the parent of a Y and this Y is the parent of Z.

The rule that does the actual searching is 'find-goal(Start, End)'. The user, in order to run this program has to key in the following goal :

```
find-goal(3,15)
```

This prompts the program to do a recursive search and look for a path starting from location 3 to location 15. Thus in the clause 'find-goal(Start,End)', Start is equated to 3 and End to 15. If the program sees a solution in the set of facts immediately, it just picks it up and prints it out. If that is not the case, it goes through the set of facts till it finds a solution.

The most important feature to be noted is that the programmer did not have to define the algorithm to be used to search the maze. The second advantage is that on increasing the size of the maze, all that the programmer will have to do is to key into the database the new path validities. The main program can remain untouched and will work for a 4 X 4 maze or a 25 X 25 maze, which means that the flow of control in the program is independent of

the set of facts.

It is for these reasons that an AI language was chosen for our application.

1.3 Introduction to the Physiology of the Heart

1.3.1. *A General Description of the Heart*

The heart is a muscular organ located in the thoracic (chest) cavity and enclosed in a fibrous sac called the pericardium [6]. It is divided longitudinally into right and left halves, each consisting of two chambers, an atrium and a ventricle. The right and left atria and the right and left ventricles thus form distinct chambers. Between the cavities of the atrium and the ventricle in each half of the heart, are atrio-ventricular valves, which permit blood flow from the atrium to the ventricle but not vice versa. The right AV valve is called the tricuspid valve and the left one, the mitral valve. There are two other sets of valves that allow the heart to transfer blood into the arteries. These are the aortic valves and the pulmonary valves. The opening and closing of the valves is a passive process and is brought about by the difference in pressure across the valves. The human heart is shown in Fig (2).

The heart has a special excitatory system for generating rhythmic impulses to cause rhythmical contraction of the heart muscle and a conducting system to conduct these impulses throughout the heart [7]. A large share of the illnesses of the heart are contributed to by the abnormalities that arise in these excitatory and conducting systems. Fig (3) shows the excitatory and conducting system of the heart.

An adult human heart, normally contracts at a rhythmic rate of about 72 beats per minute. These cardiac contractions are strictly controlled by the excitatory and conducting systems. The sino-atrial (SA) node is where the normal, rhythmic, self-excitatory impulse is generated. At the atrio-ventricular (AV) node, the impulse from the atria is delayed before passing into the ventricles. The AV bundle (also called the 'Bundle of His') conducts the impulse from the atria to the ventricles. The Bundle of His divides into the left and right bundle branches. The Purkinge fibers conduct the cardiac impulse from the Bundle Branches to all parts of the ventricles. Shown in Fig. (4) is the time-delay from the origin of the impulse to the its distribution in the ventricles. The numbers on the figure are in seconds and represent the delay in the various stages of transmission of the impulse. Therefore, the SA node triggers these cardiac impulses at the rate of 70 - 80 times per minute which is why the SA node is called the 'pacemaker' of the heart.

1.3.2. *Depolarization and Repolarization*

All cells, under resting conditions, have an electrical potential difference across the cell membrane oriented so that the inside of the cell is negatively charged with respect to the outside. This is called the resting membrane potential of the cell and can vary from 5 mV to 100 mV in magnitude [6]. The transient changes in the membrane potential from its resting level constitute electric signals that alter cell activity. Depolarization and repolarization are terms that are used to describe the direction of changes in the membrane potential relative to the resting potential.

The membrane is said to be depolarized when the membrane potential becomes less negative, closer to zero or positive, with respect to the resting level. This, in fact, could cause polarity reversal making the inside of the cell positively charged with respect to the outside. Fig. (5) gives a graphical representation of these potentials. Thus, depolarization is said to have occured if the membrane potential is shifted upwards, along the Y axis, above the resting level. Repolarization is said to have occured when a depolarized cell is brought back to its original resting level.

1.3.3. *The Electrocardiogram*

As the cardiac impulse passes through the heart, electric currents spread into the tissues surrounding the heart, and a small proportion of these spread all the way to the surface of the body [7]. Thus, if electrodes are placed in suitable places on the body, the electric potentials generated by the heart can be recorded; this recording is called the electrocardiogram. A normal electrocardiogram (or EKG as it is commonly known) is shown in Fig. (6).

A normal EKG is composed of a 'P wave', a 'QRS complex' and a 'T wave'. A 'U wave' sometimes follows the T wave and is of the same polarity as the T. It normally goes unnoticed because of its low magnitude. Its mechanism is unknown, but it becomes taller in hypokalemia and inverted in heart disease [17]. A heartbeat is considered to be normal even in the absence of the U wave. The QRS complex is formed by the Q wave, the R wave and the S wave [7]. The P wave is produced by the currents that result when the atria depolarize prior to the contraction. The QRS complex is produced by the currents that are

generated when the ventricles depolarize, prior to the contraction. Thus, both the P wave and components of the QRS complex are depolarization waves. The T wave is caused by currents generated as the ventricles recover from the state of depolarization, and such a wave is called a repolarization wave.

1.3.4. *Voltage and Time Calibration of the EKG*

All recordings of electrocardiograms are made with appropriate calibration lines on standard recording paper. As shown in Fig. (7), the calibration lines are so arranged that ten small divisions in the vertical direction in the standard electrocardiogram represent 1 mV, with positivity in the upward direction and negativity in the downward direction [7].

The vertical lines on the electrocardiogram are time calibration lines. Each millimeter in the horizontal direction is 0.04 second and at every 5 mm, there is a darker vertical line; the intervals between these lines representing 0.20 second [7].

The voltages recorded on an electrocardiogram depend on the manner in which the electrodes are applied to the surface of the body. When an electrode is placed directly over the heart and a second one elsewhere on the body, the voltage of the QRS complex may be 3-4 mV. If this is measured as a monophasic action potential directly from the heart muscle, one might get a reading close to 120 mV. When electrocardiograms are recorded from electrodes on the two arms or one arm and one leg, the QRS complex is usually 1 mV from the top of the R wave to the bottom of the S wave, the voltage of the P wave is between 0.1 to 0.3 mV, and that of the T wave is between 0.2 to 0.3 mV.

The normal P-R interval is approximately 0.16 second and the Q-T interval 0.30 second.

The heartrate can be determined from these electrocardiograms since the time interval between two successive beats is the reciprocal of the heart rate. For example, if the interval between two successive QRS complexes is 0.83 second then, the heart rate is 60/0.83 beats per minute, or 72 beats per minute.

1.3.5. *Electrocardiographic Leads*

There are three standard limb lead arrangements from which electrocardiograms are recorded. Fig. (8) illustrates the actual connections between the 'standard' limb leads and the electrocardiograph.

Lead I : To record limb lead I, the negative terminal of the electrocardiograph is connected to the the right arm and the positive terminal to the left arm.

Lead II : In recording limb lead II, the negative terminal of the electrocardiograph is connected to the right arm and the positive terminal to the left leg.

Lead III : To record limb lead III, the negative terminal of the electrocardiograph is connected to the left arm and the positive terminal to the left leg [7].

The above three limb leads obey Einthoven's Law, the statement of which follows : If the electric potentials of any two of the three standard electrocardiographic leads are known at any given instant, then the third one can be determined mathematically by simply vector-summing the other two [7].

Fig. (9) shows the simultaneous recordings of the EKG in leads I, II and III. On analysis of the EKGs we can see that at any given instant, the sum of the potentials in leads I and III equals the potential in lead II thus comfirming the validity of Einthoven's Law.

In this thesis, EKGs are recorded using the lead II arrangement.

1.3.6. *A General Introduction to Cardiac Arrhythmias*

Of all the disorders that could occur in the heart, the abnormalities with regard to the rhythmicity of the heart are most prevalent. The conditions wherein the EKG strips display abnormalities with regard to the rhythmicity of the heart are clinically termed cardiac arrhythmias [7].

These abnormal cardiac rhythms are generally caused by the following conditions [7] :

1) Abnormal rhythmicity of the pacemaker itself.

2) The shift in location of the pacemaker from the sino-atrial node to other parts of the heart.

3) Blocks at different points in the transmission of the impulse through the heart.

4) Spontaneous generation of abnormal impulses in any part of the heart.

5) Physical abnormalities in the heart.

6) Effect of external agents like drugs.

The expert system in this thesis possesses the ability to identify 43 different kinds of cardiac arrhythmias. These are grouped under 7 major sub-categories a description of which follows :

1.3.6.1) **Sinus Rhythms**

i) *Normal Sinus Rhythm*

Under this condition, the heart is said to be normal. The P wave, the QRS complex and the T wave are all normal and the heart rate is between 60 and 100 beats per minute. The P-P and R-R intervals are regular too.

ii) *Bradycardia and Tachycardia*

The term bradycardia means a slow heart rate while tachycardia means a fast heart rate. The former is defined as slower than 60 beats per minute and the latter as faster than 100 beats per minute. Bradycardia can occur due to any circulatory reflex that stimulates the vagus nerve [7]. It can also be seen in an athlete's heart which is considerably stronger than that of a non-athlete's. Tachycardia generally occurs due to the following three reasons: increased body temperature, stimulation of the heart by the autonomic nervous system, and the toxic conditions of the heart [7].

iii) *Sinus Arrhythmia*

This condition occurs when the heart rate increases with inspiration and decreases with expiration. It is common and not considered to be pathological in children and must be treated only in older patients. On the EKG strip one can see cyclical variation in the P-P and R-R intervals.

iv) *Sinus Block*

When the sino-atrial node produces an impulse to depolarize the atria, but this impulse is blocked and thus prevented from leaving the sino-atrial node, a sinus block is said to have occured. This could result in one or multiple missed beats i.e, missed cardiac cycles. Here, the P-P and R-R intervals are irregular and the long P-P and R-R intervals are multiples of the short P-P and R-R intervals respectively. The fact that impulses are indeed produced but are blocked, is not obvious from the EKG but is a known fact from other experiments [17].

v) *Sinus Arrest*

This condition occurs due to the failure of impulse formation within the sino-atrial node. This results in an escape beat which is caused by the production of an impulse from a lower pacemaker region. Hence, because of the production of the escape beat, both P-P and R-R intervals are irregular but the long P-P and R-R intervals are not multiples of the short P-P and R-R intervals respectively. On a surface EKG, there is no foolproof way to distinguish complete sino-atrial block from sinus arrest [17].

1.3.6.2) **Atrial Abnormalities**

i) *Wandering Atrial Pacemaker*

This condition occurs when different sites within the atrial muscle initiate the heart beat, and thus the pacemaker is said to be wandering in nature and not constant. The major feature here is that the P waves, under this condition, are dissimilar, i.e, of varying shapes.

ii) *Premature Atrial Contraction*

This condition is initiated by an ectopic focus located anywhere within the atria. The ectopic focus is a freak, spontaneous impulse which causes an early heartbeat. Thus a P wave occurs before the next heartbeat is due to occur. This premature P wave is different from other P waves and is followed by a pause, with a later return to normal sinus rhythm.

iii) *Paroxysmal Atrial Tachycardia*

These are runs of premature atrial contractions which have a rapid rate usually between 150 to 250 beats per minute. This condition is also characterized by sudden onset and offset.

iv) *Atrial Flutter*

This condition shows a rapid, almost coordinated [7], rhythm caused by an ectopic, atrial focus. The P waves are produced at a rate of 250 to 350 beats per minute. These P waves look like sawtooths.

v) *Atrial Fibrillation*

This condition shows an even more rapid, uncoordinated [7] rhythm caused by multiple atrial ectopic foci. The waves are not discernible as P waves. The rate is between 250 to 350 beats per minute and the baseline is generally noisy.

1.3.6.3) Junctional Abnormalities

i) *Junctional Rhythm*

The tissue of the atrio-ventricular node and its surrounding area is called junctional tissue. If the rate of impulses entering this tissue from the atria falls below 60 beats per minute, then it may start to send out impulses at its own rate, generally between 40 and 60 beats per minute. This is termed junctional rhythm. The impulses generated here are conducted back to the atria. Because of this, the P wave is usually abnormal and could appear before or after the QRS complex.

ii) *Junctional Escape Beat*

If the impulse from the sino-atrial node fails to trigger a heart beat, then a pause in the normal heart rhythm occurs. To escape a long pause in rhythm, the atrio-ventricular junctional tissue may initiate an escape beat. If the sino-atrial node fails to resume pacemaker activity, the junctional tissue may continue to produce impulses and this condition is thus called junctional rhythm.

iii) *Premature Junctional Contraction*

This condition occurs due to the irritable nature of the junctional tissue. A junctional impulse occuring before the next expected sino-atrial node impulse is called a premature junctional contraction. Thus, the P wave associated with a premature junctional contraction may be hidden in the QRS complex. If the P wave happens to be visible, it is abnormal. The PR interval will be of short duration if the P wave occurs before the QRS complex.

iv) *Junctional Tachycardia*

This condition, again, is due to the irritability of the junctional tissue. A

junctional rhythm occuring at a rate greater than 100 beats per minute is junctional tachycardia. This is identical to junctional rhythm in every way except for the increased rate.

v) *Ist Degree Heart Block*

If an atrial impulse shows difficulty in being conducted through the atrio-ventricular node, then an atrio-ventricular block is said to have occured. The first degree heart block (AV block) is caused by an increased conduction time through the AV node. Thus, the PR interval appears prolonged.

vi) *Wenckebach*

This condition, which is also a kind of IInd degree AV block or Mobitz Type I, is caused by the increased difficulty of successive atrial impulses to penetrate the AV node. Thus the PR interval shows a progressive lengthening until a QRS complex is dropped.

vii) *Mobitz II*

This condition is caused by a total failure of some atrial impulses to cause ventricular contraction. It is detected by a constant PR interval for conducted impulses and a dropped QRS complex for non-conducted impulses.

viii) *Third Degree AV Block*

This condition is also called complete heart block. The complete failure of atrial impulses to pass through the AV node makes the ventricles independently active. This condition generally exhibits a ventricular rate lower than 60 beats per minute while atria beat at a higher rate.

1.3.6.4) Ventricular Abnormalities

i) *Idioventricular Rhythm*

If the ventricular muscle is not excited by the conduction pathway, it may generate an impulse on its own. Regular, spontaneous impulses occuring in the ventricular muscle and causing ventricular contractions constitute an idioventricular rhythm.

ii) *Accelerated Idioventricular Rhythm*

An idioventricular rhythm with a rate between 60 and 100 beats per minute is called an accelerated idioventricular rhythm.

iii) *Ventricular Tachycardia*

An idioventricular rhythm with a rate above 100 beats per minute is called ventricular tachycardia.

iv) *Wolff-Parkinson-White*

In some hearts, the atrial impulses are conducted to the ventricles over an alternate pathway called the Bundle of Kent. Impulses travelling through the Bundle of Kent avoid the conduction delay experienced by impulses which travel through the atrio-ventricular node. Such a condition is called the Wolff-Parkinson-White syndrome. Under this condition the QRS complex is prolonged and the PR interval is a short delta wave. Fig. (36) shows the Wolff-Parkinson-White syndrome.

v) *Bundle Branch Block*

When the pacemaker impulses cannot travel through one of the Bundle Branches i.e, left or right, then a bundle branch block is said to have occurred. It could be called left bundle branch block or right bundle branch block depending on the bundle branch that does not conduct. When a branch block occurs, the impulse depolarizes the non-blocked ventricle first and later

spreads through the myocardium into the blocked ventricle.

vi) *Premature Ventricular Contractions*

These are premature contractions of the ventricular myocardium. They arise due to ectopic, ventricular impulses which occur prematurely, and thus cause the ventricular muscle to contract prematurely. Premature ventricular contractions are the commonest kind of arrhythmias. Although PVCs may occur ocassionally, their occurence at a rate of 6 or more per minute is considered pathological. PVCs occur due to the increased excitability of the ventricular tissue. This may be caused by agents like drugs, smoking, coffee, alcohol or an electrolytic imbalance. The basic feature is that the QRS occurs prematurely and is somewhat wide and distorted. Other important detection features are given below :

PVCs could be characterized the presence of a *fusion beat* which looks like a hybrid between a normal QRS complex and a PVC.

PVCs could be characterized by the presence of a full *compensatory pause.*

PVCs could be characterized by the presence of an *interpolated beat*, i.e, when a PVC inserts itself between two QRS complexes but does not disturb the basic rhythm.

PVCs could be characterized by their *unifocal* nature, i.e, they might have arisen from the same ectopic focus and are identical in shape.

PVCs could be characterized by their *multifocal* nature, i.e, they might have arisen from different ectopic foci.

PVCs could be characterized by the presence of *bigeminy*, *1:2 trigeminy*, *2:1 trigeminy* or *3:1 quadrigeminy.* All of these are characterized by the ratio

of occurence of normal beats to that of PVCs. That is, *bigeminy* is a repeating sequence of one normal beat followed by one PVC, *1:2 trigeminy* is a repeating sequence of one normal beat followed by two PVCs, and so on.

vii) *Ventricular Tachycardia*

A run of three or more premature ventricular contractions is called ventricular tachycardia. Ventricular tachycardia is dangerous when the amount of blood pumped out of the heart is insufficient to maintain circulation. Also, ventricular tachycardia may degenerate into ventricular fibrillation or cardiac arrest, which could lead to the death of the patient. These could be of the following types :

A run of ventricular tachycardia which shows sudden onset and sudden offset is called *paroxysmal ventricular tachycardia.*

Ventricular tachycardia could also be characterized by the presence of a *fusion beat*, which results from multiple foci being activated in the same region of the myocardium, thus giving rise to a hybrid waveform. Here, the P wave could be absent altogether or if present, shows an abnormal PR interval.

Ventricular tachycardia could also be characterized by the presence of *capture beats.* This is also known as a *Dressler beat.* A normal looking QRS complex shows up between a run of ventricular tachycardia in this condition and is caused due to a rare, normal, ventricular depolarization that 'captures' a conduction pathway impulse.

viii) *Ventricular Flutter*

This is a rapid run of ventricular beats that is seen as a smooth sine wave, or regular zig-zag rhythm. The rate of ventricular flutter is generally between 150 to 300 beats per minute. Under this condition, there is no organized

contraction of the heart and thus the amount of blood pumped out by the heart is greatly reduced.

ix) *Ventricular Fibrillation*

Numerous ectopic ventricular foci firing simultaneously produce irregular and chaotic undulations of the EKG baseline that are devoid of any repeating waveform. This condition is called ventricular fibrillation. This, together with cardiac arrest form two of the most deadly conditions of the heart.

1.3.6.5) Enlarged Hearts

A heart chamber becomes enlarged due to either volume or pressure overload. Both atria and ventricles are susceptible to enlargements. Enlarged chambers possess a greater mass. Because of this increased mass, the waves of depolarization produced by the enlarged chambers have larger amplitudes and take a longer time to travel through the tissues.

i) *Atrial Enlargement*

These could be of three kinds, left atrial, right atrial and biatrial. The shape and amplitude of the P wave is affected by these conditions. For Lead II left atrial enlargement produces either a notched or widened P wave. In right atrial enlargement, the P wave is peaked and in biatrial enlargement, the P wave has a large amplitude.

ii) *Ventricular Enlargement*

This condition is characterized by either ST segment depression or T wave inversion.

1.3.6.6) Damaged Hearts

Lack of adequate supply of blood to the heart can damage it. The conditions that arise are known as the three I's of heart attacks. These are ischemia, injury and infarction. All of these are characterized by ST segment elevation or depression and/or T wave inversion.

i) *Ischemia*

Ischemia is the mildest form of heart damage and is caused when the amount of blood supplied to the heart is inadequate for metabolic requirements.

ii) *Injury*

Continued ischemia results in injury. These injured cells can no longer repolarize and depolarize fully.

iii) *Infarction*

The death of myocardial tissue is called infarction. This is the severest form of damage to the heart tissue. The QRS complexes may show significant Q's in Lead II.

1.3.6.7) Drug and Electrolyte Effects

Abnormal levels of calcium and potassium in the blood can alter the electrical activity of the myocardial tissue, which produces changes in the EKG.

Anti-arrhythmic drugs like digitalis, quinidine and propranolol alter the activity of the myocardial tissue and hence the EKG. Such drug-related changes are called drug effects.

i) *Hypocalcemia*

A low concentration of calcium in the blood causes hypocalcemia. It affects the EKG by prolonging the QT interval.

ii) *Hypercalcemia*

A high concentration of calcium in the blood causes hypercalcemia. It affects the EKG by shortening the QT interval.

iii) *Hypokalemia*

A low concentration of potassium in the blood causes hypokalemia. This affects the EKG by decreasing the T wave amplitude and increasing the U wave amplitude such that the amplitude of the T wave is less than or equal to that of the U wave.

iv) *Hyperkalemia*

A high concentration of potassium in the blood causes hyperkalemia. This affects the EKG by causing tall, tented or peaked T waves, a flattening of the P wave and prolonging of the PR interval and the QRS complex.

v) *Digitalis*

Digitalis is a drug that slows the the heartrate by slowing the rate of spread of depolarization. Thus it is used to treat conditions like atrial flutter and atrial fibrillation. Extra slowing of the impulse conduction could cause sinus bradycardia or sinus block.

vi) *Quinidine/Propranolol*

These are drugs that decrease the electrical activity of the heart muscle. Such drugs are called myocardial depressants. These drugs, like digitalis, are hence useful in treating arrhythmias with rapid rates like flutter and fibrillation. But, the toxic effects of quinidine and propranolol may cause the

widening or notching of the P wave, prolonging of the QRS complex and the PR and QT intervals, depressing of the ST segment, the depressing , widening, notching or inverting of the T wave and lastly, a pronounced U wave.

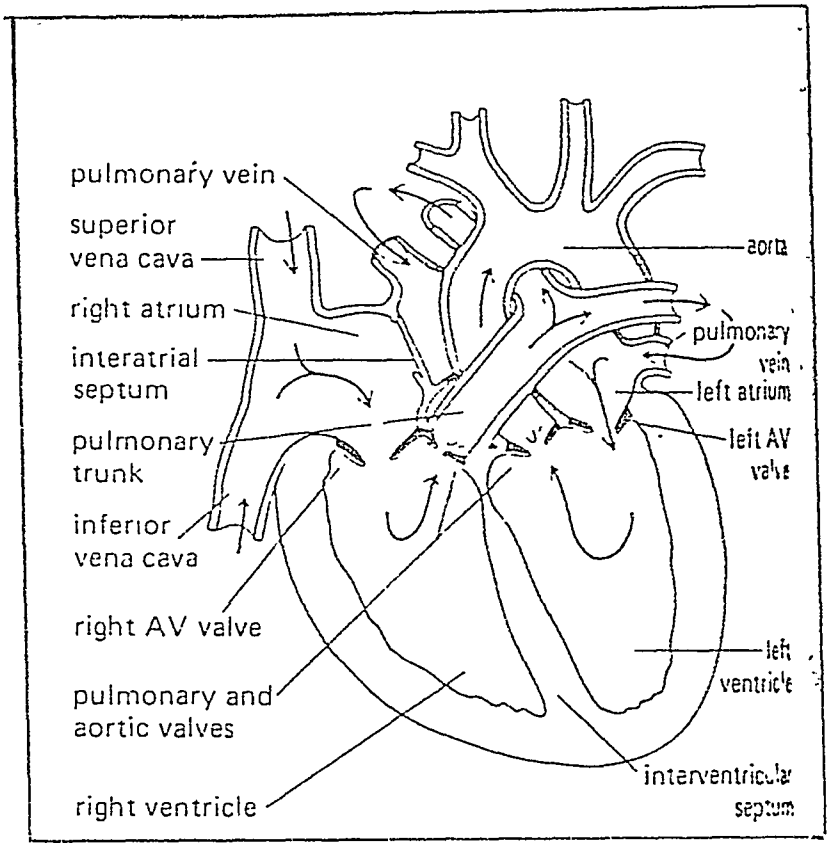


FIG. (2) : THE HUMAN HEART

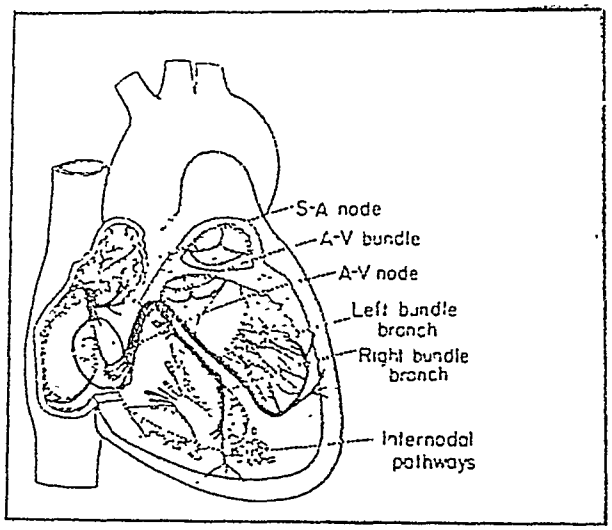


FIG. (3) : EXCITATORY AND CONDUCTING SYSTEMS

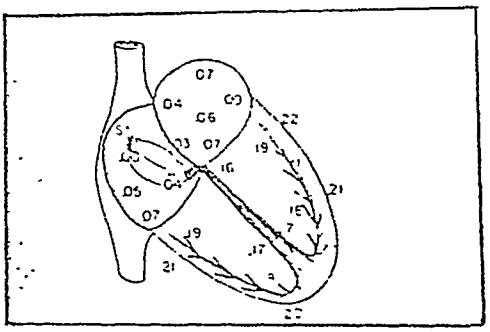


FIG. (4): TIME DELAYS IN CONDUCTION OF THE ELECTRICAL IMPULSE

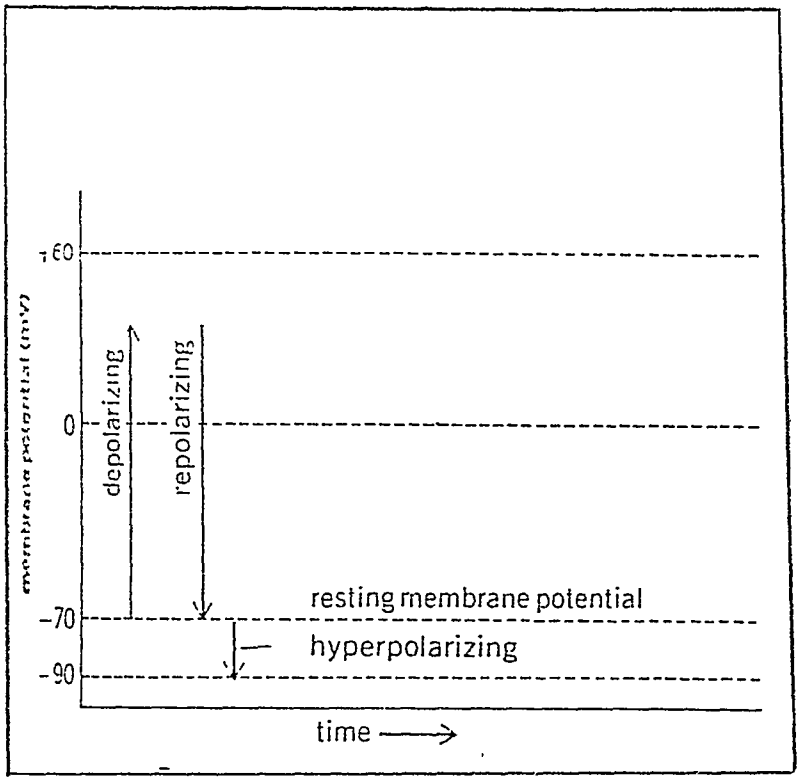
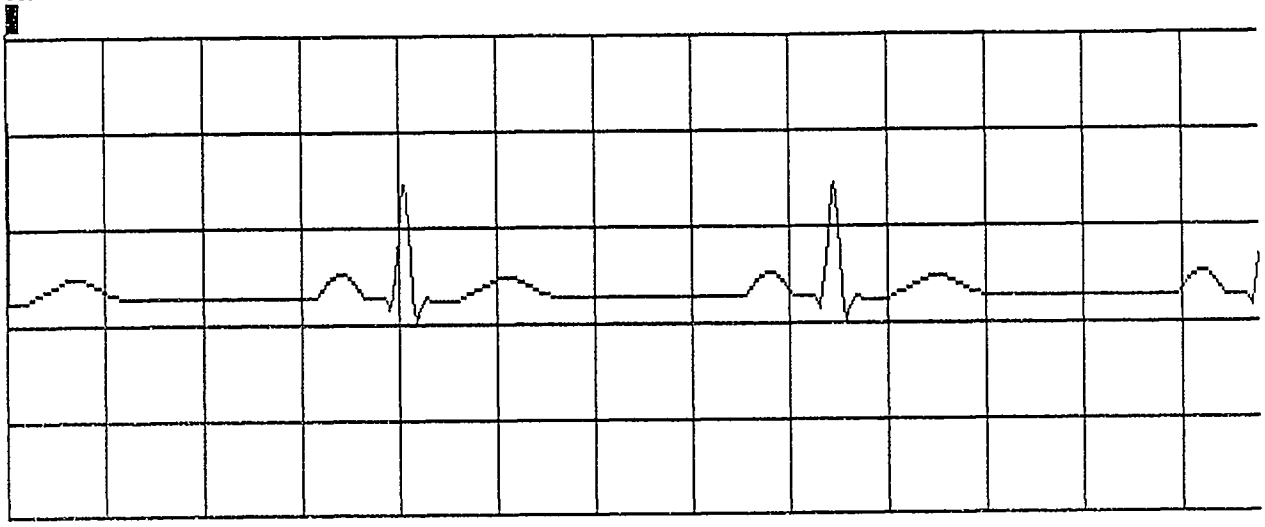


FIG. (5): DEPOLARIZATION AND REPOLARIZATION

TYPE FILE NAME? a02.dat
Ok


1LIST 2RUN← 3LOAD" 4SAVE" 5CONT← 6,"LPT1 7TRON← 8TROFF← 9KEY 0SCREEN

FIG. (6) : A NORMAL ELECTROCARDIOGRAM

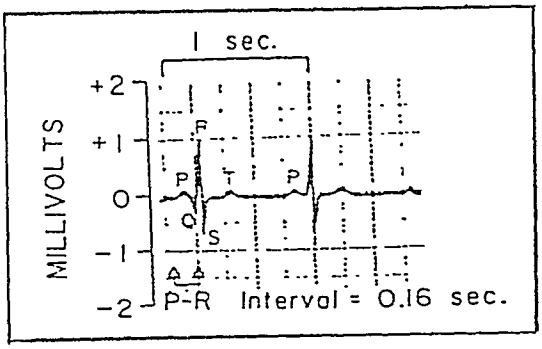


FIG. (7) : CALIBRATION LINES OF THE EKG

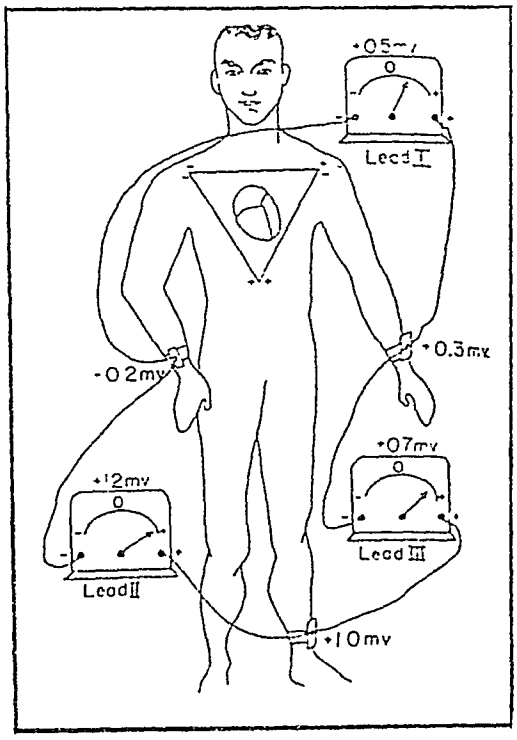


FIG. (8) : STANDARD LIMB CONNECTIONS

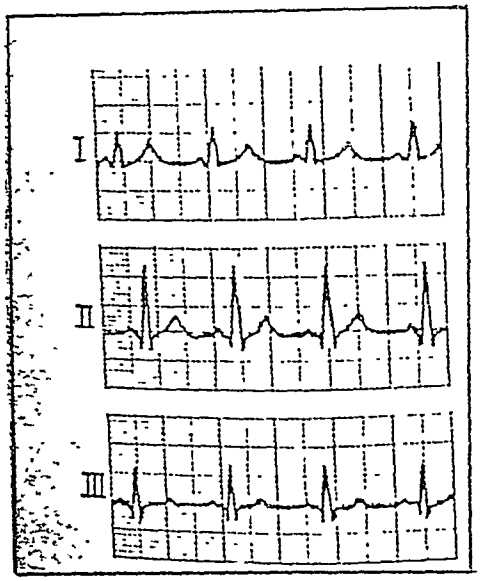


FIG. (9) : SIMULTANEOUS LEADS I, II & III

2. An Outline of the EKGCHALLENGER

2.1 *The EKGCHALLENGER in a Nutshell*

The EKGCHALLENGER is an intelligent electrocardiogram tutorial package. The user, ideally an undergraduate medical student, can use it to learn and improve his electrocardiogram reading skills. To use this package successfully, the user has to have a basic knowledge of cardiac electrophysiology and EKG waveforms. In case this is lacking, one should go back to a package called the EKGTUTOR [18], which is designed specifically to teach the user the basic principles of the heart.

The EKGCHALLENGER can be used in two basic modes :

a) The *tutorial mode* where the user can practice diagnosing EKGs. The EKGCHALLENGER displays EKG strips of increasing difficulty on the screen and the accompanying text shows a step-by-step approach to diagnosing them.

b) The *challenger mode* where the user is asked to diagnose a randomly selected strip chosen from the EKG database. The user's diagnosis is verified by comparing it with that of the expert system's interpretation of the strip, and a score is awarded to the user, which is a measure of his competence in reading EKGs.

Apart from these two basic modes, the EKGCHALLENGER's expert system can, by itself, be used as a stand alone unit either by the student as a practice tool or by a non-trained individual as a preliminary diagnostic tool to

assist patients entering the emergency medical system. A detailed description of this is found in section 5.2.3.

Because of the use of an artificial intelligence technique, namely the expert system, the EKGCHALLENGER is called an 'intelligent' electrocardiogram tutorial package.

2.2 *The Database of EKG Strips*

The EKGCHALLENGER uses an EKG database containing EKG strips which are used as practice/test strips to teach the user how to diagnose EKGs. This large EKG database contains disk based files that of sufficient number of normal and abnormal EKG strips; a number which ensures that no file is repeated often enough for the student to be able to 'remember' it, and diagnose it by strip recognition. The EKG strips that are stored in this database, fall under the following major categories :

1) Cardiac Rhythms
2) Atrial Abnormalities
3) Junctional Abnormalities
4) Ventricular Abnormalities
5) Enlarged Hearts
6) Damaged Hearts
7) Drug and Electrolyte effects

In the challenger mode, a small random-number generator program coupled

with a display program is used to pick a strip from the database at random and display it on the screen.

A detailed description of the EKG database is given in Chapter 3.

2.3 *The Expert System Program*

Once the student has completed the diagnosis of a particular EKG strip, his diagnosis has to be verified so that a score could be awarded to him as a measure of his performance. This is done by the use of an expert system program that has the capability to diagnose cardiac arrhythmias.

All of the strips in the EKG database are run through the expert system by the system programmer during the creation of the package. This, coupled together with a run through the string manipulation program (refer to Appendix A), produces output files in a pre-determined format. These files are stored in the computer in an orderly manner, for future use.

The student's diagnosis of a particular EKG strip too, is stored in the standard file format. This file is then compared with the appropriate file that has already been generated by the expert system, to enable the awarding of a score.

Let us assume that the student is asked to diagnose strip 58. His diagnosis is then stored in a temporary file. Now the EKGCHALLENGER pulls up file 58 generated by the expert system and compares it with the student's output file. Thus, a score can be awarded.

This whole process is called the *challenger mode* of operation and could be repeated for as many randomly generated EKG strips as the student wishes

to diagnose.

In the *tutorial mode* of operation, the student is tutored by the EKGCHALLENGER, and learns the method of step-by-step diagnosis of EKG strips that are selected from the EKG database. A detailed description and analysis of the above mentioned modes is given in Chapter 5.

2.4 *Creation of the Shell*

The success of a package like the EKGCHALLENGER depends on how well all of the programs used in the making of various sections of the package can be integrated into a whole. This aspect is addressed in EKGCHALLENGER by writing a master program called the 'shell'. The shell has in it, as statements, a list of the programs comprising EKGCHALLENGER in the exact order in which they are to be executed. These programs could be interlinked with one another in the form of user libraries in the way the designer chooses them to be.

Thus, in order to run EKGCHALLENGER, the user would have to execute just the shell, and everything else would follow in the correct order. A detailed description of the shell and other accessory programs used in EKGCHALLENGER is given in Appendix A.

3. Creation of the EKG Database

In order for the EKGCHALLENGER to be a good educational tool, the EKG database must have variety and depth. Therefore, data for the EKG database was collected in the following three ways :

3.1. *Method A*

This method was used to collect real data. The real data was provided on 13 spools of tape from the MIT - BIH arrhythmia collection [14]. These data then had to be converted and stored in digital form in a computer. Fig. (10.a) shows the system arrangement for this method.

The spools were played on an instrumentation recorder and were continuously monitored on a cathode ray oscilloscope. On finding a suitable strip of EKG data, the output from the recorder was fed to an EKG pen-recorder through a suitable pre-amplifier circuit, to obtain a hard copy of the EKG strip on standard EKG recording paper. This process was continued till a suitable number of EKG recordings were obtained.

The next step was to digitize these analog EKG waveforms and store them in the computer in different files with proper indexing.

Fig. (10.b) shows the system configuration used for this purpose. Before digitizing, the EKG strips were enlarged using a photocopier so that they corresponded to the grid size on the computer screen. A digitizing tablet along with a digitizing pen was interfaced to an IBM - PC clone. A computer aided design program called PRO-DESIGN [13] was used to create the files in the digitized form, i.e, in the form of X-Y coordinates. The whole process worked

in the following way :

A suitable EKG strip was taken and placed on the digitizing tablet. Care was taken to see that the respective axes coincided both on the screen and on the digitizing tablet. Now, using the pen, the EKG waveform was traced out in the form of points. Thus, for every point traced out on the EKG strip, a corresponding X-Y coordinate was stored in a file, on the computer.

Optimal storage allocation techniques were employed by storing EKG strips with identical, repetitive cycles as single cycle waveforms, which could later be replicated during actual display of the file. Only the EKG waveforms with non-replicated cycles were stored completely.

All the different kinds of arrhythmias were indexed and categorized by suitable filenames.

3.2. *Method B*

This method was used to collect simulated data. Fig. (11) shows the system arrangement used for this purpose. A cardiac arrhythmia simulator called the Laerdal HEARTSIM 20000 was used for this purpose [11]. The HEARTSIM 2000 is a versatile EKG and Haemodynamic Waveform Simulator which can be used either as a stand-alone training aid or with a Laerdal training mannequin. This simulator produced an analog signal output in the 3 mV range. Thus, it had to be amplified and fed through an analog-to-digital converter before it could be stored in the computer.

An analog to digital (A/D) converter called the DASH-8, marketed by MetraByte Corp. was used for this purpose [12]. The DASH-8 is an 8 channel,

12 bit, high speed, successive approximation A/D converter and timer/counter suitable for use with an IBM - PC or its clones. It can be fitted in a 'half slot'.

Thus, the analog signal from the simulator, after suitable pre-amplification, was fed into the DASH-8 board for conversion into digital form.

Suitable software had to be used to instruct the DASH-8 board to perform the requisite conversion, display the waveform on the computer terminal and store the data in a file, on a floppy disk. This was done in BASIC using the input and output instructions for the I/O ports of the computer. Once again, care was taken to see that the display on the terminal was calibrated to match the length-to-width ratio that appeared on standard EKG paper. The program source code for A/D conversion using the DASH-8 board is given in Appendix A.

The following procedure was used to perform the A/D conversions. The simulator was set up to produce a suitable waveform, say, 80 Hz, Normal Sinus Rhythm. The program for activating the DASH-8 was then loaded and executed. A suitable sampling frequency was chosen (220 Hz) and the conversion was performed with the EKG signal being converted to a 640 point format, suitable for display on a standard computer screen. This process was repeated for the required number of files which were then adequately categorized and indexed for use in the EKG database. Examples of EKG database screens are shown in Figs. (12), (13) and (14).

3.3 *Method C*

This method had to be used as the number of normal EKG strips recorded

using Methods A and B was not sufficient. Here, EKG recordings were taken off normal people. The set-up was exactly the same as the one used in Method B, with the exception that EKGs produced from people were used to produce the analog signal, instead of using the simulator as the input.

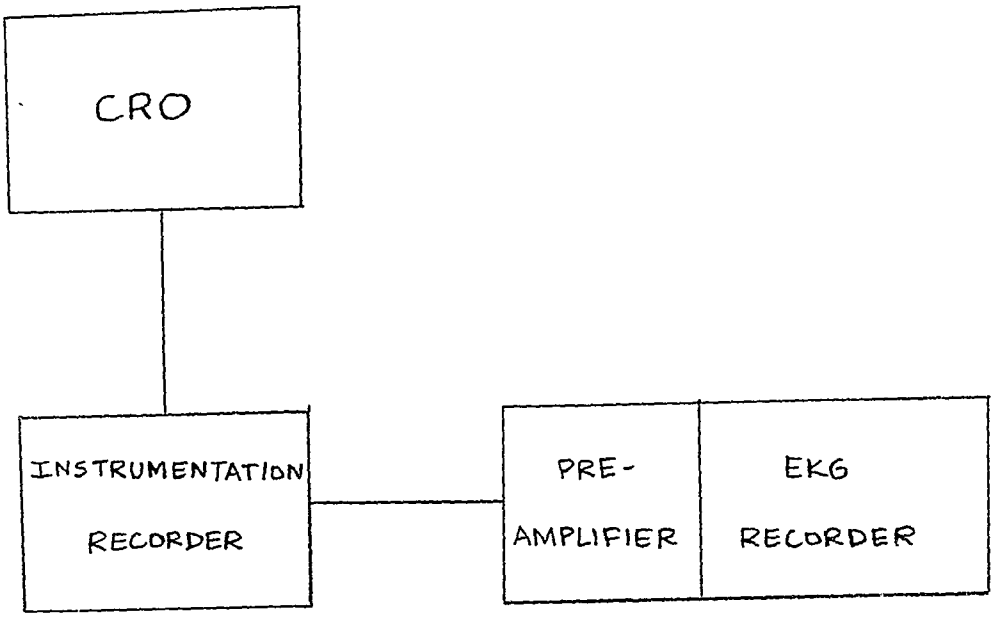


FIG (10.a) : METHOD 'A' OF DATA ACQUISITION

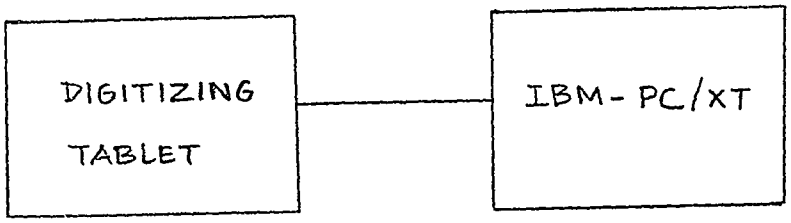


FIG (10.b) : METHOD 'A' OF DATA ACQUISITION

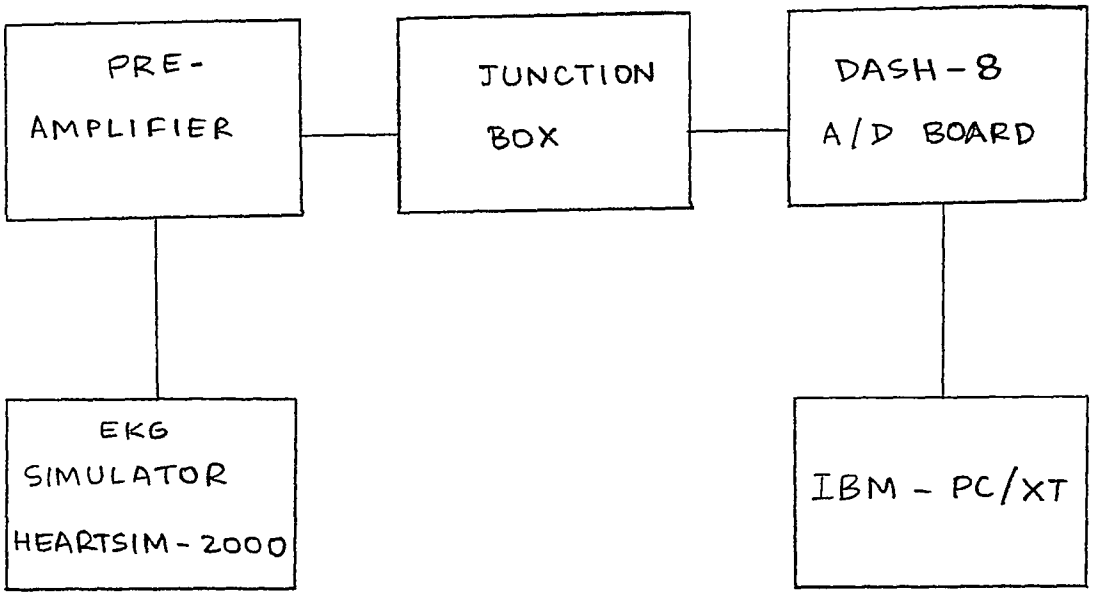
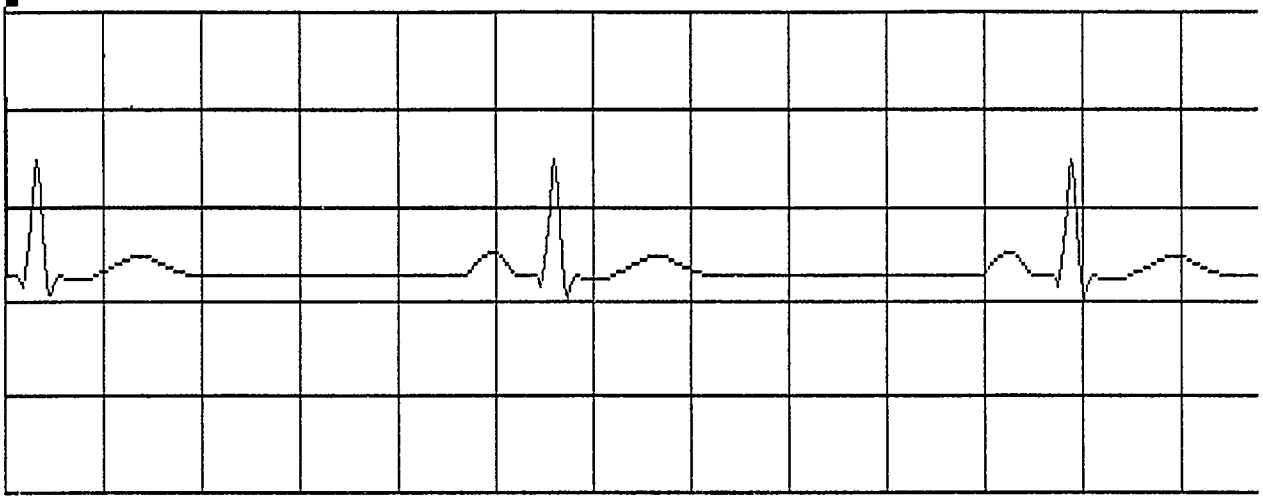


FIG (11) : METHOD B OF DATA ACQUISITION

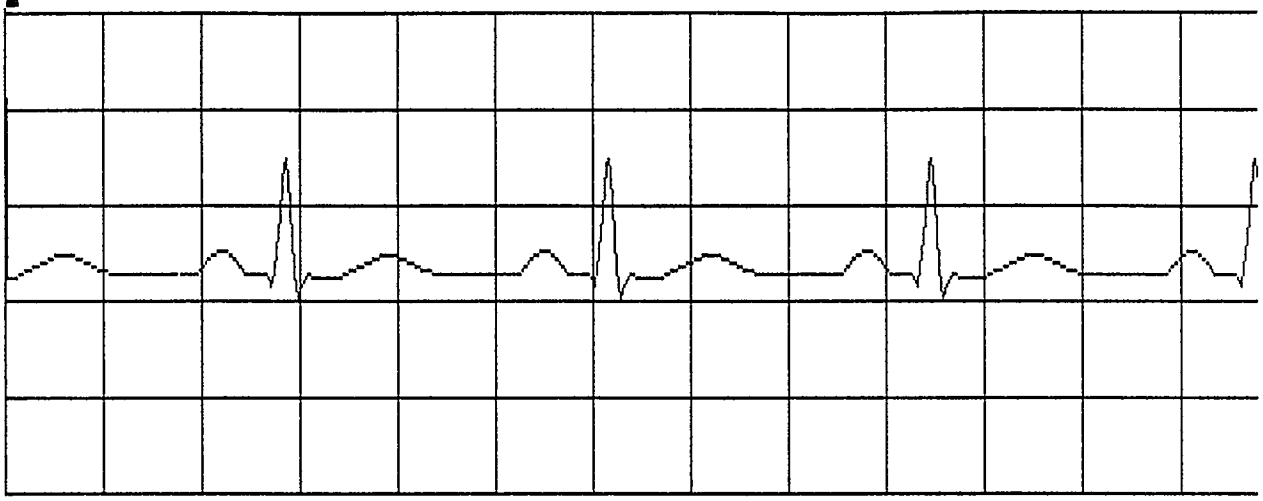
TYPE FILE NAME? a03.dat
Ok



1LIST 2RUN← 3LOAD" 4SAVE" 5CONT← 6,"LPT1 7TRON← 8TROFF← 9KEY 0SCREEN

FIG. (12) SAMPLE EKG

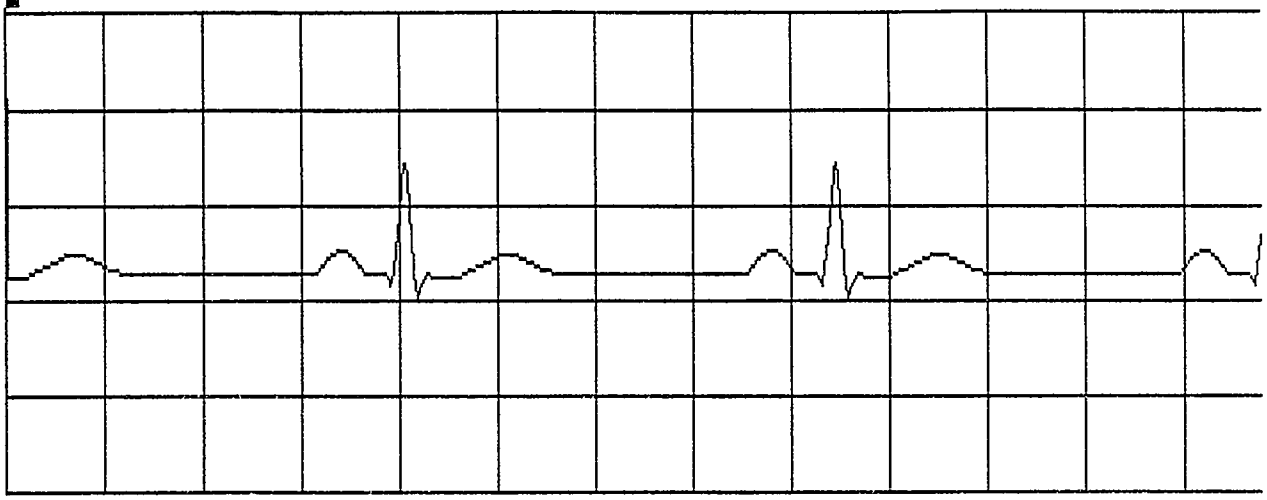
TYPE FILE NAME? a01.dat
Ok



1LIST 2RUN← 3LOAD" 4SAVE" 5CONT← 6,"LPT1 7TRON← 8TROFF← 9KEY 0SCREEN

FIG. (13) : SAMPLE EKG

TYPE FILE NAME? a02.dat
Ok



1LIST 2RUN← 3LOAD" 4SAVE" 5CONT← 6,"LPT1 7TRON← 8TROFF← 9KEY 0SCREEN

FIG. (14) : SAMPLE EKG

4. A Description of the Expert System

4.1 *Why Prolog was Chosen for this Application*

The expert system had to have an ability to diagnose cardiac arrhythmias, and hence, had to be composed of rules (in the 'if-then' format) and facts. Secondly, it had to be IBM - PC based, i.e, portable on floppy disks. Finally, it had to be fast, and thus, had to be modifiable into an executable file, which incidentally, would allow it to be linked along with other parts of the EKGCHALLENGER.

TURBO - PROLOG, [10] a compiled version of the original Prolog, marketed by Borland International Inc., possesses the capacity to support such a project.

TURBO - PROLOG is a compiler with a pull down menu interface and full arithmetic, graphic and system level facilities. It also has a built-in linker for creating .EXE files. It has a good trace facility that makes debugging easy. It is fully modular and thus has the capability to call and execute subroutines written in conventional languages like Pascal and C. Most important, the fact that the compiler has been implemented in C makes it very fast and hence suitable for real-time processing.

4.2 *Description of the Program and its Knowledge Base*

EKGCHALLENGER makes use of an expert system that has the capability of diagnosing cardiac arrhythmias. This expert system is used to diagnose the

arrhythmia in question (the one that the student has been asked to diagnose) and produce a result in a certain predecided format. This diagnosis, which is already stored in a file in the computer is retrieved when required and compared with that of the student's. The diagnosis of the expert system is used as the basis for scoring the student. The expert system can also be used by itself as a stand-alone unit (a description of which is given in the next subsection).

Consider, at first, the general structure of any rule-based expert system. An expert system must have access to an organization of facts according to the validity of its domain, which is known as the knowledge base [2]. The system must also be able to infer conclusions from the available information in the knowledge base during a consultation session. Thus, an expert system can be said to consist of three distinct units :

1. A knowledge base (KBS)
2. An inference engine (INE)
3. A user interface system (UIS)

The organization of these three units in the expert system is as shown in Fig. (15) :

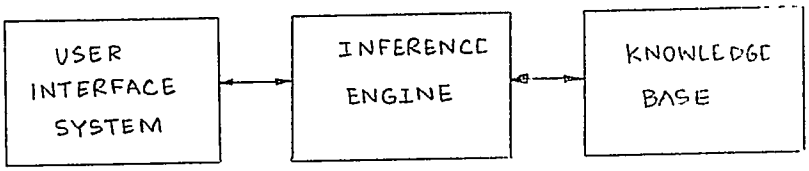


FIG. (15): PARTS OF AN EXPERT SYSTEM

The 'knowledge base' is the central part of the expert system. It contains rules describing relations or phenomena, methods and facts for solving problems in the system's area of expertise. The information that the knowledge base contains can be factual (the sun rises in the east) or inferential (if you stand in the rain for a long time, you will catch a cold) [3].

The 'inference engine' consists of operating rules and principles. It knows how to use the knowledge base so that consistent conclusions can be drawn out of the information in the knowledge base. The inference engine executes the rules, determines when an acceptable solution has been found, and finally passes on the results to the user interface.

The 'user interface' is the part of the expert system that is in direct communication with the user. It is in this part of the expert system that all the user-friendliness has to be accommodated. This interface, generally is a 'natural- language' interface that aims to put the user at complete ease when using the expert system.

A description of the expert system implemented in the EKGCHALLENGER is given below :

which is the compiler version of a subset of the original Edinburgh Prolog [5]. The program source code is given in Appendix B of this thesis. This program too, like any other rule based expert system has the basic three parts, namely, the User Interface System, the Inference Engine and the Knowledge Base.

4.2.1) *User Interface System* : A good user interface system supports the following features [2] :

1. Handling keyboard and screen input and output.
2. Supporting dialog between the user and the system.
3. Recognizing cognitive mismatches between the user and the system.
4. Providing user friendly features.

A menu driven system could be modified by replacing the menu with a natural language interface. Our user interface supports two basic clauses which 'fire' by getting the system to run through an internally generated top goal namely 'do-expert-job' (i.e, to do the expert job at hand). These are 'do-consulting' and 'ask'. The 'do-consulting' clause gets the system to look for an illness, while the 'ask' clause prompts the user to answer the y/n type questions that the system generates, in order to diagnose the illness. Finally, this user interface either prints out a 'the condition maybe xx' kind of answer or a 'sorry, unable to diagnose' kind of message for the user. The program could be rerun from this point at the request of the user. The set of facts that led to the diagnosis of a particular illness is stored in a file called 'result.pro'.

This file is then processed further by a piece of code written in Pascal (the string manipulation program - see Appendix A) so as to create a standard output file in a pre-decided format. This file can then be stored for future use, that is, for comparison with the file generated by the student's diagnosis. A detailed description of the use of 'result.prô' is given in Appendix A.

4.2.2) *Inference Engine* : The inference engine built into this expert system is called the 'production rule interpreter' [3] as the information in the knowledge base is stored as 'if-then' rules of the form :

([conclusion] if [condition1][condition2][condition3]..)

What we understand from the above is that if conditions 1,2,3 and so on are true, then the given conclusion can be established. Prolog typically works in what is known as the 'backward chaining' [5] mode. It works as follows :

It scans the rules in the knowledge base in the order in which they are placed, and goes through them non heuristically, i.e, trying to establish [condition1], then [condition2] and so on in a 'depth first' mode to try and arrive at the conclusion.

Assume that a particular problem has three unique solutions. These solutions can be represented by a structure called a tree, as shown in Fig. (16). Each branch of the tree represents a unique solution path. A system is then said to be operating in the 'depth - first' mode if it pursues a single branch (solution path) of a tree until it yields a solution or until some pre-determined depth has been reached, and only then go back and explore other branches for other solutions.

(solution path) of a tree until it yields a solution or until some pre-determined depth has been reached, and only then go back and explore other branches for other solutions.

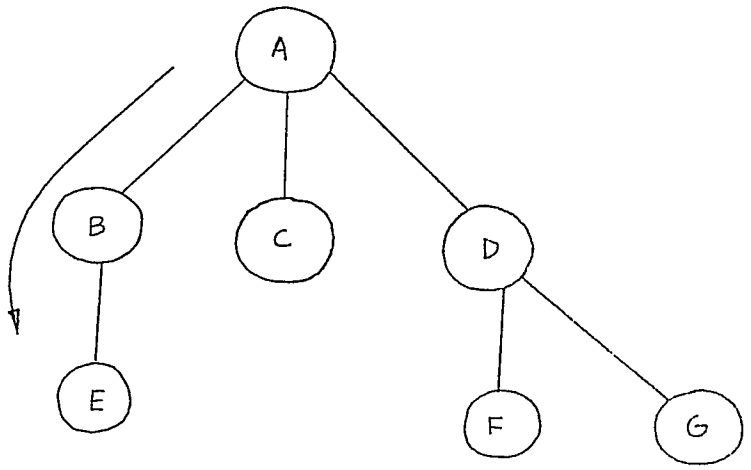


FIG. (16) : SEARCH - 'DEPTH FIRST' MODE

In case a situation arises in the expert system where, say [condition1] cannot be satisfied, then it automatically skips over to the next rule.

Our inference engine uses two basic kinds of clauses, 'positive' and 'negative' that determine whether a given symptom supports a particular condition or is a negative aspect for that particular condition. For example, assuming that the condition is 'normal sinus rhythm', a 'yes' to the question 'Is the P wave present ?' is a positive symptom, that is, it could lead to the deduction of the fact that the condition is indeed 'normal sinus rhythm'. But a 'no' to the question 'is the QRS complex present ?' is a negative symptom and will cause the expert system to eliminate the possibility of the condition being 'normal sinus rhythm' as it tries to search the list of possible conditions

form an array of the symptoms (stored in 'result.pro', as mentioned earlier) that leads to a particular condition being diagnosed. Also used in the inference engine are other clauses like 'clear-facts' (which clears the memory, thus preparing for a rerun), 'redo' and 'run-again' (which provide the user the option of a rerun) and finally a 'remember' (which asserts symptoms onto the database).

4.2.3) *Knowledge Base* : This is the brain bank of the expert system where all the information is housed. Our knowledge base is organized in three hierarchical levels namely 'illness-is', 'it-is' and 'positive'. The 'positive' clause is the most primitive clause and builds on to the 'it-is' clause which in turn builds on to the 'illness-is' clause. For example consider 'bundle branch block'. It is coded in the following manner in the knowledge base of the expert system.

```
illness-is("bundle branch block","177") :-
it-is("QRS complex prolonged"),
positive(is,"QRS with R-R' ","037").
```

The above rule means that the condition is bundle branch block if QRS complex is prolonged and the QRS complex possesses an extra R-R' wave. The 'positive' clause for R-R' is of the lowest heirarchical level, but the 'QRS prolonged' clause (i.e the it-is clause) is further broken up as :

```
it-is("QRS complex prolonged") :-
positive(is,"QRS complex present","032"),
not(positive(is,"QRS complex duration less that or equal to 0.1 sec." ,"565")).
```

Numbers are attached to individual clauses in order to 'index' [2] them, that is, to establish an identification tag for each of the clauses which enables the creation of an array in serial order, going from entry 001 up to entry 252. An elaborate account of the use of these indexes is given in Appendix A along with the string manipulation program.

Our knowledge base has the capability to diagnose 43 different illnesses which are grouped according to the categories given below :

1. Rhythms
2. Atrial Abnormalities
3. Junctional Abnormalities
4. Ventricular Abnormalities
5. Enlarged Hearts
6. Damaged Hearts
7. Drug and Electrolyte Effects

There are 93 different rules that are used in this program to diagnose 43 kinds of illnesses.

The expert system asks the user a series of questions in the form of symptoms that the EKG report of the patient in question might show, and prompts the user to answer in a yes/no format. Then the inference engine begins its work and singles out the result (i.e, the illness) and hands it to the user interface system, which prints out the result for the user. A pictorial represen-

tation of the detailed organization of our expert system is given in Fig. (17). It illustrates both the flow of control and the flow of data in the expert system.

4.3 *The Expert System as an Independent Unit*

Although the expert system program described in the above section is an integral part of the EKGCHALLENGER, it is of a modular form and has the capability to function by itself as a self-sufficient unit. There are two basic ways in which this could be done :

1) The expert system as a practice tool which would enable the student to practice diagnosing EKGs.

2) The expert system as a preliminary diagnostic tool which would enable non-trained individuals to assist patients entering the emergency medical system. An elaborate account is given in the next chapter.

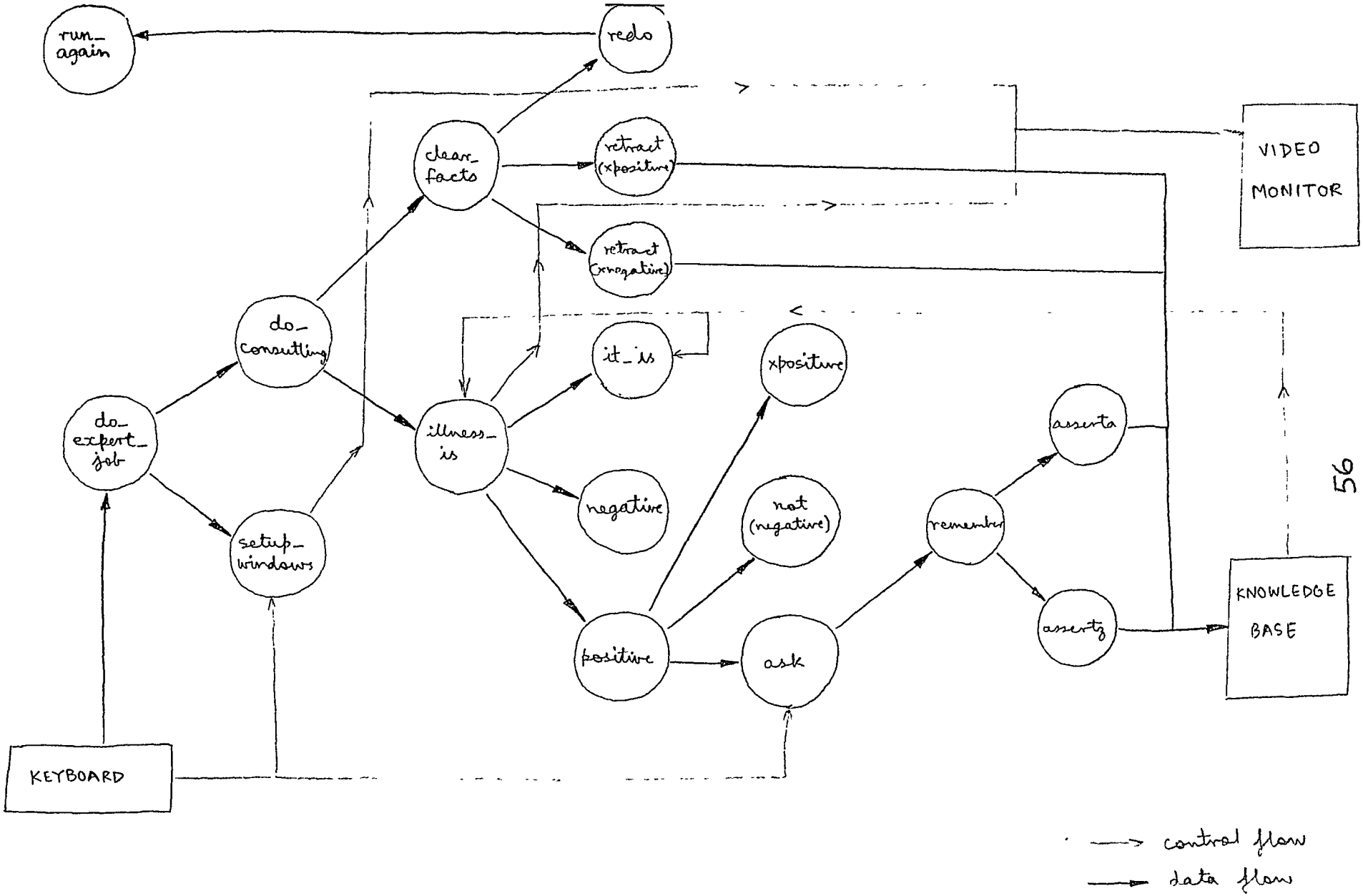


FIG (17) : CONTROL AND DATA FLOW IN THE EXPERT SYSTEM

5. Modes of Operation of the EKGCHALLENGER

5.1 *Creation of the Shell*

All of the sub-programs written for different parts of the EKGCHALLENGER have to be arranged and executed in an orderly manner, which enables EKGCHALLENGER to be termed as a complete 'package'.

The controlled execution of the various sub-programs is performed by creating a master program called the shell.

The shell is an executable program written in Microsoft's QuickBasic [16], which is the PC-based version of compiled Basic. It is composed of executable sub-programs that are arranged in a certain pattern, which was decided by the designers of the EKGCHALLENGER. Some examples of these sub-programs are - the expert system program, the set of programs used in the tutorial mode, etc. Thus, when the shell is executed, each of these sub-programs are executed in the correct order, which enables the user to run through the complete package from beginning to end.

Some of these sub-programs are used in a particular sequence very often during the execution of EKGCHALLENGER. For example, the EKG display program coupled together with the EKG database is an often used sequence. Such sub-programs are linked together to form 'user libraries'. Other sub-programs in EKGCHALLENGER could use these user libraries. For example, the expert system is linked to a user library which is made up of two sub programs, namely the EKG database and the EKG display program. Also,

two different sub-programs could share a common user library or a single sub-program may be linked to more than one user library.

Hence, a 'hypothetical' shell program would be designed as shown below :

SHELL PROGRAM

1. Sub-program 1.
2. Sub-program 2 / link User library 1.
3. Sub-program 3 / link User library 2.
4. Sub-program 4 / link User library 1.
5. Sub-program 5.

The user, by executing the shell program, executes sub-programs 1 through 5 in the order specified above, with sub-programs 2 through 4 making use of their respective user libraries. After executing sub-program 5, the shell program terminates and exits out into the operating system.

A general outline of the shell implemented in EKGCHALLENGER for the different modes of operation is :

1) The 19 sub-programs for the *tutorial mode* of operation of the EKGCHALLENGER (Note that each of the clauses below is a separate section and thus a separate sub-program) :

a) Criteria for the normal heartbeat.

b) How to measure heartrate.

c) How to tell normal from abnormal heartrates.

d) Pacemaker problems in the sino-atrial node.

e) When atrial muscle acts as a pacemaker.

f) **Self Test One** – Identifying normal EKGs and supra-junctional abnormalities.

g) When the atrio-ventricular node acts as a pacemaker.

h) When pacing impulses have difficulty getting through the atrio-ventricular node.

i) **Self Test Two** – Identifying junctional arrhythmias and heart blocks.

j) When the ventricular pacemaker is below the atrio-ventricular node (Part I).

k) When the ventricular pacemaker is below the atrio-ventricular node (Part II).

l) When the ventricular pacemaker is below the atrio-ventricular node (Part III).

m) **Self Test Three** – Identifying ventricular arrhythmias.

n) When the heart is enlarged.

o) When the heart's blood supply fails.

p) Serum electrolytes and drugs.

q) **Self Test Four** – Atrial and ventricular enlargement, ischemia, injury and infarction, drugs and electrolytes.

r) The EKG database.

s) The EKG display program.

2) The sub-programs for the *challenger mode* of operation of EKGCHAL-

LENGER :

a) EKG database.

b) The EKG display program.

c) The output files generated by the expert system.

d) Scoring strategy.

3) The mode wherein the student uses the expert system to practice diagnosing EKGs :

a) EKG database.

b) The expert system.

c) The EKG display program.

d) Scoring strategy.

4) The mode wherein an untrained individual uses the expert system to do a preliminary diagnosis of patient's EKG output, whom he is assisting for admission to the emergengy medical system :

a) The expert system.

The execution of these sub-programs in the above mentioned order would thus result in the execution of EKGCHALLENGER in particular modes of operation.

5.2 *Basic Modes of Operation of the EKGCHALLENGER*

5.2.1 *The Tutorial Mode*

As mentioned before, EKGCHALLENGER is basically used by undergraduate medical students to learn or improve their EKG reading skills. Thus, there are two basic modes of operation of EKGCHALLENGER, the first where the student is tutored, and the second where the student is tested.

The tutorial mode is comprised of 17 basic sections (1(a) through 1(q)) as stated previously. Thirteen of these sections are purely tutorial where EKG strips are displayed on the screen accompanied by texts which teach a step-by-step methodology of diagnosiing the EKG strips in question. The remaining four sections are 'self-tests' that are put in so that the student can do a self-analysis on himself. Thus by the end of the tutorial mode the student develops skills enough to be able to take his final test which is to do unaided diagnoses of EKG strips randomly selected from the EKG database.

5.2.2 *The Challenger Mode*

In this mode the student attempts to diagnose EKG strips all by himself. EKG strips are picked out randomly from the vast EKG database (see chapter 3) and displayed on the screen. The student then makes his diagnosis, which is stored in a temporary file of a pre-determined format. Now a score has to be awarded to the student as a reflection of his ability. This is done by pulling up the permanent output file for the EKG strip in question as generated by

the expert system. The two files are compared and a score is awarded to the student.

The above process can be repeated by the student for as many EKG strips as he chooses to diagnose.

5.2.3 *The Expert System Modes*

The expert system built into the EKGCHALLENGER can by used by itself as a self-sustaining modular unit. It can be used in two basic modes as mentioned previously.

The first is as a practice tool. A student could use EKG strips from an EKG machine, a textbook or the EKG database in EKGCHALLENGER and try to diagnose them with the help of the expert system. The expert system, as mentioned before has the capability to diagnose 43 cardiac arrhythmias and thus the student can gain valuable practice by understanding the strategies employed by the expert system in diagnosing arrhythmias.

The second mode of use of the expert system is as a preliminary diagnostic tool by a non-trained individual who is assisting patients entering the emergency medical system. The expert system has the capability to diagnose almost all of the conditions categorized as 'cardiac arrhythmias seen in emergencies'. Hence it could be used by paramedics at the site of an emergency before transporting the patient to the nearest hospital.

6. Conclusion and Scope for Future Work

This thesis is devoted basically towards the development of an educational aid, namely EKGCHALLENGER, which teaches undergraduate medical students a method of diagnosing EKGs. The expert system in EKGCHALLENGER is a self-sufficient modular unit which can be used separately, either by students to practice diagnosing EKGs, or by personnel of an Emergency Medical System to do an on-site, preliminary diagnosis while assisting patients with cardiac ailments in being admitted into hospitals.

The expert system has the ability to diagnose 43 cardiac arrhythmias and can be expanded in the future with the addition of a small user interface which would enable the user to 'teach' the expert system to diagnose new arrhythmias by putting in the appropriate rules in its knowledge base. The EKG database too, can be made larger by putting in more examples and thus covering a wider domain of EKGs. An example run of the expert system is given in Appendix B.

Appendix A

1. *String Manipulation Program*

After the student has understood the electrophysiology of different kinds of arrhythmias presented to him in the tutorial mode of operation of EKGCHALLENGER, he faces his final test and that is to diagnose the randomly picked EKG strips displayed on the screen in the *challenger mode* of operation of the package.

The output of the student's diagnosis is stored in the following array format in a file :

y	217
n	324

Here, the 'y' and 'n' correspond to yes and no respectively, and the numbers are references to particular conditions (clauses) like 'P wave present' or 'QRS complex with premature beat'. There are a total of 137 such clauses in EKGCHALLENGER and the output file (student's diagnosis) has 252 entries in it. The number of entries in the output file is almost double the number of clauses because the student is given the option of using either lowercase or uppercase lettering to answer the y/n type questions. A listing of all the clauses used in EKGCHALLENGER is given in Appendix B. Thus the file is said to have been indexed.

At this stage, the appropriate output file generated by the expert system is put to use. As mentioned before, the system programmer, during the creation

of the package, runs all of the EKG strips in the EKG database through the expert system to produce output files in a pre-determined format (a format that is the same as the format of the output file generated by the student's diagnosis) that are indexed and stored in the computer. Once the student completes his diagnosis, it is verified by comparing it with the output file generated by the expert system for that particular strip.

The expert system, as described previously, is composed of 'if-then' rules that identify cardiac arrhythmias. The diagnosis of a particular arrhythmia is made in a certain number of steps (for example atrial fibrillation could be diagnosed in three short steps), depending on the type of arrhythmia. In short, the user, when using the expert system would never have to go over all the 137 clauses to come up with a diagnosis.

The output from the expert system is obtained in the following format :

xpositive("is","baseline noisy","509")
xpositive("is","QRS complex present","032")
xnegative("is","P wave present","012")
xillness-is("atrial fibrillation","151")

Here, xpositive("is","baseline noisy","509") indicates that the baseline *is* noisy in the EKG strip in question and is equivalent to the following in the array format :

y 509

Thus, for comparison purposes, this string format has to be converted to the array format with all 252 entries. To facilitate this, a string manipulation program written in Pascal [15] is used. It converts the above string format to the following array format :

y 509

y 032

n 012

y 151

This file with 4 entries is further augmented by asking the user some questions, the answers to all of which are numeric data, which the user types in by referring to the EKG strip which he was asked to diagnose.

Example : Enter heartrate in BPM :

Until now, we have just a few entries in the output file from the expert system, whereas we need all 252 of them. Therefore, a default file is used which contains the default values of all the 252 entries. These two files (the output file from the expert system and the default file) are superimposed and merged to result in a final output file from the expert system which has all the 252 entries in the proper array format. Listings of the default file and the final output file from the expert system are given in Appendix B.

Now we are left with two files (one each from the student and the expert system) with 252 entries each, which are compared, resulting in percentage

points being awarded to the student. The source code for this string manipulation program is given at the end of this chapter.

2. *The EKG Display Program*

This is a small graphic display program written in Basic that enables the display of EKG files that are stored in the EKG database in the form of rectangular coordinates. The waveform is displayed on a grid which helps the student read off the lengths/amplitudes of the various intervals/peaks in the waveform. Care is taken to see that the display on the screen corresponds in ratio to that obtained on standard EKG recording paper. The source code for this program is given at the end of this chapter.

3. *Multiple Cycle Generating Program*

This program is written in Pascal and is used to make proper utilization of the available memory on the EKG database disks. The EKG files that are repetitive, i.e, possessing identical cycles, are stored in the EKG database in a single cycle format. Thus the multiple cycle generation program picks out the single cycle from the EKG database and replicates it into a 4 cycle format, making it suitable for display on the screen. The source code for this program is given at the end of this chapter.

4. *The Analog to Digital Conversion Program*

This program is written in Microsoft QuickBasic [16], which is a Basic compiler written in C. As described in chapter 3, this program is for use with the DASH-8 [12] analog to digital converter board for the IBM-PC. Analog EKG signals are generated by an EKG simulator which have to be converted to digital form to enable storage in the computer. Hence this analog signal is fed through the DASH-8 board which, with the help of this program converts the analog signal into digital form. A detailed explanation of the setup was given in chapter 3.

This program loads the call routine in the DASH-8 board, initializes the system, prompts the user to select an appropriate sampling rate and then starts the analog to digital conversion. This is a general purpose program that can be used for the frequency range 37 Hz to 1 MHz.

In this thesis, a 220 Hz sampling rate was used and the analog signal was converted to a 640 point digital output file, which is ideal for display on a standard computer terminal. The source code of this program is given at the end of this chapter.

```
{The string manipulation program.}


program all (input,output);



(*******************************************************)


{ This proc. takes the input from result.pro, which is}
{ the result from the prolog program and creates a new  }
{ output file called inter1.pas (y/n).}


procedure proc1;

var
a:string[100];
b:string[9];
f1,f2 :text;
i,pts :integer;
d : char;


begin
assign(f1, 'result.pro');
assign(f2, 'inter1.pas');
rewrite (f2); reset(f1);

while not eof(f1) do
begin
readln(f1,a);
b:= copy(a,1,9);
if (b = 'xpositive')
then  d:='y'
  else begin
  if (b = 'xillness_') then d:='y' else d:='n'; end;
    writeln(f2,d,'     ',copy(a,(length(a)-4),3));
  end;



  close(f2);
end;


(*******************************************************)


{ This proc. uses inter1.pas and outputs inter2.pas which }
{ has Y/N in the e-1th place and is also devoid of 500+ #.}
```

```
procedure proc2;

var
b:string[1];
d:string[1];
f2,f3 :text;
e :integer;

begin
assign(f2, 'inter1.pas');
assign(f3, 'inter2.pas');
rewrite(f3); reset(f2);


while not eof(f2) do
begin
readln(f2,b,e);
if (b = 'y') and (e < 500)
then
begin
d := 'Y';
writeln(f3,d,'    ',e-1);
         writeln(f3,b,'    ',e);
        end;
       if (b = 'n') and (e < 500)
       then
         begin
           d := 'N';
           writeln(f3,d,'    ',e-1);
           writeln(f3,b,'    ',e);
       end;
        end;
        close(f3);


end;


(*********************************************************)


{ This proc. creates an array file new.pas with either Y/N}
{ or y/n  OR an 'x' to indicate a blank.-- slots}


procedure proc3;

type
a = array[1..254] of string[4];
c = array[1..254] of char;
```

```
var
x : a;
b:c;
f2,f3 :text;
arr : array [1..254] of integer;
k,e,i :integer;
test1,test2,test3,test6,test7,test8,test9, test10 : char;
rep1,rep2,rep4,rep5,rep6,rep7,rep8,rep9,rep10,
rep11,rep12,rep13,rep14,rep15,rep16,rep17,rep18,
rep19,rep20,rep21,rep22,rep23,rep24,rep25,rep26,rep27,rep28,
rep29,rep30,rep31,rep32,rep33,rep34,rep35,rep36,rep37 :
string[4];


(* Main program *)

begin
assign(f2, 'inter2.pas');
  assign(f3, 'new.pas');
  rewrite(f3); reset(f2);

(* Here, i is the length of the default file *)

for i := 1 to  254 do
 x[i] := 'x';

i := 0;
while not eof(f2) do
  begin
     i := i + 1;
     readln (f2, b[i], arr[i]);
  end;

for k := 1 to i  do
  begin
    x[arr[k]] := b[k];
  end;

(* Tester inputs are requested first *)

clrscr; gotoxy(15,3); write('If invalid question, enter x');
gotoxy(5,15); write('Is P-P rate > 60 BPM (y/n)?  ');
read(test1);

clrscr; gotoxy(15,3); write('If invalid question, enter x');
gotoxy(5,15); write('Is P-P rate < 100 BPM (y/n)?  ');
read(test2);

clrscr; gotoxy(15,3); write('If invalid question, enter x');
gotoxy(5,15); write('Is QRS duration <= 0.1 sec. (y/n)?  ');
read(test3);

clrscr; gotoxy(15,3); write('If invalid question, enter x');
```

```
                gotoxy(5,15); write('Is PR interval duration >= 0.12 sec.
 (y/n)?  ');
                read(test6);

                clrscr; gotoxy(15,3); write('If invalid question, enter x');
                gotoxy(5,15); write('Is PR interval duration <= 0.2 (y/n)?
 ');
                read(test7);

                clrscr; gotoxy(15,3); write('If invalid question, enter x');
                gotoxy(5,15);
                writeln('Is QT > 0.375 R-R but < 0.5 R-R rate for HR 65-90 bpm
 (y/n)? ');
                read(test8);

                clrscr; gotoxy(15,3); write('If invalid question, enter x');
                gotoxy(5,15);
                writeln('Has the illness been diagnosed as :');
                write('ventricular enlargement or ischemia or injury or in-
 farction (y/n)? ');
                read(test9);

                clrscr; gotoxy(15,3); write('If invalid question, enter x');
                gotoxy(5,15);
                writeln('Has the illness been diagnosed as :');
                write('ischemia or injury or infarction (y/n)? ');
                read(test10);


                (* User input of the rules *)

                clrscr; gotoxy(15,3); write('If invalid question, enter x');
                gotoxy(5,15); write('Inspiration/expiration marks (y/n)? ');
                read(rep1); x[2] := rep1;
                if x[2]='y' then x[1]:='Y' else x[1]:='N';

                clrscr; gotoxy(15,3); write('If invalid question, enter x');
                gotoxy(5,15); write('Baseline stable (y/n)? ');
                read(rep2); x[4]:= rep2;
                if x[4]='y' then x[3]:='Y' else x[3]:='N';

                clrscr; gotoxy(15,3); write('If invalid question, enter x');
                gotoxy(5,15);
                writeln('P wave
'rounded/notched/biphasic/peaked/flattened/sawtoothed');
                writeln(' Enter 1/2/3/4/5/6 ' ); read(rep4);  x[19]:=rep4;

                clrscr; gotoxy(15,3); write('If invalid question, enter x');
                gotoxy(5,15); write('P-P rate in BPM '); read(rep5);
 x[20]:=rep5;

                clrscr; gotoxy(15,3); write('If invalid question, enter x');
                gotoxy(5,15); write('P wave amplitude (mV)? '); read(rep6);
 x[21]:=rep6;
```

```
                clrscr; gotoxy(15,3); write('If invalid question, enter x');
                gotoxy(5,15);
                write('Enter heartrate in BPM '); read(rep28); x[111]:=rep28;

                clrscr; gotoxy(15,3); write('If invalid question, enter x');
                gotoxy(5,15);
                write('QRS complex upright and similar (y/n)? '); read(rep29);
x[223]:=rep29;
                if x[223]='y' then x[222]:='Y' else x[222]:='N';

                clrscr; gotoxy(15,3); write('If invalid question, enter x');
                gotoxy(5,15);
                write('QRS duration acceptable (y/n)? '); read(rep30);
x[225]:=rep30;
                if x[225]='y' then x[224]:='Y' else x[224]:='N';

                clrscr; gotoxy(15,3); write('If invalid question, enter x');
                gotoxy(5,15);
                write('T wave upright,rounded,assymetrical and similar (y/n)?
');
                read(rep31); x[227]:=rep31;
                if x[227]='y' then x[226]:='Y' else x[227]:='N';

                clrscr;  gotoxy(15,3); write('If invalid question, enter x');
                gotoxy(5,15);
                write('QT interval duration normal (y/n)? '); read(rep32);
x[239]:=rep32;
                if x[239]='y' then x[238]:='Y' else x[238]:='N';

                clrscr; gotoxy(15,3); write('If invalid question, enter x');
                gotoxy(5,15);
                write('If premature,P wave different shape than others(y/n)?
');
                read(rep33); x[241]:=rep33;
                if x[241]='y' then x[240]:='Y' else x[240]:='x';

                clrscr; gotoxy(15,3); write('If invalid question, enter x');
                gotoxy(5,15);
                write('P-P rate between 150 and 250 BPM (y/n)?  ');
read(rep34);x[245]:=rep34;
                if x[245]='y' then x[244]:='Y' else x[244]:='N';

                clrscr; gotoxy(15,3); write('If invalid question, enter x');
                gotoxy(5,15);
                write('Number of P waves on the strip ? '); read(rep35);
x[246]:=rep35;

                clrscr; gotoxy(15,3); write('If invalid question, enter x');
                gotoxy(5,15);
                write('P wave not followed by QRS complexes (Enter ***> Y/N)?
');
                read(rep36); x[247]:=rep36;
```

```
clrscr; gotoxy(15,3); write('If invalid question, enter x');
gotoxy(5,15);
write('Block ratio in II degree block ?  '); read(rep37);
x[252]:=rep37;


(* Rules can be written here *)

if (x[12]='n') then
   begin
      x[13]:='N';
      x[14]:='n';
      x[15]:='N';
      x[16]:='n';
      x[17]:='N';
      x[18]:='n';
      x[19]:='0';
      x[20]:='000';
      x[21]:='000';
      x[22]:='000';
      x[23]:='N';
      x[24]:='n';
      x[25]:='N';
      x[26]:='n';
      x[29]:='N';
      x[30]:='n';
      x[69]:='N';
      x[70]:='n';
      x[71]:='N';
      x[72]:='n';
      x[73]:='0';
      x[74]:='0';
      x[75]:='0';
      x[76]:='N';
      x[77]:='n';
      x[78]:='0';
      x[87]:='N';
      x[88]:='n';
      x[89]:='N';
      x[90]:='n';
      x[91]:='0';
      x[92]:='0';
      x[93]:='0';
      x[98]:='N';
      x[99]:='n';
      x[236]:='N';
      x[237]:='n';
      x[216]:='N';
      x[217]:='n';
      x[218]:='N';
      x[219]:='n';
      x[240]:='N';
      x[241]:='n';
      x[242]:='N';
```

```
      x[243]:='n';
      x[244]:='N';
      x[245]:='n';
      x[248]:='N';
      x[249]:='n';
      x[250]:='N';
      x[251]:='n';
      x[253]:='N';
      x[254]:='n';
      end;



if ((x[12]='y')or(x[12]='x')) and
        ((x[14]='y')or(x[14]='x')) and
        ((x[16]='y')or(x[16]='x')) and
        ((x[18]='y')or(x[18]='x')) and
        ((x[19]='1')or(x[19]='x')) and
        ((x[24]='y')or(x[24]='x')) and
        ((x[254]='y')or(x[254]='x')) and
        ((x[217]='y')or(x[217]='x')) and
        ((x[219]='y')or(x[219]='x')) and
        (test1='y') and
(test2='y') then begin
                x[112]:='Y';
                x[113]:='y';
                end
                else begin
                x[112]:='N';
                x[113]:='n';
                end;


if ((x[32]='y')or(x[32]='x')) and
        ((x[34]='y')or(x[34]='x')) and
        ((x[39]='y')or(x[39]='x')) and
        ((x[37]='n')or(x[37]='x')) and
        ((x[51]='n')or(x[51]='x')) and
        ((x[221]='n')or(x[221]='x')) and
        (test3='y') then begin
                x[114]:='Y';
                x[115]:='y';
                end
                else begin
                x[114]:='N';
                x[115]:='n';
                end;


if ((x[55]='y')or(x[55]='x')) and
        ((x[57]='y')or(x[57]='x')) and
        ((x[59]='y')or(x[59]='x')) and
        ((x[61]='y')or(x[61]='x')) and
```

```
                x[199]:='y';
                x[200]:='Y';
                x[201]:='y';
                x[202]:='Y';
                x[203]:='y';
                end;

              if (test10='y')
                    then begin
                    x[198]:='Y';
                    x[199]:='y';
                    x[200]:='Y';
                    x[201]:='y';
                    x[202]:='Y';
                    x[203]:='y';
                    end;


              (* The required output file is created here *)

              for k := 1 to 254 do
                       writeln (f3,x[k]);

                      close(f3);
                      end;


(*****************************************************************)

              { This program compares new.pas with the default file de-
fault.pas}
              { and creates a new file,  which is the final desired output.}



              procedure proc4;

              var
              d : array[1..254] of string[4];
              n : array[1..254] of string[4];
              i :integer;
              str1 : string[15];
              f1, f2, f3 :text;

              begin
              assign (f1, 'default.pas');
              assign (f2, 'new.pas');
              clrscr;gotoxy(5,5); write('Type the name of the output file :
');
              read(str1);
              assign (f3,str1);
              reset(f1);
```

```
reset (f2);
rewrite (f3);

(* Main program *)

for i := 1 to 254 do
       begin
        readln(f1,d[i]);
         readln(f2,n[i]);

        if n[i] = 'x' then
begin
        writeln(f3,d[i]);
        end;
        if d[i] = n[i] then
        begin
        writeln(f3,d[i]);
        end;
        if (d[i] <> n[i])and (n[i] <> 'x') then
        begin
         writeln(f3,n[i]);
        end;

end;
        close(f3);
end;

(*************************************************************)


(* MAIN PROGRAM which calls the procedures one by one. *)

begin
proc1;
proc2;
proc3;
proc4;
end.
```

```
 10 CLS
 20 DIM B(650)
 30 SCREEN 2
 35 INPUT "PLEASE TYPE IN THE INPUT FILENAME : ";N$
 40 OPEN "I",#1,N$
 50 FOR N=1 TO 640
 60 INPUT #1,B(N)
 70 PSET (N,B(N))
 75 LINE (N,B(N))-(N-1,B(N-1))
 80 NEXT N
 90 FOR X=0 TO 600 STEP 50
100 LINE (X,25)-(X,150)
110 NEXT X
120 FOR Y=25 TO 150 STEP 25
130 LINE (0,Y)-(640,Y)
140 NEXT Y
```

```
{This is the short program used to generate multiple}
{cycles of a repetitive EKG strip. Such a program is}
{useful as it saves valuable disk space.}


program convert (input , output);
type
 a = array [1..200] of real;
var
  xa,ya,xb,xc,xd : a;
  f1 : text;
  f2 : text;
  str1 : string[20];
  str2 : string[20];
  i, pts : integer;

begin
 clrscr;
 gotoxy (5,5); write ('Input Filename : ');
 read (str1);
 gotoxy (5,6); write ('Output Filename: ');
 read (str2);
 assign(f1,str1); reset(f1);
 pts := 0;
while not eof(f1) do
 begin
   pts := pts + 1;
   readln (f1,xa[pts],ya[pts]);
 end;
writeln;
assign(f2,str2); rewrite (f2);
for  i := 1 to pts do
    xb[i] := xa [i] + xa[pts];
for i := 1 to pts do
    writeln (f2,xa[i]:8:4,' ',ya[i]:8:4);
for i := 1 to pts do
    writeln (f2,xb[i]:8:4,' ',ya[i]:8:4);
for i := 1 to pts do
    xc[i] := xb[i] + xa[pts];
for i := 1 to pts do
    writeln (f2,xc[i]:8:4,' ',ya[i]:8:4);
for i := 1 to pts do
    xd[i] := xc[i] + xa[pts];
for i := 1 to pts do
    writeln (f2,xd[i]:8:4,' ',ya[i]:8:4);
close(f2);
end.
```

```
1 'program name ekgdraw
10 'THIS PROGRAM LOADS THE CALL ROUTINE, INITIALIZES, ALLOWS THE USER TO
20 'SELECT THE A/D SAMPLING RATE AND STARTS THE A/D CONVERSION
30 'LOADING AND INITIALIZATION
40 DIM A%(7500)
45 DIM B(7500)
50 DEF SEG = &H3000
60 BLOAD "DASH8.BIN",0
70 OPEN "DASH8.ADR" FOR INPUT AS #1
80 INPUT #1, BASADR%
90 CLOSE #1
100 DASH8 = 0
110 FLAG% = 0
120 MD% = 0
130 CALL DASH8 (MD%, BASADR%, FLAG%)
135 INPUT "TYPE FILE NAME";N$
140 'SELECT SAMPLING RATE
150 INPUT "Desired output frequency in Hz? (Range 37 - 1,000,000): ",FREQ
160 IF FREQ <37 THEN PRINT:PRINT"Frequency too low":PRINT:GOTO 150
170 IF FREQ > 1000000! THEN PRINT:PRINT"Frequency too high":PRINT:GOTO 150
180 DIVIDER = 2386400! / FREQ : DIVIDER = INT(DIVIDER + .5)
190 PRINT:PRINT USING "Actual output frequency will be #######.## Hz";2386400
IVIDER
200 'SET UP COUNTER 2
210 DIO%(0) = 2
220 DIO%(1) = 3
230 MD% = 10
240 CALL DASH8 (MD%, DIO%(0), FLAG%)
250 IF DIVIDER > 32767 THEN DIVIDER = DIVIDER - 65536!
260 DIO%(1) = DIVIDER
270 MD% = 11
280 CALL DASH8 (MD%,DIO%(0), FLAG%)
290 MD% = 1: LT%(0) = 7 : LT%(1) = 7
300 CALL DASH8(MD%, LT%(0), FLAG%)
310 MD% = 2 : CH% = 7
320 CALL DASH8 (MD%, CH%, FLAG%)
330 'START A/D CONVERSION
340 INPUT "Number of conversions desired? ", N
350 PRINT "Converted data appears in A%(J)"
360 MD% = 5
370 TRAN%(0) = VARPTR(A%(0))
380 TRAN%(1) = N
390 FLAG% = 0
400 CALL DASH8(MD%, TRAN%(0), FLAG%)
410 SCREEN 2
415 CLS
420 FOR N=1 TO 640
430 B(N)=(A%(N)+2050)/20
440 PSET (N,B(N))
450 NEXT N
460 OPEN "O",#1,N$
470 FOR N=1 TO 640
480 PRINT #1,B(N)
490 NEXT N
500 CLOSE #1
510 END
```

Appendix B

Source code and Test Run of the Expert System

An example diagnosis is presented in the next few pages. The example chosen here is Normal Sinus Rhythm. The following is the order in which it is presented :

1) The EKG strip to be diagnosed.

2) A portion of the consultation session with the expert system.

3) A listing of all the clauses (137 of them) used in the EKGCHALLENGER.

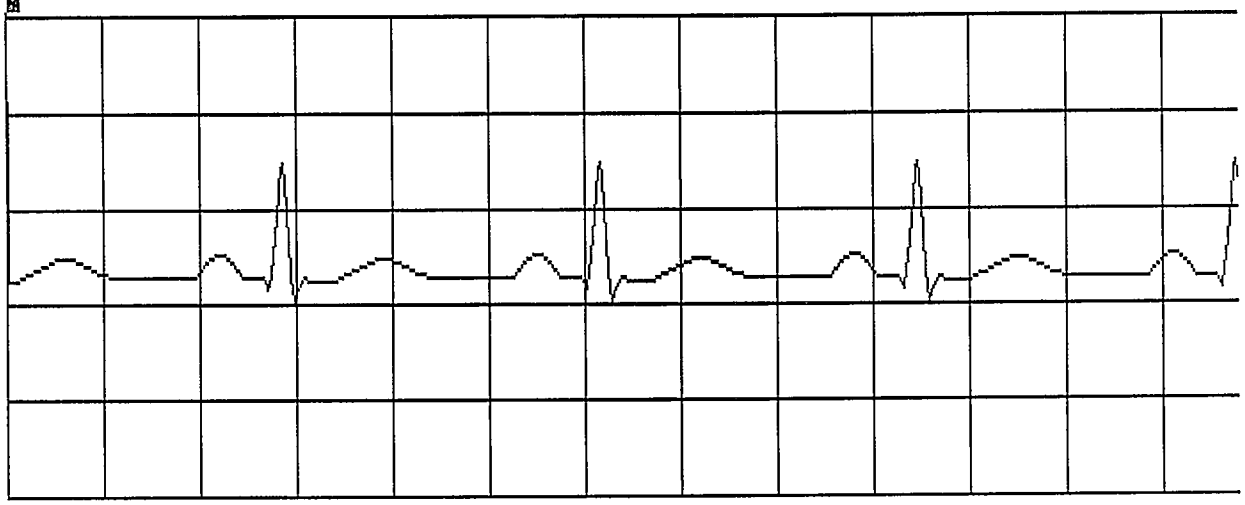
4) The output file generated by the expert system after the consultation, namely 'result.pro'.

5) The default file used for comparison and augmentation of 'result.pro'.

6) The array format created by the string manipulation program after processing 'result.pro' and comparing it with the default file called 'default.pas'. This is the final output file that holds the 'expert opinion' on the particular EKG strip, normal sinus rhythm in this case.

7) Source code, in Prolog, of the expert system.

```
PLEASE TYPE IN THE INPUT FILENAME : ? b:a01.dat
Ok
```



```
1LIST   2RUN←   3LOAD"  4SAVE"  5CONT←  6,"LPT1 7TRON←  8TROFF← 9KEY    0SCREEN
```

```
ARRHYTHMIA EXPERT

* * * * * * * * * * * * * * * * * * * * * * * *
* WELCOME TO THE ARRHYTHMIA DETECTION SYSTEM  *
*                                             *
*  This is an arrhythmia identification       *
*  system. Please respond by typing in        *
*  'y' for yes and 'n' for no.                *
*                                             *
*  Thank You !!                               *
* * * * * * * * * * * * * * * * * * * * * * * *

Question :-- is the person using cardiac drugs ? n
Question :-- is the P wave present ? y
Question :-- is the P wave upright ? y
Question :-- is the P wave monophasic ? y
Question :-- is the P wave rounded ? y
Question :-- is the P wave amplitude not > 0.3 mV ? y
Question :-- is the P wave duration not > 0.12 sec. ? y
Question :-- is the P wave all similar ? y
Question :-- is the P wave ahead of the QRS ? y
Question :-- is the P wave present in each cycle ? y
Question :-- is the QRS complex present ? y
Question :-- is the QRS complex upright ? y
```

Clauses / Queries used in the EKGCHALLENGER

1. Inspiration / expiration marks ?
2. Baseline stable ?
3. Accelerated rhythm with sudden on / off ?
4. Pause in rhythm ?
5. Cardiac drugs in use ?
6. P waves present ?
7. P waves all similar ?
8. P waves upright ?
9. P waves monophasic ?
10. P waves rounded/notched/biphasic/peaked/flattened/sawtoothed ?

Enter 1, 2, 3, 4, 5, 6.

11. P wave rate in BPM ?
12. P wave amplitude (mV) ?
13. P wave duration (sec.) ?
14. P wave ahead of the QRS complex ?
15. P wave premature ?
16. P wave, if premature, followed by pause ?
17. P wave rate between 250-350 BPM ?
18. QRS complex present ?
19. QRS complex upright ?
20. QRS duration (sec.) ?
21. QRS complex with R-R' ?
22. QRS complex all similar ?

23. QRS complex with premature beat ?

24. QRS complex with fusion beat ?

25. QRS complex with capture beat ?

26. QRS complex with interpolated beat ?

27. QRS complex with escape beat ?

28. QRS complex with significant Q's ?

29. PVC's ? Unifocal/multifocal/bigeminy/trigeminy/1:2 trigeminy/2:1 trigeminy /3:1 quadrigeminy , enter 1, 2, 3, 4, 5, 6.

30. T waves present ?

31. T waves upright ?

32. T waves rounded and assymetrical ?

33. T waves all similar ?

34. T wave amplitude (mV) ?

35. T wave duration (sec.) ?

36. U waves present ?

37. U waves upright and similar ?

38. U wave amplitude (mV) ?

39. PR interval present ?

40. PR interval constant ?

41. If PR interval constant, then duration (sec.) ?

42. If PR interval varying, then shortest duration (sec.) ?

43. If PR interval varying, then longest duration (sec.) ?

44. PR segment present ?

45. PR segment is isoelectric/elevated/depressed/sagging ? Enter 1, 2, 3, or 4.

46. ST segment present ?

47. ST segment is isoelectric/elevated/depressed/sagging ? Enter 1, 2, 3, or 4.

48. QT interval present ?

49. QT interval duration (sec.) ?

50. P-P interval present ?

51. P-P regular ?

52. If regular, P-P duration (sec.) ?

53. If irregular, P-P shortest (sec.) ?

54. If irregular, P-P longest (sec.) ?

55. P-P showing pause followed by return to NSR ?

56. P-P cyclical variation ?

57. Long P-P a multiple of short P-P ?

58. R-R interval present ?

59. R-R interval regular ?

60. If regular, R-R duration (sec.) ?

61. If irregular, shortest R-R (sec.) ?

62. If irregular, longest R-R (sec.) ?

63. R-R cyclical variation ?

64. Long R-R a multiple of short R-R ?

65. Enter heartrate (BPM).

66. P wave normal ?

67. QRS complex normal ?

68. T wave normal ?

69. U wave normal ?

70. PR interval normal ?

71. PR segment normal ?

72. ST segment normal ?

73. QT interval normal ?

74. Heartbeat normal ?

75. Normal Sinus Rhythm ?

76. Tachycardia ?

77. Bradycardia ?

78. Sinus arrhythmia ?

79. Sinus block ?

80. Sinus arrest ?

81. Wandering atrial pacemaker ?

82. Premature atrial contraction ?

83. Paroxysmal atrial tachycardia ?

84. Atrial flutter ?

85. Atrial fibrillation ?

86. Junctional rhythm ?

87. Junctional escape beat ?

88. Premature junctional contraction ?

89. Junctional tachycardia ?

90. I degree heart block ?

91. Wenckebach ?

92. Mobitz II ?

93. III degree heart block ?

94. Idioventricular rhythm ?

95. Accelerated idioventricular rhythm ?

96. Ventricular tachycardia ?

97. Wolff-Parkinson-White ?

98. Bundle branch block ?

99. Premature ventricular contraction ?

100. Paroxysmal ventricular tachycardia ?

101. Ventricular tachycardia with fusion beat ?

102. Ventricular tachycardia with capture beat ?

103. Ventricular flutter ?

104. Ventricular fibrillation ?

105. Left atrial enlargement ?

106. Right atrial enlargement ?

107. Biatrial enlargement ?

108. Ventricular enlargement ?

109. Ischemia ?

110. injury ?

111. Infarction ?

112. Hypocalcemia ?

113. Hypercalcemia ?

114. Hypokalemia ?

115. Hyperkalemia ?

116. Digitalis ?

117. Quinidine / Propranolol ?

118. P wave amplitude not greater than 0.3 mV ?

119. P wave duration not greater than 0.12 sec ?

120. QRS complex with some missing ?

121. QRS complex upright and similar ?

122. QRS duration acceptable ?

123. T wave upright, rounded, assymetrical and similar ?

124. T wave amplitude less than or equal to 0.5 mV ?

125. T wave amplitude greater than that of U wave ?

126. T wave duration less than or equal to 0.2 sec. ?

127. U wave amplitude less than that of T wave ?

128. P-P equal to R-R ?

129. QT interval duration normal ?

130. Premature P wave different shape than others ?

131. P wave, after pause, return to NSR ?

132. P-P rate between 150-250 BPM ?

133. Number of P waves on the strip ?

134. P wave not followed by QRS complexes ?

135. PR interval short ?

136. PR interval prolonged ?

137. Block ratio in II degree block ?

```
        xpositive("is","P wave present","012")
        xpositive("is","P wave upright","016")
        xpositive("is","P wave monophasic","018")
        xpositive("is","P wave rounded","599")
        xpositive("is","P wave amplitude not > 0.3 mV","217")
        xpositive("is","P wave duration not > 0.12 sec.","219")
        xpositive("is","P wave all similar","014")
        xpositive("is","P wave ahead of the QRS","024")
        xpositive("is","P wave present in each cycle","254")
        xpositive("is","QRS complex present","032")
        xpositive("is","QRS complex upright","034")
        xpositive("is","QRS complex duration <= 0.1 sec","565")
        xpositive("is","QRS complex all similar","039")
        xpositive("is","T wave present","055")
        xpositive("is","T wave upright","057")
        xpositive("is","T wave rounded and assymetrical","059")
        xpositive("is","T wave all similar","061")
        xpositive("is","T wave duration <= 0.2 sec.","233")
        xpositive("is","T wave amplitude <= 0.5 mV","229")
        xpositive("is","PR interval present","070")
        xpositive("is","PR interval < 0.12 sec","249")
        xpositive("is","ST segment present","081")
        xpositive("is","ST segment isoelectric","571")
        xpositive("is","QT interval present","085")
        xpositive("is","QT > 0.5 R-R for heartrate between 65-90 BPM","900")
        xnegative("is","person using cardiac drugs","010")
        xnegative("is","QRS complex with some missing","221")
        xnegative("is","QRS with R-R'","037")
        xnegative("is","QRS with significant Q's","051")
        xnegative("is","U wave present","065")
        xnegative("is","QT > 0.375 R-R but < 0.5 R-R for HR of 65-90
BPM","573")
        xillness_is("hypocalcemia","205")
```

This is the default file used to augment the output generated by the expert system, by comparing and superimposing.

N
n
Y
y
N
n
N
n
N
n
Y
y
Y
y
Y
y
Y
y
1
000
000
000
Y
y
N
n
Y
y
N
n
Y
y
Y
y
0.09
N
n
Y
y
N
n
N
n

N
n
N
n
N
n
N
n
N
n
Y
y
Y
y
Y
y
Y
y
000
000
N
n
Y
y
000
Y
y
Y
y
0.15
0.15
0.15
Y
Y
1
?
Y
Y
1
?
Y
y
0.91
Y
Y
Y
y
0.91
0.91
0.91
N
n
N
n

Y
y
Y
y
Y
y
0.91
0.91
0.91
N
n
Y
y
0.90
Y
y
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y
Y
y
Y
y
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y
Y
N
n
000
N
N
n
N
n
000
Y
y

This is the final output file generated for the condition "normal sinus rhythm" after passing through both the expert system and the string manipulation program.

```
N
n
Y
y
N
n
N
n
N
n
Y
y
Y
y
Y
y
Y
y
1
65
.1
.1
Y
y
N
n
Y
y
N
n
Y
y
Y
y
.12
N
n
Y
y
N
```

n
N
n
N
n
N
n
N
n
N
n
N
n
Y
y
Y
y
Y
y
Y
y
.23
.2
Y
y
Y
y
.12
Y
y
Y
y
.2
0.15
0.15
Y
y
1
?
Y
y
1
?
Y
y
.2
Y
y
Y
y
.23
0.91
0.91
N

n
N
n
Y
y
Y
y
Y
y
.92
0.91
0.91
N
n
Y
y
77
Y
y
Y
y
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Y
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Y
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```
code=3000

domains


database

  xpositive(symbol,symbol,symbol)
  xnegative(symbol,symbol,symbol)
  xillness_is(symbol,symbol)

predicates


  do_expert_job
  do_consulting
  illness_is(symbol,symbol)
  ask(symbol,symbol,symbol)
  it_is(symbol)
  positive(symbol,symbol,symbol)
  negative(symbol,symbol,symbol)
  remember(symbol,symbol,symbol,symbol)
  clear_facts
  redo
  run_again(symbol)



goal
  do_expert_job.

clauses

/* USER INTERFACE SYSTEM */

do_expert_job :-
   makewindow(1,7,7,"ARRHYTHMIA EXPERT",0,0,25,80),
   nl,write("* * * * * * * * * * * * * * * * * * * * * * * * * *
*"),
   nl,write("* WELCOME TO THE ARRHYTHMIA DETECTION SYSTEM
*"),
   nl,write("*
*"),
   nl,write("*  This is an arrhythmia identification
*"),
   nl,write("*  system. Please respond by typing in
*"),
   nl,write("*  'y' for yes and 'n' for no.
*"),
   nl,write("*
*"),
   nl,write("*  Thank You !!
*"),
```

```
   nl,write("* * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*"),
   nl,nl,
   do_consulting,
   write("    Press the space bar. "),
   readchar(_),
   clearwindow,
   exit.

do_consulting :-
   illness_is(O,P), assertz( xillness_is(O,P)),!,
   nl,write("The condition maybe ",O,"."),
   nl,clear_facts.



do_consulting :-
   nl,write("Sorry, I'm unable to determine this condition."),
   nl, clear_facts.



ask(X,Y,Z) :-
  write("Question :-- ",X," the ",Y," ","?"," "),
  readln(Reply),
  remember(X,Y,Z,Reply).

/* INFERENCE ENGINE */


positive(X,Y,Z) :-
   xpositive(X,Y,Z), !.

positive(X,Y,Z) :-
  not(negative(X,Y,Z)),!,
  ask(X,Y,Z).



negative(X,Y,Z) :-
  xnegative(X,Y,Z),!.

remember(X,Y,Z,y) :-
  assertz( xpositive(X,Y,Z)).

remember(X,Y,Z,n) :-
  assertz(xnegative(X,Y,Z)),
  fail.



clear_facts :-
  nl,write("I have saved the diagnostic conditions"),
```

```
   nl,write("in a file called 'result.pro'."),
/*  readln(Filename),*/
   save("result.pro"),
/*  retract(xnegative(_,_)),*/
   retract(xpositive(_,_,_)),
   fail.

clear_facts :-
    retract(xnegative(_,_,_)),
    retract(xillness_is(_,_)),
    fail.

clear_facts :-
    nl,nl, write("Program finished."),
    nl,nl,redo.

redo :-
  write("Run the program again (y/n) ? "),
  readln(Response),
  run_again(Response).

run_again(y) :-
  nl,nl,
  do_expert_job.

run_again(n) :-
  nl,nl.



/* PRODUCTION RULES */


/* Rhythms*/

illness_is("normal sinus rhythm","131") :-
  it_is("heartbeat normal"),
  positive(is,"P-P regular","090"),
  positive(is,"R-R regular","103"),
  it_is("P-P equal to R-R"),
  positive(is,"BPM between 60 and 100","501"), !.

illness_is("tachycardia","133") :-
  it_is("heartbeat normal"),
  positive(is,"P-P regular","090"),
  positive(is,"R-R regular","103"),
  it_is("P-P equal to R-R"),
  positive(is,"BPM > 100","503"), !.

illness_is("bradycardia","135") :-
  it_is("heartbeat normal"),
  positive(is,"P-P regular","090"),
  positive(is,"R-R regular","103"),
  it_is("P-P equal to R-R"),
```

```
  positive(is,"BPM < 60","505"), !.

illness_is("sinus arrhythmia","137") :-
  it_is("heartbeat normal"),
  not(positive(is,"P-P regular","090")),
  not(positive(is,"R-R regular","103")),
  positive(is,"P-P varying cyclically","097"),
  positive(is,"R-R varying cyclically","108"),
  it_is("P-P equal to R-R"), !.

illness_is("sinus block","139") :-
  it_is("heartbeat normal"),
  not(positive(is,"P-P regular","090")),
  not(positive(is,"R-R regular","103")),
  it_is("long P-P a multiple of the short P-P"),
  it_is("long R-R a multiple of the short R-R"),
  it_is("P-P equal to R-R"), !.

illness_is("sinus arrest","141") :-
  it_is("heartbeat normal"),
  not(positive(is,"P-P regular","090")),
  not(positive(is,"R-R regular","103")),
  it_is("long P-P not a multiple of the short P-P"),
  it_is("long R-R not a multiple of the short R-R"),
  it_is("P-P equal to R-R"), !.

/************************************************/

/***** Drug Effects ****************/


illness_is("effect of quinidine/propranolol","215") :-
  positive(is,"person using cardiac drugs","010"),
  not(it_is("P wave rounded")),
  positive(is,"P wave notched","541"), !.

illness_is("effect of quinidine/propranolol","215") :-
  positive(is,"person using cardiac drugs","010"),
  not(positive(is,"P wave duration not > 0.12 sec.","219")),


illness_is("effect of quinindine/propranolol","215") :-
  positive(is,"person using cardiac drugs","010"),
  it_is("T wave inverted"), !.

illness_is("effect of quinidine/propranolol","215") :-
  positive(is,"person using cardiac drugs","010"),
  not(positive(is,"T wave rounded and assymetrical","059")),
  positive(is,"T wave notched","755"), !.

illness_is("effect of quinidine/propranolol","215") :-
  positive(is,"person using cardiac drugs","010"),
  positive(is,"T wave present","055"),
  positive(is,"U wave present","065"),
```

```
                not(it_is("T wave amplitude > than that of U wave")), !.


              illness_is("effect of quinidine/propranolol","215") :-
                positive(is,"person using cardiac drugs","010"),
                it_is("ST segment depressed"), !.

              illness_is("effect of digitalis","213") :-
               positive(is,"person using cardiac drugs","010"),
               it_is("ST segment sagging"), !.

              illness_is("effect of digitalis","213") :-
                positive(is,"person using cardiac drugs","010"),
                positive(is,"QRS complex present","032"),
                positive(is,"T wave present","055"),
                positive(is,"QT interval present","085"),
                not(positive(is,"QT > 0.375 R-R but < 0.5 R-R for HR of 65-
90 BPM","573")),
                positive(is,"QT < 0.375 R-R for heartrate between 65-90
BPM","901"), !.

              illness_is("effect of quinidine/propranolol","215") :-
                positive(is,"person using cardiac drugs","010"),
                positive(is,"QRS complex present","032"),
                positive(is,"T wave present","055"),
                positive(is,"QT interval present","085"),
                not(positive(is,"QT > 0.375 R-R but < 0.5 R-R for HR of 65-
90 BPM","573")),
                positive(is,"QT > 0.5 R-R for heartrate between 65-90
BPM","900"), !.



              /********* Quick answer block  I
*****************************/

              /* i have put all the quick triggering questions */
              /* here, in order to avoid unnecessary search. also note */
              /* that these conditions are themselves in order */
              /* i.e, P, QRS, T, ....and so on .*/

              illness_is("atrial fibrillation","151") :-
                 it_is("baseline noisy"),
                 positive(is,"QRS complex present","032"), !.

              illness_is("ventricular fibrillation","189") :-
                it_is("baseline chaotic"),
                not(positive(is,"QRS complex present","032")), !.

              illness_is("ventricular flutter","187") :-
                it_is("baseline sinusoidal"),
                not(positive(is,"QRS complex present","032")), !.

              illness_is("hyperkalemia","211") :-
```

```
    not(positive(is,"person using cardiac drugs","010")),
    positive(is,"P wave present","012"),
    not(it_is("P wave rounded")),
    positive(is,"P wave flattened","751"), !.

illness_is("bundle branch block","177") :-
    it_is("QRS complex prolonged"),
    positive(is,"QRS with R-R'","037"),!.


illness_is("infarction","203") :-
    not(positive(is,"person using cardiac drugs","010")),
    positive(is,"QRS complex present","032"),
    positive(is,"QRS with significant Q's","051"), !.

/*****************************************************/

/* Atrial Abnormalities*/

illness_is("wandering atrial pacemaker","143") :-
    it_is("P wave of varying shape"),
    it_is("QRS complex normal"),
    positive(is,"P-P regular","090"),
    positive(is,"R-R regular","103"),
    it_is("P-P equal to R-R"),
    positive(is,"BPM between 60 and 100","501"), !.

illness_is("paroxysmal atrial tachycardia","147") :-
    it_is("P wave of varying shape"),
    positive(is,"rhythm accelerated with sudden on/off","006"),
    it_is("P-P equal to R-R"),
    positive(is,"BPM between 150 and 250","507"),!.

illness_is("premature atrial contraction","145") :-
    it_is("P wave of varying shape"),
    positive(is,"P wave premature","026"),
    positive(is,"premature P wave followed by pause ","028"),
    positive(is,"premature P wave returning to NSR after the
pause","243"),
    it_is("QRS complex normal"),!.


/******* Quick trigger block II ***********/

illness_is("ventricular enlargement or ischemia or injury or
infarction","701") :-
    not(positive(is,"person using cardiac drugs","010")),
    it_is("T wave inverted"), !.



illness_is("hyperkalemia","211") :-
    not(positive(is,"person using cardiac drugs","010")),
    positive(is,"T wave present","055"),
```

```
   it_is("P wave not preceding the QRS complex"),
   it_is("QRS complex prolonged"),
   positive(is,"R-R between 20 and 40 BPM","511"), !.

illness_is("accelerated idioventricular rhythm","171") :-
  it_is("P wave not preceding the QRS complex"),
  it_is("QRS complex prolonged"),
  positive(is,"R-R between 40 and 100 BPM","513"), !.

illness_is("ventricular tachycardia","173") :-
  it_is("P wave not preceding the QRS complex"),
  it_is("QRS complex prolonged"),
  positive(is,"R-R > 100 BPM","515"), !.


illness_is("paroxysmal ventricular tachycardia","181") :-
  it_is("QRS complex prolonged"),
  positive(is,"rhythm accelerated with sudden on/off","006"),
  positive(is,"R-R > 100 BPM","515"), !.


illness_is("ventricular tachycardia with fusion beat","183")

  it_is("P wave absent"),
  it_is("QRS complex prolonged"),
  positive(is,"QRS complex with fusion beat","043"),
  positive(is,"R-R > 100 BPM","515"),!.

illness_is("ventricular tachycardia with capture beat","185")

  it_is("P wave absent"),
  it_is("QRS complex prolonged"),
  positive(is,"QRS complex with capture beat","045"),
  positive(is,"R-R > 100 BPM","515"), !.

illness_is("ventricular tachycardia with fusion beat","183")

  positive(is,"P wave present","012"),
  it_is("QRS complex prolonged"),
  positive(is,"QRS complex with fusion beat","043"),
  it_is("PR interval abnormal"),
  positive(is,"R-R > 100 BPM","515"),!.

illness_is("ventricular tachycardia with capture beat","185")

  positive(is,"P wave present","012"),
  it_is("QRS complex prolonged"),
  positive(is,"QRS complex with capture beat","045"),
  it_is("PR interval abnormal"),
  positive(is,"R-R > 100 BPM","515"), !.


illness_is("atrial flutter","149") :-
```

```
    not(it_is("P wave rounded")),
    it_is("P wave sawtoothed"),
    positive(is,"P-P between 250 and 350 BPM","030"),
    it_is("P-P not equal to R-R"), !.


**************************************************************/

    /* Junctional Abnormalities */


illness_is("first degree heart block","161") :-
    it_is("P wave normal"),
    it_is("QRS complex normal"),
    it_is("PR interval prolonged"),
    it_is("P-P equal to R-R"),!.

illness_is("wenckebach","163") :-
    it_is("P wave normal"),
    positive(is,"QRS complex with some missing","221"),
    it_is("PR interval varying"),
    positive(is,"P-P regular","090"),
    not(positive(is,"R-R regular","103")), !.

illness_is("mobitz II block","165") :-
    it_is("P wave normal"),
    positive(is,"QRS complex with some missing","221"),
    positive(is,"P-P regular","090"),
    not(positive(is,"R-R regular","103")),
    it_is("long R-R a multiple of the short R-R"),!.


illness_is("third degree heart block","167") :-
    it_is("P wave normal"),
    it_is("QRS complex normal"),
    positive(is,"P-P regular","090"),
    positive(is,"R-R regular","103"),
    positive(is,"P-P greater than R-R","523"), !.

/******Type I**********************/

illness_is("junctional escape beat","155") :-
    it_is("P wave absent"),
    positive(is,"QRS complex present","032"),
    positive(is,"QRS complex with an escape beat","049"),
    positive(is,"rhythm showing a pause","008"),!.

illness_is("premature junctional contraction","157") :-
    it_is("P wave absent"),
    it_is("QRS complex normal"),
    it_is("PR interval absent"),
    not(positive(is,"R-R regular","103")),
    it_is("long R-R not a multiple of the short R-R"),!.
```

```
illness_is("junctional tachycardia","159") :-
  it_is("P wave absent"),
  it_is("QRS complex normal"),
  it_is("PR interval absent"),
  positive(is,"R-R > 100 BPM","515"),!.


/**********************/


illness_is("premature junctional contraction","157") :-
  it_is("P wave abnormal"),
  it_is("QRS complex normal"),
  it_is("PR interval absent"),
  not(positive(is,"R-R regular","103")),
  it_is("long R-R not a multiple of the short R-R"),!.

illness_is("junctional tachycardia","159") :-
  it_is("P wave abnormal"),
  it_is("QRS complex normal"),
  it_is("PR interval absent"),
  positive(is,"R-R > 100 BPM","515"),!.

/**********************/

illness_is("junctional escape beat","155") :-
  it_is("P wave abnormal"),
  positive(is,"QRS complex present","032"),
  positive(is,"QRS complex with an escape beat","049"),
  it_is("PR interval short"),
  positive(is,"rhythm showing a pause","008"), !.

illness_is("premature junctional contraction","157") :-
  it_is("P wave abnormal"),
  it_is("QRS complex normal"),
  it_is("PR interval short"),
  not(positive(is,"R-R regular","103")),
  it_is("long R-R not a multiple of the short R-R"), !.

illness_is("junctional tachycardia","159") :-
  it_is("P wave abnormal"),
  it_is("QRS complex normal"),
  it_is("PR interval short"),
  positive(is,"R-R regular","103"),
  positive(is,"R-R > 100 BPM","515"),!.

illness_is("junctional rhythm","153") :-
  it_is("P wave absent"),
  it_is("QRS complex normal"),
  positive(is,"R-R < 100 BPM","525"), !.

illness_is("junctional rhythm","153") :-
  it_is("P wave abnormal"),
```

```
  it_is("QRS complex normal"),
  it_is("PR interval short"),
  positive(is,"R-R < 100 BPM ","525"),!.

illness_is("premature ventricular contraction","179") :-
  it_is("QRS complex prolonged"),
  positive(is,"QRS complex with premature beat","041"),
  positive(is,"QRS complex with fusion beat","043"),!.

illness_is("premature ventricular contraction","179") :-
  it_is("QRS complex prolonged"),
  positive(is,"QRS complex with premature beat","041"),
  positive(is,"QRS complex interpolated","047"),!.

illness_is("premature ventricular contraction","179") :-
  it_is("QRS complex prolonged"),
  positive(is,"QRS complex with premature beat","041"),
  positive(is,"wave unifocal","529"),!.

illness_is("premature ventricular contraction","179") :-
  it_is("QRS complex prolonged"),
  positive(is,"QRS complex with premature beat","041"),
  positive(is,"wave multifocal","531"),!.

illness_is("premature ventricular contraction","179") :-
  it_is("QRS complex prolonged"),
  positive(is,"QRS complex with premature beat","041"),
  positive(is,"wave bigeminous","533"),!.

illness_is("premature ventricular contraction","179") :-
  it_is("QRS complex prolonged"),
  positive(is,"QRS complex with premature beat","041"),
  positive(is,"wave 1:2 trigeminous","535"),!.

illness_is("premature ventricular contraction","179") :-
  it_is("QRS complex prolonged"),
  positive(is,"QRS complex with premature beat","041"),
  positive(is,"wave 2:1 trigeminous","537"),!.

illness_is("premature ventricular contraction","179") :-
  it_is("QRS complex prolonged"),
  positive(is,"QRS complex with premature beat","041"),
  positive(is,"wave 3:1 quadrigeminous","539"),!.

illness_is("premature ventricular contraction","179") :-
  it_is("QRS complex prolonged"),
  positive(is,"QRS complex with premature beat","041"),
  it_is("P-P equal to R-R and has a compensatory pause"),!.



/*********************************************************/

  /* Enlarged Hearts */
```

```
illness_is("left atrial enlargement","191") :-
  not(positive(is,"person using cardiac drugs","010")),
  positive(is,"P wave present","012"),
  not(it_is("P wave rounded")),
  positive(is,"P wave notched","541"),
  not(it_is("PR interval short")), !.


illness_is("right atrial enlargement","193") :-
  positive(is,"P wave present","012"),
  not(it_is("P wave rounded")),
  positive(is,"P wave peaked","545"),
  not(it_is("PR interval short")), !.

illness_is("biatrial enlargement","195") :-
  positive(is,"P wave present","012"),
  not(positive(is,"P wave amplitude not > 0.3 mV","217")),
  not(it_is("PR interval short")), !.

illness_is("left atrial enlargement","191") :-
  not(positive(is,"person using cardiac drugs","010")),
  positive(is,"P wave present","012"),
  not(positive(is,"P wave duration not > 0.12 sec.","219")),
  not(it_is("PR interval short")), !.

/***************************/




/*
_____________________________________________________________ */


it_is("P wave rounded") :-
  positive(is,"P wave present","012"),
  positive(is,"P wave rounded","599"), !.


it_is("QRS complex prolonged") :-
  positive(is,"QRS complex present","032"),
  not(positive(is,"QRS complex duration <= 0.1 sec","565")),!.

it_is("heartbeat normal") :-
  not(positive(is,"person using cardiac drugs","010")),
  it_is("P wave normal"),
  it_is("QRS complex normal"),
  it_is("T wave normal"),
  it_is("U wave normal"),
```

```
  it_is("PR interval normal"),
  it_is("PR segment normal"),
  it_is("ST segment normal"),
  it_is("QT interval normal"), !.

it_is("P-P equal to R-R") :-
  positive(is,"P wave present","012"),
  positive(is,"QRS complex present","032"),
  positive(is,"P-P equal to R-R","237"),!.

it_is("P wave not preceding the QRS complex") :-
  positive(is,"P wave present","012"),
  not(positive(is,"P wave ahead of the QRS","024")),!.

it_is("ST segment depressed") :-
  positive(is,"T wave present","055"),
  positive(is,"ST segment present","081"),
  not(positive(is,"ST segment isoelectric","571")),
  positive(is,"ST segment depressed","553"),!.

it_is("ST segment elevated") :-
  positive(is,"T wave present","055"),
  positive(is,"ST segment present","081"),
  not(positive(is,"ST segment isoelectric","571")),
  positive(is,"ST segment elevated","555"),!.

it_is("ST segment sagging") :-
  positive(is,"T wave present","055"),
  positive(is,"ST segment present","081"),
  not(positive(is,"ST segment isoelectric","571")),
  positive(is,"ST segment sagging","752"), !.

it_is("T wave inverted") :-
  positive(is,"T wave present","055"),
  not(positive(is,"T wave upright","057")),!.

it_is("P wave sawtoothed") :-
  positive(is,"P wave present","012"),
  not(positive(is,"P wave rounded","599")),
  positive(is,"P wave sawtoothed","557"), !.



it_is("P wave normal") :-
  positive(is,"P wave present","012"),
  positive(is,"P wave upright","016"),
  positive(is,"P wave monophasic","018"),
  positive(is,"P wave rounded","599"),
  positive(is,"P wave amplitude not > 0.3 mV","217"),
  positive(is,"P wave duration not > 0.12 sec.","219"),
  positive(is,"P wave all similar","014"),
  positive(is,"P wave ahead of the QRS","024"),
  positive(is,"P wave present in each cycle","254"), !.
```

```
it_is("QRS complex normal") :-
  positive(is,"QRS complex present","032"),
  positive(is,"QRS complex upright","034"),
  positive(is,"QRS complex duration <= 0.1 sec","565"),
  positive(is,"QRS complex all similar","039"),
  not(positive(is,"QRS complex with some missing","221")),
  not(positive(is,"QRS with R-R'","037")),
  not(positive(is,"QRS with significant Q's","051")), !.

it_is("T wave normal") :-
  positive(is,"T wave present","055"),
  positive(is,"T wave upright","057"),
  positive(is,"T wave rounded and assymetrical","059"),
  positive(is,"T wave all similar","061"),
  positive(is,"T wave duration <= 0.2 sec.","233"),
  positive(is,"T wave amplitude <= 0.5 mV","229"),
  it_is("T wave amplitude > than that of U wave"), !.

it_is("T wave amplitude > than that of U wave") :-
  positive(is,"U wave present","065"),
  positive(is,"T wave amplitude > than that of U
wave","231"),!.

it_is("T wave normal") :-
  positive(is,"T wave present","055"),
  positive(is,"T wave upright","057"),
  positive(is,"T wave rounded and assymetrical","059"),
  positive(is,"T wave all similar","061"),
  positive(is,"T wave duration <= 0.2 sec.","233"),
  positive(is,"T wave amplitude <= 0.5 mV","229"), !.

it_is("U wave normal") :-
   positive(is,"U wave present","065"),
   positive(is,"U wave upright and similar","067"),
   positive(is,"U wave amplitude < that of T wave","235"),!.

it_is("U wave normal") :-
  it_is("U wave absent"),!.

it_is("U wave absent") :-
   not(positive(is,"U wave present","065")),!.

it_is("PR interval normal") :-
  positive(is,"PR interval present","070"),
  not(it_is("PR interval short")),
  not(it_is("PR interval prolonged")),
  positive(is,"PR interval constant","072"), !.

it_is("PR segment normal") :-
  positive(is,"PR segment present","077"),
  positive(is,"PR segment isoelectric","569"), !.

it_is("ST segment normal") :-
```

```
it_is("long R-R a multiple of the short R-R") :-
   not(positive(is,"R-R regular","103")),
   positive(is,"long R-R a multiple of the short R-
.R","110"),!.

it_is("long P-P not a multiple of the short P-P") :-
  not(it_is("long P-P a multiple of the short P-P")),!.

it_is("long R-R not a multiple of the short R-R") :-
  not(it_is("long R-R a multiple of the short R-R")),!.

it_is("PR interval varying") :-
  not(positive(is,"PR interval constant","072")),!.

it_is("PR interval short") :-
  positive(is,"PR interval present","070"),
  positive(is,"PR interval < 0.12 sec","249"), !.

it_is("PR interval prolonged") :-
  positive(is,"PR interval present","070"),
  positive(is,"PR interval > 0.2 sec","251"),!.

it_is("PR interval abnormal") :-
  not(it_is("PR interval normal")),!.


it_is("baseline noisy") :-
   not(positive(is,"P wave present","012")),
   positive(is,"baseline noisy","509"), !.


it_is("baseline sinusoidal") :-
   not(positive(is,"P wave present","012")),
   positive(is,"baseline sinusoidal","521"), !.


it_is("baseline chaotic") :-
   not(positive(is,"P wave present","012")),
   positive(is,"baseline chaotic","519"), !.


/* End */
```

Appendix C

Arrhythmias Diagnosable by the Expert System

Presented in this appendix are the conditions used by the expert system to diagnose each cardiac condition. Each of them (wherever possible) is accompanied by the actual EKG strip that exhibits the particular condition.

The conditions are stored in the form of three clauses, that is :

a) *xpositive*, where the clauses are positive symptoms of the diagnosed condition.

b) *xnegative*, where the clauses are negative symptoms of the diagnosed condition.

c) *xillness-is*, where the clause states the diagnosed condition.

```
xpositive("is","P wave present","012")
xpositive("is","P wave upright","016")
xpositive("is","P wave monophasic","018")
xpositive("is","P wave rounded","599")
xpositive("is","P wave amplitude not > 0.3 mV","217")
xpositive("is","P wave duration not > 0.12 sec.","219")
xpositive("is","P wave all similar","014")
xpositive("is","P wave ahead of the QRS","024")
xpositive("is","P wave present in each cycle","254")
xpositive("is","QRS complex present","032")
xpositive("is","QRS complex upright","034")
xpositive("is","QRS complex duration <= 0.1 sec","565")
xpositive("is","QRS complex all similar","039")
xpositive("is","T wave present","055")
xpositive("is","T wave upright","057")
xpositive("is","T wave rounded and assymetrical","059")
xpositive("is","T wave all similar","061")
xpositive("is","T wave duration <= 0.2 sec.","233")
xpositive("is","T wave amplitude <= 0.5 mV","229")
xpositive("is","PR interval present","070")
xpositive("is","PR interval constant","072")
xpositive("is","PR segment present","077")
xpositive("is","PR segment isoelectric","569")
xpositive("is","ST segment present","081")
xpositive("is","ST segment isoelectric","571")
xpositive("is","QT interval present","085")
xpositive("is","QT > 0.375 R-R but < 0.5 R-R for HR of 65-90
BPM","573")
xpositive("is","P-P regular","090")
xpositive("is","R-R regular","103")
xpositive("is","P-P equal to R-R","237")
xpositive("is","BPM between 60 and 100","501")
xnegative("is","person using cardiac drugs","010")
xnegative("is","QRS complex with some missing","221")
xnegative("is","QRS with R-R'","037")
xnegative("is","QRS with significant Q's","051")
xnegative("is","U wave present","065")
xnegative("is","PR interval < 0.12 sec","249")
xnegative("is","PR interval > 0.2 sec","251")
xillness_is("normal sinus rhythm","131")
```

```
xpositive("is","P wave present","012")
xpositive("is","P wave upright","016")
xpositive("is","P wave monophasic","018")
xpositive("is","P wave rounded","599")
xpositive("is","P wave amplitude not > 0.3 mV","217")
xpositive("is","P wave duration not > 0.12 sec.","219")
xpositive("is","P wave all similar","014")
xpositive("is","P wave ahead of the QRS","024")
xpositive("is","P wave present in each cycle","254")
xpositive("is","QRS complex present","032")
xpositive("is","QRS complex upright","034")
xpositive("is","QRS complex duration <= 0.1 sec","565")
xpositive("is","QRS complex all similar","039")
xpositive("is","T wave present","055")
xpositive("is","T wave upright","057")
xpositive("is","T wave rounded and assymetrical","059")
xpositive("is","T wave all similar","061")
xpositive("is","T wave duration <= 0.2 sec.","233")
xpositive("is","T wave amplitude <= 0.5 mV","229")
xpositive("is","PR interval present","070")
xpositive("is","PR interval constant","072")
xpositive("is","PR segment present","077")
xpositive("is","PR segment isoelectric","569")
xpositive("is","ST segment present","081")
xpositive("is","ST segment isoelectric","571")
xpositive("is","QT interval present","085")
xpositive("is","QT > 0.375 R-R but < 0.5 R-R for HR of 65-90
BPM","573")
xpositive("is","P-P regular","090")
xpositive("is","R-R regular","103")
xpositive("is","P-P equal to R-R","237")
xpositive("is","BPM > 100","503")
xnegative("is","person using cardiac drugs","010")
xnegative("is","QRS complex with some missing","221")
xnegative("is","QRS with R-R'","037")
xnegative("is","QRS with significant Q's","051")
xnegative("is","U wave present","065")
xnegative("is","PR interval < 0.12 sec","249")
xnegative("is","PR interval > 0.2 sec","251")
xnegative("is","BPM between 60 and 100","501")
xillness_is("tachycardia","133")
```

```
xpositive("is","P wave present","012")
xpositive("is","P wave upright","016")
xpositive("is","P wave monophasic","018")
xpositive("is","P wave rounded","599")
xpositive("is","P wave amplitude not > 0.3 mV","217")
xpositive("is","P wave duration not > 0.12 sec.","219")
xpositive("is","P wave all similar","014")
xpositive("is","P wave ahead of the QRS","024")
xpositive("is","P wave present in each cycle","254")
xpositive("is","QRS complex present","032")
xpositive("is","QRS complex upright","034")
xpositive("is","QRS complex duration <= 0.1 sec","565")
xpositive("is","QRS complex all similar","039")
xpositive("is","T wave present","055")
xpositive("is","T wave upright","057")
xpositive("is","T wave rounded and assymetrical","059")
xpositive("is","T wave all similar","061")
xpositive("is","T wave duration <= 0.2 sec.","233")
xpositive("is","T wave amplitude <= 0.5 mV","229")
xpositive("is","PR interval present","070")
xpositive("is","PR interval constant","072")
xpositive("is","PR segment present","077")
xpositive("is","PR segment isoelectric","569")
xpositive("is","ST segment present","081")
xpositive("is","ST segment isoelectric","571")
xpositive("is","QT interval present","085")
xpositive("is","QT > 0.375 R-R but < 0.5 R-R for HR of 65-90
BPM","573")
xpositive("is","P-P regular","090")
xpositive("is","R-R regular","103")
xpositive("is","P-P equal to R-R","237")
xpositive("is","BPM < 60","505")
xnegative("is","person using cardiac drugs","010")
xnegative("is","QRS complex with some missing","221")
xnegative("is","QRS with R-R'","037")
xnegative("is","QRS with significant Q's","051")
xnegative("is","U wave present","065")
xnegative("is","PR interval < 0.12 sec","249")
xnegative("is","PR interval > 0.2 sec","251")
xnegative("is","BPM between 60 and 100","501")
xnegative("is","BPM > 100","503")
xillness_is("bradycardia","135")
```

```
xpositive("is","P wave present","012")
xpositive("is","P wave upright","016")
xpositive("is","P wave monophasic","018")
xpositive("is","P wave rounded","599")
xpositive("is","P wave amplitude not > 0.3 mV","217")
xpositive("is","P wave duration not > 0.12 sec.","219")
xpositive("is","P wave all similar","014")
xpositive("is","P wave ahead of the QRS","024")
xpositive("is","P wave present in each cycle","254")
xpositive("is","QRS complex present","032")
xpositive("is","QRS complex upright","034")
xpositive("is","QRS complex duration <= 0.1 sec","565")
xpositive("is","QRS complex all similar","039")
xpositive("is","T wave present","055")
xpositive("is","T wave upright","057")
xpositive("is","T wave rounded and assymetrical","059")
xpositive("is","T wave all similar","061")
xpositive("is","T wave duration <= 0.2 sec.","233")
xpositive("is","T wave amplitude <= 0.5 mV","229")
xpositive("is","PR interval present","070")
xpositive("is","PR interval constant","072")
xpositive("is","PR segment present","077")
xpositive("is","PR segment isoelectric","569")
xpositive("is","ST segment present","081")
xpositive("is","ST segment isoelectric","571")
xpositive("is","QT interval present","085")
xpositive("is","QT > 0.375 R-R but < 0.5 R-R for HR of 65-90
BPM","573")
xpositive("is","long P-P a multiple of the short P-P","099")
xpositive("is","long R-R a multiple of the short R-R","110")
xpositive("is","P-P equal to R-R","237")
xnegative("is","person using cardiac drugs","010")
xnegative("is","QRS complex with some missing","221")
xnegative("is","QRS with R-R'","037")
xnegative("is","QRS with significant Q's","051")
xnegative("is","U wave present","065")
xnegative("is","PR interval < 0.12 sec","249")
xnegative("is","PR interval > 0.2 sec","251")
xnegative("is","P-P regular","090")
xnegative("is","R-R regular","103")
xnegative("is","P-P varying cyclically","097")
xillness_is("sinus block","139")
```

```
                xpositive("is","P wave present","012")
                xpositive("is","P wave upright","016")
                xpositive("is","P wave monophasic","018")
                xpositive("is","P wave rounded","599")
                xpositive("is","P wave amplitude not > 0.3 mV","217")
                xpositive("is","P wave duration not > 0.12 sec.","219")
                xpositive("is","P wave all similar","014")
                xpositive("is","P wave ahead of the QRS","024")
                xpositive("is","P wave present in each cycle","254")
                xpositive("is","QRS complex present","032")
                xpositive("is","QRS complex upright","034")
                xpositive("is","QRS complex duration <= 0.1 sec","565")
                xpositive("is","QRS complex all similar","039")
                xpositive("is","T wave present","055")
                xpositive("is","T wave upright","057")
                xpositive("is","T wave rounded and assymetrical","059")
                xpositive("is","T wave all similar","061")
                xpositive("is","T wave duration <= 0.2 sec.","233")
                xpositive("is","T wave amplitude <= 0.5 mV","229")
                xpositive("is","PR interval present","070")
                xpositive("is","PR interval constant","072")
                xpositive("is","PR segment present","077")
                xpositive("is","PR segment isoelectric","569")
                xpositive("is","ST segment present","081")
                xpositive("is","ST segment isoelectric","571")
                xpositive("is","QT interval present","085")
                xpositive("is","QT > 0.375 R-R but < 0.5 R-R for HR of 65-90
BPM","573")
                xpositive("is","P-P varying cyclically","097")
                xpositive("is","R-R varying cyclically","108")
                xpositive("is","P-P equal to R-R","237")
                xnegative("is","person using cardiac drugs","010")
                xnegative("is","QRS complex with some missing","221")
                xnegative("is","QRS with R-R'","037")
                xnegative("is","QRS with significant Q's","051")
                xnegative("is","U wave present","065")
                xnegative("is","PR interval < 0.12 sec","249")
                xnegative("is","PR interval > 0.2 sec","251")
                xnegative("is","P-P regular","090")
                xnegative("is","R-R regular","103")
                xillness_is("sinus arrhythmia","137")
```

```
xpositive("is","P wave present","012")
xpositive("is","P wave upright","016")
xpositive("is","P wave monophasic","018")
xpositive("is","P wave rounded","599")
xpositive("is","P wave amplitude not > 0.3 mV","217")
xpositive("is","P wave duration not > 0.12 sec.","219")
xpositive("is","P wave all similar","014")
xpositive("is","P wave ahead of the QRS","024")
xpositive("is","P wave present in each cycle","254")
xpositive("is","QRS complex present","032")
xpositive("is","QRS complex upright","034")
xpositive("is","QRS complex duration <= 0.1 sec","565")
xpositive("is","QRS complex all similar","039")
xpositive("is","T wave present","055")
xpositive("is","T wave upright","057")
xpositive("is","T wave rounded and assymetrical","059")
xpositive("is","T wave all similar","061")
xpositive("is","T wave duration <= 0.2 sec.","233")
xpositive("is","T wave amplitude <= 0.5 mV","229")
xpositive("is","PR interval present","070")
xpositive("is","PR interval constant","072")
xpositive("is","PR segment present","077")
xpositive("is","PR segment isoelectric","569")
xpositive("is","ST segment present","081")
xpositive("is","ST segment isoelectric","571")
xpositive("is","QT interval present","085")
xpositive("is","QT > 0.375 R-R but < 0.5 R-R for HR of 65-90
BPM","573")
xpositive("is","P-P equal to R-R","237")
xnegative("is","person using cardiac drugs","010")
xnegative("is","QRS complex with some missing","221")
xnegative("is","QRS with R-R'","037")
xnegative("is","QRS with significant Q's","051")
xnegative("is","U wave present","065")
xnegative("is","PR interval < 0.12 sec","249")
xnegative("is","PR interval > 0.2 sec","251")
xnegative("is","P-P regular","090")
xnegative("is","R-R regular","103")
xnegative("is","P-P varying cyclically","097")
xnegative("is","long P-P a multiple of the short P-P","099")
xnegative("is","long R-R a multiple of the short R-R","110")
xillness_is("sinus arrest","141")
```

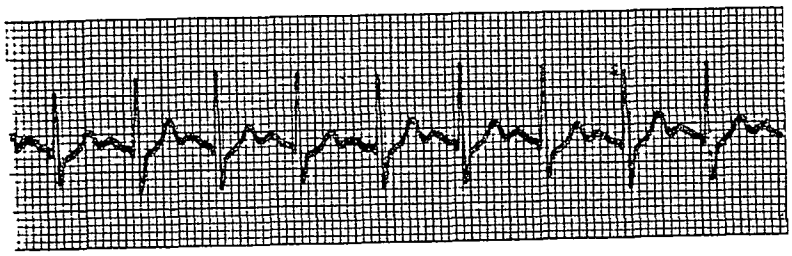


FIG. (18) - SINUS TACHYCARDIA

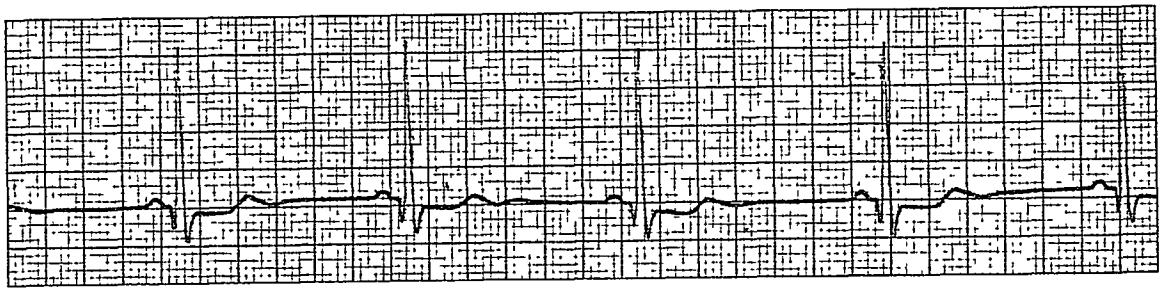


FIG. (19) - SINUS BRADYCARDIA

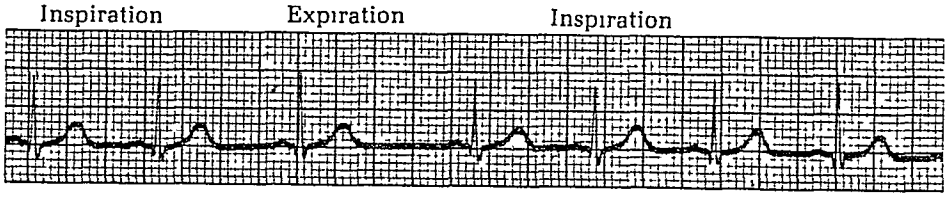


FIG. (20) - SINUS ARRHYTHMIA

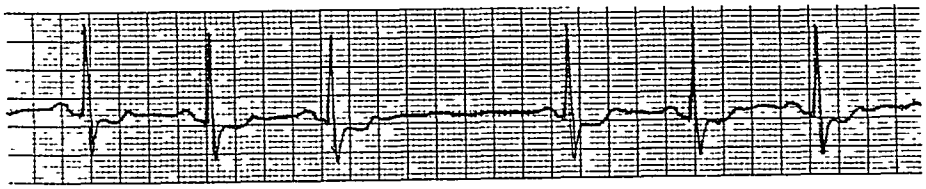


FIG. (21) - SINUS BLOCK

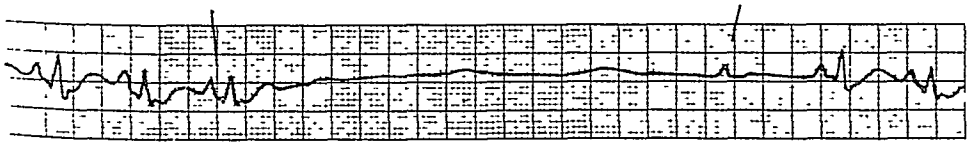


FIG. (22) - SINUS ARREST

```
xpositive("is","P wave present","012")
xpositive("is","P wave upright","016")
xpositive("is","P wave monophasic","018")
xpositive("is","QRS complex present","032")
xpositive("is","QRS complex duration <= 0.1 sec","565")
xpositive("is","P wave all similar","014")
xpositive("is","T wave present","055")
xpositive("is","T wave upright","057")
xpositive("is","T wave rounded and assymetrical","059")
xpositive("is","ST segment present","081")
xpositive("is","ST segment isoelectric","571")
xpositive("is","QT interval present","085")
xpositive("is","QT > 0.375 R-R but < 0.5 R-R for HR of 65-90
BPM","573")
xpositive("is","P wave ahead of the QRS","024")
xpositive("is","P wave sawtoothed","557")
xpositive("is","P-P between 250 and 350 BPM","030")
xnegative("is","person using cardiac drugs","010")
xnegative("is","P wave rounded","599")
xnegative("is","P wave flattened","751")
xnegative("is","QRS with significant Q's","051")
xnegative("is","U wave present","065")
xnegative("is","P-P equal to R-R","237")
xillness_is("atrial flutter","149")
```

```
xpositive("is","P wave present","012")
xpositive("is","P wave upright","016")
xpositive("is","P wave monophasic","018")
xpositive("is","P wave rounded","599")
xpositive("is","P wave amplitude not > 0.3 mV","217")
xpositive("is","P wave duration not > 0.12 sec.","219")
xpositive("is","QRS complex present","032")
xpositive("is","QRS complex duration <= 0.1 sec","565")
xpositive("is","QRS complex upright","034")
xpositive("is","QRS complex all similar","039")
xpositive("is","P-P regular","090")
xpositive("is","R-R regular","103")
xpositive("is","P-P equal to R-R","237")
xpositive("is","P wave premature","026")
xpositive("is","premature P wave followed by pause ","028")
xpositive("is","premature P wave returning to NSR after the
pause","243")
xnegative("is","person using cardiac drugs","010")
xnegative("is","P wave all similar","014")
xnegative("is","QRS with significant Q's","051")
xnegative("is","QRS complex with some missing","221")
xnegative("is","QRS with R-R'","037")
xnegative("is","BPM between 60 and 100","501")
xnegative("is","rhythm accelerated with sudden on/off","006")
xillness_is("premature atrial contraction","145")
```

```
xpositive("is","P wave present","012")
xpositive("is","P wave upright","016")
xpositive("is","P wave monophasic","018")
xpositive("is","P wave rounded","599")
xpositive("is","P wave amplitude not > 0.3 mV","217")
xpositive("is","P wave duration not > 0.12 sec.","219")
xpositive("is","QRS complex present","032")
xpositive("is","QRS complex duration <= 0.1 sec","565")
xpositive("is","QRS complex upright","034")
xpositive("is","QRS complex all similar","039")
xpositive("is","P-P regular","090")
xpositive("is","R-R regular","103")
xpositive("is","P-P equal to R-R","237")
xpositive("is","rhythm accelerated with sudden on/off","006")
xpositive("is","BPM between 150 and 250","507")
xnegative("is","person using cardiac drugs","010")
xnegative("is","P wave all similar","014")
xnegative("is","QRS with significant Q's","051")
xnegative("is","QRS complex with some missing","221")
xnegative("is","QRS with R-R'","037")
xnegative("is","BPM between 60 and 100","501")
xillness_is("paroxysmal atrial tachycardia","147")
```

```
xpositive("is","P wave present","012")
xpositive("is","P wave upright","016")
xpositive("is","P wave monophasic","018")
xpositive("is","P wave rounded","599")
xpositive("is","P wave amplitude not > 0.3 mV","217")
xpositive("is","P wave duration not > 0.12 sec.","219")
xpositive("is","QRS complex present","032")
xpositive("is","QRS complex duration <= 0.1 sec","565")
xpositive("is","QRS complex upright","034")
xpositive("is","QRS complex all similar","039")
xpositive("is","P-P regular","090")
xpositive("is","R-R regular","103")
xpositive("is","P-P equal to R-R","237")
xpositive("is","BPM between 60 and 100","501")
xnegative("is","person using cardiac drugs","010")
xnegative("is","P wave all similar","014")
xnegative("is","QRS with significant Q's","051")
xnegative("is","QRS complex with some missing","221")
xnegative("is","QRS with R-R'","037")
xillness_is("wandering atrial pacemaker","143")
```

```
xpositive("is","baseline noisy","509")
xpositive("is","QRS complex present","032")
xnegative("is","person using cardiac drugs","010")
xnegative("is","P wave present","012")
xillness_is("atrial fibrillation","151")
```

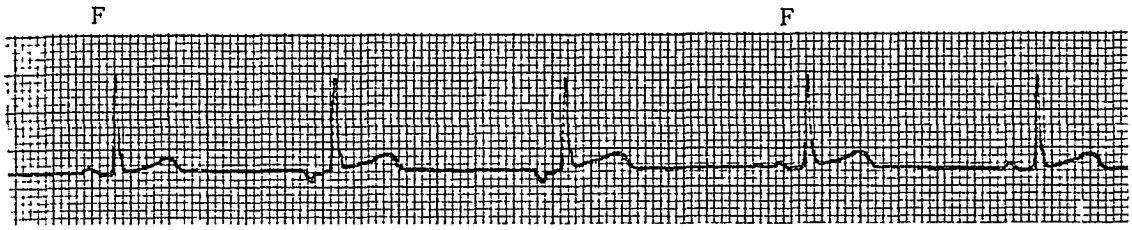


FIG. (23) .- WANDERING ATRIAL PACEMAKER

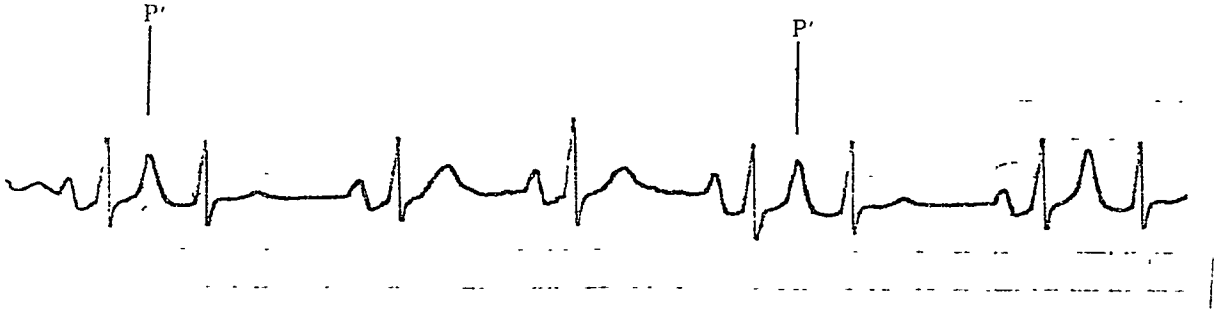


FIG. (24) - PREMATURE ATRIAL CONTRACTION

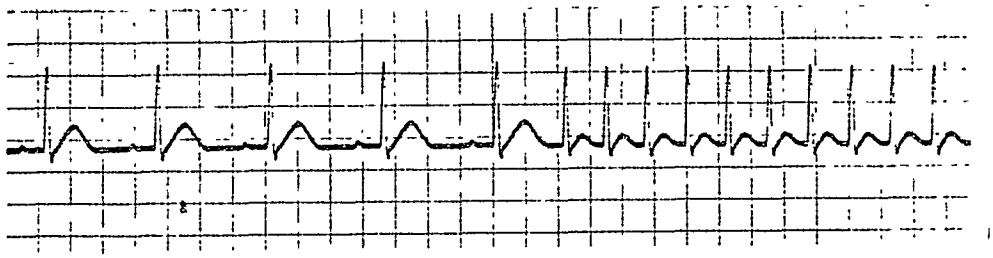


FIG. (25) - PAROXYSMAL ATRIAL TACHYCARDIA

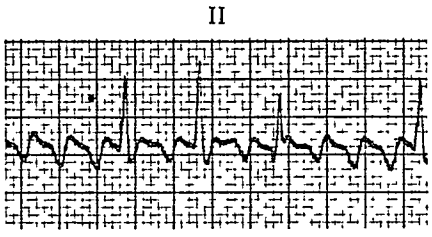


FIG. (26) – ATRIAL FLUTTER

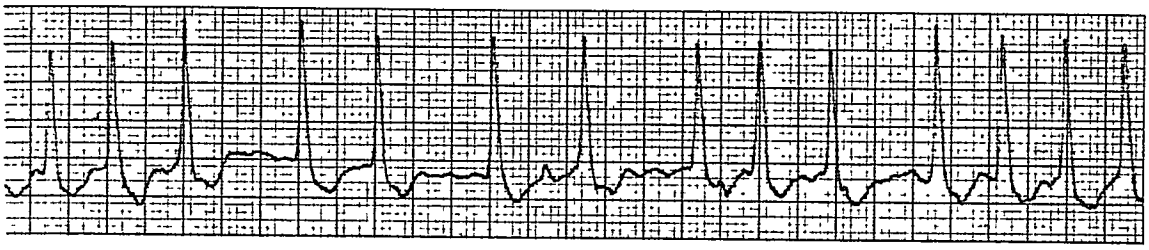


FIG. (27) – ATRIAL FIBRILLATION

```
xpositive("is","P wave present","012")
xpositive("is","P wave upright","016")
xpositive("is","P wave monophasic","018")
xpositive("is","P wave rounded","599")
xpositive("is","P wave amplitude not > 0.3 mV","217")
xpositive("is","P wave duration not > 0.12 sec.","219")
xpositive("is","P wave all similar","014")
xpositive("is","P wave ahead of the QRS","024")
xpositive("is","P wave present in each cycle","254")
xpositive("is","QRS complex present","032")
xpositive("is","QRS complex upright","034")
xpositive("is","QRS complex duration <= 0.1 sec","565")
xpositive("is","QRS complex all similar","039")
xpositive("is","T wave present","055")
xpositive("is","T wave upright","057")
xpositive("is","T wave rounded and assymetrical","059")
xpositive("is","T wave all similar","061")
xpositive("is","T wave duration <= 0.2 sec.","233")
xpositive("is","T wave amplitude <= 0.5 mV","229")
xpositive("is","PR interval present","070")
xpositive("is","PR interval > 0.2 sec","251")
xpositive("is","ST segment present","081")
xpositive("is","ST segment isoelectric","571")
xpositive("is","QT interval present","085")
xpositive("is","QT > 0.375 R-R but < 0.5 R-R for HR of 65-90
BPM","573")
xpositive("is","P-P equal to R-R","237")
xnegative("is","person using cardiac drugs","010")
xnegative("is","QRS complex with some missing","221")
xnegative("is","QRS with R-R'","037")
xnegative("is","QRS with significant Q's","051")
xnegative("is","U wave present","065")
xnegative("is","PR interval < 0.12 sec","249")
xillness_is("first degree heart block","161")
```

```
                xpositive("is","P wave present","012")
                xpositive("is","P wave upright","016")
                xpositive("is","P wave monophasic","018")
                xpositive("is","P wave rounded","599")
                xpositive("is","P wave amplitude not > 0.3 mV","217")
                xpositive("is","P wave duration not > 0.12 sec.","219")
                xpositive("is","P wave all similar","014")
                xpositive("is","P wave ahead of the QRS","024")
                xpositive("is","P wave present in each cycle","254")
                xpositive("is","QRS complex present","032")
                xpositive("is","QRS complex upright","034")
                xpositive("is","QRS complex duration <= 0.1 sec","565")
                xpositive("is","QRS complex all similar","039")
                xpositive("is","QRS complex with some missing","221")
                xpositive("is","T wave present","055")
                xpositive("is","T wave upright","057")
                xpositive("is","T wave rounded and assymetrical","059")
                xpositive("is","ST segment present","081")
                xpositive("is","ST segment isoelectric","571")
                xpositive("is","QT interval present","085")
                xpositive("is","QT > 0.375 R-R but < 0.5 R-R for HR of 65-90
BPM","573")
                xpositive("is","P-P regular","090")
                xnegative("is","person using cardiac drugs","010")
                xnegative("is","QRS with significant Q's","051")
                xnegative("is","U wave present","065")
                xnegative("is","PR interval constant","072")
                xnegative("is","R-R regular","103")
                xillness_is("wenckebach","163")
```

```
xpositive("is","P wave present","012")
xpositive("is","P wave upright","016")
xpositive("is","P wave monophasic","018")
xpositive("is","P wave rounded","599")
xpositive("is","P wave amplitude not > 0.3 mV","217")
xpositive("is","P wave duration not > 0.12 sec.","219")
xpositive("is","P wave all similar","014")
xpositive("is","P wave ahead of the QRS","024")
xpositive("is","P wave present in each cycle","254")
xpositive("is","QRS complex present","032")
xpositive("is","QRS complex upright","034")
xpositive("is","QRS complex duration <= 0.1 sec","565")
xpositive("is","QRS complex all similar","039")
xpositive("is","QRS complex with some missing","221")
xpositive("is","T wave present","055")
xpositive("is","T wave upright","057")
xpositive("is","T wave rounded and assymetrical","059")
xpositive("is","ST segment present","081")
xpositive("is","ST segment isoelectric","571")
xpositive("is","QT interval present","085")
xpositive("is","QT > 0.375 R-R but < 0.5 R-R for HR of 65-90
BPM","573")
xpositive("is","PR interval constant","072")
xpositive("is","P-P regular","090")
xpositive("is","long R-R a multiple of the short R-R","110")
xnegative("is","person using cardiac drugs","010")
xnegative("is","QRS with significant Q's","051")
xnegative("is","U wave present","065")
xnegative("is","R-R regular","103")
xillness_is("mobitz II block","165")
```

```
xpositive("is","P wave present","012")
xpositive("is","P wave upright","016")
xpositive("is","P wave monophasic","018")
xpositive("is","P wave rounded","599")
xpositive("is","P wave amplitude not > 0.3 mV","217")
xpositive("is","P wave duration not > 0.12 sec.","219")
xpositive("is","P wave all similar","014")
xpositive("is","P wave ahead of the QRS","024")
xpositive("is","P wave present in each cycle","254")
xpositive("is","QRS complex present","032")
xpositive("is","QRS complex upright","034")
xpositive("is","QRS complex duration <= 0.1 sec","565")
xpositive("is","QRS complex all similar","039")
xpositive("is","T wave present","055")
xpositive("is","T wave upright","057")
xpositive("is","T wave rounded and assymetrical","059")
xpositive("is","T wave all similar","061")
xpositive("is","T wave duration <= 0.2 sec.","233")
xpositive("is","T wave amplitude <= 0.5 mV","229")
xpositive("is","PR interval present","070")
xpositive("is","PR interval constant","072")
xpositive("is","PR segment present","077")
xpositive("is","PR segment isoelectric","569")
xpositive("is","ST segment present","081")
xpositive("is","ST segment isoelectric","571")
xpositive("is","QT interval present","085")
xpositive("is","QT > 0.375 R-R but < 0.5 R-R for HR of 65-90
BPM","573")
xpositive("is","P-P regular","090")
xpositive("is","R-R regular","103")
xpositive("is","P-P greater than R-R","523")
xnegative("is","person using cardiac drugs","010")
xnegative("is","QRS complex with some missing","221")
xnegative("is","QRS with R-R'","037")
xnegative("is","QRS with significant Q's","051")
xnegative("is","U wave present","065")
xnegative("is","PR interval < 0.12 sec","249")
xnegative("is","PR interval > 0.2 sec","251")
xnegative("is","P-P equal to R-R","237")
xillness_is("third degree heart block","167")
```

This condition will also be diagnosed for the following condition :

1. P wave present but abnormal and PR interval short.

```
xpositive("is","QRS complex present","032")
xpositive("is","QRS complex duration <= 0.1 sec","565")
xpositive("is","T wave present","055")
xpositive("is","T wave upright","057")
xpositive("is","T wave rounded and assymetrical","059")
xpositive("is","ST segment present","081")
xpositive("is","ST segment isoelectric","571")
xpositive("is","QT interval present","085")
xpositive("is","QT > 0.375 R-R but < 0.5 R-R for HR of 65-90
BPM","573")
xpositive("is","QRS complex with an escape beat","049")
xpositive("is","rhythm showing a pause","008")
xnegative("is","person using cardiac drugs","010")
xnegative("is","P wave present","012")
xnegative("is","baseline noisy","509")
xnegative("is","baseline chaotic","519")
xnegative("is","baseline sinusoidal","521")
xnegative("is","QRS with significant Q's","051")
xnegative("is","U wave present","065")
xillness_is("junctional escape beat","155")
```

This condition will also be diagnosed for the following conditions also :

1. P wave present but abnormal and PR interval absent.
2. P wave present but abnormal and PR interval present but short.

```
xpositive("is","QRS complex present","032")
xpositive("is","QRS complex duration <= 0.1 sec","565")
xpositive("is","T wave present","055")
xpositive("is","T wave upright","057")
xpositive("is","T wave rounded and assymetrical","059")
xpositive("is","ST segment present","081")
xpositive("is","ST segment isoelectric","571")
xpositive("is","QT interval present","085")
xpositive("is","QT > 0.375 R-R but < 0.5 R-R for HR of 65-90
BPM","573")
xpositive("is","QRS complex upright","034")
xpositive("is","QRS complex all similar","039")
xnegative("is","person using cardiac drugs","010")
xnegative("is","P wave present","012")
xnegative("is","baseline noisy","509")
xnegative("is","baseline chaotic","519")
xnegative("is","baseline sinusoidal","521")
xnegative("is","QRS with significant Q's","051")
xnegative("is","U wave present","065")
xnegative("is","QRS complex with an escape beat","049")
xnegative("is","QRS complex with some missing","221")
xnegative("is","QRS with R-R'","037")
xnegative("is","PR interval present","070")
xnegative("is","R-R regular","103")
xnegative("is","long R-R a multiple of the short R-R","110")
xillness_is("premature junctional contraction","157")
```

This condition will also be diagnosed for the following cases :

1. P wave present but abnormal and PR interval absent.
2. P wave present but abnormal and PR interval present but short.

```
xpositive("is","QRS complex present","032")
xpositive("is","QRS complex duration <= 0.1 sec","565")
xpositive("is","T wave present","055")
xpositive("is","T wave upright","057")
xpositive("is","T wave rounded and assymetrical","059")
xpositive("is","ST segment present","081")
xpositive("is","ST segment isoelectric","571")
xpositive("is","QT interval present","085")
xpositive("is","QT > 0.375 R-R but < 0.5 R-R for HR of 65-90
BPM","573")
xpositive("is","QRS complex upright","034")
xpositive("is","QRS complex all similar","039")
xpositive("is","R-R regular","103")
xpositive("is","R-R > 100 BPM","515")
xnegative("is","person using cardiac drugs","010")
xnegative("is","P wave present","012")
xnegative("is","baseline noisy","509")
xnegative("is","baseline chaotic","519")
xnegative("is","baseline sinusoidal","521")
xnegative("is","QRS with significant Q's","051")
xnegative("is","U wave present","065")
xnegative("is","QRS complex with an escape beat","049")
xnegative("is","QRS complex with some missing","221")
xnegative("is","QRS with R-R'","037")
xnegative("is","PR interval present","070")
xillness_is("junctional tachycardia","159")
```

This condition will also be diagnosed for the following case :

1. P wave present but abnormal and PR interval present but short.

```
xpositive("is","QRS complex present","032")
xpositive("is","QRS complex duration <= 0.1 sec","565")
xpositive("is","T wave present","055")
xpositive("is","T wave upright","057")
xpositive("is","T wave rounded and assymetrical","059")
xpositive("is","ST segment present","081")
xpositive("is","ST segment isoelectric","571")
xpositive("is","QT interval present","085")
xpositive("is","QT > 0.375 R-R but < 0.5 R-R for HR of 65-90
BPM","573")
xpositive("is","QRS complex upright","034")
xpositive("is","QRS complex all similar","039")
xpositive("is","PR interval present","070")
xpositive("is","R-R < 100 BPM","525")
xnegative("is","person using cardiac drugs","010")
xnegative("is","P wave present","012")
xnegative("is","baseline noisy","509")
xnegative("is","baseline chaotic","519")
xnegative("is","baseline sinusoidal","521")
xnegative("is","QRS with significant Q's","051")
xnegative("is","U wave present","065")
xnegative("is","QRS complex with an escape beat","049")
xnegative("is","QRS complex with some missing","221")
xnegative("is","QRS with R-R'","037")
xnegative("is","PR interval < 0.12 sec","249")
xillness_is("junctional rhythm","153")
```

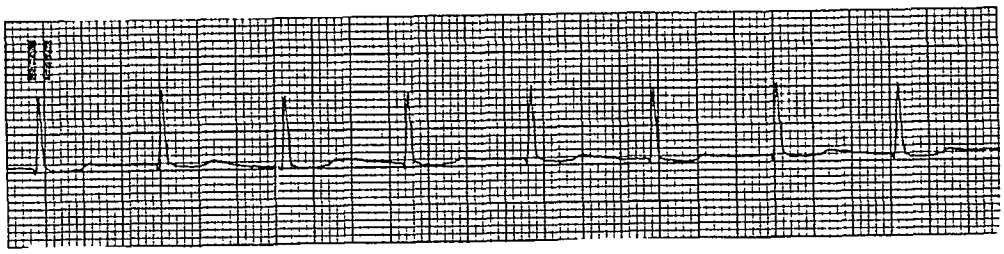


FIG. (28) - JUNCTIONAL RHYTHM

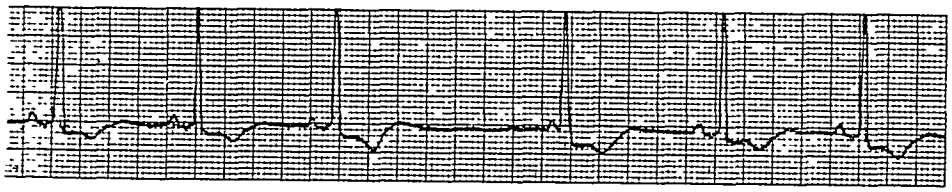


FIG. (29) - JUNCTIONAL ESCAPE BEAT

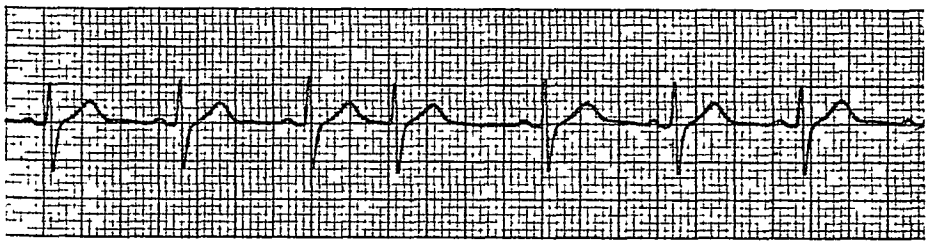


FIG. (30) - PREMATURE JUNCTIONAL CONTRACTION

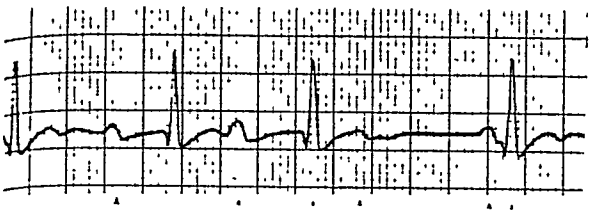


FIG. (31) -WENCKEBACH

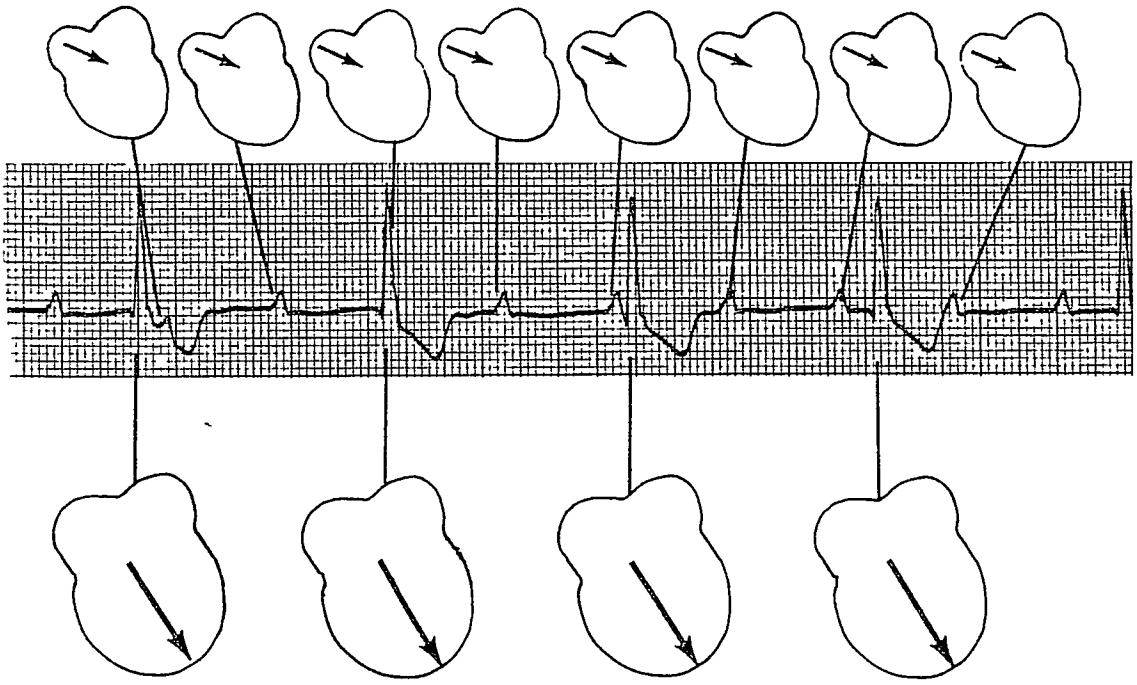


FIG. (32) - III° HEART BLOCK

```
xpositive("is","P wave present","012")
xpositive("is","P wave upright","016")
xpositive("is","P wave monophasic","018")
xpositive("is","P wave rounded","599")
xpositive("is","P wave amplitude not > 0.3 mV","217")
xpositive("is","P wave duration not > 0.12 sec.","219")
xpositive("is","P wave all similar","014")
xpositive("is","QRS complex present","032")
xpositive("is","T wave present","055")
xpositive("is","T wave upright","057")
xpositive("is","T wave rounded and assymetrical","059")
xpositive("is","ST segment present","081")
xpositive("is","ST segment isoelectric","571")
xpositive("is","QT interval present","085")
xpositive("is","QT > 0.375 R-R but < 0.5 R-R for HR of 65-90
BPM","573")
xpositive("is","R-R between 20 and 40 BPM","511")
xnegative("is","person using cardiac drugs","010")
xnegative("is","P wave ahead of the QRS","024")
xnegative("is","QRS complex duration <= 0.1 sec","565")
xnegative("is","QRS with R-R'","037")
xnegative("is","QRS with significant Q's","051")
xnegative("is","U wave present","065")
xillness_is("idioventricular rhythm","169")
```

```
xpositive("is","P wave present","012")
xpositive("is","P wave upright","016")
xpositive("is","P wave monophasic","018")
xpositive("is","P wave rounded","599")
xpositive("is","P wave amplitude not > 0.3 mV","217")
xpositive("is","P wave duration not > 0.12 sec.","219")
xpositive("is","P wave all similar","014")
xpositive("is","QRS complex present","032")
xpositive("is","T wave present","055")
xpositive("is","T wave upright","057")
xpositive("is","T wave rounded and assymetrical","059")
xpositive("is","U wave present","065")
xpositive("is","T wave amplitude > than that of U wave","231")
xpositive("is","ST segment present","081")
xpositive("is","ST segment isoelectric","571")
xpositive("is","QT interval present","085")
xpositive("is","QT > 0.375 R-R but < 0.5 R-R for HR of 65-90
BPM","573")
xpositive("is","R-R between 40 and 100 BPM","513")
xnegative("is","person using cardiac drugs","010")
xnegative("is","P wave ahead of the QRS","024")
xnegative("is","QRS complex duration <= 0.1 sec","565")
xnegative("is","QRS with R-R'","037")
xnegative("is","QRS with significant Q's","051")
xnegative("is","R-R between 20 and 40 BPM","511")
xillness_is("accelerated idioventricular rhythm","171")
```

```
xpositive("is","P wave present","012")
xpositive("is","P wave upright","016")
xpositive("is","P wave monophasic","018")
xpositive("is","P wave rounded","599")
xpositive("is","P wave amplitude not > 0.3 mV","217")
xpositive("is","P wave duration not > 0.12 sec.","219")
xpositive("is","P wave all similar","014")
xpositive("is","QRS complex present","032")
xpositive("is","T wave present","055")
xpositive("is","T wave upright","057")
xpositive("is","T wave rounded and assymetrical","059")
xpositive("is","ST segment present","081")
xpositive("is","ST segment isoelectric","571")
xpositive("is","QT interval present","085")
xpositive("is","QT > 0.375 R-R but < 0.5 R-R for HR of 65-90
BPM","573")
xpositive("is","R-R > 100 BPM","515")
xnegative("is","person using cardiac drugs","010")
xnegative("is","P wave ahead of the QRS","024")
xnegative("is","QRS complex duration <= 0.1 sec","565")
xnegative("is","QRS with R-R'","037")
xnegative("is","QRS with significant Q's","051")
xnegative("is","U wave present","065")
xnegative("is","R-R between 20 and 40 BPM","511")
xnegative("is","R-R between 40 and 100 BPM","513")
xillness_is("ventricular tachycardia","173")
```

```
xpositive("is","P wave present","012")
xpositive("is","P wave upright","016")
xpositive("is","P wave monophasic","018")
xpositive("is","P wave rounded","599")
xpositive("is","P wave amplitude not > 0.3 mV","217")
xpositive("is","P wave duration not > 0.12 sec.","219")
xpositive("is","P wave all similar","014")
xpositive("is","P wave ahead of the QRS","024")
xpositive("is","P wave present in each cycle","254")
xpositive("is","QRS complex present","032")
xpositive("is","QRS complex upright","034")
xpositive("is","T wave present","055")
xpositive("is","T wave upright","057")
xpositive("is","T wave rounded and assymetrical","059")
xpositive("is","U wave present","065")
xpositive("is","T wave amplitude > than that of U wave","231")
xpositive("is","PR interval present","070")
xpositive("is","ST segment present","081")
xpositive("is","ST segment isoelectric","571")
xpositive("is","QT interval present","085")
xpositive("is","QT > 0.375 R-R but < 0.5 R-R for HR of 65-90
 BPM","573")
xpositive("is","rhythm accelerated with sudden on/off","006")
xpositive("is","R-R > 100 BPM","515")
xnegative("is","person using cardiac drugs","010")
xnegative("is","QRS complex duration <= 0.1 sec","565")
xnegative("is","QRS with R-R'","037")
xnegative("is","QRS with significant Q's","051")
xnegative("is","PR interval < 0.12 sec","249")
xillness_is("paroxysmal ventricular tachycardia","181")
```

The same condition would have been diagnosed had the P wave been present and the PR interval had been abnormal.

```
xpositive("is","QRS complex present","032")
xpositive("is","T wave present","055")
xpositive("is","T wave upright","057")
xpositive("is","T wave rounded and assymetrical","059")
xpositive("is","ST segment present","081")
xpositive("is","ST segment isoelectric","571")
xpositive("is","QT interval present","085")
xpositive("is","QT > 0.375 R-R but < 0.5 R-R for HR of 65-90
BPM","573")
xpositive("is","QRS complex with fusion beat","043")
xpositive("is","R-R > 100 BPM","515")
xnegative("is","person using cardiac drugs","010")
xnegative("is","P wave present","012")
xnegative("is","baseline noisy","509")
xnegative("is","baseline chaotic","519")
xnegative("is","baseline sinusoidal","521")
xnegative("is","QRS complex duration <= 0.1 sec","565")
xnegative("is","QRS with R-R'","037")
xnegative("is","QRS with significant Q's","051")
xnegative("is","U wave present","065")
xnegative("is","rhythm accelerated with sudden on/off","006")
xillness_is("ventricular tachycardia with fusion beat","183")
```

The same condition would have been diagnosed had the P wave been present and the PR interval been abnormal.

```
xpositive("is","QRS complex present","032")
xpositive("is","T wave present","055")
xpositive("is","T wave upright","057")
xpositive("is","T wave rounded and assymetrical","059")
xpositive("is","ST segment present","081")
xpositive("is","ST segment isoelectric","571")
xpositive("is","QT interval present","085")
xpositive("is","QT > 0.375 R-R but < 0.5 R-R for HR of 65-90
BPM","573")
xpositive("is","QRS complex with capture beat","045")
xpositive("is","R-R > 100 BPM","515")
xnegative("is","person using cardiac drugs","010")
xnegative("is","P wave present","012")
xnegative("is","baseline noisy","509")
xnegative("is","baseline chaotic","519")
xnegative("is","baseline sinusoidal","521")
xnegative("is","QRS complex duration <= 0.1 sec","565")
xnegative("is","QRS with R-R'","037")
xnegative("is","QRS with significant Q's","051")
xnegative("is","U wave present","065")
xnegative("is","rhythm accelerated with sudden on/off","006")
xnegative("is","QRS complex with fusion beat","043")
xillness_is("ventricular tachycardia with capture beat","185")
```

```
xpositive("is","baseline chaotic","519")
xnegative("is","person using cardiac drugs","010")
xnegative("is","P wave present","012")
xnegative("is","baseline noisy","509")
xnegative("is","QRS complex present","032")
xillness_is("ventricular fibrillation","189")
```

```
xpositive("is","baseline sinusoidal","521")
xnegative("is","person using cardiac drugs","010")
xnegative("is","P wave present","012")
xnegative("is","baseline noisy","509")
xnegative("is","baseline chaotic","519")
xnegative("is","QRS complex present","032")
xillness_is("ventricular flutter","187")
```

```
This condition would have also been diagnosed for the
following cases :

1. QRS complex interpolated.
2. QRS complex with fusion beat.
3. Wave unifocal.
4. Wave multifocal.
5. Wave bigeminous.
6. Wave 1:2 trigeminous.
7. Wave 2:1 trigeminous.
8. Wave 3:1 quadrigeminous.

xpositive("is","P wave present","012")
xpositive("is","P wave upright","016")
xpositive("is","P wave monophasic","018")
xpositive("is","P wave rounded","599")
xpositive("is","P wave amplitude not > 0.3 mV","217")
xpositive("is","P wave duration not > 0.12 sec.","219")
xpositive("is","P wave all similar","014")
xpositive("is","P wave ahead of the QRS","024")
xpositive("is","P wave present in each cycle","254")
xpositive("is","QRS complex present","032")
xpositive("is","QRS complex upright","034")
xpositive("is","T wave present","055")
xpositive("is","T wave upright","057")
xpositive("is","T wave rounded and assymetrical","059")
xpositive("is","PR interval present","070")
xpositive("is","ST segment present","081")
xpositive("is","ST segment isoelectric","571")
xpositive("is","QT interval present","085")
xpositive("is","QT > 0.375 R-R but < 0.5 R-R for HR of 65-90
BPM","573")
xpositive("is","QRS complex with premature beat","041")
xpositive("is","P-P equal to R-R","237")
xpositive("is","P-P with a compensatory pause","575")
xnegative("is","person using cardiac drugs","010")
xnegative("is","QRS complex duration <= 0.1 sec","565")
xnegative("is","QRS with R-R'","037")
xnegative("is","QRS with significant Q's","051")
xnegative("is","U wave present","065")
xnegative("is","PR interval < 0.12 sec","249")
xnegative("is","rhythm accelerated with sudden on/off","006")
xnegative("is","QRS complex with fusion beat","043")
xnegative("is","QRS complex with capture beat","045")
xnegative("is","QRS complex with some missing","221")
xnegative("is","QRS complex interpolated","047")
xnegative("is","wave unifocal","529")
xnegative("is","wave multifocal","531")
xnegative("is","wave bigeminous","533")
xnegative("is","wave 1:2 trigeminous","535")
xnegative("is","wave 2:1 trigeminous","537")
xnegative("is","wave 3:1 quadrigeminous","539")
xillness_is("premature ventricular contraction","179")
```

```
xpositive("is","P wave present","012")
xpositive("is","P wave upright","016")
xpositive("is","P wave monophasic","018")
xpositive("is","P wave rounded","599")
xpositive("is","P wave amplitude not > 0.3 mV","217")
xpositive("is","P wave duration not > 0.12 sec.","219")
xpositive("is","P wave all similar","014")
xpositive("is","P wave ahead of the QRS","024")
xpositive("is","P wave present in each cycle","254")
xpositive("is","QRS complex present","032")
xpositive("is","QRS complex upright","034")
xpositive("is","T wave present","055")
xpositive("is","T wave upright","057")
xpositive("is","T wave rounded and assymetrical","059")
xpositive("is","PR interval present","070")
xpositive("is","PR interval < 0.12 sec","249")
xpositive("is","PR segment a delta wave","517")
xnegative("is","person using cardiac drugs","010")
xnegative("is","QRS complex duration <= 0.1 sec","565")
xnegative("is","QRS with R-R'","037")
xnegative("is","QRS with significant Q's","051")
xnegative("is","U wave present","065")
xillness_is("wolff-parkinson-white syndrome","175")
```

```
xpositive("is","P wave present","012")
xpositive("is","P wave upright","016")
xpositive("is","P wave monophasic","018")
xpositive("is","P wave rounded","599")
xpositive("is","P wave amplitude not > 0.3 mV","217")
xpositive("is","P wave duration not > 0.12 sec.","219")
xpositive("is","P wave all similar","014")
xpositive("is","P wave ahead of the QRS","024")
xpositive("is","P wave present in each cycle","254")
xpositive("is","QRS complex present","032")
xpositive("is","QRS complex upright","034")
xpositive("is","QRS with R-R'","037")
xnegative("is","person using cardiac drugs","010")
xnegative("is","QRS complex duration <= 0.1 sec","565")
xillness_is("bundle branch block","177")
```

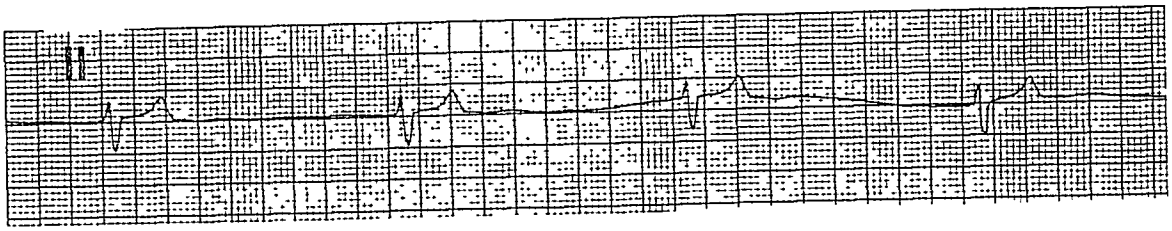


FIG. (33) - IDIOVENTRICULAR RHYTHM

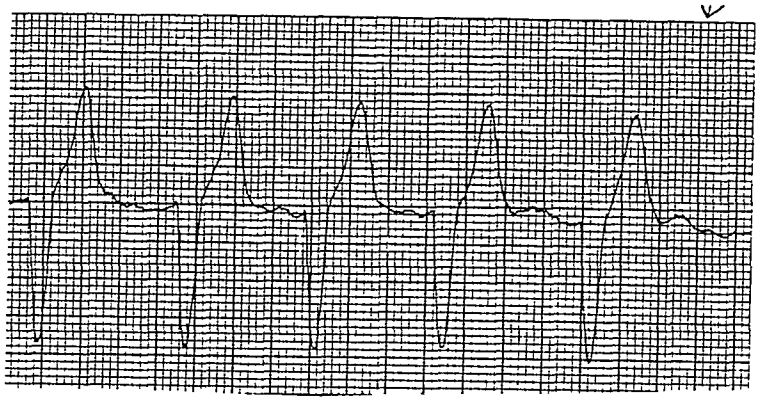


FIG. (34) - ACCELERATED IDIOVENTRICULAR RHYTHM

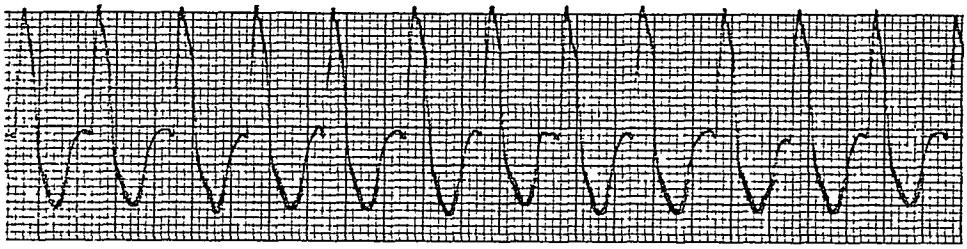


FIG. (35) - VENTRICULAR TACHYCARDIA

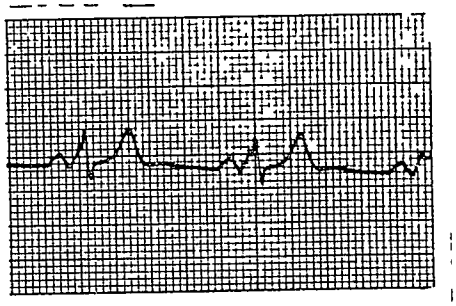


FIG. (36) – WOLFF-PARKINSON-WHITE SYNDROME

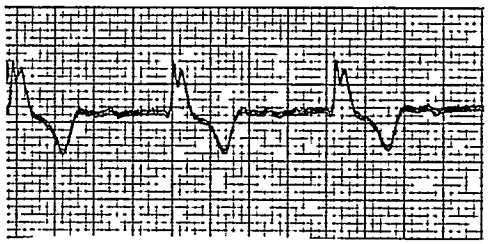


FIG. (37) – BUNDLE BRANCH BLOCK

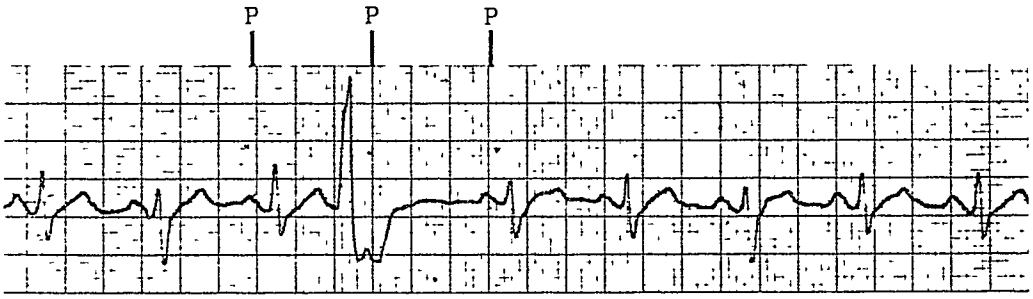


FIG. (38) – PREMATURE VENTRICULAR CONTRACTION

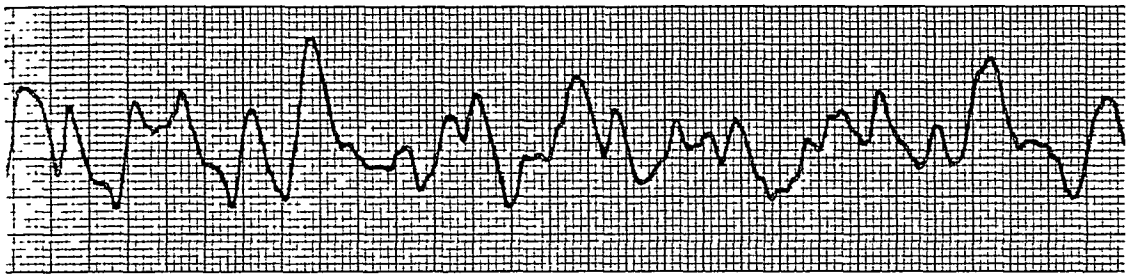


FIG. (39) - VENTRICULAR FIBRILLATION

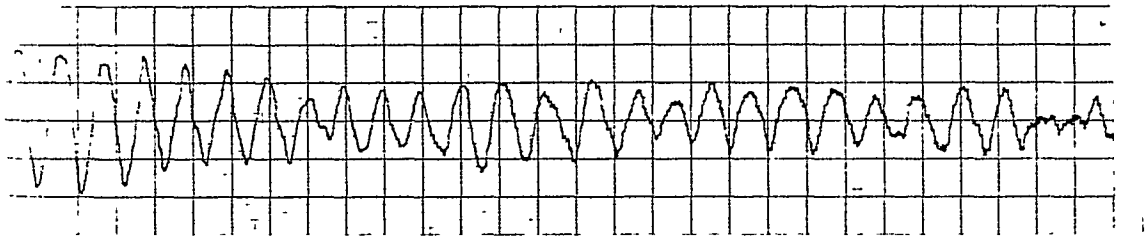


FIG. (40) - VENTRICULAR FLUTTER

```
xpositive("is","P wave present","012")
xpositive("is","P wave upright","016")
xpositive("is","P wave monophasic","018")
xpositive("is","P wave rounded","599")
xpositive("is","QRS complex present","032")
xpositive("is","QRS complex duration <= 0.1 sec","565")
xpositive("is","P wave all similar","014")
xpositive("is","T wave present","055")
xpositive("is","T wave upright","057")
xpositive("is","T wave rounded and assymetrical","059")
xpositive("is","ST segment present","081")
xpositive("is","ST segment isoelectric","571")
xpositive("is","QT interval present","085")
xpositive("is","QT > 0.375 R-R but < 0.5 R-R for HR of 65-90 BPM","573")
xpositive("is","P wave ahead of the QRS","024")
xpositive("is","QRS complex upright","034")
xpositive("is","QRS complex all similar","039")
xpositive("is","PR interval present","070")
xnegative("is","person using cardiac drugs","010")
xnegative("is","P wave amplitude not > 0.3 mV","217")
xnegative("is","QRS with significant Q's","051")
xnegative("is","U wave present","065")
xnegative("is","QRS complex with some missing","221")
xnegative("is","QRS with R-R'","037")
xnegative("is","QRS complex with an escape beat","049")
xnegative("is","PR interval < 0.12 sec","249")
xillness_is("biatrial enlargement","195")
```

```
        xpositive("is","P wave present","012")
        xpositive("is","P wave upright","016")
        xpositive("is","P wave monophasic","018")
        xpositive("is","P wave rounded","599")
        xpositive("is","QRS complex present","032")
        xpositive("is","QRS complex duration <= 0.1 sec","565")
        xpositive("is","P wave all similar","014")
        xpositive("is","T wave present","055")
        xpositive("is","T wave upright","057")
        xpositive("is","T wave rounded and assymetrical","059")
        xpositive("is","ST segment present","081")
        xpositive("is","ST segment isoelectric","571")
        xpositive("is","QT interval present","085")
        xpositive("is","QT > 0.375 R-R but < 0.5 R-R for HR of 65-90
BPM","573")
        xpositive("is","P wave ahead of the QRS","024")
        xpositive("is","QRS complex upright","034")
        xpositive("is","QRS complex all similar","039")
        xpositive("is","PR interval present","070")
        xnegative("is","person using cardiac drugs","010")
        xnegative("is","P wave amplitude not > 0.3 mV","217")
        xnegative("is","QRS with significant Q's","051")
        xnegative("is","U wave present","065")
        xnegative("is","QRS complex with some missing","221")
        xnegative("is","QRS with R-R'","037")
        xnegative("is","QRS complex with an escape beat","049")
        xnegative("is","PR interval < 0.12 sec","249")
        xillness_is("biatrial enlargement","195")
```

```
        xpositive("is","P wave present","012")
        xpositive("is","P wave upright","016")
        xpositive("is","P wave monophasic","018")
        xpositive("is","QRS complex present","032")
        xpositive("is","QRS complex duration <= 0.1 sec","565")
        xpositive("is","P wave all similar","014")
        xpositive("is","T wave present","055")
        xpositive("is","T wave upright","057")
        xpositive("is","T wave rounded and assymetrical","059")
        xpositive("is","ST segment present","081")
        xpositive("is","ST segment isoelectric","571")
        xpositive("is","QT interval present","085")
        xpositive("is","QT > 0.375 R-R but < 0.5 R-R for HR of 65-90
BPM","573")
        xpositive("is","P wave ahead of the QRS","024")
        xpositive("is","QRS complex upright","034")
        xpositive("is","QRS complex all similar","039")
        xpositive("is","PR interval present","070")
        xpositive("is","P wave peaked","545")
        xnegative("is","person using cardiac drugs","010")
        xnegative("is","P wave rounded","599")
        xnegative("is","P wave flattened","751")
        xnegative("is","QRS with significant Q's","051")
        xnegative("is","U wave present","065")
        xnegative("is","P wave sawtoothed","557")
        xnegative("is","QRS complex with some missing","221")
        xnegative("is","QRS with R-R'","037")
        xnegative("is","QRS complex with an escape beat","049")
        xnegative("is","PR interval < 0.12 sec","249")
        xnegative("is","P wave notched","541")
        xillness_is("right atrial enlargement","193")
```

```
        xpositive("is","P wave present","012")
        xpositive("is","P wave upright","016")
        xpositive("is","P wave monophasic","018")
        xpositive("is","QRS complex present","032")
        xpositive("is","QRS complex duration <= 0.1 sec","565")
        xpositive("is","P wave all similar","014")
        xpositive("is","T wave present","055")
        xpositive("is","T wave upright","057")
        xpositive("is","T wave rounded and assymetrical","059")
        xpositive("is","ST segment present","081")
        xpositive("is","ST segment isoelectric","571")
        xpositive("is","QT interval present","085")
        xpositive("is","QT > 0.375 R-R but < 0.5 R-R for HR of 65-90
BPM","573")
        xpositive("is","P wave ahead of the QRS","024")
        xpositive("is","QRS complex upright","034")
        xpositive("is","QRS complex all similar","039")
        xpositive("is","PR interval present","070")
        xpositive("is","P wave notched","541")
        xnegative("is","person using cardiac drugs","010")
        xnegative("is","P wave rounded","599")
        xnegative("is","P wave flattened","751")
        xnegative("is","QRS with significant Q's","051")
        xnegative("is","U wave present","065")
        xnegative("is","P wave sawtoothed","557")
        xnegative("is","QRS complex with some missing","221")
        xnegative("is","QRS with R-R'","037")
        xnegative("is","QRS complex with an escape beat","049")
        xnegative("is","PR interval < 0.12 sec","249")
        xillness_is("left atrial enlargement","191")
```

```
        xpositive("is","P wave present","012")
        xpositive("is","P wave upright","016")
        xpositive("is","P wave monophasic","018")
        xpositive("is","P wave rounded","599")
        xpositive("is","P wave amplitude not > 0.3 mV","217")
        xpositive("is","QRS complex present","032")
        xpositive("is","QRS complex duration <= 0.1 sec","565")
        xpositive("is","P wave all similar","014")
        xpositive("is","T wave present","055")
        xpositive("is","T wave upright","057")
        xpositive("is","T wave rounded and assymetrical","059")
        xpositive("is","ST segment present","081")
        xpositive("is","ST segment isoelectric","571")
        xpositive("is","QT interval present","085")
        xpositive("is","QT > 0.375 R-R but < 0.5 R-R for HR of 65-90
BPM","573")
        xpositive("is","P wave ahead of the QRS","024")
        xpositive("is","QRS complex upright","034")
        xpositive("is","QRS complex all similar","039")
        xpositive("is","PR interval present","070")
        xnegative("is","person using cardiac drugs","010")
        xnegative("is","P wave duration not > 0.12 sec.","219")
        xnegative("is","QRS with significant Q's","051")
        xnegative("is","U wave present","065")
        xnegative("is","QRS complex with some missing","221")
        xnegative("is","QRS with R-R'","037")
        xnegative("is","QRS complex with an escape beat","049")
        xnegative("is","PR interval < 0.12 sec","249")
        xillness_is("left atrial enlargement","191")
```

```
xpositive("is","P wave present","012")
xpositive("is","P wave upright","016")
xpositive("is","P wave monophasic","018")
xpositive("is","P wave rounded","599")
xpositive("is","P wave amplitude not > 0.3 mV","217")
xpositive("is","P wave duration not > 0.12 sec.","219")
xpositive("is","P wave all similar","014")
xpositive("is","P wave ahead of the QRS","024")
xpositive("is","P wave present in each cycle","254")
xpositive("is","QRS complex present","032")
xpositive("is","QRS complex upright","034")
xpositive("is","QRS complex duration <= 0.1 sec","565")
xpositive("is","QRS complex all similar","039")
xpositive("is","T wave present","055")
xpositive("is","T wave upright","057")
xpositive("is","T wave rounded and assymetrical","059")
xpositive("is","T wave all similar","061")
xpositive("is","T wave duration <= 0.2 sec.","233")
xpositive("is","T wave amplitude <= 0.5 mV","229")
xpositive("is","PR interval present","070")
xpositive("is","PR interval constant","072")
xpositive("is","PR segment present","077")
xpositive("is","PR segment isoelectric","569")
xpositive("is","ST segment present","081")
xpositive("is","ST segment elevated","555")
xnegative("is","person using cardiac drugs","010")
xnegative("is","QRS complex with some missing","221")
xnegative("is","QRS with R-R'","037")
xnegative("is","QRS with significant Q's","051")
xnegative("is","U wave present","065")
xnegative("is","PR interval < 0.12 sec","249")
xnegative("is","PR interval > 0.2 sec","251")
xnegative("is","ST segment isoelectric","571")
xnegative("is","ST segment depressed","553")
xillness_is("ischemia or injury or infarction","703")
```

```
xpositive("is","P wave present","012")
xpositive("is","P wave upright","016")
xpositive("is","P wave monophasic","018")
xpositive("is","P wave rounded","599")
xpositive("is","P wave amplitude not > 0.3 mV","217")
xpositive("is","P wave duration not > 0.12 sec.","219")
xpositive("is","P wave all similar","014")
xpositive("is","P wave ahead of the QRS","024")
xpositive("is","P wave present in each cycle","254")
xpositive("is","QRS complex present","032")
xpositive("is","QRS complex upright","034")
xpositive("is","QRS complex duration <= 0.1 sec","565")
xpositive("is","QRS complex all similar","039")
xpositive("is","T wave present","055")
xpositive("is","T wave upright","057")
xpositive("is","T wave rounded and assymetrical","059")
xpositive("is","T wave all similar","061")
xpositive("is","T wave duration <= 0.2 sec.","233")
xpositive("is","T wave amplitude <= 0.5 mV","229")
xpositive("is","PR interval present","070")
xpositive("is","PR interval constant","072")
xpositive("is","PR segment present","077")
xpositive("is","PR segment isoelectric","569")
xpositive("is","ST segment present","081")
xpositive("is","ST segment depressed","553")
xnegative("is","person using cardiac drugs","010")
xnegative("is","QRS complex with some missing","221")
xnegative("is","QRS with R-R'","037")
xnegative("is","QRS with significant Q's","051")
xnegative("is","U wave present","065")
xnegative("is","PR interval < 0.12 sec","249")
xnegative("is","PR interval > 0.2 sec","251")
xnegative("is","ST segment isoelectric","571")
xillness_is("ventricular enlargement or ischemia or injury or
infarction","701")
```

```
xpositive("is","P wave present","012")
xpositive("is","P wave upright","016")
xpositive("is","P wave monophasic","018")
xpositive("is","P wave rounded","599")
xpositive("is","P wave amplitude not > 0.3 mV","217")
xpositive("is","P wave duration not > 0.12 sec.","219")
xpositive("is","P wave all similar","014")
xpositive("is","P wave ahead of the QRS","024")
xpositive("is","P wave present in each cycle","254")
xpositive("is","QRS complex present","032")
xpositive("is","QRS complex upright","034")
xpositive("is","QRS complex duration <= 0.1 sec","565")
xpositive("is","QRS complex all similar","039")
xpositive("is","T wave present","055")
xnegative("is","person using cardiac drugs","010")
xnegative("is","QRS complex with some missing","221")
xnegative("is","QRS with R-R'","037")
xnegative("is","QRS with significant Q's","051")
xnegative("is","T wave upright","057")
xillness_is("ventricular enlargement or ischemia or injury or
infarction","701")
```

```
xpositive("is","P wave present","012")
xpositive("is","P wave upright","016")
xpositive("is","P wave monophasic","018")
xpositive("is","P wave rounded","599")
xpositive("is","P wave amplitude not > 0.3 mV","217")
xpositive("is","P wave duration not > 0.12 sec.","219")
xpositive("is","P wave all similar","014")
xpositive("is","P wave ahead of the QRS","024")
xpositive("is","P wave present in each cycle","254")
xpositive("is","QRS complex present","032")
xpositive("is","QRS complex upright","034")
xpositive("is","QRS complex duration <= 0.1 sec","565")
xpositive("is","QRS complex all similar","039")
xpositive("is","QRS with significant Q's","051")
xnegative("is","person using cardiac drugs","010")
xnegative("is","QRS complex with some missing","221")
xnegative("is","QRS with R-R'","037")
xillness_is("infarction","203")
```

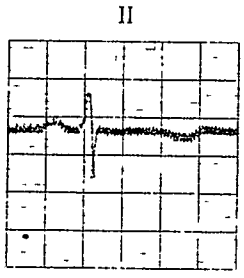


FIG. (41) - LEFT ATRIAL ENLARGEMENT

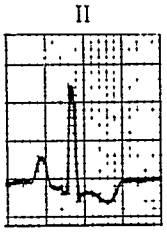


FIG. (42) - RIGHT ATRIAL ENLARGEMENT

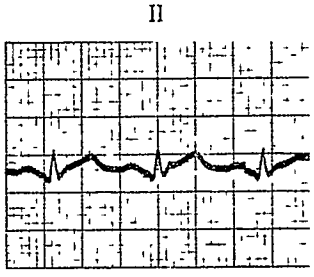


FIG. (43) - MYOCARDIAL INFARCTION

```
xpositive("is","P wave present","012")
xpositive("is","P wave upright","016")
xpositive("is","P wave monophasic","018")
xpositive("is","P wave rounded","599")
xpositive("is","P wave amplitude not > 0.3 mV","217")
xpositive("is","P wave duration not > 0.12 sec.","219")
xpositive("is","P wave all similar","014")
xpositive("is","P wave ahead of the QRS","024")
xpositive("is","P wave present in each cycle","254")
xpositive("is","QRS complex present","032")
xpositive("is","QRS complex upright","034")
xpositive("is","QRS complex duration <= 0.1 sec","565")
xpositive("is","QRS complex all similar","039")
xpositive("is","T wave present","055")
xpositive("is","T wave upright","057")
xpositive("is","T wave rounded and assymetrical","059")
xpositive("is","T wave all similar","061")
xpositive("is","T wave duration <= 0.2 sec.","233")
xpositive("is","T wave amplitude <= 0.5 mV","229")
xpositive("is","PR interval present","070")
xpositive("is","PR interval constant","072")
xpositive("is","PR segment present","077")
xpositive("is","PR segment isoelectric","569")
xpositive("is","ST segment present","081")
xpositive("is","ST segment isoelectric","571")
xpositive("is","QT interval present","085")
xpositive("is","QT < 0.375 R-R for heartrate between 65-90
BPM","901")
xnegative("is","person using cardiac drugs","010")
xnegative("is","QRS complex with some missing","221")
xnegative("is","QRS with R-R'","037")
xnegative("is","QRS with significant Q's","051")
xnegative("is","U wave present","065")
xnegative("is","PR interval < 0.12 sec","249")
xnegative("is","PR interval > 0.2 sec","251")
xnegative("is","QT > 0.375 R-R but < 0.5 R-R for HR of 65-90
BPM","573")
xnegative("is","QT > 0.5 R-R for heartrate between 65-90
BPM","900")
xillness_is("hypercalcemia","207")
```

```
xpositive("is","P wave present","012")
xpositive("is","P wave upright","016")
xpositive("is","P wave monophasic","018")
xpositive("is","P wave rounded","599")
xpositive("is","P wave amplitude not > 0.3 mV","217")
xpositive("is","P wave duration not > 0.12 sec.","219")
xpositive("is","P wave all similar","014")
xpositive("is","P wave ahead of the QRS","024")
xpositive("is","P wave present in each cycle","254")
xpositive("is","QRS complex present","032")
xpositive("is","QRS complex upright","034")
xpositive("is","QRS complex duration <= 0.1 sec","565")
xpositive("is","QRS complex all similar","039")
xpositive("is","T wave present","055")
xpositive("is","T wave upright","057")
xpositive("is","T wave rounded and assymetrical","059")
xpositive("is","T wave all similar","061")
xpositive("is","T wave duration <= 0.2 sec.","233")
xpositive("is","T wave amplitude <= 0.5 mV","229")
xpositive("is","PR interval present","070")
xpositive("is","PR interval constant","072")
xpositive("is","PR segment present","077")
xpositive("is","PR segment isoelectric","569")
xpositive("is","ST segment present","081")
xpositive("is","ST segment isoelectric","571")
xpositive("is","QT interval present","085")
xpositive("is","QT > 0.5 R-R for heartrate between 65-90
BPM","900")
xnegative("is","person using cardiac drugs","010")
xnegative("is","QRS complex with some missing","221")
xnegative("is","QRS with R-R'","037")
xnegative("is","QRS with significant Q's","051")
xnegative("is","U wave present","065")
xnegative("is","PR interval < 0.12 sec","249")
xnegative("is","PR interval > 0.2 sec","251")
xnegative("is","QT > 0.375 R-R but < 0.5 R-R for HR of 65-90
BPM","573")
xillness_is("hypocalcemia","205")
```

```
xpositive("is","P wave present","012")
xpositive("is","P wave upright","016")
xpositive("is","P wave monophasic","018")
xpositive("is","P wave rounded","599")
xpositive("is","P wave amplitude not > 0.3 mV","217")
xpositive("is","P wave duration not > 0.12 sec.","219")
xpositive("is","P wave all similar","014")
xpositive("is","P wave ahead of the QRS","024")
xpositive("is","P wave present in each cycle","254")
xpositive("is","QRS complex present","032")
xpositive("is","QRS complex upright","034")
xpositive("is","QRS complex duration <= 0.1 sec","565")
xpositive("is","QRS complex all similar","039")
xpositive("is","T wave present","055")
xpositive("is","T wave upright","057")
xpositive("is","T wave rounded and assymetrical","059")
xpositive("is","T wave all similar","061")
xpositive("is","T wave duration <= 0.2 sec.","233")
xpositive("is","T wave amplitude <= 0.5 mV","229")
xpositive("is","U wave present","065")
xpositive("is","U wave upright and similar","067")
xnegative("is","person using cardiac drugs","010")
xnegative("is","QRS complex with some missing","221")
xnegative("is","QRS with R-R'","037")
xnegative("is","QRS with significant Q's","051")
xnegative("is","T wave amplitude > than that of U wave","231")
xnegative("is","U wave amplitude < that of T wave","235")
xillness_is("hypokalemia","209")
```

```
xpositive("is","P wave present","012")
xpositive("is","P wave upright","016")
xpositive("is","P wave monophasic","018")
xpositive("is","P wave rounded","599")
xpositive("is","P wave amplitude not > 0.3 mV","217")
xpositive("is","P wave duration not > 0.12 sec.","219")
xpositive("is","P wave all similar","014")
xpositive("is","P wave ahead of the QRS","024")
xpositive("is","P wave present in each cycle","254")
xpositive("is","QRS complex present","032")
xpositive("is","QRS complex upright","034")
xpositive("is","QRS complex duration <= 0.1 sec","565")
xpositive("is","QRS complex all similar","039")
xpositive("is","T wave present","055")
xpositive("is","T wave upright","057")
xpositive("is","T wave tented","750")
xnegative("is","person using cardiac drugs","010")
xnegative("is","QRS complex with some missing","221")
xnegative("is","QRS with R-R'","037")
xnegative("is","QRS with significant Q's","051")
xnegative("is","T wave rounded and assymetrical","059")
xillness_is("hyperkalemia","211")
```

```
xpositive("is","P wave present","012")
xpositive("is","P wave upright","016")
xpositive("is","P wave monophasic","018")
xpositive("is","P wave flattened","751")
xnegative("is","person using cardiac drugs","010")
xnegative("is","P wave rounded","599")
xillness_is("hyperkalemia","211")
```

```
xpositive("is","person using cardiac drugs","010")
xpositive("is","P wave present","012")
xpositive("is","P wave rounded","599")
xpositive("is","P wave duration not > 0.12 sec.","219")
xpositive("is","T wave present","055")
xpositive("is","T wave upright","057")
xpositive("is","T wave rounded and assymetrical","059")
xpositive("is","ST segment present","081")
xpositive("is","ST segment isoelectric","571")
xpositive("is","QRS complex present","032")
xpositive("is","QT interval present","085")
xpositive("is","QT > 0.5 R-R for heartrate between 65-90
BPM","900")
xnegative("is","U wave present","065")
xnegative("is","QT > 0.375 R-R but < 0.5 R-R for HR of 65-90
BPM","573")
xnegative("is","QT < 0.375 R-R for heartrate between 65-90
BPM","901")
xillness_is("effect of quinidine/propranolol","215")
```

```
                xpositive("is","person using cardiac drugs","010")
                xpositive("is","P wave present","012")
                xpositive("is","P wave rounded","599")
                xpositive("is","P wave duration not > 0.12 sec.","219")
                xpositive("is","T wave present","055")
                xpositive("is","T wave upright","057")
                xpositive("is","T wave rounded and assymetrical","059")
                xpositive("is","ST segment present","081")
                xpositive("is","ST segment isoelectric","571")
                xpositive("is","QRS complex present","032")
                xpositive("is","QT interval present","085")
                xpositive("is","QT < 0.375 R-R for heartrate between 65-90
 BPM","901")
                xnegative("is","U wave present","065")
                xnegative("is","QT > 0.375 R-R but < 0.5 R-R for HR of 65-90
..BPM","573")
                xillness_is("effect of digitalis","213")
```

```
xpositive("is","person using cardiac drugs","010")
xpositive("is","P wave present","012")
xpositive("is","P wave rounded","599")
xpositive("is","P wave duration not > 0.12 sec.","219")
xpositive("is","T wave present","055")
xpositive("is","T wave upright","057")
xpositive("is","T wave rounded and assymetrical","059")
xpositive("is","ST segment present","081")
xpositive("is","ST segment sagging","752")
xnegative("is","U wave present","065")
xnegative("is","ST segment isoelectric","571")
xnegative("is","ST segment depressed","553")
xillness_is("effect of digitalis","213")
```

```
xpositive("is","person using cardiac drugs","010")
xpositive("is","P wave present","012")
xpositive("is","P wave rounded","599")
xpositive("is","P wave duration not > 0.12 sec.","219")
xpositive("is","T wave present","055")
xpositive("is","T wave upright","057")
xpositive("is","T wave rounded and assymetrical","059")
xpositive("is","ST segment present","081")
xpositive("is","ST segment depressed","553")
xnegative("is","U wave present","065")
xnegative("is","ST segment isoelectric","571")
xillness_is("effect of quinidine/propranolol","215")
```

```
xpositive("is","person using cardiac drugs","010")
xpositive("is","P wave present","012")
xpositive("is","P wave rounded","599")
xpositive("is","P wave duration not > 0.12 sec.","219")
xpositive("is","T wave present","055")
xpositive("is","T wave upright","057")
xpositive("is","T wave rounded and assymetrical","059")
xpositive("is","U wave present","065")
xnegative("is","T wave amplitude > than that of U wave","231")
xillness_is("effect of quinidine/propranolol","215")
```

```
xpositive("is","person using cardiac drugs","010")
xpositive("is","P wave present","012")
xpositive("is","P wave rounded","599")
xpositive("is","P wave duration not > 0.12 sec.","219")
xpositive("is","T wave present","055")
xpositive("is","T wave upright","057")
xpositive("is","T wave notched","755")
xnegative("is","T wave rounded and assymetrical","059")
xillness_is("effect of quinidine/propranolol","215")
```

```
xpositive("is","person using cardiac drugs","010")
xpositive("is","P wave present","012")
xpositive("is","P wave rounded","599")
xpositive("is","P wave duration not > 0.12 sec.","219")
xpositive("is","T wave present","055")
xnegative("is","T wave upright","057")
xillness_is("effect of quinindine/propranolol","215")
```

```
xpositive("is","person using cardiac drugs","010")
xpositive("is","P wave present","012")
xpositive("is","P wave rounded","599")
xnegative("is","P wave duration not > 0.12 sec.","219")
xillness_is("effect of quinidine/propranolol","215")
```

```
xpositive("is","person using cardiac drugs","010")
xpositive("is","P wave present","012")
xpositive("is","P wave notched","541")
xnegative("is","P wave rounded","599")
xillness_is("effect of quinidine/propranolol","215")
```

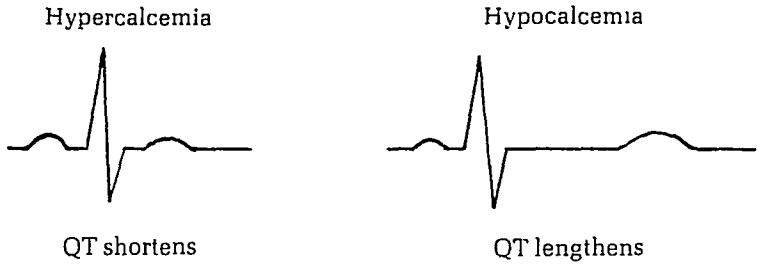


FIG. (44) - HYPERCALCEMIA AND HYPOCALCEMIA

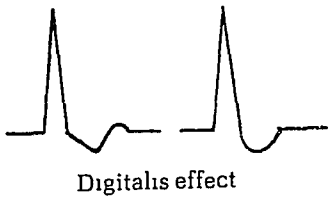


FIG. (45) - EFFECT OF DIGITALIS

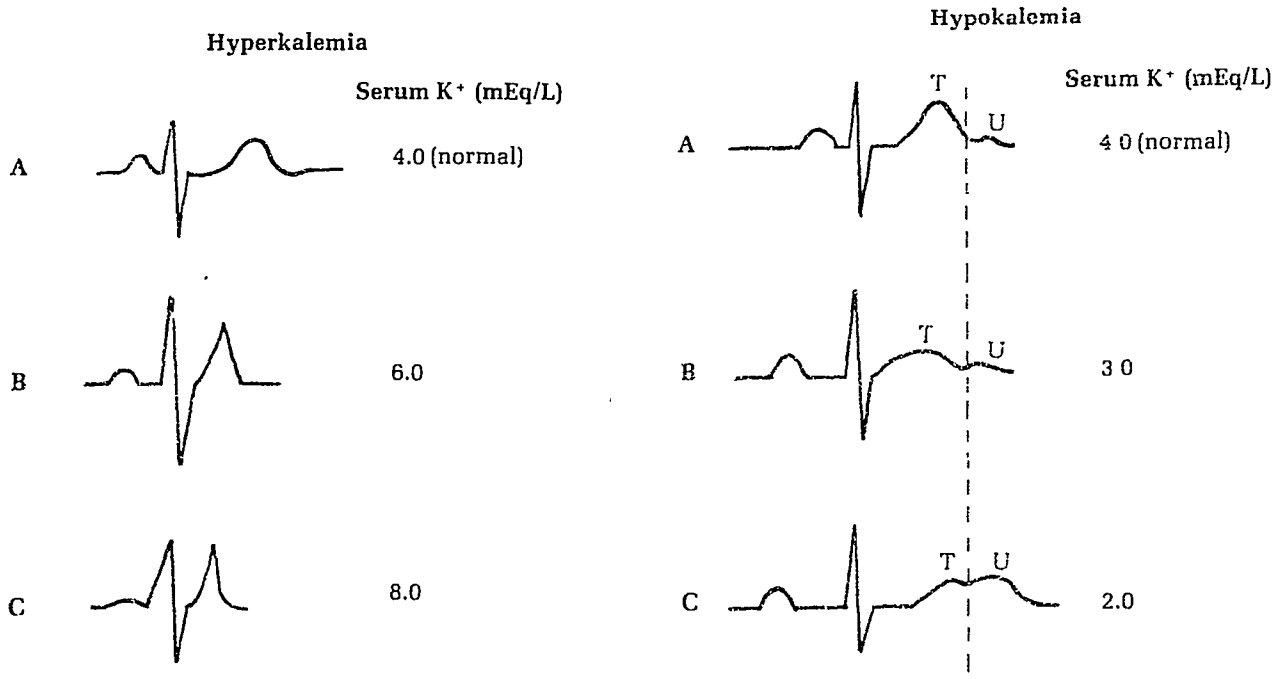


FIG. (46) - HYPERKALEMIA AND HYPOKALEMIA

Appendix D

Flow Charts

Presented in this appendix are flow charts that present the operations in the EKGCHALLENGER in a block diagram format.

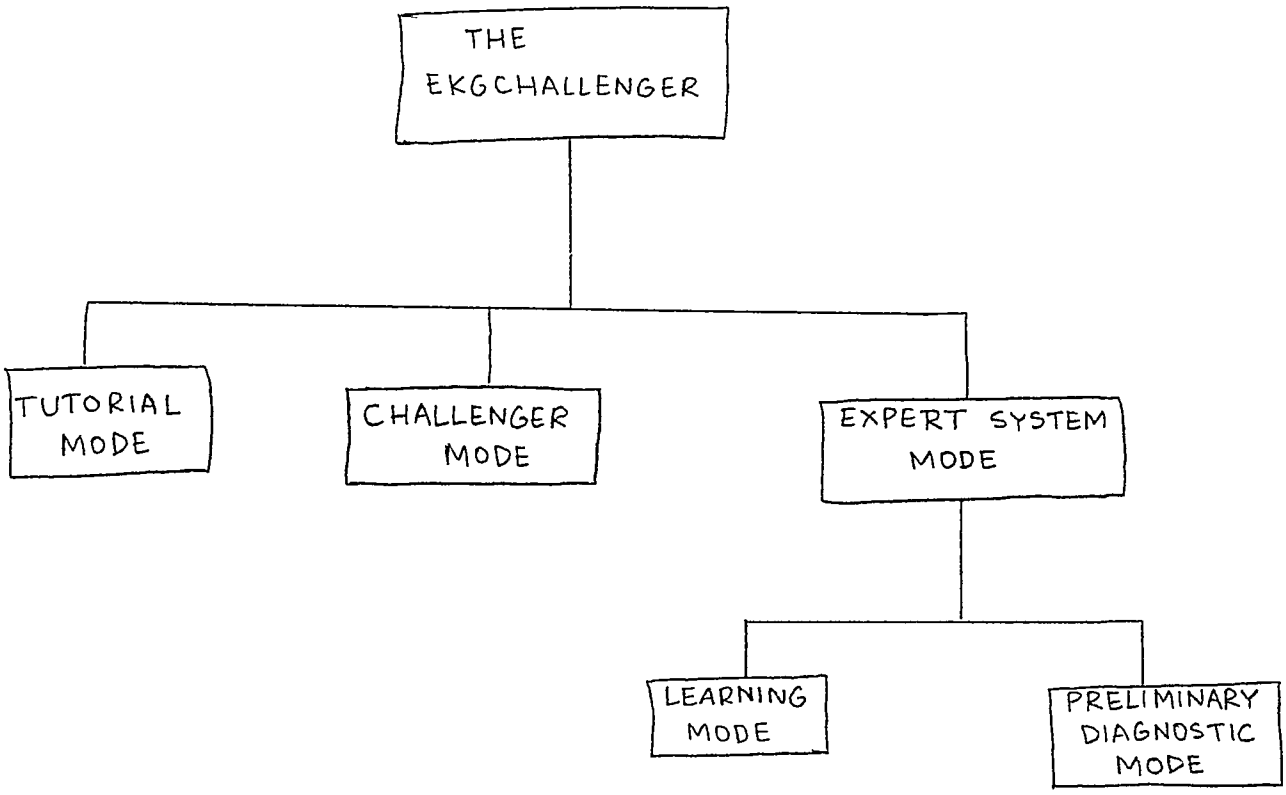
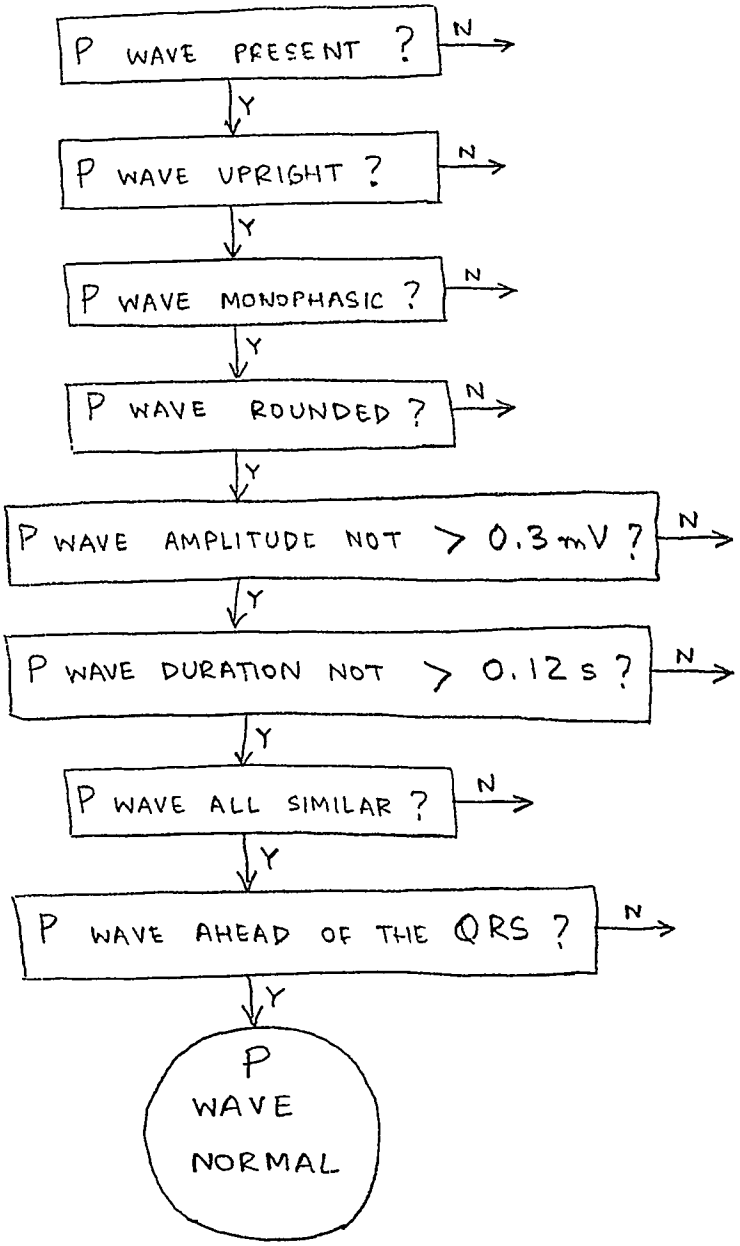


FIG. (47) - MODES OF OPERATION OF THE EKGCHALLENGER



NOTE : ALL N'S LEAD TO P WAVE ABNORMAL .

FIG. (48) - AN EXAMPLE OF THE FLOW OF LOGIC IN THE EXPERT SYSTEM

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