Universidade Estadual de Campinas
Instituto de Computação

Francisco José Nardi Filho

Hybrid Narrative and Clinical Knowledge Base for Emergency Medicine Training

Base de Conhecimento Narrativa e Clínica Híbrida para Treinamento em Medicina de Emergência

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Dissertação apresentada ao Instituto de Computação da Universidade Estadual de Campinas como parte dos requisitos para a obtenção do título de Mestre em Ciência da Computação.

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Supervisor/Orientador: Prof. Dr. André Santanchè

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A ata da defesa com as respectivas assinaturas dos membros da banca encontra-se no processo de vida acadêmica do aluno.

Campinas, 19 de maio de 2017

Dedicatória

Dedico este trabalho às pessoas mais importantes e maravilhosas da minha vida, a começar por minha amada mãe Ernestina. Também dedico ao meu querido orientador André. Aos meus adorados irmão Luiz e falecido pai Francisco (*in memoriam*). Para minhas estimadas avó Conceição e tia-avó Élide (*in memoriam*). Para meus afilhados Marina e Johnatha, Mariellen e Douglas, João Paulo e Dominique. Para meus bravos leões Aron, Camilla e Luã. Para meu prezado amigo Pedro, Jhon e sua filha Alejandra. Para meus ex-companheiros de intercâmbio Cesar, Felipe, Guilherme, João e Meigarom. Para minha admirável professora Claudia e todos os meus caros amigos do LIS: Celso, Fabrício, Fagner, Felipe, Flavia, Ivelize, Jacqueline, Jaudete, Joana, João, Juan, Kléber, Leandro, Luana (e Júnior), Lucas Batista, Lucas Carvalho, Marcela, Márcio (e Bruna), Matheus, Patrícia, Ray e Ricardo. A meus benquistos professores do IFSULDEMINAS Aline, Eugênio, Gustavo, Heber, João Marcelo, Marcos Celso, Manoel, Paulo, Raphael, Ricardo, Tiago, Vinicius e orientadores Aracele e Ramon. A tios, primos, outros parentes e pessoas tão relevantes na minha vida quantos as mencionadas acima que porventura eu tenha esquecido ou omitido.

O Dia Mais Belo: Hoje
A Coisa Mais Fácil: Equivocar-se
O Maior Obstáculo: o Medo
O Maior Erro: o Abandono
A Raiz de Todos os Males: o Egoísmo
A Distração Mais Bela: o Trabalho
A Pior Derrota: o Desânimo
As Melhores Professoras: as Crianças
A Primeira Necessidade: Comunicar-se
O Que Traz Felicidade: Ser Útil aos Demais
O Pior Defeito: o Mau Humor
A Pessoa Mais Perigosa: a Mentirosa
O Pior Sentimento: o Rancor
O Presente Mais Belo: o Perdão
O Imprescindível: o Lar
A Rota Mais Rápida: a Retidão
A Sensação Mais Agradável: a Paz Interior
A Maior Proteção: o Sorriso
O Maior Remédio: o Otimismo
A Maior Satisfação: o Dever Cumprido
A Força Mais Potente do Mundo: a Fé
As Pessoas Mais Necessárias: os Pais
A Mais Bela de Todas as Coisas: O Amor!

Santa Teresa de Calcutá

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Resumo

Software para treinamento médico normalmente segue dois tipos de abordagens para a representação de seus dados. Um tipo é o treinamento baseado em simulação ou de pacientes virtuais *(virtual patients)*, os quais possuem representações altamente estruturadas dos dados clínicos e de seus planos de simulação. Outro tipo são sistemas que se concentram na narrativa de um caso clínico em formato de texto livre, como o ambiente de aprendizado de medicina de emergência *Jacinto*. Neste caso, os dados clínicos se misturam à narrativa em formato não estruturado. Assim, propomos um modelo para uma base de conhecimento narrativa e clínica híbrida para treinamento em medicina de emergência que combine ambas as abordagens. A hipótese é que ao relacionar as narrativas com informações clínicas estruturadas, podemos tirar proveito dos pontos fortes de cada abordagem. Por um lado, os dados clínicos estruturados oferecem flexibilidade para a produção de variações de casos e planos alternativos, dando mais autonomia à máquina para avaliar o desempenho do usuário. Por outro lado, as narrativas de texto livre permitem a introdução de aspectos e contexto relevantes para o cenário real, além dos dados clínicos. Neste trabalho, apresentamos uma experiência prática envolvendo a base de dados do ambiente de aprendizagem de medicina de emergência *Jacinto*.

Abstract

Software for medical training usually follows two types of approaches for the representation of its data. One type is the software of simulation-based training or *virtual patients* – which have highly structured representations of the clinical data and simulation plans. Another type are some systems which focus on the narrative of a clinical case in free-text format – e.g., the *Jacinto* emergency medicine learning environment. In this case, the clinical data mixes with the narrative in unstructured format. Thus, we propose a model for a hybrid narrative and clinical knowledge base for emergency medicine training that combines both of the approaches. We hypothesize that by connecting narratives with structured clinical information, we can take advantage of the strongest points of each approach. On the one hand, structured clinical data offers flexibility for the production of case variations and alternative plans, which gives machine more autonomy to assess user performance. On the other hand, free-text narratives enable the introduction of real scenario relevant aspects and context, beyond clinical data. In this work, we present a practical experiment involving the database of the *Jacinto* emergency medicine learning environment.

List of Figures

List of Tables

Contents

Chapter 1

Introduction

Patient safety in a health environment relies on the adequate preparation and instruction of the health professionals [Ricciardi and De Paolis, 2014]. Therefore, more frequent and accurate training can reduce the number of patient deaths caused by medical errors or negligence [Kirch and Boysen, 2010]. Concerning the *emergency medicine*, in addition to the risks and challenges inherent to the profession, the specialty requires the capacity of rapid decision-making in a time-constrained scenario, as well as effective communication and leadership in a multi-professional team [Grangeia et al., 2016].

The emergency medicine focuses on instant decision making and essential activities to prevent death. In response to severe sickness, trauma or pain, the emergency practitioner must rapidly identify, evaluate, oversight and stabilize the patients. The care comprises an assortment of physical and behavioral circumstances, as well as demands high medical ability and technical skills. The physicians who exercise emergency medicine will always find an environment made up of hurrying, intensity, and diversity [American Board of Emergency Medicine, 2017].

According to [Mahadevan, 2005], to be an active emergency practitioner one must own characteristics as capacity, sensibility, modesty, and perspicacity. The profession requires all these traits, added to decision-making capacity on limited information and time, besides expertise in trauma and medical resuscitation. The doctors must also have the courage to share the emergency room events outcomes with the families of the patients.

In summary, the specialty demands much knowledge and preparation from the medical practitioner. This level of requirement motivates the appearance of an innovative e-learning environment like "*Jacinto Bemelhor*", and consequently, of this work. In Portuguese, the patient name sounds like "*Already-Feel Much-Better*". This on-line course of Clinical Emergency Medicine was created by a team of professors and collaborators from the Faculty of Medical Sciences at the University of Campinas. From 2013 to 2015, about 300 medical residents participated in this course, which is inspired by real clinical cases. They solved cases that offered different views of the area, such as interpretation of exams, clinical decision making, and simulation of emergency care.

The student's primary goal in all these scenarios was to be able to textually and correctly diagnosing the diseases of the virtual patients, besides describing the appropriate treatment plans. The positive correlation between the frequency of access to the system and the students' final grades attested the course effectiveness.

The remaining of this text is organized in the following way. Chapter 1 presents our Motivation, Objective, and an Illustrative Case to be carried throughout this work. Chapter 2 presents Foundations and Related Work. Chapter 3 details the Problem, Requirements and our Approach, including the steps to build our Model and Architecture. Chapter 4 presents Discussion and Validation of the Model, besides a Comparison with the Related Work. Chapter 5 concludes the work, highlighting our Contribution and Future Work.

1.1 Motivation and Importance

The *Jacinto learning environment* is undoubtedly a success, justified not only by the quality of its content and the commitment of the professors, but also by the application of well-established cognitive theories. Nevertheless, the current version of the system is not able to perform the following tasks addressed by the new version, (i) *automatic assessment and feedback*; (ii) *capacity of deriving or generating new cases with similar structure of the previous ones*; (iii) *ability of collecting data from external bases*; and (iv) *personalized training.*

Our goal has been to design a knowledge base for the emergency course which sought, (i) *to preserve the benefits of the current narrative approach*; (ii) *to enable the representation of medical cases in an structured format, apt for automatic machine interpretation and handling*, and (iii) *to support the design of learning activities as part of the training.* Therefore, we elaborated a novel model that combines four perspectives, (i) the *virtual patient*; (ii) the *causal graph*; (iii) the *medical and case plans*; (iv) the *activity plans.*

1.2 Objective

To design a hybrid narrative and clinical knowledge base for emergency medicine training. In the medical side, it will subsidize solutions that not only (i) automatize content generation, (ii) assessment, and (iii) individualized training, but also allow (iv) external incorporation of cases, without losing the advantages of the traditional narrative course. In the computational side, it combines four health informatics approaches in a single and novel knowledge base model able to address the problems mentioned above.

1.3 Illustrative Case

This section has the purpose of presenting a real clinical case. A situation which could occur precisely in the emergency room, whose specialty is the focus of our training knowledge base, the *emergency medicine.* The next chapters will retrieve fractions or extensions of this illustrative case. That will help in the understanding of different medical systems and more advanced concepts.

Except for someone who is just looking for medical advice or taking routine exams, a patient will come for a visit only if he has something to complain about his health. This annoyance is usually called *chief complaint* and can be a symptom or other kind of manifestation. It is also very common that it happens simultaneously with more *associated symptoms*. These set of factors indicate for the patient that he is sick. He expects to receive an accurate diagnosis and proper treatment.

The doctor, therefore, will ask questions and perform simple exams such as the *physical exam* or more advanced ones, as the *electrocardiography* (or *ECG*), if necessary to understand the patient condition. Since the doctor diagnoses the disease, he can give to the patient an adequate treatment, also called *treatment plan*. Many times, especially in the emergency room, the medical practitioner must conduct some safe treatment to keep the patient alive. This action happens *before* any *diagnosis*. Figure 1.1 illustrates this process when an ECG is involved.

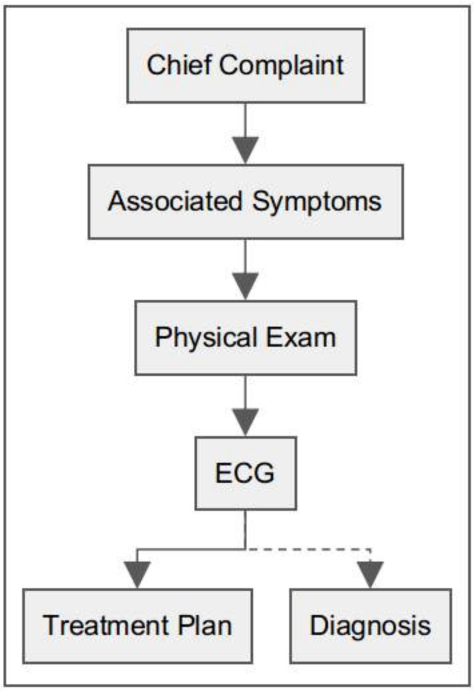

Figure 1.1: Basic Treatment/Diagnostic Process Example

Let us refine the example considering someone who visits the doctor or is taken to the emergency room complaining mainly of *palpitation*. Some of the associated symptoms the person may present are *dizziness*, i.e. a sensation of losing his balance and spinning around, besides *chest pain*. The doctor immediately performs a physical exam, obtaining, among other things, *blood pressure* and *respiratory rate*. Since these results are still insufficient to reach a diagnostic or treatment conclusion, the physician decides to request an *ECG*. Figure 1.2 shows this particular course of actions.

As soon as the doctor obtains the *ECG* result, he can match it to symptoms, exams, and remaining patient information to reasonably diagnose the infirmity and conduct treatment. Using his knowledge and experience, he may hypothesize that the diagnosis for this case is, for instance, *arrhythmia*. In a simple way, arrhythmia is a group of conditions in which the heart electrical impulses do not work properly, making the heartbeat too fast or too slow.

One of the characteristics that the waves of an ECG can display is the presence of *sinus rhythm* or *non-sinus rhythm*. Typically, owning a sinus-rhythm indicates that all or

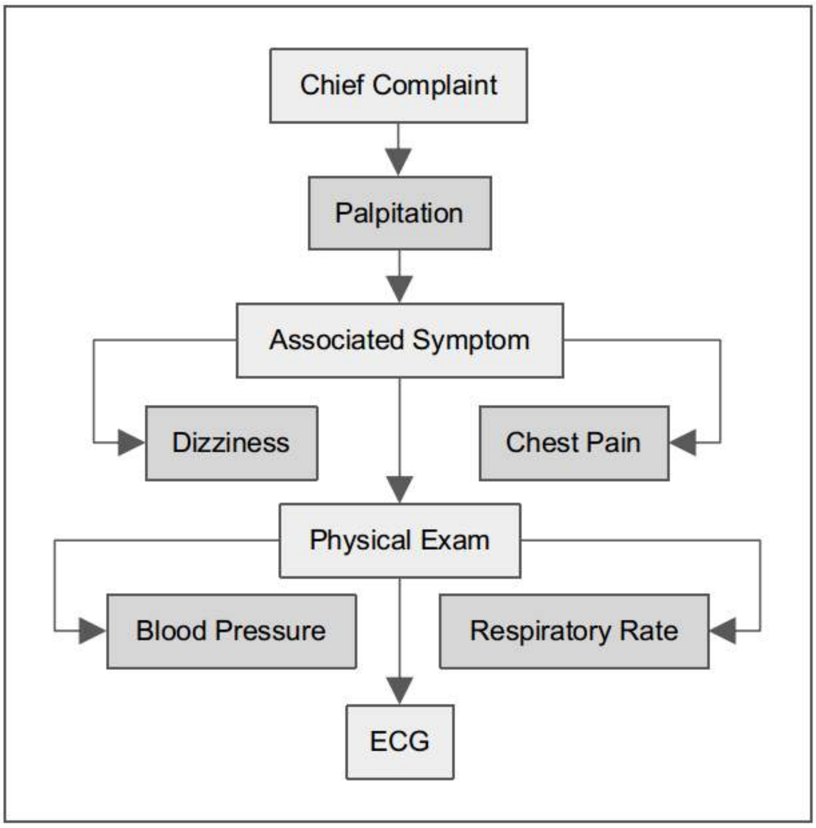

Figure 1.2: Illustrative Treatment/Diagnostic Case

most of the ECG measurements are fine. The condition is necessary but not sufficient to confirm the heart normal electrical activity. In one of the possible situations the patient ECG waves may exhibit sinus rhythm. This evidence already excludes the probability of arrhythmia.

What about the patient symptoms as palpitation, dizziness, and chest pain? First, the intensity *(e.g. weak or strong pain)* in which these symptoms are happening is critical to distinguish the diagnosis. The combination of symptoms, associated with the patient history and context, may betoken that the disease is not originated by the heart, since we rejected the chance of arrhythmia. The physician may suspect of *anxiety*, for instance.

Figure 1.3 exhibits the case treatment plan if ECG waves reveal *sinus rhythm*. In this situation, the medical practitioner should discharge the patient as there is no imminent risk to his health. This move does not mean that the patient is completely healthy, but the emergency room is not the place for moderate cases like his.

Following our example, let us consider the case where ECG waves reported non-sinus rhythm, i.e., some or most of the ECG values are not in good state. The presence of the previously mentioned symptoms conjointly to this ECG information verifies the diagnostic suspicion of arrhythmia. Figure 1.4 refers to the flowchart of this diagnosis.

The physician's next step is to decide between the treatment plan alternatives. In this case, the physician should analyze two other factors, the patient's *chest pain intensity*, in addition to his *physical exam normality*. Figure 1.5 depicts this situation.

To make the decision of giving some *medicine* to the patient *(the right path on the*

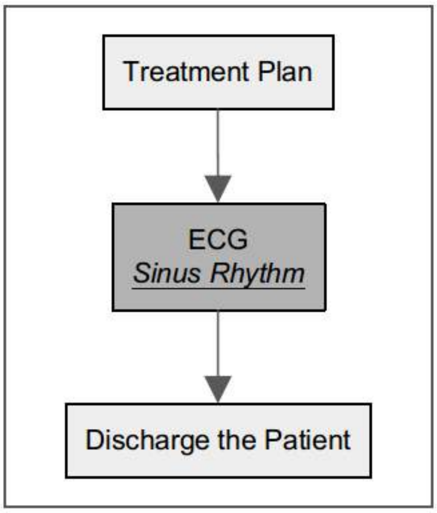

Figure 1.3: Treatment Plan - Discharge the Patient

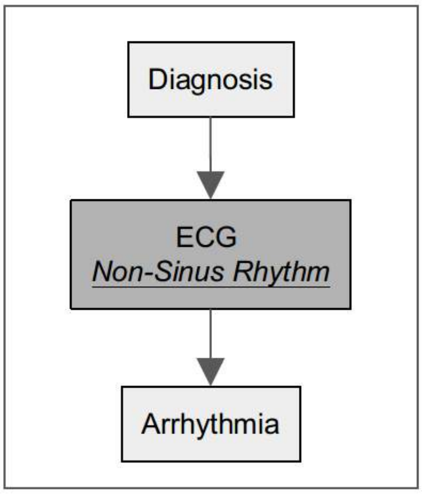

Figure 1.4: Illustrative Case Diagnosis - Arrhythmia

image), there must be a combination of *weak or absent chest pain* plus *normal physical exam*. For the alternative and more radical decision to perform an *electrical* or *chemical cardioversion* on the patient *(the left path on the image)*, there must be either a *strong chest pain* or an *abnormal physical exam*.

Cardioversion is a procedure which turns an abnormal heartbeat rhythm caused by arrhythmia in normal through the use of electricity or drugs. Only extreme circumstances require this method.

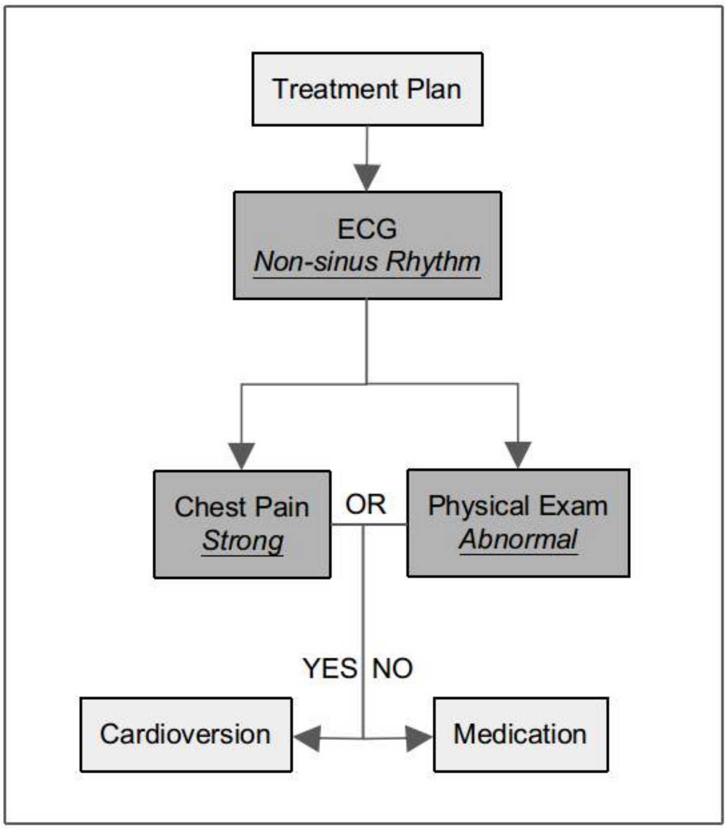

Figure 1.5: Treatment Plan Decision Alternatives

Chapter 2

Foundations and Related Work

2.1 Emergency Clerkship

Emergency clerkship is of our particular interest. While the clinical clerkship deals with the medicine of general scope, the emergency clerkship considers the emergency medicine specialty exclusively. According to [Mahadevan, 2005], the emergency medicine denotes the sole blend of quick data collection, concurrent prioritization, and constant multi-tasking in a time-constrained scenario. In addition to being a patient complaint-oriented specialty, it emphasizes stabilization based on anticipation more than diagnostic accuracy. According to [Grangeia et al., 2016], the emergency medicine will uninterruptedly require abilities as quick decision, excellent communication skills, and active leadership in a multi-professional team. Somehow emergency medicine takes risks and challenges of conventional medicine to a higher level.

This work has been developed in cooperation with the Faculty of Medical Sciences at the University of Campinas. In this context, [Grangeia et al., 2016] demonstrate how the clinical emergency rotation works. The mandatory clerkship composes the curriculum of the sixth-year students of medicine, who work eleven hours daily, from Monday to Friday. The apprentices spend one month at the Emergency Ward (EW) and the Intensive Care Unit (ICU), conjointly with another month at the Emergency Room (ER). The Jacinto emergency medicine e-learning arose precisely to supplement and enhance this period of instruction.

2.2 Jacinto Emergency Medicine e-Learning

According to [Grangeia et al., 2016], there are numerous advantages when using e-learning strategies. For example, the availability of the on-line course, the possibility of computer and mobile access, an always up-to-date content, among others.

Jacinto is also a course that benefits from cognitive and motivational conceptual frameworks, a tool capable of engaging students to learning. The environment supplements the emergency clerkship. The activities are separated in:

- **Virtual Rounds**.

- **Extreme Decisions**.
- **Emergency Quiz**.
- **Electrocardiographic Challenge**.
- **Radiology Challenge**.

2.2.1 Jacinto e-Learning Case Example

In order to illustrate how *Jacinto* works, we further present a case example of the environment in the category of *Electrocardiographic Challenge*. We notice the narrative structure, the information regarding patient demographics, diseases, exams, and so on, besides the questions demanding a textual answer. The ECG image must be interpreted.

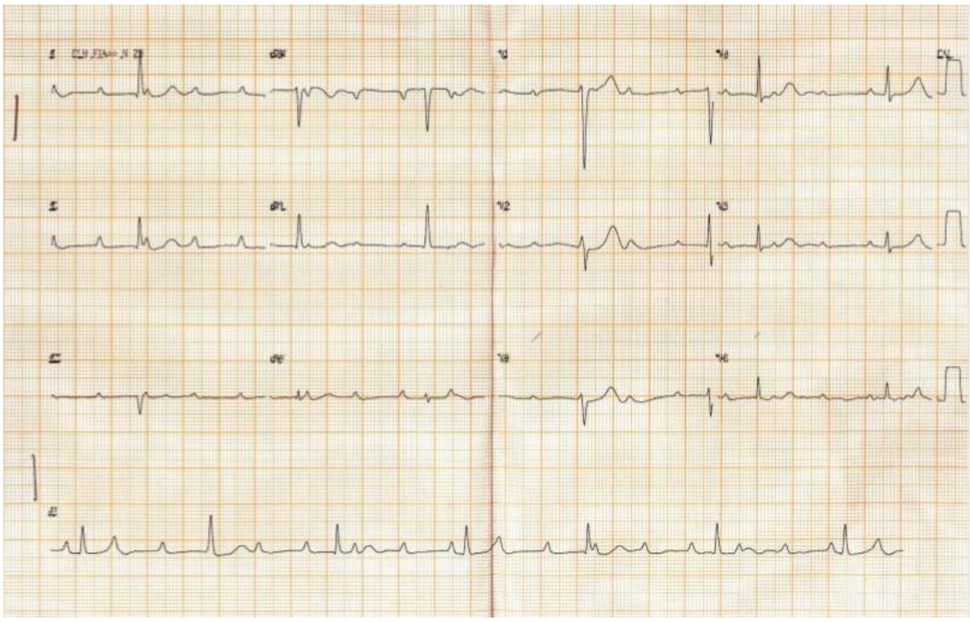

Figure 2.1: Jacinto ECG Challenge Case Example

"An 81-year-old male patient was admitted to the work room and had syncope at his home about 1 hour ago. He denies previous episodes and reports that in recent days he has been very tired, presenting nausea and reduced urinary volume, with no other complaint. He has a history of hypertension, diabetes, and smoking, suffering from acute myocardial infarction at about 3 years, and anterior descending artery angioplasty is required. It uses furosemide, carvedilol, digoxin, spironolactone, and enalapril. On admission to the emergency room, was conscious and oriented, with an arterial pressure of 124x82 mmHg, a respiratory rate of 18, SpO2 = 96%, afebrile; armpits and dry mucous membranes; ictus deviated to the left, with a systolic murmur in mitral focus +/- 4; pulmonary auscultation without changes. The remainder of physical examination without meaning" [Grangeia et al., 2016].

- *What is the electrocardiographic diagnosis?*

- *What are the most probable causes of the electrocardiographic abnormalities considering this specific patient?*

The case is presented to the users in a forum and the student answer it posting messages. A physician who is in charge of the course answers and comments the messages when necessary.

Cases take more than one round according to the type. The rounds are cycles where steps of the case are presented, followed by the interaction of students. The organization and division of content in the rounds are based in cognitive and learning theories.

2.3 Virtual Patients

Some simulations developed to complement clinical learning and training are called *virtual patients*. According to [Huang et al., 2007], in spite of being costly, virtual patient systems propitiate uncountable pedagogical and educational benefits for the medical students. In this work, we will exhibit and compare the model of the *MedBiquitous Virtual Patient* [Triola et al., 2007] [Smothers et al., 2010].

2.4 Knowledge Bases in Medicine

There is a difference between a *database* and a *knowledge base*. The point is that a *database* may only keep the information saved, organized, and ready to be retrieved. A knowledge base, in addition to that, can be combined with an inference engine. According to [Hayes-Roth et al., 1983] and [Green et al., 1986], this inference engine reasons about the stored data, using rules or other logic means to deduce new information or detect inconsistencies.

According to [Perry, 1990], knowledge bases in medicine occur in four diverse types, (1) electronic textbooks; (2) rule-based systems; (3) causal models; and (4) hypothesis or frame-based systems. Examples of each of these systems are (1) the Hepatitis Knowledge Base [Bernstein et al., 1980]; (2) MYCIN [Buchanan and Shortliffe, 1984]; (3) CASNET [Kulikowski and Weiss, 1982]; and (4) Internist-1 [Miller et al., 1986]. Figure 2.2 illustrates this differentiation.

2.5 Electronic Textbooks

Electronic textbooks help doctors to rapidly and selectively access the information they need in a medical knowledge base [Jr et al., 1985]. We have the case of the *Hepatitis Knowledge Base* [Bernstein et al., 1980] with respect to the *hepatitis* disease field.

Even though very useful in their purpose, *electronic textbooks* cannot generate new knowledge from their data in an explicit way. This observation puts in check their definition as a knowledge base.

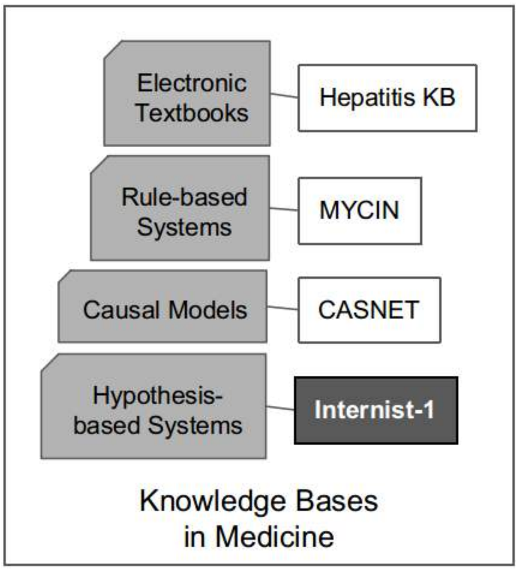

Figure 2.2: Types of Knowledge Bases in Medicine, according to [Perry, 1990]

2.6 MYCIN

Expert systems have the ability to provide advice or suggest a diagnosis. They include *rule-based systems* such as *MYCIN*.

MYCIN uses about 500 rules on an *if-then* structure to help doctors identifying and finding the disease-causing microorganisms and the proper antimicrobial therapy respectively. Additionally, it provides an explanation mechanism for the reason and the manner how the system took the decision [Buchanan and Shortliffe, 1984].

Three key components subdivide the system, (i) the *Consultation* program, which interacts with the doctors, generates diagnoses and therapies; (ii) the *Explanation* program, which substantiates the system's actions; and (iii) the *Knowledge-Acquisition* program, where experts handle and update the system's knowledge base [van Melle, 1979]. Figure 2.3 depicts the organization of the MYCIN system including these components.

The *Consultation* program functions as Figure 2.4 shows. It requests some information about the patient and, since MYCIN focuses on infectious diseases, the system asks a few additional questions regarding the collected exam culture, organism, symptoms, among others. After approximately 40 or 50 questions, the program is able to predict the disease, the bacteria causing the infection, besides the recommended therapy.

Questions from the *consultation program* are essentially binary, i.e., two-option questions such as yes or no inquiries. When it is not so, the answers are also very restricted, in which the physician user will choose among three, four or five options at most.

With all the necessary questions asked, MYCIN can suggest a diagnosis of infection and treatment plan as Figure 2.5 exhibits. In this case, *bacteremia* and the medicine *gentamicin*, respectively. The system is also able to point out the list of bacteria which may have caused the infection, in probability order, *E. Coli*, *Klebsiella*, *Enterobacter*, and *Klebsiella Pneumoniae*.

Figure 2.6 shows the *Rule N* – which is one of the applied rules – addressing the facts and presented answers. To provide a comparative perspective along the presentation of

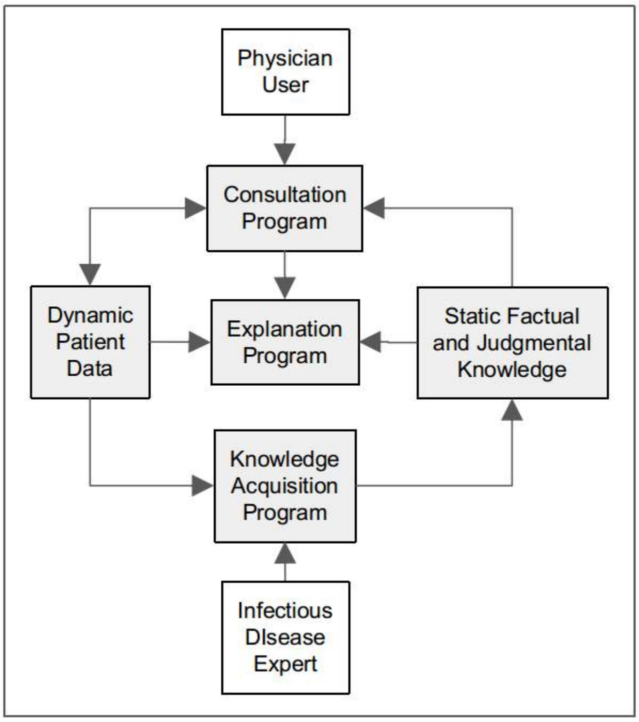

Figure 2.3: MYCIN System Organization [van Melle, 1979] (reprint)

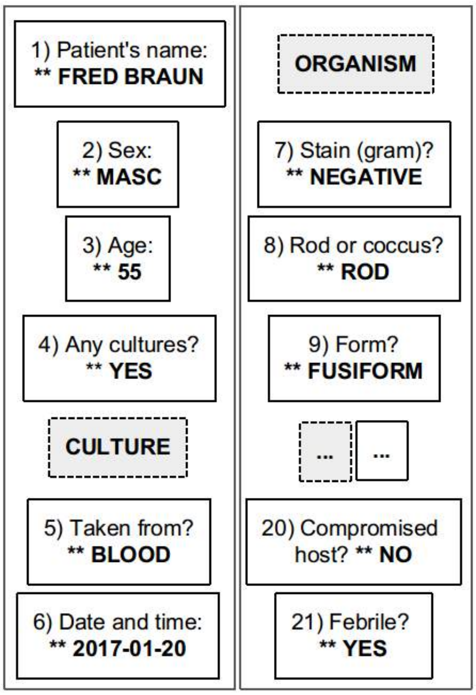

Figure 2.4: MYCIN *Consultation Program* Example [van Melle, 1979] (adapted)

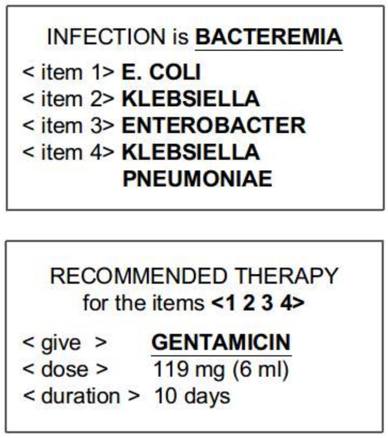

Figure 2.5: MYCIN Diagnosis and Treatment Example [van Melle, 1979] (reprint)

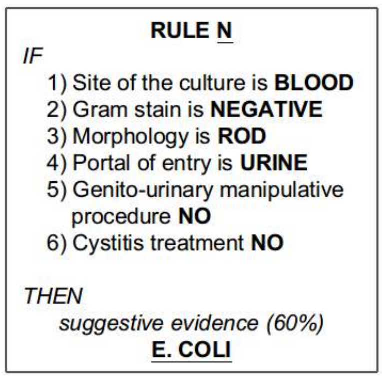

Figure 2.6: MYCIN Rule Example [van Melle, 1979] (reprint)

the several approaches, we produced hypothetical adaptations of cases to our illustrative example presented in the previous Section 1.3. These adaptations are only illustrative and they are neither implemented nor tested in the target environments. We further present such adaptation for MYCIN.

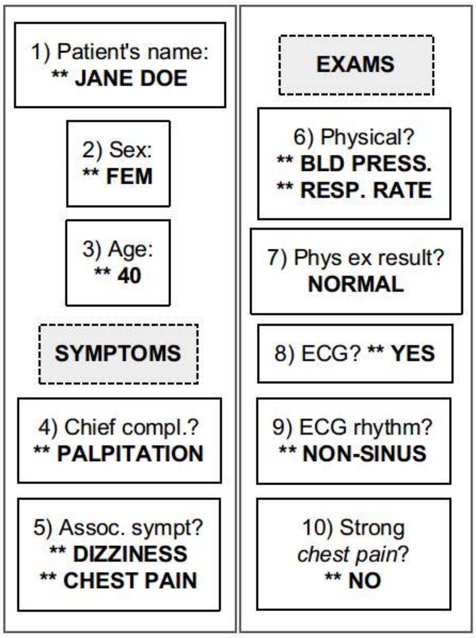

Figure 2.7: MYCIN Illustrative Case Consultation

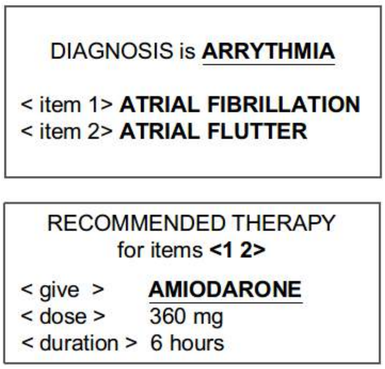

Figure 2.8: MYCIN Illustrative Case Diagnosis and Treatment

Figure 2.7 shows how MYCIN could be used adapted to the arrhythmia scenario. Thus, the focus would be on questions about *symptoms* and *exams* rather than *culture* and *organism*. The sequence of answers composes a path in the *decision trees* represented by the Figures 1.2 and 1.5 from Section 1.3 follows the *illustrative treatment/diagnostic case* in the Figure 1.2, inquiries numbers (7), (9) and (10) agree with *treatment plan decision*.

Therefore, the system can suggest a diagnosis of *arrhythmia* as we see in Figure 2.8. In Figure 2.9 we see the adapted *Rule R*, that the combination of all the factors enables MYCIN to define the likelihood of each arrhythmia type as well.

RULE R

IF

1) palpitation is a symptom **YES**
2) chest pain is a symptom **YES**
3) chest pain is strong **NO**
4) heart rate is > 100 bpm **YES**
5) ECG was performed **YES**
6) ECG QRS is narrow **YES**
7) ECG RR is irregular **YES**

THEN

suggestive evidence (80%)
ATRIAL FIBRILLATION
suggestive evidence (20%)
ATRIAL FLUTTER

Figure 2.9: MYCIN Illustrative Case Rule

2.7 CASNET

Figure 2.10 shows an example of the causal network. The plane of observations comprises signs, symptoms and test results observed in the patient before interpretation, e.g., a test of visual acuity. The plane of pathophysiological states involves the understanding of abnormal conditions or mechanisms, departing from the observations. They form a causal network in which an edge between two states A and B means that A can cause B. The plane of diseases indicates diseases that are deduced from an observed pattern (causal pathways) in the pathophysiological plane. A fourth layer, not shown in the figure, identifies treatment plans, related with diseases.

CASNET reached success of some prognostic conclusions and diagnosis, considering tests with ophthalmologists in the glaucoma domain. [Kulikowski and Weiss, 1982] recognize that the system misses a way to introduce empirical knowledge.

Other problems with CASNET are, (i) it lacks proper explanation mechanisms; (ii) the pathophysiology class is not well understood for many diseases; and (iii) it performs well only when the illness is progressive with the permanence of old symptoms, but not with diseases [Perry, 1990].

Let us retrieve our illustrative case again. Figure 2.11 shows four layers for our palpitation case. In (i), the *plane of observations*, there are symptoms, such as *palpitation*, and the exams, like *blood test* and *ECG*. Each of these nodes points to another node in (ii), the *plane of pathophysiological states*.

In that level (ii), there are nodes such as *tachyarrhythmia*, *dyspnea*, and *bloody diarrhea*. Since CASNET is a system based on a causal model, it is a set of nodes that implicates another one in the superior level.

In level (ii), we have decided to adapt the pathophysiological plane to go beyond causality, also considering that a state is related to another state – e.g., when two states related by the same cause – and one can indicate the presence of the other. For example, *bloody diarrhea* can indicate the presence of *anemia*, as well as the *blood test*.

After all, we reach the *plane of disease states* (iii), which eventually points towards the *plane of treatment states* (iv). For example, the pathway starting from *palpitation* and following to *tachyarrhythmia*, *supraventricular tachycardia*, besides extra findings, as

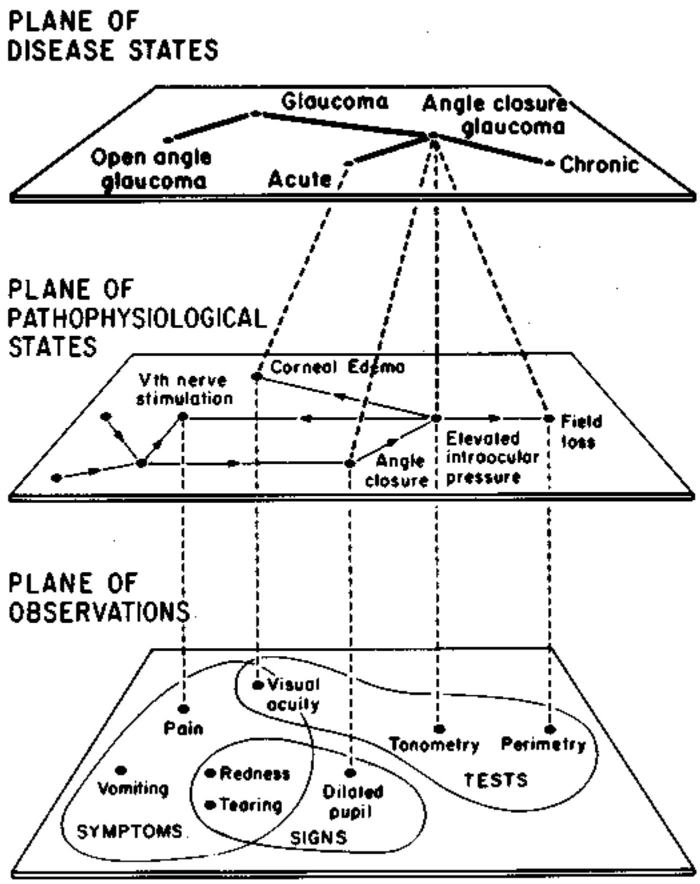

Figure 2.10: CASNET 3D Description of Glaucoma (source [Kulikowski and Weiss, 1982])

tachypnea, *dyspnea* and *non-sinus rhythm* forms a pattern that conducts to the conclusion of *atrial fibrillation*, as described in Case 192 of Jacinto. This conclusion leads to a electrical or chemical *cardioversion* treatment (amiodarone and metoprolol).

So far, we have presented and compared three different systems, (i) *an electronic textbook*, (ii) *a rule-based system*, and (iii) *a causal model*. Before presenting the next system, the *Internist-1*, which we will analyze a type of clinical knowledge base structure, the *medical ontologies*. The following sections explain clinical data organization and classification, further introducing and explaining the concept of *medical plans*.

These concepts will be fundamental to understand and analyze the *Internist-1* system and how it is important for the building of our a *knowledge base for medicine training*. We will also be able to explain part of the reasoning process used for clinical decision support systems and student performance evaluation in medical training.

2.8 Medical Ontologies

When representing information to be handled by machines, one challenge is how to represent them in a way that machines can automatically interpret these information without human intervention. Ontologies in computer science – differently from philosophy – are

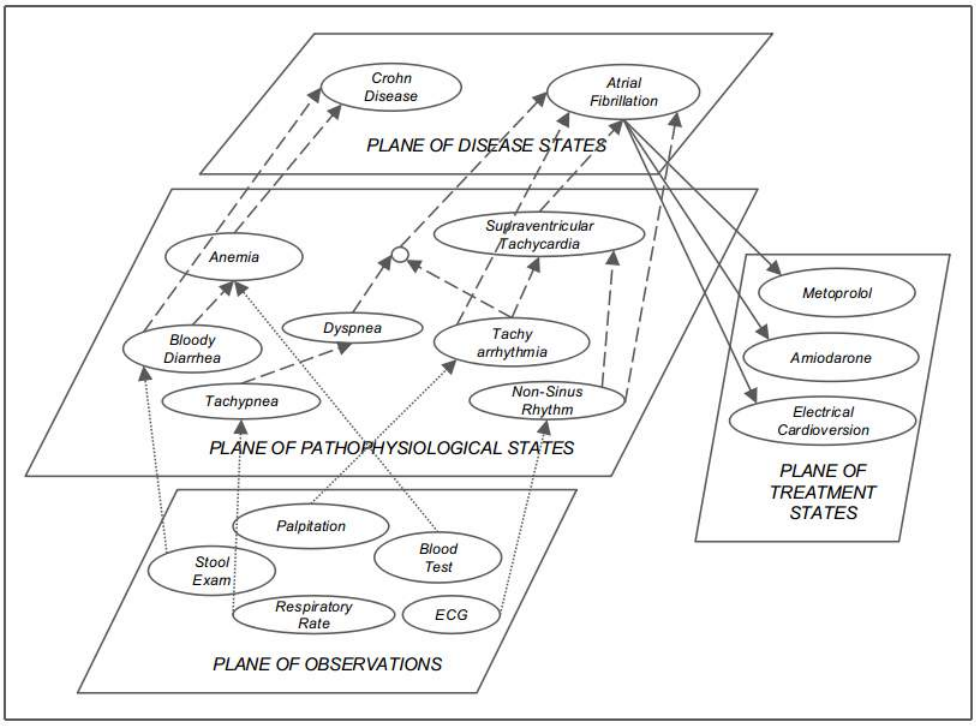

Figure 2.11: Illustrative Case CASNET Planes [Kulikowski and Weiss, 1982] (adapted)

formal representations of knowledge, able to be read and automatically interpreted by machines. Interpret means that machines can decide how to proceed with the available information.

The raise of the ontologies field is highly related to the necessity of open and standard ways to exchange and interrelate knowledge. An usual approach to represent ontologies is by producing a formal representation where knowledge is organized in interrelated classes of information and their properties.

[Jovic et al., 2007b] proposed an ontology construction process for medical knowledge representation. According to them, the steps one must follow are: (i) define the scope of the ontology; (ii) obtain medical knowledge; (iii) choose a tool and an ontology language; (iv) propose an ontology; and (v) present it in a proper way. They developed an ontology whose scope is arrhythmia and heart failure. The ontology is accessible through the link http://lis.irb.hr/heartfaid/ontology.

Beyond the model, it contains important aspects regarding diagnostics, treatment, medical procedures and patient information. The combination of these data in an ontology allows knowledge inference and reasoning. Their long-term objective is to support clinical decision making.

[Jovic et al., 2007b] define ontology as a combination of classes, individuals, properties, and relationships among classes and individuals, written mostly in OWL (Ontology Web Language). Figure 2.12 shows an example of clinical concept, the *aspirin*.

Here the properties of superclasses, such as *Treatment*, are inherited by subclasses, such as *Medication*. *indDiagnosis* is the diagnosis which requires that a particular type of *Medication*. The arrow departing from a class to the left indicates the existence of additional subclasses, e.g., *Medication* is not the only *Treatment*. *maxDailyDose* and

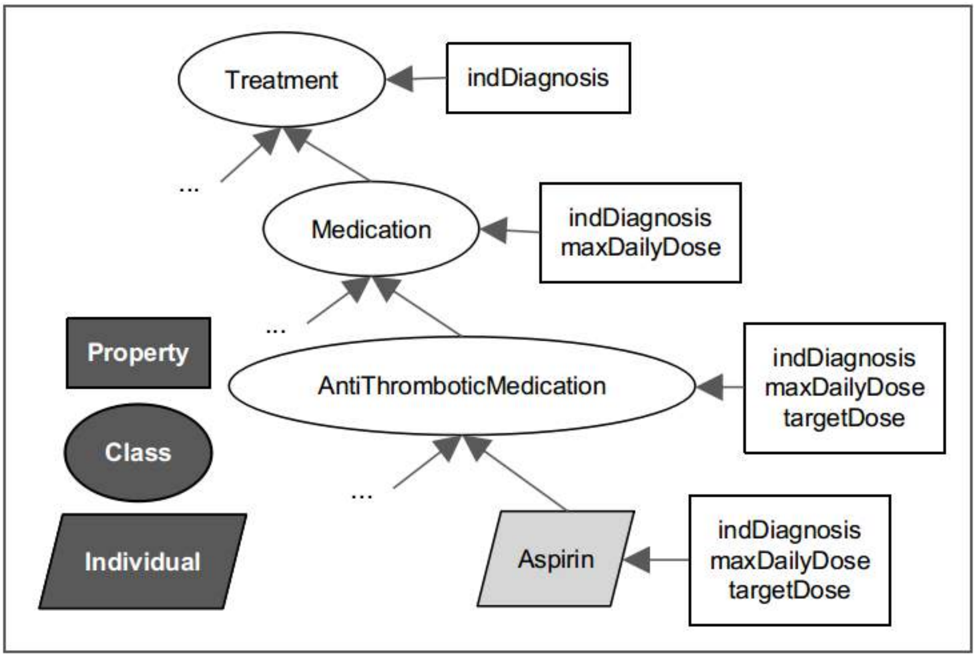

Figure 2.12: Aspirin Ontology Path [Jovic et al., 2007b] (reprint)

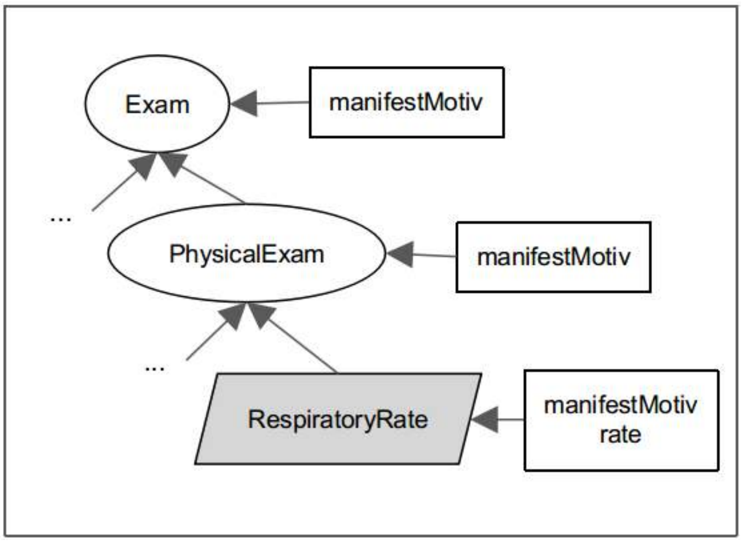

Figure 2.13: Respiratory Rate Ontology Path

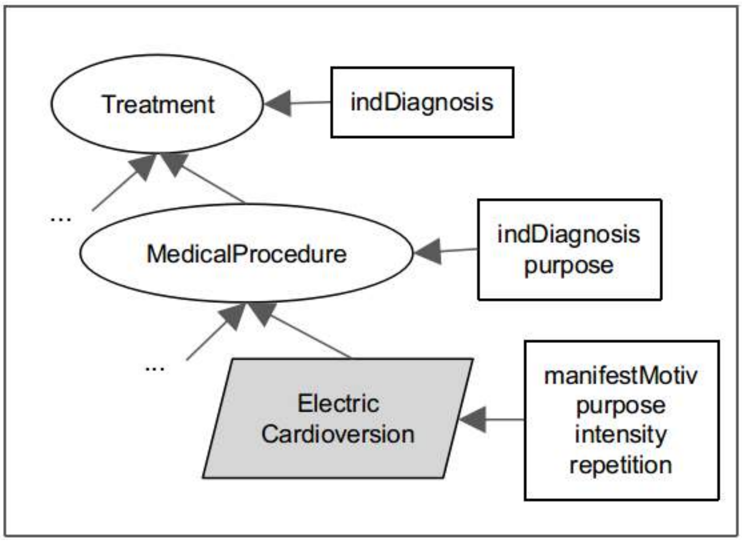

Figure 2.14: Electrical Cardioversion Ontology Path

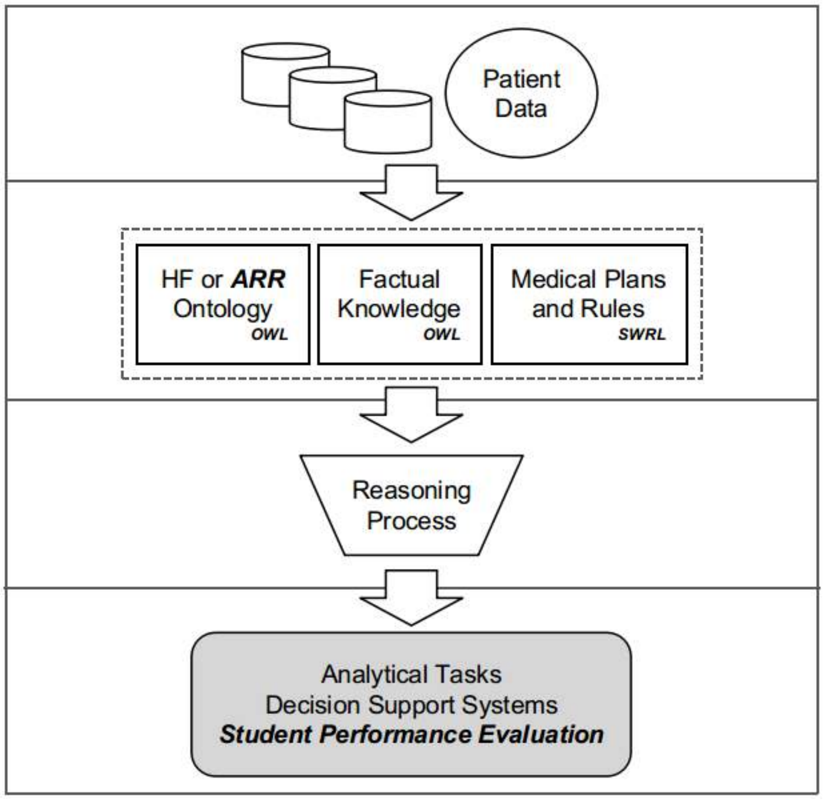

Figure 2.15: *Heartfaid* Architecture [Jovic et al., 2011] (adapted)

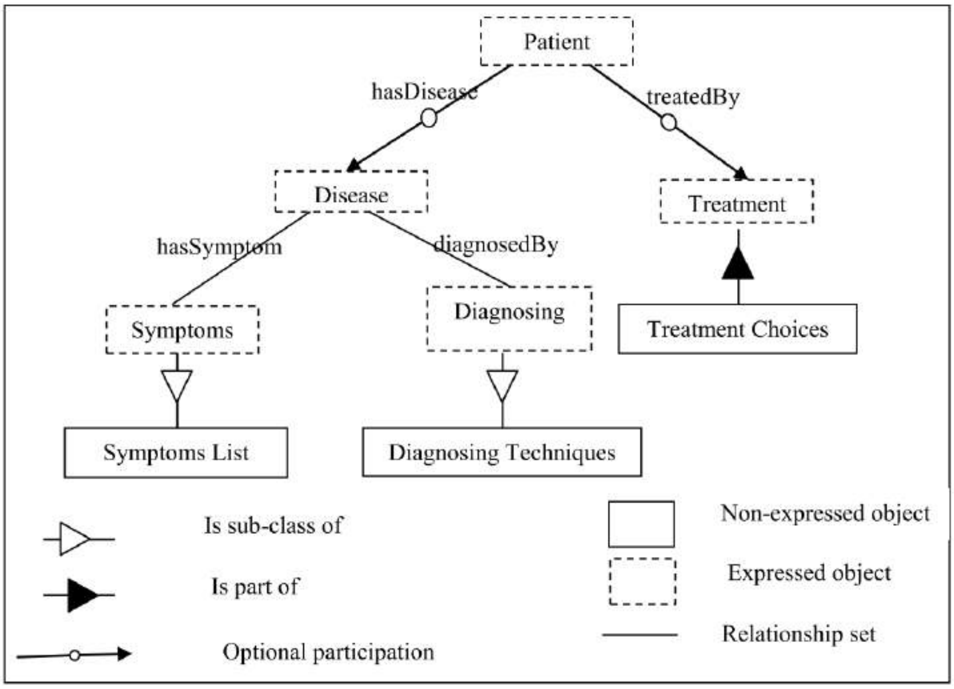

Figure 2.16: *CardioOWL* Semantic Design (source [Al-Hamadani, 2014])

targetDose are properties to be defined to each specific individual.

We can extend this example to our case, as Figure 2.13 displays, where *PhysicalExam* is a kind of *Exam*, and *RespiratoryRate* is an instance (individual) of *PhysicalExam*. *manifestMotive* is the manifestation which motivated the exam request. *rate* is the numeric value for the *RespiratoryRate*.

Ontologies defined using the Web Ontology Language (OWL) adopt an universal identifier for each class, individual and property, in such a way that it can be identified and addressed in any place through the Internet. This identifier is based in the URI (Universal Resource Identifier), the same mechanism adopted to identify Web page locations. This identification mechanism makes an ontology internationally addressable and reusable, enabling to create consensual international classifications.

For example, let us take the Heartfaid ontology and apply it to our case, as illustrated in Figure 2.14. We can adopt the *eletric cardioversion* concept to indicate the treatment for *atrial fibrillation* (which could also be taken from an ontology). Thus, the concepts become universally identifiable and interpretable by machines. *intensity* designates the number of joules applied in the electrical countershock, while *repetition* indicates whether the procedure was repeated or not plus the number of times it repeats. This ontology is part of the effort in building the *Heartfaid* platform, whose architecture is illustrated in Figure 2.15.

Factual Knowledge means the ontology part related exclusively to patient information, such as sex, age, medical history, etcetera. *Medical Plans* represent graphical schemes used for diagnosis and treatment involving certain medical domain. They express the broad, but sometimes scattered medical knowledge in an organized fashion, becoming later structured rules or guidelines [Jovic et al., 2007c].

These *rules* written in SWRL *(semantic web rule language)*, plus the *Factual Knowl-*

edge and the *Ontology* make up the necessary trio for the *Reasoning Process* enablement, depicted in Figure 2.15. They are the basis for the *Analytical Tasks*, *Decision Support Systems* and also the semi or complete automatic *Student Performance Evaluation*.

In a distinct related work, [Al-Hamadani, 2014] and [Al-hamadani and Alwan, 2015] present the *CardioOWL*, an expert system for diagnosing coronary artery disease. The authors list steps for the ontology construction process, such as [Jovic et al., 2007b] following the *Methontology* [Ferndndez and Juristo, 1997] approach.

Figure 2.16 shows the semantic design of *CardioOWL*. This ontology shows a similar organization of concepts adopted by CASNET [Kulikowski and Weiss, 1982], where symptoms are CASNET *observations* and *pathophysiological* states; diagnosing is CASNET *disease states* and treatment choices are CASNET *treatment states*.

2.9 Medical Plans

In this work, the medical plans are the basis not only for diagnostic paths or choices but also for the operation of decision support systems as Internist-1.

Medical knowledge is a cognitive and technical component, i.e., it comprises the individual's perspectives, beliefs, talents, and expertise. Challenging aspects of medical plans and medical knowledge itself are (i) time, data gathering may last years, while the answer can require only a few seconds; (ii) space, because data may arrive from many different health care units, in distinct formats; and (iii) medicine's inherent complexity, the depth of knowledge that each medical specialty offers [Jovic et al., 2007c] [Gamberger et al., 2008].

Medical plans, therefore, try to simplify these constraints. Most are not machine readable. Though, they are useful as textual and visual representations of procedures, triggered by the detection of events such as signs, symptoms or diagnosis. In a nut shell, they are an actionable view of certain medical knowledge [Gamberger et al., 2008].

Through medical plans, doctors can transmit more explicitly their way of resolving medical issues. In the *Heartfaid* ontology [Jovic et al., 2011], medical plans have levels of urgency that indicate how immediate the treatment or unit transfer of a patient should be. For instance, a pulmonary edema would require direct admission to the hospital, whereas a cough would not [Jovic et al., 2007b]. The *Heartfaid* project has developed 15 medical plans for medication prescription, and 38 for diagnosis and treatment, interconnecting signs and symptoms.

2.10 Internist-1

Among the medical systems and the knowledge bases in medicine cited in this work, *Internist-1* has the largest number of related work. *Internist-1* is also a source for the development of a medical training system [Chin and Cooper, 1989]. In the several years after its first implementation, various related papers tried to reconstruct it or to amplify it, using ontologies or similar systems. It was the case of [Musen et al., 1995] and [Szolovits and Ohno-Machado, 2005], respectively. [Shwe et al., 1991] reformulates the Internist-1's *quasi*-probabilistic diagnostic method.

In Internist-1, quantitative and qualitative evidence such as *the glucose level is 6.0 mmol/L* or *there is clouding of consciousness* are called *findings*. Meanwhile, symptoms, signs, diagnosis of diseases are called *manifestations*.

Internist-1 arisen as a decision-support tool in general internal medicine. The system has undergone constant evolution for about 30 years, until the first decade of the years 2000, becoming the QMR system (Quick Medical Reference) [Miller et al., 1986]. Both systems, the Internist-1 and its evolution QMR, were conceived and developed at the University of Pittsburg. According to [Szolovits and Ohno-Machado, 2005], the current knowledge base contains 5000 findings and 700 diagnoses, accumulating 53000 relationships between them.

By suggesting likely disease candidates, Internist-1 conducts the physician in the patient evaluation. It uses a heuristic reasoning method in conjunction with a *quasi*-probabilistic scoring scheme [Shwe et al., 1991]. A *quasi*-probability distribution is very similar to the probabilistic one, but with some relaxations.

The physicians can use the Internist-1 in three distinct but complementary manners [Shwe et al., 1991]:

1. as an *electronic textbook*, as explained under Section 2.5, relating finding-disease, disease-finding, and disease-disease relationships.

2. as a *diagnostic spreadsheet*, showing the co-occurrence groups of diseases and findings.

3. as a *expert-consultant program*, analyzing diagnostic cases, presenting diagnostic hypotheses, and listing different diseases.

The system organizes its properties in an intuitive manner, distributing weights according to the *evoking strength*, *frequency*, and *importance* of one manifestation over another. This arrangement structures the system's reasoning process, i.e., the form of how it arrives at a diagnostic conclusion.

Evoking strength or *EVOKS* denotes how strongly a physician should take into consideration a diagnosis in the presence of a finding, against all the other diagnostic possibilities. It is assigned to a finding/diagnosis pair, ranging from zero (0) to five (5). Minus one (-1) designates a type of relationship that cannot occur in this property. Zero (0) indicates a nonspecific finding, that is, it does not suggest the indicated diagnosis. Five (5) means that the finding is pathognomonic, i.e. accurately representative of the diagnosed disease, like *hemoglobin SS* and *sickle cell anemia*. Table 2.1 shows examples of the evoking strength.

Frequency or *FREQ* expresses the incidence of a finding in a determined disease. It is also distributed in a finding/diagnosis pair, ranging from one (1) to five (5). Minus one (-1) denotes a type of relationship that cannot occur in this property. One (1) means that a finding is rarely seen in the diagnosis. Five (5), on the contrary, means that the finding is present in essentially all the diagnoses such as *myalgia* in the patients with *polymyalgia rheumatica*. Table 2.2 shows the frequency scale with examples.

Importance or *IMPORT* describes how vital a finding is to be considered in any diagnostic, regardless of which specific diagnostic will be deduced. Importance does not work

Table 2.1: Evoking Strength Scale [Szolovits and Ohno-Machado, 2005] (reprint)

EVOKS	**Description**	**Finding**	**Diagnosis**
-1	NEVER (TABOS)	white race	sickle cell anemia
0	NONSPECIFIC item(s)	tachycardia	pneumococcal meningitis
1	MIN. SUG (<6%)	vertigo	systemic schistosomiasis
2	MILD. SUG. (6-35%)	hypothermia	acute cardiogenic shock
3	MOD. SUG. (36-65%)	dysuria	cystitis
4	STRONG. SUG (66-96%)	asterixis	hepatic encephalopathy
5	ALW. SUG. (>96%)	hemoglobin SS	sickle cell anemia

Table 2.2: Frequency Scale [Szolovits and Ohno-Machado, 2005] (reprint)

FREQ	**Description**	**Finding**	**Diagnosis**
-1	NEVER SEEN (TABOS)	female sex	pulmonary anthracosis
1	RAR. SEEN (<6%)	dyspnea at rest	pyogenic liver abscess
2	MIN. SEEN (6-35%)	fever	rheumatoid arthritis
3	HALF SEEN (36-65%)	history of polydipsia	chronic pyelonephritis
4	MOST. SEEN (66-96%)	tachypnea	pneumococcal pneumonia
5	ESS ALW SEEN (>96%)	myalgia	polymyalgia rheumatica

with a finding/diagnosis pair as the previous properties, but rather alone, ranging from one (1) to five (5). One (1) means that a finding rarely requires diagnostic explanation, e.g. *dark urine*, while five (5) indicates that the finding will always require diagnostic consideration, e.g. *coma*.

Table 2.3: Importance Scale [Szolovits and Ohno-Machado, 2005] (reprint)

IMPORT	**Description**	**Examples**
1	RARELY REQ.	dark urine
2	OCCASIONALLY REQ.	history of proteinuria
3	USUALLY REQ.	oliguria
4	ALMOST ALWAYS REQ.	gross hemoptysis
5	ALWAYS REQ.	coma

Differential Diagnosis with Internist-1

We further show how Internist-1 exploits the three presented properties to drive a differential diagnosis, i.e., to identify the presence of a disease when multiple alternatives are possible. In Figure 2.17 we have, departing from the findings, the first step of the Internist-1 differential diagnosis for *cough*. The numbers between parentheses are the evoking strength and frequency values of the association between manifestation and illness.

Regarding the *evoking strength* property, we observe that the presence of *cough* minimally suggests (EVOKS 1) a diagnosis of *tuberculous lymphadenitis*, while it mildly indicates (EVOKS 2) *bronchitis chronic (simple)*. Concerning the *frequency* property, *cough* is essentially always seen (FREQ 5) in the diagnosis of *bronchitis chronic (simple)*, mostly

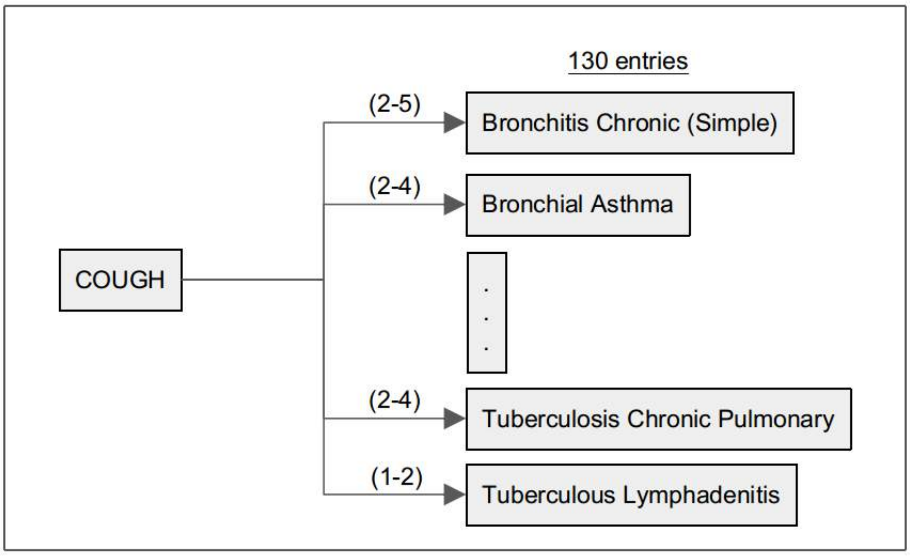

Figure 2.17: Differential Diagnosis of Cough [First et al., 1985] (reprint)

seen (FREQ 4) in *bronchial asthma* and further rarely seen in *tuberculous lymphadenitis* (FREQ 1). If there were no more findings or manifestations, considering the higher values of EVOKS and FREQ, the system would probably infer *bronchitis chronic (simple)* as the final diagnosis.

Figure 2.18 shoes the first step of the Internist-1 differential diagnosis for *CSF WBC increased up to 99*. CSF stands for *cerebrospinal fluid* and WBC for *white blood cells*.

The Internist-1 reasoning system works with the combination of differential diagnoses to progressively refine and reinforce the conclusion. Given manifestations, the system intersects the related differential diagnoses sets. The EVOKS and FREQ values are recalculated through the Internist-1 reasoning system considering the intersection. The *cat scratch disease* is absent both in Figure 2.17 and 2.18, since it is not one of the main possible diagnoses when *cough* and *CSF WBC up to 99* are considered independently. However, when they are combined, *cat scratch disease* appears as the most likely diagnosis.

Figure 2.19 shows the number of possible diagnoses reduced with the joint manifestations. In this case, 130 entries for *cough* and 34 for *CSF WBC*, reach 27 potential diagnoses when combined. It is important to notice that the knowledge base reasoning technique is not based only on intersection.

According to [First et al., 1985], if intersection were the only determinant factor, the relevant diagnosis candidate *tuberculous meningitis* would have been discarded, since it cannot explain alone the presence of *cough*. However, the *tuberculosis chronic pulmonary* can do it. Furthermore, there is a registered link in the knowledge base predisposing a *tuberculous meningitis* from a *tuberculosis chronic pulmonary*. The EVOKS and FREQ values appear associated to this relationship. Hence, the *tuberculous meningitis* remains plausible, even coming from *cough*.

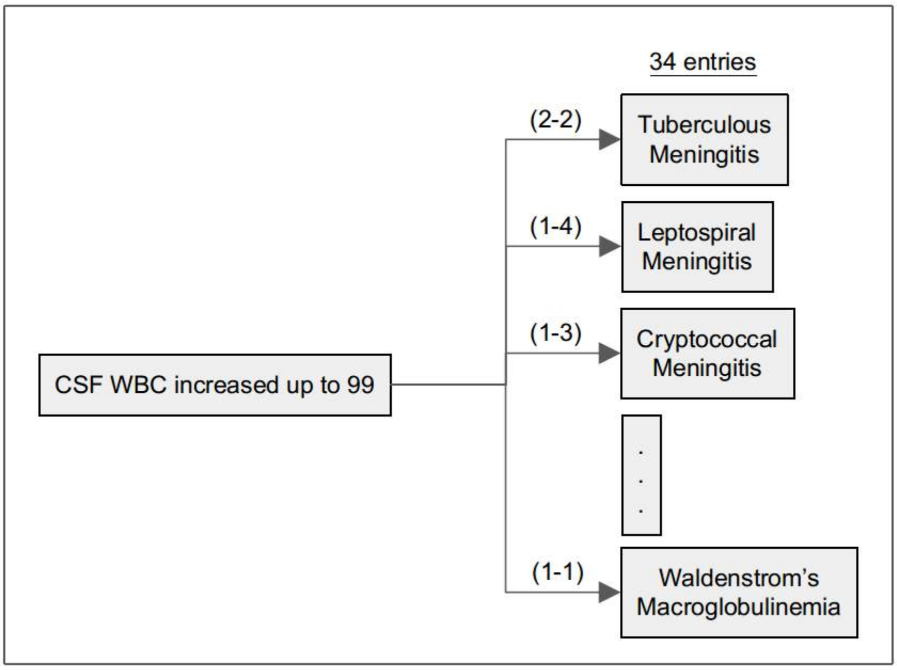

Figure 2.18: Differential Diagnosis of CSF WBC up to 99 [First et al., 1985] (reprint)

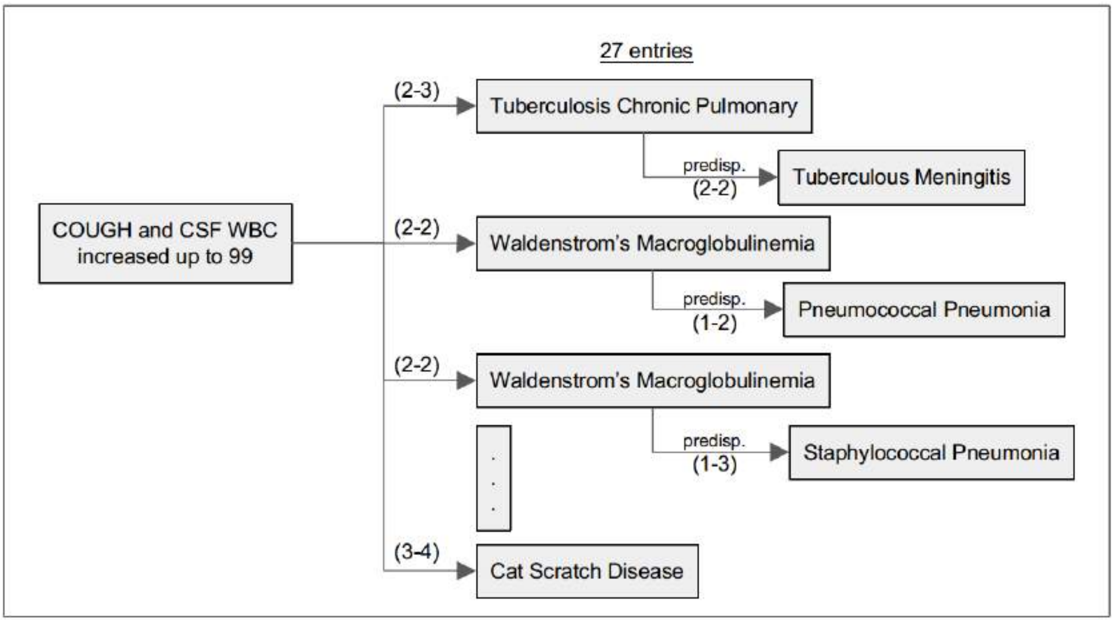

Figure 2.19: Differential Diagnosis of Cough and CSF WBC increased up to 99 [First et al., 1985] (reprint)

2.11 Medical Plans in Internist-1

In this Section we present an essay combining the notion of medical plan, presented in Sections 2.8 and 2.9, and the quasi-probabilistic score scheme of Internist-1. It will articulate some basic notions which are important for our proposal. The values for EVOKS and FREQ have only an illustrative role and are not based in any concrete study.

In Figure 2.20 we present the *palpitation medical plan*. We notice that it can lead to two distinct groups of diagnoses, (i) verifies the presence of *syncope*, *chest pain*, *sweating*, *irregular heart rate* or *dizziness*, conducting to diagnoses such as *arrhythmia* or *mitral stenosis*; (ii) verifies their absence, conducting to *hyperthyroidism*, *panic disorder*, *anemia*, and *anxiety*.

Therefore, our interpretations from this medical plan are, (i) the *palpitation* can lead to, at least, six proper diagnoses; (ii) the presence of potentially often associated symptoms restricts to only two possible cardiological diagnoses; (iii) the absence of such symptoms reaches four diagnoses of three distinct domains, the psychological (*anxiety* and *panic disorder*), the hematological (*anemia*), and the endocrinological (*hyperthyroidism*).

To estimate the EVOKS value of *palpitation* for each likely diagnosis, we need to know whether the symptoms indicated in the medical plan are often associated or not. The estimates presented here come from an analysis of 35 cases in Jacinto involving heart conditions, as presented in the Appendix B. Based on the text of each case, we have mapped observations, symptoms, exam results, diagnosis, treatment plan, among others.

Despite the fact that the sample may be biased for situations where the indicated symptoms are present, it is enough for us to illustrate the EVOKS and FREQ values. Tables 2.4, 2.5, and 2.6 exhibit the *sample's total chief complaints*, *palpitation associated symptoms*, and *total symptoms*. *Palpitation* occurs as a *chief complaint* in 17 out of 35 cases (or 50%). It mostly co-occurs with *dizziness* and *dyspnea*, totalizing 6 times each one (or 35%). As an associated symptom of other chief complaints, *palpitation* appears 5 times (15%). Finally, considering the total number of symptoms presented in the sample, *palpitation* shows up 22 times (30%), versus 15 (20%) of *dyspnea* and 12 (15%) of *dizziness*.

Table 2.4: Sample's Total Chief Complaints

Order	Symptom Name	Occurrences
1	Palpitation	17
2	Dyspnea	6
3	Dizziness	4
4	Chest Pain	3
5	Others	5
	Total	**35**

The high percentages of *palpitation* both as a chief complaint (50%) and as a general symptom (30%) already denotes that it must have a very high FREQ value. Moreover, *dizziness* (35% of co-occurrence with palpitation) and *chest pain* are present not only in the medical plan but also in the data sample. As the Internist-1 system presumes that some the most recurrent findings are also present when calculating the EVOKS value, we

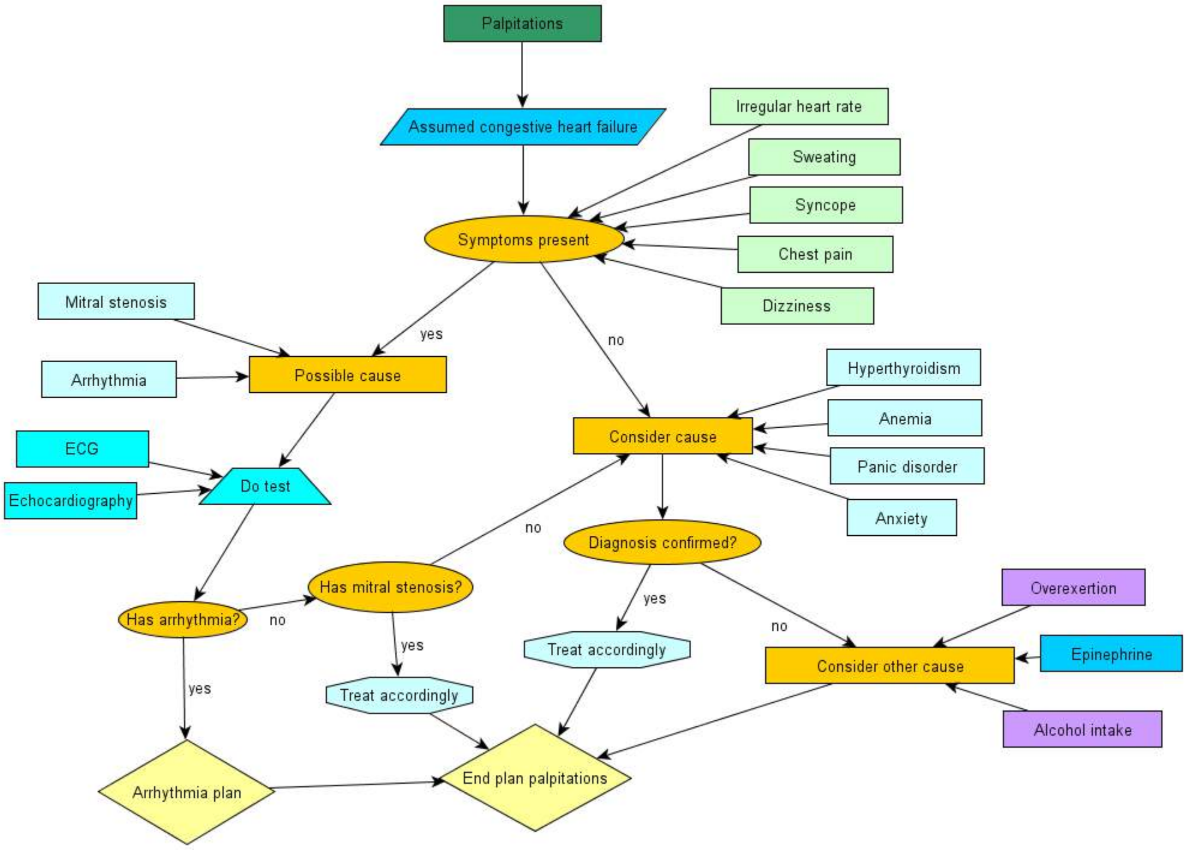

Figure 2.20: Palpitation Medical Plan (source [Jovic et al., 2007a])

infer that *palpitation* leads to *arrhythmia* and *mitral stenosis* with higher intensity than it does to the other symptoms.

Hence, we have decided to estimate the EVOKS value as 3 and the FREQ value as 4 for the *palpitation-arrhythmia* relationship, based on all this information. In Figure 2.21 we present the *hypothetical Internist-1 differential diagnosis of palpitation*. The values of EVOKS and FREQ for the other relationships were assumed to be lower than the *palpitation-arrhythmia*, following the same reasoning explained above.

In Figure 2.22 we present the *dizziness medical plan*, and in Figure 2.23 we show its respective *hypothetical differential diagnosis*. It would depend on knowing the *dizziness* often associated symptoms to suppose better the evoking strength values for the relationships with the diagnoses. In addition to that, we needed to analyze the sample's *total chief complaints*, *associated symptoms*, and *total symptoms* once more to define the frequency for the same relationships. What we realized considering the medical plans and the data sample is that both the EVOKS and the FREQ should be lower for *dizziness* than it is for *palpitation*. Thus we arrive at Figure 2.24.

Finally, we have the opportunity to present the *hypothetical differential diagnosis of palpitation and dizziness*, which resembles our illustrative case. We suppose that this combination would have an EVOKS of 4 and FREQ of 3. That is, when *dizziness* and *palpitation* are together, their value of *evoking strength* is higher than *palpitation*.

On the other hand, as we perceived through the data sample, *palpitation* is more

Table 2.5: Sample's Palpitation Associated Symptoms

Order	**Symptom Name**	**Occurrences**
1	Dizziness	6
2	Dyspnea	6
3	Cough with Yellow Phlegm	2
4	Fever	1
5	Malaise	1
6	Spasm	1
	Palpitation as associated symptom	5
	Total	**22**

Table 2.6: Sample's Total Symptoms

Order	**Symptom Name**	**Occurrences**
1	Palpitation	22
2	Dyspnea	15
3	Dizziness	12
4	Cough with Yellow Phlegm	3
5	Chest Pain	3
6	Nausea	3
7	Others	14
	Total	**72**

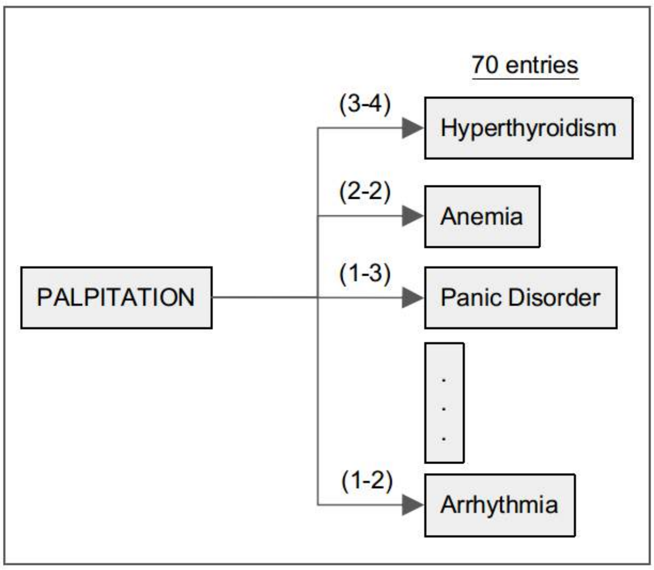

Figure 2.21: Hypothetical Internist-1 Differential Diagnosis of Palpitation

frequent than *dizziness*. Furthermore, a patient suffering from *arrhythmia* may present *palpitation* with another symptom, not only *dizziness*. Thus we assume that the frequency of *palpitation* and *dizziness* together is lower than the *palpitation*'s one alone (FREQ 3 vs. FREQ 4, respectively). As a last observation, we realized that *arrhythmia* can predispose both *bradycardia* and *tachycardia*. However, not only the EVOKS but also the FREQ values for *tachycardia* are higher than for *bradycardia*.

In Table 2.7 and 2.8, we observe that, in the entire sample, *bradycardia* occurs 10 out of 35 times (30%), while *tachycardia* happens 25 out of 35 times (70%). However, when we filter these results to those where *palpitation* is one of the symptoms, *bradycardia* appears only 3 out of 22 times (15%), while *tachycardia* shows up 19 out of 22 times (85%). Then, in Figure 2.24 we conclude that *arrhythmia* has higher EVOKS and FREQ values to predispose *tachycardia* than *bradycardia*.

Table 2.7: Sample's Arrhythmia Diagnoses

Order	**Symptom Name**	**Occurrences**
1	Bradycardia	10
2	Tachycardia	25
	Total	**35**

Table 2.8: Sample's Palpitation Associated Arrhythmia Diagnoses

Order	**Symptom Name**	**Occurrences**
1	Bradycardia	3
2	Tachycardia	19
	Total	**22**

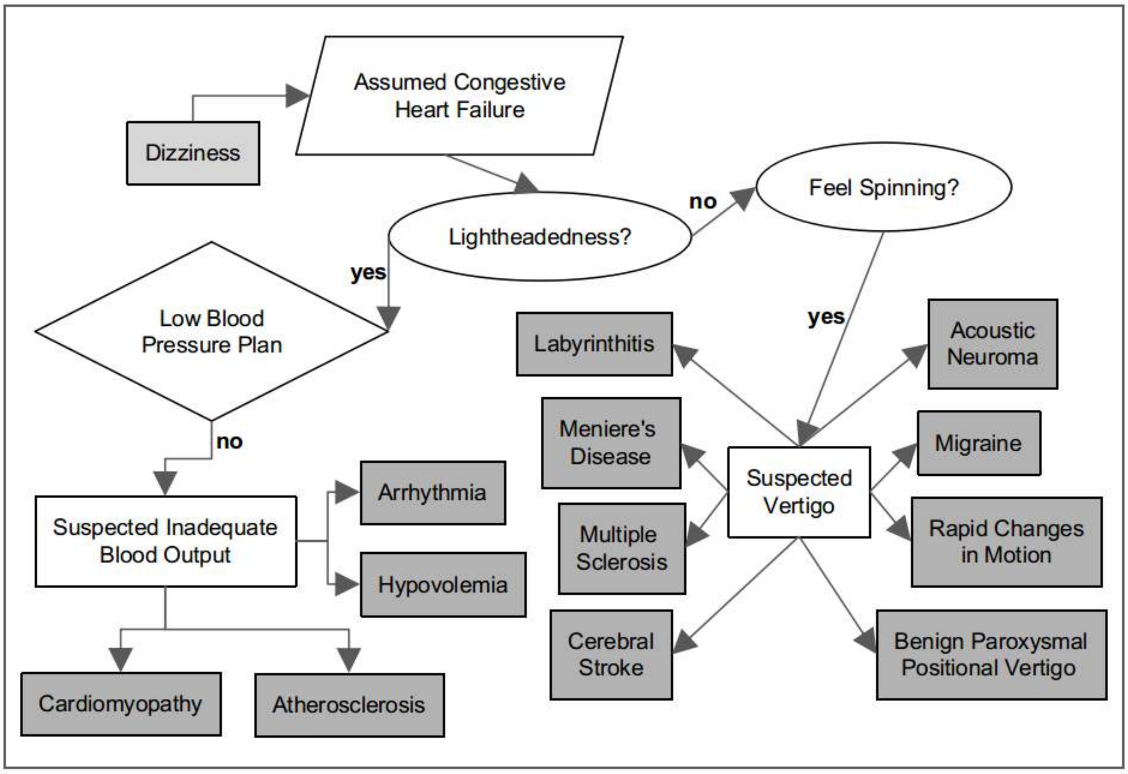

Figure 2.22: Dizziness Medical Plan [Jovic et al., 2007a] (adapted)

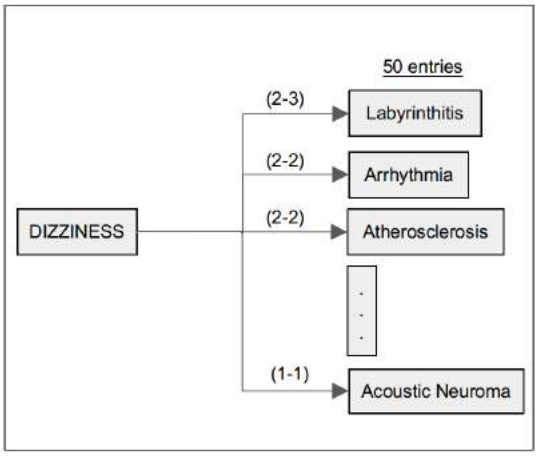

Figure 2.23: Hypothetical Internist-1 Differential Diagnosis of Dizziness

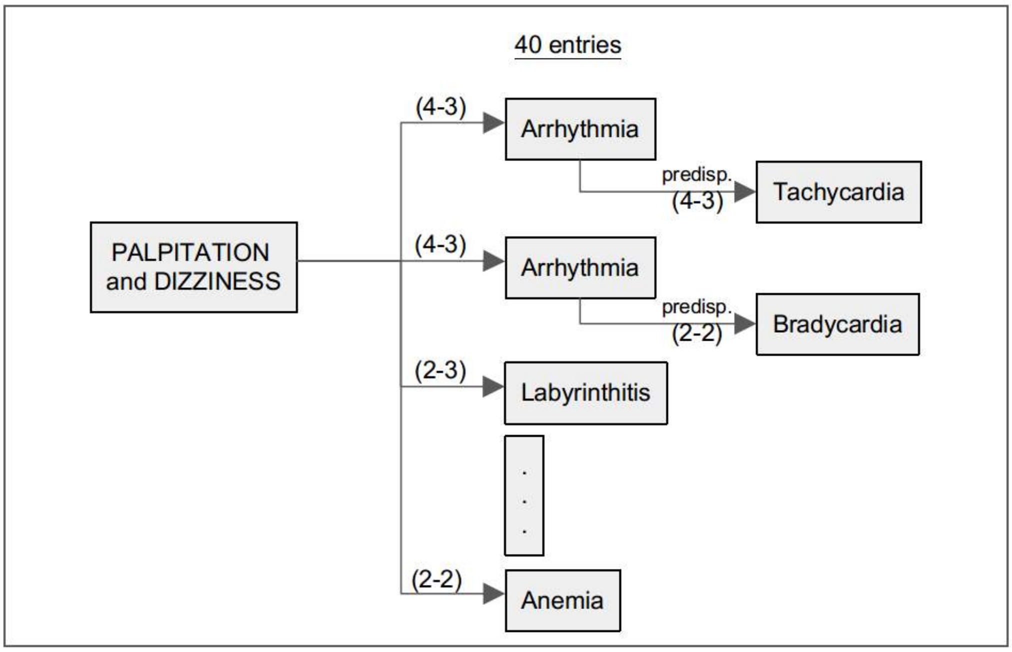

Figure 2.24: Hypothetical Internist-1 Differential Diagnosis of Palpitation and Dizziness

Chapter 3

Methodology

3.1 Problem

The forum-like structure where the Jacinto Emergency Medicine e-Learning is currently deployed has some limitations addressed in this work:

- **Manual assessment and feedback**. Professors need to spend time reading each answer from each student, even for questions with the same or closely related answers. Professors also manually give feedback for each student when necessary.
- **Incapacity to derive or generate new cases with similar structure**. There is no support if the professor wants to produce a new case derived from an existing one.
- **Inability to collect data from external bases**. The system does not collect data or interact with health data produced by other teams in different medical schools or institutions.
- **Inadequacy to propitiate personalized training**. The system can indicate which area of medical study the resident has poor performance. However, it cannot automatically suggest training or demand a particular achievement goal based on the performance data.

3.2 Requirements and Approach

The above limitations guide our proposal of a model of a hybrid narrative and clinical knowledge base for emergency medicine training would be a solution and a contribution for both the medical and the computational areas.

The Clinical Knowledge is represented as structured data, giving to the machine more autonomy to assess user performance and to give automatic feedback. It also offers flexibility for the production of case variations and alternative plans. The free-text narratives give flexibility for the learning design and enable the introduction of real scenario relevant aspects and context, beyond clinical data.

The model was designed to fulfill the following requirements:

- **To preserve the benefits of the current narrative approach**.
- **To support activity plans following a learning design**.
- **To afford automatic machine interpretation and handling of data.**.

After our state-of-the-art review, we realized that a knowledge base model able to meet the requirements and forward solutions to the problems of this work should combine the four following health informatics structures,

1. **Virtual Patient Record** [Triola et al., 2007] [Smothers et al., 2010].

   Both *Jacinto* and *Virtual Patient* systems are complementary clinical learning approaches, holding pedagogical and educational benefits. Even though, the cases in the *Virtual Patient* simulation environments already work with structured clinical data, they lack other functionalities related to medical plans and causal graphs further presented.

   Therefore, the *Virtual Patient Record* structure is responsible for the storage and organization of the *factual knowledge*, about the patient, obtained in the *patient interview*, through *exams* or by observations of *conditions*.

2. **Causal Graph** [Kulikowski and Weiss, 1982] [First et al., 1985] [Perry, 1990].

   This is the terminology we adopted to call reasoning systems which relate *manifestations*, *diseases*, and case *diagnosis*. Our causal graph model has a graph structure like the *CASNET* system, but can also represent probabilities similarly to the *Internist-1*, using properties as the *evoking strength* and *frequency*.

   This is the structure that will allow us to automatize *content assessment*, part of the *content generation* and *individualized training*.

   - *Content Assessment*.

     Since the system is able to tell the most likely diagnosis for a case, it can verify the student answer, checking if a wrong answer was close or distant of the correct one.

   - *Content Generation*.

     The *causal graph* can indicate variations for a case statistically consistent, that can generate content in conjunction with the *medical plans*. In most cases the system only suggests the variations. Thus, they would only be released after a professor approval.

   - *Personalized Training*.

     The system will be able to track specific aspects of a case in which a given student is deficient. Based on that, it can select similar cases to train the deficiency.

- *Inference Abilities.*

  Our model and architecture address inference capabilities using a blended system based on the *Internist-1* and *CASNET*. An entity in the system registers the *evoking strength* and the *frequency* of *manifestation-manifestation* relationships, as well as their implications in a graph.

  The first enables to infer the most likely diagnoses. The second determines the most probable conclusions after analyzing the degrees of the vertices in the *disease and treatment planes* of the graph.

3. **Medical Plans** [Jovic et al., 2007b].

   We can think of a *medical plan* as all the possible paths that a starting *manifestation* can follow in a workflow, within a certain medical scope. They are defined by a medical team.

   A *case plan* is an instance of the *medical plan*. It is based in a real case, in which some or all the elements of a *medical plan* are present, reaching a diagnostic or treatment conclusions already predicted by the *medical plan*.

   - *External Incorporation of Cases.*

     Workflows are shareable structures aiming to be reused. As we interpret all *plans* as workflows, all of them can be shared. Workflow processes are integrated in the knowledge base model. Therefore, beyond the *medical plans* incorporation, we could embody cases by receiving *case plans* from other teams in different medical schools and institutions.

4. **Activity Plans** [Triola et al., 2007] [Smothers et al., 2010].

   Activity plans focus on the design of the learning activity along a case development, i.e., by adding learning tasks to the *case plan*, we obtain an *activity plan*.

   - *Learning Orientation.*

     As in *medical* and *case plans*, it is possible to exchange learning tasks activity plans with external medical institutions, reinforcing the learning orientation of this project. Moreover, creating *activity plans* from *case plans* involves explaining question mistakes, giving question hints or telling curiosities, everything that can attract the student attention.

   - *Benefits Preservation.*

     The *Jacinto* environment applies two recognized cognitive and motivational frameworks to its narrative versions, making it a great tool to obtain student's best performances in the *activity plans* originated from *Jacinto* cases. We expect it to preserve the same benefits.

3.3 Construction of the Model

3.3.1 Scope Definition

In our work, we aim at building a knowledge base that could represent the different types of emergency medicine clinical cases. However, these cases range from critical care medicine to anesthesia, cardiology, neurology, obstetrics, and so on.

Even though we have designed a generic model to afford a wide range of cases, we conducted our study over palpitation related cases, i.e., cases in which the chief complaint is *palpitation*.

The choice is based on the existence of a number of clinical arrhythmia cases and ECG records in the Jacinto Emergency Medicine e-learning [Grangeia et al., 2016], besides the well-understood pathophysiology of the cardiovascular diseases [Chin and Cooper, 1989], cardiology was the selected medical specialty, while arrhythmia was the chosen diagnosis scope.

3.3.2 Prototypes and Implementations

Part of our data model was tested in implementations and prototypes presented to the emergency team, who collaborates with us in this project [Grangeia et al., 2016]. The first was the *ECG Challenge* prototype, that we see in Appendix C, based on the meeting notes from Appendix I. It required abilities of basic interpretation of ECGs, which is an essential resource for the emergency practitioner.

The second was the *Text Interactive Prototype: Leg Fracture Case*, developed during the *I UNICAMP Health Jam 2016*. The script and the program execution are available in Appendix G.

The third and last registered prototype was an evolution of the *text interactive* one. It is the *Leg Fracture Activity Plan as a Workflow*. Therefore, it is a most recent prototype, because it was developed after we have already defined our knowledge base architecture using *plans*.

3.3.3 Meetings with the Medical Team

Most of our data architecture was designed as a result of meetings with physicians. There must have been about 15 meetings in one year of intense work. The meetings have discussed mainly the following points,

- Is it possible to generalize the medical cases?

  Learned answer: Considering all the medical knowledge and specialty scopes, no. Delimiting the scope and restricting some variables, yes.

- What are the most important attributes to perform a diagnosis?

  Learned answer: Mainly the interview, the chief complaint, and exams if the diagnosis relies on them.

- What steps does one have to repeat to be successful in diagnosing cases?

  Learned answer: The way how the doctors see each manifestation is unique in their heads. When they are learning, they memorize some schemata related to that manifestation. After they gain some experience, they affirm knowing the answer without thinking much.

  The simulation of cases may help doctors to form their own schemata.

3.3.4 Data Collection

From these meetings, we decided to extract 35 cases from the *Jacinto e-Learning environment*, whose scope was an intersection between cases of arrhythmia and cases in which the ECG exam was performed. We manually registered all the attributes and values presented in the cases in spreadsheets. Some screenshots of them are available in Appendix B. Later, we developed a set of *Google* forms to continue collecting data, but in a simpler manner, for future work. These forms can be seen in Appendix A.

3.3.5 Database Construction

We first selected the most recurrent and relevant attributes revealed in the spreadsheets. Then, in another meeting with the medical team, we confirmed them and developed a relational database. The selected attributes, the simplified and complete entity-relationship models are available in Appendix D. The database was populated with the 35 cases from the spreadsheets. We used some of its data to simulate values of the Internist-1's *frequency* and *evoking strength* in Section 2.11.

3.3.6 UML Model

To construct the UML model we see in Figure 3.1, we matched the idea of *Virtual Patient Data* [Smothers et al., 2010] with our populated database. Then, we combined the *medical*, *case*, and *activity plans* with the *causal graph* structure. This composition produced our final version of *hybrid narrative and clinical knowledge base for emergency medicine training*.

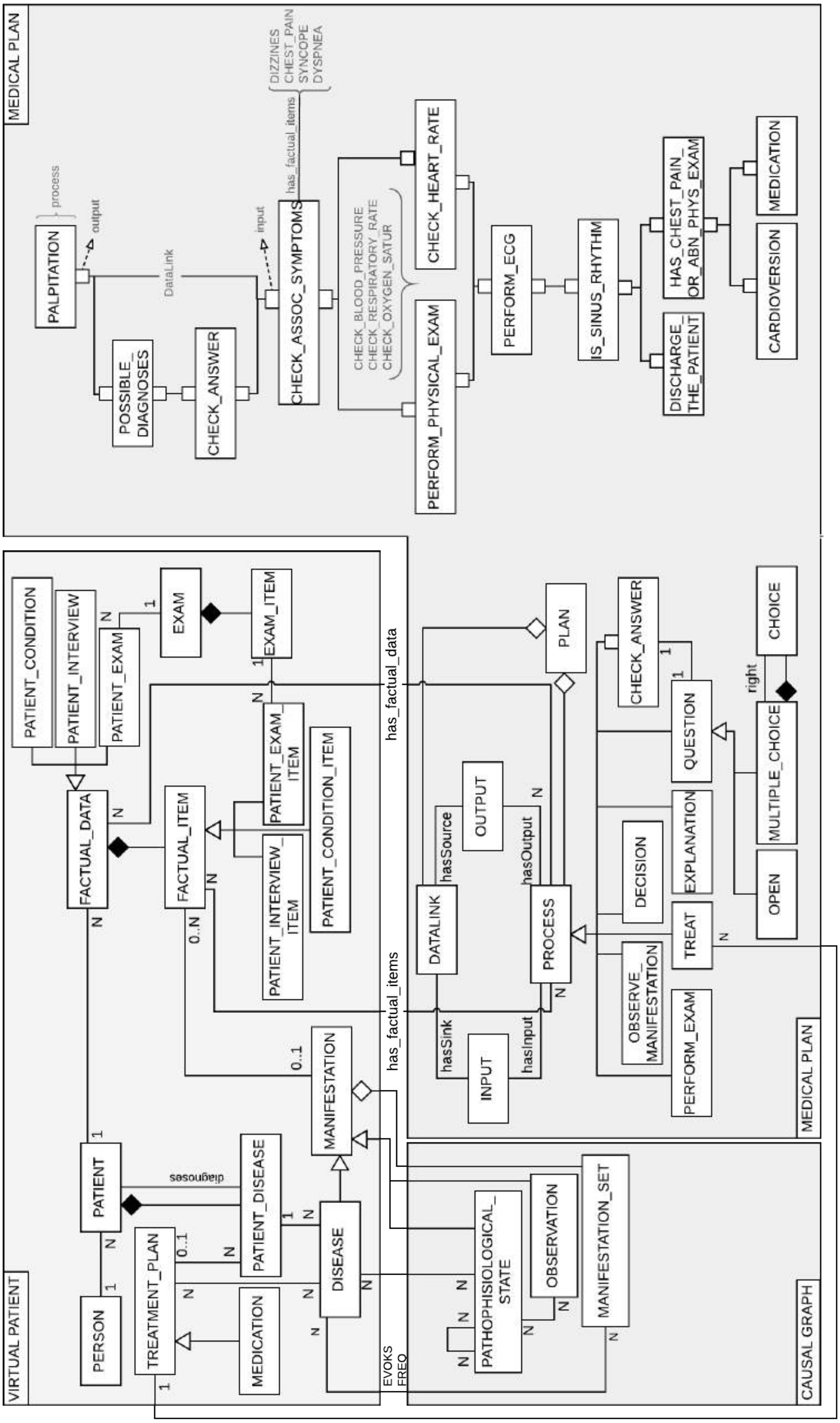

Figure 3.1: Emergency Medicine Training UML Model

Chapter 4

Results and Discussion

4.1 Discussion and Validation of the Architecture

In this Section, we will detail how our approach and architecture are capable of forwarding solutions to the mentioned problems. Using the illustrative case from Section 1.3, we will (i) describe our *Virtual Patient* structure (Figure 4.2 and Table 4.1), and then (ii) compare it to *MedBiquitous* [Smothers et al., 2010] (Figure 4.3). Subsequently, we will (iii) explain the *workflow structure of medical, case and activity plans* (Figures 4.8 and 4.6). Lastly, we will (iv) show the *causal graphs used for diagnostic and treatment inference* (Figure 4.12).

4.1.1 UML Basics

The models described here adopt the Unified Modeling Language (UML) formalism. We briefly explain the basic elements adopted in our diagrams in an informal way, addressed to nonspecialists.

Class – Represented as a rectangle with an identifying label inside it. A class can be seen as a template of data items, like a schema of a table. Therefore, the class PATIENT in the diagram of Figure 4.1 will be materialized as a table containing PATIENT records.

Relationships – Edges between two classes mean relationships between them. For example, the edge between TREATMENT_PLAN and DISEASE means that treatment plans can address specific diseases.

Inheritance – The triangle on one side of the edge means inheritance, i.e., a class A is a subclass of class B. In the diagram DISEASE is a subclass of MANIFESTATION. Therefore, DISEASE inherits all characteristics of MANIFESTATION and can add specificities.

Aggregation – A diamond on one side of the edge means that class A aggregates elements of class B. In our diagram, EXAM aggregates several EXAM_ITEMS.

4.1.2 Architecture

Figure 4.1 presents the overall architecture proposed for the new version of the training. The knowledge base designed here will fit in this architecture. Therefore, we will start by

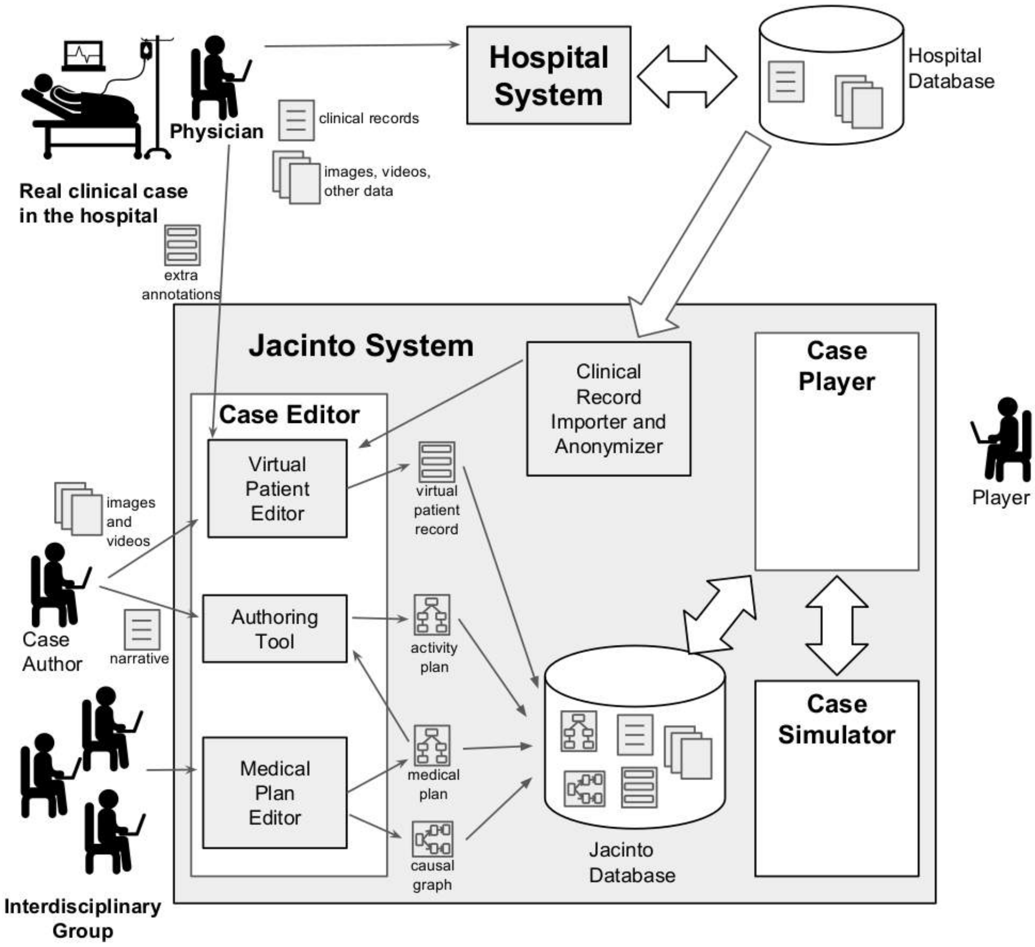

Figure 4.1: *Emergency Medicine Training* Architecture

a brief presentation of the architecture.

The game is based on the solution of cases, whose plot is derived from real cases in a hospital, as depicted in the top-left of the figure. Clinical records and extra annotations produced in the hospital will be anonymized and imported to the Jacinto base, in order to produce a Virtual Patient Record (VPR). As we will further detail, this record resembles a clinical record of a hospital but may contain extra information to be exploited in the game. The Virtual Patient Editor enables further modifications/additions in the record inside the Jacinto environment.

In parallel, an interdisciplinary group, composed of health professionals and computer specialists design Medical Plans (MP), aimed to trace classes of cases addressed in the hospital, e.g., palpitation cases. Besides the plans, they can produce Causal Graphs (CG), which relate observations, symptoms, and diseases in a correlation graph, which will be used by the game engine to automatically assess players performance and to suggest case variations.

Finally, these three components – VPR, MP, and CG – feed the Authoring Tool, where the author will produce an Activity Plan (AP) of a case. It comprises a Case Plan – i.e., a specific path of the Medical Plan, according to the real case data. An AP also include narrative aspects of the case and pedagogical concerns, as questions and explanations.

All these four components – VPR, MP, CG and AP – are part of an interconnected data model, which is proposed in this work and is its main contribution. Related work addresses only partial aspects of our model.

4.1.3 Virtual Patient Structure

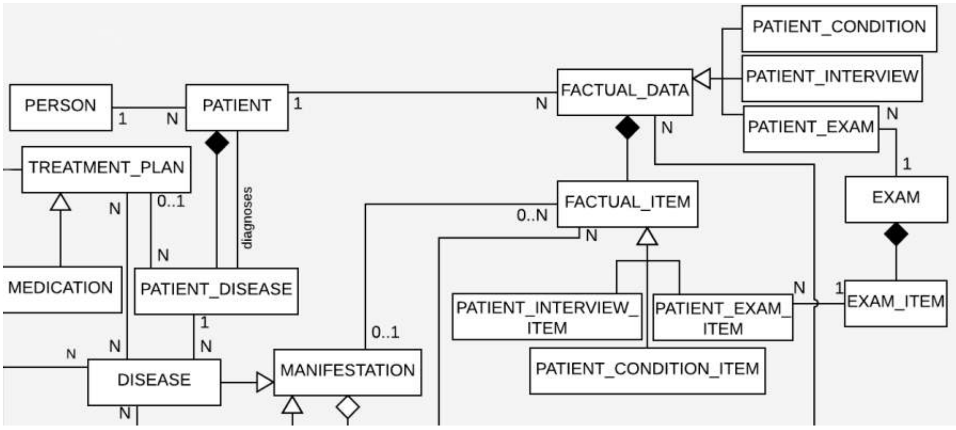

Figure 4.2: *Emergency Medicine Training* Virtual Patient Structure

Except for someone who is just looking for medical advice or taking routine exams, a patient will come for a visit only if he has something to complain about his health. This annoyance is usually called *chief complaint* and can be a *symptom* or other kind of *manifestation*. The manifestations, that also can be *patient habits* or *patient states* are recorded in the class MANIFESTATION. A DISEASE is a type of of MANIFESTATION, i.e., it is a subclass. Here, the PATIENT is a PERSON. There may be many patients, but each PATIENT is a single PERSON. There may be many PATIENTS related to the same PERSON – every time the same PERSON is involved in a new case, he will be treated as a new PATIENT.

The doctor will ask questions and perform simple exams such as the *physical exam* or more advanced ones, as the *electrocardiography* (or *ECG*), if necessary to understand the patient condition. We call this questioning of an INTERVIEW, which aggregates several PATIENT_INTERVIEW_ITEMs. The mentioned *exams* are stored in the class EXAM.

Think of someone who visits the doctor or is taken to the emergency room complaining mainly of *palpitation*. Some of the associated symptoms the person may present are *dizziness* and *chest pain*. The doctor immediately performs a *physical exam*, obtaining *blood pressure* and *respiratory rate*, items of the physical EXAM or EXAM_ITEMs.

The doctor obtains the exam result for each EXAM_ITEM, such as ECG waves displaying *sinus rhythm* or *non-sinus rhythm*, expressed by the PATIENT_EXAM_ITEM class. The set of exams the doctor asked for the patient this or any other time is kept in the class PATIENT_EXAM.

While EXAM and EXAM _ITEMS represent kind of *exams* and *items*, PATIENT _EXAM and PATIENT _EXAM _ITEM are instances (with values) respectively.

One of the assumptions is that the patient is suffering from arrhythmia. It is common to see cases in which the patient exhibits the condition of hemodynamic instability in conjunction with an arrhythmia. PATIENT_CONDITION_ITEM will record this condition if a doctor observes it. PATIENT_CONDITION will aggregate the group of conditions that the patient exhibited. If the patient has reported having a chronic illness such as diabetes, asthma or even having a serious illness already treated as hepatitis, this information will be stored in PATIENT_DISEASE, this class also stores the diagnosis made by the doctor.

Pieces of information (about *MANIFESTATIONs*, for example) obtained in different processes or different moments in time, e.g., through *exams*[1], *interviews*[2] or observations of *conditions*[3] are FACTUAL_ITEM subclasses. FACTUAL_DATA aggregates all the information regarding the patient. Therefore, it gathers all FACTUAL_ITEMs. PATIENT_CONDITION, PATIENT_INTERVIEW, and PATIENT_EXAM are types of FACTUAL_DATA. One PATIENT may have many sets of FACTUAL DATA, also corresponding to different times he visited a doctor or was hospitalized. Finally, one DISEASE may have multiple TREATMENT_PLANs and vice versa. Table 4.1 summarizes the role of the classes.

4.1.4 Comparison of Virtual Patient Models

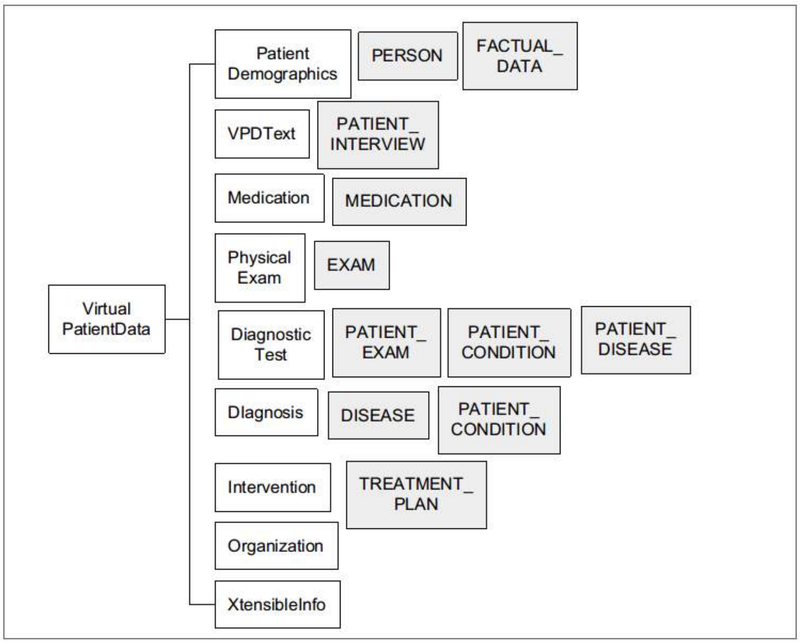

Figure 4.3: *MedBiquitous* vs. *Emergency Medicine Training* VP Model

Figure 4.3 shows the *MedBiquitous* data model and the correspondent classes of our architecture. *Patient Demographics* contains basic patient info, what we store in PERSON and FACTUAL_DATA, since *MedBiquitous* does not possess an exclusive class to centralize patient content.

[1]PATIENT_EXAM_ITEM
[2]PATIENT_INTERVIEW_ITEM
[3]PATIENT_CONDITION_ITEM

Table 4.1: Emergency Medicine Training Virtual Patient Classes

Class Name	Description
FACTUAL_DATA	All the information regarding the patient
FACTUAL_ITEM	Pieces of information obtained in different processes or different moments in time, e.g., through exams, interviews or observations of hemodynamic and clinical conditions
MANIFESTATION	Everything that represents an abnormal condition in the patient health, e.g., *symptoms*, mental or health *states*, or bad *habits* such as smoking and drinking
DISEASE	Type of manifestation, which can be chronic, diagnosed, or have been treated
EXAM	A particular type of *exam*, e.g., ECG, x-ray or physical
EXAM_ITEM	An item of the exam, e.g., patient temperature in the vital signs exam, presence of a P wave in the ECG
PERSON	Has basic human characteristics, such as name, gender, age
PATIENT	A person presenting some *manifestations*, possibly having history of *diseases* and *treatments*.
PATIENT_DISEASE	One of many *diseases* that a patient once exhibited, plus information such as identification source or chronicity
PATIENT_CONDITION	A group of *conditions* the patient once exhibited
PATIENT_ CONDITION_ITEM	One of many *conditions* the patient once exhibited
PATIENT_EXAM	The result of *exams* the patient once performed
PATIENT_ EXAM_ITEM	The result of an *exam item* the patient once performed, e.g., high blood glucose level
PATIENT_INTERVIEW	The result of an *interview* the patient once has given
PATIENT_ INTERVIEW_ITEM	The result of one item in a given *interview*
TREATMENT_PLAN	Plan which is adopted aiming to heal the patient
MEDICATION	A type of *treatment*, composed by a chemical formula, regularity, and quantity

VPDText is the text information associated with the *Patient Demographics*. The closest approximation is PATIENT_INTERVIEW, since both contain freely given clinical data about the patient. *Medication* is MEDICATION, *Physical Exam* is a specialization of *EXAM*. *Diagnostic Test* are the tests which can lead the physician to a *Diagnosis*. PATIENT_EXAM, PATIENT_CONDITION, PATIENT_DISEASE are *Diagnostic Tests*, and DISEASE is the possible *Diagnosis* as well as the PATIENT_CONDITION. *Intervention* is equivalent to TREATMENT_PLAN. Further comparisons including our relational database model are present in Figure E.1 and E.2.

4.1.5 Plans Structure

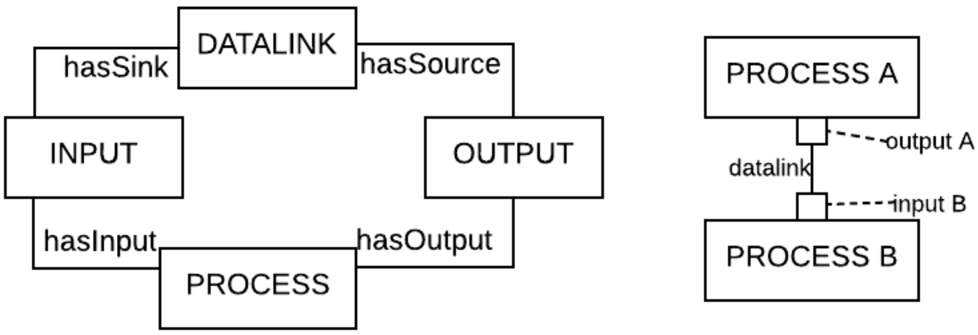

Figure 4.4: Workflow Diagrams

Medical decision-makings can be treated as the transverse of a path in a *workflow*. A *workflow* can be thought as a view or representation of real work, a kind of flowchart capable of governing computational systems in a concrete way. In a simple way, we can think of a *medical plan* as all the possible paths that a *manifestation* such as *palpitation* can follow in a workflow, within a certain medical scope, and defined by a medical team.

A *case plan* is an instance of the *medical plan*. It is a specific path of a *medical plan* derived from a real case, reaching a diagnostic or treatment conclusions already predicted by the medical plan. By adding learning tasks to the case plan, we obtain the activity plan.

The diagrams in Figure 4.4 show complementary views of a workflow basic model. In the left it is shown the data model behind a workflow, while in the right it is possible to see its materialization.

As the figure shows, a workflow is a set of processes interconnected by datalinks – see Processes A and B (right side), which are materializations of the PROCESS class (left side). Moreover, the Datalink A-B (right side) is a materialization of the DATALINK class (left side). As can be seen, a datalink connects an output related to a process to an input related to another process. In the right side, Process A has an Output A (small box) and Process B has an Input B. Both are materializations of the INPUT and OUTPUT classes (left side).

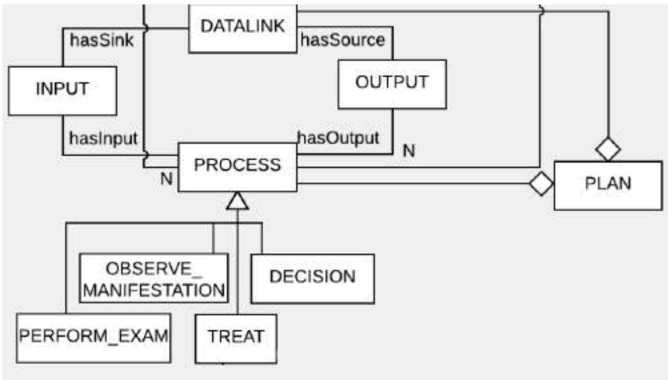

Figure 4.5: Medical Plan Structure

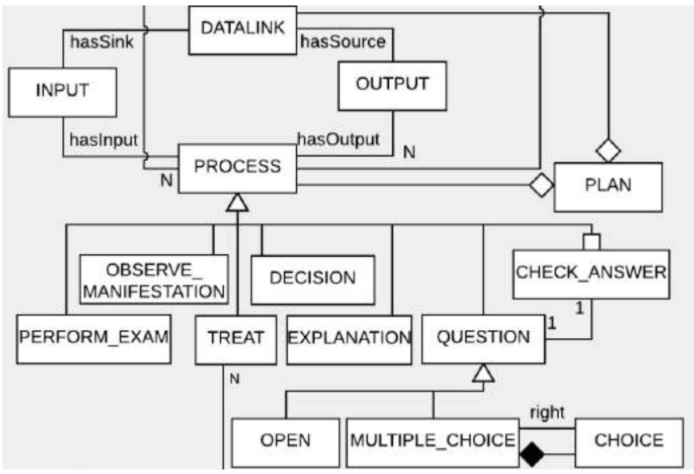

Figure 4.6: Activity Plan Structure

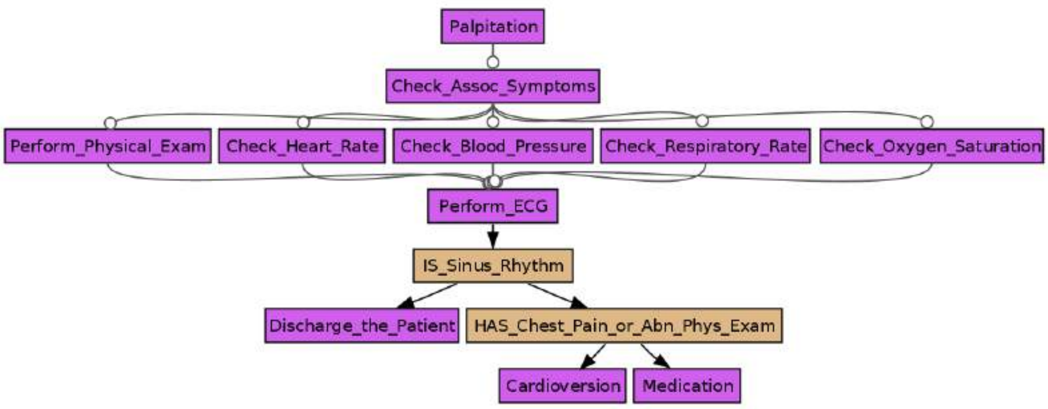

Figure 4.7: Palpitation *Medical Plan* as a Workflow

Figure 4.8 shows the *medical plan* model, which is an extension of the model presented in Figure 4.5 plus the *medical plan* elements. As in Figure 4.4, 4.8 and 4.5 are complementary views of a workflow. We further use *workflow* to refer elements of Figure 4.4 and *model* to refer elements of Figure 4.8.

In the workflow structure, CHECK _ASSOC _SYMPTOMS receives the OUTPUT of PALPITATION (the *chief complaint*) as its INPUT. It checks if the associated symptoms (*dizziness*, *chest pain*, *syncope*, *dyspnea*) are present. The differential of our model is the interrelation of the *medical plan* (workflow model) with *Virtual Patient* aspects, here defined by the subclasses of PROCESS (see Figure 4.8), i.e., specific kinds of processes: PERFORM _EXAM, OBSERVE _MANIFESTATION, TREAT and DECISION. Associated symptoms belong to the same entities that *palpitation* does. CHECK_ASSOC _SYMPTOMS (workflow) is an example of OBSERVE _MANIFESTATION (model), as well as the PERFORM _PHYSICAL_EXAM (workflow) in the sequence is an instance of PERFORM_EXAM (model).

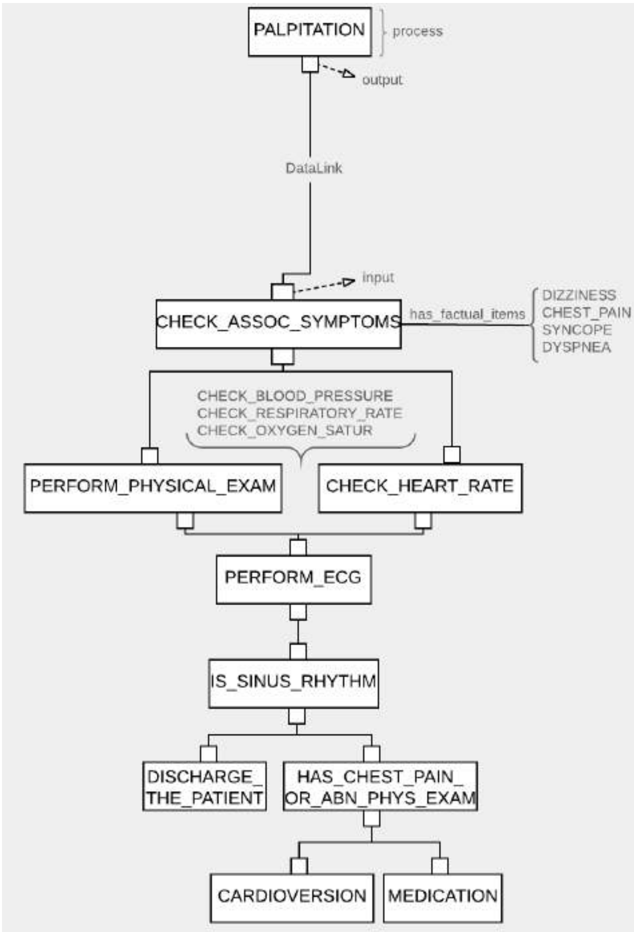

Figure 4.8: *Emergency Medicine Training* Workflow Structure

Our model for this sample of *palpitation medical plan* still predicts *blood pressure*, *respiratory rate*, *oxygen saturation*, and *heart rate* checks. After PERFORM _ECG (workflow), we see another type of PROCESS (model), the DECISION (model), which has two possible OUTPUTS, depending on the result. In this case, if the ECG has sinus rhythm, as we described in the illustrative case, the doctor should DISCHARGE

_ THE _PATIENT (workflow). Otherwise, another DECISION appears. If the patient has either *strong chest pain* or *abnormal physical exam*, the doctor should perform a CARDIOVERSION (workflow). If no, he should give a proper MEDICATION (workflow). Figure 4.7 shows the *medical plan* we just described as a *workflow* written in the software *Taverna* [Apache Software Foundation, 2017].

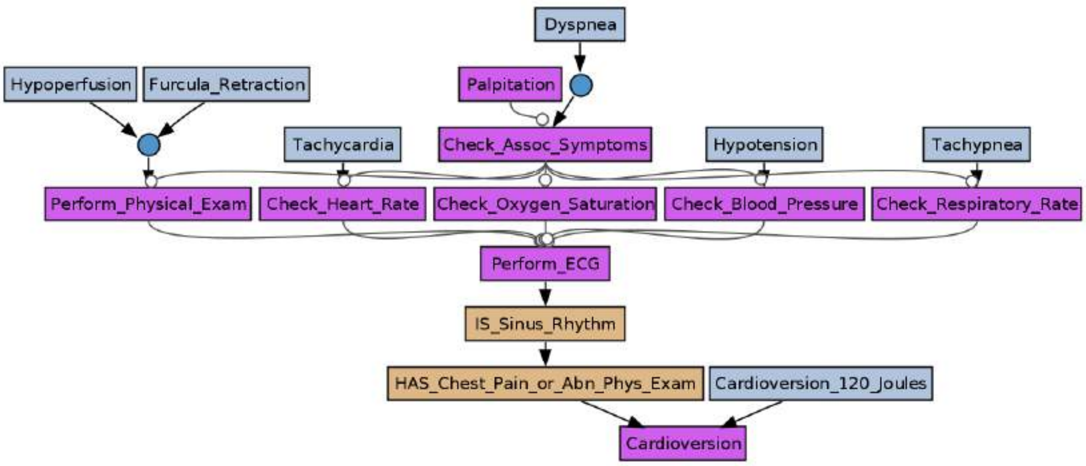

Figure 4.9: Palpitation *Case Plan* as a Workflow

In the same fashion, Figure 4.9 shows an example of *case plan as a workflow*. The *case plan* model is equivalent to the *medical plan* model previously presented. The difference is the kind of data that the workflow represents. As Figure 4.9 shows, a *case plan* is a specific path inside the *medical plan* plus data resulting from observations and exams, based on real case data. In the case of Figure 4.9, it is based in the Case 192 of the Jacinto Game.

As the *case plan* is an instance of the *palpitation medical plan*, it has values for some of the elements. Thus, *dyspnea* is an associated symptom of *palpitation*. Similarly, *hypoperfusion* and *furcula retraction* were noticed in the *physical exam*. The doctor observed *tachycardia*, *hypotension*, and *tachypnea* likewise, respectively after the *heart rate*, *blood pressure*, and *respiratory rate* checks. There was *non-sinus rhythm ECG* and *strong chest pain* or *abnormal physical exam*, leading to a *cardioversion* of *120 joules*.

This narrative could be the solution for a case in Jacinto. As one of our goals is to support a learning design, the activity plan model enables to blend into explanations during the training. As Figure 4.6 shows, the Activity Plan model is an extension of the Medical Plan model plus classes related to learning activities (EXPLANATION, QUESTION, CHOICE and CHECK _ANSWER), which are subclasses of PROCESS. As in the previous cases, since Figures 4.6 and 4.10 are complementary views of a workflow, we will use *model* to refer Figure 4.6 and *workflow* to refer Figure 4.10.

Figure 4.10 exhibits a *question about possible diagnoses*, right from the start, given only the *palpitation chief complaint*. Then, the student could opt for *Sepsis*, *Stroke* and *Atrial Fibrillation*. This is a type of QUESTION, the MULTIPLE _CHOICE one, which is an aggregation of CHOICEs. There is a CHECK _ANSWER PROCESS to analyze if the students did the right answer or not.

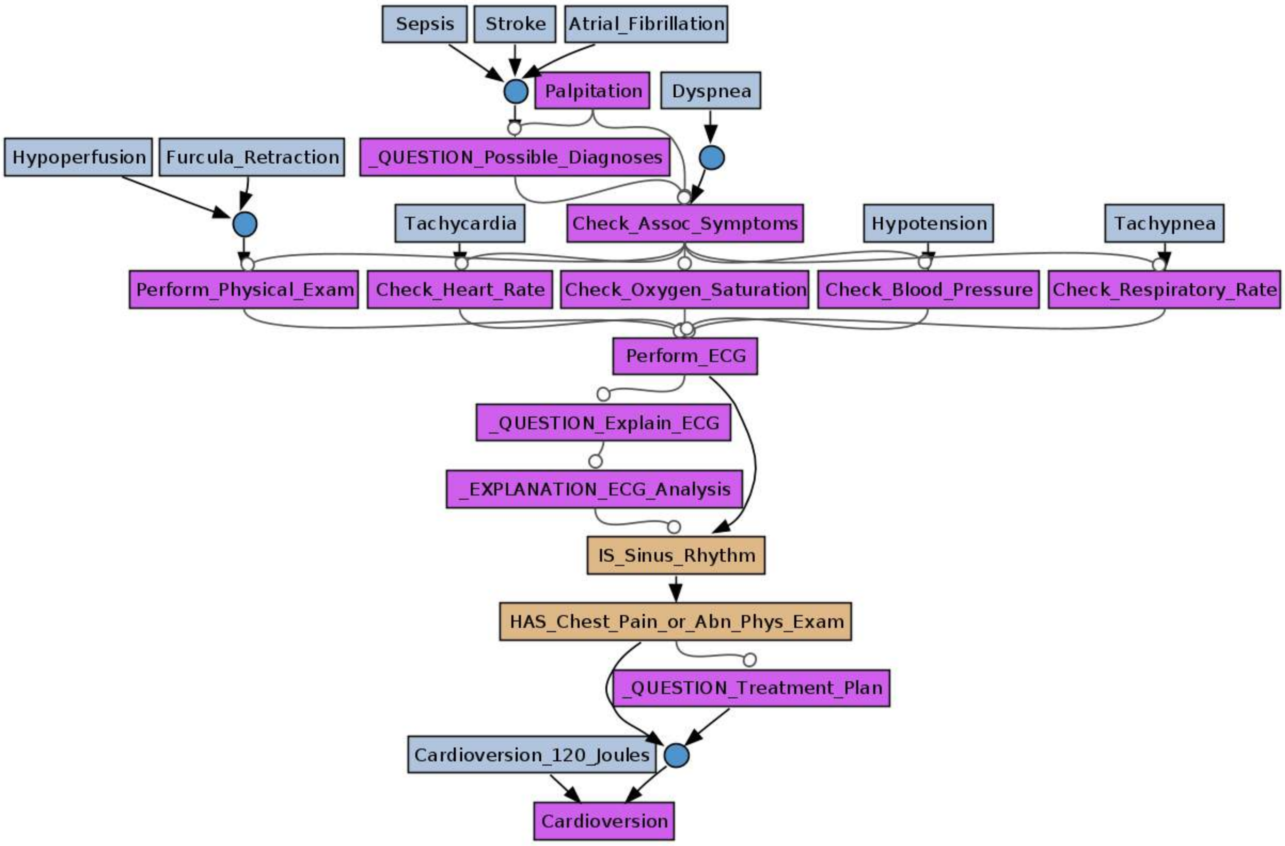

Figure 4.10: Palpitation *Activity Plan* as a Workflow

We show another question, which could be an OPEN (model) one, asking for the student to explain the ECG. We created a prototype for *ECG interpretation* called *ECG Challenge*. Some screenshots of it can be seen in Appendix C. Still, an *activity plan as a running workflow* can be found in Appendix H. An EXPLANATION with the ECG correct interpretation is shown soon after the student answer. EXPLANATION (model) is the PROCESS that not only explains the wished subject after the QUESTION, but also the story that may introduce any QUESTION (model). A narrative-like inheritance from Jacinto. The last question asks about the recommended *treatment plan* (class TREAT (model) in our model). The correct answer is *cardioversion* of *120 joules*. We based this *activity plan* in the *case 192* from *Jacinto Virtual Rounds*.

4.1.6 Causal Graph Structure

The example in Figure 4.11 is organized in four layers, which are related the classes OBSERVATION, PATHOPHISIOLOGICAL _STATE, DISEASE and TREATMENT respectively. The observation plane comprises observed signs, exams etc. In our case, observations like whether the patient feels a palpitation, or exams, like blood test, ECG and respiratory rate.

When the result of the exam leads to an abnormal state, e.g., a *palpitation* is confirmed, a *respiratory rate test* indicates *dyspnea*, or an *ECG* indicates a *non-sinus rhythm*, the

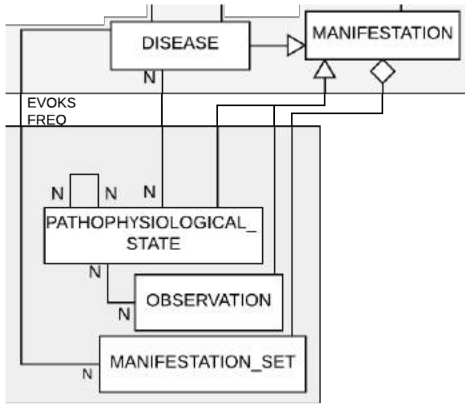

Figure 4.11: *Emergency Medicine Training* Causal Graph Structure

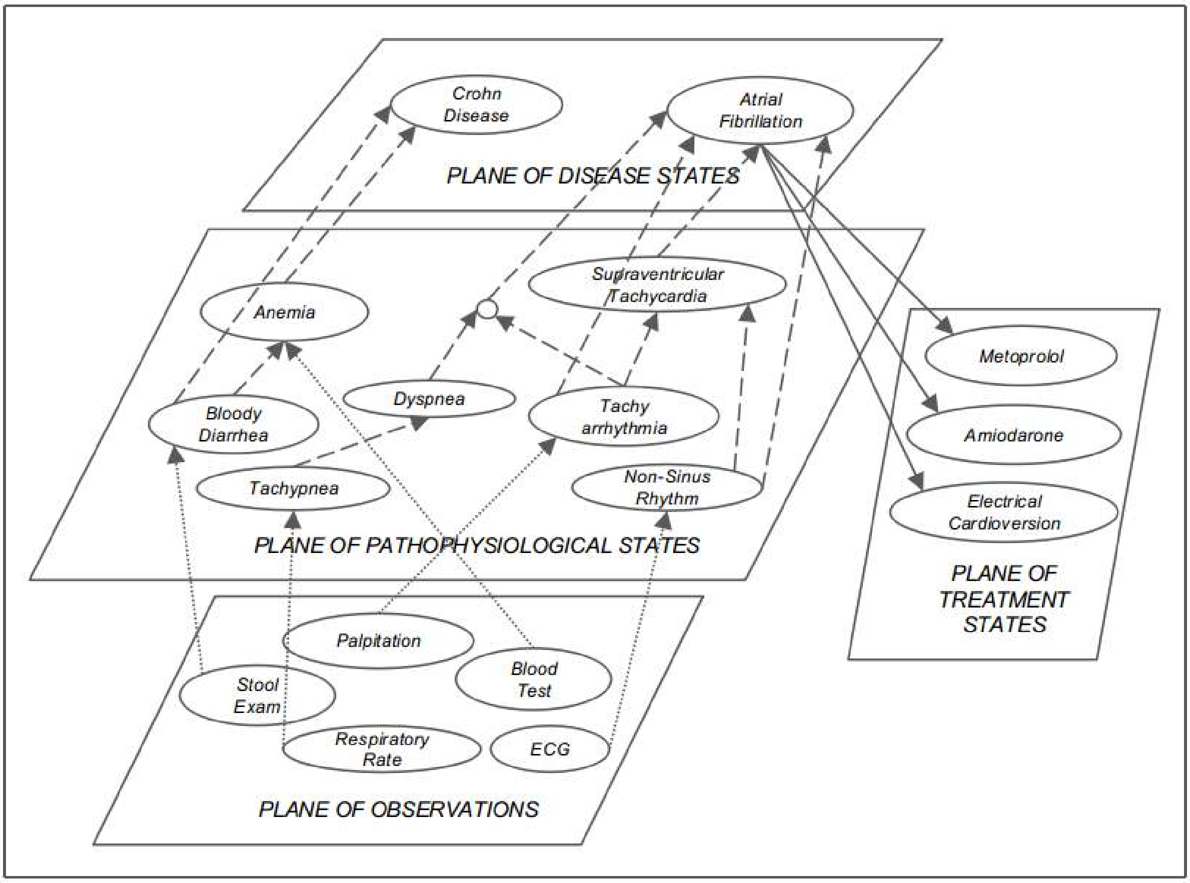

Figure 4.12: Causal Graph of *Jacinto Virtual Rounds* Case 192

observations results leads to a *pathophisiological state* in the upper layer.

Pathophisiological states are connected by themselves in a causal graph. In our model if a node A is connected with a node B, means that A causes B, or alternatively A leads to the conclusion of B. In our example, palpitation can lead to arrhythmia, which can lead to supraventricular tachycardia, irritability to heat intolerance, and diarrhea to anemia.

A path of pathophisiological states defines a pattern which induces to the conclusion of a disease in the upper plan. The path starting with *palpitation and tachypnea*, following to *tachyarrhythmia and dyspnea*; converging to *supraventricular tachycardia*, induces to a conclusion of *atrial fibrillation*. Finally, a disease can be connected to a treatment plan. The connection between pairs are illustrated by relations among classes in the model of Figure 4.12.

The MANIFESTATION_SET class has the role of combining one or more manifestations, in order to define their relations with diseases and probability values, like *evoking strength* and *frequency*.

4.2 Comparison with the Related Work

Regarding the way how the knowledge bases reach their conclusions about appropriate therapies and diagnoses, MYCIN and Heartfaid ontology, which work with rules for such purpose. MYCIN uses an external program, that is, a routine that verifies the yes/no/similar restricted answer records in the database to calculate over all the combinations the most appropriate diagnosis and treatment plan. Meanwhile, the Heartfaid ontology implements SWRL rules which, integrated to the own ontologies of patient and manifestation data, tracks classes, attributes, and values which are able to meet the rules.

Our model deals with the inference question using a blended system based on the *Internist-1* and *CASNET*. The MANIFESTATION _SET entity registers the *evoking strength* and the *frequency* of *manifestation-manifestation* relationships, as well as their implications in the *pathophysiological graph*. By using the first, the system suggests the most likely diagnoses according to his statistics. By using the second, it determines the most probable conclusions after analyzing the degrees of the vertices in the *disease and treatment planes*.

Regarding the *medical plans*, the Heartfaid ontology [Jovic et al., 2007b] does not consider it machine-readable, but only a middle term between the medical knowledge and a digital representation of this knowledge. Though, our architecture, on the other hand, integrates the medical plans as fundamental part of this functioning. As we interpret it as workflows, we can exchange information between the database and the processes. We go one step further calling *case plans* of instances of *medical plans*, which can reproduce *Jacinto* cases quickly, since the narrative and questioning that fosters better learning is provided by the implementation of *activity plans*.

Chapter 5

Conclusion

5.1 Contribution

This work proposes a model for a hybrid narrative and clinical knowledge base for emergency medicine training. It combines the best qualities of analyzed models, i.e., the ability of structuring patient data from virtual patient solutions; the narrative approach plus learning concerns of the Jacinto learning environment; the formal representation of manifestations and diseases of *CASNET* [Kulikowski and Weiss, 1982] and *Internist-1* [First et al., 1985]; the structured way of representing medical plans from *Heartfaid* [Jovic et al., 2007b].

As a result, we consider that the model meets the requirements defined here, combining a narrative format with structured clinical data. It will be the basis to produce a game able to automatically assess users' performance, giving them feedback. It will also enable to automatically produce new cases derived from existing ones and to personalize the game according to the player. All this characteristics coexist with the freedom of conducting the narrative of the game, plus the support to design learning activities as part of the activity plan. *Related work address only partial aspects of our solution.*

5.2 Future Work

Future work include:

1. The implementation of the emergency game in parallel with the production of plans. The game will be tested with medicine students of the Faculty of Medical Sciences at the University of Campinas.

2. The development of a solution to automatically convert textual case descriptions from the Jacinto environment to the format of our base.

3. The development of algorithms for automatic assessment of students and for the production of new cases derived from the existing ones.

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Appendix A

Data Collection Forms

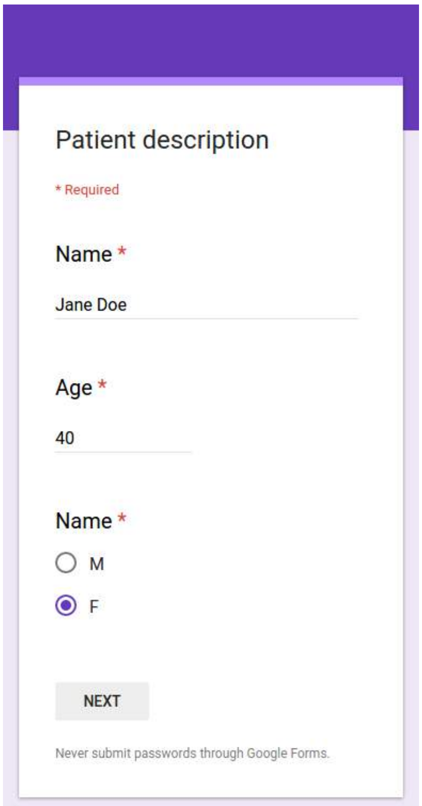
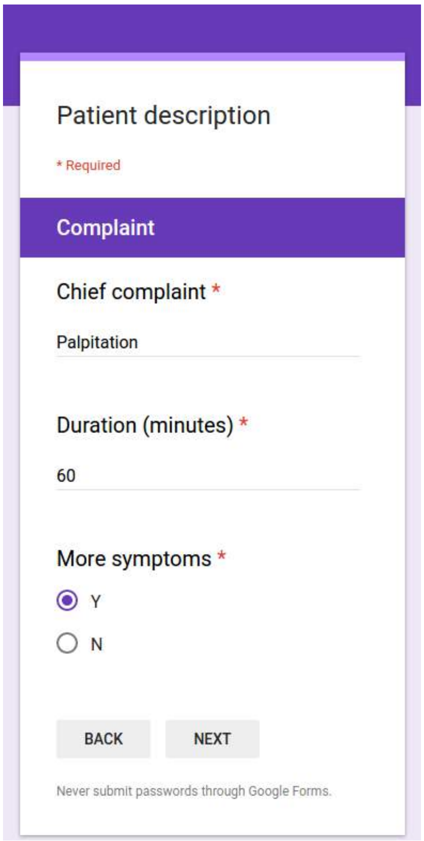


Figure A.1: Patient Demographics Form



Patient description

* Required

Complaint

Chief complaint *

Palpitation

Duration (minutes) *

60

More symptoms *

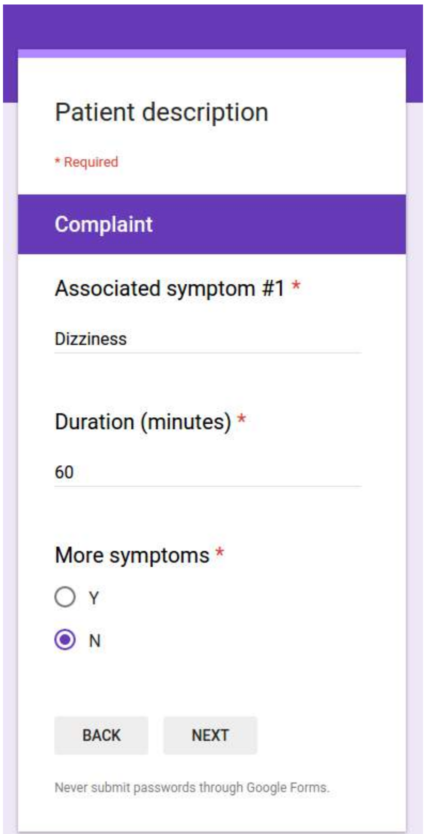
Y

N

BACK NEXT

Never submit passwords through Google Forms.

Figure A.2: Chief Complaint Form



Patient description

* Required

Complaint

Associated symptom #1 *

Dizziness

Duration (minutes) *

60

More symptoms *

Y

N

BACK NEXT

Never submit passwords through Google Forms.

Figure A.3: Associated Symptoms Form

Appendix B

Data Collection Spreadsheets

Case	Age	Gender	Chief complaint	Chief complaint – specification 1	CC duration (hour)	Associated symptom 1	AS 1 duration (hour)	Associated symptom 2	AS 2 duration (hour)	Associated symptom 3	AS 3 duration (hour)	Previous disease 1	Previous disease 1 start date (year)	Previous disease 2
2														
4	81	M	syncope		1	tiredness	48	nausea	48	oliguria	48	hypertension		diabetes
7	68	M	dyspnea		24	wheezing	24	productive cough	24			dyspnea on exertion	5	
13														
14														
20	65	M	chest pain	radiating to the right upper limb	1									
24	45	F	palpitation		1	dyspnea	1					primary pulmonary hypertension		chronic dyspnea
30	22	M	palpitation		24									
31	72		infectious exacerbation		1							chronic obstructive pulmonary disease		hypertension
32	31	M	palpitation	with spontaneous remission	1							palpitation with spontaneous remission	0	
36	55	M	palpitation		24							hypertension		dyspnea on exertion
37	26	F	dyspnea		1	palpitation	1	dizziness	1					
42	53	F	dyspnea		1	palpitation	1	dizziness	1					

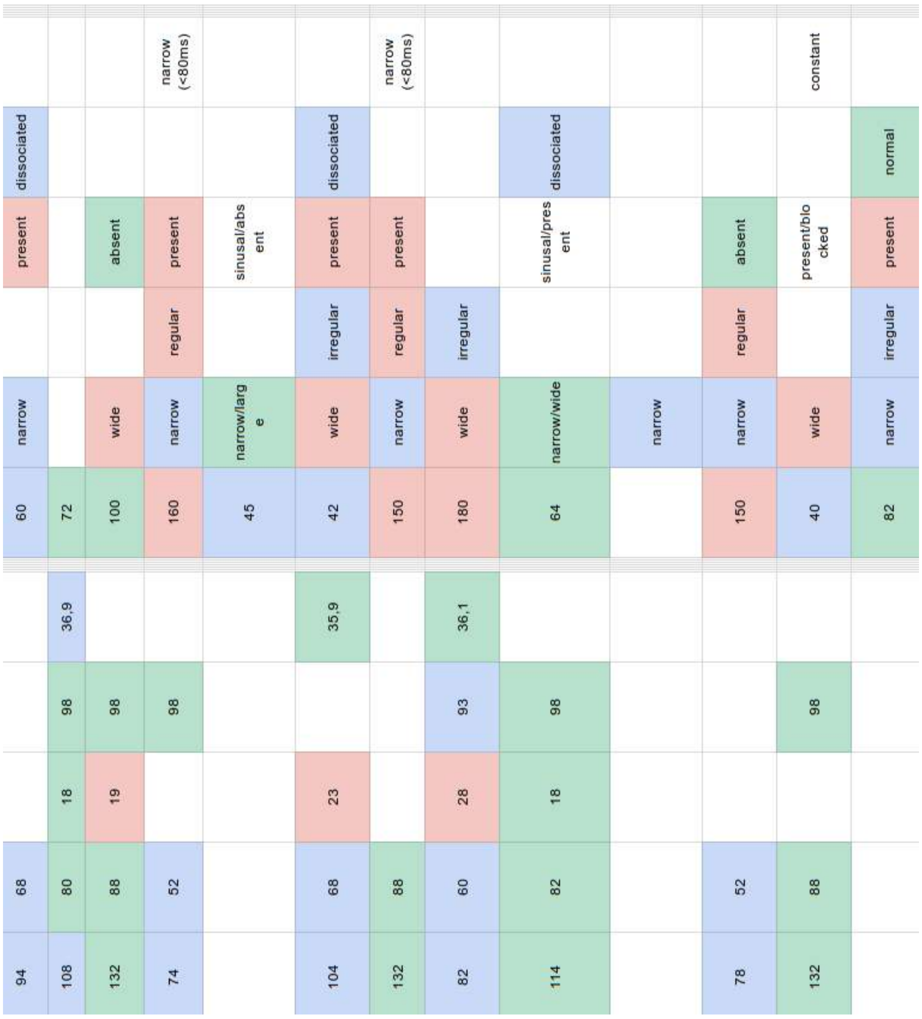
Figure B.1: Spreadsheet Screenshot #1

46	34	M	palpitation		1							Chagas disease	
47	78	M	dizziness		24	nausea	24					hypertension	
50	80	M	dizziness		48	dyspnea	48					hypertension	
51	72	M	chest pain	radiating to the upper limbs	1	dyspnea	1	nausea	1				
53	45	F	palpitation		1	dizziness	1						
55	72	M	palpitation		24	dizziness	24	cough with yellow phlegm				hypertension	30
59	73	M	dyspnea		1	dizziness	1					hypertension	
63	42	F	dysuria		1	fever	1	palpitation	1				
64	38	M	palpitation		1	dizziness	1	dyspnea	1				
65	80	M	dizziness		48	malaise	48	ischemic and hypertensive cardiomyopathy				cardiac failure	
68	30	M	chest pain	suspected myocardial infarction	1	palpitation	1	deep breathing	1				
71	71	M	dyspnea		1	dizziness	1					acute coronary syndrome	0

Figure B.2: Spreadsheet Screenshot #2

Vital sign: diastolic pressure	Vital sign: systolic pressure	Vital sign: respiratory rate (rpm)	Vital sign: spO2 (%)	Vital sign: temperatur e (°C)	ECG: heart frequency	ECG: QRS interval	ECG: RR interval	ECG: P wave	ECG: PR interval	ECG: RP interval
					110	narrow	irregular	absent		
124	82	18	96	36	40	narrow		90	dissociated	
					120	narrow	irregular	varied		
					35	wide		varied	constant	
					200	wide			constant	
120	80	15	96	36	85	wide		absent		
86	50		95		150	narrow	regular	absent		
120	80	15			140	narrow	regular	present	normal	wide (>80ms)
142	88	28	86		130	narrow	irregular	absent		
120	80	15	96	36	80	narrow		sinusal	narrow	
					100	wide	irregular	sinusal	wide	
88	56	32		36,9	140	narrow	irregular	absent		
90	58	30	98	36	170	narrow	regular	present	wide	narrow (<80ms)

Figure B.3: Spreadsheet Screenshot #3



94	68				60	narrow		present	dissociated	
108	80	18	98	36,9	72					
132	88	19	98		100	wide		absent		
74	52		98		160	narrow	regular	present		narrow (<80ms)
					45	narrow/large		sinusal/absent		
104	68	23		35,9	42	wide	irregular	present	dissociated	
132	88				150	narrow	regular	present		narrow (<80ms)
82	60	28	93	36,1	180	wide	irregular			
114	82	18	98		64	narrow/wide		sinusal/present	dissociated	
						narrow				
78	52				150	narrow	regular	absent		
132	88		98		40	wide		present/blocked		constant
					82	narrow	irregular	present	normal	

Figure B.4: Spreadsheet Screenshot #4

bradycardia	atrioventricular block	3rd-degree	hemodynamic instability						
bradycardia	atrioventricular block								
tachycardia	atrial fibrillation	left bundle branch block		acute coronary syndrome					
tachycardia	nodal reentrant	supraventricular				electrical cardioversion			
bradycardia	bigeminy	ventricular extrasystoles with compensatory pause	hemodynamic stability	digitalis intoxication		dose digoxinemia and renal function	dose potassium	suspend digoxin	continuous monitoring of heart
bradycardia	atrioventricular block	3rd-degree	hemodynamic instability			inserting artificial cardiac pacemaker	identify electrolytic disturbances	identify kidney failure	identify drug intoxication
tachycardia	nodal reentrant	supraventricular	hemodynamic stability			carotid sinus massage	adenosine infusion		
tachycardia	atrial fibrillation	with Wolff-Parkinson-White syndrome	hemodynamic instability			synchronized electrical cardioversion			
bradycardia	atrioventricular block	3rd-degree				suspend digoxine	suspend digoxine	suspend furosemide	inserting artificial cardiac pacemaker
bradycardia	ventricular extrasystoles with compensatory pause								
tachycardia	atrial flutter	with 2:1 atrioventricular block	hemodynamic instability			synchronized electrical cardioversion			
bradycardia	atrioventricular block	2nd-degree - Mobitz type I or II	hemodynamic stability			suspend metoprolol	prescribe adenosine	inserting artificial cardiac pacemaker	
tachycardia	atrial tachycardia			digitalis intoxication		electrical cardioversion	prescribe metoprolol	prescribe varapamil	prescribe amiodarone

Figure B.5: Spreadsheet Screenshot #5

Appendix C

ECG Challenge Prototype

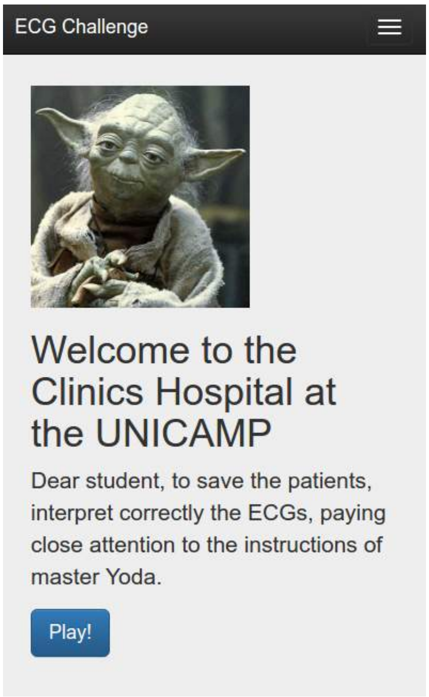


Figure C.1: ECG Challenge Main Screen

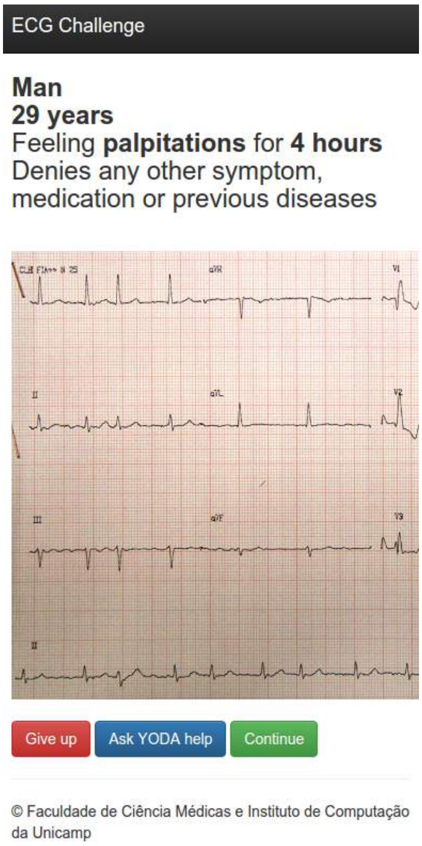


Figure C.2: ECG Challenge Case Introduction

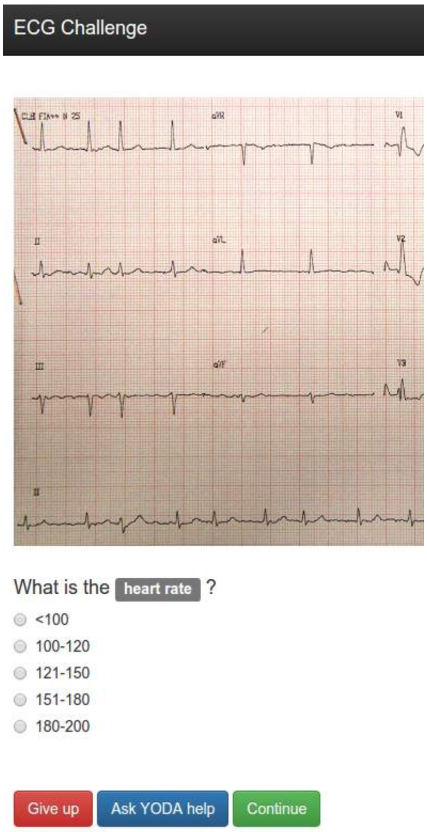


Figure C.3: ECG Challenge Question

Appendix D

Knowledge Base Data Model

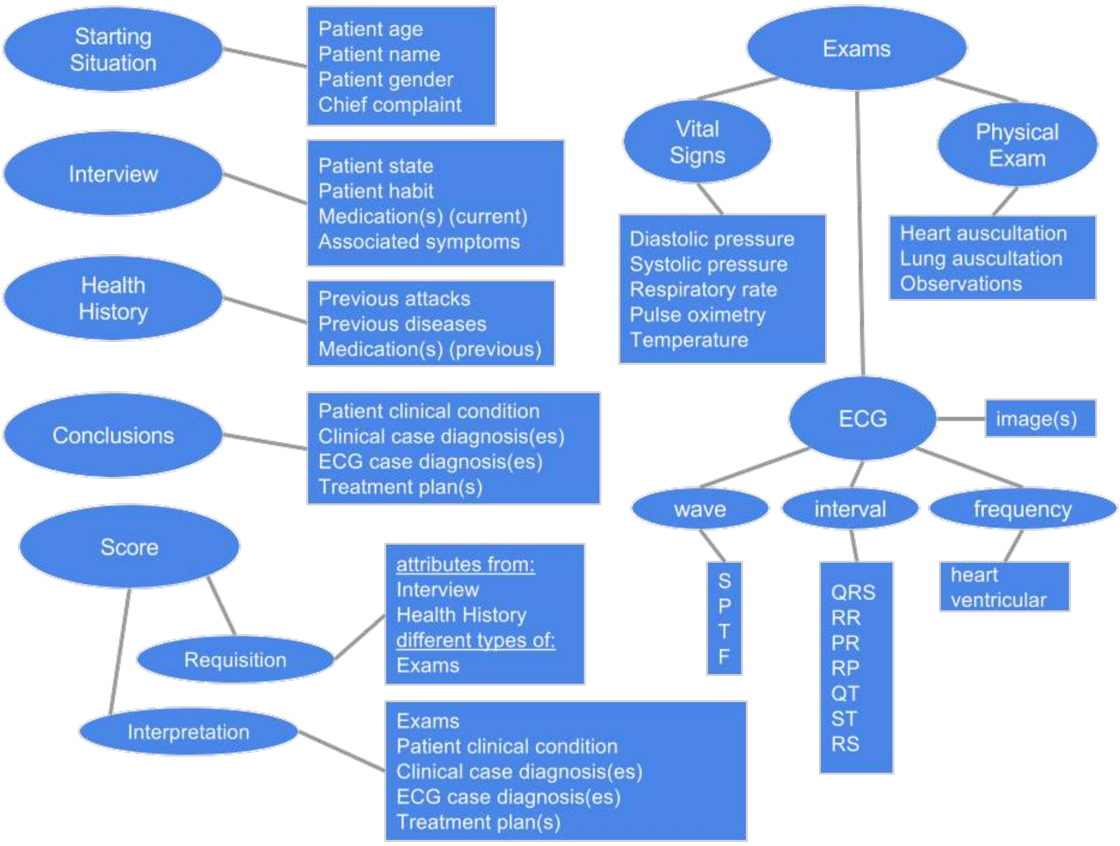


Figure D.1: Selected Attributes and Classes for the Emergency-Arrhythmia Scope

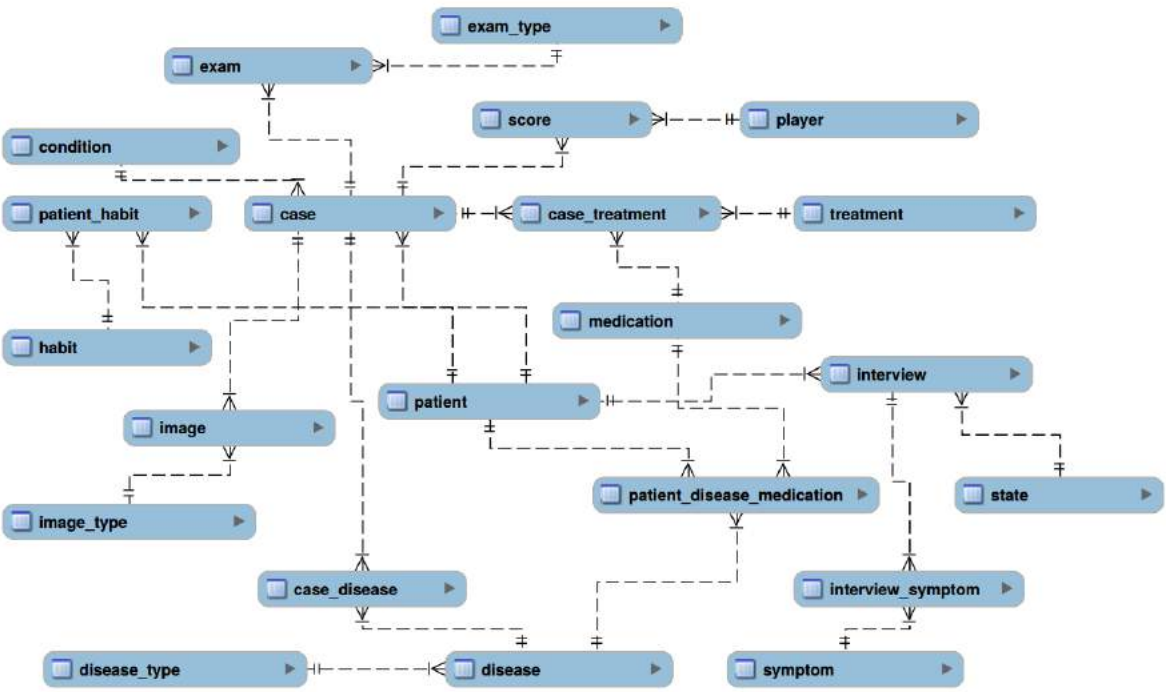


Figure D.2: Simplified Entity Relationship Model

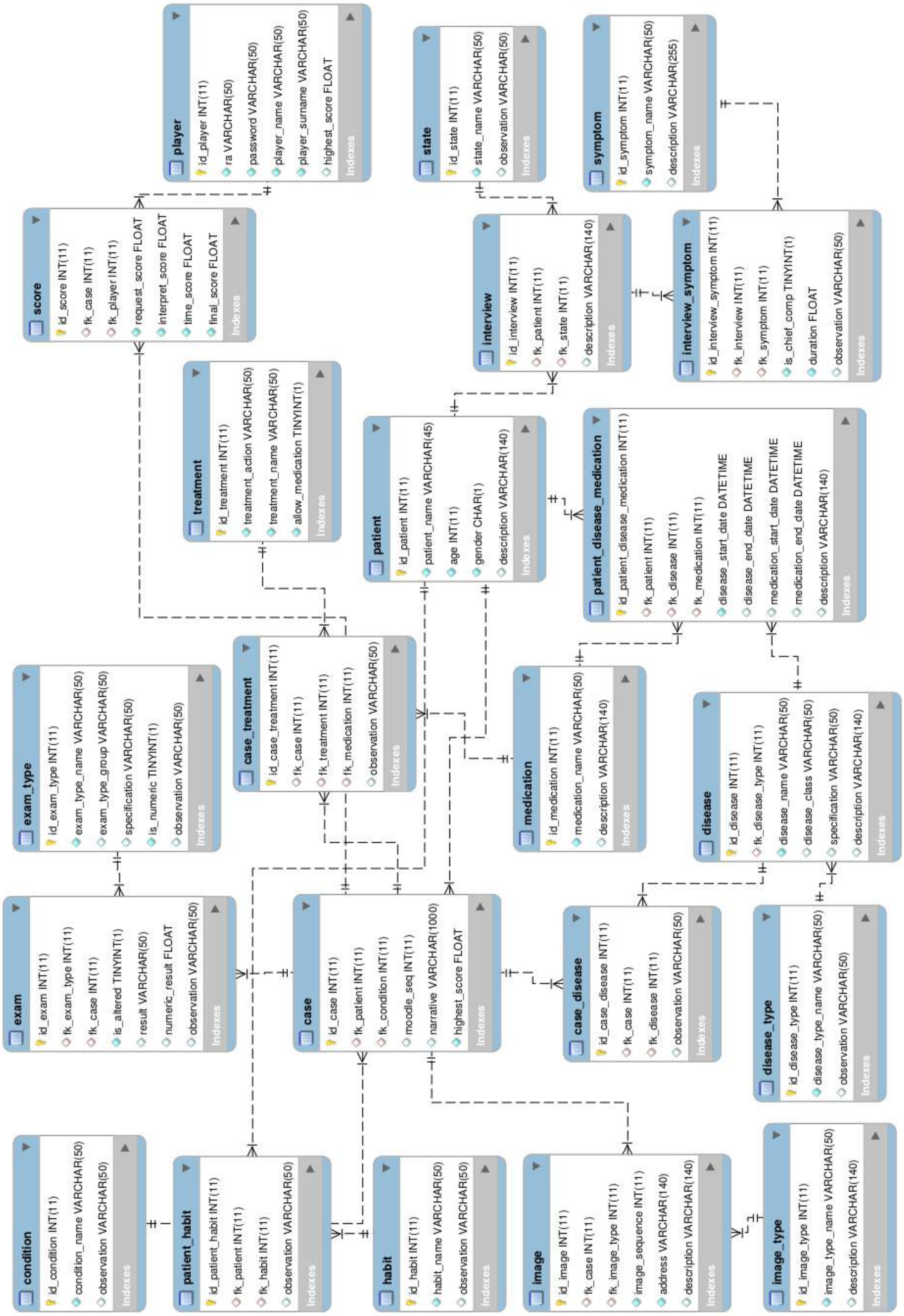


Figure D.3: Complete Entity Relationship Model

Appendix E

Comparison of Models

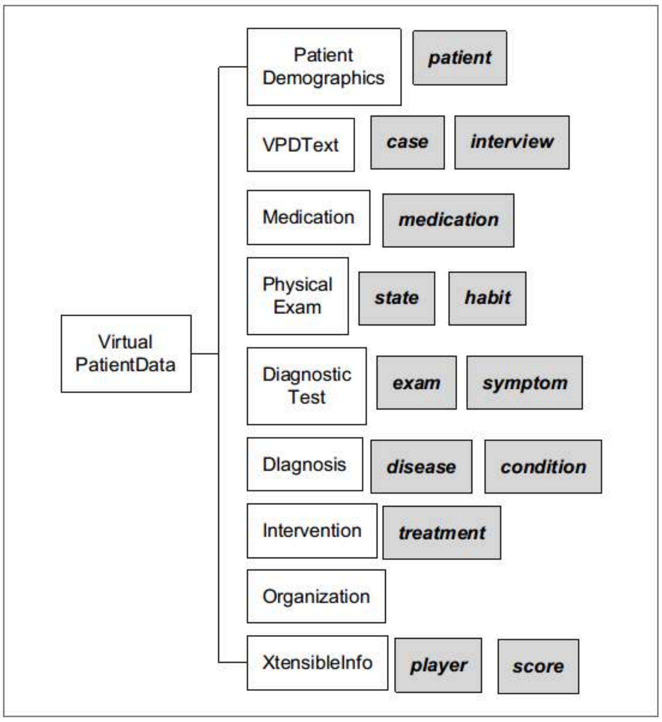


Figure E.1: *MedBiquitous* vs. *Simplified ER* Models

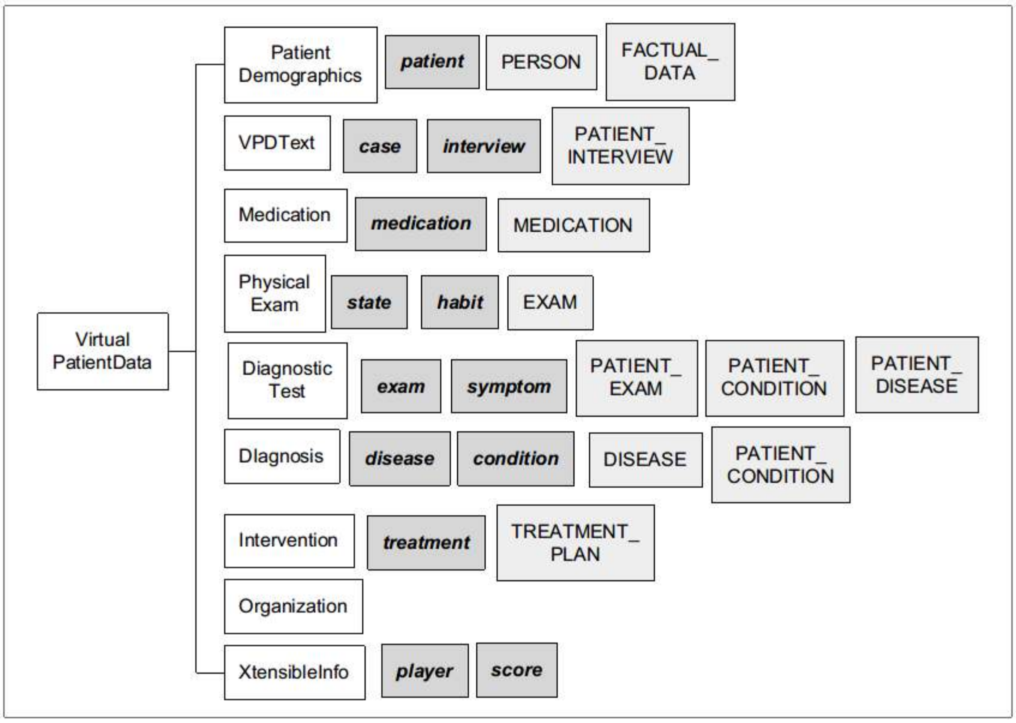


Figure E.2: *MedBiquitous* vs. *Simplified ER* vs. *EMT* Models

Appendix F

Medical and Activity Plans

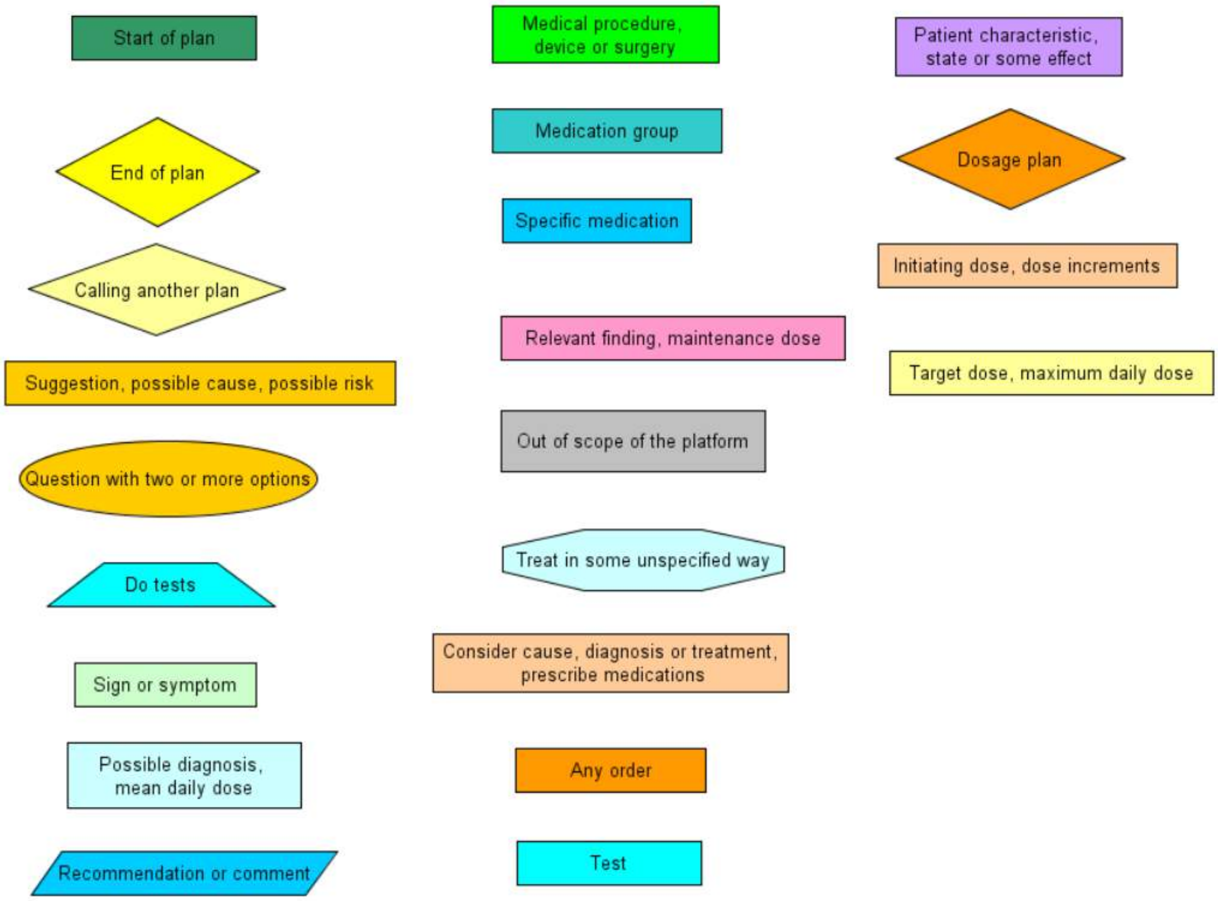


Figure F.1: Legend of Classes in a Medical Plan (source [Jovic et al., 2007b])

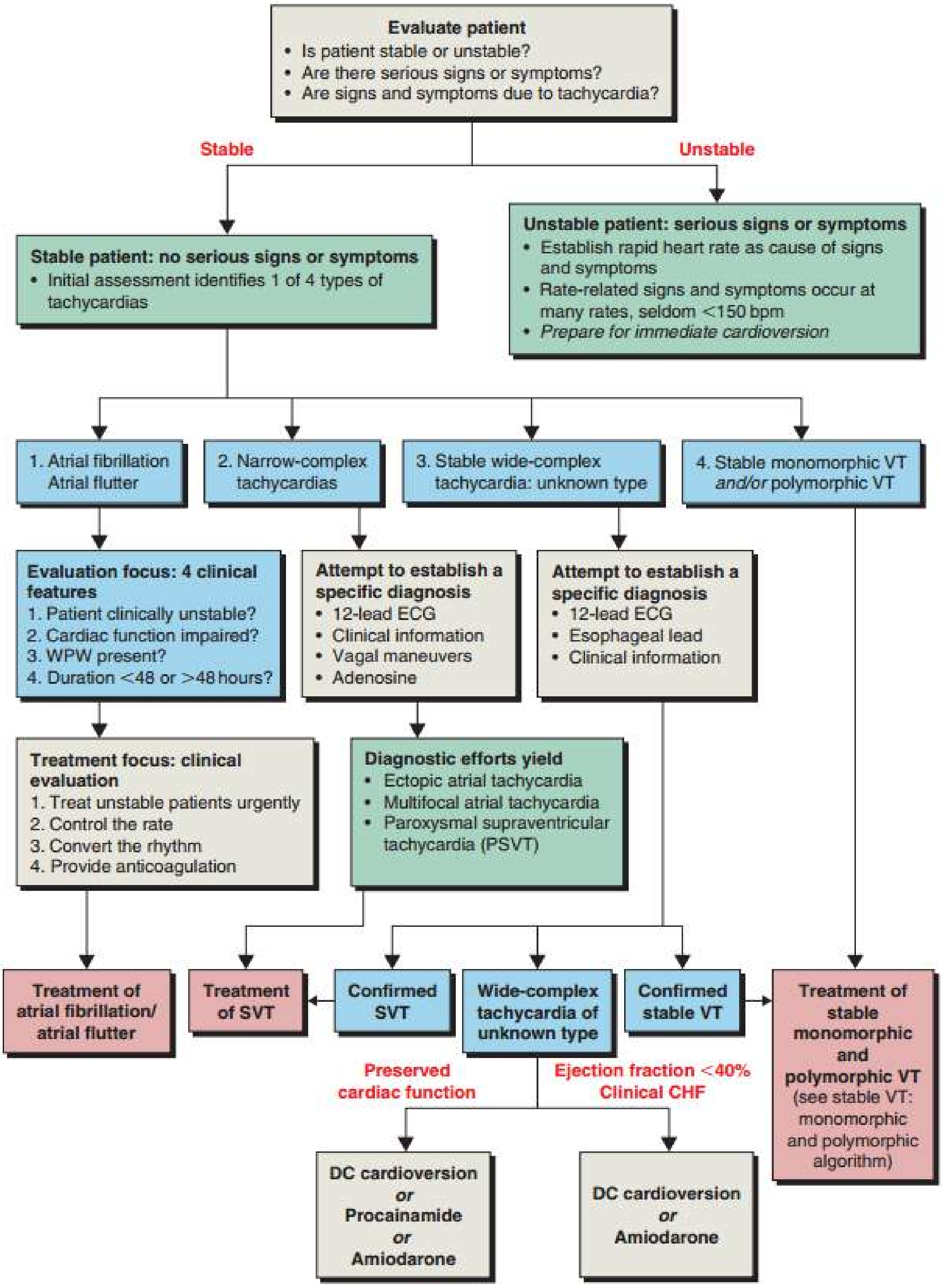


Figure F.2: Tachycardia Medical Plan (source [Mahadevan, 2005])

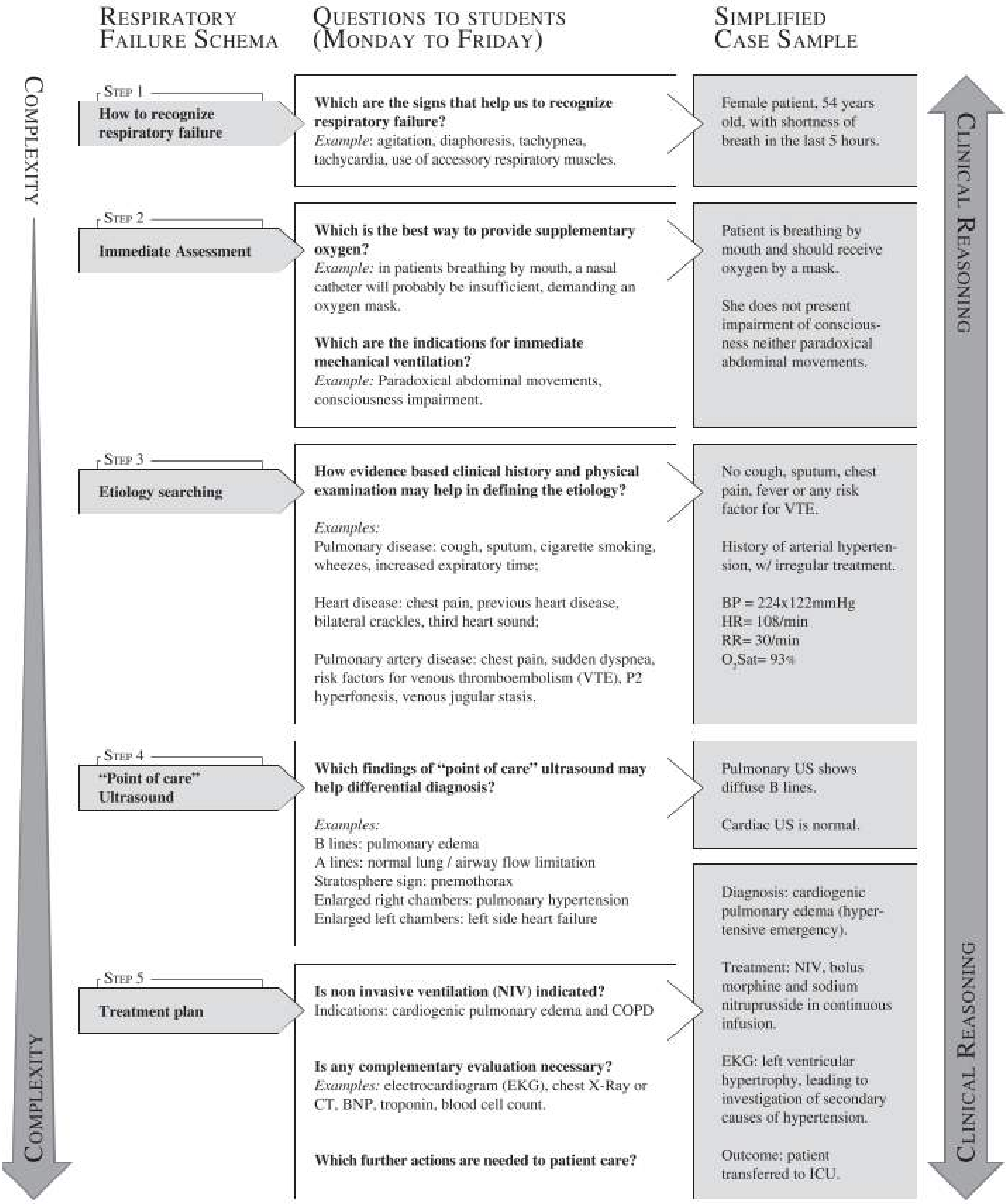


Figure F.3: Respiratory Failure Activity Plans (source [Grangeia et al., 2016])

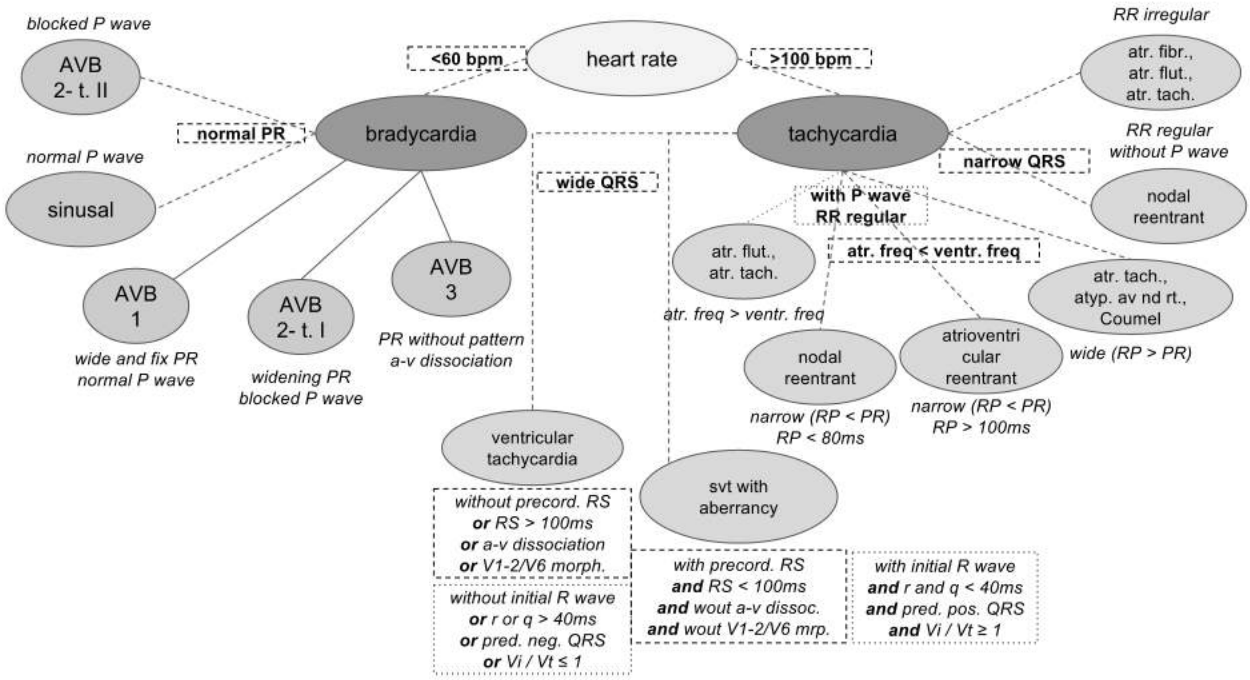


Figure F.4: Arrhythmia ECG Medical Plan (author's hypotheses)

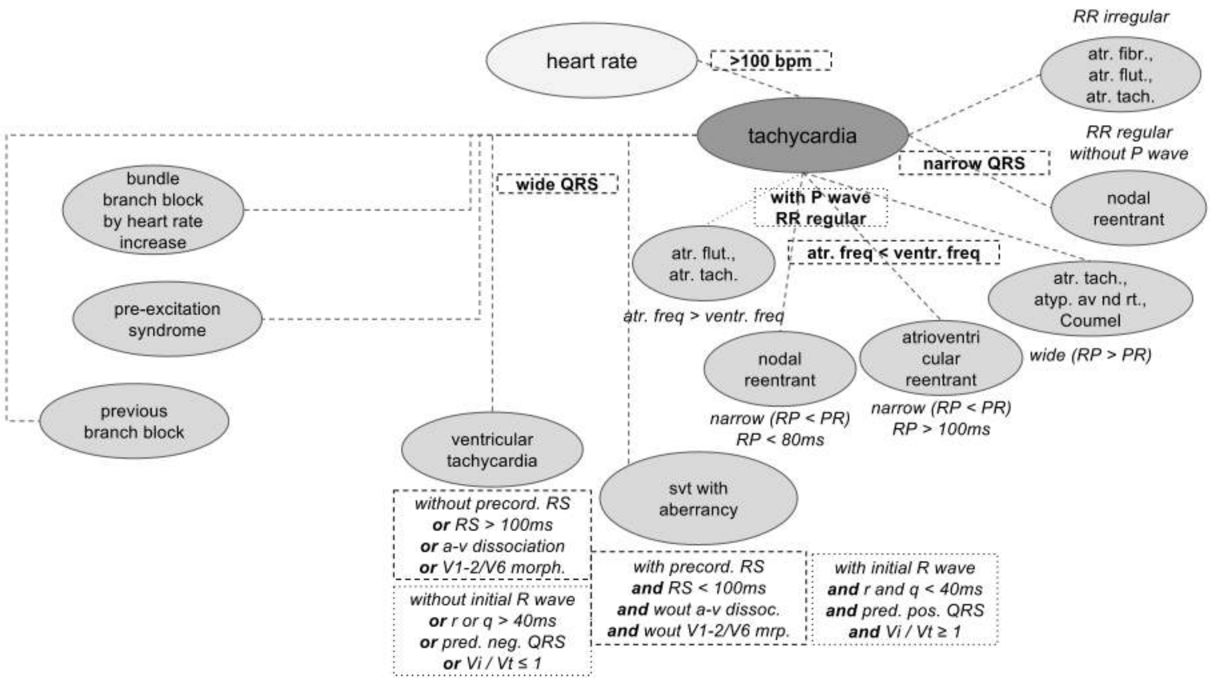


Figure F.5: Tachycardia ECG Medical Plan (author's hypotheses)

Appendix G

Text Interactive Prototype

```
"breaking-the-emergency-room" by text-coders (francisco, andre, pedro, felipe)

The Resting Room is a room. "A quiet place to try to rest."
The Emergency Room is a room. "This is a busy emergency room."

South of the Resting Room is the Emergency Room.

Doctor, and patient are kinds of person.

Yoda is in the Emergency Room. "Yoda, the master, is in the room." Yoda is a doctor.

Joao is a patient in the Emergency Room. "João enters in the emergency room. [line break]João da Silva, 37 years, single, bus
driver. Came to the ER with strong pain on his left leg. He is unable to put his weight on it, or use it to walk. The pain
started after he fell down while playing a pelada (amateur soccer).".
Joao has some text called anamnesis. The anamnesis of Joao is usually "empty".
Joao has some text called physical. The physical of Joao is usually "empty".
Joao has some text called xray. The xray of Joao is usually "empty".
The description of Joao is "anamnesis: [anamnesis of Joao][line break]physical: [physical of Joao][line break]xray: [xray of Joao].".

A machine is a kind of thing.

The x-ray machine is a machine in the emergency room.

The machine is fixed in place.

Yoda has some text called master message. The master message of a Yoda is usually "May the force be with you."

Yourself has some number called patient state. The patient state of yourself is usually 1.
Yourself has some number called higher state. The higher state of yourself is 0.
Yourself has some number called score. The score of yourself is usually 0.
Yourself has some number called share. The share of yourself is 25.

[List of Actions]
Talk list is an action applying to nothing. Understand "talk" as talk list.
After talk list:
  say "to patient[line break]to companion[line break]to Yoda.".

Perform list is an action applying to nothing. Understand "perform" as perform list.
After perform list:
  say "anamnesis[line break]physical exam[line break]foot pulse assessment[line break]x-ray examination.".
```

Figure G.1: *Inform 7* Implementation Script #1

```
[Talk to Yoda]
Talk Yoda is an action applying to nothing. Understand "talk to Yoda" as talk Yoda.
After talk Yoda:
    if the patient state of yourself is 1, say "Very informative conversation is." instead;
    if the patient state of yourself is 2, say "Very important physical examination is." instead;
    if the patient state of yourself is 3, say "Very contributory foot pulse is." instead;
    if the patient state of yourself is 4, say "Very helpful x-ray examination is." instead;
    if the patient state of yourself is 5, say "Final step immobilizing the leg is. It fine is. BUT YOUR DUTY, YOU DID NOTHING."
instead; end the story.

[Talk to patient]
Talk patient is an action applying to nothing. Understand "talk to patient" as talk patient.
After talk patient:
  say "My leg is hurting very bad doctor. Do you think I broke something?".

[Talk to companion]
Talk companion is an action applying to nothing. Understand "talk to companion" as talk companion.
After talk companion:
  say "João is alone.".

[Anamnesis]
Anamnesis is an action applying to nothing. Understand "perform anamnesis" as anamnesis.
```

Figure G.2: *Inform 7* Implementation Script #2

```
After anamnesis:
  now the patient state of yourself is 2;
  now anamnesis of Joao is "He fell down while playing soccer. His left leg has been hurting since then, it's swollen and he
can't put that foot on the ground.";
  if the patient state of yourself > higher state of yourself, increase the score of yourself by share of yourself;
  if the patient state of yourself > higher state of yourself, now higher state of yourself is patient state of yourself;
  say "You ask João to explain to you how the accident happened. He tells that he was running with the ball, right in front
of the goal, when someone tackled on him from the right. He fell down, hard, on his left side. He was feeling pain all over
his arms and legs, but most of it faded by now. Except on his left leg.".

[Physical examination]
Physical examination is an action applying to nothing. Understand "perform physical exam" as physical examination.
After physical examination:
  now the patient state of yourself is 3;
  now physical of Joao is "All his vitals are normal. João got some scratches on his left arm. His left leg is very swollen,
bruised and hurts when pressed.";
  if the patient state of yourself > higher state of yourself, increase the score of yourself by share of yourself;
  if the patient state of yourself > higher state of yourself, now higher state of yourself is patient state of yourself;
  say "Patient was examined.[line break]All his vitals are normal. João got some scratches on his left arm. His left leg is very
swollen, bruised and hurts when pressed.".

[Foot pulse assessment]
Foot pulse examination is an action applying to nothing. Understand "perform foot pulse assessment" as foot pulse examination.
After foot pulse examination:
  now the patient state of yourself is 4;
  if the patient state of yourself > higher state of yourself, increase the score of yourself by share of yourself;
  if the patient state of yourself > higher state of yourself, now higher state of yourself is patient state of yourself;
  say "Foot pulse present and regular.".

[X-ray examination]
X-ray examination is an action applying to nothing. Understand "perform x-ray examination" as x-ray examination.
After x-ray examination:
  now the patient state of yourself is 5;
  now xray of Joao is "His tibia is broken, with the fracture line about half the distance between the knee and the ankle.";
  if the patient state of yourself > higher state of yourself, increase the score of yourself by share of yourself;
  if the patient state of yourself > higher state of yourself, now higher state of yourself is patient state of yourself;
  say "X-Ray performed.[line break]His tibia is broken, with the fracture line about half the distance between the knee and
the ankle.".

[Diagnose]
Diagnose is an action applying to nothing. Understand "diagnose" as diagnose.
After diagnose:
  say "You diagnosed João with a broken tibia on his left leg.[line break]You put a cast on his left leg, and instructed him to
rest and take it easy for a while. If the pain get's too strong, he should take some analgesics.[line break]You made [score of
yourself]";
  end the story.
```

Figure G.3: *Inform 7* Implementation Script #3

breaking-the-emergency-room
An Interactive Fiction by text-coders (francisco, andre, pedro, felipe)
Release 1 / Serial number 170510 / Inform 7 build 6M62 (I6/v6.33 lib 6/12N) SD

Resting Room
A quiet place to try to rest.

>perform
anamnesis
physical exam
foot pulse assessment
x-ray examination.

>perform anamnesis
You ask João to explain to you how the accident happened. He tells that he was running with the ball, right in front of the goal, when someone tackled on him from the right. He fell down, hard, on his left side. He was feeling pain all over his arms and legs, but most of it faded by now. Except on his left leg.

>perform physical exam
Patient was examined.
All his vitals are normal. João got some scratches on his left arm. His left leg is very swollen, bruised and hurts when pressed.

>perform foot pulse assessment
Foot pulse present and regular.

>perform x-ray examination
X-Ray performed.
His tibia is broken, with the fracture line about half the distance between the knee and the ankle.

>diagnose
You diagnosed João with a broken tibia on his left leg.
You put a cast on his left leg, and instructed him to rest and take it easy for a while. If the pain get's too strong, he should take some analgesycs.
You made 100

*** The End ***

Figure G.4: Leg Fracture Case Interaction

Appendix H

Activity Plans as a Running Workflow

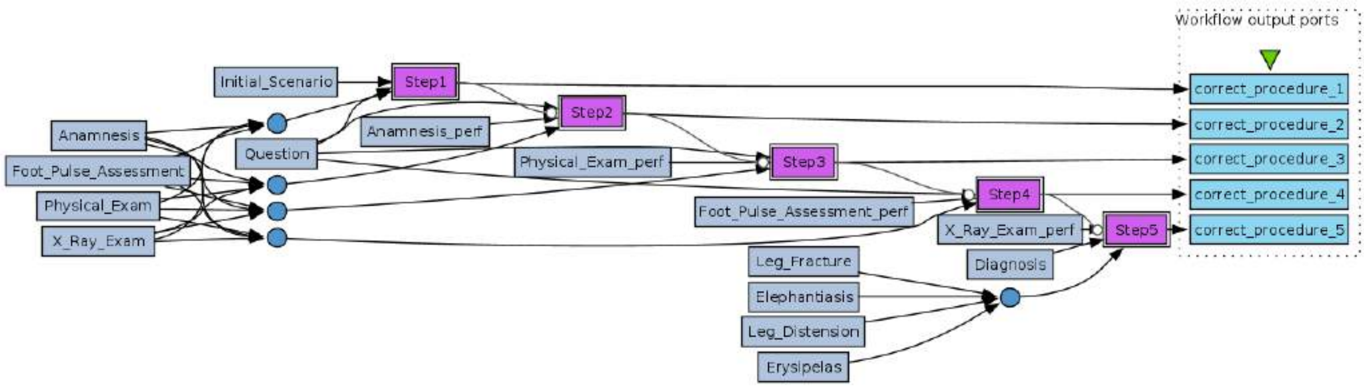


Figure H.1: Leg Fracture Activity Plan as a Workflow

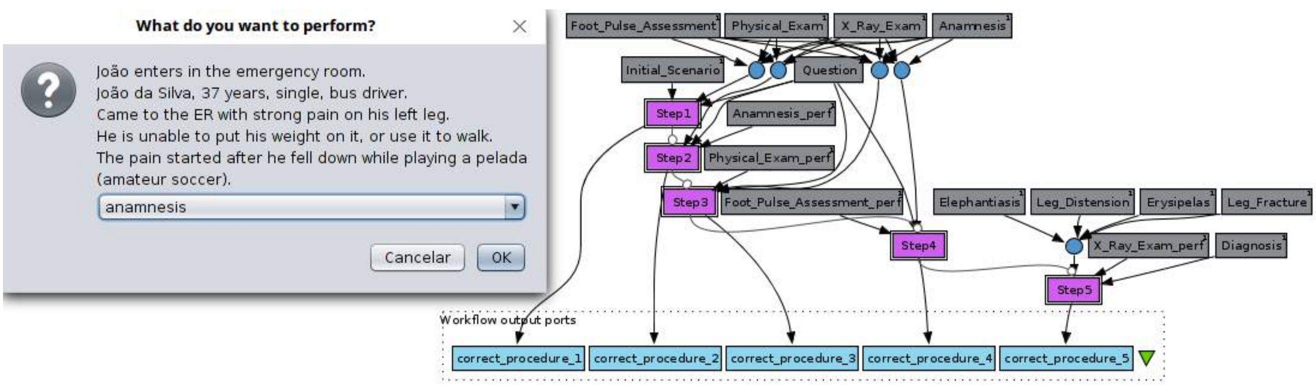


Figure H.2: Workflow Step #1: Initial Scenario

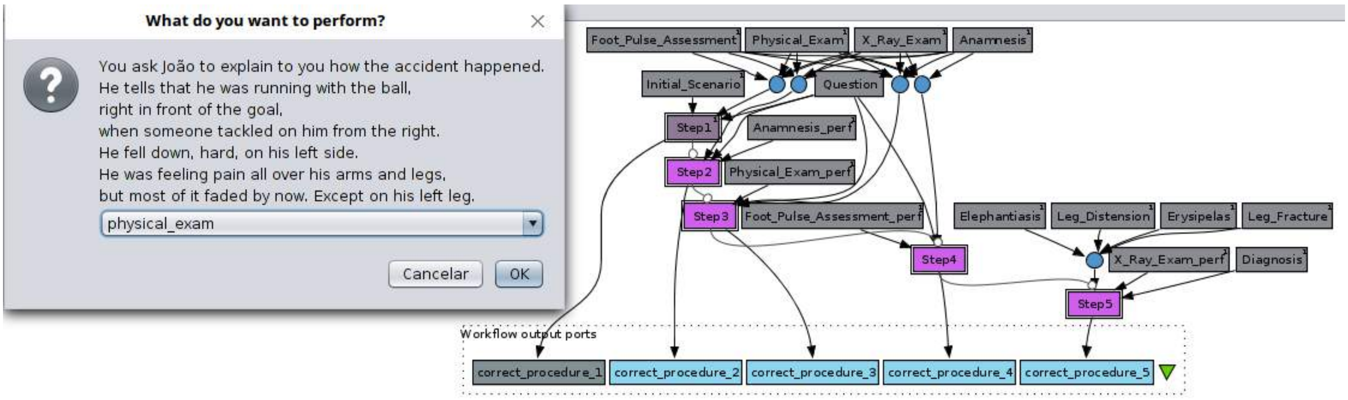


Figure H.3: Workflow Step #2: Anamnesis Performed

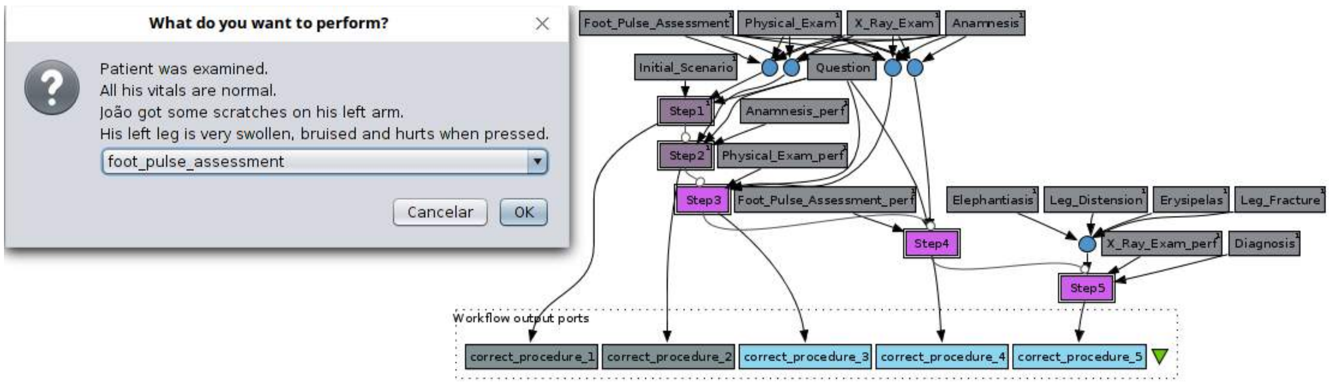


Figure H.4: Workflow Step #3: Physical Exam Performed

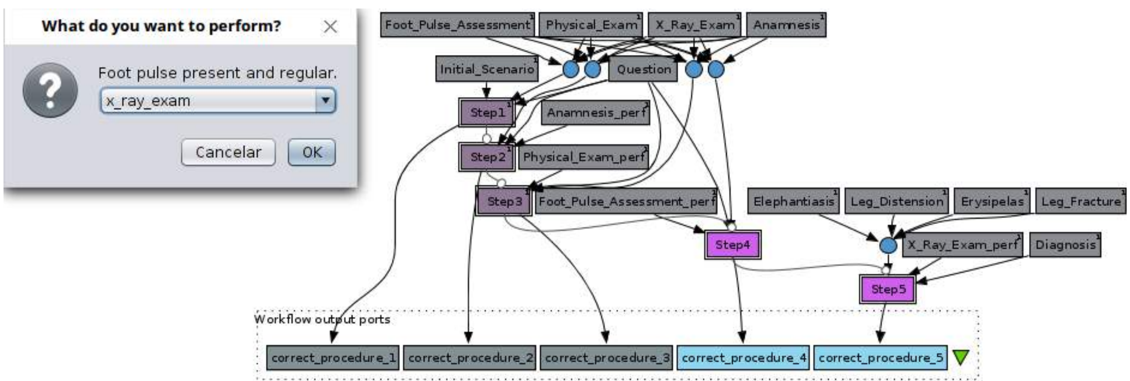


Figure H.5: Workflow Step #4: Foot Pulse Assessment Performed

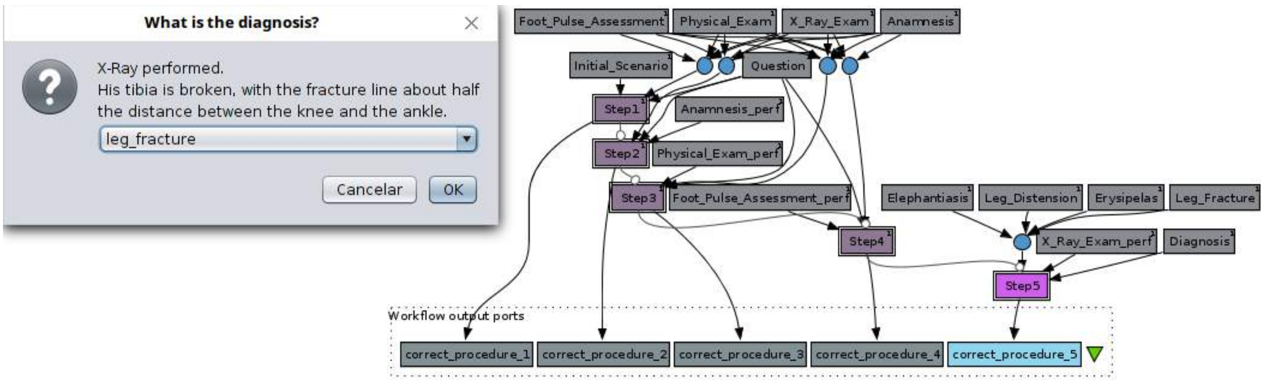


Figure H.6: Workflow Step #5: X-Ray Exam Performed

Appendix I

Notes of Meetings with the Medical Team

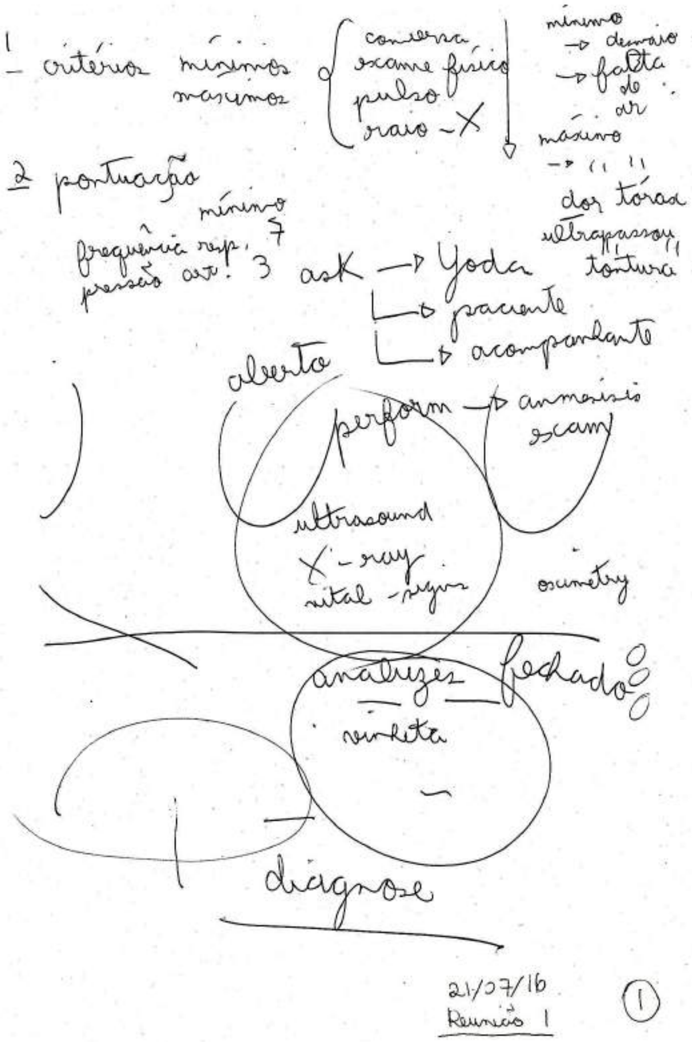


Figure I.1: Meeting Note #1

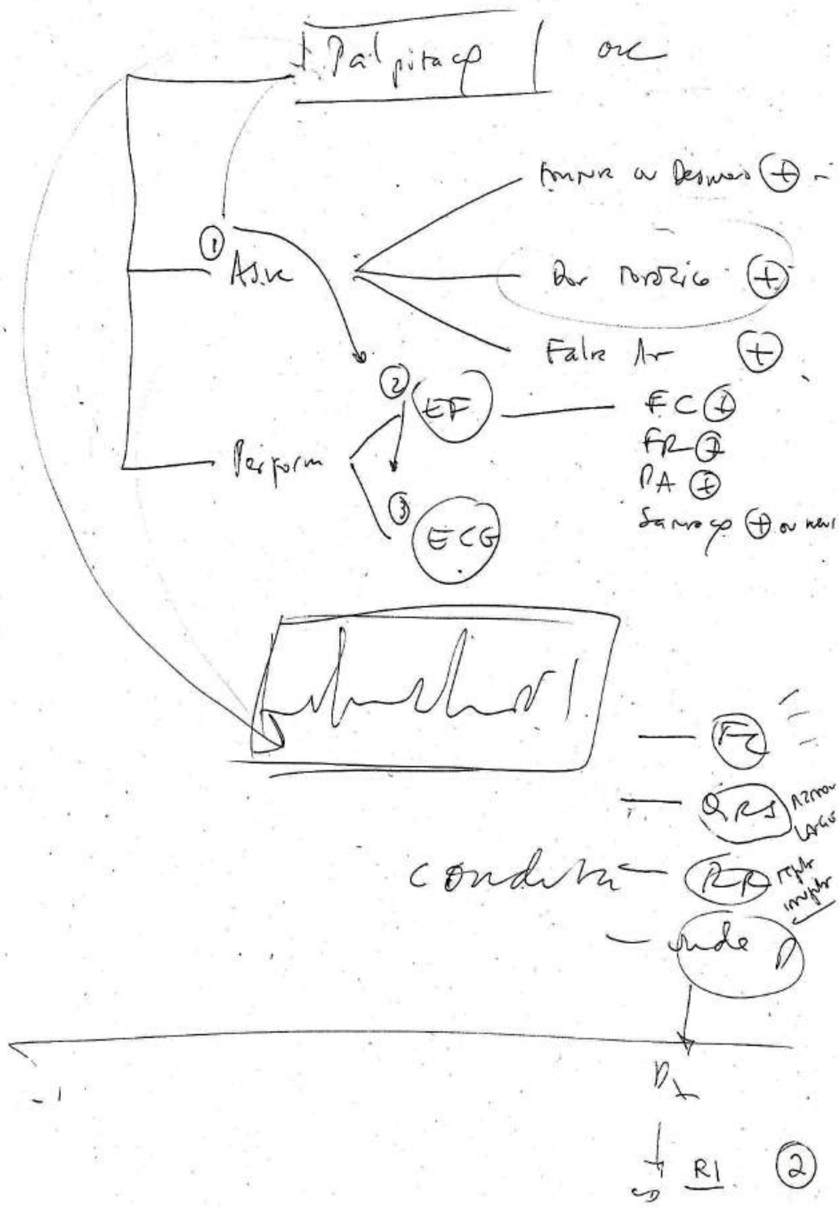
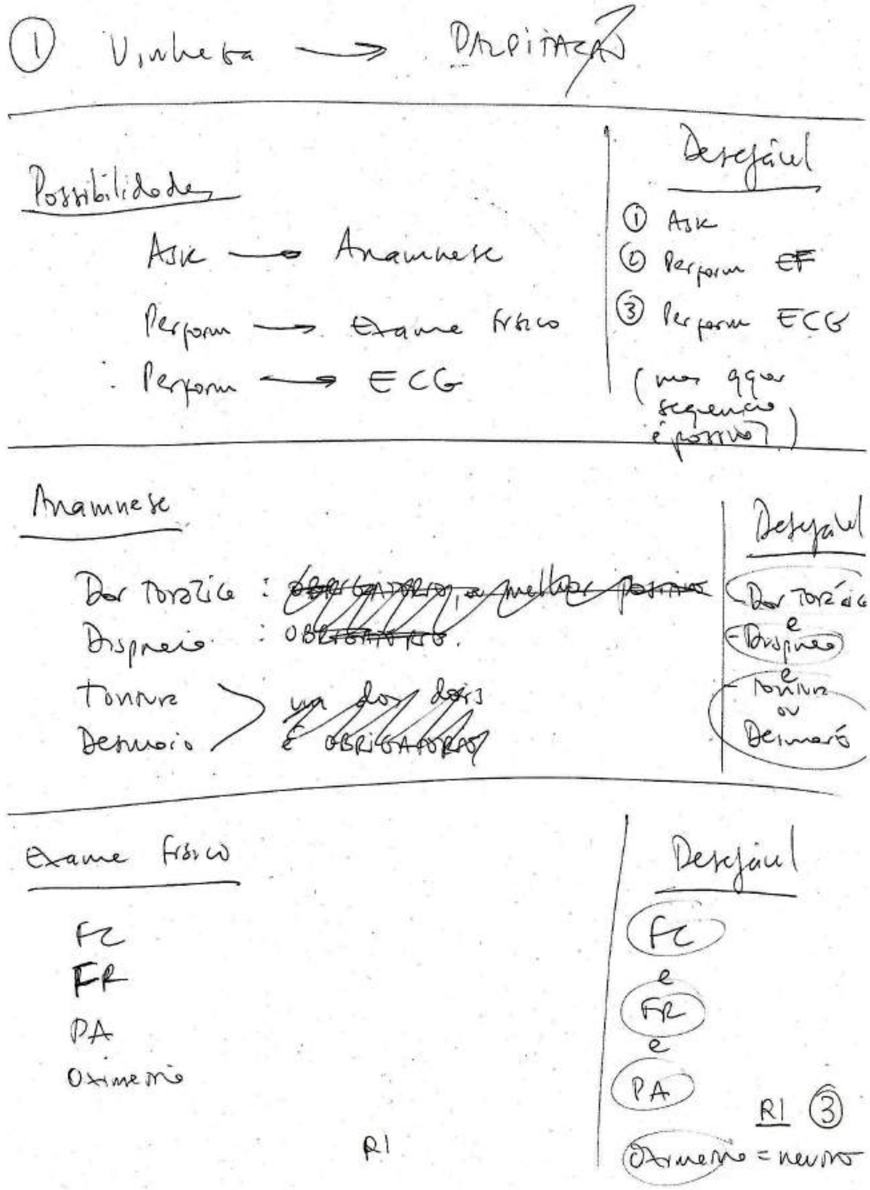


Figure I.2: Meeting Note #2



① Vinheta → PALPITAÇÃO

Possibilidades

Ask → Anamnese

Perform → Exame físico

Perform → ECG

Desejável

① Ask

② Perform EF

③ Perform ECG

(mas qquer sequência é possível)

Anamnese

Dor torácica : ~~OBRIGATÓRIO, a melhor possível~~

Dispneia : OB~~RIGATÓRIO~~.

Tontura > ~~um dos dois é OBRIGATÓRIO~~

Desmaio

Desejável

Dor torácica e Dispneia e Tontura ou Desmaio

Exame físico

FC

FR

PA

Oximetria

RI

Desejável

FC e FR e PA

RI ③

Oximetria = neutro

Figure I.3: Meeting Note #3

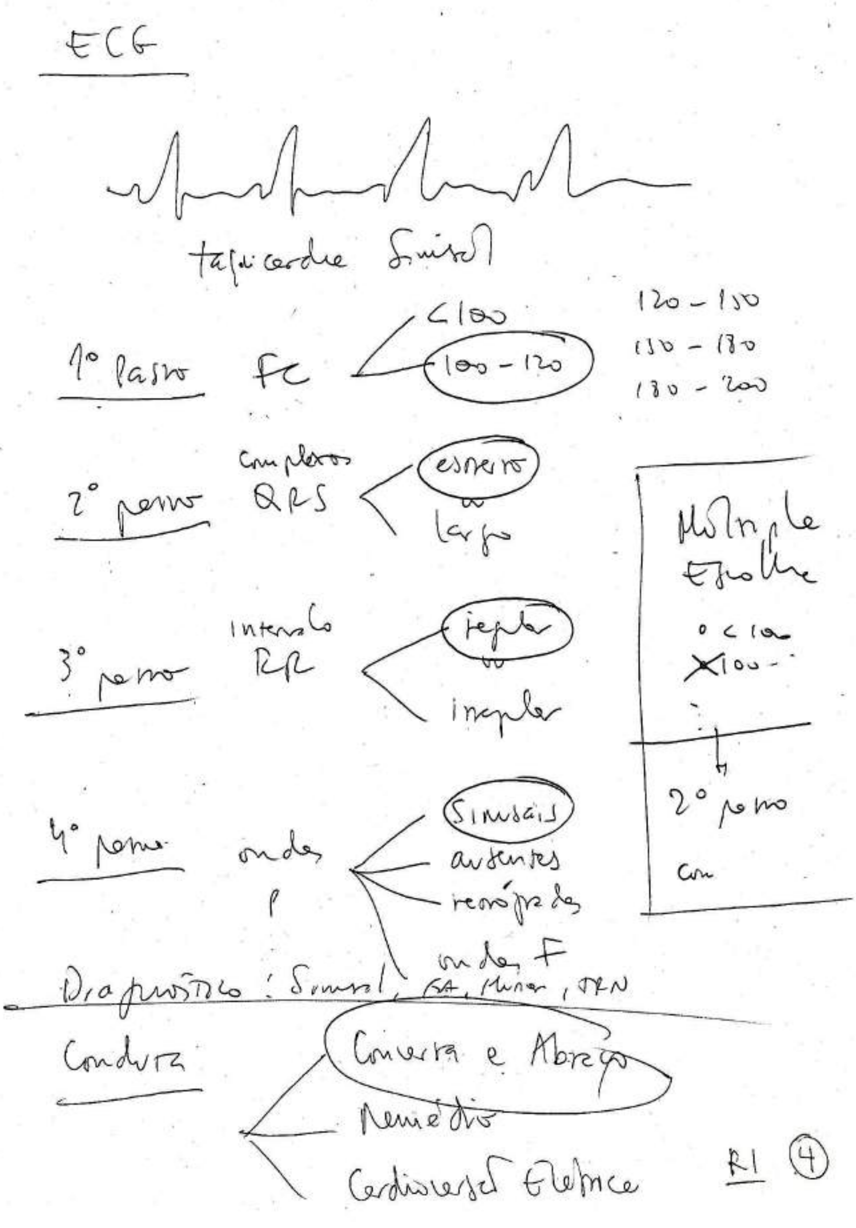


Figure I.4: Meeting Note #4

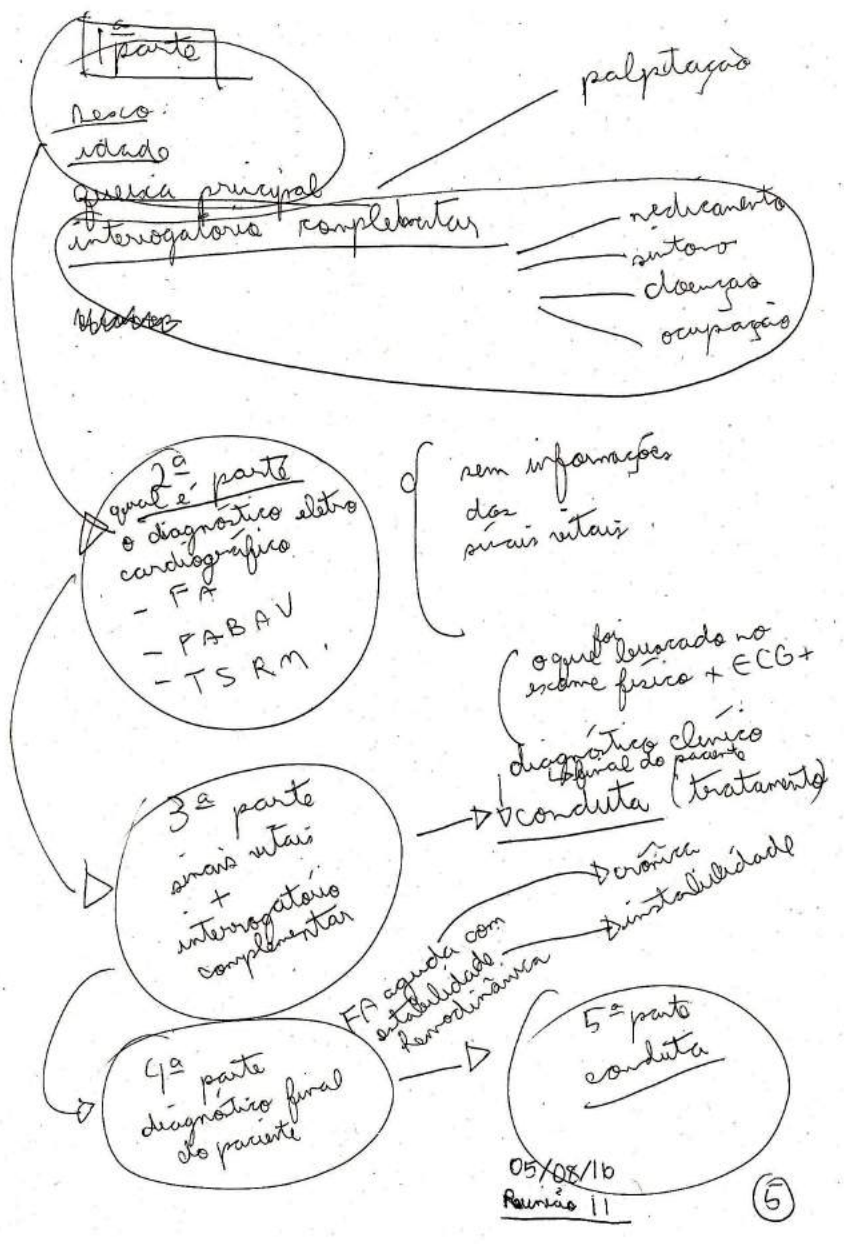


Figure I.5: Meeting Note #5

- manter o esquema
ampliar p/ mais casos

-

casos resolvidos
* recorde pessoal = Yoda score
modo zen
treinamento sussa — pontuação
modo insano
▷ vida real
▷ * pontuação

muito tempo demorando etc...
pedir ajuda vergonha não é
implementar usando bibliotecas do moodle que façam relatório de performance, tempo,

dicas p/ quando tem a imagem ECG
descrever como interpretar
algum dos fatores
1 Yoda — tempo
2 Yoda — sem tempo
3 clica e aparece balãozinho
questões de raciocínio

05/08/16
Reunião 11
6

muita ajuda você pedindo está que a força esteja com paciente!

limitar nº de ajuda

Figure I.6: Meeting Note #6

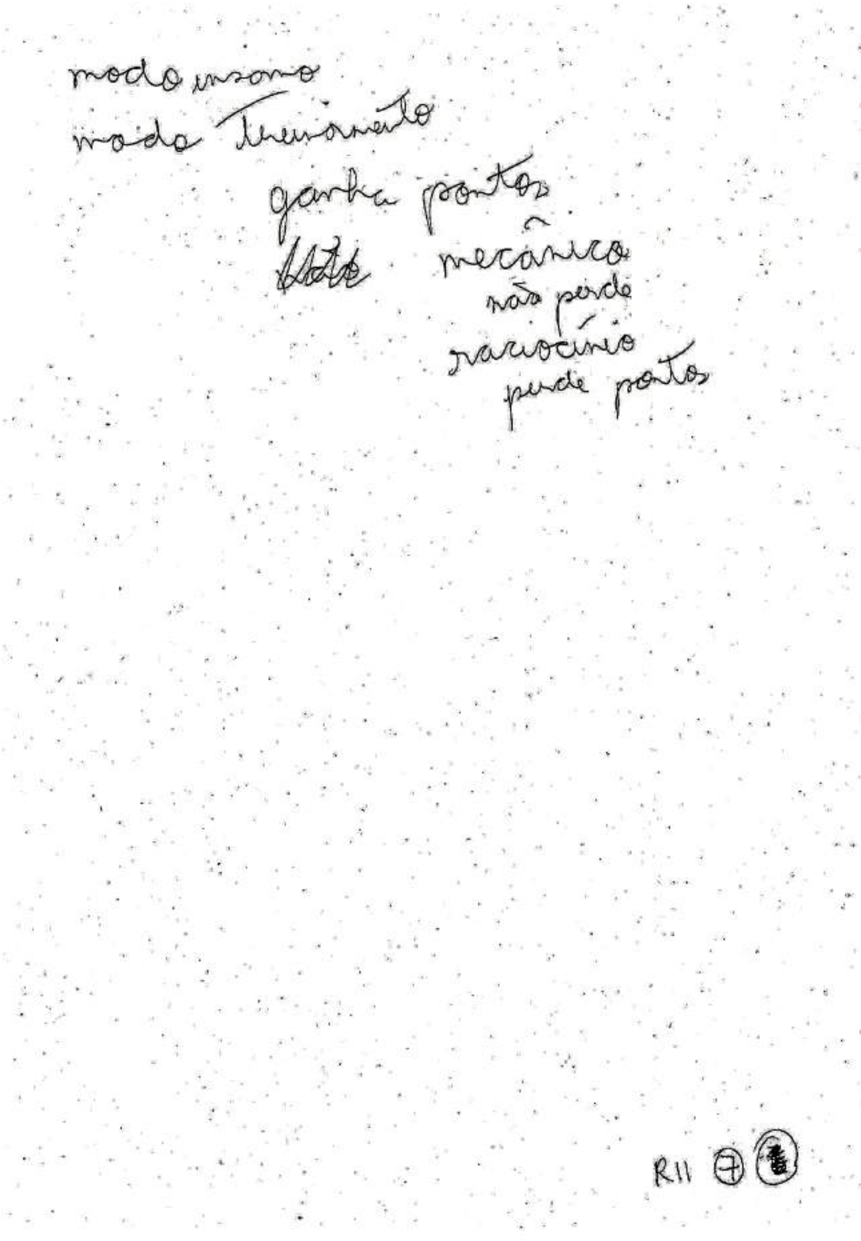

modo uníssono
modo Treinamento
ganha pontos
~~[illegible]~~ mecânico
não perde
raciocínio
perde pontos
R11 7

Figure I.7: Meeting Note #7