AN OWL ONTOLOGY FOR MODELING HL-7 COMPLIANT ELECTRONIC PATIENT RECORDS FOR CHRONIC DISEASE MANAGEMENT

by

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DALHOUSIE UNIVERSITY

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Signature of Author

DEDICATION

TO THE SOUL OF MY FATHER SYED WASI-UL-HASSAN ZAIDI (LATE)

MY MOTHER ANJUM ZAIDI

MY LOVING WIFE SHIRIN HAIDER ZAIDI

AND

MY SON WASI HAIDER ZAIDI

To them I dedicate this thesis

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ABSTRACT

The management process of chronic diseases is longitudinal in nature. Patient records in electronic format provide information at the point of care and support decision-making processes. In our research, we analyzed the clinical pragmatics of Chronic Disease Management (CDM) and formulated a knowledge model to develop Ontology-based EMR. Our research involved knowledge abstraction, knowledge modeling, and ontology engineering. We applied the Knowledge Management approach to knowledge sources including medical literature, the Chronic Care Model (CCM), CPR Ontology and HL-7 RIM. We studied CDM in detail to abstract conceptual knowledge involved in the process of CDM. The abstracted knowledge was modeled into a formal model called CD-EMR Model. We adapted Methontology and developed an OWL-based ontology from the CD-EMR Model. We evaluated the ontology by instantiating longitudinal clinical cases of chronic diseases. CD-EMR ontology allows (a) computerization of longitudinal patient records, (b) semantic interoperability, and (c) reasoning for clinical decision support.

LIST OF ABBREVIATIONS USED

ADL	Activities of Daily Living
AI	Artificial Intelligence
CCM	Chronic Care Model
CDSS	Clinical Decision Support Systems
CDM	Chronic Disease Management
CPG	Clinical Practice Guideline
CP	Care Plan
CIS	Clinical Information System
CNS	Central nervous system
CPR	Computerized Patient Record
CVS	Cardiovascular system
DIS	Drug Information System
EBM	Evidence Based Medicine
HIMSS	Health Information Management System Society
EMR	Electronic Medical Record
EHR	Electronic Health Record
GPE	General Physical Examination
HIS	Health Information System
I/V	Intra-venous
LIS	Laboratory Information system
LOINC	Logical Observation Identifier Names and Codes
NCD	Non-communicable diseases
N/G Tube	Naso-gastric Tube
NPO	Nothing per oral
PACS	Picture archiving and communication system
PO	Per Oral
SNOMED-CT	Systematized Nomenclature of Medicine-Clinical Terms
WHO	World Health Organization

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CHAPTER 1: INTRODUCTION

1.1 INTRODUCTION

Chronic diseases confront patients, their families, and healthcare providers with a restricted and uncertain future, a variable degree of impact, and burdens associated with controlling the disease process. According to the World Health Organization (WHO) chronic diseases are characterized as diseases that have long course and slow progression [1]. Due to the complex nature and long course, one of the most significant challenges of 21st century is to manage chronic diseases [2]. The burden of chronic diseases is an ever increasing issue faced by individuals, their families, communities, and the health care system [3]. Chronic diseases result in increase morbidity and mortality both in developed and developing nations [4].

Due to the fact that chronic diseases cannot be fully treated, and because once diagnosed, patient has to live with and face the disease throughout the life span makes the management of these conditions more complex. The fact that patients have to live with the diseases for the rest of their life makes the chronic diseases more than just a pathological problem. This is the beginning of a new life experience that the patient has to face, and for this reason the impact of chronic diseases are not only limited to the patient but involve their families and social life.

Therefore, the management of chronic diseases must consider both the pathological state of the disease as well as the behavioral impacts [5]. All possible treatment options must be considered while developing the management plan. Multiple healthcare providers, in the form of healthcare team [6], must be involved to manage different aspects of disease [5, 6]. Evidence based recommendations should be followed and a comprehensive management plan should be developed to capture the various aspects of chronic diseases [5]. Availability of patient information at the point of care helps in decision making and planning the right intervention which is suitable and according to patient's need.

Healthcare data exists in various forms. Patient information lies in medical records, which contain information about signs and symptoms, clinical investigations, test results, and treatment. This data is mostly paper based or distributed across various

heterogeneous health information systems (HIS). Evidence based recommendation are present in the form of Clinical Practice Guideline (CPG) and Care Plan (CP) which are needed for treatment planning and decision support. Health information systems are designed according to different domains of medical science. For example laboratory information system (LIS) stores information about lab data, Picture archiving and communication system (PACS) stores radiological data, and drug information system (DIS) stores the information about drugs and prescriptions. These HIS provide the data at point of care. The Electronic Medical Record (EMR) is a component of HIS which stores patient information in systemic manner. Electronic data entry is helpful in simultaneous data access and retrieval by multiple users at the point of care. It reduces redundant information, medical errors and delays.

1.2 PROBLEM STATEMENT

We are aware of the facts that chronic diseases are complex in nature and have multifaceted impacts, such as psychological, behavioral and social impacts. Besides, the pathology of the chronic diseases, the notion of impact is not limited to patients, but it negatively influences their families, friends, and relationships. Although there are standard models for chronic disease management, such as the Chronic Care Model (CCM); electronic medical record systems, such as Computer Based Patient Record (CPR) ontology; and the messaging standard, HL7 v3, these models are not integrated to capture the longitudinal care process of chronic disease management (CDM).

> We argue that the available standard models such as the chronic care model CCM, Computer Based Patient Record (CPR) ontology, and HL7 v3 are under-utilized and need to be integrated at a single platform so that they can capture the longitudinal process of CDM.

In this thesis, we try to address the above mentioned issues by our research work; our aim is to reach the following research goals and objectives.

1.3 GOALS AND OBJECTIVES

Our main goal is to develop a knowledge model for chronic disease management. This model must contain all the components of the holistic care needed to manage chronic

diseases, which means it should capture the core concepts of chronic diseases management. The objective to develop this knowledge model is to separate the linguistics entities, which are common within and across various healthcare domains, from the conceptual knowledge. For example “return to clinic after 4 weeks with blood work done” is a common phrase used by healthcare providers, but it contains two important concepts which are follow- up and investigations. This knowledge will then be used to develop the conceptual model of chronic disease management which captures both the workflow, and at the same time serve as the information model to capture the information generated during the process of care.

Using the above mentioned knowledge model, we will develop an ontology based EMR system that can support chronic disease management and is semantically interoperable. The rationale for developing an ontological framework for our EMR system is to achieve semantic interoperability, among health information systems and patient data repository, which is a prime functionality of EMR. In order to achieve semantic interoperability we will be using the components of two standard models, CPR Ontology and HL7 RIM.

In summary, our goals and objectives to develop the comprehensive knowledge model of chronic disease management and CD-EMR ontology are focused on the reuse of the components of standard models, such as CCM, CPR Ontology, and HL-7 RIM. The objective behind reusing the components of these knowledge sources, CCM, CPR Ontology, and HL-7 RIM, lies in the facts (a) the CD-EMR model should be comprised of elements from all these standard models, (b) integration of CD-EMR model with CPR Ontology and HL-7 RIM helps to achieve semantic interoperability, (c) the reuse of concepts form CCM, CPR Ontology and HL-7 RIM helped us in the naming process of classes and sub-classes during ontology engineering. We named the concepts used in CD-EMR Ontology by assigning a standardized concepts name which was adapted from the standard models (i.e. CCM, CPR Ontology, and HL-7 RIM). This will extend the reusability of our ontology beyond this project, and (d) the CD-EMR model should lies in the middle of these knowledge sources and serve as a confluence where all of the models connect with each other via CD-EMR as shown in Figure 1-1.

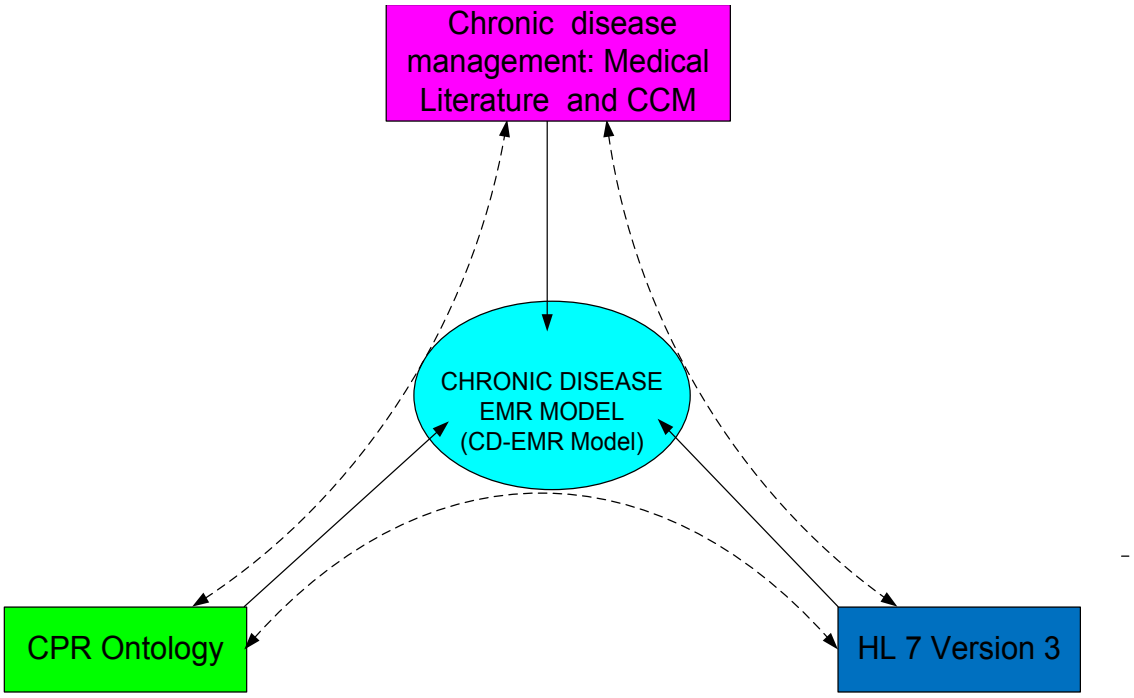


Figure 1-1 Central position of CD-EMR Model among the chosen standard models

1.4 RESEARCH CHALLENGES

As mentioned above, the main goal of our research is to abstract the conceptual knowledge of chronic diseases management and represent it in terms of a knowledge model. The model should represent the core concepts, functional aspects of chronic disease management, and the workflow that occur within the healthcare system. This model will then be used to develop an ontology based EMR system for chronic diseases. To accomplish this goal we identify the following research challenges:

- CCM does not provide a specific data representation model, however it provides some guiding principles regarding the aspects of patient data that must be employed while providing CDM.

- CPR Ontology does not support aspects of longitudinal nature of CDM. It does not explicitly capture certain aspects of patient data that pertain to CDM.

- We need to map HL7 terminology with an ontological model, capable of capturing all aspects of CDM, in order to transform HL7 encoded data into that model.

1.5 SOLUTION APPROACH

In order to meet our research objective we have designed a comprehensive methodology consisting of several steps and which is based on a knowledge management approach. The steps of our methodology are as follows:

Step1: Study of various aspects of chronic diseases to understand the process of chronic diseases management.

Step2: Investigation and identification of clinical and non-clinical concepts essential in the process of chronic diseases management.

Step3: Abstraction of conceptual knowledge by separating the linguistics entities from the conceptual knowledge.

Step4: Development of a conceptual model of chronic disease management by using the abstracted knowledge, from medical literature and standard model of chronic disease management i.e. CCM.

Step5: Alignment and integration of the conceptual knowledge model with a standard ontological framework, i.e. CPR ontology, and with a messaging standard, i.e.HL7 v3.

Step6: Validation of the model to evaluate model richness and knowledge gaps in term of missing concepts.

Step7: Formalization of the conceptual model so that it can be computerized and implemented in an ontological framework to achieve semantic interoperability and develop the CD-EMR Ontology.

Step8: Comprehensive evaluation of the CD-EMR Ontology to evaluate the ontological framework both technically and functionally.

The rational to develop this comprehensive multi-step methodology is it will guide us to remain focused on achieving our aims and objectives, and help us to search for solutions at the knowledge level for each of our research problem. Figure 1-2 shows the steps of our solution approach to develop our CD-EMR Ontology.

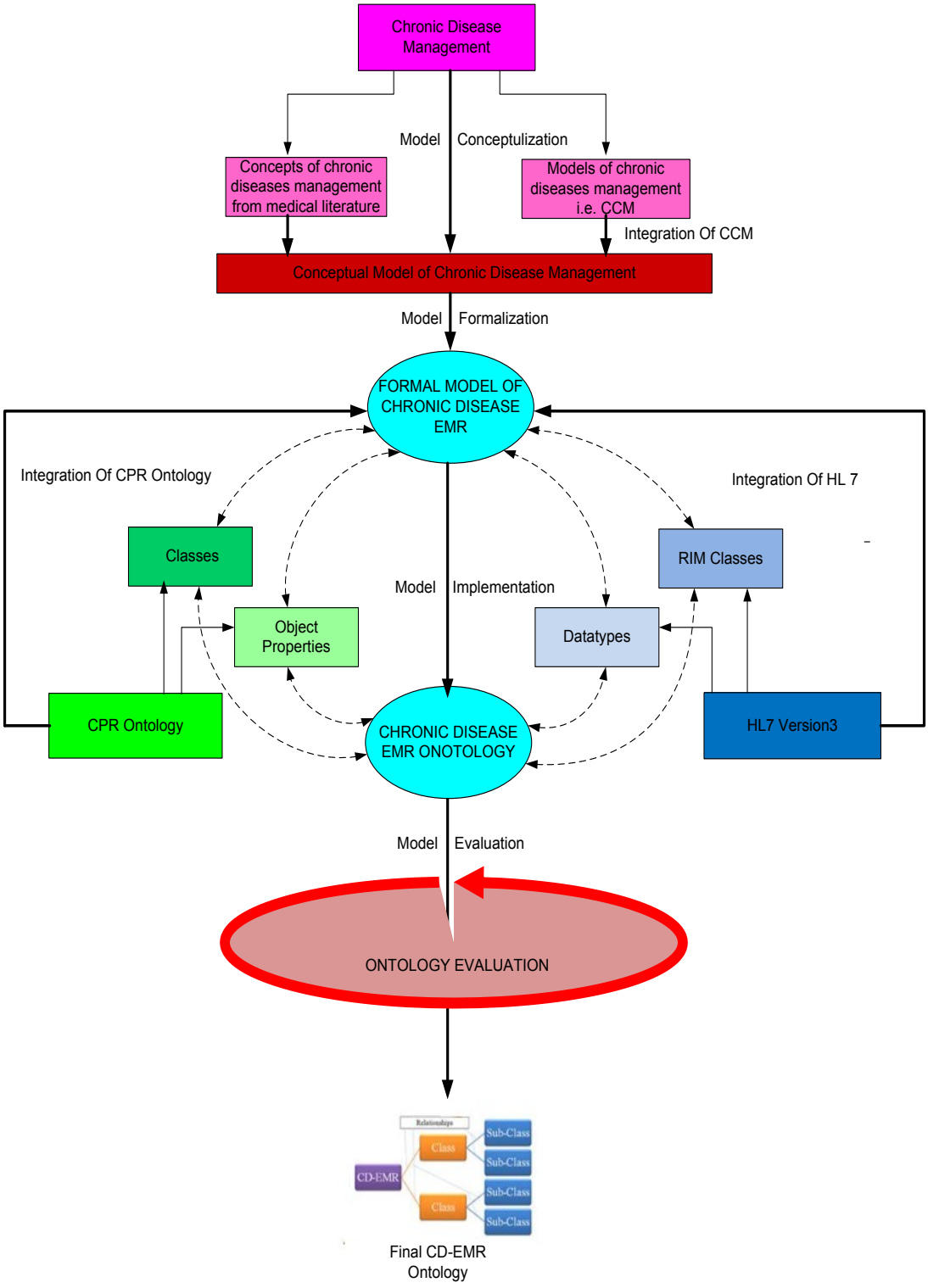


Figure 1-2 Steps of solution approach to develop CD-EMR Ontology

1.6 THESIS CONTRIBUTION

Our research will provide a comprehensive Knowledge Model which captures the notion of holistic care for chronic diseases. This model will represent the process of chronic disease management and will be fully aligned with CPR Ontology and HL7 RIM.

CD-EMR Ontology will provide an ontological framework which will capture the workflow involved in chronic disease management and will also serve as the information model to store the information generated during the process of chronic care. Besides chronic diseases, the CD-EMR Ontology will also cover acute diseases and co-morbid conditions. Perhaps, the CD-EMR Ontology will provide a semantically interoperable platform for storage, sharing, and retrieval of information within and across various domain and HIS.

1.8 THESIS ORGANIZATION

This thesis is organized in the following chapters,

Chapter 2: Describes the background and presents a thorough literature review of (a) Chronic diseases and models for chronic disease management such as CCM, (b) EMR, various standard of EMR, and the messaging standard HL7 version3 , and (c) W3C CPR ontology, ontology development methodologies and medical vocabularies such as SNOMED CT and LOINC.

Chapter 3: Outlines our adapted research methodology, the steps of the methodology, and gives an idea of how our research methodology will guide us to achieve our goals and search for scientific solutions to the research problems.

Chapter 4: Describes the process of development of conceptual model for chronic diseases management. This chapter will explain in detail the process of knowledge abstraction, integration and mapping.

Chapter 5: Discuses the process of model formalization and the process of implementation i.e. ontology engineering to develop the CD-EMR ontology.

Chapter 6: Discuses the comprehensive evaluation of the CD-EMR Ontology.

Chapter 7: Concludes the thesis by mentioning the limitation of the work, future directions and recommendations.

CHAPTER 2: BACKGROUND

2.1 INTRODUCTION

It is difficult to define the term ‘health’ and ‘disease’. In a general perspective healthy states are those states which everyone desires; on the contrary, disease state are those which everyone wants to avoid. During the course of life everyone experiences a variable level of healthy and unhealthy (i.e. disease) state. There are several different types of diseases that can affect the healthy status of an individual. Some of them are acute diseases, immunologic diseases, genetic disorders, allergic reactions, and chronic diseases [7]. Sometimes the diseases are short term, which are either self settling or respond well to the treatment given. These short term conditions are mostly referred to as acute diseases. Some diseases, however, become a part of life and will stay forever. These diseases cannot be fully eradicated but can only be treated symptomatically; these medical conditions are called chronic diseases. Dealing with short term or acute diseases is not very complex. These conditions can be fully treated to restore the healthy status of the individual, but on the other hand, managing chronic diseases is complex and there is no way to eliminate the disease; the symptoms are persistent and there is no cure [8]. Chronic diseases are long term conditions which stay during the course of life affecting the individual physically, mentally, psychologically, socially and spiritually [9]. The physical, psychological and social impact; the limitation of activities of daily life (ADL); and impermanent of normal function are results of chronic diseases. These elements do not necessarily coincide, rather they may come one after the other leaving the individual in a state of trauma and misery. The nature of chronic diseases is therefore more complex and difficult to treat and manage. Due to the multi- dimensional nature of chronic disease, management is not similar to acute care.

During the course of chronic diseases a lot of information is generated and recorded in the form of medical records. Recording these pieces of information about the patient and the disease plays a vital role in healthcare practice; according to L. Weed [10] the medical record has influential impacts on healthcare delivery and patient outcome. Healthcare professionals have a tradition of recording patient history and clinical data using paper based charts. Although this paper based recording seems user friendly, these

records have displayed problems like illegible handwriting, poor data quality, incompleteness, and with the passage of time these records become so bulky that it is hard to review them to get the specific pieces of information needed [11,12]. Particularly while dealing with chronic diseases, which are characterized by long course and slow progress [1], the bulkiness of these medical records results in the problem like duplication of information, and unavailability of the record to be reviewed by multiple healthcare professionals involved in care management. In the subsequent section of this chapter, we will discuss the complexities and impact of chronic diseases on health care followed by description of Electronic Medical Record, messaging standards like HL7, CPR ontology and an overview of different ontology development methodologies.

2.2 CHRONIC DISEASES

Chronic diseases are long term conditions [1] that may not necessarily lead to immediate death but result in irreversible change or disability in one's life. Chronic diseases are a major cause of morbidity and mortality [13]. Due to the long course of chronic disease it is necessary to have a comprehensive treatment plan for management. In order to understand the process of chronic disease management, it is important to develop an understanding of diseases versus illness and then acute versus chronic diseases. This helps us to better understand the nature of chronic diseases and also provide an insight of the diseases process.

2.2.1 DISEASES VERSUS ILLNESS

Traditionally, healthcare professionals often use the terms disease and illness interchangeably; but there exists a difference between them [14]. Derivation of the term disease occurs from the medical model [9]; disease refers to the conditions that result in a change in structure or function of the body system [9, 14]. On the other hand, illness means human experience of the disease, symptoms, and suffering. Illness refers to how a person perceives the disease, how he/she lives with it, and the response of the individual and families toward the disease [14]. While dealing with chronic diseases, it is important to recognize the pathophysiological process of disease but at the same time, consideration of the illness experience is the key to planning comprehensive care needed to manage chronic diseases patients.

2.2.2 ACUTE VERSUS CHRONIC DISEASE

After defining the differences between disease and illness, it is vital to understand the differences and similarities between acute and chronic diseases. Acute diseases are often characterized by sudden onset, episodic nature, short course and having signs and symptoms that are related to the disease itself [14]. The causes of the acute diseases can be identified clearly; acute diseases mostly affect a limited portion of the body and are particularly confined to a single system. Acute diseases respond well to treatment with resumption of prior activities and the previous state of life [15]. Seldom, acute diseases cause a permanent functional impairment, disability or death [14, 15]. Chronic diseases, on the other hand, are long term conditions caused by non-reversible pathologic alteration [14]. Chronic diseases are characterized by long course, uncertain outcome, multi systemic involvement, and influencing the patient physically, mentally, and spiritually [15]. It is complex to define the notion of chronic disease. Table 2-1 presents some of the differences and similarities that occur between acute and chronic diseases and in the subsequent section we will mentions some of the definition of chronic diseases.

Table 2-1 Differences and similarities between acute and chronic illnesses. Taken from [15]

Related Factors	Acute	Chronic
Time period	Limited	Long-term
Prognosis	Usually curable	Uncertain
Lifestyle	Some intrusion	Intrusive
Financial	Sometime limited	Excessive
Caregiver burden	Self-care usual	May be present
Follow-up care	Few	Many
Technology	Initial phase	Continual
Monistic	Single system	Multiplicity
Pain	Initial phase	May be chronic
Social isolation	Infrequent	Frequent
Psycho-logic impact	Depends on individual	More common

Spiritual	Little change	Loss/grief
Role adjustment	Few	Many
Coping	Adjustment common	Difficult
ADL	Brief interruption	Normalization Continuous

2.2.3 DEFINING CHRONICITY

It is complex to define 'Chronicity'. Several attempts have been made in the past to present all-encompassing definitions of chronic diseases; here we present some of the most accepted definitions of chronic diseases.

The Commission on Chronic Diseases (1995) [14] defines chronic diseases as "All impairments and deviations that have one or more characteristics: are permanent, leave residual disability, are caused by non-reversible pathologic alteration, require special training of the patient for rehabilitation, and may be expected to require a long period of supervision, observation or care".

Feldman in 1974 [14] defines chronic diseases as "Ongoing medical condition with spectrum of social, economic and behavioral complications that require continuous personal and professional involvement."

According to Cluff (1981) [14], chronic disease is "A condition not cured by medical intervention, requiring periodic monitoring and supportive care to reduce the degree of illness, maximizing the person's functioning and their responsibility for self care."

Curtin and Lubkin (1995) [14] define chronic illness as "Chronic illness is the irreversible presence, accumulation, or latency of disease state or impairment that involves the total human environment for supportive care and self-care, maintenance of function and prevention of further disability."

2.2.4 PHASES OF CHRONIC ILLNESSES

As explained earlier in section 2.2.1, illness is the human experience of a disease. Dealing with chronic diseases, the characteristic long-term nature of the disease results the

variable experiences in terms of symptoms and course. The impact of this variability is multifold (a) it causes confusion for healthcare providers in planning the long-term treatment (b) complicates the treatment process and (c) it may affect the treatment relationship of the healthcare provider and the patient [16]. To resolve this variability, various models has been developed by researches to articulate the diseases experience, needs, and treatment plans of chronic diseases with respect to the patient's perspective. Fennell in 2003 has presented a heuristic model of chronic illness that consists of four phases [16]:

> ***Phase 1: Crisis.*** The onset of illness is the start point which triggers a crisis against which individuals seek relief through various channels, such as medical diagnosis, treatment plan, spiritual consultations and help, or sometimes even substance abuse. In this phase of crisis the most common experience is family, relatives, friends and healthcare provider may not be trusted and the patient responds with disbelief, rejection and revulsion. The most important and the basic task of this phase is to deal with the new experience of illness that the patient is facing, which may includes signs and symptoms of the disease, pain, mental and physical trauma, and the physiological impact.
>
> ***Phase 2: Stabilization***. With time, the pain of the crisis phase becomes everyday routine for the patient. At this point, a plateau of symptoms is reached in which the patient becomes more familiar with the illness. This phase leads to reversion toward the normal activity of daily living and the patient attempts to regain the pre-illness activity level. The basic task of this phase is to promote stabilization and lifestyle modification by restructuring life patterns and perceptions.
>
> ***Phase 3: Resolution***. After passing through the crisis and stabilization phases, the patient develops an understanding of the illness. A level of acceptance is reached which helps the patient to realize that they have to live with the illness and to learn other responses to it. The basic task for this phase is to evolve a new self with a meaningful philosophy of life.

Phase 4: Integration. After acceptance and remolding their life, patients are encouraged toward a new life in which, if they can work, the task is to provide them appropriate employment, provision of a supportive social network of friends and family, and to integrate their illness within a spiritual or philosophical framework. The main aim is to achieve the highest possible level of wellness despite the compromised or failing health status.

The above mentioned model describes four phases that occur during the course of chronic illness. According to [16] it is not necessary that every patient suffering from chronic illness passes through all the above mentioned four phases. It is important to note during the long course of chronic illness most patients loop between Phase 1 and Phase 2. This recurring loop occurs due to the fact that, after gaining stabilization, some new crises occur that develop new wounding and again cause destabilization. The main reason for this looping is that most of the patients do not accept their illness initially –illness denial-. An appropriate management plan with focused multi-dimensional intervention could break this recurring cycle and help the patient to move towards phase 3 and phase 4 [16]. Without a comprehensive management plan, chronically ill patients either find themselves in crises or circles in an endless loop between crises and stabilization. This causes a huge impact on patients and their families, both socially and economically, increasing the burden created by chronic diseases. In the subsequent sections we will define some important concepts, such as impairment, disability, and handicap, which are closely related to chronic diseases and analyze some statistical facts about the burden of chronic diseases, both globally and in Canada, we further discuss some common risk factors that are shared with most of the chronic diseases, and also mention the importance and role of determinants of health.

2.2.5 IMPAIRMENT, DISABILITY AND HANDICAP

The concepts impairment, disability, and handicap are not new in chronic diseases. Although, the terms impairment, disability, and handicap**,** are sometime used interchangeably, they have different meanings and define three separate concepts [9]. In order to promote the proper use of these concepts, the WHO in 1980 established the

International Classification of Impairment, Disability, and Handicap [9], according to which the definition of these concepts are as follows:

> ***Impairment:*** is defined as, any loss or abnormality of psychological, physical or anatomical structure or function which occur at system or organ level. This loss or abnormality may or may not be permanent, and it may or may not cause disability.
>
> ***Disability:*** is defined as, restriction or limitation of an activity in a patient which is the result of impairment.
>
> ***Handicap:*** is defined as, the disadvantage to the patient resulting from impairment or disability which creates a barrier to perform a role or to achieve a goal.

2.2.6 BURDEN, MORTALITY AND MORBIDITY OF CHRONIC DISEASES

According to the WHO report published in 2011 [17], chronic diseases, which are also referred as non-communicable diseases (NCD), are the major cause of morbidity and mortality all over the world [17]. According to the WHO estimate [18, 17] out of 57 million deaths that occur globally in 2008, 63% (36 million) were due to chronic diseases. Among the chronic diseases, cardiovascular diseases, diabetes, cancers, and chronic respiratory diseases were the major causes of death [18, 17]. According to 2008 data cardiovascular diseases accounted for 17 million deaths (48% of NCD deaths), cancers caused 7.6 million (21% of NCD deaths), chronic respiratory diseases, such as asthma and chronic obstructive pulmonary diseases (COPD) were the cause of 4.2 million deaths, and diabetes additionally caused 1.3 million deaths [18]. The report also estimated that there will be a 15% (44 million) global increase in the number of deaths cause by chronic diseases between the year 2010 and 2020 [18]. Figure 2-1 shows the proportion of deaths under the age of 70 years by different chronic diseases.

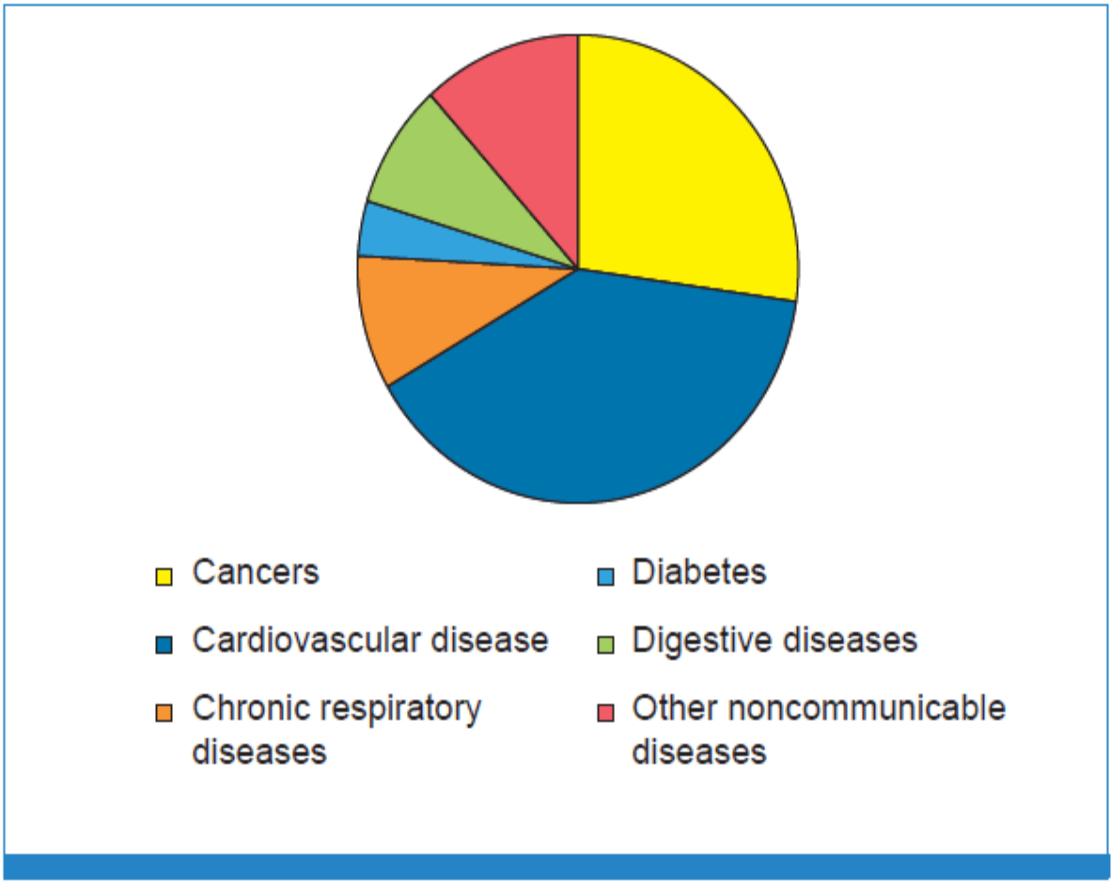


Figure 2-1 Proportion of global NCD deaths cause under the age of 70, by cause of death, 2008. Taken from [18]

The Figure 2-1 shows that the leading cause of death in people under the age of 70 years is cardiovascular diseases, which account for 39%, followed by cancers which resulted 27% of deaths, chronic respiratory diseases, such as asthma, COPD; digestive diseases and other NCDs together caused approximately 30% of deaths, and diabetes was responsible for 4% of deaths [18].

2.2.7 BURDEN OF CHRONIC DISEASES IN CANADA

Canada is also facing the challenges posed by chronic diseases. According to a recent report from the Public Health Agency of Canada (2011) [19], each year, two-thirds of the deaths in Canada result from chronic diseases [19]. In Canada, like elsewhere in the

world, cancer, diabetes, cardiovascular diseases, and respiratory diseases are the four most common chronic diseases [19, 20]. According to the report [19], each year, 177,800 people are diagnosed with cancer, resulting in 75,000 Canadian deaths due to cancer only. Likewise, 6.2 percent of Canadians are living with diagnosed diabetes, and about 0.9 percent of the population (nearly 300,000) is living with undiagnosed diabetes. Additionally, 1.6 million Canadians have cardiovascular diseases or affected by stroke, and over 3 million Canadians are suffering from respiratory diseases [19]. Figure 2-2 shows the statistical representation of cause of death in 2007 in Ontario due to chronic diseases [20].

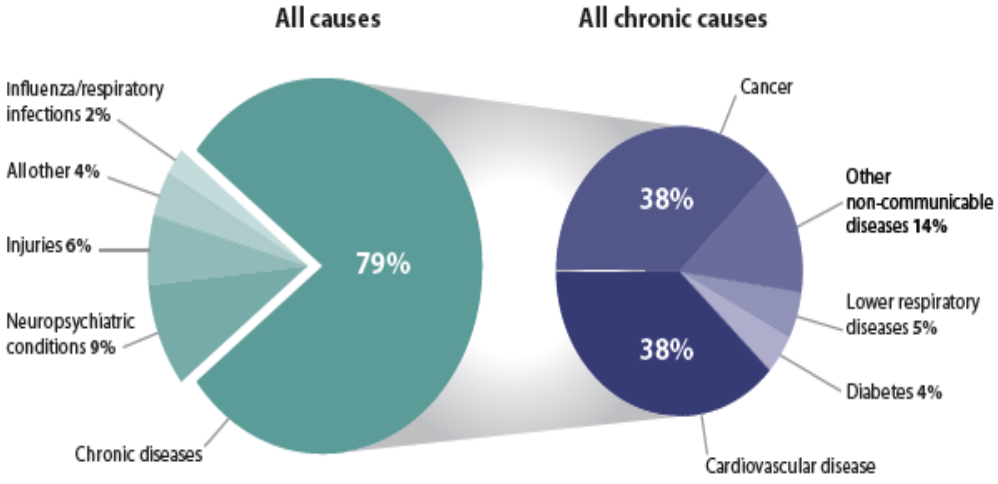


Figure 2-2 Mortality of chronic diseases in Ontario 2007. Taken from [20]

Besides these statistical figures, the real alarming situation continues with the fact that two out of five Canadians (12 years and older) are actually suffering from at least one chronic disease, and four out of five are facing the risk of developing a chronic disease [19].

2.2.8 ECONOMIC BURDEN OF CHRONIC DISEASES IN CANADA

As discussed earlier, the impact of chronic diseases is multifaceted. Chronic diseases not only affect the person's health status but carry a heavy toll of physical, mental, psychological, social, and behavioral impacts [8]. These factors could possibly limit the activities of daily life (ADL), which in turn reduce the productivity of the individual

suffering from the disease. So the economic impact of chronic diseases is both direct, which is due to unhealthy state, and also indirect due to limited ADL and productivity. The direct cost of chronic diseases can include the expenditure on hospitalization, doctors, medical staff, prescriptions, and drugs [8], while the indirect cost can be due to time lost as a result of disability, premature death, and absence from work [8]. In 2004 the direct cost was estimated at 38.9 billion annually [8], which increased to 68 billion in 2010 [20]. At the same time, the indirect cost in 2004 was $54.4 billion, which increased to $122 billion in 2010 [20]. These figures show how the chronic diseases are affecting the Canadian economy and the burden is significantly increasing with the progression of time.

2.2.9 RISK FACTORS

Chronic diseases which are often referred to as non-communicable diseases are the major cause of morbidity and mortality [20, 19]. Despite the fact that chronic diseases have a long course and once diagnosed they cannot be fully treated or eliminated but could be symptomatically cured [8], chronic illnesses are among the most preventable medical problems [13]. Chronic diseases are preventable because most of them share common risk factors and conditions [13]. Slight modification and behavioral change could possibly delay or prevent the onset of diseases [13]. Figure 2-3 shows that tobacco use, unhealthy diet, physical inactivity, and alcohol account for substantial proportion of chronic diseases [13].

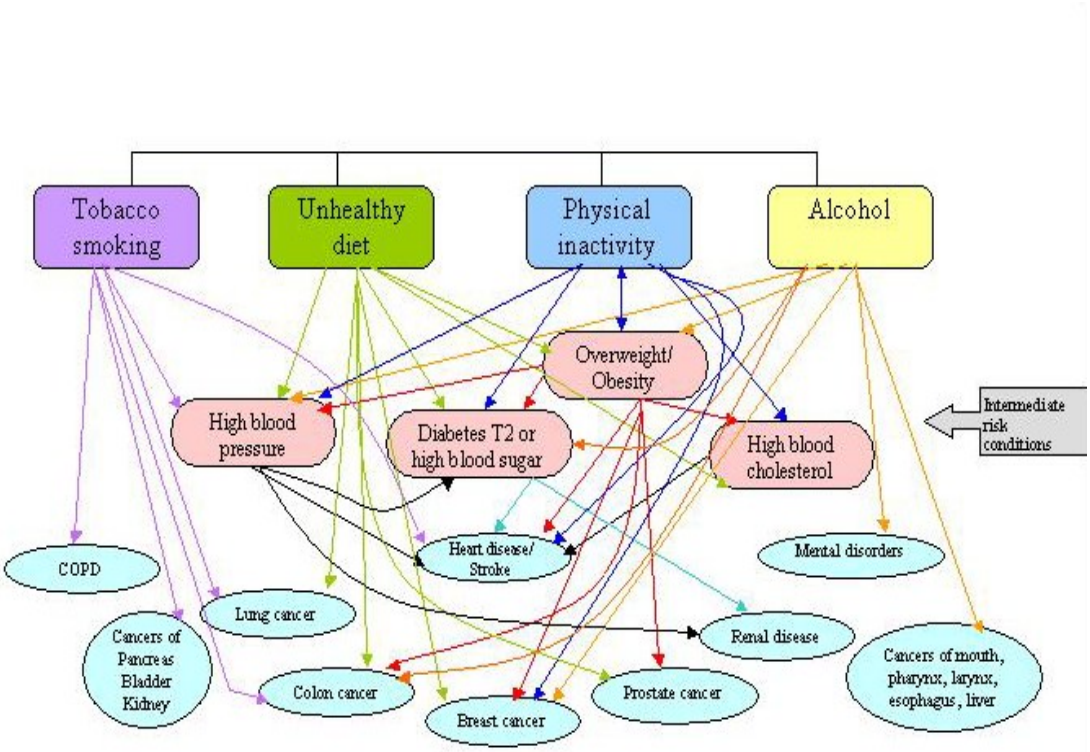


Figure 2-3 Common risk factors among chronic diseases. Taken From [13]

The above figure shows that how tobacco use, unhealthy diet, physical inactivity and alcohol trigger the intermediate risk conditions, such as high blood pressure, obesity, high blood glucose levels, and diabetes, which in turn cause several chronic diseases. Exposure to risk factors plays a critical role in the progression of chronic diseases.

2.2.10 DETERMINANTS OF HEALTH

Besides the above mentioned risk factors presence of a full range of elements determine the health of populations and play a key role not only in management but also in prevention of chronic diseases [13]. These elements, called the determinants of health, range from individual genetic make-up to socio-economic factors, such as income and education [13]. The living conditions, social practices, and lifestyle have a great influence on health. The concept of social determinants of health is not new in the Canadian health system; the importance of living condition on health was established in mid-1800 and has been included in Canadian government policy documents since the mid-1970s [22]. Among various existing models of social determinants of health, we will

consider the model that was developed at the York University Conference held in Toronto, 2002 [22]. This model presents the following fourteen social determinants of health.

1. Aboriginal status
2. Gender
3. Disability
4. Housing
5. Early life
6. Income and income distribution
7. Education
8. Race
9. Employment and working conditions
10. Social exclusion
11. Food insecurity
12. Social safety net
13. Health services
14. Unemployment and job security

The rational for choosing this model is (a) the fact that this model explains why some of the Canadians have a better health status than other, (b) secondly each of these above mentioned

social determinants of health has been shown to have a greater impact on the health of Canadians then the risk factors like smoking, diet, physical activity [22]. The Figure 2-4 shows the pathway how social determinants, i.e. living and working conditions, early life, genetic makeup, social, and cultural factors affect the health and illness.

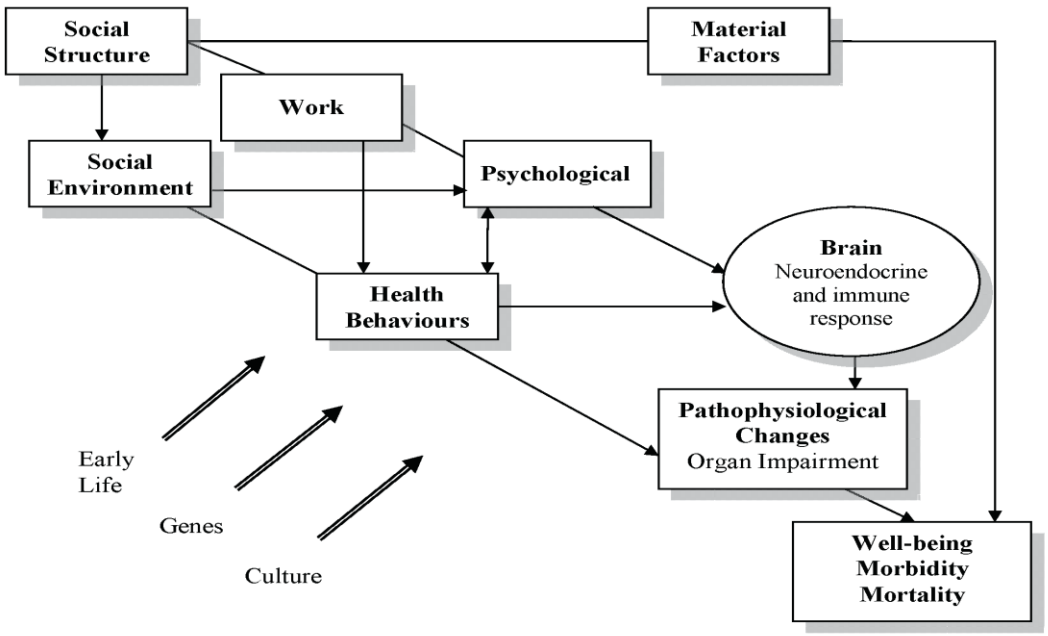


Figure 2-4 Impact of Social Determinants of Health on Health and illness. Taken from [22]

These social determinants for health play a critical role in the progression of chronic diseases. The impact is not always direct but they can trigger the progression of the diseases along with risk factors [20]. The social determinants are the actual underlying cause that exposes the person to risk factors. In turn, these risk factors either cause the chronic disease or help the progression of chronic diseases. Figure 2-5 shows the causal link that occurs between the underlying social determinants and risk factors in the progression of chronic diseases.

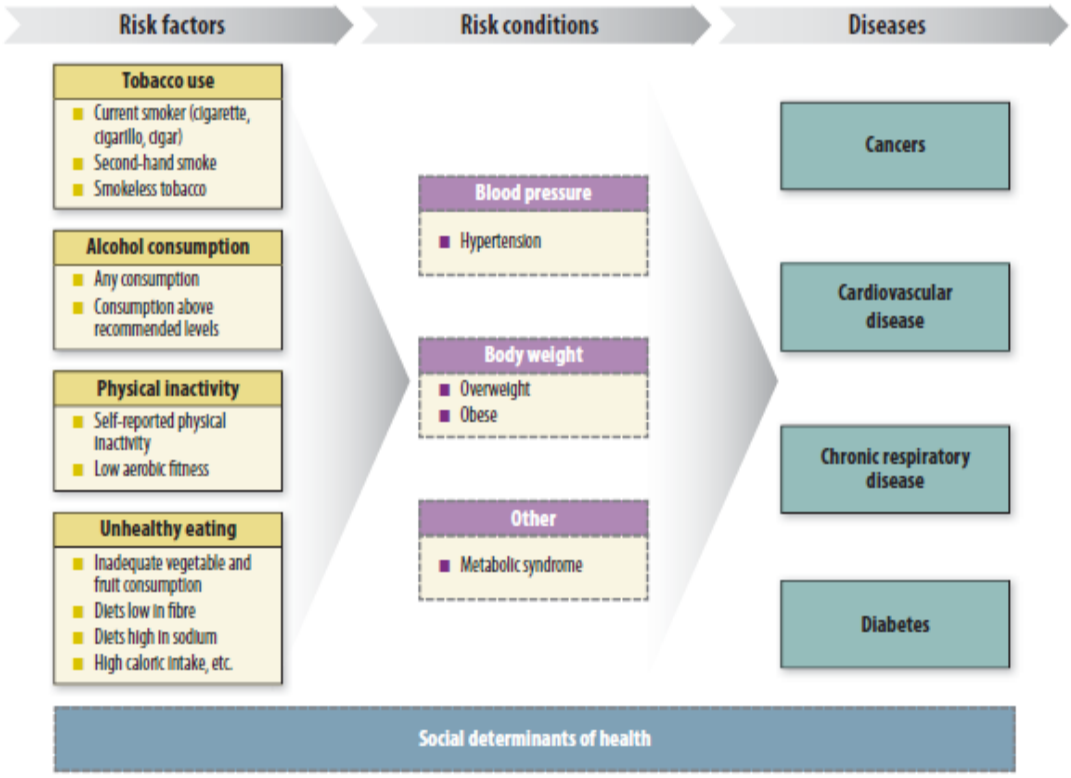


Figure 2-5 Association of social determinants of health and risk factors in progression of chronic diseases. Taken from [20].

2.2.11 MANAGEMENT OF CHRONIC DISEASES

Chronic diseases have a complex nature and long course, so the management process of these illnesses is not straight forward. Unlike acute diseases that respond well to the medical treatment [15], chronic disease management spans the continuum of care from prevention to long-term maintenance [23]. The process of chronic disease management involves a thorough assessment of an individual and then developing a longitudinal plan to treat and manage the ongoing problems [23]. The management of chronic diseases is patient centered and longitudinal; the development of the management plan is achieved by proactive interactions, which focus on various treatment options and patient education in order to achieve the best possible outcome [23]. The characteristics of chronic diseases show that the nature of chronic illness is multidimensional, interdependent, ongoing, disabling, and personal, while our health care delivery system is designed as single-dimensional, segmented, episodic, disease oriented, and institutional [23]. It is therefore

difficult to implement the comprehensive plan for chronic diseases management. It is identified that the primary healthcare system has been ill-prepared to deliver the required standard, longitudinal, comprehensive and continuing care for the individuals with chronic diseases [24]. Table 2-2 highlights the gaps that exist between the needs of chronic disease patients and the services that are provided to them by the healthcare system [24].

Table 2-2 The gaps between the needs and services for chronic illnesses. Taken from [24]

Needs of patient with chronic diseases	**Services provided in Canada**
Long-term trusting relationships with a small group of people	Short-term episodic care from people they may not know and who may not know them
Consistent, competent, comprehensive services	Inconsistent, incomplete services.
Convenient, readily accessible services	Delay and inaccessible services
Good quality, secure health records	Minimal record often missing when needed
Partnership and nourishment of self-management capability	Increased anxiety and decreased confidence in the healthcare system.

In order to address these gaps, several models have been developed around the world to standardize the management of chronic diseases. The Chronic Care Model (CCM) developed by Ed Wagner et al [33] is the most widely accepted and mostly widely used [33] model for chronic diseases management all over the world. Its components are adapted in several healthcare facilities and have proven to be effective by showing

improved outcome in chronically ill patients [26]. In the following section we will describe the various components of chronic care model.

2.2.12 CHRONIC CARE MODEL (CCM)

It is a well known fact that the incidence of chronic disease is increasing, which for turn increases the need of effective and efficient management of chronic diseases [25]. It is hard to achieve patient's satisfaction suffering from chronic diseases, because the treatment process is long term and the outcome are not immediate, as in the case of acute care. Often times it is noticed that the treatment given to patients is either not according to their needs or is different from what they want [33]. The reason behind this is the traditional treatment did not seem to be patient centered. On the basis of Cochran review by Renders et al. [26], multi pronged strategies have proven to be the most effective intervention in the process of chronic disease management. A similar approach has been adapted in the development of the Chronic Care model [26].

In the year 1990, Ed Wagner et al. developed a comprehensive model for the management of chronic diseases named as The Chronic Care Model [25, 26] shown in Figure 2-6.

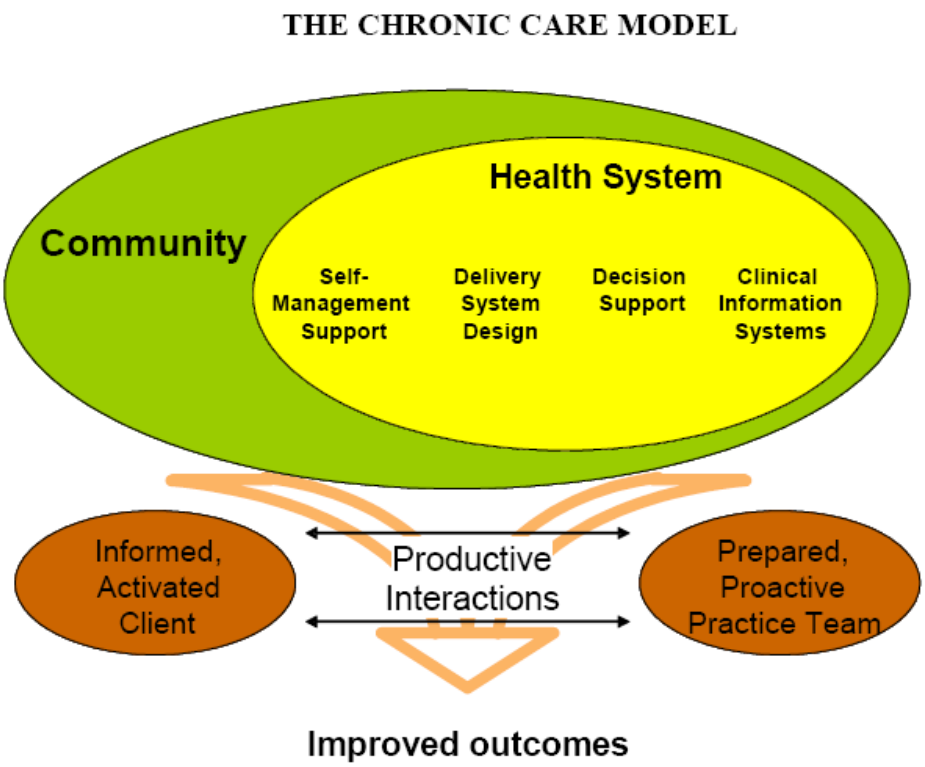


Figure 2-6 The Chronic Care Model. Taken from [25]

The Chronic Care Model came into being when it was evident that the management of chronic disease based on the principles and processes of acute care failed to provide the comprehensive nature of care essential for chronic diseases [25].

Components of CCM.

The chronic care model is based on the following components which are discussed below.

- Self-Management/ Develop Personal Skills
- Delivery system design/ Re-orient Health Services
- Decision Support
- Clinical Information System
- Health System
- Community

Self-Management/ Develop Personal Skills. Chronic care model is based on informed active patient involvement [25]. Self-management emphasizes the patient central role in the management of disease [26]. By doing this act, a sense of responsibility is developed in the patient for their own health. This in turn enables the patient to cope with the disease and also encourage them to learn personal skills, which are helpful in managing the disease. Effective self-management is being designed on the strategies like assessment, goal setting, action planning, problem solving and follow up [27].

Delivery system design/ Re-orient Health Services: This component emphasizes transforming the healthcare system from reactive to proactive; introducing team based care by defining roles and distribution of tasks among team members; and supporting evidence based care using planned interactions [28]. It not only determines what care is the best for the patient, but also ensures that the patient gets the care using structured, planned interactions [28]. For this reason, follow-up is the integral part of this component and considered as standard protocol. Defining follow-up as a standard protocol helps to prevent the patients from being left on their own once they leave the doctor's office [29, 30, 31]. Health literacy and cultural competencies are considered as key elements of this component [25, 27]. These elements help the providers to develop the management plan which is the most suitable and according to the cultural needs of the patient [28].

Decision Support: This component promotes the use of evidence-based guidelines in clinical practice. Selection of treatment options must be based on explicit and evidence based guidelines, in order to ensure the provision of best possible care to the patients. All possible treatment options must be discussed with the patient so that he/she can understand the principles behind their care. It is important for the healthcare providers to keep themselves up-to-date with the latest evidence and emerging knowledge. This can be achieved by integrating provider's education methods in practice [25, 27]. The involvement of supportive

specialists, especially in the primary care for patients, with more complex illness and treatment needs is an important educational modality [32]

Clinical Information System (CIS): The CCM presented the idea of informed activated patient and patient-centered care, so information sharing among the health team and patient is necessary. CIS provides a medium to share information among patient and care provider in order to facilitate efficient and effective care. Moreover CIS also serve to generate timely reminder based on evidence-based care, and identification of relevant sub population for proactive care.

Health System: The health system provokes the need for building a culture, organization and mechanism that promotes safe and high quality chronic illness care. These can be achieved by promoting multidisciplinary teamwork, alignment of incentives, by encouragement of proper and systemic handling of medical errors and quality problems, and improvement of care coordination within and across organizations.

Community: Mobilization of community resources to meet patients needs. Patient's involvement in community programs, with the help of community organizations development of interventions that fill the gaps in required services.

The whole CCM can be summarized in Table 2-3.

Table 2-3 Componenets of the Chronic Care Model. Taken From [26]

Table 1 The Chronic Care Model (Wagner et al. 1999)

MODEL COMPONENTS		EXAMPLES
Health System - Organization of Healthcare	Program planning that includes measurable goals for better care of chronic illness	• Visible support of improvements provided by senior leadership • Incentives for care providers
Self-Management Support	Emphasis on the importance of the central role that patients have in managing their own care	• Educational resources, skills training and psychosocial support provided to patients to assist them in managing their care
Decision Support	Integration of evidence based guide-lines into daily clinical practice	• Wide dissemination of practice guidelines • Education and specialist support provided to healthcare team
Delivery System Design	Focus on teamwork and an expanded scope of practice for team members to support chronic care	• Planned visits and sustained follow-up • Clearly define roles of healthcare team
Clinical Information Systems	Developing information systems based on patient populations to provide relevant client data	• Surveillance system that provides alerts, recall and follow-up information • Identification of relevant patient subgroups requiring proactive care
Community Resources and Policies	Developing partnerships with community organizations that support and meet patients' needs	• Identify effective programs and encourage appropriate participation • Referral to relevant community-based services

2.2.13 HOLISTIC CARE

In contrast to acute diseases, where the symptoms of the disease can be treated with complete recovery, chronic diseases usually result in more frequent symptoms and affect the physical, emotional, and mental functioning of the body. A common assumption about symptoms is that they are the result of disease condition [64]. In case of chronic diseases some of the symptoms could be the contributing factors to the other symptoms [64], and on a whole all can make each other worse. In other words, in chronic diseases, symptoms can feed on each other [64]. For example, fatigue is the result of depression, tense muscles are due to stress, and together these symptoms could lead to a more painful condition or result in shortness of breath, and the cycle continues [64]. This interaction

among symptoms makes the disease state even worse. It is considered a vicious cycle [64] Figure 2-7 that only worsen with time and continues unless we find a way to break the cycle.

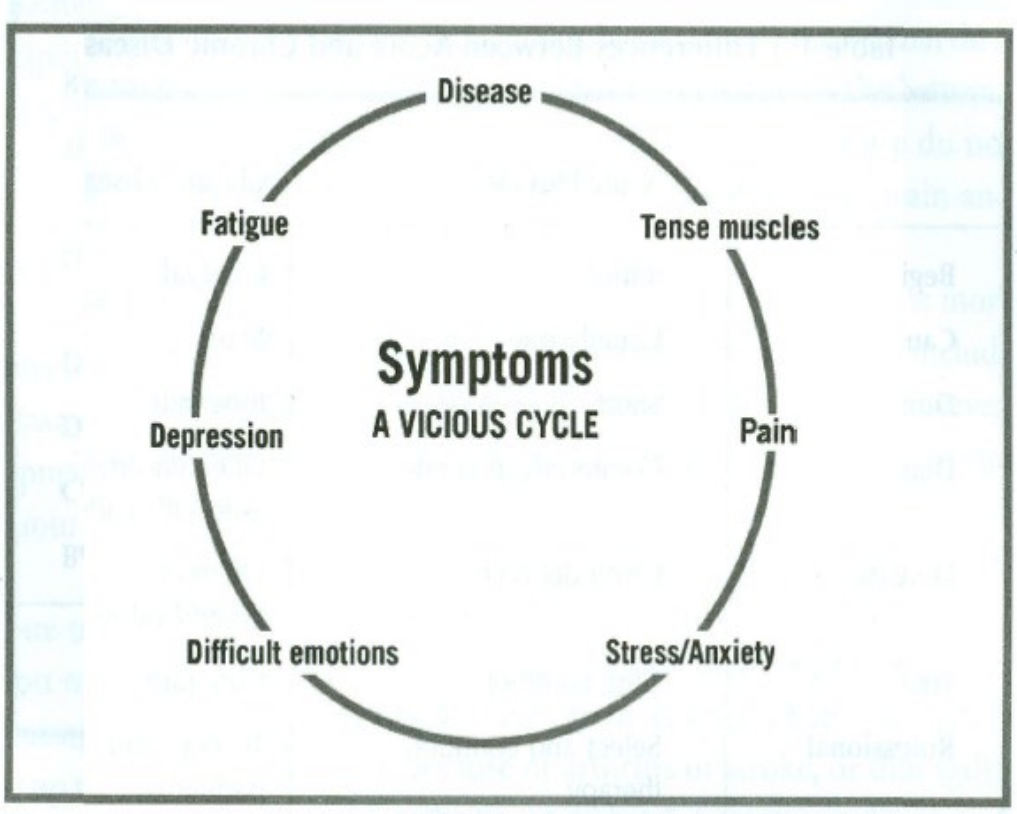


Figure 2-7 The Vicious Symptom Cycle. Taken From [64]

Conventional treatment options, such as medications and surgery, seem more effective in acute disease treatment rather than in chronic disease management. Due to the diverse nature of chronic diseases and the notion of stigma and wide ranging impacts along with the pathology of the disease, these treatment options are not considered sufficient as they are more focused on the pathology of the disease. Even two thousand years ago Plato observed [65]:

> *"The great error in the treatment of the human body is that physicians are ignorant of the whole. For the part can never be well unless the whole is well."*

Keeping the same theme in mind, the notion of *holistic care* or *holistic medicine* is very important while dealing with chronic diseases. This concept serves as a mean to capture the comprehensive nature of chronic disease management. Holistic care fosters a cooperative environment by developing healthy relationships among the different roles involved in the process of care, and therefore directs the process of care towards achievement of an optimal wellness continuum [66]. Holistic care focuses on attaining the optimal level of physical, mental, emotional, social, and spiritual aspects of health [67, 21] needed for chronically ill patients. Holistic care emphasizes the fact that the management plan should be developed by evaluation of a patient as a whole [67, 21], which means analysis of each and every aspect of physical, nutritional, environmental, emotional, social, spiritual, and lifestyle values of chronically ill patients [b]. Holistic care presents how the physical, mental, emotional, and spiritual elements of the body are interconnected to each other and maintain the wellness and healthy status of an individual [21]. Holistic care considers each and every option available for diagnosing and managing the disease process, which includes the available medical therapies, drugs, surgical treatment [67]. One of the most important aspects of holistic care is it specifically focuses on patient education and responsibility for personal efforts to achieve a healthy and balance life [67].

2.2.14 DISCUSSION

In this part of the chapter we have mentioned various characteristics of chronic diseases. These characteristics highlighted the various aspects and nature of chronic diseases. We have discussed that chronic diseases are not similar to acute diseases. In case of chronic diseases, it is not just the pathological condition that needs to be treated but the notion of stigma should also be properly managed. The multifaceted impact of chronic diseases not only affect the patients suffering from the disease, but goes beyond and involve their family, friends, relationships, and social life, leaving them in a state of misery and discomfort. While managing the chronic diseases it is vital to treat the pathology of the diseases to relieve signs and symptoms, and at the same time it is necessary to manage the stigma, and the psychological and behavioral impacts of chronic diseases. The pathological state can be treated by using the available treatment options, such as medications, drug prescriptions, and surgeries which are more diseases centric options. In

order to provide holistic care these treatment options must be aligned with patient centric options that can help to treat the stigma, and the psychological and behavioral impacts of chronic diseases. CCM, which is the most widely accepted model for chronic diseases management has provided several important concepts such as patient-centered care, longitudinal care, patient education, self-management support, which are needed in the management of chronic diseases. The paradigm to treat and manage chronic disease is shifting from episodic to longitudinal care [33]. Due to the nature of chronic disease the management plan is now more patient centric, longitudinal and team based [25, 26]. A chronic disease management team involves several healthcare providers from different clinical and non clinical domains. Well integrated communication among the members of chronic disease management team is necessary to ensure the effective disease management and also results in better outcomes [25, 34]. It has been noticed that the availability of information about various aspects of chronic disease and patient condition at the point of care helps in making correct decisions. Medical records play a vital role in the development of a management plan for chronic illnesses. Electronic medical record is a mean to establish efficacious communication [35]. In the subsequent section we will describe various aspects of electronic medical record (EMR), various standards of EMR, CPR ontology and messaging standards.

2.3 ELECTRONIC MEDICAL RECORD (EMR)

The concept of the Electronic Medical Record (EMR) is not new in health industry; EMR has existed since the early use of computers in healthcare [36]. The journey of the electronic medical record started in late 1960s and early 1970s when the first significant effort was made to automate clinical information [36]. With the passage of time and advancement of technology, this concept has undergone significant refinement and transformation as shown in Figure 2-8 [36] .

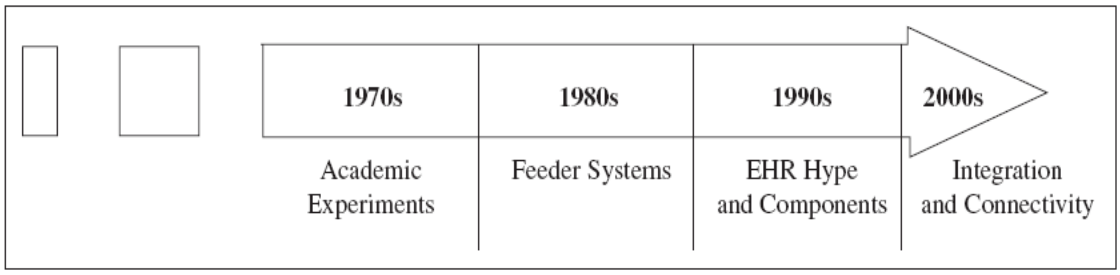


Fig: 2-8 History of EMR. Taken from [36]

Fig 2.7 shows the journey of EMR evolution [36] , starting from the conceptual level in the 1960s till its integration, but still the concept of EMR is not a mature concept; various efforts have been made around the world to develop electronic medical record systems [37, 38, 39, 40] . In order to understand the concept of EMR various definitions, functionalities, and components are described in subsequent sections.

2.3.1 ELECTRONIC MEDICAL RECORD DEFINITIONS

Health Information Management System Society (HIMSS), defines EMR as follows [41]

> *"The Electronic Health Record (EHR) is a longitudinal electronic record of patient health information generated by one or more encounters in any care delivery setting. Included in this information are patient demographics, progress notes, problems, medications, vital signs, past medical history, immunizations, laboratory data, and radiology reports. The EHR automates and streamlines the clinician's workflow. The EHR has the ability to generate a complete record of a clinical patient encounter, as well as supporting other care-related activities directly or indirectly via interface—including evidence-based decision support, quality management, and outcomes reporting."*

In 2003 IOM Patient Safety Report describes an EMR as encompassing [42]:

1. *"a longitudinal collection of electronic health information for and about persons*
2. *[immediate] electronic access to person- and population-level information by authorized users;*
3. *provision of knowledge and decision-support systems [that enhance the quality, safety, and efficiency of patient care] and*
4. *support for efficient processes for health care delivery."*

As mentioned earlier, the concept of EMR is not new in medicine. More than a decade ago (in 1997) the Institute of Medicine's Report, The Computer Based Patient Record: An Essential Technology for Health Care, provides the following more extensive definition [42]:

> *"A patient record system is a type of clinical information system, which is dedicated to collecting, storing, manipulating, and making available clinical information important to the delivery of patient care. The central focus of such systems is clinical data and not financial or billing information. Such systems may be limited in their scope to a single area of clinical information (e.g., dedicated to laboratory data), or they may be comprehensive and cover virtually every facet of clinical information pertinent to patient care (e.g., computer-based patient record systems)."*

Most of the definitions of Electronic Medical Record emphasize the electronic storage of various aspects of patient's data i.e. both clinical and non clinical. This electronic storage is meant to provide several functionalities including, systemic storage, multiple user accessibility, accountability, provision of evidence based medicine, and decision support. In order to fulfill these functionalities Raymond and Dole [35] describe the following functional component of EMR.

2.3.2 FUNCTIONAL COMPONENTS OF ELECTRONIC MEDICAL RECORD (EMR)

Tim Scott et al. in his book, Implementing Medical Record System [35], discuss various functionalities and components of the electronic medical record system as described by Raymond et al. in his report in the year 2000. Table 2-4 summarizes these various functional components of EMR.

Table 2-4 Components of electronic medical record. Taken From [35]

Function/ Application	Description
Practitioner order entry: • laboratory management • pharmacy management • diagnostic imaging management • referral management, • decision support • alerts	These components support laboratory test, drug prescription, diagnostic imaging, and consult or referral requests. Decision support and alerts are typically integrated into order entry capabilities.
Electronic patient record	Integrated storage and presentation of patient information
Document management	Allow clinicians to record, in code or text the actions they have taken in diagnosing, managing and treating the patient. This could also include physicians and nursing progress notes and the medication administration record.
Clinical decision support	Alerts are based on current data from the electronic medical record, evidence-based practice guidelines, or more complex artificial intelligence systems for diagnostic support which are provided at the time the clinician is formulating an assessment of the patient's

	condition and making ordering decisions.
Administrative data	Access to administrative data such as admission, discharge, and transfer records, surgery schedules, demographic data, and room assignments.
Integrated communication support	Tools that facilitate effective and efficient communication among team members including the patients to support continuity care among multiple providers.
Access to knowledge	Online information including reference materials, journal articles, guidelines etc, at the time of decisions are being made regarding patient care.

The functional components mentioned in Table 2.5 shows that EMR is not only a data storage tool. It not only hold patient's information, but the components such as clinical decision support, access to knowledge, and integrated communication support, emphasize the fact that the impact of EMR is multifaceted in management of both acute and chronic disease processes. For this reason EMR acquires a central position i.e. lies at the intersection of Clinical Information System (CIS), Clinical Decision Support Systems (CDSS), and patient/clinical data repositories as shown in Figure 2-9.

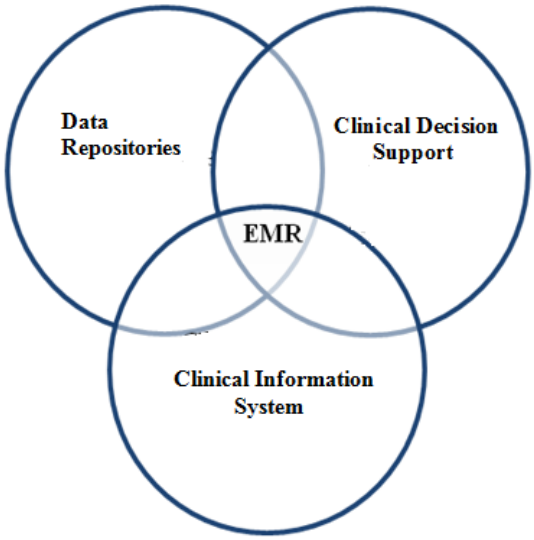


Figure 2-9 Centre position of EMR among CIS, CDS, and Data Repositories

2.3.3 STANDARDS OF ELECTRONIC MEDICAL RECORDS

We are passing through the era of information technology. The revolutions of research and development have changed the faces of several traditional practices in medical science. Globally researchers are working to formalize the standards, which are required for the development of comprehensive standardized models for maintaining health care records electronically i.e. EMR. The main focus behind the development of these models is the provision of logical structure of information content, specifying the relationship of the content to the clinical concepts and defining the syntax and representation of EMRs. Some of the logical standards, such as, OpenEHR and POMR are discussed below.

2.3.3.1 OPEN-EHR

OpenEHR is a result of the European Union's GEHR-Project in the early 1990, and can be defined as a comprehensive and open approach towards EHR systems [43]. The results of GEHR project have been extended, refined, and modified by several other projects (i.e. the Australian GEHR projects and the EU Synapses and SynEx projects) [43]. Open EHR is a two level model approach. The first level is the reference model that supports the medico-legal requirements and records the management function. The second level is the open EHR archetypes, which share the evolving clinical information providing the architectural standard for EMR. Archetype can be considered as a model of clinical content, such as what is recorded in a urinalysis, or an ante-natal visit [44] which means

archetypes provides common definitions of clinical information through a shared archetype repository [45]. The first level provides the syntactic interoperability and the second level of open EHR approach provides the semantic interoperability [43, 46]. The reference model of Open EHR comprehends an information model that defines many classes. Entry is one of the main classes of open EHR and corresponds to the clinical statement like in other models i.e. CEN EN13606-1 and HL7 CDA [47]. Open EHR reference model defines six different types of entries and five of them are defined in the information model i.e. an 'ADMIN_ENTRY' and four types of CARE_ENTRY: OBSERVATION, EVALUATION, INSTRUCTION, and ACTION [47, 44], which are shown in Figure 2-10 and explained below.

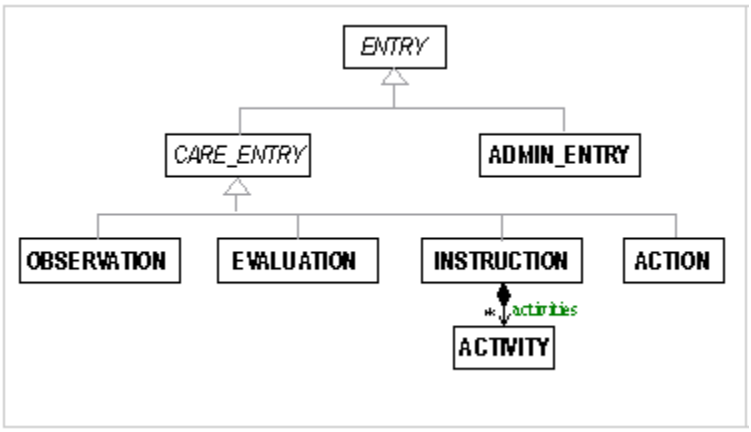


Figure 2-10 Types of Entry in Open-HER. Taken from [47]

ADMIN_ENTRY. Open EHR ADMIN_ENTRY class records all non clinical information related to administrative purposes such as admission, discharge, and consents.

CARE_ENTRY. This class of open EHR captures clinical information that is related to the patient or generated during the care delivery process through its four subdivisions, OBSERVATION, EVALUATION, INSTRUCTION, and ACTION as explained below.

- OBSERVATION. This sub-class of CARE_ENTRY stores information from the patient's world, any phenomenon or state of interest to do with the patient and include any observation by a clinician, or patient, such as

signs, symptoms, complaints or events' as well as laboratory investigation result.

- EVALUATION. This sub-class of CARE_ENTRY records clinical notes and statements, such as medical problems, clinical diagnoses, assessment of risk factors, and goals.
- INSTRUCTION. This sub-class of CARE_ENTRY records orders, such as prescriptions, requested interventions, and ordered lab investigations.
- ACTION. This sub-class of CARE_ENTRY records actions, such as drug administrations, or performing a procedure. These actions may be the result of instructions.

The approach of OpenEHR is more "technology-based" than "standards-based" [45]. The advantages of OpenEHR as follows: it provides leading-edge architecture along with a comprehensive reference model, support for archetypes, a coherent design philosophy, and plans for a Shared-EHR solution which is fully compliant with TS18308 [45]. Despite these advantages, openEHR has faced resistance from stakeholders, and the incorporation of OpenEHR components in health information systems has been extremely low due to cost, disruption and risks [45]. Adtionally OpenEHR is still considered as a research and development platform which is subjected to ongoing change. Although the reference model of openEHR defines the top-level generalized structure of medical information, it is fully dependent on its controlled archetype repository

2.3.3.2 CEN EN 13606

CEN EN 13606 is an open_EHR archetype based European standard of EHR. According to the EN 13606 Association the goal of this standard are [38].

"*The overall goal of this standard is to define a rigorous and stable information architecture for communicating part or all of the electronic health record (EHR) of a single subject of care (patient). This is to support the interoperability of systems and*

components that need to communicate (access, transfer, add or modify) EHR data via electronic messages or as distributed objects:

- *preserving the original clinical meaning intended by the author,*
- *reflecting the confidentiality of that data as intended by the author and patient.*"

EN 13606 has adapted dual model architecture to separate information from knowledge. The information representation is achieved through the *Reference Model* that possesses basic entities for the representation of EHR information. The knowledge is captured through the archetypes. These archetypes define clinical concepts like, discharge report, family history, and blood pressure measurement. As this standard is developed on several years of open-EHR work so it shares many of its constructs [39], and these constructs are: (a) Reference Model for information exchange and communication between heterogeneous systems, (b) Archetype Specification defining clinical concepts - business objects- through a constraint-based approach. These clinical "business objects" are built from the Reference Model which is adopted from open-EHR (c) Reference Archetypes and Term Lists is an initial set of inter-reference model conversion archetypes, which maps to OpenEHR and to the HL7 version 3 RIM Act classes. (d) Security determination it deals with access rights, consent ,and audit-ability of EHR.(f) Interface specification is message based or service based interface to enables EHR and archetype communication.

2.3.4 POMR

Problem Oriented Medical Records (POMR) was introduced by L Weeds in 1968 [48, 49]. POMR provides a substratum to record patient information in well structured manner [48]. The proper structure of POMR helps physician to store patient's notes properly and later on provides a good understanding of patient history. This approach of maintaining patient record has been validated by the American Institute of Medicine [48]. Problem oriented medical record consists of four distinct sections [50], which are:

- **Database**, which contains patient information such as patient history, physical evaluation, and lab result.

- **Problem List**, which contains record of all patients problem.
- **Treatment Plan**, which contain information about the treatment given to the patient.
- **Progress Notes**, which contain information about patient progress, which is recorded in chronological order, regardless of discipline.

In POMR patient information is recorded according to the patient's medical and social problems, which helps in either developing a diagnosis or planning treatment for the problem [51]. POMR also provides a mean to record the results of actions taken in response to the problems or the outcomes of the treatment given to the patient. As mentioned earlier all the patient problems are recorded under the problem list. The problem list is constantly updated on the basis of changes observed in the patient. The problem list is used as 'problem-oriented summary index' [(5)] for patient's information which is recorded in different part of the medical record. Figure 2-11 shows a sample POMR which represents information about the possible problem, the actions that are taken regarding the problem, treatment administered, and the results of the actions taken [51].

Problem: Pneumonia
Assertion Certainty: Present
Treatments:
    Treatment: Antibiotic
    Successful: Yes
Causes: None
Associated Problems: Respiratory distress
Proof: Chest x-ray

Figure 2-11 Sample POMR showing information about the problem 'Pneumonia'. Taken from [51]

In the Figure 2-10 the problem is *pneumonia* which was *present* in the patient and identified by the investigation result i.e. *chest X-Ray,* the problem is successfully treated with *antibiotics.* The causes of the problem were mentioned, but it presented information about an associated medical problem *respiratory distress,* which co-occurred with pneumonia. Its shows the structure of information recorded in POMR.

Although POMR provides a structured format to present patient information in a problem oriented manner but still this approach has some limitations [52] which are: POMR is quick to pick up but with the passage of time, especially dealing with long-term conditions, it is complex to maintain. While dealing with long-term conditions it is rare to have single problem consultation, which means several issues could be discussed during the consultation and these issues have to be addressed and recorded. Not all the issues are problem and can be listed as problem. POMR only provides a crude measure of the state of a problem i.e. in POMR a problem is either 'Current', 'Dormant' or 'Resolved'. It is observed that there are conditions that tend to occur in cyclic manner, which means the condition gets better and then get worse over a period of time, for example Asthma.

2.3.5 DISCUSSION

The concept of EMR is not limited to data storage and retrieval. The functionalities such as multiple user accessibility, accountability, provision of evidence based medicine, and decision support, which accompany this concept make EMR an essential tool in healthcare practice. Although there are several standards of EMR, most of them are focused on episodic and disease centric care processes which is more suitable in cases of acute diseases. These systems are not designed to support the longitudinal and patient centric nature of chronic diseases and therefore lack the comprehensiveness necessary to sustain the longitudinal care process of chronic disease management and to support the holistic care.

2.4 COMPUTER BASED PATIENT RECORD (CPR) ONTOLOGY

The institute of medicine defined computer based patient records as [53]:

"An electronic patient record that resides in a system specifically designed to support users by providing accessibility to complete and accurate data, alerts, reminders, clinical decision support systems, links to medical knowledge, and other aids".

In the year 2006 W3C had started building the Problem Oriented Medical Record ontology. These efforts resulted in the formation of Web Ontology Language based ontology. This ontology was called Computer Based Patient Record (CPR) ontology in the year 2009 [54]. The CPR ontology was developed is such a way that it shares the concepts of some high level ontologies, such as BioTop, BFO, FMA, and SNOMED-CT as shown in the Figure 2-12. It is also coherent with the medical terminology and messaging standards like HL7 RIM [54], which enables it to represent healthcare information.

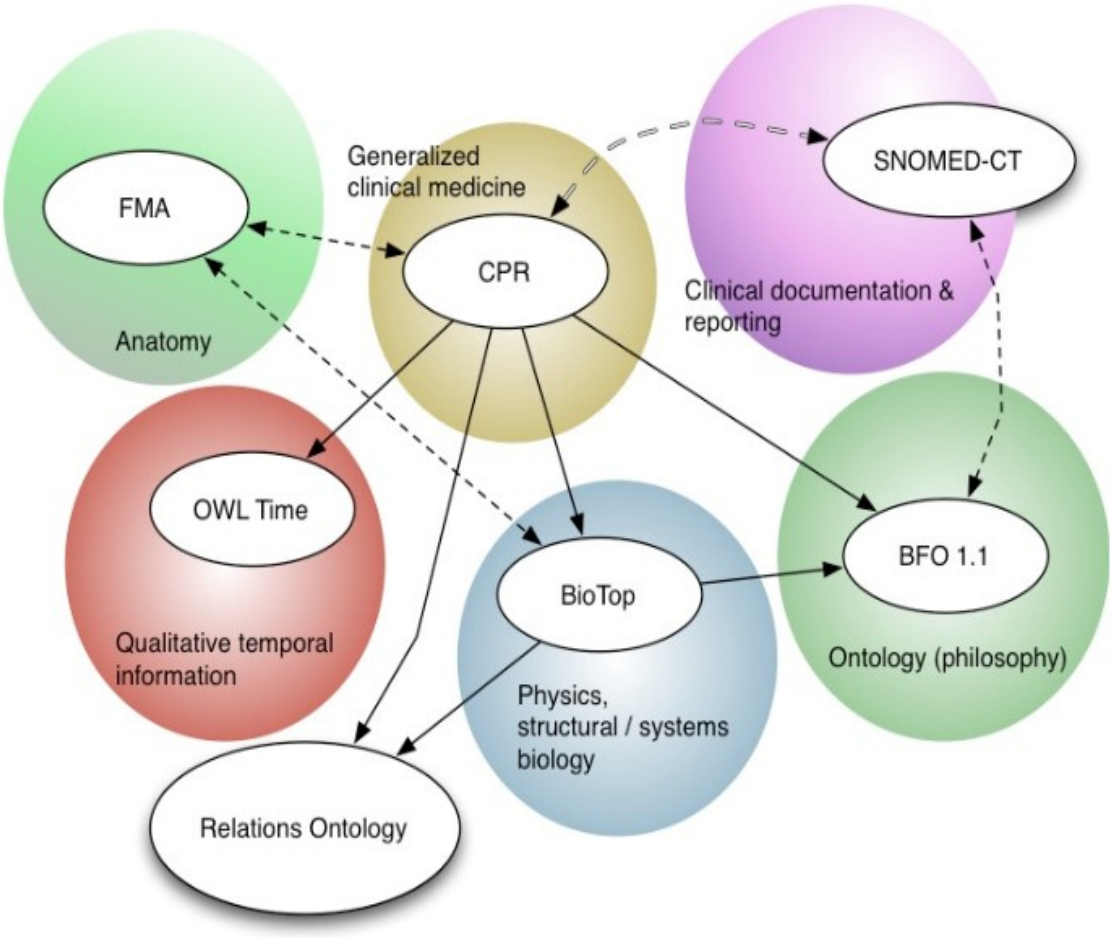


Figure 2-12 Connections of CPR Ontology with top-level Ontologies. Taken from [53]

The representation of complex and ambiguous clinical information into simple processes like activities, tasks, and actions is not a new concept in healthcare knowledge representation. By dividing complex health processes into simpler tasks, such representation is helpful in capturing the information flow within healthcare. CPR ontology is designed in such a way that it captures the notion of clinical activities, tasks, information flow, procedure, and findings within its main concepts, as explain in the subsequent sections.

Clinical Act: It captures the notion of various clinical activities and tasks, as well as the flow of information while performing these tasks and activities. In CPR ontology the clinical processes are defined as workflow models as proposed by Bayegan et al. [55] for defining clinical communication and documentation. The Clinical Act in CPR ontology seems to fulfill the functionalities that overlap with the Act class of HL7 RIM [56]. The Clinical Act covers four different types of clinical activities namely *Clinical Administration Act, Clinical Investigation Act, Procedure,* and *Therapeutic Act.*

Clinical Administration Act: It covers all the administrative activities, such as appointments, admissions, and demographic information, which are not investigatory or diagnostic, but are carried out to perform either assessment or treatment.

Clinical Investigation Act: It covers the investigatory action used to determine the patient's status. It further covers four different types of acts as subclasses, namely, Clinical Analysis Act (helps to generate clinical hypothesis), Diagnostic Procedure (includes the processes used for diagnosis; covers both laboratory and radiologic procedures), Laboratory Tests (performs a quantitative or qualitative test of a substance in the laboratory), Screening Act (collects patient data from different aspects including clinical examination, medical history, social history, and family history in order to identify any problem).

Procedure: It can be taken in order to improve the patient's condition. In CPR ontology it is aligned with the concept of Procedure in HL7 RIM. It has been used in the ontology to cover procedure that can either be diagnostic or therapeutic in nature.

Therapeutic Ac: It includes all the actions taken to improve the patient's physical state. This concept covers various aspects of therapies, such as medical therapy, surgical procedures, exercise, and psychological therapy.

Medical Problem: In CPR Ontology the concept of medical problem includes signs and symptoms which are used to determine the disease process. Signs are the observation of a healthcare provider during clinical examination, while symptoms are the conditions reported by the patient to the healthcare provider. The framework proposed by Scheuermann et al. [57] for disease diagnosis has been reused in CPR ontology and the diseases process has been captured as either a pathologic disease or an etiologic agent.

Finding: It includes the clinical examination (general physical examination) performed by a health care expert over various body parts in order to access the patient's condition during a health care encounter.

Diagnosis: Is the hypothesis made during a health care encounter (clinical analysis act) that is not yet confirmed.

Person: In CPR ontology a person covers a wide range of roles, such as patient, health care provider, specialist, therapist, nurse, and radiologist. This concept of CPR ontology is analogous to the notion Role in HL7 RIM [58]

In summary CPR ontology has been developed in OWL, it covers several essential concepts of electronic medical records, and is also compliant with the concepts of HL7 RIM [54]. Although the structure of CPR ontology is rich enough that it cover several

important concept of EMR such as Act, Role, and Diagnosis, but the CPR Ontology design is based on Problem Oriented Medical record which is problem oriented or diseases centric rather than patient centric. The CPR model is more suitable for acute disease and provides a strong ontological structure for EMR that can support reactive care rather than proactive care. In order to use this model for chronic diseases, CPR Ontology needs to be aligned with the concepts and requirements of chronic disease management, so that it can provide a framework for proactive, patient-centric, and longitudinal care.

2.5 HEALTH LEVEL 7 (HL7)

HL7 is a non- profit, ANSI-accredited standards developing organization, founded in the year 1987 [58]. Organization was founded in order to provide a comprehensive framework for the exchange, integration, sharing, and retrieval of electronic health data. HL7 was developed with a vision to create the best and most global standard in health care. The mission of the organization is to ensure interoperability by providing a standard which in turn improves care delivery, optimizes work, and reduces ambiguity among several different health care domains [58].

In version 3, HL7 introduces the object model called Reference Information Model (RIM). RIM has attributes, codes, vocabularies and can represents the logical relationship among the individuals involved in clinical information domains. RIM is also capable of specifying the complete life cycle of an event that a message or a group of related messages will carry [56].HL7 Version 3 provides a human and machine readable XML based messaging standard called Clinical Documentation Architecture (CDA). CDA specifies the controlled architecture of content in shared clinical documentation.

As discussed earlier the relationship among health care entities and the life cycle of the health care events, as carried by messages, are captured by the object oriented model called RIM. RIM is based on the following core classes as shown in Figure 2-13.

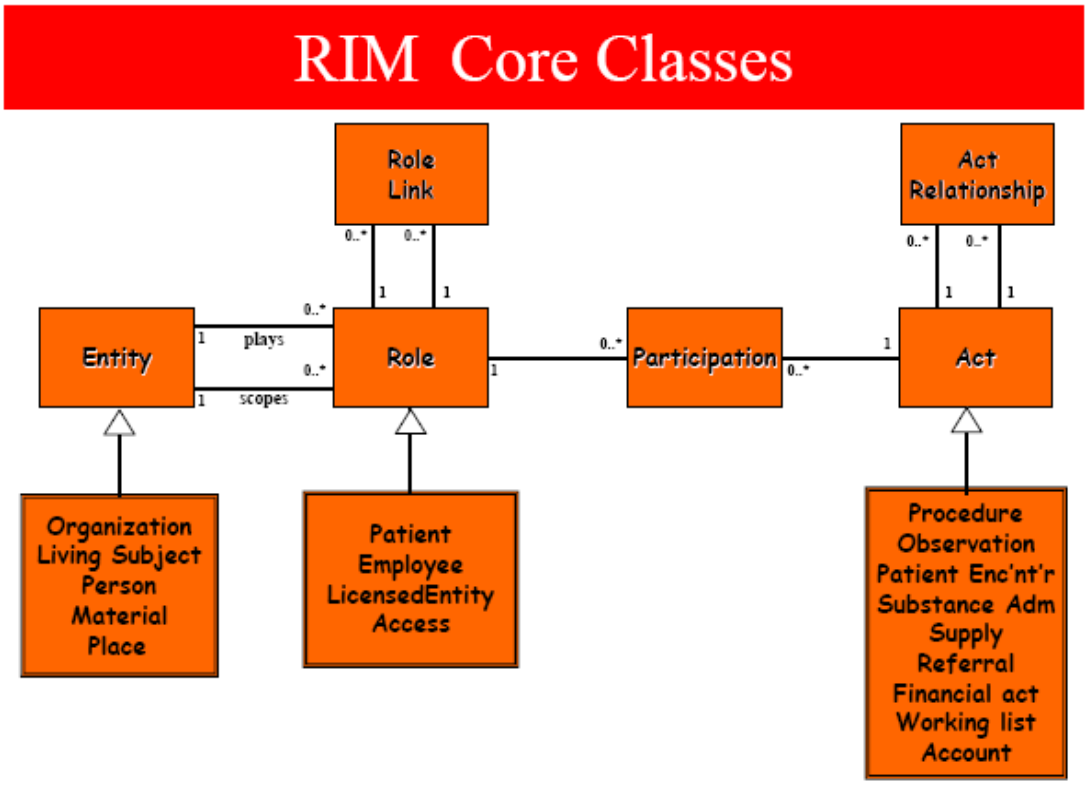


Figure 2-13 Core Classes of HL7 RIM. Taken form [59]

The six backbone classes of RIM are Entity, Act, Role, Participation, Role Link and Act Relationship. All the actions are defined by the class Act and are linked with other actions through the class ActRelationship. Entity represents any physical thing, or a group of things, or an organization. Acts are performed by Entities playing a certain Role. Two roles are connected by using the class RoleLink which displays dependencies between two roles. The class Participation is used to define the association between an Act and a Role.

For each of the above explained classes there are specialized attributes defined for each class [60]. The designated vocabulary domain for each attribute strengthens the semantic representation and help in accessing the data [60]. HL7 has its own data-type standard. These data-types are divided into five main groups, which are Basic, Foundational, Quantities, Quantity Collection, and Uncertainties [61].

BASIC: It stands for the basic building blocks and covers information like name, address, coded concept, and text.

FOUNDATION: It provides the structural data types i.e. Boolean, item collection (whether ordered or unordered) and history.

QUANTITIES: It covers simple numeric numbers i.e. integer, complex quantities, and ratio.

QUANTITY COLLECTION: It covers the time specification necessary to capture the complex expressional facilities needed for sophisticated concepts.

UNCARTAINTIES: It expresses the uncertain values and outcomes.

HL7 standards claim to support interoperability among health information systems; it standardized the format and protocol for electronic exchange of medical data [62]. HL7 version 3 supports semantic interoperability among various HIS and applications through its Reference Information Model (RIM), HL-7 V3 also provides a comprehensive set of data-type standard [61], which enables the user to capture the data in a specified data field. HL7 is the widely used and globally accepted standard; however Roos [63] argues that the basic design of HL7v3 does not support an interoperable health record system because of the fact that it is not designed to capture the medical knowledge. He argued that the design of HL7 is more toward modeling procedures and is closer to a workflow management system [63]. Along with these argument, Gonzalez et al [62] has also pointed out that the intended goal to achieve semantic interoperability with HL7 V3 has not been completely achieved; the reasons are (a) the complexity of the standard, due to which HL7 experts are required in the interface implementation process, (b) missing over-arching principles, and (c) inconsistencies, overlapping, and instability of the various HL7 version3 models. The objective to use HL7 in our research is to attain semantic interoperability in our model. Our approach is we will use the HL7 RIM backbone classes to capture the workflow within and across various healthcare domains, facilities and services; and to store the information or medical knowledge we will use the specified data type properties.

2.6 ONTOLOGY DEVELOPMENT METHODOLOGIES

To develop an ontology, a standard development methodology must be followed in order to attain functionalities, such as reusability and interoperability. Following a standard methodology is also helpful in successful implementation and maintenance of ontology. Though ontology engineering is still considered as an immature discipline, its roots go back to early 80s, where we found description of standards methodologies for ontology development [68, 69]. There are several different kinds of approaches within these standard methodologies such as emphasizing the ontology building from scratch, reusing the pre-existing ontologies, or following the standard software development.

In Table 2-5 is a comparison of different ontology development methodologies [70]. In the subsequent section is the explanation of the methodology that we have adapted to develop our model.

Table 2-5 Comparison of different ontology development methodologies. Taken From [70]

	Inheritance From Knowledge Engineering	***Detail of the methodology***	***Recommendations for formalization***	***Strategy for building applications***	***Strategy for identifying concepts***	***Recommended life cycle***	***Differences from IEEE 1074-1995***	***Recommended techniques***	***Ontologies and applications***	***Collaborative and distributive construction***
Uschold y King	Partial	Very little	None in particular	Application independent	Middle-out	None	Processes missing - Activities missing	Not known	One domain only	Not documented
Grüninger y Fox	Small	Little	Logic	Application semi dependent	Middle-out	To be detailed	Processes missing - Activities missing	Not known	One domain only	Not documented
Bernaras	Big	Very Little	None	Application dependent	Top-down	None	Processes missing - Activities missing	Not known	One domain only	Not documented

METHONTOLOGY	Big	A lot	None	Application independent	Middle-out	Evolving prototype	Pre-development process missing - Activities missing	Some activities missing	Several domains	Not documented
SENSUS	None	Medium	Sementic network	Application independent	Not specified	To be detailed	Processes missing - Activities missing	Not known	Several domains	Not documented

2.6.1 METHONTOLOGY

Fernandez Lopez et al. developed Methontology at University of Politecnica Madrid in 1997 [71]. Methontology is a well structured methodology and enables the user to develop ontology from scratch [72]. Methontology is a combination of ontology development activities both from software development processes and knowledge engineering methodologies [75]. Methontology framework [73] supports ontology building at knowledge level [74], which is based on identification of activities/tasks, such as planning, specification, knowledge acquisition, conceptualization, integration, implementation, and documentation; specification of techniques to perform these activities, and ontology life cycle based on evolving prototypes. The Foundation for Intelligent Physical Agents (FIPA), which promotes interoperability among agent based application, has proposed Methontology methodology for ontology construction [75]. Methontology is also supported by both ODE and Web ODE tools [71, 75]. The phases in the life cycle of methontology are illustrated in Figure 2-14.

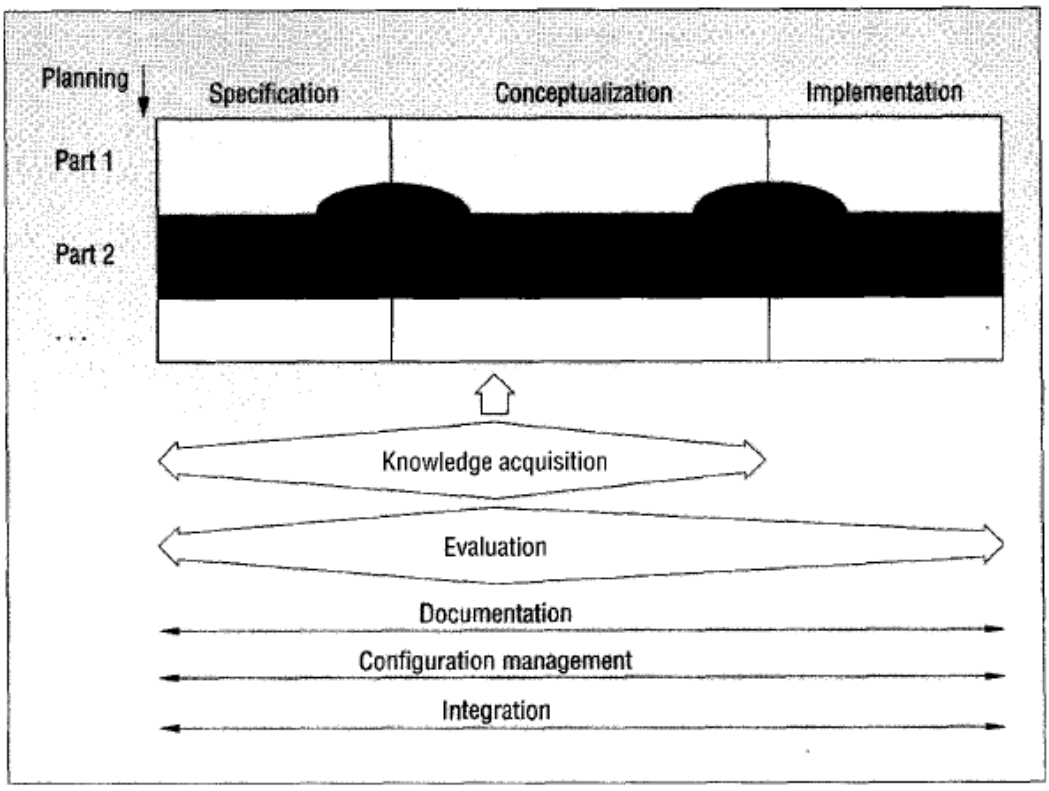


Figure 2-14 Phases in the life cycle of ontology development. Taken from [74]

Specification: This phase is designed to produce documentation which could be informal, semi-formal or formal, written in natural language [72]. The purpose of this is to clearly state and specify the primary objective, purpose, granularity level, and scope of the ontology. The main focus is to identify a set of term for representation and explain their characteristics and granularity. This phase of the cycle must be concise and should also display completeness. The specification document must cover the important aspects, such as *Domain, Purpose, Scope,* and *Knowledge Source*.

Knowledge Acquisition: In ontology development knowledge acquisition is an independent process. However, it coincides with other activities. In this approach general knowledge about the domain is first acquired which then gradually goes into the details. There are several different kinds of techniques: (a) Non-structured interviews with experts, (b) Informal text analysis, (c) Formal text analysis, and (d) Detailed reviews by the experts.

Conceptualization: After source identification and acquiring specific domain knowledge, the ontologist has to organize the unstructured knowledge that is acquired. Conceptualization organizes the acquired knowledge by using external representations which are independent of implementation language and environment. During this phase the informal precise view of the domain has been converted into semi-formal specification by the use of IRs (intermediate relationships) that the domain expert and ontologist can understand. These IRs function as a bridge between how people think about the domain and language in which the ontologies are built.

Implementation: Implementation is the process in which the conceptual model is codified in a formal language, such as CLASSIC, BACK, LOOM, Ontolingua, Prolog, C++ , or OWL.

Evaluation: This methodology proposes to carry evaluation activities throughout the entire lifetime of the ontology development process. Conceptualization phase [73] is the one where most of the evaluation is done. The Ontology created by METHONTOLOGY is by no means considered to be final, but is considered to be an "Evolving Prototype".

2.7 DISCUSSION

Our main aim is to develop a generic model of EMR for chronic diseases management. In order to develop the information model that can capture chronic diseases, it was necessary to understand various aspects of chronic diseases. Literature review helped us to identify the various concepts related to chronic diseases, differences between acute and chronic conditions, highlight the needs of chronic disease patients, and gaps in the process of chronic care. Chronic diseases are not just pathological conditions; these conditions bring with them a heavy load of personal, physical, psychological, and behavioral impact, which makes the nature of chronic diseases complex. The phenomenon of stigma and illness denial further increase the complexity in the nature of chronic diseases, and make the process of chronic care distinct from acute and emergency care. Developing the management plan for chronically ill patients means considering all the possible treatment options to treat the pathology of the disease, providing a way out to the patient from the impacts, and overcoming the stigma of the disease. Thorough assessment of the patient and the availability of patient information at the point of care, regarding previous medical conditions, investigation results, and treatment taken by the patient, help in planning the appropriate management plan for the patient suffering with chronic disease. Provision of patient information at the point of care can be achieved if we have well integrated HIS and EMR in situ. There are several available EMR but none of them serve the purpose needed for chronic care, which means either they are developed on standards suitable for acute and emergency care or they lack the

comprehensiveness, patient centeredness and longitudinal nature which are needed for the provision of holistic care to chronically ill patient. Development of comprehensive and well integrated EMR systems is therefore needed to capture the various aspects of chronic diseases. These systems should be well integrated and semantically interoperable; to achieve the semantic interoperability they should be developed using a standard such as HL7 and should also use terminology standards to store clinical information and data in standard format.

2.8 CONCLUSION

Detailed study of chronic disease management helped us to develop a conceptual understanding of: (a) the process of chronic diseases and (b) the needs that should be considered while developing the management plan. This understanding of the disease process enabled us to identify the concepts related to chronic diseases and avoid the linguistics entities, which are commonly used during the care process. This separation and identification of concepts will be beneficial in choosing the core concepts when modeling the process of chronic care and the development of the conceptual knowledge model for chronic disease management. This understanding also avoids the risk of confusion and ambiguities that could occur from the selection of unnecessary elements during the knowledge abstraction and model development process. Study of various existing EMR systems reveals that most of these systems have been developed using the POMR approach. Although POMR provides a well structured format to record patient information, this approach is episodic and disease/ problem centric in nature, which means that it lacks the notion of longitudinal care and patient centeredness, which are the assets of chronic disease management. In order to design an EMR system that is capable of capturing the chronic care, there is a need to develop a new system which is comprehensive, and according to the needs of chronic disease management. Alternatively, we can reuse a pre-existing system by aligning it with the needs and requirements of chronic disease management. There exist models, e.g. CCM, that are developed to support and improve the care process of chronically ill patients. These models need is to used at the point of care by integrating them into EMR and other HIS to achieve best possible outcomes.

CHAPTER 3: RESEARCH METHODOLOGY

3.1 INTRODUCTION

In this chapter we will discuss our research methodology for development of a model for Electronic Medical Record (EMR) that can capture, support, and manage information generated during chronic disease management. Our main focus is to develop an information model of EMR that should be rich enough to capture various aspects of chronic diseases, but at the same time the proposed information model should also provide a platform to capture acute disease and co-morbid conditions.

3.2 RESEARCH GOALS, OBJECTIVE AND MOTIVATION

The goal of this thesis is to investigate the process of chronic diseases management and then develop an information model of EMR to capture patient information that is generated during the care process, especially for chronic diseases. As mentioned in chapter 1, we aim to develop an ontology based information model of EMR for chronic disease management. The model will represent concepts of chronic disease management, key components of medical record and will also be HL7 compliant to attain semantic interoperability. The reason for developing an ontology based information model is to achieve semantic interoperability in order to ensure effective communication with other knowledge models and CIS.

The objective and our motivation to develop the knowledge model for chronic diseases management which can be used as an information model and computerized as EMR ontology for chronic diseases lies in the following research question:

1- What are the key elements −both clinical and non-clinical− involved in chronic disease management and how chronic care is different from acute care?

2- What is the inherent structure for Electronic Medical Record? Can we reuse this structure to develop an ontological model for electronic medical record that captures chronic disease management?

3- How can the key elements that are specific to chronic disease management be captured and represented in our proposed ontological model of EMR?

4- Can we map our ontological model of EMR with a messaging standard like HL7 RIM in order to achieve electronic data exchange and semantic interoperability?

3.3 RESEARCH METHODOLOGY

In order to answer the above mentioned research questions we need a research methodology which helps and guides us to search for a scientific solution for each of the above mentioned problems. We have devised our research methodology which is based on the Knowledge Management approach [81]. Our research methodology is inspired by knowledge management framework which consists of four sequential activities as described by Karl Wiig et at [81]. The four activities of the framework are Review, Conceptualize, Reflect and Act. In an effort to explain each of these activities and how we use these activities in the development of our research methodology, we make use of the Knowledge Management cycle as shown in Figure 3-1.

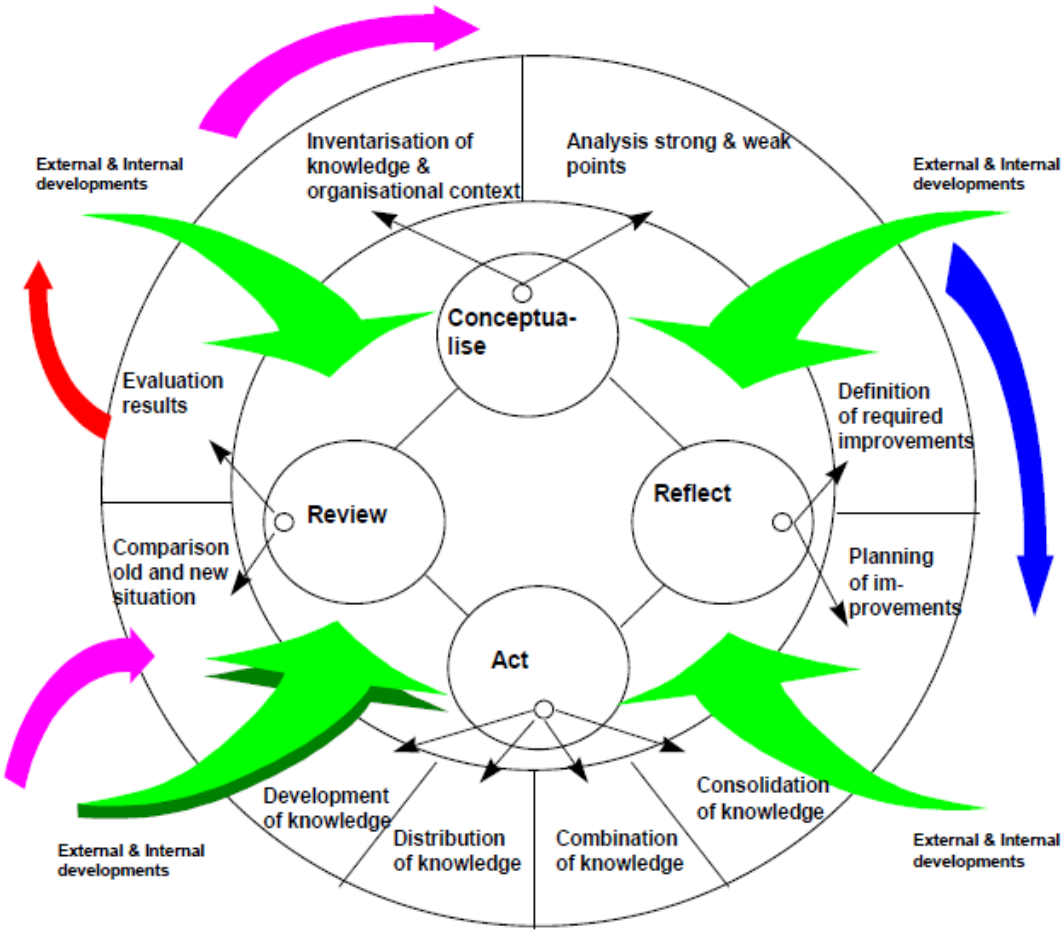


Figure 3-1 Knowledge management cycle. Taken from [81]

In the knowledge management cycle shown in Figure 3-1, knowledge management is split into four separate activities. Each of the activity deals with a particular aspect. The cycle starts with the reviewing which investigates what has been done and achieved in the past and also evaluates the current state of affairs. After analyzing the state, the cycle proceeds to the second activity which is Conceptualize. In this activity the observed knowledge is analyzed to investigate the strong and weak points, search for bottlenecks. The most important aspect of this activity is to find the answers to the following questions: which deals with what is the use of knowledge; which knowledge is used; where the knowledge is going to be used; when the knowledge is used; and which organizational role provides the knowledge. Reflect deals with selecting an optimal plan to overcome the bottlenecks and also provides risk analysis which accompanies the

implementation. Act deals with the actual effectuation of the plan; mostly it involves a single or a combination of actions like developments, evaluation, distribution and consolidation [81].

By using the above mentioned activities of the knowledge management framework we have adapted the knowledge management approach and designed our research methodology which consists of 5 phases. Each phase in itself consists of multiple steps of research activities that not only guide our research to remain on the right path and provide high quality solutions to the research problems that we have to address. The five phases of our research methodology are mentioned below and shown in Figure 3-2.

Phase 1: Knowledge Specification.

Phase 2: Knowledge Acquisition & Knowledge Abstraction.

Phase 3: Conceptualization, integration with CPR Ontology & HL-7 RIM and validation.

Phase 4: Model selection, formalization and implementation.

Phase 5: Model Evaluation

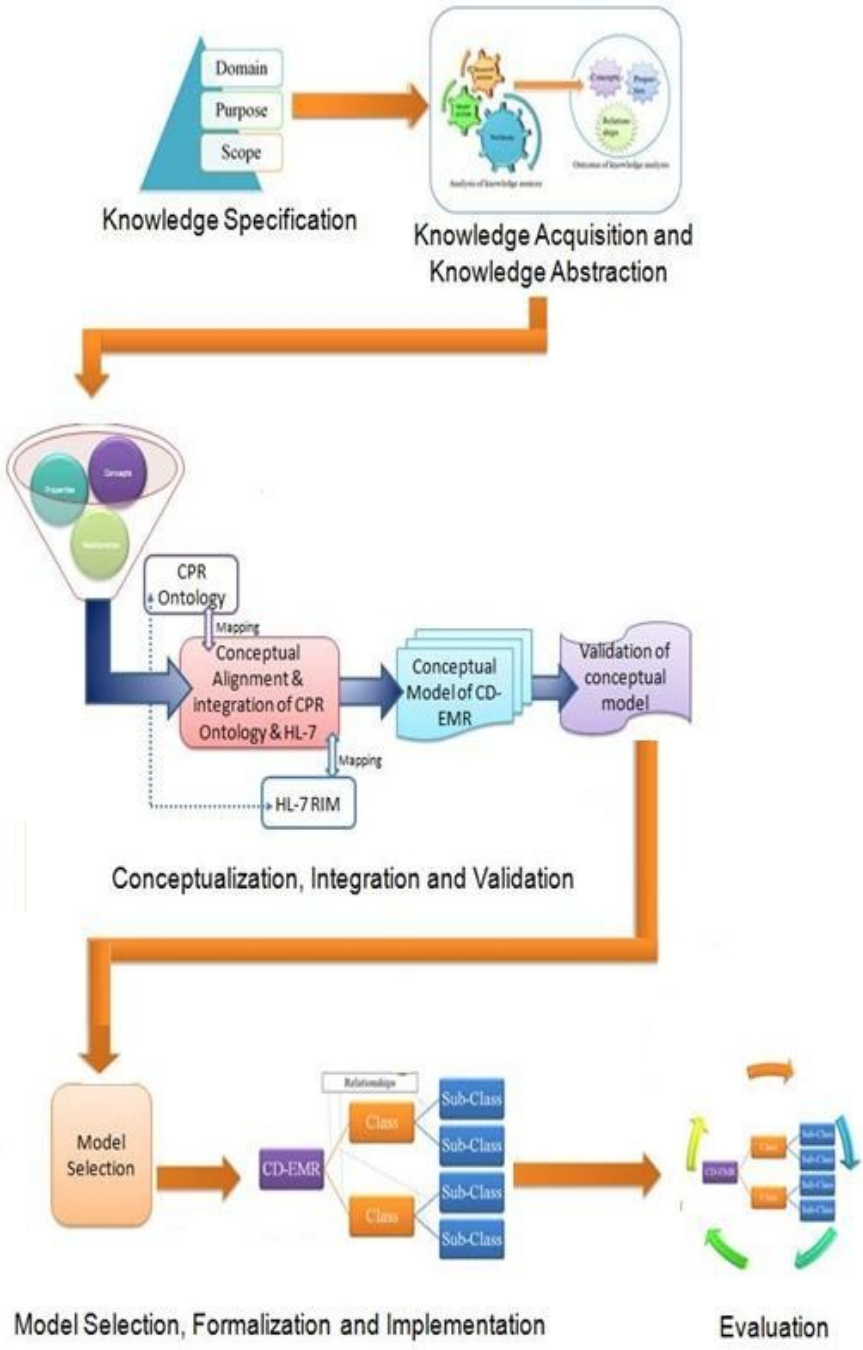


Figure 3-2 Phases of our Research Methodology

These phases of our research methodology are aligned with the knowledge management activities explained which are mentioned above. The first phase of our research deals with the specification of the domain, purpose, and scope of our research. In the second phase, an analysis of the pre-existing literature, books, and knowledge source has been done to evaluate the current state and work done in the area. This analysis helped us in abstraction of relevant concepts their properties and the existing relationship. After the knowledge acquisition and abstraction phase, the abstracted knowledge is used to develop the conceptual model which is then integrated with CPR ontology [54] and HL7 RIM classes [56]. Validation of the conceptual model has been accomplished by using clinical test cases. In order to develop the formal model selection of the model was done, and the formal model is developed and implemented as OWL ontology using protégé. To eliminate the risk accompanied with the model development, the ontological model was evaluated to ensure the comprehensiveness, quality, and usability. The phases of our research methodology and the outcome of each phase is given in Table 3-1.

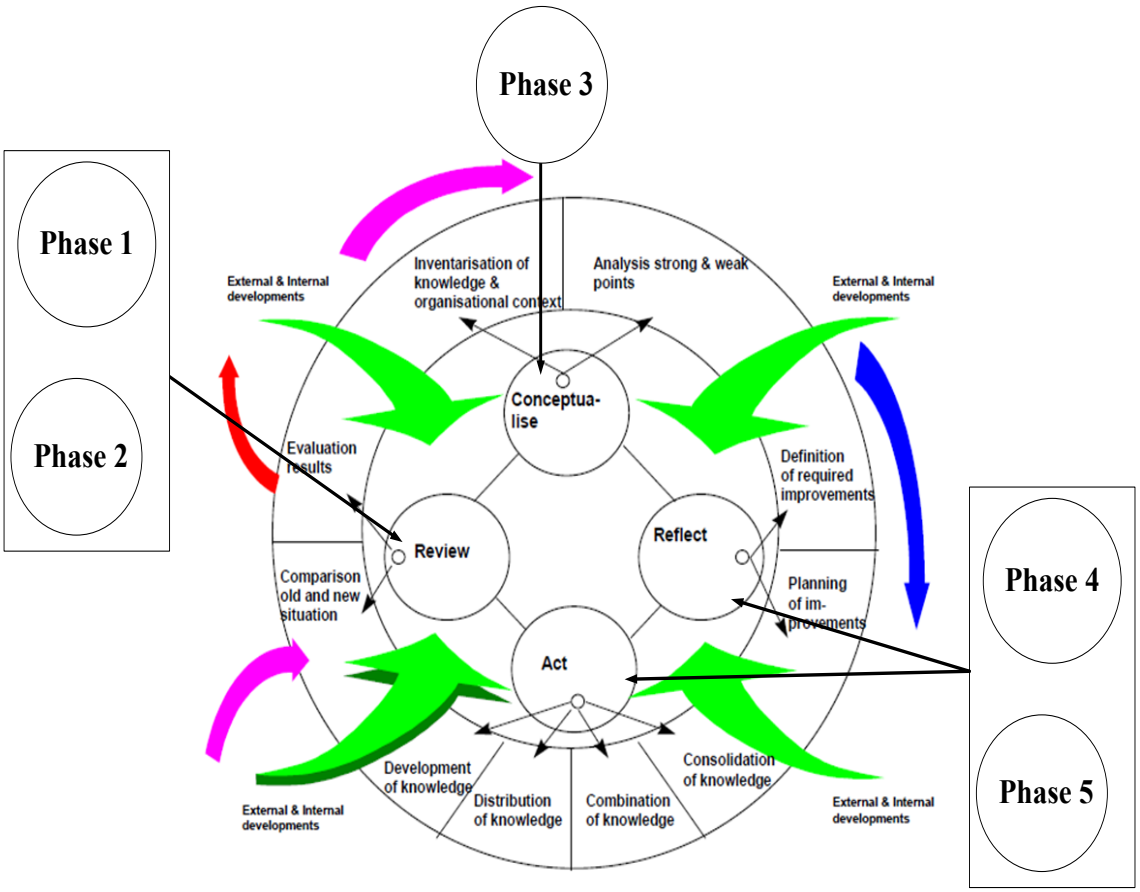
Table 3-1 Phases of research methodology and their outcomes

Phases of Research Methodology	**Outcome of each phase**
Knowledge Specification	Specification of domain, purpose and scope.
Knowledge Acquisition and Knowledge Abstraction	Selection of knowledge sources by using predefined set of criteria's. Abstraction of relevant and essential concepts along with their properties and relationships among them.
Conceptualization, integration with CPR Ontology and HL-7 RIM and validation.	Conceptual alignment of abstracted knowledge to develop conceptual model and integration with CPR Ontology and HL-7 RIM by performing mapping. Validation of the conceptual model

Model selection formalization and implementation.	Development of formal computable model of CD-EMR and implementing it as CD-EMR Ontology
Model Refinement	Model Refinement against clinical scenarios and implementation of model in the form of ontology.
Model Evaluation	Evaluation of ontological model using Pellet reasoner, clinical scenarios, HL-7 message and Bordenreider principle

3.3.1 PHASES OF OUR RESEARCH METHODOLOGY AND KNOWLEDGE MANAGEMENT CYCLE

The first two phases of our research are analogous to the first activity of the knowledge management cycle which is *Review*. In the first two phases we have specified the knowledge sources and have performed a literature review to evaluate the current state of affairs and abstract the conceptual knowledge. The third phase of our research methodology captures the second activity, *Conceptualize*, of the knowledge management cycle. In this phase the abstracted conceptual knowledge is used to develop the conceptual model, which satisfies the questions including what, where, and how the knowledge has to be used. The last two phases of our research methodology capture the idea presented by activities *Reflect and Act* of the knowledge management cycle. In these phases we selected the most suitable standard to develop our knowledge model and then formalized the conceptual model. Model formalization ignites the process of ontology engineering (development) which finally ends with ontology evaluation. Figure 3-3 shows the activities of the knowledge management cycle and the corresponding phases of our research methodology.



Phase 1: Knowledge Specification.

Phase 2: Knowledge Acquisition & Knowledge Abstraction.

Phase 3: Conceptualization, integration with CPR Ontology & HL-7 RIM and validation.

Phase 4: Model selection, formalization and implementation.

Phase 5: Model Evaluation

Figure 3-3 Phases of research methodology and Knowledge management cycle

To ensure high quality research outcome each phase of our research methodology consist a series of research activities. These five phases are interdependent, which mean (a) some of them occur in a parallel fashion (b) these steps may follow a sequential pattern and (c) the end result of one step could be the start point of the other stage. For these reasons it is vital to perform each research phase in a precise manner i.e. to define a set of criteria for each phase which serves as the guiding principal to pursue that phase in an organized manner. Following these preset criteria for each phase will not affect the integrity of other phases and preserve the quality of research outcome. In the subsequent sections of this chapter we will discuss in detail each phase of our research methodology.

3.3.2 PHASE 1: KNOWLEDGE SPECIFICATION

The first and most important step is the specification of domain, purpose and scope of our research. According to our goal we have aimed to develop an information model for chronic disease management and this model serves as the starting point of our research. Later we will computerize the model in the form of ontology to develop the electronic medical record for chronic disease management. In this knowledge specification phase we will define the domain, purpose, and scope of our research.

a) ***Domain:*** Specifying a particular domain for our research guide us to remain focused and to achieve our goal. According to our goal the domain of our research work is chronic disease management. After specifying the domain, detailed study of various aspects of chronic disease management helped us to investigate and identify (a) various concepts and their properties, which are an essential part of chronic care, (b) integral steps involved in the process of chronic disease management, and (c) the differences between acute and chronic care, which helps in the development of the model.

b) ***Purpose***: After specifying the domain it is vital to determine the purpose of the research work. This step is important in order to maintain integrity and high quality of the research outcome. In our case the purpose of our research is to investigate the essential components involved in the management of chronic diseases. The identified components will then be used to develop an ontology

based and HL7 compliant information model of EMR to capture various aspects of chronic diseases.

c) ***Scope***: This step needs specification of model richness which means how much knowledge needs to be represented to satisfy the purpose. The scope should always be limited and achievable. Our main scope is to capture chronic disease in EMR Ontology; however, our proposed information model should also provide a platform to capture acute disease and co morbid conditions.

In the first phase of our research methodology we specified the domain, purpose and scope of the knowledge used in our research. Knowledge specification is an integral part of the research to develop knowledge based expert system. It assists and guides the researcher to remain focused and produce high quality research. In our case specifying the domain, purpose and scope of our research helped us in the next step to select knowledge sources and development of criteria's for knowledge acquisition.

3.3.3 PHASE 2: KNOWLEDGE ACQUISITION AND KNOWLEDGE ABSTRACTION

Knowledge acquisition is an independent process; however, it coincides with other activities and continues throughout the development cycle. We have followed the approach of collection and analysis of domain specific knowledge. In our research the step of knowledge acquisition consists of two parts which are (a) development of selection criteria for knowledge sources and (b) abstraction of knowledge from the selected sources. In the process of knowledge acquisition, we followed a text analysis approach. While doing text analysis the selection of text is mainly based on the following criteria.

a) ***Details and Granularity of the text:*** Text books, detailed reports and standard models about the domain were collected and studied. This analysis resulted in resolving the ambiguities and clarifying the domain concepts.
b) ***Authenticity of text in research community.*** Text was collected from well reputed websites and databases, e.g. Pubmed, OpenClinical, Ocean Informatics,

that are well known in research community. This in depth collection approach ascertains the validity of research work.

c) ***Alignments with Innovative and current trends.*** Knowledge about recent trends and potential ideas were the sources of innovation and serves the purpose of alignment of research work with current need. Published articles from research journals including AMIA, JAMIA, International Journal of Medical Informatics (Elsevier), were thoroughly analyzed in search of innovation.

The detail of knowledge acquisition is given in table 3-2.

Table 3-2 Details of Knowledge sources

SUB DOMIAN	**Knowledge Source Type**	**Knowledge Source Name**	**Knowledge Source Author/ Editor**
CHRONIC DISEASE MANAGEMENT (CDM)	Book	Chronic Illness Impact and intervention [14]	Lubkin I M. Larsan P D
	Book	Treatment of chronic medical conditions [16]	Sperry L
	Book	Emerging approaches to chronic disease management in primary healthcare [2]	Dorland J, McMoll M A.
	Book	Nutritional and clinical management	Bronner F

		of chronic conditions and diseases	
	Book	Patient self-management of chronic diseases [87]	Redman B K
	Book	Medical and psychological aspects of chronic illness and disability [9]	Falvo D
	Book	Cancer informatics. Essential technologies for clinical trials. [80]	Silva J S, Ball M J, Chute C G, Douglas J V, Lanhlotz C P, Niland J C, Scherlis W L.
	Book	Chronic disease management [77]	Nuovo J.
	Book	Living a healthy life with chronic conditions [64]	Lorig K, Sobel D, Gonzalez V, Minor M
	Book	Group wellness program for chronic pain and disease	McManus C A

		management [65]	
	Book	Effective Patient Education: A Guide to Increased Adherence [82]	Falvo D R
MEDICAL RECORD	Book	PROBLEM ORIENTED MEDICAL RECORD IMPLEMENTATION : ALLIED HEALTH PEER REVIEW [79]	Berni R and Readey H.
	Book	Implementing and electronic medical record system. Success, failure and lessons [35]	Scott T, Rundall T G, Vogt T M, Hsu J
	Book	Developing a unified patient record a practical guide [76]	Thompson D, Wright K.
	Technical Report (AMA)	Technical and financial guide to EHR Implementation. [78]	Hartley C P, Jones E D, Ens D, Whitt D.
MESSAGING	Book	HL-7 CDA R2 [83]	Roebuck K

STANDARD	Technical report	Package Note to Readers. May 2012 [99]	Retrieved from: http://www.hl7.org/v3ballot/html/welcome/environment/index.html
	Book	Principles of Health Interoperability HL7 and SNOMED [34]	Benson T

After selection of text sources the selected knowledge was analyzed to abstract knowledge. Analysis of the knowledge helped us to identify the conceptual and practice-oriented knowledge related to chronic disease management. In the knowledge abstraction process, the essential concepts related to chronic diseases management were abstracted. Properties related to each concept were identified, which helped us to fully understand the concept. We also search whether there is any relationship that exists among these concepts. Figure 3-4 shows that the acquired knowledge is analyzed and the outcome of this research activity is the abstracted knowledge in the form of concepts, their properties and relationships.

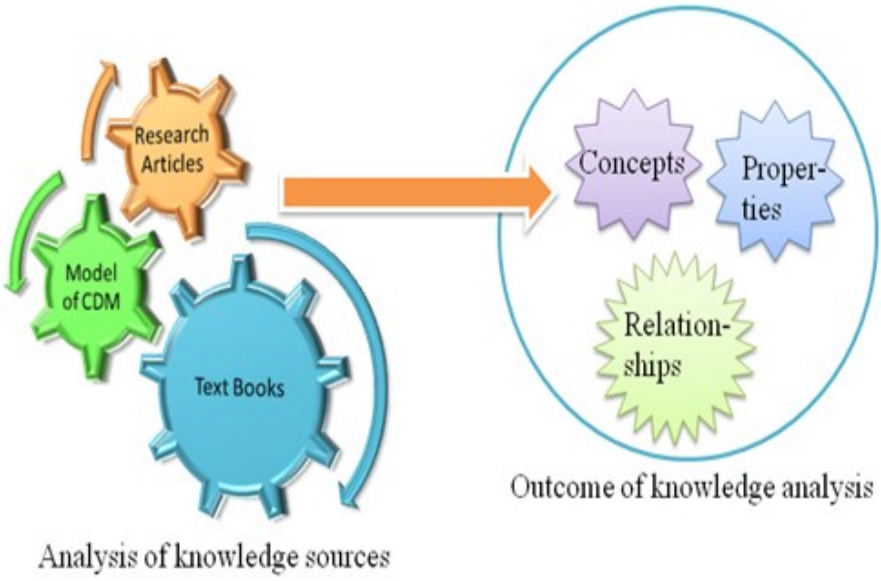


Figure 3-4 Knowledge Acquisition and Knowledge Abstraction

In this phase we had first identified the knowledge sources and then used these sources to abstract relevant knowledge i.e. concepts, their properties and relationships. The selection criteria helped us to select the most recent, relevant, and authentic knowledge sources which in turn enable us to analyze the most recent trends in chronic diseases management. The analysis of the recent knowledge sources resulted in abstraction of the most up-to-date and current domain knowledge. In this steps along with some traditional concepts such as assessment, clinical examination, and patient history we came across some modern innovative ideas such as providing patient education [82], introduction of life style modification [26] and self-management support [87] which are more patient-centric then the usual traditional ones such as medical therapy, surgical treatment which are more disease-centric or physician-centric.

3.3.4 PHASE 3: CONCEPTUALIZATION, INTEGRATION AND VALIDATION

This phase of our research methodology consists of three steps. These steps occur in a sequential manner i.e. one after the other, and the result of each step is the start point of the next step. These three steps are:

- **Step1**: Development of conceptual model of chronic disease management

- **Step2**: Integration and mapping of conceptual model with the CPR Ontology and HL7 RIM Classes.
- **Step3**: Validation of the conceptual model of chronic disease management

Step1: *Development of conceptual model of chronic disease management.* Conceptualization occurs after the specification and knowledge acquisition. After performing the above two aforementioned phases, we not only had a clear understanding of our domain, but we also had abstracted knowledge in the form of concepts, their properties and relationships. In this phase of our research we will perform three tasks, which are: (a) alignment of the abstracted knowledge to form the conceptual model for chronic disease management; (b) integration of the model with HL-7 and CPR ontology by performing conceptual mapping; and (c) validation of the conceptual model in order to eliminate risk that can possibly evolve during formalization and model implementation. The phase begins with the analysis of the abstracted knowledge, which was the outcome of the last two phases of our research. The abstracted knowledge is in fragmented form i.e. concepts, properties and relationships. In the conceptualization step we align this knowledge to develop our model and try to achieve a sequential flow of activities in our model. Knowledge alignment was done by using properties and relationships that each concept possesses. The concepts that possess similar properties were grouped under a common heading. For example, performing clinical examination, taking vital-signs, and performing the systemic examinations were all clustered under the main concept of *Assessment*. Similarly, the concepts such as blood test, urine analysis, and sputum sample are all groups under *Laboratory Test* and concepts such as X-Ray, ultrasound, EKG are all grouped under the umbrella *Radiology and Scans*. Furthermore the two concepts of *Laboratory Test* and *Radiology and Scans* are listed under a generic concept *Investigations*. After grouping the concepts, the relationships were used to connect different groups, which created the sequential flow in the model. By performing knowledge alignment, we developed a conceptual model which

consists of groups of concepts with similar properties and these groups are linked together according to the relationships.

Step2: *Integration and mapping of conceptual model with the CPR Ontology and HL7 RIM Classes.* Once we developed the conceptual model for chronic disease management, our next task was to investigate the common concepts across the chronic disease management model, the CPR ontology and the HL7 RIM. In this phase of our research we first mapped the conceptual chronic disease model with the CPR Ontology. This mapping was done manually on the basis of domain knowledge and we searched for similarities that exist among the concepts of the two models. During this mapping we found several concepts that are common across the two models. For example the concept of vital signs is successfully mapped across the two models; similarly, the concepts such as medical history, investigations, and treatment options were also successfully mapped between the CPR ontology and the conceptual model for chronic disease management which we had developed. It worth mentioning here that both models are structurally different i.e. CPR is an ontology based model while the chronic disease management model is not yet an ontological framework but exists as a conceptual model. For this reason some of the concepts which are intrinsic to the ontological model, such as the notion of temporal entity, are mapped on the basis of conceptual equivalency [92] which means they do not have a perfect map but there exist other concepts that serve the same purpose. For example temporal entity is mapped to the concepts that represent the timeframe in the model such as scheduled health care encounters, investigation date and time, duration of follow-up. The notion of health related role, health professional role and physician role are mapped to health care team, long term care team. After mapping the chronic disease model with CPR Ontology the next step of this phase of our research is to map our chronic disease model with HL-7 RIM. In this mapping the concepts such as entity, role and act are successfully mapped across the two models.

Step3: *Validation of the conceptual model of chronic disease management.* The final step of this phase is to validate that the conceptual model that has been

developed until now is comprehensive and rich enough to handle the variances that occur in the chronic disease management process. In this regard the model was tested against a number of clinical scenarios related to chronic diseases. Successful accomplishment of this task validated that the conceptual model is now rich enough and is ready for formalization and implementation. The developmental details of chronic disease model and the mapping process are explained in depth in chapter 4. Figure 3-5 shows Conceptualization, Integration and Validation steps.

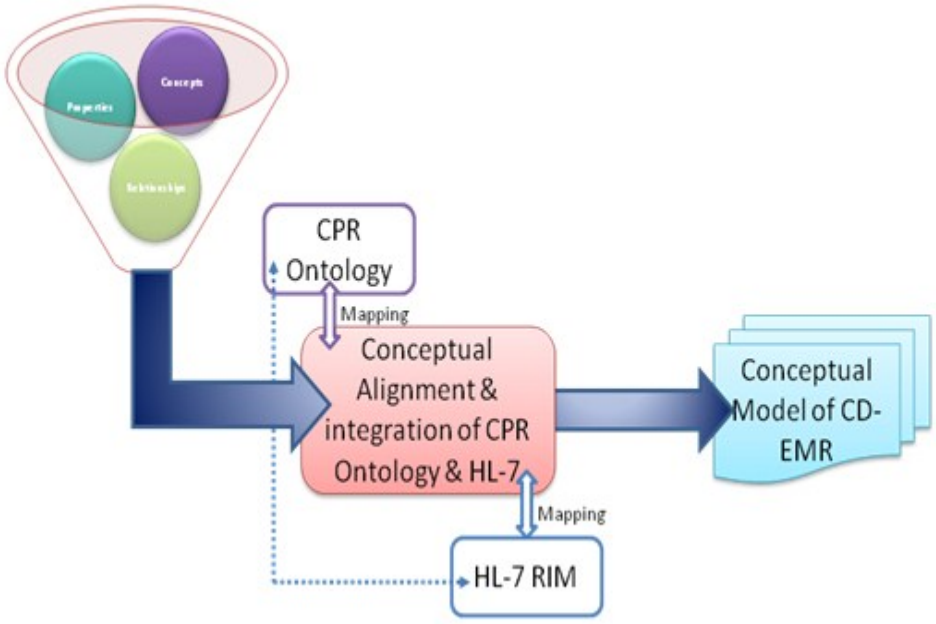


Figure 3-5 Conceptualization, Integration and Validation

Discussion: In this step of our research we aligned the abstracted knowledge and develop the conceptual model of chronic disease management. This model was developed by using the concepts and relationships that were abstracted during the knowledge acquisition and abstraction processes. The concepts were grouped together on the basis of similar properties and then linked together based on relationships. After conceptual alignment we mapped our conceptual model of chronic disease management with CPR ontology and HL-7 RIM. The mapping was done manually on the basis of domain

knowledge and similarities that exist among three models. After the mapping process, we have our conceptual model of chronic diseases management which now consists of core concepts related to chronic disease management and the common concepts that exists among the three working models, i.e. chronic diseases management, the CPR Ontology and HL7 RIM. Model validation is a crucial step and helped us to determine and eliminate any risk that accompanies the conceptual model development. This risk could be in the form of knowledge gaps and missing concepts, which means the conceptual model is not rich enough and lack some essential concepts related to chronic disease management. An additional risk could be in the form of improper sequential flow which means sequential flow is not properly handled during conceptualization phase. Most of the validation and evaluation activities occur during conceptualization phase of the research [c]. Validation not only eliminates these risks but also proves that the conceptual model in now mature enough to be formally presented and ready for computerization.

3.3.5 PHASE 4: MODEL SELECTION, FORMALIZATION AND IMPLEMENTATION

After formulation of the conceptual model of chronic disease management, but before the formalization and implementation of this model, it is necessary to select the most appropriate standard in which the implementation of the model has to be done. According to or pre-set goals we deemed to develop an information model that is semantically interoperable, capable of data storage and retrieval, and should also communicate with other knowledge model in order to perform the function of data and information exchange. In phase two of our research we found that clinical models that are developed in OWL as Ontologies [89, 93, 94, 95] serve our purpose and prove to be the most suitable frameworks to to represent medical knowledge. For this reason, after developing the conceptual model of chronic disease management and integrating it with the CPR Ontology and HL-7 RIM, this model is formalized as CD-EMR model in order to implement it in the form of CD-EMR Ontology. The process of model formalization consists of evolving a formal model from the conceptual model by using the main concepts as the classes and further defining each concept using their properties. This formal model can later be implemented in ontological framework. As mentioned earlier, during model selection that we have chosen web ontology language (OWL) to implement

our information model in the form of ontology. In the formalizations phase we have explicated CD-EMR Model which is detailed in Chapter 5. The next step of our research was to implement this model into ontology in order to (a) achieve semantic interoperability and (b) to make our model HL7 complaint. To develop the ontology in OWL from our CD-EMR model we used Protégé and the ontology development process was guided by Methontology [71, 72], which promotes the development of ontology at knowledge level [74]. We used Methontology because it is a combo of ontology development activities from both software development processes and knowledge engineering methodologies [75]; details of methontology is explained in Chapter 2 . The whole process of ontology engineering and as well as the structure of our CD-EMR ontology i.e. classes, class hierarchy, attributes and relationships are discussed in details in chapter 5.

3.3.6 PHASE 5: EVALUATION

Evaluation is necessary to check consistency and richness of the model. Evaluation provides a multi-axial validation of the model at (a) knowledge level, (b) structurally, and (c) technically, and determines any flaws that are present in the model. In our case, we evaluated our model in four different ways which are (a) using Pelllet Reasoner to check the consistency (b) instantiation of clinical scenarios to check model richness, i.e. knowledge level (c) instantiation of HL7 based medical record in our ontology to assure semantic interoperability, and (d) evaluation against the ontological design principles i.e Bodenreider [96] principles. The details of each of the evaluation step are explained in Chapter 6.

3.4 CONCLUSION

Research methodology is the guiding principle that allows the researcher to focus on the pre-set aims. Selection or development of a proper research methodology preserves the quality of research activities and ensures the successful completion of the research within a precise timeline providing high quality research outcomes. In our research the phase of

our research methodology helped us to achieve our goals in a step-wise manner. Proper selection of knowledge sources enabled us to analyze the most relevant knowledge about chronic disease management. This in turn resulted in the abstraction of the most essential clinical, non-clinical, and procedural concepts related to the topic. The abstracted knowledge was used in the development of the conceptual model. The validation step, which was performed during the conceptualization phase allowed us to deal with the phenomenon of concept saturation. Validation of model against clinical scenarios eliminates the factor of knowledge loss at the level of knowledge abstraction. This research activity assured us that the conceptual model is now ready to formalize and can be implemented into the ontological framework using the best selected model. Even after implementation of the formal model into the ontological framework, the comprehensive evaluation of the ontological framework has eliminated all the embedded risks which were associated with the research. Hence the adaptation of knowledge based approach has guided us to pursue our research at knowledge level. We were therefore able to develop an ontology based knowledge model of EMR for chronic diseases management which is aligned with the most recent clinical, nonclinical, behavioral aspects and relevant technical trends in the area.

CHAPTER 4: DEVELOPMENT OF CONCEPTUAL MODEL FOR CHRONIC DISEASE MANAGEMENT

4.1 INTRODUCTION

The management of chronic diseases is not similar to acute diseases and emergency care [15]. Due to the long course and variable illness experience, chronic diseases need a comprehensive management plan. This treatment plan needs to be developed by mutual understanding, cooperation and acceptance of both the patient and healthcare provider, which is referred to as shared decision making in informatics literatures, and patient centric care in chronic diseases management [26, 82]. In this chapter we will develop a generic knowledge model which captures the various aspects of chronic diseases. In order to devise this knowledge model it is necessary (a) to develop an understanding of the process of chronic care and (b) search the key element of chronic disease management. Once we develop the generic knowledge model we then apply this knowledge model to formulate EMR for chronic diseases management. The characteristic features of this knowledge model are (a) it captures the longitudinal care involved in chronic disease management (b) it could later be computerized in the form of EMR ontology so as to integrate it with HL-7 messages (c) it could be rich enough to capture various multidisciplinary aspects of chronic disease management and at the same time this model is capable of covering acute illnesses. By capturing the core concepts, requirements and essential elements of chronic disease managements, our proposed ontological model should be patient centric, hold longitudinal patient information, be capable of understanding and recording information transferred in standard messaging format in order to ensure semantic interoperability.

In this chapter we will explain the formulation of our generic model for chronic disease management. We developed our model by investigation the essential components of chronic disease management mainly from two sources, which are (a) a medical literature review and (b) available models for chronic diseases management i.e. the Chronic Care Model (CCM) [26]. After abstracting the main concepts for chronic diseases management these concepts were aligned in a sequential format to achieve a systemic modular representation. After developing the chronic disease management model we integrated

this model with CPR Ontology and HL-7 Rim by mapping the similarities among them. The rational to perform mapping lies in the fact that (a) CPR provides an ontology for capturing different pieces of information the Electronic Patient Record (EPR) and (b) HL7 also provides a structure to capture workflow, and data types of HL7 help in systemic storage of patient information.

4.2 STEP OF MODEL DEVELOPMENT

The main design criteria to develop our chronic disease EMR model consist of the following steps.

Step 1: Knowledge abstraction from literature review of medical text books and models of chronic disease management to develop a model that represents the process of chronic disease management.

Step 2: Integration of the model which is developed in step 1 with CPR Ontology and HL-7 RIM by investigating and mapping the similarities among the three models.

Step 3: Validation of CD-EMR Model by using case scenarios.

In the subsequent section of this chapter we will explain in detail each of the above mentioned steps of our research which demonstrates the development of a comprehensive model for chronic diseases management.

4.3 STEP 1: KNOWLEDGE ABSTRACTION TO DEVELOP CONCEPTUAL MODEL OF CDM

In the first step of our model development we have performed a literature review to investigate the process of chronic disease management. While performing the literature review we made use of medical knowledge in order to abstract the fundamental concepts involved in care process of chronic diseases. Due to the long course and complexities of chronic illnesses it is important to develop an understanding of the nature of the diseases in order to design the comprehensive management plan. The impact of chronic diseases is massive both on the patient and families [14, 15]. For this reason the management plan of chronically ill patients should not only be confined to medical treatment of the diseases,

but it should also involve behavioral and psychological aspects to deal with the debilitating trauma that accompanies the chronic illness. Management of chronic diseases needs a continuous (longitudinal), multi-axial, and patient centric [82] intervention plan that covers all different aspects of chronic diseases. We abstracted the following components from [16], which are the assessment and intervention components of the integrative protocol to manage chronic diseases; shown in Figure 4-1a.

1. Patient Profile
2. Illness Profile
3. Intervention Planning
4. Intervention Implementation
5. Intervention monitoring.

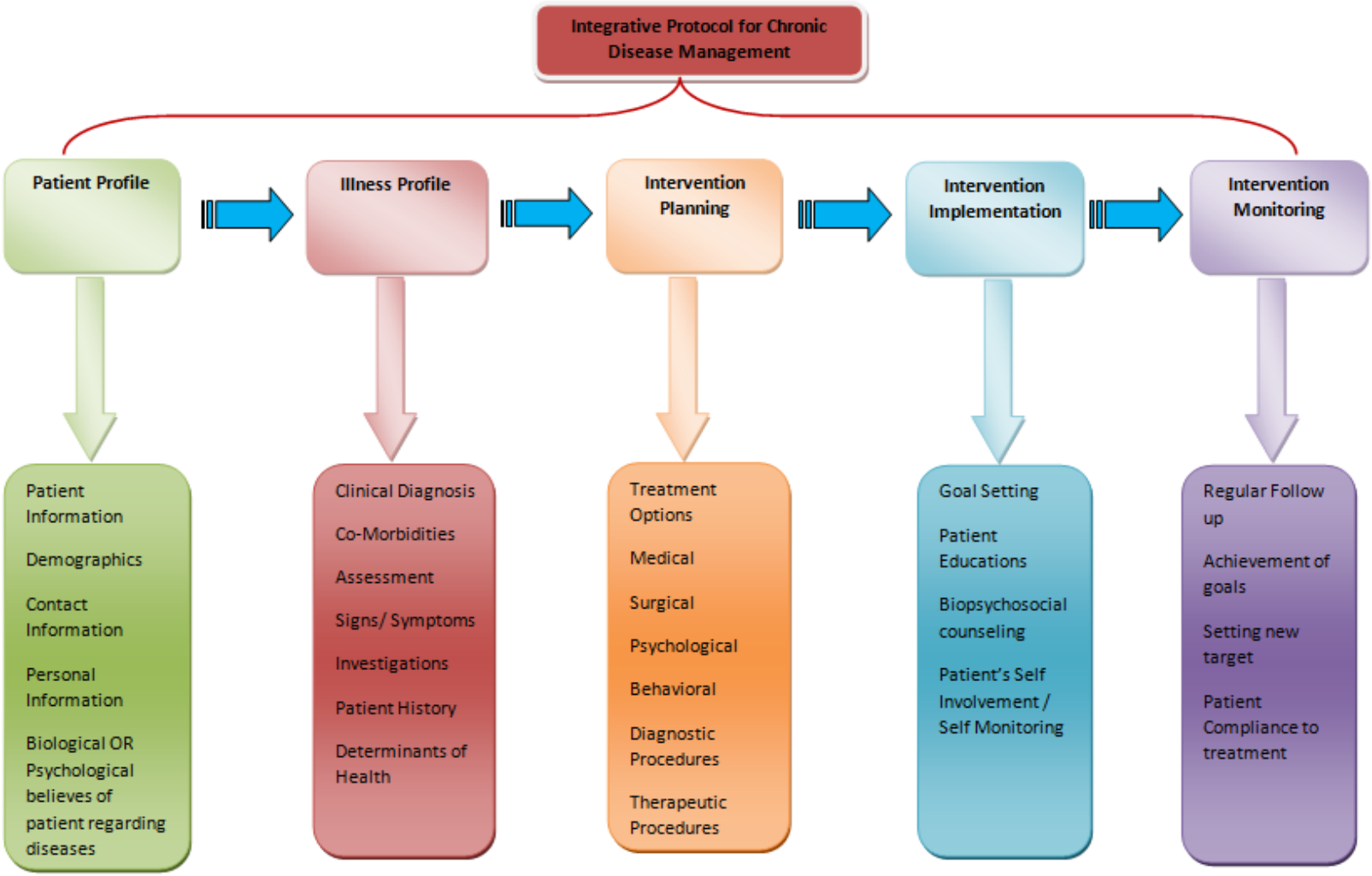


Figure 4-1a Components of the integrative protocol for management of chronic diseases

Figure 4-1a shows the five component of the integrative protocol for management of chronic diseases [16]**.** Each component covers different aspects of the chronic care process. In the subsequent section we will describe each component, and explain how we used this integrative protocol in our model development.

Patient Profile: The main aim behind developing a patients profile is to a collect each and every piece of information about the patient that can be helpful in the care management process. This profile captures the patient's general information, such as address and emergency contact information as well as patient's personal information such as weight, height, and BMI, which give an idea of general health status. The profile will also contains patients demographics that provide the information about race and ethnicity which is helpful in determining some common disease patterns associated with the particular geographical area. Information about patient's belief and religious obligations would be helpful in planning interventions. Aside from this information, an important aspect is to capture the patient's biological and psychological beliefs regarding the diseases which plays vital role in illness acceptance or treatment denial.

Illness Profile: Maintaining an illness profile helps in providing every bit of information related to the chronic disease. It includes information related to clinical diagnosis, co-morbid conditions, and illness presentation, i.e. signs, symptoms, and presenting complaints. It also covers information about the records of assessment, records of investigations, patient's history, social determinants of health, and exposure to risk factors. All this information which develops the illness profile helps in determining the state of disease, and developing a preventive or management plan.

Intervention Planning: Intervention planning includes all the possible options for treatment of the chronic condition. These could be the traditional medical, surgical or therapeutic options. Medical treatment involves drugs and medication to relieve pain and subside signs and symptoms, surgical or therapeutic options to manage surgical problems due to complication. Beside these traditional treatment

options the psychological impacts of the chronic disease also need to be treated. So the intervention planning also considers behavioral therapies to control emotional stress and psychological therapies to manage the physiological impact and lifestyle management.

Intervention Implementation: As chronic diseases are long term conditions, an important point lies in the fact that just planning the intervention is not enough to treat the disease and to get positive outcomes. In chronic diseases the essential part of intervention planning is to ensure that the plan is also implemented and the patient is following the treatment plan. Implementation is achieved by (a) providing patient education, (b) setting goal for the patient, and (c) biophysical counseling. To further explain, patient education helps in creating awareness about the diseases that increase the compliance and helps to decrease the factor of illness denial. It also develops a sense of responsibility in the patient to take control of their own health conditions which is called patient centeredness [82]. Setting goal helps in developing an urge in patients to achieve better health, it involves setting goals for the patients and encouraging them to achieve targets, which helps them to achieve what they want. Biophysical counseling helps to properly follow the treatment plan in order to get best possible outcomes.

Intervention Monitoring: In chronic diseases management planning and implementing intervention are crucial steps, but there is a need to constantly monitor the treatment. This monitoring is important to determine whether the intervention plan is working for the patient and also to ensure it is properly implemented. Monitoring is also vital because it provides room to adjust the treatment plan according the most recent needs based on disease state. If the patient condition is improving, monitoring helps to determine the positive outcomes, but if the plan is not working monitoring helps in adjusting the plan according to the needs. Monitoring is achieved by regular follow-ups in which evaluation is done, and preset goal are analyzed to check whether the patient has achieved the goals. If they have not been achieved, then new targets have to be

set. Patient compliance is evaluated, and the level of illness acceptance or denial is determined during the process of monitoring.

The integrative protocol has served as the starting point of our model development. Providing a big picture of holistic care contains in itself several important concepts. Deeply studying each component in detail provides us with several important concepts. From the five components of the integrative protocol several important concepts have been abstracted including assessment, investigations, signs and symptoms, patient history, and treatment options. This activity serves as the starting point of knowledge abstraction for development of our knowledge model. We also found that these concepts serve as the basic elements of the care process. Besides the medical text book literature we also made use of the most well know and widely accepted model for chronic disease proposed by E H Wagner [26] called the Chronic Care Model. CCM has been discussed in detail in Chapter 2. It is evident from the literature that the components of this model are most widely used [33, 84] for management of chronic diseases all over the world. For this reason we have utilized this knowledge source and reused some of the elements of this model to develop our conceptual model. Figure 4-1b shows the selected components and concepts of CCM that we will use in the development of our conceptual model.

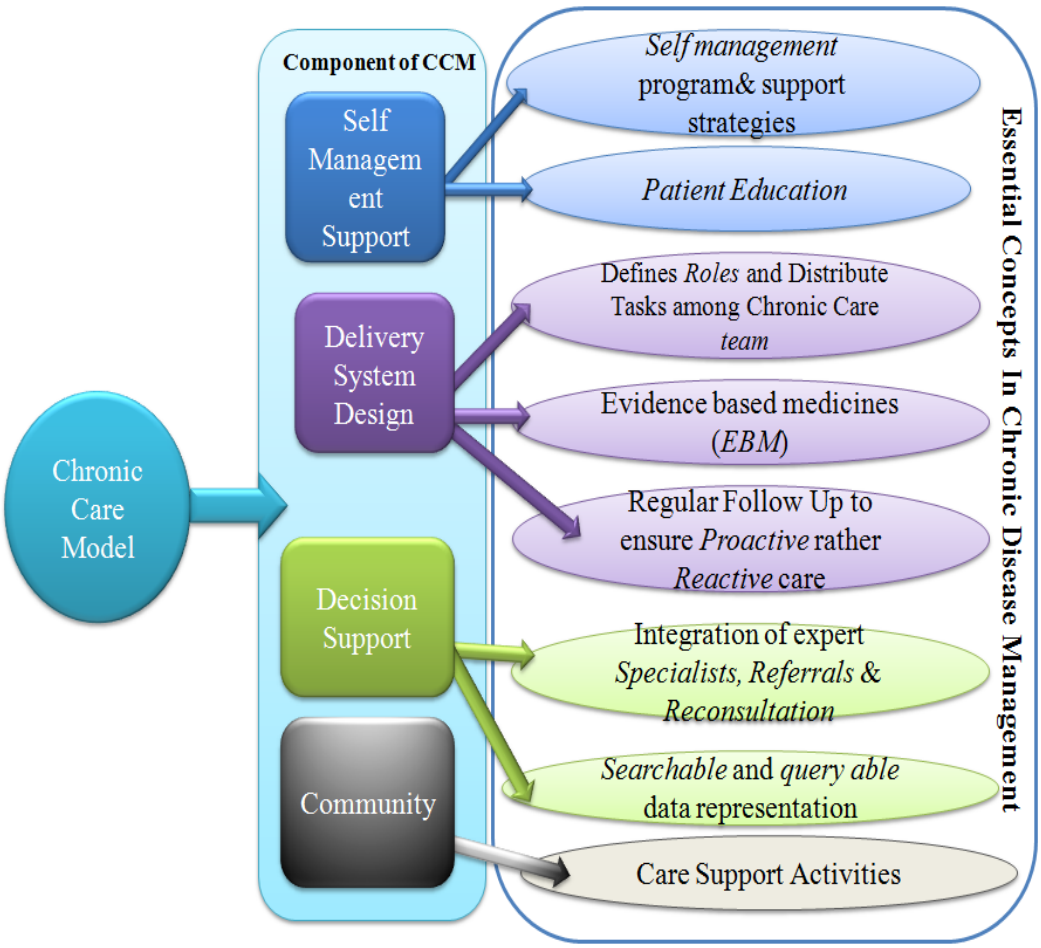


Figure 4-1b Selected components and concepts from CCM

Now we explain the reason for selecting these above components from CCM. We have selected the concepts of self-management support because it helps patients to manage their own-selves, provide them an opportunity to gain control of their conditions and hence promote the notion of patient centeredness. We found that the concepts of Patient Education and follow-up are also defined in the CCM. We have already chosen these two concepts from the integrative protocol, but we found these concepts in CCM as well, which means that the concepts of Patient Education and follow-up are common to both the integrative protocol and the CCM. When we find a concept common across several different sources it validates the importance of the concept. The concept of role is adapted from CCM to ensure the involvement of multiple healthcare providers in the

form of a chronic care team in the process of chronic disease management. Moreover, it also covers the selected concepts of expert opinion and referral to specialists to ensure the quality of care. Selection of EBM was done to ensure the care process follows the recommended care protocols for management of chronic diseases; it also helps in system evaluation and provides a mean to eliminate medical errors. The main functionally of an EMR system is to store information in a systemic manner and then provide the stored information at the point of care to support the decision making process. For this reason, we have chosen the component decision support. The reason for choosing the community component of CCM is to ensure the involvement of non-clinical and community-based bodies. These involvements facilitate the care process of chronic disease management and fulfill the non-clinical aspects, which are physical, mental, emotional, social, and spiritual, of chronically ill patients and therefore capture the notion of holistic care.

It is evident that the care in chronic diseases should be patient centric [26, 84], longitudinal and comprehensive. In the real world individuals pass through various conditions during their life spans that impact their health status. Taking this into consideration, these conditions play a vital role in disease presentation, progression and management. In Figure 4-2 with patient as the center of our model we tried to visualize various factors related to patients life span (Side A) which play important role in diseases processes and we also capture activities that occur during the healthcare encounter (Side B). So considering the patient as the center of our model we arrange the factors related to the patient life (Side A) and the concepts related to the care process (Side B) on opposite sides of the patient.

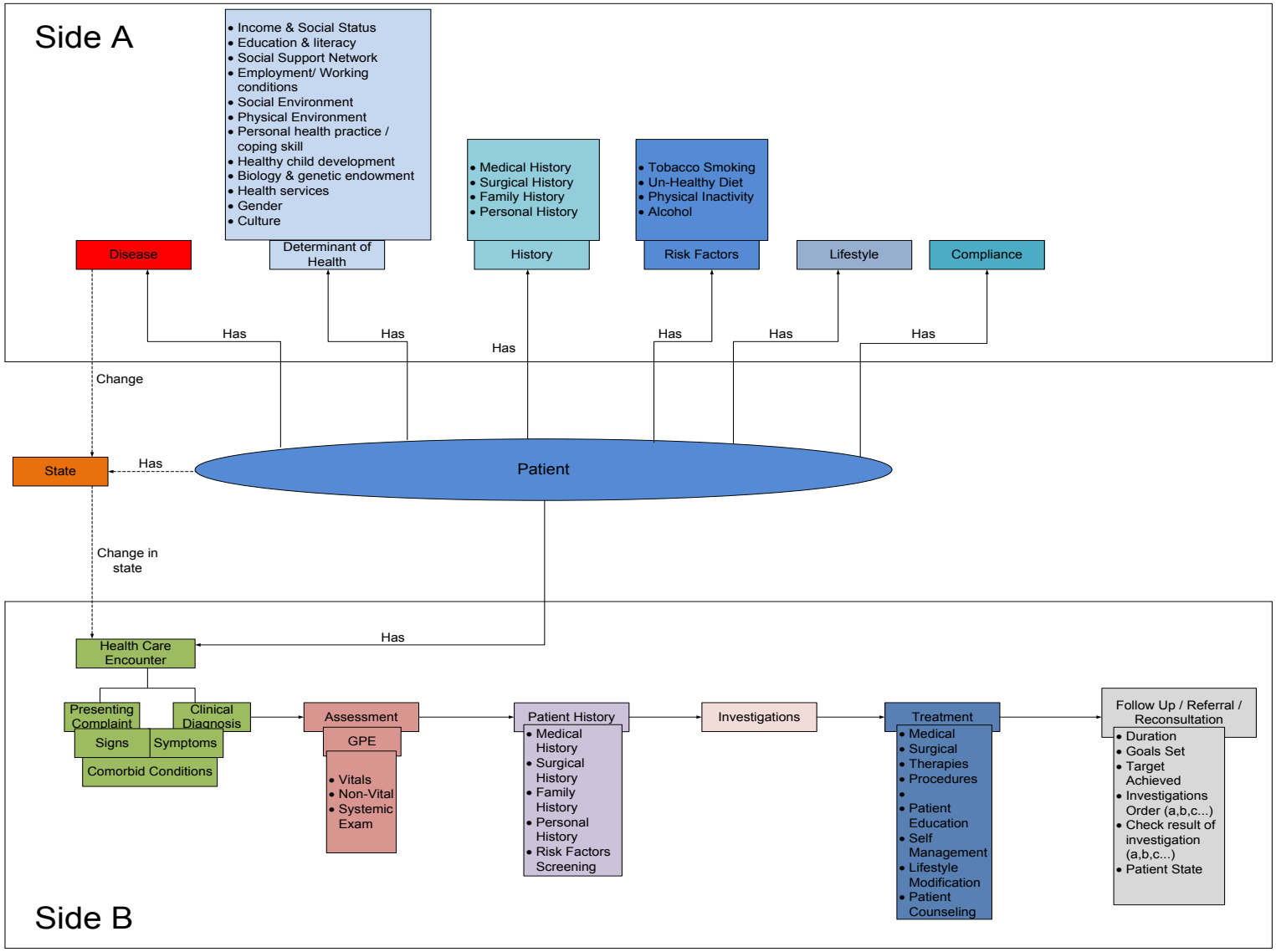


Figure 4-2 Factors related to the patient life (Side A) and the concepts related to the care process (Side B).

In Figure 4-2 (Side A) shows that, during the course of life an individual passes through different phases and faces various factors such as determinants of health, risk factors, lifestyle, and diseases. When the patient has a healthcare encounter the activities that occur during that healthcare encounter are arranged on the other side of the patient (Side B). This healthcare encounter could be due to a pre-diagnosed disease or patient could have some presenting complaints that resulted in signs and symptoms. During the care process, once the patient enters the healthcare system a thorough assessment is done, patient's history is taken and if needed, investigations are ordered. A treatment regimen is given in order to cure the ailment and finally the patient is called after a particular period of time for a follow-up visit to monitor the state of the patient. After arranging the patient factors and healthcare activities we have noticed that in most cases the healthcare encounter occurs due a change in the equilibrium of the state of patient. This change in state causes the disease to express with several presenting complaints and signs and symptoms. As mentioned earlier, during the encounter a thorough assessment is done in order to evaluate the current state of the disease and patient. During the process of assessment, vitals and non-vitals are measured and systemic examination is done. Patients history is recorded which gives an idea of the patient's medical health, any previous surgical procedure, any history of familial diseases or genetic disorder in the family, or patient personal habits such as smoking, addiction, and exposure to risk factors. Although ordering investigations is not a mandatory step, it depends on the state of patient. After patient evaluation is completed, a treatment plan is made by a mutual co-operation of the patient and the healthcare provider. The plan consists of medical, surgical or therapeutic options as needed. Along with these conventional treatment options patient education material about the disease is provided, which makes the patient aware about the disease and helps the patient to take control of the diseases by performing various tasks and activities independently (self-management support). The lifestyle of the patient is observed and modifications are advised by designating some goals and setting new targets. Close monitoring of these goals and targets must be done during the follow up visit, in which the state of the patient is evaluated once again.

After analyzing the above process, we develop connections between the patient's factors and health care process on the basis of common grounds as shown in Figure 4-3.

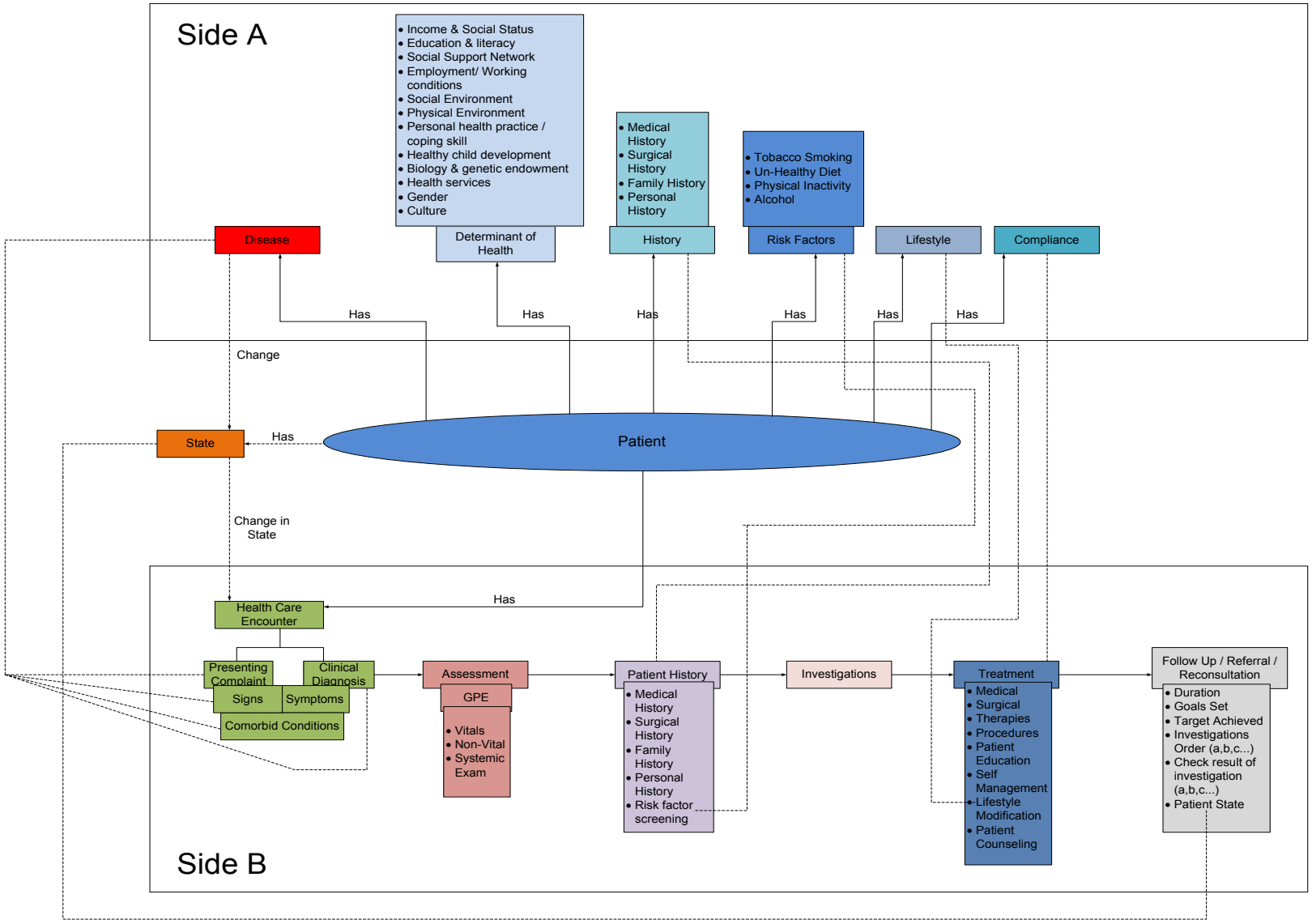


Figure 4-3 Mapping common concepts between patients factors and activities of healthcare process

Figure 4-3 shows the common concepts that occur between patient's factors and the healthcare process. By using the above five concepts of the healthcare process i.e. assessment, patient history, investigation, treatment, and follow-up; we started the development of our model for chronic disease management. In this model patient lies at the center of the care process and controls his/her own health (patient centeredness). At first we arrange these concepts in a sequential manner around the patient Figure 4-4.

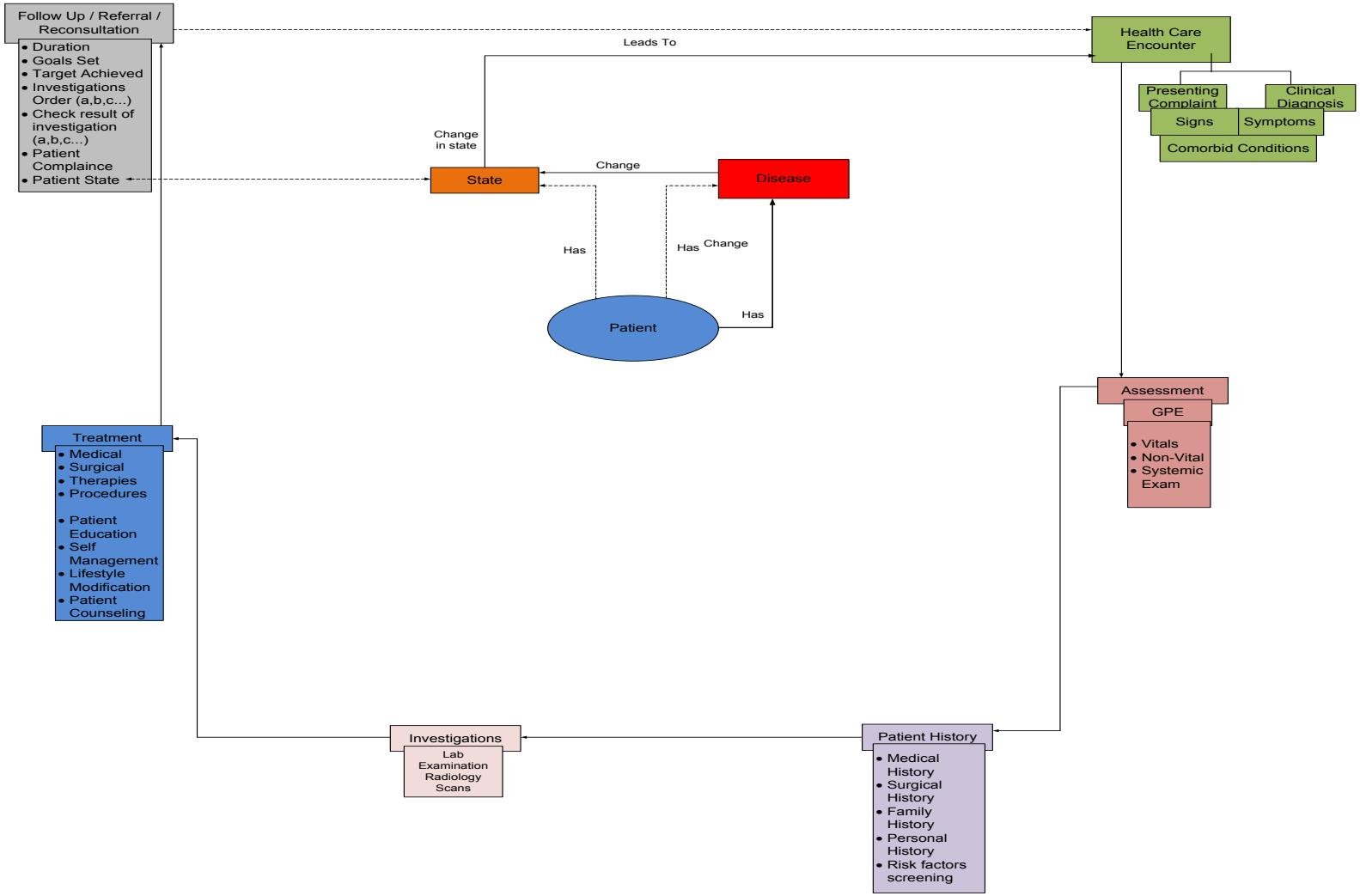


Figure 4-4 Initial phase of model development: Arranging the concepts of healthcare around the patient

After developing the initial model as shown in Figure 4-4 we further refined it by establishing the connections among the concepts, and at the same time we also added the important concept of patient physician relationship which is essential while dealing with chronic diseases. As the care process in chronic diseases is patient-centric [84] and the physician no long has the complete authority to treat patient on his own, so it is crucial to develop a well communicated and clear relationship to ensure proper treatment planning with mutual understanding and coordination [84]. While establishing the connections, the concept of disease is connected with presenting complaints, signs, symptom, and co-morbid conditions which are all the manifestations of the disease. The concepts of State is connected with the disease with a solid line which shows that the disease process is responsible to change the equilibrium of state, The concepts of assessment, patient history and investigation are also connected to the concept of State, which means that the results of assessment and investigations; and the information gathered through patient's history help in determining the state of the patient, as shown in Figure 4-5.

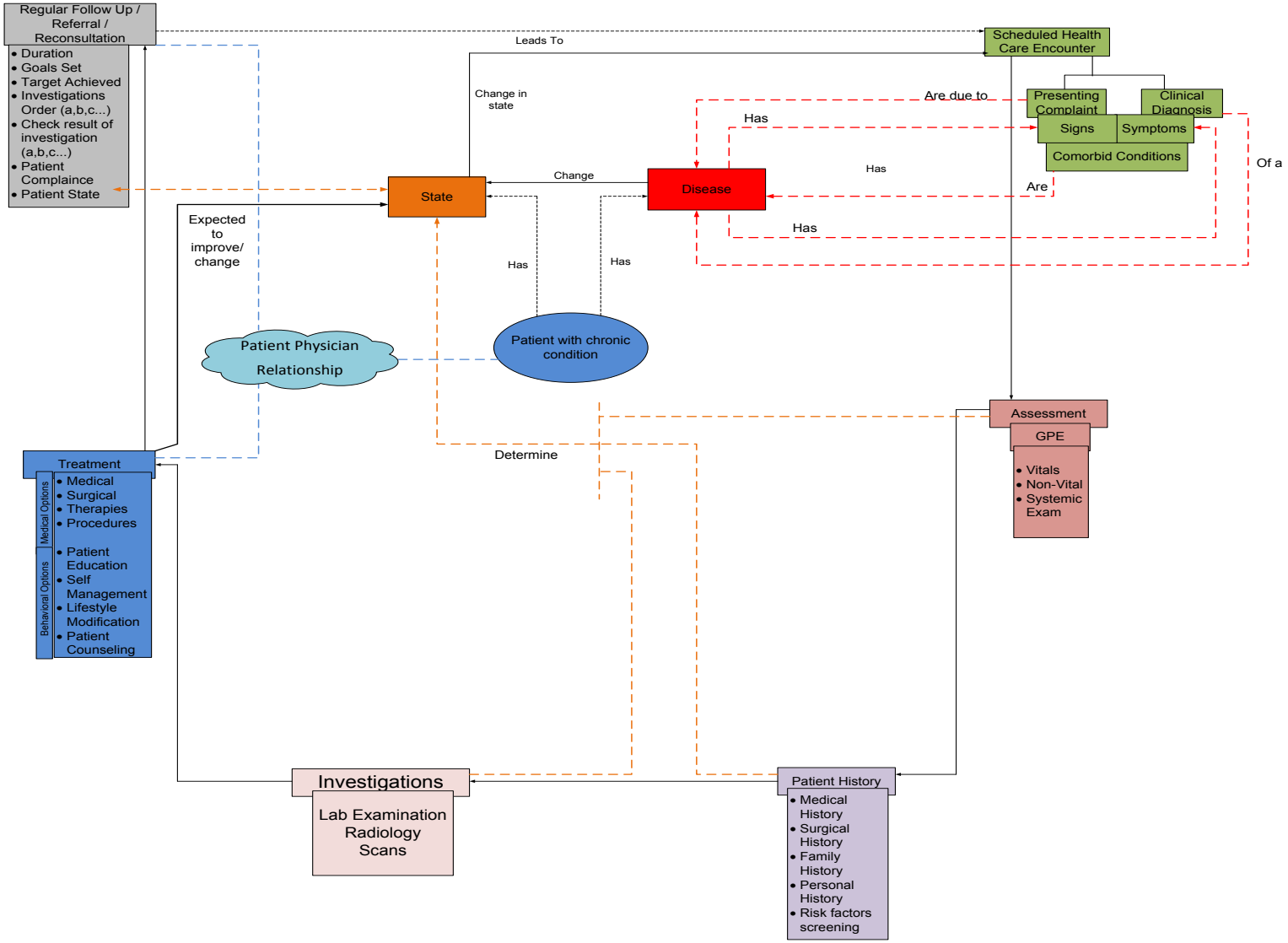


Figure 4-5 Establishing connection among the concepts of the model.

Now we will explain each of these concepts in order to develop an understanding of how we have used them in our model.

Patient: In our model we define patient as the individual who is suffering from a diseases. As we are developing a model for chronic diseases so we consider that the disease is a chronic illness. The reason for starting our model with the patient, and not with the disease itself lies in the fact that having the patient in our model helps us in developing the patient profile which is the first component of the integrative protocol [16]. While maintaining the patient profile we take into consideration three main factors, which are (a) capturing information about the patient identification, (b) contact information, and (c) personal information. The properties of each of these factors are presented in Table 4-1

Table 4-1 Properties of concept 'Patient' to maintain patient profile

Properties		Description
Identification	Name Prefix/Title	Mr, Mrs, Miss.
	Last Name	
	First Name	
	Name Suffix	Examples: Jr, Sr, III.
	Gender	Male/ Female
	Date of Birth	mm/dd/yyyy
	Health Card Number	
	Health Card Province	
	Preferred Official Language	English, French, others
	Preferred Spoken Language	English, French, others
	Primary Physician	
	Notes	

Contact Information	Address Type	Examples: business, mailing, residence
	Street Address	
	City/Municipality	
	Province/State	
	Country	
	Postal/Zip Code	
	Telephone Type	Home phone, cell phone etc
	Telephone Number	
	Phone Extension	For Work phone
	E-Mail Address	
	Emergency contact Person	
Personal Information	Religion	
	Ethnic Group	
	Education	
	Occupation	
	Marital Status	
	Height	
	Weight (BMI)	
	Clinical diagnosis	

Disease: Disease is a shift or change from the normal state of function; or in other words an abnormal or incorrect function of the organ, structure or a system of the body caused by genetic or developmental disorder, infection, toxin, nutritional imbalance or deficiency, adverse environmental factors [85, 86]. In our research we focused on chronic diseases, but at the same we have claimed that our model should provide a platform for all medical condition and aliments along with chronic diseases. We have already discussed the various aspects of chronic diseases in detail in Chapter 2. To understand

how we capture the diseases in our model some of the properties of diseases are presented in Table 4-2.

Table 4-2 Properties of concepts 'Disease' and their description

	Properties	**Explanation**
Disease	Has signs	Redness, warms, bristles, rash etc
	Has symptoms	Pain, headache etc
	Has complications	Retinopathy, neuropathy.
	Has duration	Capture Time frame
	Has state	Active, non-active
	Treated by	Role involved
	Presenting complaints	Cough, fever

Health Care Encounter: The concept of healthcare encounter, in our model, represents a patient visit to a healthcare facility. This visit could be due to due to several reasons, which include referral, follow-up, reconsultation, or it could also be due to some recent manifestation of the disease. The manifestation could be in the form of presenting complaints accompanied with signs, and symptoms. Healthcare encounter also take into consideration the notion of co-morbid conditions.

Presenting complaints are the clinical manifestation of the disease reported by the patient to the healthcare provider for example cough, fever, sleeplessness etc. Signs are the expression of the disease but are often missed by the patient and observed by the physician during the encounter. For example, abnormal redness of a body part, swelling over joints are considered as signs. Symptoms are usually told by the patient to the healthcare provider and include any abnormal feeling that the patient is having due to disease, such as headache, nausea, vomiting. The properties of healthcare encounter, sign and symptoms are given in Table 4-3a and 4-3b which show how we have used these concepts in our model.

Table 4-3a Properties of the concept ‘Healthcare Encounter’ and their description

Properties	**Description**
Name of the patient	First name, last name, suffex
Reason for encounter	Follow up visit, referral, ER encounter
Attending Healthcare person	Physician, Therapist, Dietician
Clinical Diagnosis	
Co-morbid conditions	
Presenting Complaints	
Date and time of onset	

Table 4-3b Properties of the concepts ‘Signs’ and ‘Symptoms’ and their description

Properties	**Description**
Name	
Anatomical site	The exact anatomical location e.g. lateral side of fore-arm, right inguinal region, palmer surface of index finger.
Aggravating factor	Sitting position, light or dark,
Relieving factor	Lying down in supine position.
Event related periodic interval	Any event that trigger the symptom. Is the symptom is periodic in nature.
Date of onset	

Time of onset	
Age at onset	

Assessment: During healthcare the encounter assessment of patient is done by performing the clinical examination. The assessment in our model represents the notion of General Physical Examination (GPE) of the patient. During GPE the physician performs vital-signs measurements, non-vital examination, and systemic examination. Vital-signs measurement includes, recording Blood Pressure, Pulse, Respiration Rate and Temperature. Non-vital examination includes assessment of anemia, chilonche, jaundice, thyroid examination, palpable lymph-nodes etc. Systemic examination includes CVS exam, CNS exam, abdominal exam and respiratory exam. Tables ,4-4, 4-5, and 4-6 shows how we have used these concepts in our model

Table 4-4 Properties of the concept 'Vital' and their description

Properties	**Description**
Name of Examination	Temperature, BP, Pulse etc
Results/ value of Exam	Exact values
Normal Range	
Rate	
Rhythm	
Volume	
Date and Time of Exam performed	
Duration	
Site of Examination	Anatomical site of exam
Exam performed by	Role ID

Table 4-5 Properties of the concept ‘Non Vital’ and their description

Properties	**Description**
Name of Examination	Thyroid exam, lymph nodes exam, JVP etc
Results/ value of Exam	Normal, abnormal, raised etc
Normal Range	
Date and Time of Exam performed	
Duration	
Site of Examination	Anatomical site of exam

Table 4-6 Properties of the concept ‘Systemic-Exam’ and their description

Properties	**Description**
Name of Examination	CVS, CNS, Abdominal
Examination Finding Normal	
Examination Finding Abnormal	
Audible Sounds Normal	Gut sounds
Audible Sounds abnormal	Murmur, crept, crunckle
Organomegally	Organ enlargement e.g. Hepatomegalley , spleenomegally
Reflexes	Hyper reflixia, brisk
Date and Time of Exam performed	
Duration	
Site of Examination	Anatomical site of exam

Patient History: The concept of patient history focuses on capturing the various aspects of a patient's life that are related to the disease process. In order to make a systemic and well organized record of the events related to disease, we further categorize the concept of patient history into five categories Figure 4-6; which are medical history, surgical history, family history, personal history, and history related to risk factor exposure.

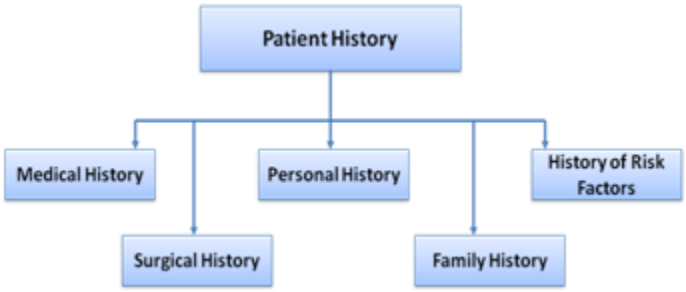


Figure 4-6 Categorization of the concept 'Patient History' into medical, surgical, family, personal history, and history related to risk factor exposure

In the medical history section, the record of all past medical conditions and ailments is maintained. This record include the past medical conditions, treatment taken by the patient, record of drugs and therapies taken by the patient, any adverse reaction to the drug or treatment. In the surgical history section, the record of previous surgical procedures is maintained, which includes the reason for surgical procedure, any complication during or after the surgery, recovery, progress, and the information about the procedure, i.e. time and date of procedure, who performed the surgery, pre and post-operative orders. In the family history section, a record of any diseases or genetic disorders that runs in the family is made. This helps to determine if there is any related trend or risk of having a disease in the family. In the personal history section, the record of all personal activities and habits is made which includes, smoking, alcohol intake, addiction, sleep habits, allergies or adverse reactions. We also maintain a record of risk factors exposure, duration of exposure, the extent of exposure, the age at which the individual is exposed to risk factors. Table 4-7 shows the properties of concepts Medical, Surgical and Family History. Table 4-8 presents the properties of the concepts Personal history and Table 4-9 presents the properties of the concepts Risk Factors.

Table 4-7 Properties of concepts ‘Medical, Surgical and Family History’ and their description

Properties		**Description**
Start Date		
Age at Onset		
Diagnosis / Problem Description	Disease	A description that identifies the family history item or a problem.
	Surgical Problem	
	Allergy	
	Addiction	
Treatment	Medical	Type or nature of the treatment delivered
	Surgical	
	Therapies	
	Counseling	
	Community Services	
Complication		Complication during or after surgeries.
Relationship		Relationship to the person.
Notes		Field to capture additional notes about family history.
Record for patient		
Recorded By		Role ID

Table 4-8 Properties of the concept ‘Personal History’ and their description

Properties		**Description**
Diagnosis / Problem Description	Disease	A description that identifies the family history item or a problem.
	Surgical Problem	

Treatment	Medical	Type or nature of the treatment delivered
	Surgical	
	Therapies	
	Counseling	
	Community Services	
Start Date		
Age at Onset		
Alcohol Intake		Occasional, regular or heavy drinker, # of drinks per day, per week etc
Smoking		Occasional, regular or chain smoker, # of packs per day
Addiction		
Bowel Habit		
Micturation		Any issues with urinations burning, incontinence, # of time wake up during night
Sleep Habit		Insomnia, hyper-somnia , use of sleep inducing drugs
Socioeconomic status		Jobless, occasional worker, or permanent employ,
Allergies and adverse reactions	Offending Agent	Text description of offending agent, whether drug or non-drug.
	Start Date	Start Date of Allergy or Adverse Reaction System should allow for an exact date, or an approximate date, if the exact date is unknown.

	Severity	Severity of the allergy or adverse reaction as identified by the provider.
	Reaction Type	Identifies reaction as an allergy or adverse reaction.
	Reaction Description	Type of reaction such as rash and/or bristle etc
	Recorded Date	Date the allergy/adverse reaction is recorded in the CMS
Notes		Field to capture additional notes about personal history.
Record for patient		
Recorded By		Role ID

Table 4-9 Properties of concepts 'Risk factors' and their description

Characteristics	**Explanation**
Risk Factor name	Examples: nicotine, alcohol, asbestos, etc.
Exposure Details	Specific agent details of the exposure Examples 2 packs per day; 10 bottles of wine per week, etc
Age at Onset	
Start Date	
End Date	
Notes	Field to capture additional notes about a risk factor
Snomed CT Code	

Investigations: In chronic diseases, investigation results help in determining the progression of the disease's state. There is a variety of investigations, which includes: blood test, such as, CBC, UCE, PT and APPTT; urine tests, such as urine D/R and urine C/S; sputum analysis; X-Rays, such as chest X-Ray (CXR) and knee joint X-Ray; Ultrasounds; EKG. All these investigations are commonly ordered at some point for patients suffering with chronic diseases. In our model investigation is the main concept; in order to cover the various types of investigations, we divided the main concept into two sub concepts, which are: laboratory test and radiology and scan as shown in Figure 4-7.

Figure 4-7 Categorization of 'Investigation' into 'Laboratory Tests' and 'Radiology and Scan'

The sub concept Laboratory test will cover all the tests that are related to the laboratory, such as, various types of blood tests, serum tests, urine, stool and sputum tests. The other sub concept radiology and scan cover different types of X-Rays, ultrasound scans, EKG etc. Table 4-10 present the properties of the concept 'Laboratory tests', while Table 4-11 present the properties of the concept 'Radiology and Scan'.

Table 4-10 Properties of the concept 'Laboratory tests' and their description

Properties	**Description**
Laboratory Test Name	Test name as reported by laboratory
Collection Date/Time	Date & Time the specimen was collected.
Test Description/Name	Test Name or description as

	entered by CMS or system user
Test Result Value	Test results may be numeric or text, depending on the requested text
Result Unit of Measure	Unit of measure as supplied by the lab associated with the test result value.
Reference Range Low	Numeric Reference Range limit, when available
Reference Range High	Numeric Reference Range limit, when Available
Reference Range (Text-based)	When lab-provided reference range cannot be depicted numerically.
Abnormal Indicator	Flag to indicate a test result is deemed normal, abnormal, or unknown.
Notes from Lab	
Physician Notes	Field to capture additional physician notes about lab result.
Laboratory Name	Lab responsible for issuing the test result
Test Code	Test Code Reported by the Laboratory.
Lab Requisition Date/Time	Date & Time the lab test was ordered
Date/Time results entered in CMS	Date & Time the lab result is received on the CMS.

Reviewer Identity	Provider who signs off on lab result.
Review Date/Time	Date & Time lab result was reviewed (signed off)
Record for patient	
Encounter ID	
Ordered by	Role ID
Snomed CT/ LOINC Code	

Table 4-11 Properties of the concept 'Radiology and Scan' and their description

Properties	**Description**
Name of scan	X-Ray, U/S, Cath scan, EKG
Date/Time of scan	Date & Time the scan was done.
Physician Notes	Field to capture additional physician notes about scan result.
Laboratory Name	Lab responsible for issuing the scan result
Test Code	Test Code Reported by the Laboratory.
Lab Requisition Date/Time	Date & Time the scan was ordered
Date/Time results entered in CMS	Date & Time the lab result is received on the CMS.
Reviewer Identity	Provider who signs off on lab result.
Review Date/Time	Date & Time lab result was reviewed (signed off)

Encounter ID	
Ordered by	Role ID
Snomed CT/ LOINC Code	

Treatment option

In the initial phases of our model development, when we were mapping the activities that occur during the healthcare encounter, we mention the concept of treatment options. This concept has various available options to manage the health problem. As discussed in Chapter 2, our health care system is single-dimensional, discreet, segmented, episodic, diseases oriented and institutional [23, 82], which is not aligned to deal with the multi-dimensional nature of chronic illness. When we studied the process of chronic diseases management in depth [24, 26, 84] we came across the fact that the concepts of patient education [82], self-management support [26, 87] and lifestyle modification [84] are not a part on conventional treatment options, but they themselves, are independent concepts and play a vital role in the management of chronic care [84]. The Chronic Care Model also highlights the importance of self-management [26, 87], patient education [26, 82] and lifestyle modification [26]. In addition to these concepts, involvement of several non-health related services and persons have also proven their vital role and hold an important position in chronic diseases management [26, 84]. For this reason, we have included this vital concept in our model in the form of 'Care Support Activities', which cater to the community-based services as advised by Wegner et al. in CCM [26, 84]. In our model instead of keeping treatment option we adapted the notion of intervention planning. We further divide this main concept, intervention planning into (a) Medical options, and (b) Behavioral options. Medical options cover the available medical, surgical and other therapeutic options. On the other hand, behavioral options cover options such as self-management, patient education, lifestyle modification, and care support activities. Figure 4-8 shows this division.

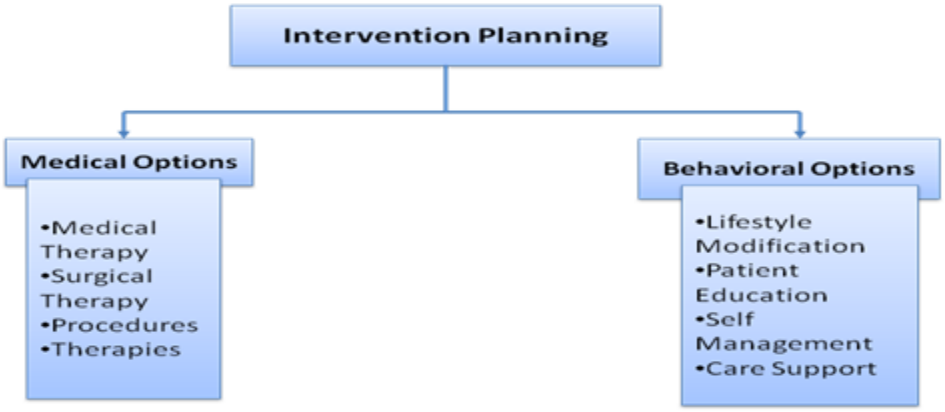


Figure 4-8 Division of Intervention Planning into Medical and Behavioral Options

In order to foster holistic care to chronically ill patients, we realize that after a proper assessment and determination of patient state proper intervention planning is essential to provide the effective treatment to the patient. In planning this holistic care, the intervention planning not only includes the traditional treatment options, such as medical, surgical and therapeutic options, but at the same time, we make use of the concepts, such as lifestyle modification [26, 84], self-management support [26, 87] , patient education [82] and support care activities [26, 84]. Now we will describe each of these concepts in the subsequent section.

Medical Therapy: This concept covers the variety of therapies available for medical treatment of the diseases. These therapies mostly include the usage of different types of drugs and medication through various routes. These therapies could include the general analgesic that can be used as needed, to deal with the a general problem such as pain, or could be in the form of a prescription, which contains more precise information about a specific drug, for a particular patient, in a defined dose, at the prescribed time, at a specified schedule and for a particular duration. Table 4-12 show the properties of the concept medical therapies.

Table 4-12 Properties of the concept 'Medical Therapies' and their description

Properties	**Description**
Start Date	The start date of the current

		prescription
End Date		The end date of the current prescription
Prescription Written Date		
Medication Name		
Drug	Indication	
	Contraindication	
	Route of excretion	
	Allergies	
	Adverse Reaction	
Dosage		Once a day. Twice a day
Drug Strength		
Frequency		8 hourly, 6 hourly
Number of Refills/Repeats		
Last Refill Date		
Route		Per oral, I/V
Duration		No. of days
Patient Compliance		Typically used to indicate whether the patient is compliant with the medication as prescribed
Prescription Instructions		Refers to directions for use.
Prescribed By		

Surgical therapy: In our model, the concept of surgical therapy is used to cover various different types of surgical procedures. This concept will cover both the major and minor surgical procedures. In this concept we will cover every bit of information related to a surgical procedure. This information could be in the form of: the type of anesthesia used;

the name of the surgeon who performed the surgery; pre- and post-operative orders; surgical and anesthesia notes; nursing orders etc. Table 4-13 further explain the properties of this concept.

Table 4-13 Properties of the concept 'Surgical Therapies' and their description

Properties	Description
Name of surgical procedure	
Type of Anesthesia used	GA, Spinal, Epidural, Local
Performed by	Role ID
Role Involved	Surgical Nurse, OT staff
Pre-Operative orders	Instructions before surgery
Operative Notes	Description of surgical procedure
Post-operative orders	Orders to follow after surgery
Anesthesia Notes	Report by Anesthetist
Complications	Any complications during or after the surgery
Date and Time of procedure	
Nursing orders	

Therapies: There are several different types of therapies which are different from medical and surgical approaches and are commonly used as a part of treatment for chronic patient. These therapies include physiotherapy, psychotherapy, respiratory therapy, music therapy or spiritual therapy etc. In our model the concept of therapies covers the variance of available therapies and their different aspects, such as what is the goal of therapy, who prescribes the therapy, what is the duration of therapy, and who performs the therapy. Table 4-14 provides a detail of the characteristics of this concept.

Table 4-14 Properties of the concept ‘Therapies’ and their description

Properties	Description
Name of Therapy	Physiotherapy, psychotherapy, , music therapy,
Prescribed by	
Performed by	Role ID
Role Involved	Physiotherapist, psychiatrist etc
Therapy start date	
Therapy end date	
Recommended duration	
Patient compliance	
Complications	
Notes	
Target of therapy	

Procedure: In the routine practice there are certain activities that are neither specifically surgical procedures nor therapies. These include applying cast on a fracture limb, sutures, maintaining I/V line, nebulizing a patient with breathing difficulty etc. In our model the concept of procedure covers the details of all such activities. The characteristics of this concept are given in Table 4-15

Table 4-15 Properties of the concept ‘Procedure’ and their description

Properties	Description
Name of procedure	IV, IM Injection, blood transfusion, sutures, putting plaster cast on fracture.
Prescribed by	
Performed by	Role ID

Procedure date and time	
Reason for which procedure is performed	Fracture limb, cut wound
Recommended care	
Patient compliance	
Complications	
Notes	

Lifestyle Modification: Lifestyle modification allows the physician to evaluate a patient's lifestyle and habits. After evaluation some changes in lifestyle that are necessary to achieve good health without any medical treatment were advised by developing a plan with mutual discussion between patient and the physician. These changes could be in the form of the introduction of physical activities to eliminate a sedentary life style. It could also be in the form of dietary modifications such as following a particular diet plan for diabetic patient or low cholesterol diet plan for patients with atherosclerosis, hypertension or coronary artery diseases. These modifications not only have a direct impact but sometimes actions such as introductions of physical activities directly help in elimination of sedentary lifestyle, and indirectly help the patient to overcome stressful routines or situations and thus coupled their benefits by reducing the stress levels in daily life. There is a particular pattern to introduce these changes in one's life, which make these changes more effective and easy to monitor. Lifestyle modification was done be setting targets and these targets ultimately help the patient to achieve a particular goal. Table 4-16 shows the properties of this concept.

Table 4-16 Properties of the concept 'Lifestyle modification' and their description.

Properties	**Description**
Lifestyle Evaluation	Sedentary, active
Physical activities	Sports activities, exercise, aerobics etc.
Dietary Intake	Dietary habits
Stress levels	Due to work load, stressful

	domestic situations,
Goal settings	
Treatment targets	
Patient counseling	
Record for patient	
Encounter ID	

Self-Management Support: This concept allows the patients to manage some of the health problems on their own. Self-management support provides authority and sense of responsibility to the patient. It enhances: health behaviors, which includes exercise, cognitive symptom management, and communication with physicians; self-efficacy, which is one's power or ability to deal with a situation, in other words, it is also defined as the willingness of the patient to perform a task; and health status, which includes, fatigue, shortness of breath, pain, role function, depression, and health distress [88]. Self-management support improve patient's problem solving skills [88] which in turn provides confidence by enabling them to manage their health problems. The overall effect is reduction in unnecessary visits to the emergency department [88]. Sometimes proper training is needed to teach some of the procedures such as self breast examination in the case of breast cancer patients. In most cases, patient education material is really helpful in increasing awareness and learning new skills and techniques, which helps them in self-management. Table 4-17 show the properties of the concept 'Self-Management Support'

Table 4-17 Properties of the concept 'Self-Management Support' and their description

Properties	**Description**
Self Monitoring	Self examinations like breast exam, foot and nail exam in diabetes care
Problem solving skill	
Patient Training	
Self management support tool kit	If following any of the available self management

	support tool kit
Level of Self-Efficacy	Low, high or moderate
Goal setting	
Patient counseling	In case if patient need counseling in case to deal with the factor, such as illness denial, treatment refusal
Treatment target	

Patient Education: Providing patient educations material helps the patients to become more aware about their diseases and health status. It also helps in provision of EBM because of the adoption of a particular CPG or clinical pathway to treat the ongoing disease. Knowing more about the disease helps the patient to follow the treatment plan in order to get the best possible outcome. Providing the knowledge and information about the diseases helps to modify patient behaviors and their beliefs toward the disease to counter the phenomenon of illness denial. Table 4-18 shows the properties and the description of the concepts 'Patient Education'.

Table 4-18 Properties of the concept 'Patient Education' and their description

Properties	**Description**
Evidence based medicine	EBM recommendation about the disease.
Clinical practice guideline	
Care plan	General disease care plan or patient specific care plan
Institution specific care pathways	
Source/ Reference	
Patient Training	
Medium of Patient education	Face to face, text messages, e-mails, mails etc
Patient counseling	

Behaviors Modification	
Treatment target	
Record of patient	
Encounter ID	

Support Care Activities: As mentioned earlier, the management of chronic diseases also involves several non health related professional [84] such as social workers, long-term care team and also sometime spiritual and religious persons. Several different kinds of activities like group meetings, social gatherings and musical therapies sessions help in provision of care for chronically ill patient. Considering these activities while planning the intervention for chronic disease is essential because by participating in these activities the patient gets a chance to meet with other individuals who have similar problem; they get a chance to realize the fact that they are no alone in this condition, which helps them to overcome the notion of stigma. These activities allow the involvement of non-health professional and community services in the care of chronically ill patient. Our model captures this important concept as well, the properties and the description of which is given in Table 4-19.

Table 4-19 Properties of the concept 'Support Care Activities' and their description

Properties	**Description**
Community Services	Receiving or a part of any community program or group
Long-term care team	Associated with any long-term care facility or team.
Nursing Home	Receiving services from a nursing home or LTC facility
Social marketing and other population health strategies	Health promotion
Treatment target	
Record of patient	
Encounter ID	

After addition of all these concepts we finalize our model for chronic diseases management. In this model we have cover all possible options available for chronic care and also attempts to captures various relationships that are present in chronic care management. The model is shown in Figure 4-9.

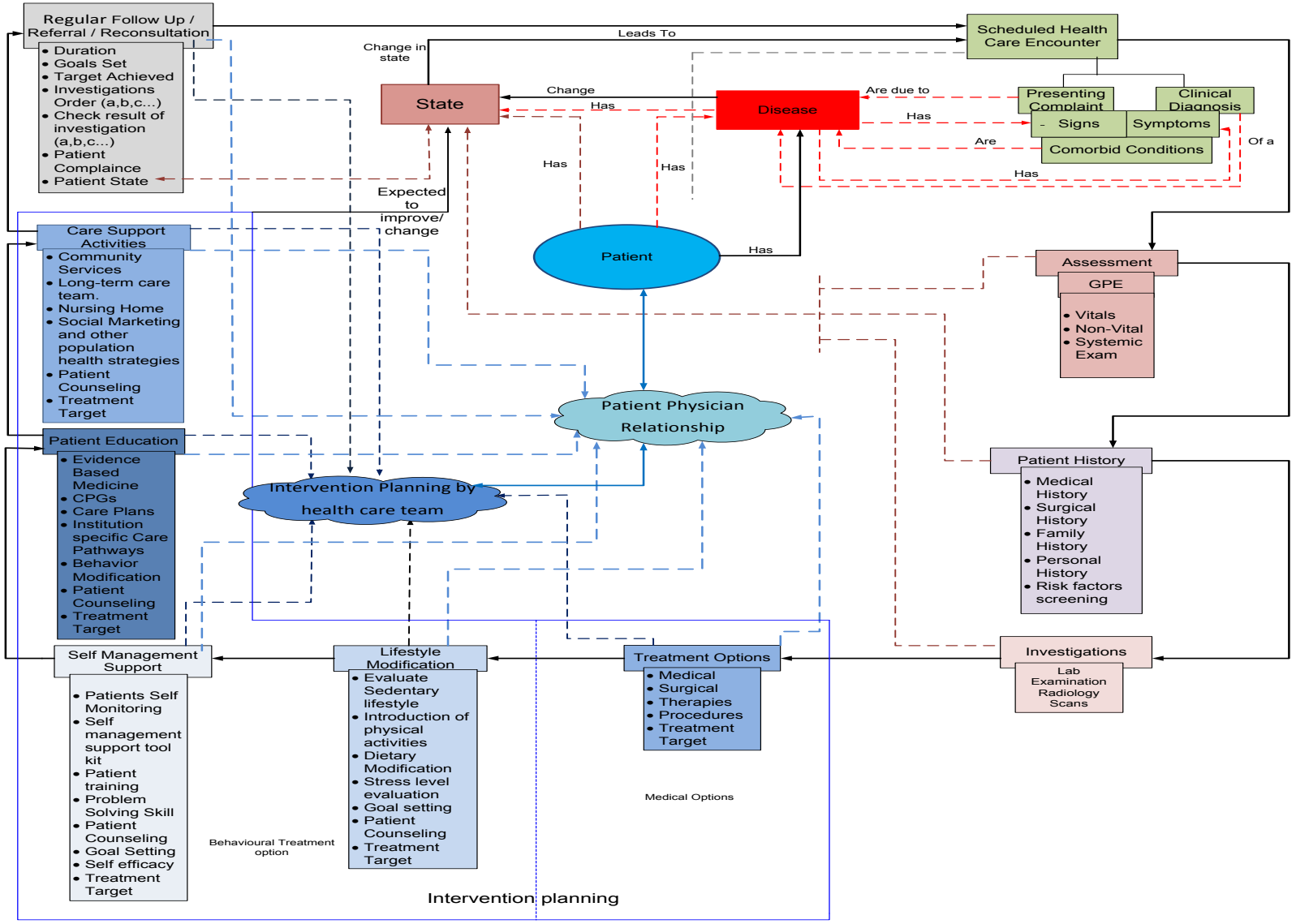


Figure 4-9 Conceptual model of Chronic Disease Management

4.3.1 DISCUSSION

During the development of the conceptual model, we successfully captured the phases of integrative protocol [16]. The concept of Patient in our model covers the various aspects of patient profile. The concepts of disease, healthcare encounter, patient history and investigations helps in developing the illness profile, by capturing the various key elements that create the illness profile. These key elements are signs, symptoms, presenting complaints, vitals, non-vitals, investigation results, information about previous experiences of disease in the form of patient history, and risk factors. After developing the patient and illness profile, the notion of intervention planning is covered in our model by providing every possible treatment option, which includes both the medical treatment options as well as behavioral treatment options, to manage the pathology and the impact and stigma of the chronic diseases. As discussed earlier simply planning the right intervention in not enough to achieve the best possible outcomes, which occur when the plan is properly implemented and followed by the patient. Successful implementation can be achieved by providing awareness and education to the patient about the disease, which produce a sense of responsibility and enhance the patient's level of compliance towards the treatment. Our model covers the notion of intervention implementation by providing patient education, setting goals for the patient, and involvement of the patients in performing certain tasks by themselves in the form of self-monitoring and self-management, which in turn help in successful implementation of the intervention plan. Planning the intervention implementation does not guarantee that the patient is following the plan, so proper evaluation or monitoring of the plan is done after a certain period of time. Intervention monitoring is achieved in our model by planning scheduled healthcare encounters in the form of follow-up, referral or reconsultation, during which patient evaluation is done and the status of the pre-set goals, whether achieved, partially achieved or not achieved, is analyzed.

Besides providing the every possible treatment options in the form of intervention planning our model also represent several connections and participations. These connections and participations are presented mostly with dotted lines in our model as shown in Figure 4-9 and represent the connection of the concepts with each other. In the

model all the concepts of the possible treatment options and the concept of follow-up/referral/reconsultation are connected to two concepts which are: *Intervention planning by the healthcare team* and *Patient-physician relationship*. The first connection of all possible treatment options and the concept of follow-up/referral/reconsultation with *Intervention planning by the healthcare team,* means that while planning the intervention the healthcare team will consider all these available options. The second connection of all possible treatment options and the concept of follow-up/referral/reconsultation with *Patient-physician relationship* represent the idea that by developing good relationships with the patient the healthcare provider must discuss all possible options with the patient in order to choose the best possible options to plan the treatment.

We have claimed that our model will be patient-centric and longitudinal in nature. Patient-centered care presumes active involvement of patient in development of the intervention plan. In our model we have three concepts, namely Intervention planning by healthcare team, patient physician relationship, and patient with chronic diseases; all three concepts are connected with each other with a solid line, as shown in Figure 4-9. By connecting these concepts we mean that the notion of patient-physician relationship emphasize the fact that developing a strong, trustworthy, and healthy relationship between the patient and the healthcare provider is necessary to achieve active participation and involvement of the patient in developing the intervention plan for chronic diseases. Discussing every possible treatment option with the patient helps to get patients' views about what treatment option is most suitable for them and helps plan the intervention according to their needs. Once the treatment plan has been developed then patients are not on their own once they leave the doctor's office; our model provides the notion of scheduled healthcare encounters, which help the patients visit the healthcare facility according to a planned schedule, making our model longitudinal in nature.

4.4 STEP 2: INTEGRATION OF THE CHRONIC DISEASE MODEL WITH CPR ONTOLOGY AND HL-7 RIM

In this step of our model development, we will integrate our chronic disease model with CPR ontology, and HL-7 RIM. This integration was achieved by performing mapping of similar concepts, which exist among the three models. The rational for performing this

mapping is to align and integrate our conceptual chronic disease model with the standard ontological framework (CPR ontology) and messaging standard (HL-7 RIM). This integration helps us to achieve our goal, which is to develop an Ontology based, HL-7 complaint and semantically interoperable EMR for chronic diseases management. In order to perform the mapping, we first split our chronic disease model into two parts, (a) Patient Evaluation, and (b) Intervention Planning as shown in Figure 4-10. Patient evaluation begins with the healthcare encounter, through evaluation of signs, symptoms, and presenting complaints; assessment of the patient by performing the general physical examination, which includes recording vital-signs, clinical examination of non-vitals, and systemic review; recording of a detailed patient's history; and review of previous investigation results or ordering of new investigations if needed. After the evaluation, intervention planning was done by considering several available options. As explained earlier our model captures the patient centric approach [82] to develop the intervention plan.

The splitting of our model into Patient Evaluation and Intervention Planning has served two purposes: (a) It removed the complexities, which were in the model in the form of connections and participations, and (b) The splitting separated the main concepts from the others, which serve better to perform the conceptual mapping among the concepts of working models. As mentioned earlier in Chapter 3, the three working model are structurally different, which means that the chronic disease model is a conceptual model which we have developed during our research, CPR is an ontological model, and HL-7 RIM is the messaging standard for electronic data exchange. Due to structural dissimilarities, the process of mapping [89] was done manually on the basis of domain knowledge. We pursue the mapping step in two stages. First, the mapping between the chronic disease model and CPR ontology was performed, and second the mapping between the chronic diseases model and HL-7 RIM was done. In the subsequent sections we will explain each stage of the mapping process followed by the results of the stage.

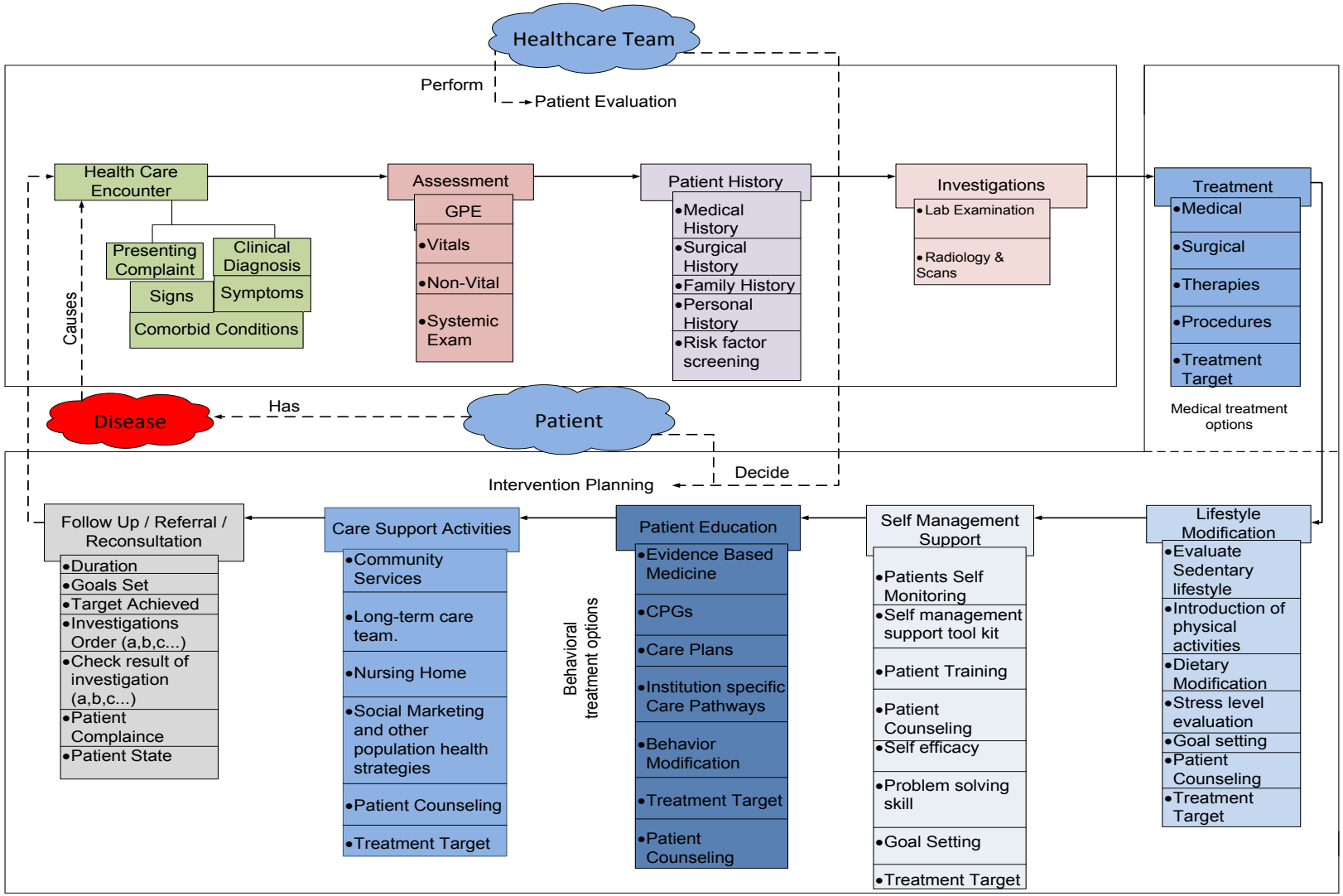


Figure 4-10 Splitting of Conceptual Model of Chronic Disease Management into Patient Evaluation and Intervention Planning to perform mapping

4.4.1 MAPPING BETWEEN CHRONIC DISEASES MODEL AND CPR ONTOLOGY

Mapping between the conceptual chronic diseases model and CPR Ontology was done manually, which means each concept was studied in detail in one model and search of similar concepts was done in the second one. During the mapping process we found several concepts that have an exact match between the two models, such as, the concept of *Signs* in our model is perfectly matched to *cpr:sign* and *cpr:sign-finding*; similarly the concepts *Symptoms* and *Clinical Diagnosis* are also perfectly matched to *cpr:symptom-finding* and *cpr:clinical-diagnosis* respectively. Besides these perfectly matching concepts, we found some concepts in our conceptual model that do not have a perfect match in CPR Ontology. When we studied the concepts of CPR ontology we found that, although there is no perfect match for such concepts in CPR Ontology, there exist some concepts that serve the same purpose and are used with the same meaning. For example, we have the concepts of *Disease* in our model and we found the concept *cpr:medical-problem* serves the same purpose, so we mapped diseases to *cpr:medical-problem.* Similarly, the concept *GPE* of our model was mapped to *cpr:clinical-examination; Radiology and Scans* was mapped to *cpr:image* and *cpr:diagnosic-image*; *Therapies* was mapped to *cpr:physical-therapy* and *cpr:psychological-therapy*. Due to the structural differences between our model and CPR Ontology, we found a concept, *cpr:temporal-entity*, in CPR Ontology that is intrinsic to ontological framework. In ontological frameworks the concept of *temporal* is use to represent timeframe. Our conceptual model handles the notion of timeframe by specifying scheduled healthcare encounter, duration of next visit, and regular investigations. Along with the successfully mapped concepts, there are several concepts that were not mapped between the two models. Some of these concepts are, Risk factors; Surgical, personal and family history; Lifestyle Modification; Patient Education and Self-Management. The mapping is shown in Figure 4-11.

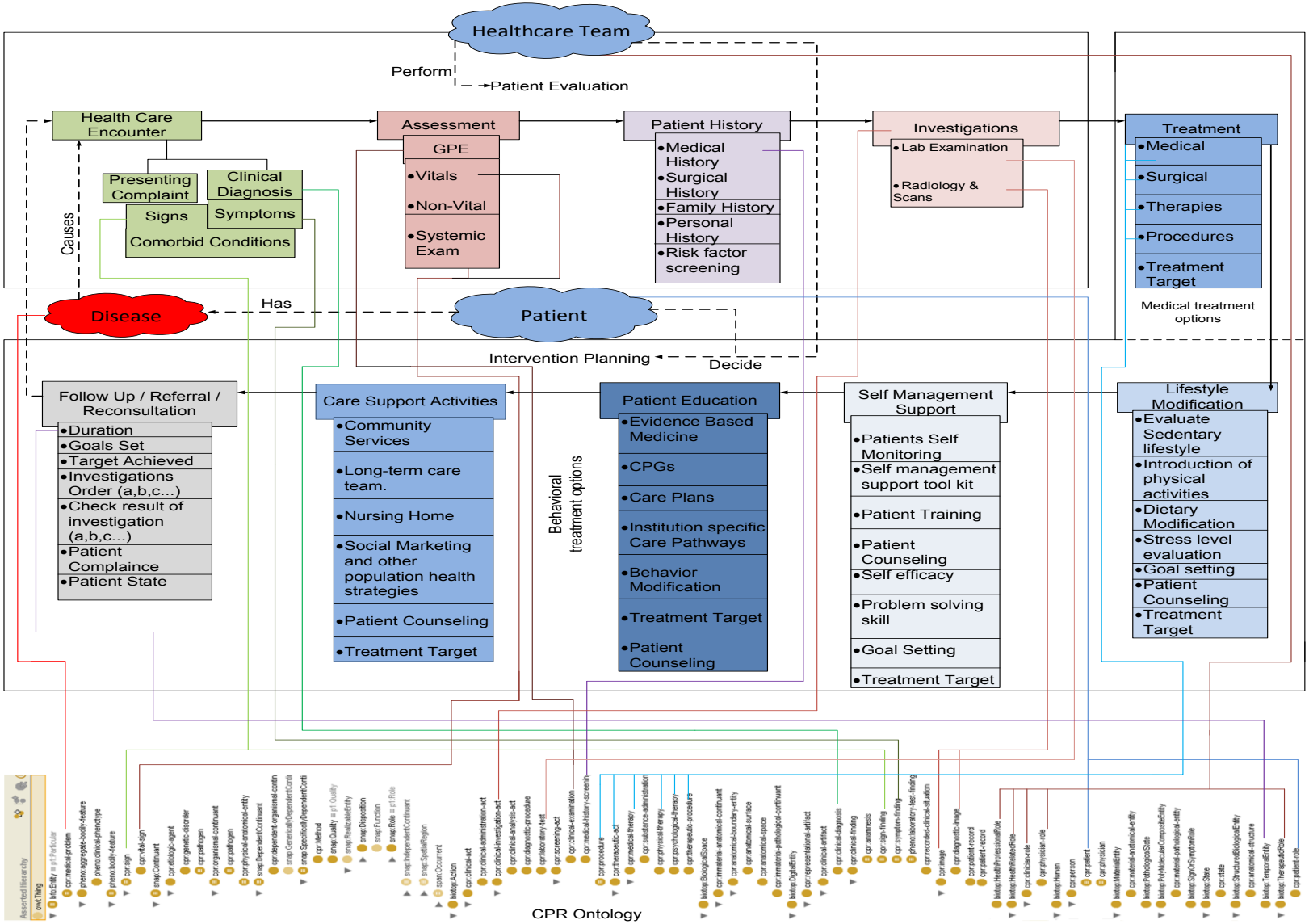
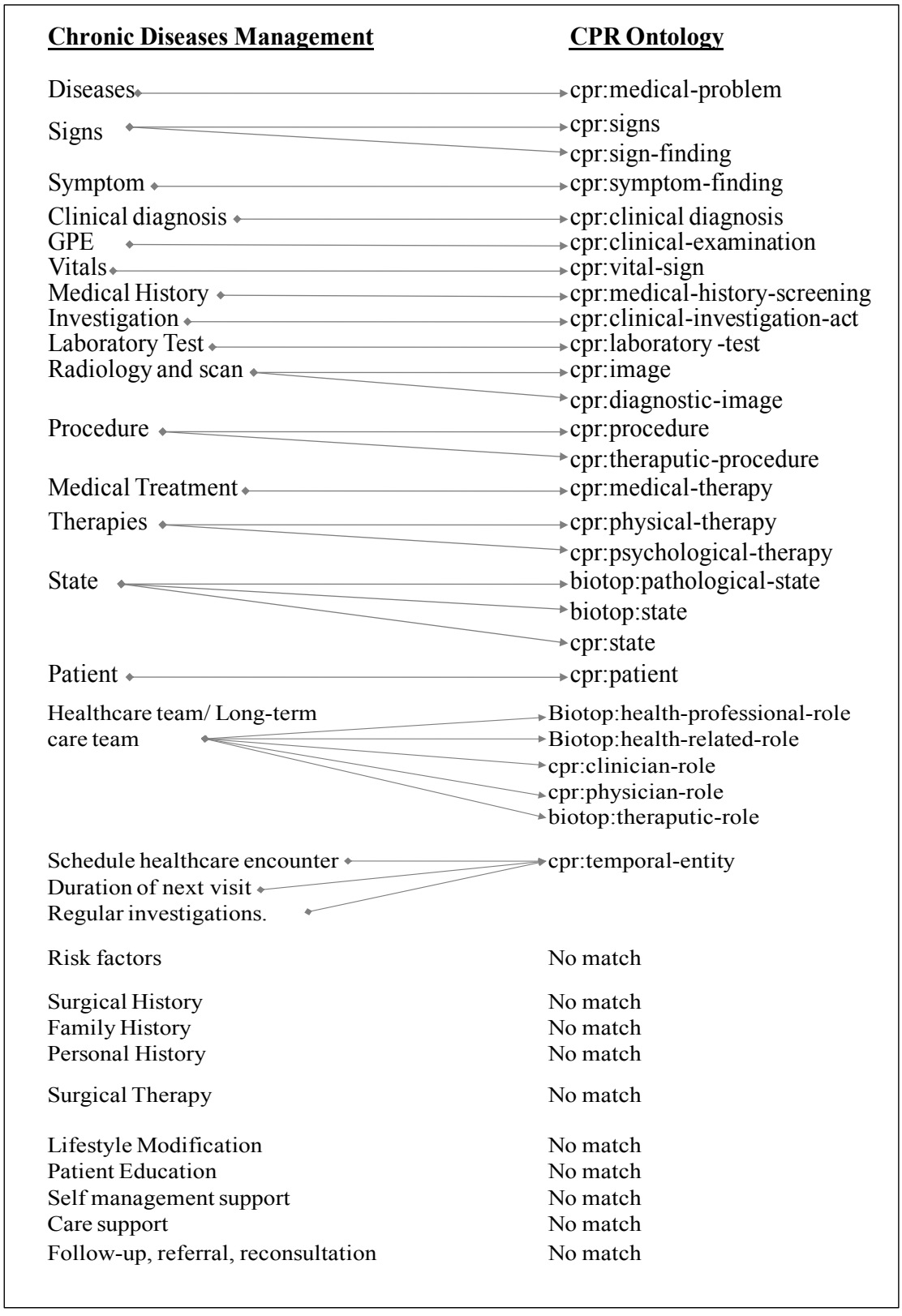


Figure 4-11 Mapping between Chronic Disease Model and CPR Ontology

4.4.1.1 MAPPING RESULTS

After successfully performing the mapping, which was manually performed on the basis of domain knowledge, between the conceptual model of chronic disease management and the CPR Ontology, we have three sets of concepts, which are (a) Concepts that have a perfect match between the two models, (b) Concepts that are used in a similar meaning and perform the same function between the two models, and (c) Concepts that are not matched between the two models. The first two sets of concepts, which were mapped between the two models, have successfully achieved the integration of the conceptual model of chronic diseases management and CPR ontology. At the same time, the successful mapping of our conceptual model of chronic disease management to the ontological framework of CPR Ontology has also proved the fact that our conceptual model has the potential to be formalized and implemented in the form of ontology in the later stages of our research. The reason that we were unable to find matching or equivalent maps for the third set of concepts lies in the fact that the reason for the development of CPR Ontology was an effort to develop a Patient Record ontology by encoding Coronary Artery Bypass Graft (CABG) Procedure Guideline using Notation 3 rules and OWL [54]. CABG is not it-self a chronic disease but it is the surgical procedure which is usually performed to avoid acute and emergency health condition due to complications of a disease such as angina or atherosclerotic conditions, e.g. coronary artery diseases [90, 91]. The third set of concepts mostly contains concepts that play a vital role in the management of chronic diseases, such as Lifestyle Modification, Patient Education, and Self Management. Now, we can conclude that our conceptual model is rich enough to cover acute diseases and also have concepts that are essential and pay vital role in chronic diseases management. Table 4-20 shows the successfully mapped concepts and in Figure 4-12 successfully mapped concepts are highlighted in the conceptual model of chronic disease management.

Table 4-20 Results of mapping between conceptual model of chronic disease management and CPR Ontology.



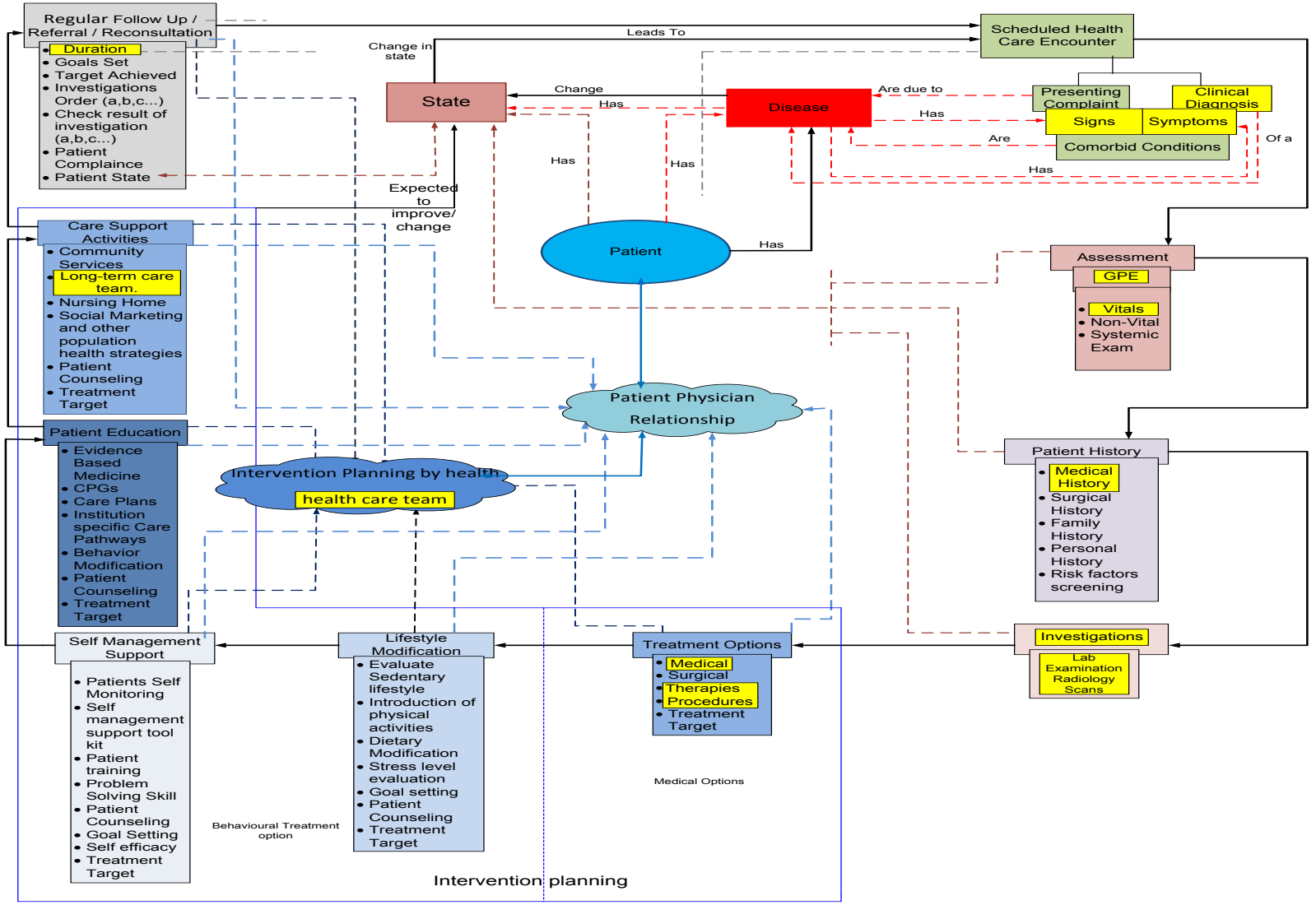


Figure 4-12 Successfully mapped concepts (Highlighted) between conceptual model of chronic disease management and CPR Ontology

4.4.2 MAPPING BETWEEN CHRONIC DISEASES MODEL AND HL-7 RIM CLASSES

In this stage of mapping the conceptual model of chronic disease management was mapped with the classes of HL-7 RIM. Once again, due to structural dissimilarities that occur between the two models, the mapping was done manually at the knowledge level using domain knowledge. HL-7 version 3 Rim consists of a backbone structure having three main classes, namely *Act, Role,* and *Entity*, and three associative classes, which are, *ActRelationship, Participation,* and *RoleLink;* these associative classes provide the linkage among the main classes. Tim Benson [34] explains the HL-7 V3 classes as follows. In HL7 version 3, whatever happens is considered as an *Act*, he further mentioned that in English this *Act* is analogous to *verb*. Every *Act* may involve a number of *Participations*; these *Participations* are in the form of *Roles* and are played by *Entities*. Thus, he mentioned that the class *Role* and *Entity* are analogous to *noun*. To perform this mapping at knowledge level we have adapted the approach of *Conceptual Equivalence* [92].The notion of Conceptual Equivalence is not new in the field of AI [92]. Using the domain knowledge, a search was done to investigate conceptually equivalent concepts between the two models, which means concepts that are similar at knowledge level, possess the same properties, function in a similar manner and serve the same purpose. The rationale behind using the approach lies in the following: (a) the mapping was performed manually at knowledge level using the domain knowledge, and (b) due to the vast structural differences between the two models, it is difficult to investigate for perfect matches; so this approach has proven to be the most suited approach for our purpose. It helped us in searching the concepts that are similar at knowledge level and serve the same purpose

In our conceptual model, we found concepts such as Assessment, Taking patient history, Evaluation of patient lifestyle and stress levels are showing some actions and analogues to the class *Acts* of HL-7 RIM. Similarly the concepts, such are *Patient, Long term care team* and *Healthcare team* display several different roles; so these concepts were successfully mapped to the class *Role*. Likewise, the concepts, such as *CPG's, Care plan, Institution specific care pathway, Community services,* and *Nursing home* of our

model were found to be similar to the class *Entity*. The process of mapping is shown in Figure 4-13.

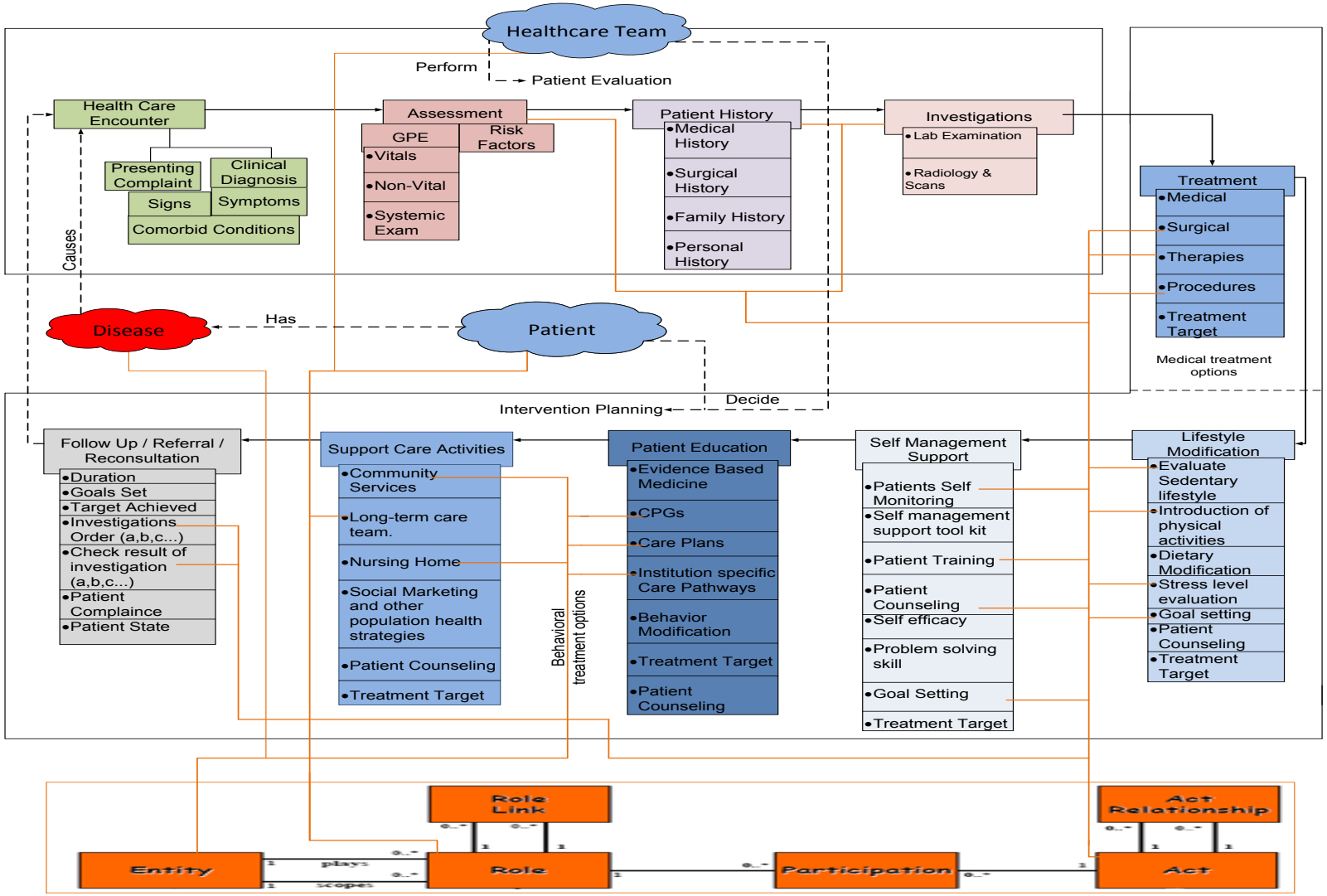


Figure 4-13 Mapping between Chronic Disease Model and HL7 RIM Classes

4.4.2.1 MAPPING RESULTS

The mapping of our conceptual model with HL-7 RIM classes helped us to align our conceptual model with the messaging standard. Although, we were unable to find perfectly matching concepts, still we find several concepts that are conceptually and semantically equivalent across the two models. The successful mapping will help us in the future when the conceptual model will be formally implemented as an ontological framework to achieve semantic interoperability. Besides this conceptual mapping we have also integrated our model with the data types properties that are used during ontology engineering. The concepts that are successfully mapped between the two models are presented in Table 4-21

Table 4-21 Results of mapping between the Conceptual Model of Chronic Diseases Management and HL-7 RIM Classes.

Chronic diseases management	HL-7 RIM Classes
• Assessment • Taking patient history • Order Investigations • Evaluation of patient lifestyle and stress levels • Patient training • Introduction of physical activity • Behavioral modification	Act
• Patient • Long term care team • Healthcare team	Role
• CPG's • Care plan • Institution specific care pathway • Community services	Entity

• Nursing home	
• Healthcare encounter • Patient education • Follow-up, referral, reconsultation	Not Mapped

The overall mapping of the conceptual model with CPR Ontology and HL7 RIM classes is shown in Figure 4-14. During this mapping we incorporated our conceptual model of chronic disease management with two more concepts, which are *Role* and *Temporal Entity*. Although we have successfully mapped these concepts to our model during the mapping process, the rational for adding these concepts into our model is these concepts will be useful during the process of model formalization and implementation. The final conceptual model for chronic disease management is shown in Figure 4-15.

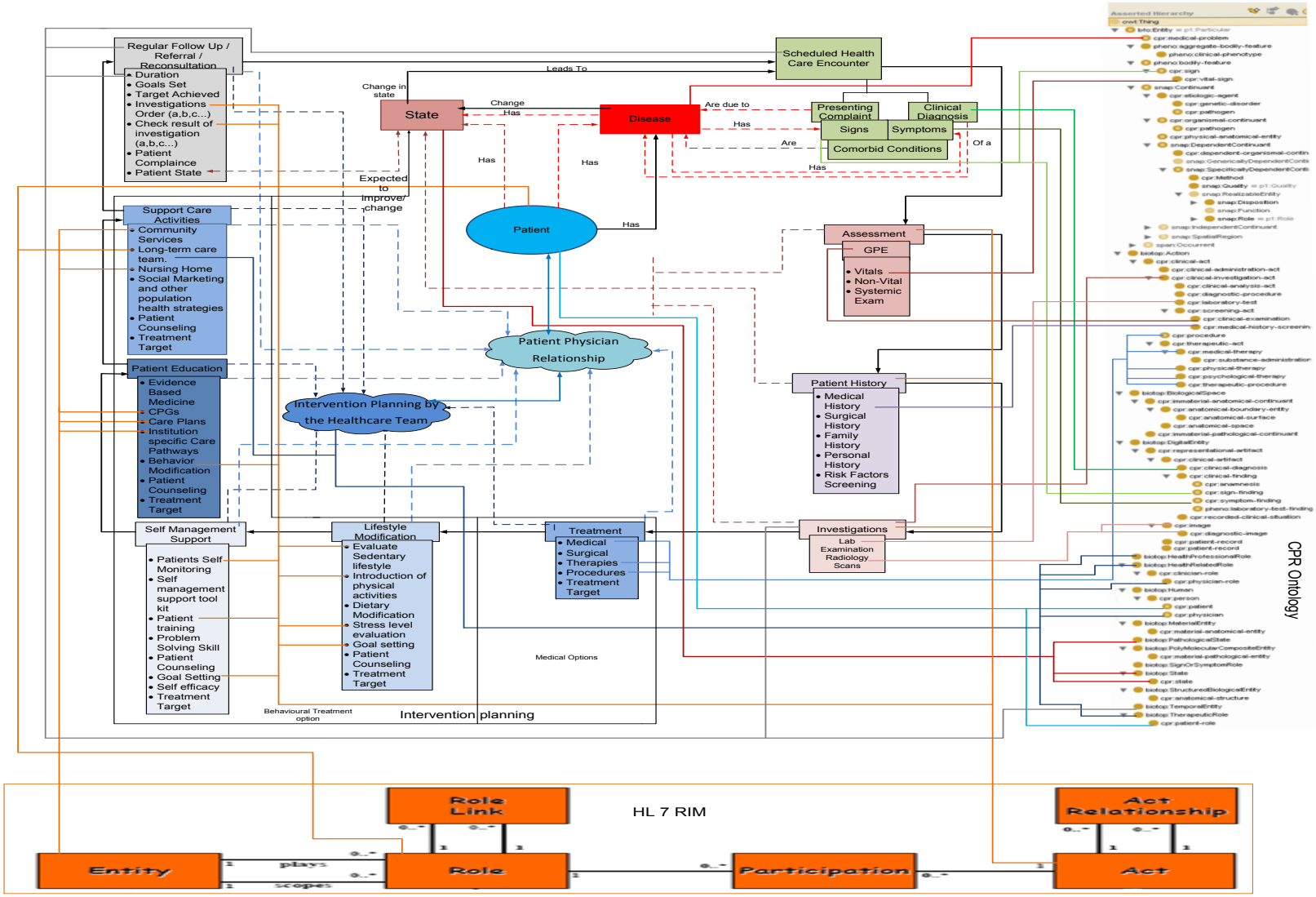


Figure 4-14 Mapping and integration of conceptual Model of chronic disease management with CPR Ontology and HL7 RIM Classes

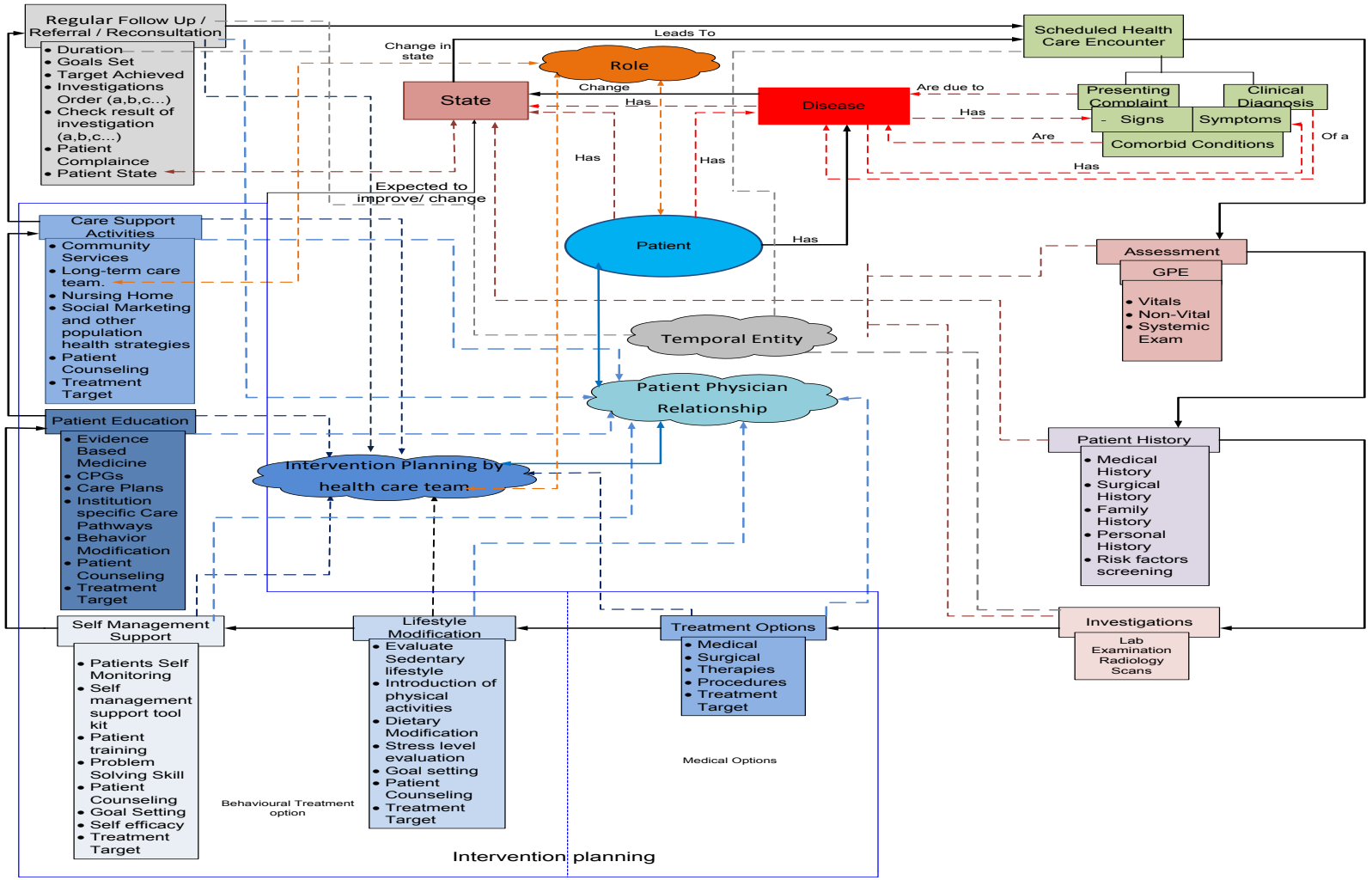


Figure 4-15 The Conceptual Knowledge Model for Chronic disease management after adding the concepts, Role and Temporal Entity

4.5 STEP 3: VALIDATION OF CD-EMR MODEL BY USING CASE SCENARIOS

After successful completion of conceptual model development and mapping process, we will now validate our conceptual model. The process of validation is done by using clinical scenarios which contain information about the patient and knowledge about the disease. The reasons to perform the validation of our model using clinical scenarios are: (a) to check the richness of the model at knowledge level and (b) to check whether there are any gaps or conceptual deficiencies in our model.

In order to perform the validation step, we used the clinical scenarios for chronic diseases that are available through different online sources. The rationale for using the available scenarios and not developing the clinical cases our-self is to eliminate the chance of author bias. If we had developed the clinical scenario using the author's clinical knowledge there could be a chance of developing scenarios according to our model. In order to avoid this bias we chose to select scenarios through different available sources. In order to select the clinical scenarios, besides a mandatory condition that all scenarios must be of chronic diseases, we have developed a selection criteria based on the following steps.

- **Disease Information**: The scenarios should contain detailed information about the various aspects of the disease, such as signs, symptoms, co-morbid conditions if any, or any complication
- **Patient information**: The scenarios should contain detailed patient information.
- **Laboratory and Radiology Data**: The scenarios should contain clinical data related to lab test results and radiology reports.
- **Patient History**: The scenarios should provide information about patient's previous conditions or risk factors.
- **Treatment Plan**: The scenarios should contain information about the current or previous treatment plan.

To meet all the above-mentioned selection criteria in one clinical case was a difficult task, so we selected cases which represent any two or more of the above-mentioned criteria. After selection, the clinical cases were mostly in descriptive form; we separated the clinical and non-clinical concepts from the linguistic entities and then performed the

validation. In validation we check whether our model had enough concepts that can handle the clinical and non-clinical conceptual knowledge that we have in the form of clinical scenarios.

4.5.1 SCENARIO 1: CHRONIC RENAL FAILURE [97]

A 56 years old Malay housewife from Melaka, admitted to the hospital with generalized body weakness and fatigue for 2 days. She is a known to have diabetes mellitus for past 13 years and hypertension for 1 year. She was told to have low Hb level and 3 packs of blood have been transfused. She also gave history of frothy urine. No history of oliguria, hematuria. Patient also gives history of pedal edema for past 2 months. No history of breathlessness, dyspnea on exertion. There is history of polyuria. She is on insulin for the past 6 months. She is also on treatment for hypertension. On examination, patient's vitals sign are stable. She is alert and cooperative. There is no pallor, JVP not raised, there is anarsaca. CVS examination is normal. RS examination also normal.

Diagnosis: chronic renal failure

Discussion

Blood pressure in this patient should be maintain below 135/85mmHg. ACE inhibitors or angiotensin receptor blocker are drug of choice.

Blood glucose level should be well controlled. Insulin therapy will be the drug of choice. Higher dose might be required. Oral hypoglycemic drug should be avoided.

Associated diabetic retinopathy tends to progress rapidly. Therefore, frequent ophthalmic supervision required.

She should be follow up regularly.

From the above clinical scenario we abstracted the information and the Table 4-22 shows that how our conceptual model handle this information.

Table 4-22 Concepts of our conceptual model of chronic disease management cover the information form case scenario

Information form case scenario	**Concepts of the conceptual model cover the information.**
Malay	Patient (Patient ethnicity)
Housewife	Marital Status (married) Gender (Female) Occupation (Housewife)
From Melaka	Address
56 years old	Patient Age
Chronic renal failure	Disease (clinical diagnosis)
Low Hb level	Investigation Results
Generalized body weakness and Fatigue for 2 days	Presenting complaints with duration
• Diabetes mellitus for past 13 years and hypertension for 1 year. • History of frothy urine • No history of breathlessness, dyspnea on exertion. • There is history of polyuria • She is on insulin for the past 6 months • History of pedal edema for past 2 months	Medical history Past Drug history
• 3 packs of blood have	Personal history

been transfused • No history of oliguria, hematuria	
Patient's vitals sign are stable	Vital-Signs
• There is no pallor, • JVP not raised, • There is anarsaca.	Non-Vitals
• CVS examination is normal. • RS examination also normal.	Systemic examination
• Blood pressure in this patient should be maintain • Blood glucose level should be well controlled.	Goal setting
BP should be below 135/85mmHg	Treatment target
• ACE inhibitors • Angiotensin receptor blocker • Insulin therapy	Medical Treatment
• Diabetic retinopathy tends to progress rapidly	Disease complication
Frequent ophthalmic supervision required.	Referral / Consultation Role: Ophthalmologist
She should be follow up regularly.	Follow-up

4.5.2 SCENARIO 2: SECONDARY HYPERTENSION [98]

A 47-year-old female patient underwent a 24-day treatment program at The Center for Chronic Disorders for treatment of hypertension due to kidney damage. The patient's problem began at age 17 when she was admitted to the hospital for obstruction of the right kidney. She underwent surgery to relieve the obstruction; however, the kidney had been damaged. She was told this damage would be permanent and, as a result, she could expect to have elevated blood pressures for the rest of her life. For the following thirty years the patient had widely varying blood pressures, with most pressures being significantly elevated.

Blood pressure readings were obtained during the two months preceding treatment at The Center and averaged 146/97. (Blood pressure is considered high when the upper number, the systolic pressure, is 140 or higher, or when the lower number, the diastolic pressure, is 90 or higher.) During the 24-day Chronic Disorders Program, the patient received a multimodality in-residence program, including the use of the newly introduced Vedic Sound Therapy which the patient felt played a central role in her subsequent improvement.

Following in-residence treatment, the patient was placed on a home program including dietary recommendations and specific herbal preparations. Within a few days of leaving The Center, the patient's blood pressure dropped significantly and became normal.

Two months later, they continued within the normal range, averaging 129/85. The patient reported that she had not had blood pressures this low since adolescence. In addition, an initial 24-hour creatinine clearance test (a sensitive measure of overall kidney function) was obtained at the beginning of the treatment program and repeated several weeks after its completion. The initial creatinine clearance was moderately diminished (67 ml/minute, with normal being between 80-120 ml/minute), indicating diminished overall kidney functioning. The follow-up was in the normal range at 85 ml/minute.

From the above clinical scenario we abstracted the information and the Table 4-23 shows that how our conceptual model handle this information.

Table 4-23 Concepts of our conceptual model of chronic disease management cover the information form case scenario

Information form case scenario	**Concepts of the conceptual model cover the information.**
47-year-old	Patient Age
female patient	Patient gender
Secondary Hypertension	Clinical Diagnosis
The Center for Chronic Disorders for treatment of hypertension due to kidney damage.	Intervention Planning: Care Support Activity
24-day treatment program	Duration of therapy
initial creatinine clearance 67 ml/minute The follow-up creatinine clearance 85 ml/minute.	Investigation result before treatment Investigation result after treatment
The patient's problem began at age 17 when she was admitted to the hospital for obstruction of the right kidney For the following thirty years the patient had widely varying blood pressures, with most pressures being significantly elevated	Patient History (Medical History)
She underwent surgery to relieve the obstruction	Patient History (Surgical History)
Kidney damage	Disease complication
Blood pressure readings were obtained during the two months preceding	Vital-sign measurements

treatment at The Center and averaged 146/97	
Vedic Sound Therapy	Therapy
patient felt played a central role in her subsequent improvement	Patient centeredness
Dietary recommendations	Lifestyle Modification
Maintain Blood pressure	Treatment target
Within a few days of leaving The Center, the patient's blood pressure dropped significantly and became normal BP continued within the normal range, averaging 129/85	Target achieved
Two months later	Follow-up
BP continued within the normal range, averaging 129/85	Vital Signs at follow-up

The above two examples show that how our conceptual model covers the information related to various aspect of the disease and the patient. Our model successfully cover the information about patient, patient history, healthcare encounter, patient history, investigation results, roles and different options of intervention planning such as medical therapy, therapies, lifestyle modifications and care support activities. Along with this, our model also handles the information related to patient centric role and longitudinal nature of treatment. This validation proves that our model is rich enough to handle the knowledge about chronic diseases and information about the patient.

4.6 DISCUSSION

The process of chronic disease management was studied in detail using the knowledge sources such as Text books, models for chronic disease management (CCM), and the

published research articles. By performing the text analysis, we abstracted the knowledge regarding the process of chronic disease management. While performing the review of literature about chronic disease management, we came across two important facts which make the chronic care distinct from acute and emergency care. These facts are: (a) Due to the long course and slow progression of chronic diseases, as well as the delayed treatment outcomes the process of chronic disease management is longitudinal and proactive in nature. As a result, the patients suffering with chronic diseases are planned to visit the healthcare facility according to scheduled healthcare encounters. The impact of these scheduled healthcare encounters is twofold i.e. they make the process of chronic disease management proactive rather than reactive, and at the same time make the process of care longitudinal rather than fragmented, and (b) the chronic diseases are not just pathological conditions but also carry a huge impact for the patients and their families. Besides treating the pathology of the disease, it is important to manage the impact and stigma of chronic diseases as well. In order to provide a comprehensive management that covers the various aspects of chronic diseases, it is important to develop a healthy patient physician relationship, which helps the physician to discuss every possible treatment option with the patient. The patient can then select the treatment options according to their needs, which makes the process of chronic disease management patient centric rather than disease or physician centric. Patient centeredness helps to develop the intervention plan which is according to the patient's choice and satisfy all their needs. As mentioned earlier, our model covers both these concepts along with every possible treatment option. Our conceptual model not only captures the various aspects of chronic disease management, but it is fully aligned with the CPR ontology and HL7 RIM. In the integration and mapping step, we have seen successful mapping between our model and the concepts of CPR ontology and the backbone classes of HL7 RIM. It also proves to be a rich information model that can handle the information and captures the data. The validation step of our model development has already proven the richness of our model.

4.7 CONCLUSION

An effort was made to abstract the key elements and core concepts of the process of chronic disease management, and to present the abstracted knowledge in the form of conceptual knowledge model for chronic care. We successfully developed the conceptual

model, which not only covers the various aspects of chronic disease management but is also patient centric and longitudinal in nature. This conceptual model mainly consists of two parts: (a) Patient Evaluation, and (b) Intervention Planning. The first part, patient evaluation, consists of concepts that help in evaluation of patient state, such as assessment of signs, symptoms and performing clinical examination, screening of patient's history and risk factors, and analysis of patient investigations results. After evaluation of patient state, the second part, intervention planning of the conceptual model provides all possible treatment options to manage chronic disease patients. Besides providing the conceptual framework, our model provides a rich information model that can capture information related to various aspects of chronic diseases and also provide a platform to represent information related to acute diseases, emergency situations, and co-morbid conditions. In the later stages of our research we will formalize our conceptual model so that it can be implemented as an ontological framework to serve the purpose of electronic medical record for chronic disease management.

CHAPTER 5: MODEL FORMALIZATION AND ONTOLOGY ENGINEERING

5.1 INTRODUCTION

In this chapter, we will discuss the formalization of the conceptual model of chronic diseases management, into CD-EMR Model and describe the ontology engineering process. We have already discussed the development of the conceptual model of chronic disease management in previous chapters. Now that we have the conceptual model, we will arrange these concepts in an array with respect to their properties and relationships, which can be formalized and later be implemented as a computerized EMR system. Before discussion of the formalization and implementation phases it is necessary to select the standard model which will serve as a basis for formalization and later can be implemented accordingly. So this chapter consists of three steps: (a) Model Selection, (b) Model Formalization, and (c) Model Implementation. As discussed earlier, we are using two standard models, which are HL7 RIM and CPR ontology. During the process of formalization, we make use of HL7 RIM classes and data-types to capture the data elements and workflow. The class structure of CPR ontology will guide us to align our concepts in such a way that will be helpful to us during the implementation phase.

5.2 STEP 1: MODEL SELECTION

In this step of our research our aim is to select a standard model which serves as a basis for formalization and implementation phases. In the previous chapter, we have successfully captured the process of Chronic Disease Management (CDM) using the empirical and explicit knowledge into a conceptual model. According to Chen [100] ontology provides a substratum to develop knowledge-base system. In the literature [101, 102, 103, 104] it is clear that ontology provides an infrastructure that defines an entity, attribute, and relationship among the knowledge concepts within a domain. Moreover, ontology provides explicit description and specification of knowledge artifacts in an interoperable format, which can be interpreted by humans and machines [100], and therefore ontology can be used to develop knowledge-base systems. Besides the academic knowledge representation projects, ontology has gained the interest of the commercial world [105] by providing a vast range of multifaceted functionalities such as

interoperability among heterogeneous data sources [105]. We have aimed to developed an EMR system that captures the holistic care process of CDM and is semantic interoperable. We have already captured the care process of CDM in our conceptual model. The need is to select a standard model that helped us to achieve semantic interoperability. From the above mentioned facts and the literature review [106, 107, 108] we have found that ontologies provide the most suitable environment to formally represent the knowledge and achieve interoperability in a heterogeneous, distributed, and dynamically evolving environment such as healthcare [106].

On the basis of the above discussion and literature review, we have chosen ontology as our standard model to develop the EMR system for CDM. We will develop our ontology in OWL-DL using Protégé as the editor. The rationale for selecting OWL-DL as the ontology development language lies in the facts (a) OWL-DL is more expressive and amenable to automated reasoning [109], and (b) Automatic reasoning helped us to compute the classification hierarchy and check for inconsistencies in the ontology [109]. In the subsequent section we will discuss the model formalization and the model implementation to develop CD-EMR Ontology.

5.3 STEP 2: MODEL FORMALIZATION

Model formalization is an important step because it enables us to use the conceptual model and formalize it so that it can be implanted as CD-EMR Ontology. As mentioned earlier we have chosen two standards which are, CPR Ontology, and HL-7 v3. During this step of our research we will use the structural and functional aspects of these two standard models to develop the formal model of CD-EMR. Now we will explain the main concepts of our formal model.

ADMINISTRATION ACT

As mentioned earlier, during the process of chronic care a lot of information is generated. This information needs to be stored so that it can be utilized to make decisions. This information is related to both clinical and

non-clinical processes which occur when the patient moves across the healthcare facility. The clinical information includes information related to assessment,

clinical examinations, and investigation results. The non-clinical information means information related to administrative processes such as providing a referral to the patient, the record of patient's admission to a particular facility, and the record of patient condition at the time when the patient leaves the healthcare facility, which could be in the form of discharge summary. During the formalization we capture the administrative aspects of discharge and patient-visit to a healthcare facility under a concept called Administration Act. Besides the non-clinical aspects of discharge and patient-visit, the notion of Administration Act also captures the clinical information related to the clinical processes along with the non-clinical supportive information during admissions that is generated during the process of care.

CLINICAL INVESTIGATION ACT

As mentioned earlier in Chapter 4, investigation results help in determining the progression of the disease's state. Abnormal investigation results help to determine any functional or structural abnormality of an organ or a system. For example, a raised level of serum urea and creatinine is suggestive of renal malfunction; likewise lab investigations with abnormal results, such as raised ESR, is suggestive of active body response and this activated defense mechanism of the body could possibly be due to an ongoing infection. Similarly abnormal scans results of X-Rays and Ultrasound scans helps us in finding structural abnormalities in the form of fracture and soft tissue abnormality such as fatty liver respectively. In our conceptual model we have covered the variety of lab and radiological test under the heading of Investigations. While formalizing our model we used the concept of the *Clinical Investigation Act* from CPR Ontology and utilized it in a similar manner to cover the different types of investigations commonly used in the process of chronic disease management.

CLINICAL SCREENING ACT

The chronicity of a disease is not an overnight process. It is the result of a series of health-related events that could directly be related to the patient's life,

their family medical history and their social, economical, psychological, behavioral aspects and risk factor exposure. Having knowledge about the patient's previous medical conditions helps in the process of chronic disease management, therefore screening of patient history and risk factors is essential and helps in both (a) establishing a clinical diagnosis and (b) planning the management of chronic disease. Patient information about the past history and risk factor has already been covered in the conceptual model under the heading of Patient's History. During model formalizations the concept of Clinical Screening Act which comes from CPR Ontology captures the concept of Patient's History and covers all the possible information related to patient's history and exposure to risk factors.

CLINICAL EXAMINATION ACT

Performing clinical examination is a routine practice during the health care encounter. In our conceptual model the notion of Assessment covers vital, non-vital and systemic examination. During model formalization we have captured the concept of Assessment as Clinical Examination Act which is adapted from CPR Ontology.

CLINICAL ARTIFACT

In our conceptual model we have seen that the presentation of the disease occurs in the form of sign, and symptoms. To capture these representational aspects of the disease in our formal model we defined the concepts of Clinical Artifact adapted from CPR Ontology. This concept captures the clinically significant information related to clinical recording of natural phenomena (i.e. sign and symptoms).

ENTITY

As mentioned in Chapter 4, Entity is one of the main classes of HL-7 RIM which is analogous to noun and represents participations. During model formalization we have used the concept of Entity to cover information related to (a) different types of drugs used in the process of care, (b) any material entity

such as the healthcare facility; a particular unit of the hospital such as the surgical or medical unit; or a use of a wheel chair during the process of care, and (c) it also covers the information related to disease or medical problem.

ROLE

The process of chronic disease management involves several different roles. To capture these roles we have defined the concepts of Role in our formal model. This concept covers different health related roles such as physician, surgeon and nurse, as well as the non-health related roles such as social workers, and community voluntaries. In our formal model patients are also considered as role. The concept of role is adapted from all three models i.e. CPR Ontology, CCM and HL7 RIM.

INTERVENTION PLANNING

There are several options to manage a chronically ill patient and we have already discussed these options in detail in Chapter 4. During model formalization we have captured all these options under the notion of Intervention Planning which is adapted from CPR Ontology. So the concept of Intervention Planning covers the various medical and behavioral options used in the process of CDM.

ORDERS

During the process of CDM we have seen several types of orders such as, pre and post operative orders, nursing orders, and ordering a prescription. In our formal model we have covered all these actions under the concept of Orders.

GOALS AND TARGET

Setting goals play a vital role in developing motivation in patients suffering with chronic diseases. Goals are bound with particular targets which help and guide the patient to maintain their own health. We have seen in our conceptual model that most of the management options such as lifestyle modifications, patient education, and self-management support use several

different types of goals and target to manage the patient. In our formal model we have defined the Goals and Target as two separate concepts which cover all goals and targets used during the process of CDM.

PATIENT RECORD

The notion of Patient Record is useful in storing each and every bit of information, clinical and non-clinical, related to the patient in a well-organized format. This information can be easily retrievable when needed by the healthcare professional for decision making and disease management purposes. In our formal model we use the concept of Patient Record to store all patient data in a semantically interoperable format.

HEALTHCARE ENCOUNTER

In order to maintain a longitudinal patient record it is necessary to keep track of patient visits to the healthcare facility. During the model formalization we have covered the notion of patient visits through the Healthcare Encounter. The reason for making Healthcare Encounter a separate concept in our formal model lies in the fact that every patient must have a single record, and that single record keeps track of the multiple patient visits to the healthcare facility in the form of Healthcare Encounter. It enables our system to store patient information in a single place in an organized manner and eliminate the risk of storage of redundant information and multiple records for the same patient.

VOCABULARY

The concept of vocabulary is included in the formal model in order to store generic knowledge of CDM. The reason to develop this concept is to use the generic knowledge multiple times for patients to store patient-specific information, such as results of investigations and examinations and findings of signs and symptoms. The specific details of this concept are explained latter during ontology engineering.

Figure 5-1 shows the formal model of EMR for chronic disease management (CD-EMR). In this formal model the Patient Record serves as a hub and stores all the patient data in a common place. All the concepts are connected to the Patient Record via Healthcare Encounter. Healthcare Encounter establishes the connection among the concepts and helps in getting a particular piece of information such as investigation results, previous treatment, past medical history or information about allergies for the patient record.

We will now use this formal model to develop our ontology of EMR for chronic disease management (CD-EMR Ontology). In the subsequent sections we will explain the process of ontology engineering and detailed the various aspects of CD-EMR Ontology.

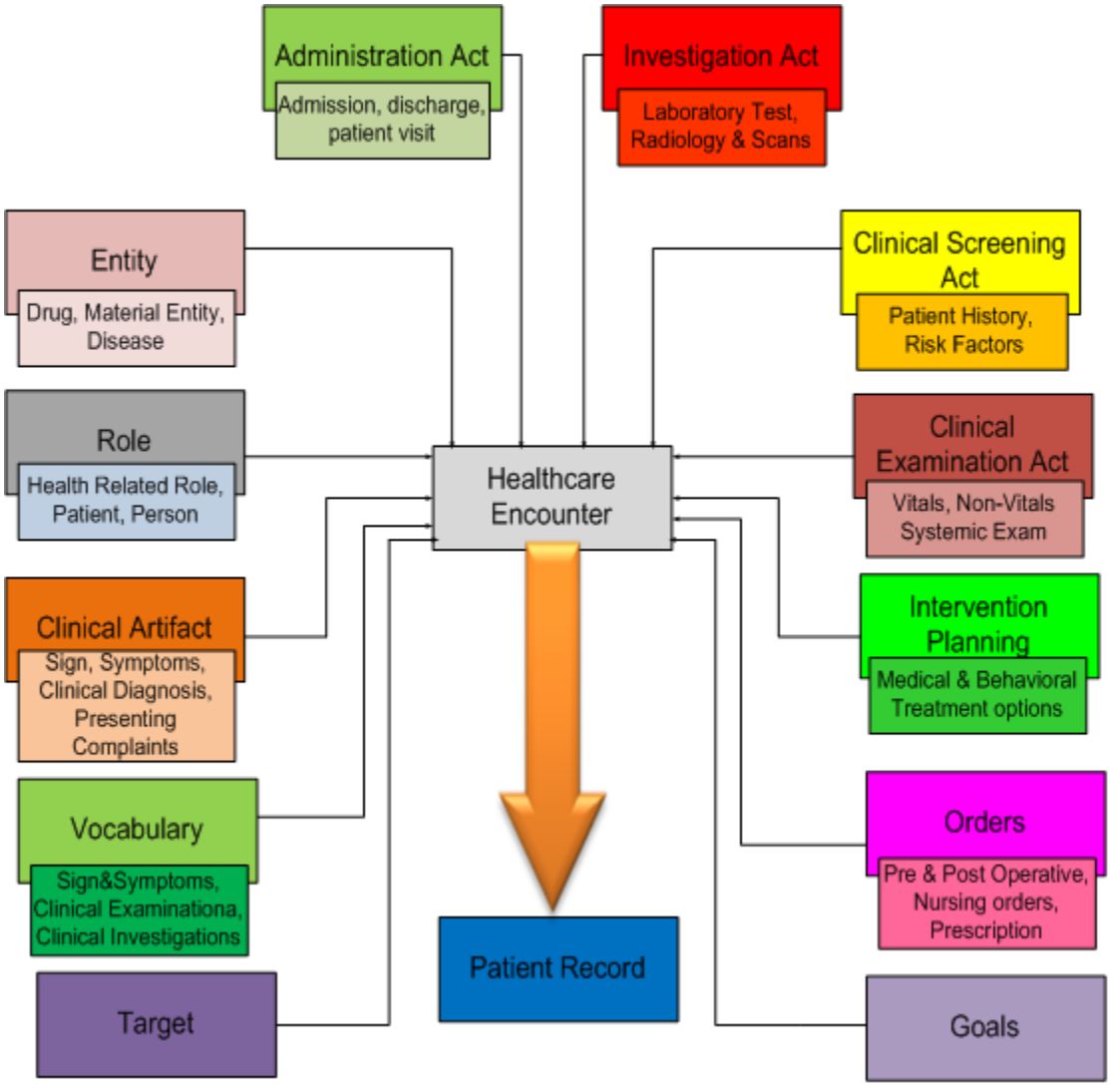


Figure 5-1 Formal Model of EMR for Chronic Disease Management (CD-EMR)

5.4 STEP 3: IMPLEMENTATION (ONTOLOGY ENGINEERING)

In this step of our research we will use the formal model and develop the CD-EMR ontology in OWL-DL using Protégé. The design of our CD-EMR Ontology is focused on (a) achieving semantic interoperability, (b) reusing the components of standard models of EMR such as CPR Ontology, CCM, and HL7 RIM, and (c) providing a holistic information model as an ontological framework that can capture CDM. The concepts of the conceptual and formal models are represented as classes and sub-classes in the CD-ERM ontology. The interconnections between and among the classes and subclasses are achieved by using object properties, whereas the detailed information is captured by using data-type attributes. The description of classes, sub-classes and the properties is explained in the subsequent section of this chapter.

5.4.1 CONCEPTS OF CD-EMR ONTOLOGY

The main concepts of the formal model have been used to create the classes in the CD-EMR Ontology, so our ontology has 14 main classes. Out of these 14 main classes, nine classes further have 32 sub-classes which are shown in Figure 5-2. The classes and their subclasses are presented in Table 5-1 and the description is explained below.

Table 5-1 Classes and sub-classes of CD-EMR Ontology

Main Class	Sub-Class
1. Administration_Act	• Admission • Discharge • Next Visit
2. Clinical_Investigation_Act	• Laboratory test Finding • Radiology And Scan Finding
3. Clinical_Examination_Act	• Vital Examination Finding • Non- Vital Examination Finding • Systemic Examination Finding
4. Clinical_Screening_Act	• Medical History Screening • Surgical history screening • Family history screening

	• Personal history screening • Risk factors screening
5. Clinical_Artifact	• Sign Finding • Symptom Finding
6. Entity	• Drugs • Material entity • Medical problem / Disease
7. Role	• Health related role • Person • Patient
8. Intervention_Planning	• Medical Therapy • Surgical Therapy • Therapeutic Procedure • Therapies • Lifestyle Modification • Self management support • Patient Education • Care Support Activities
9. Patient_Record	• N/A
10. Goals	• N/A
11. Target	• N/A
12. Healthcare_Encounter	• N/A
13. Orders	• N/A
14. Vocabulary	• Sign and Symptoms • Clinical Examinations • Clinical Investigations

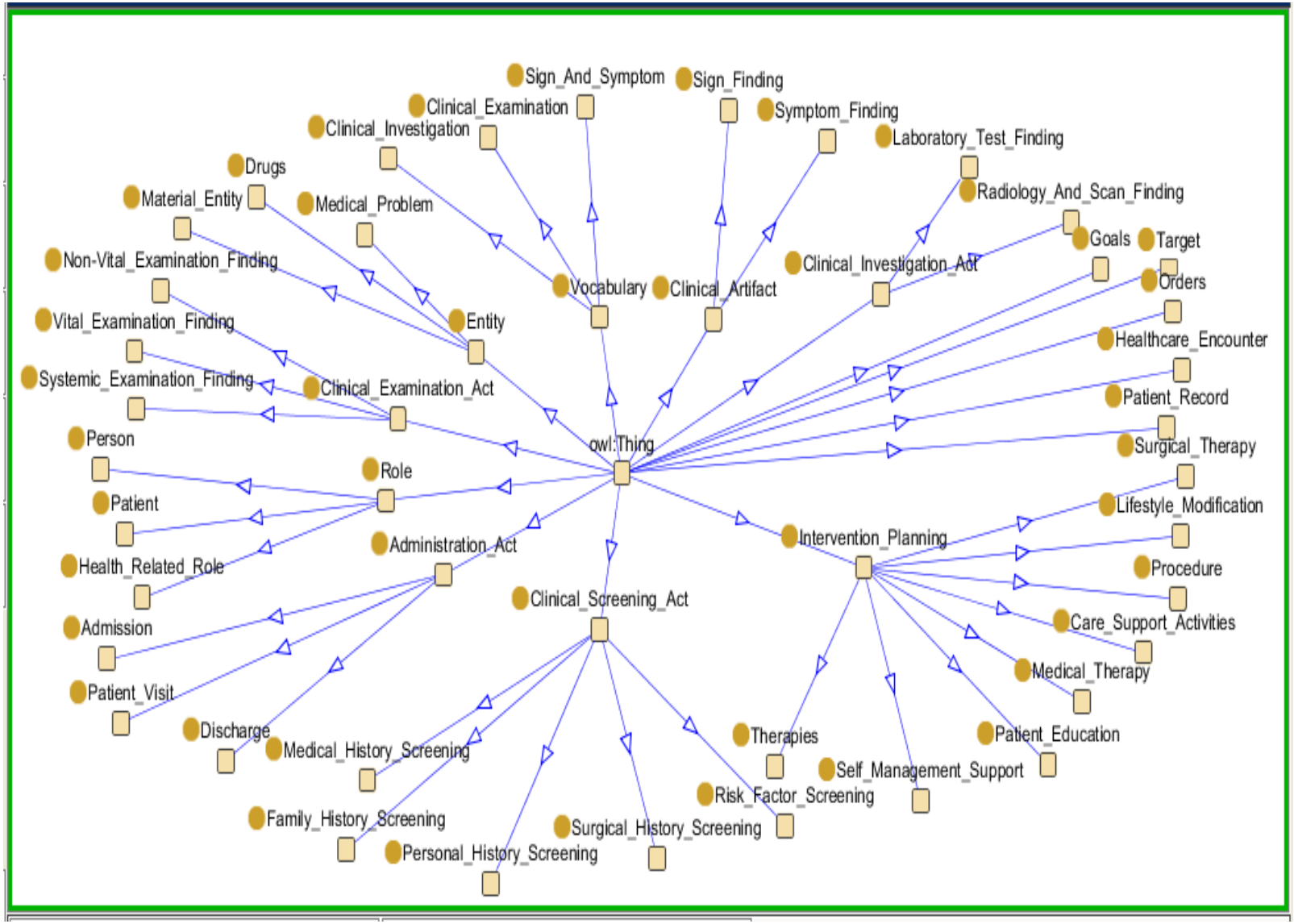


Figure 5-2 Classes and sub-classes of CD-EMR Ontology

(a) Administration_Act is defined as a main class to capture the information related to the non-clinical and administrative processes of CDM. This class is adapted from CPR Ontology and analogous to the backbone class *Act* of HL7 RIM. This main class has 3 sub-classes namely *Admission, Discharge* and *Patient_Visit*.

(i) The sub-class *Admission* captures the information related to the reason of admission, who has admitted the patient, the plan of admission, date and time of admission. Moreover, it also captures the detail of clinical processes such as interventions, investigations, clinical examination, signs, and symptoms of the patient during patient's stay in the healthcare facility after admission.

(ii) The sub-class *Discharge* captures the details of discharge summary, including the information related to (a) the discharge destination which covers the different places where the patient has to be moved such as, a nursing home, or a long-term care facility, (b) the discharge plan which has the information related to the medications and other instructions that the patient has to follow once they leave the healthcare facility, (c) the description of the patient conditions at the time of discharge, and (d) the healthcare provider who discharges the patient form the facility.

(iii) The sub-class *Patient_Visit* captures the details about (a) the schedule of the next visit such as date and time, (b) the nature of the visit which could be a follow-up or referral, as well as the information about the emergency visits in case of acute episodes of chronic diseases, (c) the type of visit i.e. whether scheduled or unscheduled , and (d) the information related to the healthcare provider who has advised the visit, and the information about the healthcare provider to whom the visit has been advised in cases of referral.

The class *Administration_Act* and its sub-classes are connected to the *Health_Related_Role* which is a sub-class of class *Role* and class *Patient* via the object properties *Role_Involved* and *Record_For_Patient* respectively. The properties of the main class and the sub-classes are mentioned in Table 5-2.

(b) Clinical_Examination_Act is defined to capture the information regarding the patient specific results of general physical examination. This main class covers the information regarding the date and time of the exam, the name of the examination being performed, who performed the exam, record of the patient, the anatomical site of the exam, and the results of examination through its data and object type properties. This class is analogous to the backbone class *Act* of HL7 RIM. This main class has three sub-classes, namely *Vital_Examination_Finding, Non-Vital_Examination_Finding,* and *Systemic_Examination_Finding.*

(i) The sub-class *Vital_Examination_Finding* captures the information related to measurement of vital-signs which are temperature, blood pressure, pulse/heart rate, and respiration rate. It covers the detailed characteristics of each vital sign via data type attributes such as rate, rhythm, volume, duration, results, and site of examination. In the case of temperature reading the site could be oral, axillary, or rectal; in case of pulse it could be radial pulse, cubital or brachial pulse. In addition to the actual results of the examination, this sub-class also covers the information about the reference ranges and the standard terminology codes via the data type properties *Reference_Range* and *SNOMED-CT_Code* respectively.

(ii) The sub-class *Non-Vital_Examination_Finding* captures the information about the examinations of non-vitals such as thyroid examination, lymph node examination, and examination of anemia,

or jaundice. It covers the results of the examination via the data type properties *Examination_Finding_Normal* and *Examination_Finding_Abnormal.*

(iii) The sub-class *Systemic_Examination_Finding* captures the information related to the systemic examinations which are Central Nervous System (CNS), Cardio-Vascular System (CVS), respiratory, and abdominal examinations. In this sub-class, the information about the normal and abnormal findings, reflexes, tenderness, organomegaly, audible sounds both normal and abnormal are captured via data type properties.

The class *Clinical_Examination_Act* and its sub-classes are connected to the *Health_Related_Role* which is a sub-class of class *Role, Clinical_Examination* which is a sub-class of class *Vocabulary*, and the class *Patient* via object properties *Performed_By, Name_Of_Examination,* and *Record_For_Patient* respectively. The properties of the main class and the sub-classes are mentioned in Table 5-2.

(c) Clinical_Investigation_Act is defined to capture the information related to various lab tests and investigation results. The data-type attributes cover the information such as name of the laboratory; reason of the investigations, either diagnostic or therapeutic; requisition date and time; review date and time; and SNOMED-CT code for the lab test. This class is analogous to the backbone class *Act* of HL7 RIM. The class Clinical_Investigation_Act has two sub-classes namely *Laboratory_Tests_Finding* and *Radiology_And_Scan_Finding.*

(i) The sub-class *Laboratory_Tests_Finding* covers the detail of each lab test, ranging from the collection date and time; patient specific results; and the physician remarks. The data types cover the information such as test result value; the measurement unite; the reference range, both low and high; the time when the test results

enters into the HIS; description of the test; and the physician notes. This sub-class is connected to *Clinical_Investigations* which is a sub-class of class *Vocabulary*, via object property *Name_Of_Investigation.*

(ii) The sub-class *Radiology_And_Scan_Finding* covers the detail of different types of scans rsults via data type attributes. This detail covers the information about the nature of the scan such as invasive or non-invasive, indication or contraindication about the scan, the results of the scan, and any complication that occurred during the scan. This sub-class is connected to *Clinical_Investigations* which is a sub-class of class *Vocabulary*, via object property *Name_Of_Scan.*

The class *Clinical_*Investigation*_Act* and its sub-classes are connected to the *Health_Related_Role* which is a sub-class of class *Role* and the *Patient* via object properties *Ordered_By* and *Record_For_Patient* respectively. The properties of the main class and the sub-classes are mentioned in Table 5-2.

(d) Clinical_Screening_Act is defined as a main class to capture the information related to patient history. It covers the various elements of patient history such as age at onset of any medical problem, any complication during the course of life, and it also specifies anything that is not known to the patient via the data type *ask_but_unknow*. This class has five sub-classes, namely *Medical_History_Screening, Surgical_History_Screening, Family_HistoryScreening, Personal_History_Screening,* and *Risk_Factors_Screening.* This class is analogous to the backbone class *Act* of HL7 RIM. A complete list of properties of the main class and the sub-classes are mentioned in Table 5-2.

(i) The sub-class *Medical_History_Screening* covers the detail of various aspects of information related to the medical history of the

patient through its data type attributes. This sub-class covers the information about any past or present medical problem (disease), any complications due to that disease, history of adverse reaction, and any treatment advised or taken by the patient. This sub-class is connected to the sub-classes *Medical_Therapy* and *Drugs* via object property *Treatment_Taken.*

(ii) The sub-class *Surgical_History_Screening* covers the detail of history related to any surgical procedure, the reason for the surgery, name of surgical procedure, types of anesthesia, and surgical notes through data-types attributes. The information about the healthcare providers who performed the surgery as well as those who are involved in the surgical procedure such as OT staff and nurses is covered through object type attribute *Performed_by and Role_Involved*. The different types of orders, including pre and post-operative orders, and nursing orders are also captured through object type properties. This sub-class is linked to (a) sub-class Health_Related_Role via *Performed_by and Role_Involved,* (b) class Orders via *Pre-Operative_Orders, Post-Operative_Orders,* (c) the sub-class *Surgical_Intervention* via *Surgical_Procedure_Performed*, (d) the class *Patient* via *Record_For_Patient.*

(iii) The sub-class *Family_History_Screening* covers the details of information related to the history of any genetic disorder or family medical problem (disease) of any member of the family, such as parents or siblings, duration of disease, history of any medical or surgical treatment related to any family member, and the cause of death of the deceased family member. This subclass is linked with (a) the subclass *Medical_Problem* via object properties *Has_Disease*, (b) the sub-class *Person* via *Relationship_With_Patient*, (c) the sub-class *Surgical_Intervention*

via *Surgical_Procedure_Performed,* and (d) the class *Patient* via *Record_For_Patient.*

(iv) The sub-class *Personal_History_Screening* captures the details of personal history and social determinants of health. The data type attributes cover the information about the start date and end date of any issue, allergies , offending agent, type of reaction, addiction, alcohol intake, smoking, bowel habits, micturation, sleep habits, socioeconomic status, immunization, and blood transfusion.

(v) The sub-class *Risk_Factor_Screening* captures the details of any exposure to any risk factor during the course of life. The data-type properties cover the details about the duration of exposure, start and end date of exposure, name of risk factor, and exposure detail i.e. the extent of risk factors exposure.

(e) Entity is defined as a main class and captures the information related to the medical problem which covers all the diseases, both acute and chronic diseases, and co-morbid conditions, drugs and any material thing such as, healthcare facility or wheel-chair that is used in the process of care. This class captures the generic conceptual knowledge which is not patient specific. As mentioned earlier this class is analogous to the backbone class *Entity* of HL7 RIM. This main class has three sub-classes, namely *Drugs, Medical_Problem, and Material_Entity*. The properties of the main class and the sub-classes are mentioned in Table 5-2.

(i) The sub-class *Drug* captures the detail of the medications used in the process of care. Though its data type attributes this sub-class covers the information related to the name of drug, the family of the drug, indications and contraindication of the drug, the possible route of administration, route of excretion from the body, adverse effects, possibility of allergic reaction, and any specific instructions.

(ii) The sub-class *Medical_Problem* covers the information about the diseases. The data-type attributes capture the information related to disease name, duration, any complication, presenting complaints, and the state of the disease (whether active or resolved). The signs and symptoms of the disease are captured through the object properties, *Has_Signs* and *Has_Symptoms* respectively. These properties get their values from the sub-class *Signs_And_Symptoms* and also develop the linkage between these sub-classes. This sub-class is also connected to the class *Patient_Record* and sub-class *Health_Related_Role* through object properties *Rocord_For_Patient* and *Treated_By* respectively.

(iii) The sub-class *Material_Entity* covers the detail about any entity used in the process of CDM via data type properties. This information could be in the form of type of material entity and its usage if it is used for support purposes such as crutches, or wheelchair, or eye glasses. If the material entity is a healthcare facility, such as clinic or hospital, the data type property coves the information about the address, name and description of the entity.

(f) Role is defined as a main class and covers the notion of different roles performed by various individuals. As mentioned earlier this class is analogous to the backbone class *Role* of HL7 RIM. Through its data type attributes, this class captures the information about role ID which is unique to each role, role name, address and gender. The main class has three sub-classes, namely *Health_Related_Role, Patient and Person.* A complete list of properties of the main class and the sub-classes are mentioned in Table 5-2.

(i) The sub-class *Health_Related_Role* captures the information of all possible individuals who are related to healthcare profession such as, physician, surgeon, nurses, and OT staff etc. Data-type properties are defined to cover the information related to the particular designation of the role and the contact information.

(ii) The sub-class *Patient* captures the information about any individual who is suffering from any health related issues or disease. This class captures the detail information about the individual via data types attributes. The data type properties cover the information about the address, contact number, emergency contact, date of birth, place of birth, marital status, occupation, religion, race, and ethnic group. The object properties *Examine_By* and *Treated_By* link this sub-class to the *Health_Related_Role.*

(iii) The sub-class *Person* covers the information related to any person who is neither a patient nor a healthcare provider. A person could be any individual who is either a relative of the patients, such as a sibling, parent, or any individual who plays any role in the process of CDM. The data-type attributes cover the information such as name, address, date and place of birth, and role ID of the person.

(g) Clinical_Artifact is defined as a main concept to cover the representational aspects of the disease that occurs in the form of signs and symptoms. The data types attributes covers the characteristics features such as, aggravating and relieving factors, duration, interval of time, name, and date and time of onset. This class is analogous to the *class Clinical_Artifact* of CPR ontology and is linked with the Health_Realted_Role via object property *Recorded_By. Clinical_Artifact* has two sub-classes, *Sign_Finding* and *Symptom_Finding.* A complete list of properties of the main class and the sub-classes are mentioned in Table 5-2.

(i) The sub-class *Sign_Finding* covers the patient specific information about the sign presentation. As mentioned earlier, signs are presentations of the medical problems that are observed by the clinician. This subclass is connected to the sub-class *Signs_And_Symptoms* via object property *Has_Sign*. We have reused this sub-class from the CPR Ontology to capture the notion of signs in CD-EMR Ontology

(ii) The sub-class *Symptom_Finding* covers patient specific information about the symptoms through the data type properties. These attributes cover the characteristics of the symptoms, such as course of the symptom, quality, severity, location of the symptom and the nature of the symptom onset. This subclass is connected to the sub-class *Signs_And_Symptoms* via object property *Has_Symptom.*

(h) Intervention_Planning is defined as a main class of CD-EMR ontology and captures the various treatment options of holistic care for chronic diseases management. It covers the information about the duration of treatment, the level of patient compliance, and any specific instruction about the treatment through the data type attributes. This class is linked with the *Patient_Record* and *Health_Related_Role* via object properties *Record_For_Patient* and *Advised_By* respectively. This concept is adapted from the CPR Ontology and is used to capture the different available treatment options by incorporation of the eight sub-classes in it. These sub-classes are, *Medical_Therapy, Surgical_Therapy, Therapeutic_Procedure, Therapies, Lifestyle_Modification, Self_Management_Support, Patient_Education,* and *Care_Support_Activities*

(i) The sub-class *Medical_Therapy* covers the information of the medical treatment provided to the patient in the form of drugs or medications. It captures the detail of medications through its data types attributes such as, duration of therapy, start and end date, dose such as, once a day, two time a day or three times a day, schedule, prescribed strength, route of therapy, such as per oral, or intravenous, frequency for intravenous therapy, number of refills, Drug Identification Number (DIN), and any specific instruction about the prescription or therapy. The object properties link the individuals of this class to, (a) the individuals

of the class Drug via *Medication_Name,* as mentioned earlier that the information about the drugs and medications is covered in the class *Drug*, (b) to the individual of class *Health_Related_Role* via *Prescribed_By* and *Advised_By*, (c) the individual of class *Order* via *Prescription* which covers the prescription details, and (d) the individual of the class *Patient* via *Record_For_Patient.*

(ii) The sub-class *Surgical_Therapy* covers the detail of surgical procedures. The data type attributes of this class captures the details about the name of surgical procedures, date and time of the surgery, surgical and anesthesia notes, type of anesthesia used during surgery, and details of any complications. The object properties connect the individuals of *Surgical_Therapy* to the individuals of *Order* via *Pre-Operative_Orders, Post-Operative_Orders and Nursing_Orders,* similarly the object properties Role_Involved, Performed_By and Advised_By linked the individuals between *Surgical_Therapy* and *Health_Related_Role.* The linkage between the individuals of *Patient* and *Surgical_Therapy* is achieved by the object property *Record_For_Patient.*

(iii) The sub-class *Therapies* is defined to cover the treatment options that are distinct from the medical and surgical treatment, but still considered as therapies, for example, physiotherapy, sports, music, or psychotherapy. The information captured via data-type attributes includes duration of therapy, start and end date of therapy, level of patient compliance, any complication during the therapy, and the recommended duration of the therapy. The specified goal and target of the therapy is covered through the object properties which connect the individuals of this class to the individual of the classes *Goals* and *Targets* via *Has_Goals* and *Has_Targets*. The information about who

advised the therapy and who performed it is achieved via object properties *Recommended_By* and *Perfromed_By*. These properties also linked the individuals between *Therapies* and *Health_Related_Role.* The linkage between the individuals of *Patient* and *Therapies* is achieved by the object propert*y Record_For_Patient.*

(iv) The sub-class *Procedures* covers those processes that do not require the special arrangement of surgical procedures these processes could include applying or removal of sutures on or from a cut wound, or insertion of catheter, or N/G Tube. The data type attributes covers the information about date and time of procedure, reason for procedure, complications during or after the procedure, and recommended care after the procedure. The object properties *Advised_By* and *Performed_By* link the individuals of this class to *Health_related_Role*, similarly the object property *Record_For_Patient* performs the linkage between *Patient* and *Procedure.*

(v) The sub-class *Lifestyle_Modification* covers the notion of providing care to chronically ill patients by alternation in lifestyle, with or without medical interventions. This is achieved by setting goals and targets for the patients. Several aspects of the present lifestyle of the patient need to be evaluated such as dietary intake, level of physical activity or sedentary nature of every day routine, and stress levels. After the evaluations goal setting is done. Each goal is bound with some particular targets that need to be achieved by the patient in a particular time-frame. The data-type attributes of this sub-class cover the information related to evaluation process, the duration of goal achievement, and the level of patient compliance which could be high, low, or moderate. In cases of low compliance, patients need counseling. The aspect of providing or seeking counseling

is also covered via data type property. The individuals of this class are linked to the individuals of classes *Goal* and *Target* via object properties *Has_Goal* and *Has_Target* . Similarly the object properties *Recommended_By* link the individuals of this class to *Health_related_Role,* and *Record_For_Patient* performs the linkage between *Patient* and *Lifestyle_Modification.*

(vi) The sub-class *Self_Management_Support* provides a mean to capture those processes, such as self-monitoring, that chronically ill patients can perform themselves to keep a record of their illness progression. It covers those maneuvers that help patients to manage their own health conditions and thereby prevent unnecessary healthcare encounters. To perform these procedures by themselves, patients sometimes need some training, either to develop the skill or to enhance the problem-solving skill. The data type attributes cover the information related to the training to perform self-management, level of patient's self-efficacy, and problem solving skill. The object properties link the individuals of this class to the individuals of classes *Goal* and *Target* via *Has_Goal* and *Has_Target* . Similarly the object properties *Recommended_By* link the individuals of this class to *Health_related_Role,* and *Record_For_Patient* performs the linkage between *Patient* and *Self_Management_Support*

(vii) The sub-class *Patient_Education* is defined to cover the information related to the provision of patient education and Evidence-Based Medicine (EBM) that helps to increase awareness in the patient about their health status and also helps in modification of patient's behavior towards the disease. The data-type attributes capture the data related to evidence-based recommendations and the source of EBM and patient education

material which could be in the from a Care Plan, CPG, Care Pathway, the medium of patient education, and behavioral modification. The object properties link the individuals of this class to the individuals of classes *Goal* and *Target* via *Has_Goal* and *Has_Target* , similarly the object properties *Recommended_By* link the individuals of this class to *Health_related_Role,* and *Record_For_Patient* performs the linkage between *Patient* and *Patient_Education*

(viii) The sub-class Care_Support_Activities helps to capture information about the community based care support programs and services. The data type properties cover the information about the involvement of any community based service or long-term care team in the process of care. The object properties *Community_Center and Long_Term_Care_Facility* link the individual of this class to the individuals of class *Material_Entity.* The linkage of the individuals of this class to the individuals of classes *Goal* and *Target* is achieved via object properties *Has_Goal* and *Has_Target* ,similarly *Recommended_By* links the individuals of this class to *Health_related_Role,* and *Record_For_Patient* performs the linkage between *Patient* and Care_Support_Activities.

(i) Goals is defined as a main class and captures the information related to the goal setting process. The data-type attributes cover the information related to the goal statement, start date and time, recommended duration to achieve the goal and current state of the goal, which is used to access the progress to achieve goals in the next visit. The object property *Recommended_By* links the individuals of this class to *Health_related_Role,* and *Recommended_To* performs the linkage between *Patient* and *Goals.*

(j) Targets is defined as a main class to cover information about the specific targets related to the goals. Targets are time sensitive. The data-type attributes cover the information related to the start date and time and recommended duration. The object property *Recommended_By* links the individuals of this class to *Health_related_Role,* and *Recommended_To* performs the linkage between *Patient* and *Targets*.

(k) Orders is defined as a maim class and capture the information about various types of orders such as nursing orders, pre and post-operative order and even prescription. The data-type attributes covers the information about the nature and type of order and the date and time of the order, while the object properties cover the information about who gives the order and for whom. The object properties *Ordered_By* and *Role_Involved* links the individuals of this class to *Health_related_Role,* and *Order_For_Patient* performs the linkage between the classes *Patient* and *Orders*.

(l) Healthcare_Encounter is defined as a main class and captures all the information related to care delivery during a healthcare encounter which includes patient history, clinical examination, investigations, treatment, and the next scheduled visit. This class keeps the record of each healthcare encounter while the class Patient_Record keeps the record of all healthcare counters. Thus, these two classes' together help in storage of patient information in a systemic and organized manner and enable the CD_EMR ontology to maintain the longitudinal record of each patient.

(m) Patient_Record is defined as a main class in CD-EMR ontology and it covers all the aspects of patients data and records all information related to the process of care delivery by keeping a record of all healthcare encounters. This class is also adapted from the CPR ontology. In CD-EMR Ontology we have incorporated this class with object and data type attributes which helped us to

cover the vast range of information related to the care process in the form of EPR.

(n) Vocabulary is defined as a main class in CD-EMR ontology and it covers the generic knowledge related to CDM. The class captures the knowledge that is not patient specific. The main purpose of defining this class is to capture the concepts that are common to all chronic disease such as signs and symptoms, clinical investigations and clinical examinations. So this class is further classified into three sub-classes which are, *Sign_And_Symptom, Clinical Examinations and Clinical_Investigations.* These sub-classes are adapted from CPR Ontology and are discussed below.

(i) *Sign_And_Symptom* captures the general information related to different signs and symptoms that develop during the course of chronic diseases such as nausea, vomiting, abdominal pain or distension. This class captures the general information related to signs and symptoms such as aggravating and relieving factors, SNOMED-CT Code, and description. This generic information can be used in a patient specific manner through the classes' *Sign_Finding* and *Symptom_Finding.*

(ii) *Clinical Examinations* captures the general information related to various types of examinations such as blood pressure examination, respiratory examination, abdominal examination or JVP measurement. This class covers the generic information related to clinical examination which can be used in a patient specific manner through the classes' *Laboratory_Test_Finding* and *Radiology_And_Scan_Finding.*

(iii) *Clinical_Investigations* captures the general information related to various types of lab investigations used in the

process of CDM such as serum electrolytes, urine analysis or radiograph chest. The general information such as normal ranges, related to clinical investigations has been covered in this class. This generic information can be used in a patient specific manner through the classes' *Vital_Examination_Finding* *Non_Vital_Examination_Finding* and *Systemic_Examination_Finding*

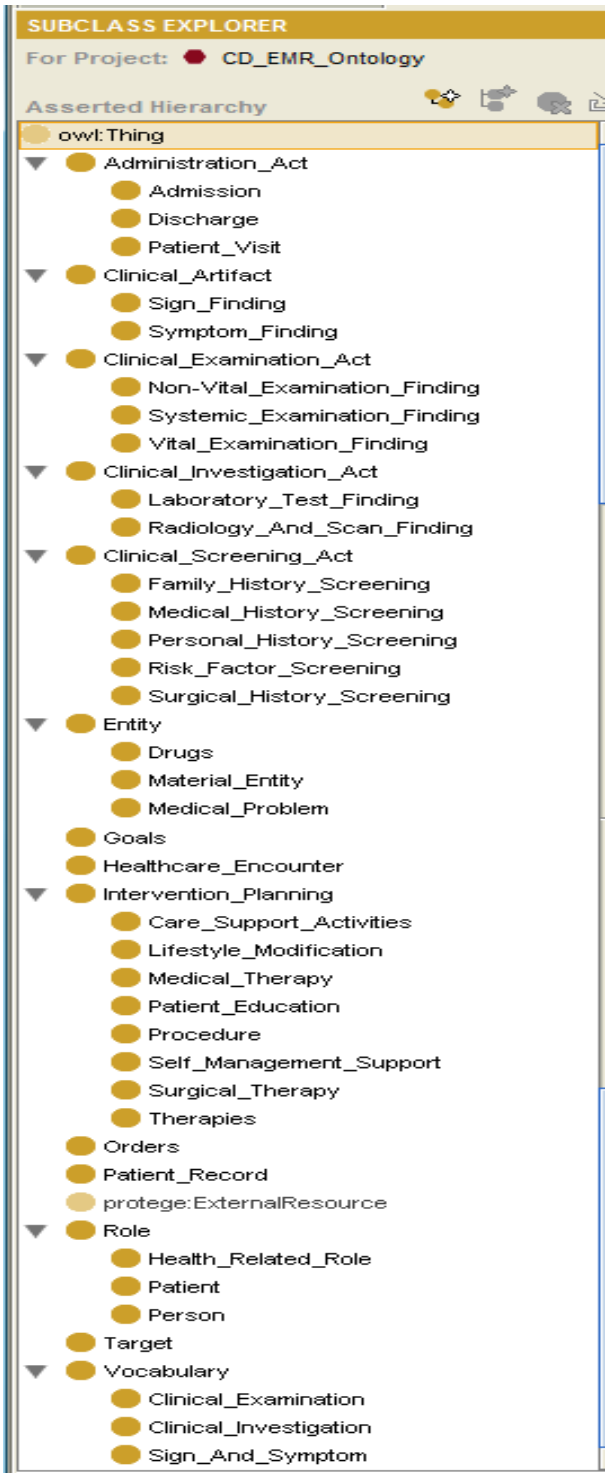

SUBCLASS EXPLORER
For Project: CD_EMR_Ontology
Asserted Hierarchy
owl:Thing
Administration_Act
Admission
Discharge
Patient_Visit
Clinical_Artifact
Sign_Finding
Symptom_Finding
Clinical_Examination_Act
Non-Vital_Examination_Finding
Systemic_Examination_Finding
Vital_Examination_Finding
Clinical_Investigation_Act
Laboratory_Test_Finding
Radiology_And_Scan_Finding
Clinical_Screening_Act
Family_History_Screening
Medical_History_Screening
Personal_History_Screening
Risk_Factor_Screening
Surgical_History_Screening
Entity
Drugs
Material_Entity
Medical_Problem
Goals
Healthcare_Encounter
Intervention_Planning
Care_Support_Activities
Lifestyle_Modification
Medical_Therapy
Patient_Education
Procedure
Self_Management_Support
Surgical_Therapy
Therapies
Orders
Patient_Record
protege:ExternalResource
Role
Health_Related_Role
Patient
Person
Target
Vocabulary
Clinical_Examination
Clinical_Investigation
Sign_And_Symptom

Figure 5-3 Class Hierarchy of CD-EMR Ontology
(Showing classes and sub-classes)

Table 5-2 Classes and sub-classes or CD-EMR Ontology with their properties

Classes & Sub Classes		**Properties**	**Property Type**
Main Class	**Sub-Class**		
Administration_ Act		Record_For_Patient	Object type
		Role_Involved	Object type
		Has_Date_And_Time	Data type
		Has_Description	Data type
	Admission	Admitted_By	Object type
		Admitted_To	Object type
		Has_Clinical_Examination	Object type
		Has_Intervention	Object type
		Has_Investigations	Object type
		Has_Orders	Object type
		Has_Signs	Object type
		Has_Symptoms	Object type
		Reason_For_Admission	Data type
		Admission_Plan	Data type
		Notes	Data type
	Discharge	Discharge_By	Object type
		Discharge_Destinaion	Object type
		Discharge_Plan	Data type
	Patient_Visit	Nature_Of_Visit	Data type
		Scheduled_Date_And_Time _For Next_Visit	Data type
		Place_Of_Healthcare_Enco unter	Object type

		Next_Visit	Object type
		Visit_Type (Scheduled/ Unscheduled)	Data type
Clinical_ Investigation_Act		Encounter_ID	Data type
		Record_For_Patient	Object type
		Requisition_Date_And_Time	Data type
		Ordered_By	Object type
		Reason_For_Test	Data type
		Laboratory_Name	Data type
		Date/Time results entered in HIS	Data type
		Review_Date/Time	Data type
	Laboratory_Test _Findin	Laboratory_Test_Name	Object type
		Collection_Date_And_Time	Data type
		Test_Description	Data type
		Test Result Value	Data type
		Result Unit of Measure	Data type
		Reference Range Low	Data type
		Reference Range High	Data type
		Reference Range (Text-based)	Data type
		Abnormal_Indicator	Data type
		Notes from Lab	Data type
		Physician Notes	Data type
	Radiology_And _ Scan_ Finding	Name of Scan	Object type
		Nature of Scan (Diagnostic, Therapeutic, Invasive, Non-invasive)	Data type
		Normal Findings	Data type

		Abnormal findings	Data type
		Has_Indication	Data type
		Has_Contraindication	Data type
		Any complication	Data type
		Notes	Data type
Clinical_ Examination_Act		Name_Of_Examination	Object type
		Date_And_Time_Of_ Exam_Performed	Data type
		Encounter_ID	Data type
		Performed_By	Object type
		Record_For_Patient	Object type
		Site_Of_Examinaton	Data type
		Notes	Data type
	Vital_Examinati on	Results (value of Exam)	Data type
		Reference_ Range	Data type
		Rate	Data type
		Rhythm	Data type
		Volume	Data type
		Has_Duration	Data type
	Non-Vital_ Examination	Results (value of Exam)	Data type
		Examination_Finding_Nor mal	Data type
		Examination_Finding_Abno rmal	Data type
	Systemic_ Examination	Audible sound Normal	Data type
		Audible sound Abnormal	Data type
		Examination Finding Normal	Data type
		Examination Finding	Data type

		Abnormal	
		Tenderness	Data type
		Organomegaly	Data type
		Reflexes	Data type
		Has_Duration	Data type
Clinical_ Screening_ Act		Has_Disease	Object type
		Age_At_Onset	Data type
		Any_Complication	Data type
		Record_For_Patient	Object type
		Ask_But_Unknown	Data type
		SNOMED-CT_Code (8410007)	Data type
		Notes	Data type
	Medical_History_ Screening	Treatment_Taken	Object type
		Treatment_Given	Data type
		History_Of_Adverse_Reaction	Data type
		Has_Duration	Data type
	Surgical_History_ Screening	Reason_Of_Surgery	Data type
		Nature_Of_Surgery	Data type
		Type_Of_Anesthesia	Data type
		Performed_By	Object type
		Role_Involved	Object type
		Surgical_Notes	Data type
		Pre_Operative_Order	Object type
		Post_ Operative_Order	Object type
	Family_History_ Screening	Number_Of_Siblings	Data type
		Relationship_With_Patient	Object type
		Duration_Of_Diseases	Data type
		Treatment_Given	Data type

		Cause_Of_Death	Data type
		Familial_Diseases	Object type
		Genetic_Disorders	Object type
		Medication_Used	Data type
		Surgical_Procedure_Perfromed	Object type
	Personal_History _Screening	Start_Date	Data type
		End_Date	Data type
		Addiction	Data type
		Alcohol_Intake	Data type
		Number_oF_Drinks	Data type
		Smoking	Data type
		Number_Of_Cigarettes_Per_Day	Data type
		Bowel_Habits	Data type
		Micturation	Data type
		Sleep_Habits	Data type
		Allergies	Data type
		Type_Of_Allergic_Reaction	Data type
		Extent_Of_Reaction	Data type
		Offending_Agent	Data type
		Reaction_Description	Data type
		Socio-economic_status	Data type
		Immunization_Status	Data type
		Blood_Transfusion	Data type
		Has_Duration	Data type
	Risk_Factors_Screening	Risk_Factor_Name	Data type
		Exposure_Detail	Data type
		Start_Date	Data type
		End_Date	Data type

		Has_Duration	Data type
Clinical_Artifact		Encounter_ID	Data type
		Has_Date_And_Time	Data type
		Anatomical_Site	Data type
		Ask_But_Unknown	Data type
		Interval_Of_Time	Data type
		Date_And_Time_Of_Onset	Data type
		Aggravating_Factors	Data type
		Relieving_Factors	Data type
		Has_Duration	Data type
		Recorded_By	Object type
		Record_For_Patient	Object type
	Sign_Finding	Has_Sign	Object type
		Examination_Finding	Data type
		Examined_By	Object type
	Symptom_Findi ng	Has_Symptom	Object type
		Location_Of_Symptom	Data type
		Nature_Of_Symptom_Onse t (acute, sub acute, chronic or insidious)	Data type
		Course_Of_Symptom (static, progressive, relapsing, remitting)	Data type
		Quality_Of _Symptom (stabbing, stinging, lightning, pounding)	Data type
		Severity	Data type
		Associated_Symptoms (pain, headache, nausea, vomiting weakness, and	Data type

		seizures)	
Goals		Current_State	Data type
		Goal_Statement	Data type
		Has_Duration	Data type
		Has_Target	Object type
		Notes	Data type
		Order_Date_and_Time	Data type
		Recommended_By	Object type
		Recommended_To	Object type
Healthcare_Encounter		Encounter_ID	Data type
		Has_Clinical_Examination	Object type
		Has_Date_And_Time	Data type
		Has_Days_Of_Admission	Object type
		Has_Discharge_Summary	Object type
		Has_Family_History	Object type
		Has_Goals	Object type
		Has_Intervention	Object type
		Has_Investigations	Object type
		Has_Medical_History	Object type
		Has_Orders	Object type
		Has_Personal_History	Object type
		Has_Medical_Problem	Object type
		Has_Presenting_Complaints	Data type
		Has_Risk_Factors	Object type
		Has_Signs	Object type
		Has_Surgical_History	Object type
		Has_Symptoms	Object type
		Has_Target	Object type
		Nature_Of_Encounter	Data type
		Note	Data type

		Place_Of_Healthcare_Encounter	Object type
		Record_For_Patient	Object type
		Role_Involved	Object type
		Scheduled_Next_Visit	Object type
Patient_Record		Record_For_Patient	Object type
		Has_Healthcare_ Encounter	Object type
		Patient_Record_Number	Data type
		Has_Clinical_Diagnosis	Object type
		Notes	Data type
Entity		Has_Name	Data type
		Has_Description	Data type
	Drugs	Has_Family	Data type
		Has generic name	Data type
		Has_Indication	Data type
		Has_Contraindication	Data type
		Has_Adverse_Effects	Data type
		Has_Allergic_Reactions	Data type
		Has_Route_Of_Intake	Data type
		Has route_Of_Excretion	Data type
		Notes	Data type
	Material_Entity	Type)Of_Material_Entity (Clinic, hospital, long-term care facility, wheelchair, crèches)	Data type
		Address	Data type
		Organization_Name	Data type
		Use_Of_Material_Entity (healthcare service, care support material)	Data type

	Medical_Problem	Has_Signs	Object type
		Has_Symptoms	Object type
		Has_Complications	Data type
		Has_Duration	Data type
		Has_State	Data type
		Treated_By	Object type
		Has_Presenting_Complaints	Data type
		Record_For_Patient	Object type
Role		Role ID	Object type
		Name	Data type
		Gender	Data type
		Address	Data type
	Health_Related_Role	Has_Designation	Data type
		Contact_Information	Data type
	Person	Occupation	Data type
		Contact_Information	Data type
		Date_Of _Birth	Data type
		Place_Of _Birth	Data type
		Person_Name	Data type
	Patient	Home_Address	Data type
		Work_Address	Data type
		Phone_Number	Data type
		E-mail_Address	Data type
		Emergency_Contact	Data type
		Has_Age	Data type
		Date_Of _Birth	Data type
		Place_Of _Birth	Data type
		Date_Of_Death	Data type
		Place_Of_Death	Data type
		Cause_Of_Death	Data type

		Marital_Status	Data type
		Occupation	Data type
		Ethnic_Group	Data type
		Race	Data type
		Religion	Data type
		Examine_By	Data type
		Treated by	Data type
Intervention_ Planning		Advised_By	Object type
		Record_For_Patient	Object type
		Medical_Equipement_Used	Object type
		Has_Duration	Data type
		Patient_Compliance	Data type
		Notes	Data type
	Medical_Therapy	Start_Date	Data type
		End_Date	Data type
		Prescriptions	Object type
		Medication_Name	Object type
		Dose	Data type
		Drug_Strength	Data type
		Once_A_Day	Data type
		Two_Time_A_day	Data type
		Three_Time_A_day	Data type
		Four_Times_A_day	Data type
		Frequency_Others	Data type
		Schedule	Data type
		Number of Refills	Data type
		Last_Refill_Date	Data type
		Route	Data type
		Therapy_Instructions	Data type
		Prescription_Instructions	Data type

		Prescribed_By	Object type
		Drug Identification Number (DIN)	Data type
	Surgical_Therapy	Name_Of_Surgical_Procedure	Data type
		Type_Of_Anesthesia_Used	Data type
		Performed_By	Object type
		Role_Involved	Object type
		Pre_Operative_Orders	Object type
		Nursing_Orders	Object type
		Operative_Notes	Data type
		Post_Operative_Orders	Object type
		Anesthesia_Notes	Data type
		Any_Complications	Data type
		Date_And_Time_Of_Procedure	Data type
	Procedure	Name_Of_Procedure	Data type
		Performed_By	Object type
		Date_And_Time_Of_Procedure	Data type
		Reason_For_Procedure	Data type
		Recommended_Care	Data type
		Any_Complications	Data type
	Therapies	Name_Of_Therapy	Data type
		Recommended_By	Object type
		Performed_By	Object type
		Role_Involved	Object type
		Start_Date	Data type
		End_Date	Data type

		Recommended_Duration	Data type
		Therapy_Instructions	Data type
		Has_Target	Object type
		Any_Complication	Data type
	Lifestyle_ Modification	Evaluation_Of_Lifestyle	Data type
		Evaluation_Of_Physical_Activities	Data type
		Dietary_Intake	Data type
		Evaluation _Of_Stress_Level	Data type
		Has_Goal	Object type
		Has_Targets	Object type
		Patient_Counseling	Data type
		Has_Recomendation	Data type
		Recommended_By	Object type
	Self_Management_ Support	Self_Monitoring	Data type
		Level_Of_Problem_Solving _Skill	Data type
		Patient_Training	Object type
		Self management support tool kit	Data type
		Level_Of_Self_Efficacy	Data type
		Has_Goal	Object type
		Patient_Counseling	Object type
		Has_Target	Data type
	Patient_Education	Evidence_Based_Recomendation	Data type
		Clinical_Practice_Guideline	Data type
		Care_Plan	Data type
		Institution_Specific_Care_P	Data type

		athways	
		Source_Of_Patient_Education_ Material	Data type
		Patient Training	Data type
		Recommended_By	Object type
		Medium_Of_Patient_Education	Data type
		Patient_Counseling	Data type
		Behaviors_Modification	Data type
		Has_Goal	Object type
		Has_Trget	Object type
	Care_Support_ Activities	Community_Services	Data type
		Community_Center	Object type
		Longterm_Care_Facility	Object type
		Longterm_Care_Team	Data type
		Nursing_Home	Object type
		Patient_Counseling	Data type
		Recommended_By	Object type
		Has_Goal	Has_Goal
		Has_Trget	Has_Trget
Orders		Has_Investigation_Name	Data type
		Instructions	Data type
		Medication_Name	Object type
		Order_Date_And_Time	Data type
		Order_For_Patient	Object type
		Ordered_By	Object type
		Role_Involved	Data type
		Type_Of_Order	Data type
Target		Has_Duration	Data type

		Order_Date_And_Time	Data type
		Recommended_By	Data type
		Recommended_To	Data type
Vocabulary		Concept_Name	Data type
		Has_Description	Data type
		SNOMED_CT_Code	Data type
	Clinical Examination	Site_Of_Examination	Data type
	Clinical_Investigation	Nature_Of_Scan	Data type
		Reason_For_Test	Data type
	Sign_And_Symptom	Anatomicalite	Data type

5.4.2 REUSE OF CONCEPTS FROM CPR ONTOLOGY, CCM AND HL7 RIM IN CD-EMR ONTOLOGY

In our research objectives we have claimed that we will reuse the concepts from three standard models CCM, CPR Ontology and HL7 RIM. Figure 5-4 shows how we have used the concepts of the above mentioned standard models on our CD-EMR Ontology. In the middle of Figure 5-4, we have presented the classes and sub-classes of CD-EMR Ontology. On either side of the concepts the circles represent the standard models and the dotted lines shows the derivation of concepts from the standard models. For example, the classes *Administration_Act, Clinical_Examination_Act, Clinical_Screening_Act, and Clinical_Investigation_Act* come from CPR ontology, and these concepts are also analogous to the class *Act* of HL-7 RIM. Similarly the concept of Role is common across all three standard models and is used as a class *Role* in CD-EMR Ontology. The concept of Entity comes from HL7 RIM, while the concepts Self_Management_Support, Patient_Education, Support_Care_Activity, and Next_Visit (which covers the notion of follow-up, referral, or reconsultation) are derived from CCM.

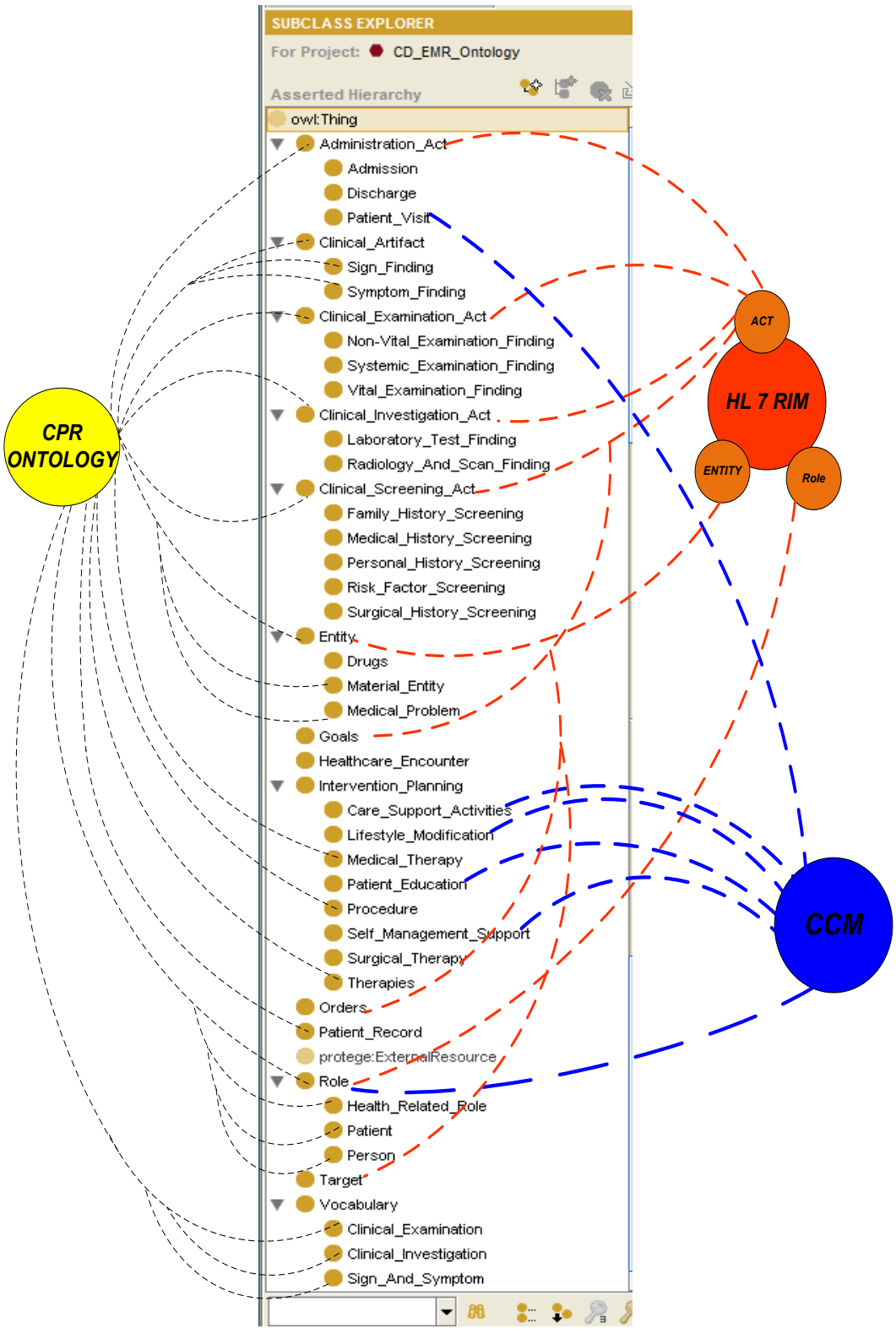


Figure5-4 Reuse of concepts from CCM, CPR Ontology and HL7 RIM in CD-EMR Ontology

5.4.3 PROPERTIES OF CD-EMR ONTOLOGY

In OWL, relationships are represented through properties; OWL defines two major types of properties which are (a) Object type, and (b) Data-type properties [109]. In the subsequent section we will explain the aforementioned properties and how we have used these properties in our CD-EMR Ontology.

(i) **Object Properties** are defined as properties that link an individual to an individual [109]. Object properties have specified *domain* and *range.* The linkage between the individuals occur in a manner that the individual from domain are linked to the individual from range via object property [109]. The detail of object properties with their domain and range is presented in Table 5-3.

Table 5-3 Object Properties with domains and ranges

Object Property	**Domain**	**Range**
Admitted_By	Admission	Health_Related_Role
Admitted_To	Admission	Material_Entity
Advised_By	Intervention_Planning	Health_Related_Role
Community_Centres	Care_Sopport_Activities	Material_Entity
Discharged_By	Discharge	Health_Related_Role
Discharge_Destination	Discharge	Material_Entity
Examine_By	Sign_Finding Patient	Health_Related_Role
Familial_Diseases	Family_History_Screening	Medical_Problem
Genetic_Disorders	Family_History_Screening	Medical_Problem
Has_Clinical_Diagnosis	Patient_Record	Medical_Problem
Has_Clinical_Examination	Healthcare_Encounter Admission	Clinical_Examination_Act
Has_Days_Of_Admission	Healthcare_Encounter	Admission

Has_Discharge_Summary	Healthcare_Encounter	Discharge
Has_Disease	Clinical_Screening_Act	Medical_Problem
Has_Family_History	Healthcare_Encounter	Family_History_Screening
Has_Goal	Patient_Education Self_Management_Support Care_Support_Activitie Lifestyle_Modification Healthcare_Encounter	Goals
Has_Healtcare_Encounters	Patient_Record	Healtcare_Encounters
Has_Intervention	Healthcare_Encounter Admission	Intervention_Planning
Has_Investigations	Healthcare_Encounter Admission	Clinical_Investigation_Act
Has_Investigation_Name	Orders	Clinical_Investigation
Has_Medical_History	Healthcare_Encounter	Medical_History_Screening
Has_Medical_Problem	Healthcare_Encounter	Medical_Problem
Has_Order	Healthcare_Encounter Admission	Orders
Has_Personal_History	Healthcare_Encounter	Personal_History_Screening
Has_Risk_Factors	Healthcare_Encounter	Risk_Factors_Screening
Has_Signs	Healthcare_Encounter Admission Medical_Problem	Sign_Finding
Has_Surgical_History	Healthcare_Encounter	Surgical_History_Screening
Has_Sign	Sign_Finding	Sign And_Symptom

Has_Symptoms	Healthcare_Encounter Admission Medical_Problem	Symptom_Finding
Has_Symptom	Symptom_Finding	Sign And_Symptom
Has_Target	Patient_Education Self_Management_Support Therapies Care_Support_Activitie Lifestyle_Modification Healthcare_Encounter Goals	Target
Laboratory_Test_Name	Laboratory_Test_Finding	Clinical_Investigation
Longterm_Care_Facility	Care_Sopport_Activities	Material_Entity
Medical_Equipement_Used	Intervention_Planning	Material_Entity
Medication_Name	Medical_Therapy Orders	Drugs
Name_Of_Examination	Clinical_Examination_Act	Clincal_Examination
Name_Of_Scan	Radiology_And_Scan_Finding	Clinical_Investigation
Next_Visit.	Next_Visit.	Heathcare_Encounter
Nursing_Home	Care_Sopport_Activities	Material_Entity
Nursing_Orders	Surgical_Therapy	Orders
Order_For_Patient	Order	Patient
Ordered_By	Clinical_Investigation_Act Orders	Health_Related_Role
Performed_By	Clinical_Examination_A	Health_Related_Role

	ct Surgical_History_Screening Surgical_Therapy Procedure Therapies	
Patient_Training	Self_Management_Support	Patient_Education
Performed_By	Clinical_Examination_Act Surgical_History_Screening Surgical_Therapy Procedure Therapirs	Health_Related_Role
Place_Of_Healthacre_Encounter	Healthacre_Encounter Patient_Visit	Material_Entity
Post-Operative_Orders	Surgical_History_Screening Surgical_Therapy	Order
Pre-Operative_Orders	Surgical_History_Screening Surgical_Therapy	Order
Prescribed_By	Medical_Therapy	Health_Related_Role
Prescriptions	Medical_Therapy	Drug Order
Recommended_By	Patient_Education Self_Management_Support Therapies Care_Support_Activitie	Health_Related_Role

	Lifestyle_Modification Goals Targets	
Recommended_To	Goals Targets	Patient
Record_For_Patinet	Administration_Act Clinical_Investigation_Act Clinical_Examination_Act Clinical_Screening_Act Patient_Record Medical_Problem Intervention_Planning Healthacre_Encounter	Patient
Recorded_By	Clinical_Artifact	Health_Related_Role
Relationship_With_Patient	Family_History_Screening	Person
Role_Involved	Administration_Act Surgical_History_Screening Surgical_Therapy Therapies Orders Healthacre_Encounter	Health_Related_Role
Surgical_Procedure_Performed	Surgical_History_Screening Family_History_Screening	Surgical_Therapy
Scheduled_Next_Visit	Healthacre_Encounter	Next_Visit
Treated_By	Medical_Problem	Health_Related_Role

	Patient	
Treatment_Taken	Medical_History_Screening	Medical_Therapy Drugs

(i) **Data-type Properties** are defined as the properties that describe the characteristics of an individual i.e. delineate relationships of individual to data values. The most vital function of these properties lies in the fact that these properties perform linkage of individual to an XML Schema Datatype value or an rdf literal [109]. In CD-EMR Ontology we have successfully used this functionality to link our ontology to HL-7 v3 schema which enables us to achieve semantic interoperability. We have successfully used the data type properties specified by HL-7 v3 in our CD-EMR Ontology, for example: *Ask_but_Unknown, Entity_Name, Organization_Name, Person_Name, Two_Times_A_Day, Three_Times_A_Day, and Four_Times_A_Day.* By doing this, our ontology is capable of capturing clinical documentation written in HL7 V.3 as well as communicating with other HIS which have an HL7 V3 interface. Figure 5-5 shows a snap shot of some data type attributes of CD-EMR Ontology.

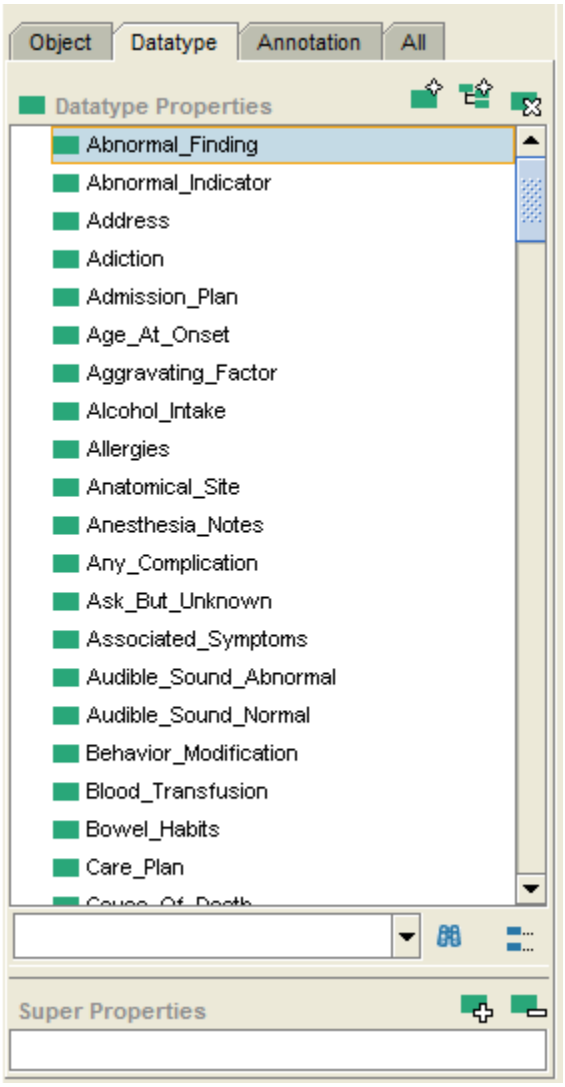


Figure5-5 Data-types attributes of CD-EMR Ontology

5.5 WORKING DESIGN OF CD-EMR ONTOLOGY

In the earlier part of this chapter we have explained the structural elements (i.e. classes, sub-classes and properties) of CD-ERM Ontology. Before validation of CD-EMR Ontology by instantiation of clinical scenarios, it is essential to describe the working design of CD-EMR Ontology. This explains (a) how CD-EMR Ontology captures the generic knowledge about chronic diseases management, and (b) how CD-EMR Ontology captures the patient specific information and heterogeneous data related to multiple sources, such lab investigations results, sign and symptoms findings, results and findings of clinical examinations. The CD-EMR Ontology is designed in such a manner that we

can separate the classes of CD-EMR Ontology in two separate modules which are (a) Knowledge Module, and (b) Patient-specific Module, Figure 5-6..

a. Knowledge Module. In this part of the ontology the classes hold generic information related to CDM. This information is not case specific or patient specific in nature so it can be used multiple times for different patients and in different ways. For example, the sub-class Drug captures the information related to drugs and medications. Through its properties it defines the various characteristics of the drugs such as drug indications, drug contra-indications, allergies and adverse reactions, allowed dose and the family of drug. So this class holds the generic information related to the drugs. This information can be used in several different ways such as previous medication history of the patient, prescription for a patient, or in case of medical therapy during a hospital admission. Similarly the class Sign and symptoms, Clinical examinations, Lab Investigations and material entity all contain generic information about CDM.

b. Patient-Specific Module. This part of the CD-EMR Ontology uses the generic information from the knowledge module and stores the patient specific information in a systemic manner. For example, X has blood pressure 110/90 mmHg. The class Vital Examination Finding (Of Patient specific module) stores the results for systolic and diastolic BP of Patient X. The class Clinical Examination (Of knowledge module) provides the generic information related to systolic and diastolic blood pressure, such as Concept Name and SNOMED CT Code for diastolic and systolic BP, through the property name of examination.

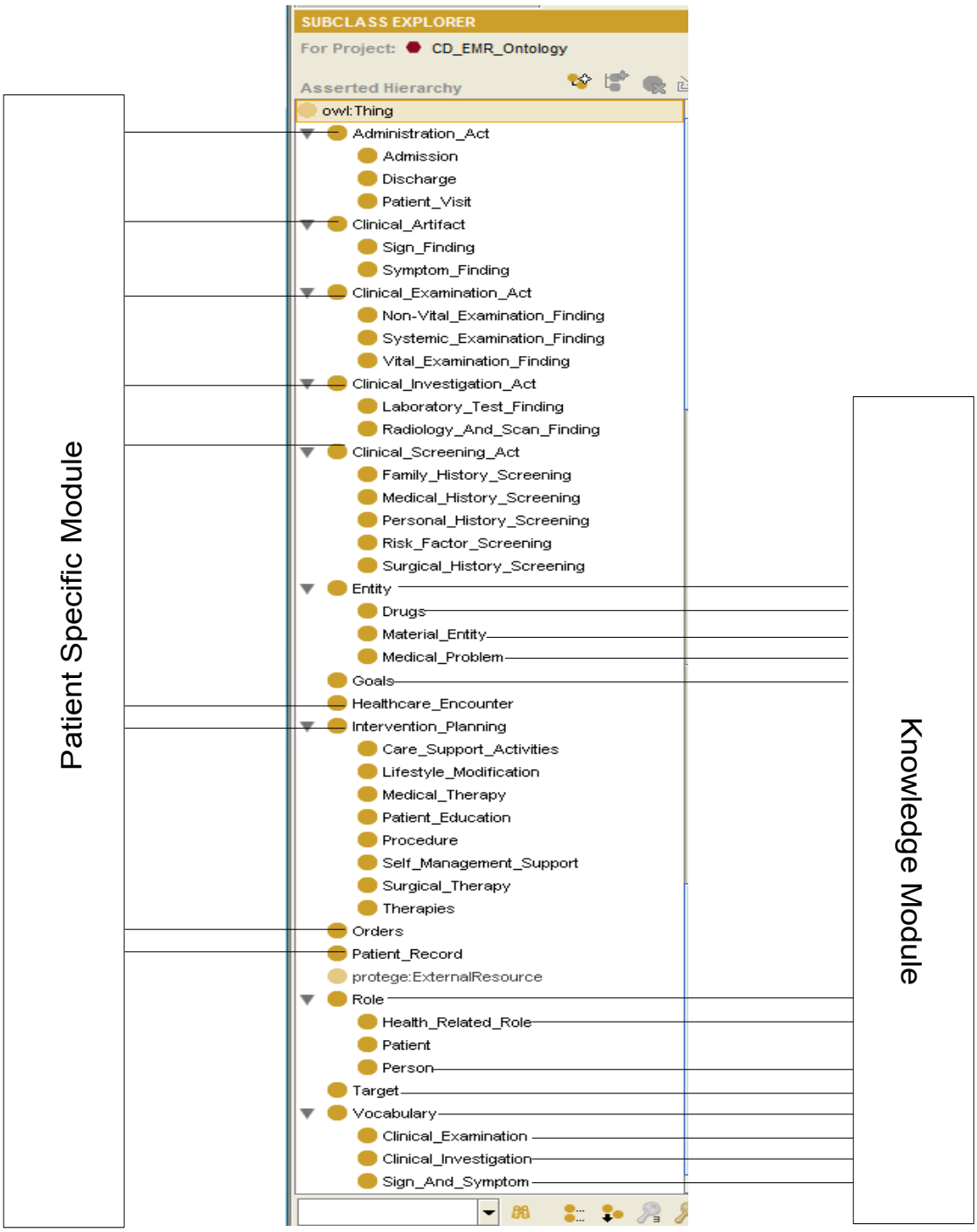


Figure5-6 CD-EMR Ontology showing Knowledge Module and Patient Specific Module

5.5.1 DATA HANDLING AND INTERACTION BETWEEN KNOWLEDGE AND PATIENT SPECIFIC MODULE

In our CD-EMR Ontology we have stored the generic knowledge of CDM and patient specific information in separate modules. In our EMR system both modules interact with each other to maintain patient record. This interaction occurs to store patient specific information by using the generic knowledge which is captured in the knowledge module. For example, patient X has symptoms A, B, and C for 2 weeks, and the symptoms get worse in the sunlight. The CD-EMR Ontology captures this information in the patient specific module using the class *Symptom_Finding*. The patient specific information such as duration 2 weeks and aggravating factor sunlight is captured through data type properties *Has_ Duration* and *Has_Aggrivating_Factor*. The class *Symptom_Finding* has object property *Has_Symptoms* which gets the information from the class *Sign_And_Symptom* of knowledge module. Hence the knowledge module provides the symptoms A, B and C along with the generic information which is symptom name and SNOMED_CT Code. Similarly the class *Clinical_Examination_Act* and *Clinical_Investigation_Act*, are also connected to the knowledge module and uses the stored generic information. Figure 5-7 shows the interactions and some of the connections between the patient specific module and the knowledge module via object properties.

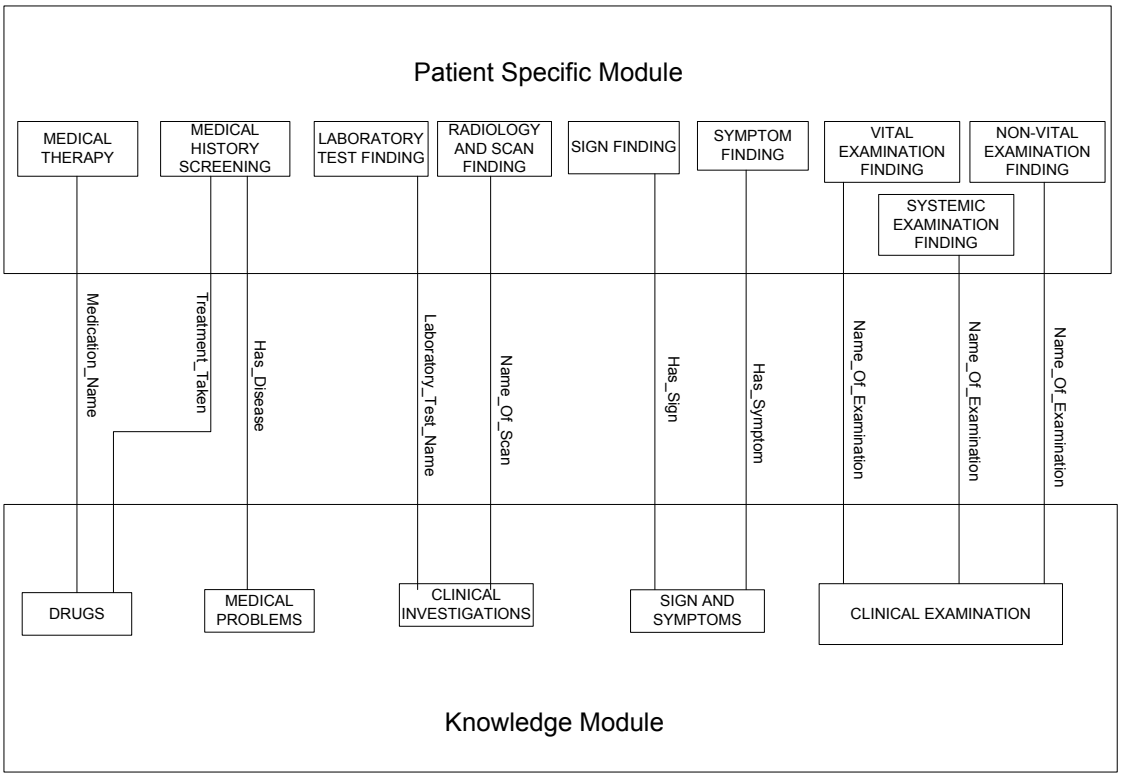


Figure5-7 Interaction between Knowledge Module and Patient Specific Module in CD-EMR Ontology

5.6 VALIDATION OF CD-EMR ONTOLOGY BY INSTANTIATION OF CLINICAL CASES

After successful implementation of the formal model into CD-EMR Ontology and the description of ontology elements, structural design, and data handling in CD-EMR ontology, we will now perform some practical validation of the structure of CD-EMR ontology by instantiation of clinical scenarios of chronic diseases with multiple healthcare encounters. The validation will help us to determine (a) any knowledge gap or structural short-come that occurs during model formalization, and (b) any error which could occur during the implementation process.

In order to perform the validation step, we used the clinical scenarios for chronic diseases that are available through different online sources. Most of the scenarios presented a single healthcare encounter and there was no date and time mentioned in the case presentations. In order to make these cases longitudinal we developed the second

healthcare encounter using domain knowledge and also inserted the date and time of healthcare encounters. In the second scenario the name of the patient was not specified, so we have incorporated the name of the patient in that scenario. After instantiation of these clinical scenarios we will instantiate a longitudinal case in all three model i.e. CD-EMR ontology, CPR Ontology and HL7 V3 in order to validate the expressivity of our CD-EMR Ontology.

5.6.1 SCENARIO I

Nov 15th, 2011. 10:15am

"R.C. is a 57-year-old man with type 2 diabetes first diagnosed 2 years ago. Other medical problems include obesity and hypothyroidism. He has a history of heavy alcohol use but quit drinking alcohol 2 years ago. He presents now for routine follow-up and is noted to have a blood pressure of 168/100 mmHg. He is asymptomatic.

Physical exam reveals a height of 5 feet, 8 inches, weight of 243 lb, blood pressure of 160/100 mmHg, and a regular pulse of 84 beats/min. There is no retinopathy or thyromegaly. There is no clinical evidence of congestive heart failure or peripheral vascular disease.

Laboratory evaluation reveals trace protein on urinalysis, blood urea nitrogen of 14 mg/dl, serum creatinine of 1.2 mg/dl, random serum glucose of 169 mg/dl, normal electrolytes, and normal thyroid-stimulating hormone levels. A 24-h urine collection reveals a urinary albumin excretion rate of 250 mg/day" [110].

Based on the patient's condition and lab results, the treatment Enalipril (5mg BID) and the oral hypoglycemic Metformin (500mg BID) are given to the patient.

R.C is advised to visit after 3 months (Feb 20, 2012 at 2:00pm) for follow-up with lab investigations RBS, HBA1C, Serum Creatinine, and 24-hour urine analysis to evaluate the effects of treatments. he was advised to have the investigations done 1 week prior to the next appointment. Along with medications, R.C is advised to reduce his weight by 10% and is also encouraged towards mild physical activities such as walking or exercise in his daily routine to eliminate the sedentary living.

Feb 20th, 2012. 2:00pm

After 3 months R.C presents with the following lab results.

HBA1C 7.2 %, RBS 154 mg/dl, Serum creatinine 1.0mg/dl, and no protein in urine.

O/E: Weight 235 lb, BP 140/90mmHg, with normal pulse and R/R.

He is advised to continue the oral hypoglycemic and physical activities, and the dose of Enalipril is increased to 10 mg BID.

Instantiation of Scenario in CD-EMR Ontology

The above mentioned scenario of patient R.C comprises two healthcare encounters. Our ontology has captured each encounter in the patient record of R.C. Moreover, the patient record also stores information such as patient record number, clinical diagnosis, record for patient and any specific notes related to the record as shown in Figure 5-8 and presented in Table 5-4.

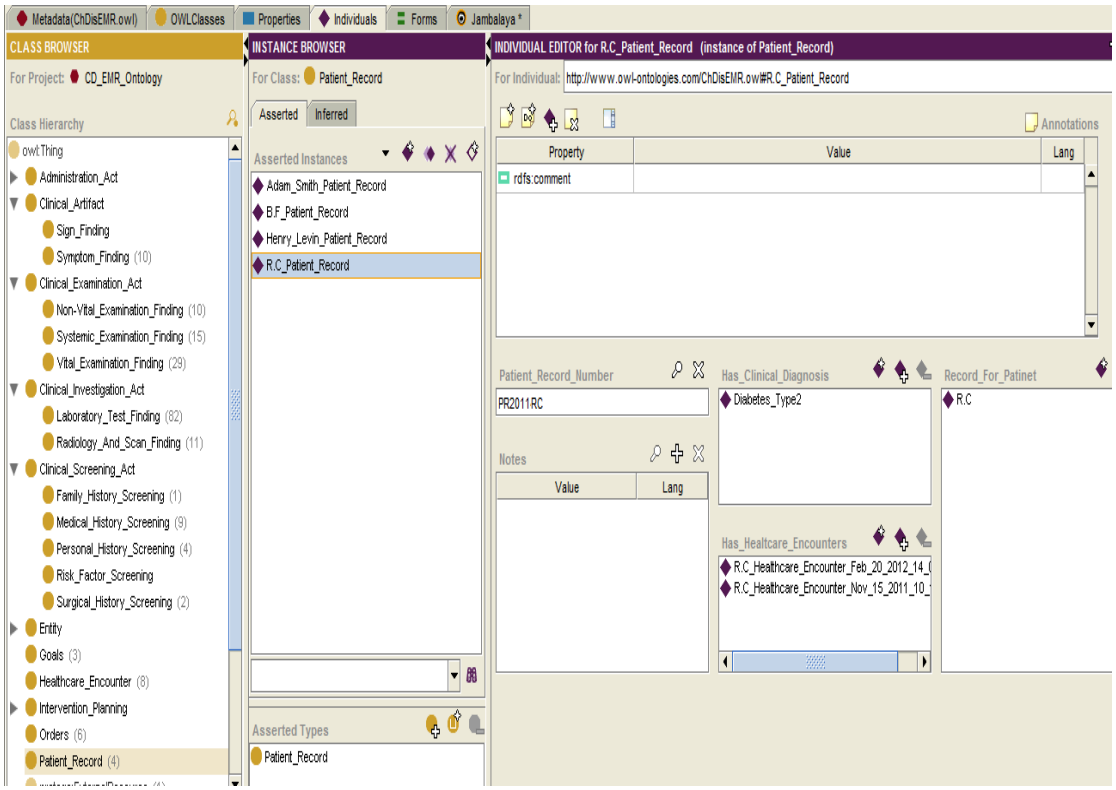


Figure 5-8 R.C Patient Record in CD-EMR Ontology

Table 5-4 Patient Record of R.C

Class	**Instances**	**Properties**		**Values**
		Object Properties	**Data-type Properties**	
Patient Record	R.C_Patient_Record	Has_Clinical_Diagnosis		Diabetes_Type2
		Has_Healthcare_Encounters		R.C_Healthcare_Encounter_Feb_20_2012
				R.C_Healthcare_Encounter_Nov_15_2011
		Record_For_Patient		R.C
			Patient_Record_Number	PR2011RC
			Notes	

The details of each visit, which consists of patient's information related to examinations, investigation results, and treatment is captured in the class healthcare encounter and each individual of this class represents the patient visit (i.e. healthcare encounter). The information of the healthcare encounter on Nov 15th, 2011 at 10:15am is instantiated in the ontology as, the history of alcoholism is captured as personal history, the values of BP and pulse examination is captured through *Vital_Examination_Finding*, whereas the examination of height, weight, eye exam (retinopathy) and thyroid exam is captured in *Non_Vital_Examination_Finding*, and the information about CHF and peripheral vascular disease is captured through the *Systemic_Examination_Finding* of CVS examination. Similarly, the lab results are captured using the class *Laboratory_Test_Findings*. The medication part is captured in drugs and the treatment is covered through the class *Medical_Therapy*. *Lifestyle_Modification* captures the information about introduction of physical activity and exercise. Weight reduction is

captured as a goal and the target is to reduce weight by 10%. The information about the next scheduled follow-up visit after 3 months is captured through *Patient_Visit* and the order of lab test for next visit is captured in Orders. The instantiation is shown in Figure 5-9 and details are presented in Table 5-5.

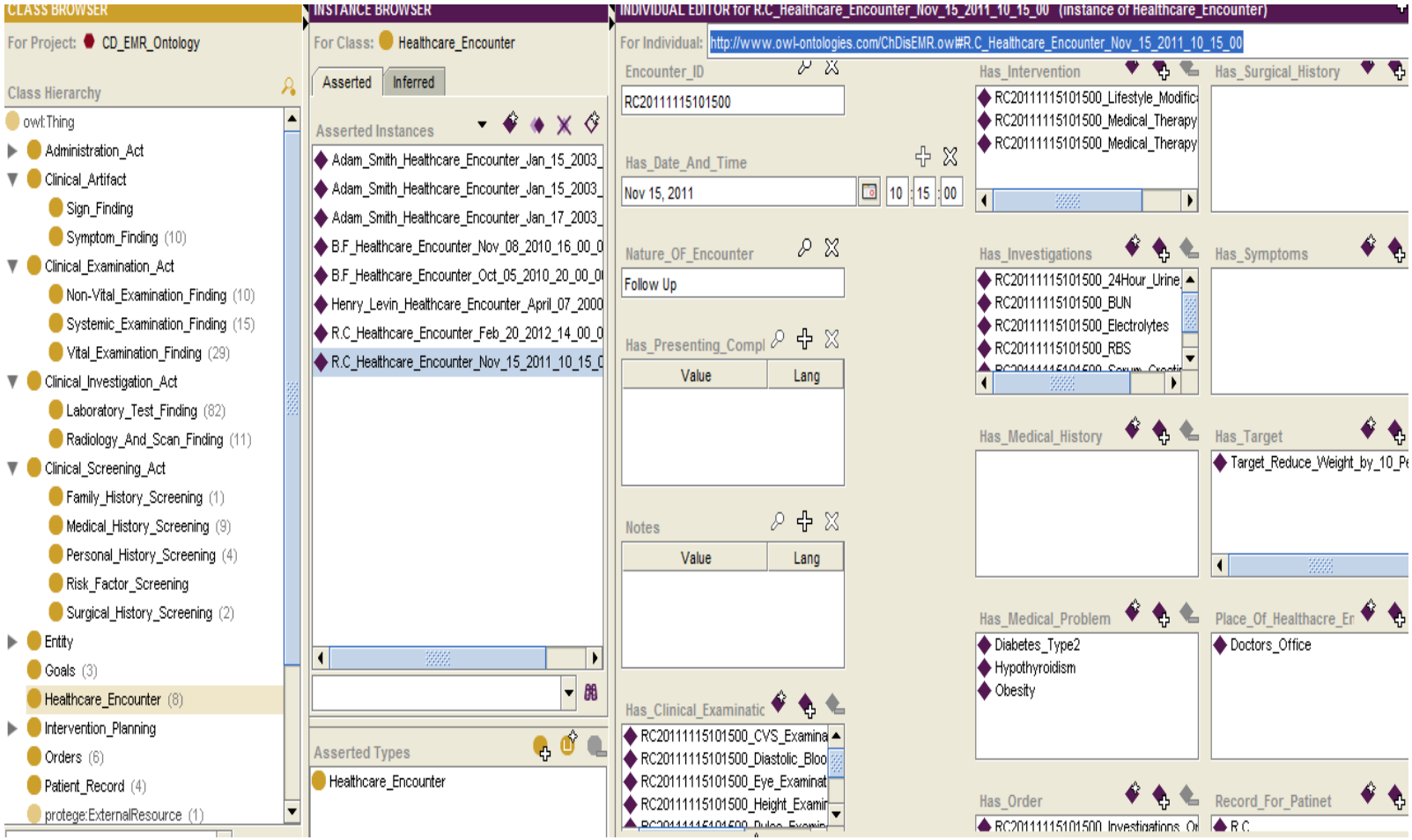


Figure 5-9 Instantiation of R.C Healthcare encounter on Nov 15th, 2011 at 10:15am

Table 5-5 Details of instantiation of R.C Healthcare encounter on Nov 15th, 2011 at 10:15am

Class	***Instances***	***Properties***				
		Object Properties			***Data-type Properties***	***Values Of Data_types***
		Property	***Value (Individual Of Other classes)***	***Individual of class***		
Healthcare_Encounter	R.C_Healthcare_Encounter_Nov_15_2011	Has_Medical_Problem	Diabetes_Type2 Hypothyroidism Obesity		Has_Date_And_Time	Nov_15_2011 15:00:00
		Has_Clinical Examination	RC20111115101500_Systolic_Blood_Pressure_Examination (Results: 168 mmHg SNOMED CT Code: 271649006)	Clinical_Examination_Act: (Vital_Examination_Finding)	Has_Encounter_ID	RC20111115101500
			RC20111115101500_Diastolic_Blood_Pressue_Examination (Results: 100 mmHg SNOMED CT Code: 271650006)	Clinical_Examination_Act: (Vital_Examination_Finding)		
			RC20111115101500_Pulse_Examination (Results: Normal,	Clinical_Examination_Act: (Vital_Examination_Finding)		

			Rhythm: Regular SNOMED CT Code: 364075005)			
			RC20111115101500_CVS_Examination (Examination_Finding_ Normal: No congestive heart failure. No peripheral vascular disease)	Clinical_Examination_ Act: (Systemic_Examination_ Finding)		
			RC20111115101500_Eye_Examination (Examination_Finding_ Normal: No retinopathy)	Clinical_Examination_ Act: (Systemic_Examination_ Finding)		
			RC20111115101500_Thyroid_Examination (Examination_Finding_ Normal: No Thyromegaly)	Clinical_Examination_ Act: (Non-Vital_ Examination_ Finding)		

			RC20111115101500_Height_ Examination (Results: 5.8 feet)	Clinical_Examination_ Act: (Non-Vital_ Examination_ Finding)		
			RC20111115101500_Weight_ Examination (Results: 243 lb SNOMED CT Code: 162763007)	Clinical_Examination_ Act: (Non-Vital_ Examination_ Finding)		
		Has_Personal_ History	RC20111115101500_Personal _History_Alcoholosim (Alcohol Intake: heavy alcohol use but quit drinking alcohol 2 years ago)	Personal_History_Screeni ng	Nature_Of_ Encounter	Follow-Up
		Has_Investigati ons	RC20111115101500_24Hour_ Urine_Analysis (Test Result: Albumin excretion rate 250 mg/day) RC20111115101500_BUN (Test Result value: 14 mg/dl)	Clinical_Investigation_A ct (Laboratory Exam)		

			RC20111115101500_RBS (Test Result value: 169 mg/dl) RC20111115101500_Serum_ Creatinine (Test Result value: 1.2 mg/dl) RC20111115101500_TSH (Test Result value: Normal) RC20111115101500_Electroly tes (Test Result value: Normal)			
		Has_Interventi on	RC20111115101500_Medical _Therapy_Metformin (Medication Name: Metformin Dose: 500 mg BID) RC20111115101500_Medical _Therapy_Enalipril (Medication Name: Enalipril	Intervention_Planning Medical_Therapy		

			Dose: 5 mg BID) RC20111115101500_Lifestyle_Modification (Diet_Plan: No diet plan followed. Evaluation_Of_Lifestyle: Sedentary. Has_Goal: Reduce weight Has_Target: Reduce weight by 10% in three months. Recommendation_For_Lifestyle_Modification: Introduce physical activity, walking/moderate exercise)	Lifestyle_Modification		
		Has_Order	RC20111115101500_Investigations_Order_For_Next_Visit (Has_Investigation_Name: RBS, HBA1C, BUN, Serum Creatinine, 24 Hours Urine.)	Order		
			RC20111115101500_Prescription (Instructions:	Order		

			Metformin 500mgBID Enalipril 5mg BID)			
		Has_Goal	Goal_Reduce_Weight	Goal		
		Has_Target	Target_Reduce_Weight_by_ 10_Percent (Duration: 3months)	Target		
		Place_Of_Healthcare_Encounter	Doctors_Office	Material_Entity		
		Record_For_Patient	R.C	Patient		
		Scheduled_Next_ Visit	RC20111115101500_Follow-up_Visit (Date and time of next schedules visit: Feb 14, 2012, 14:00:00)	Patient_Visit		

The follow-up visit of R.C that occurred on Feb 20th, 2012 at 2:00 pm was captured in a similar manner as explained above. The instantiation is shown in Figure 5-10 and details are presented in Table 5-6.

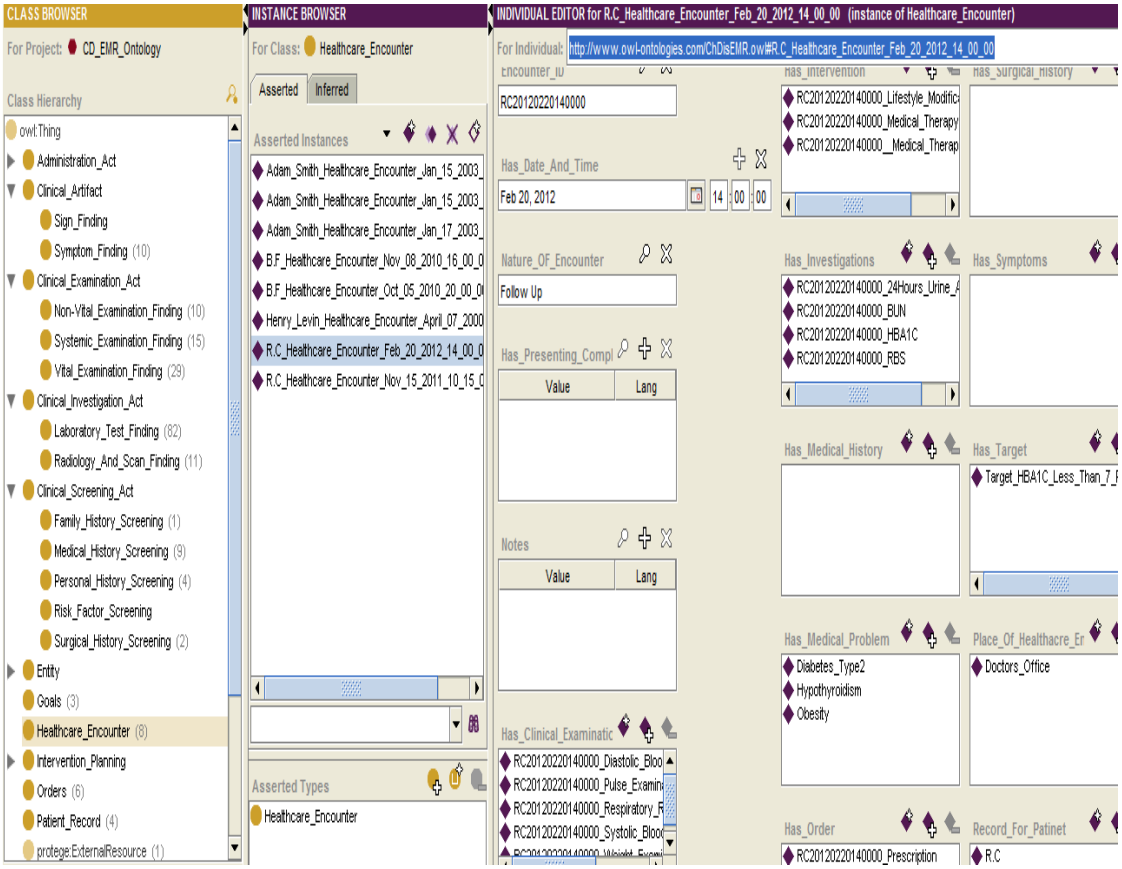


Figure 5-10 Instantiation of R.C Healthcare encounter on Nov 15th, 2011 at 10:15am

Table 5-6 Details of instantiation of R.C Healthcare encounter on Feb 20th, 2012, at 2:00 pm

Class	***Instance***	***Properties***				
		Object Properties			***Data-type Properties***	***Value***
		Property	***Value (Individuals of other classes)***	***Individuals of other classes***		
Healthcare_Encounter	R.C_Healthcare_Encounter_Feb_20_2012_14_00_00	Has_Medical_Problem	Diabetes_Type2 Hypothyroidism Obesity	Medical_Problem	Has_Date_And_Time	Nov_15_2011 15:00:00
		Has_Clinical_Examination	RC20120220140000_Systolic_Blood_Pressure_Examination (Results: 140 mmHg SNOMED CT Code: 271649006)	Vital_Examination_Finding	Has_Encounter_ID	RC20120220140000
			RC20120220140000_Diastolic_Blood_Pressure_Examination (Results: 90 mmHg SNOMED CT Code: 271650006)	Vital_Examination_Finding		
			RC20120220140000_Pulse_Examination (Results: Normal SNOMED CT Code:	Vital_Examination_Finding		

			364075005)			
			RC20120220140000_Respiratory_Rate_Examination (Results: Normal SNOMED CT Code: 86290005)	Vital_Examination_Finding		
			RC20120220140000_Weight_Examination (Results: 235lb SNOMED CT Code: 162763007)	Non-Vital_Examination_Finding		
		Has_Intervention	RC20120220140000_Medical_Therapy_Enalipril (Enalipril 10mg BID)	Medical_Therapy	Nature_Of_Encounter	Follow-Up
			RC20120220140000__Medical_Therapy_Metformin (Metformin 500 mg BID)	Medical_Therapy		
			RC20120220140000_Lifestyle_Modification (Diabetes diet plan, No more sedentary lifestyle, Mild physical activity)	Lifestyle_Modification		
		Has_Goal	Goal_Reduce_Weight_Result (Partially Achieved)	Goal		

			Goal_Reduce_Weight (Reduce weight by 10 percent in next three months)			
		Has_Target	Target_HBA1C_Less_Than_7_Percent (Duration:3 months)	Target		
		Has_Orders	RC20120220140000_Prescription (Enalipril 10 mg BID Metformin 500mg BID)	Orders		
		Place_Of_Healthcare_Encounter	Doctors_Office	Material_Entity		
		Record_For_Patient	R.C	Patient		

5.6.2 SCENARIO II

B.F healthcare encounter Oct 05, 2010 at 8PM

"A 37 y/o black female with a history of asthma, presents to the ER with tachypnea, and acute shortness of breath with audible wheezing. Patient has taken her prescribed medications of Cromolyn Sodium and Ventolin at home with no relief of symptoms prior to coming to the ER. A physical exam revealed the following: HR 110, RR 40 with signs of accessory muscle use. Ausculation revealed decreased breath sounds with inspiratory and expiratory wheezing and pt was coughing up small amounts of white sputum. SaO2 was 93% on room air. An arterial blood gas (ABG) was ordered with the following results: pH 7.5, PaCO2 27, PaO2 75. An aerosol treatment was ordered and given with 0.5 cc albuterol with 3.0 cc normal saline in a small volume nebulizer for 10 minutes. Peak flows done before and after the treatment were 125/250 and ausculation revealed loud expiratory wheezing and better airflow. 20 minutes later a second treatment was given with the above meds. Peak flows before and after showed improvements of 230/360 and on ausculation there was clearing of breath sounds and much improved airflow. RR was 24 at this time and HR 108. Symptoms resolved and patient was given prescription for inhaled steroids to be used with current home meds. Instruction was given for use of inhaled steroids and the patient was sent home" [111].

Patient was advised follow-up visit after four weeks even if he is feeling perfectly fine.

B.F healthcare encounter Nov 08th, 2010 4:00pm

B.E visited his doctor's office for regular follow-up. The patient was examined for breath sounds and air flow.

O/E patient had clear breath sounds on auscultation and much improved air follow; RR 22/min and HR 82/min. Patient was asymptomatic. B.F is advised to continue medications and use inhaled steroids as needed. Follow-up after 6 weeks.

Instantiation of Scenario in CD-EMR Ontology

The above mentioned scenario of patient B.F comprises two healthcare encounters, our ontology has captured each encounter in the patient record of B.F. Moreover, the patient record also store information such as patient record number, clinical diagnosis, record for patient any specific notes related to the record as shown in Figure 5-11 And presented in Table 5-7

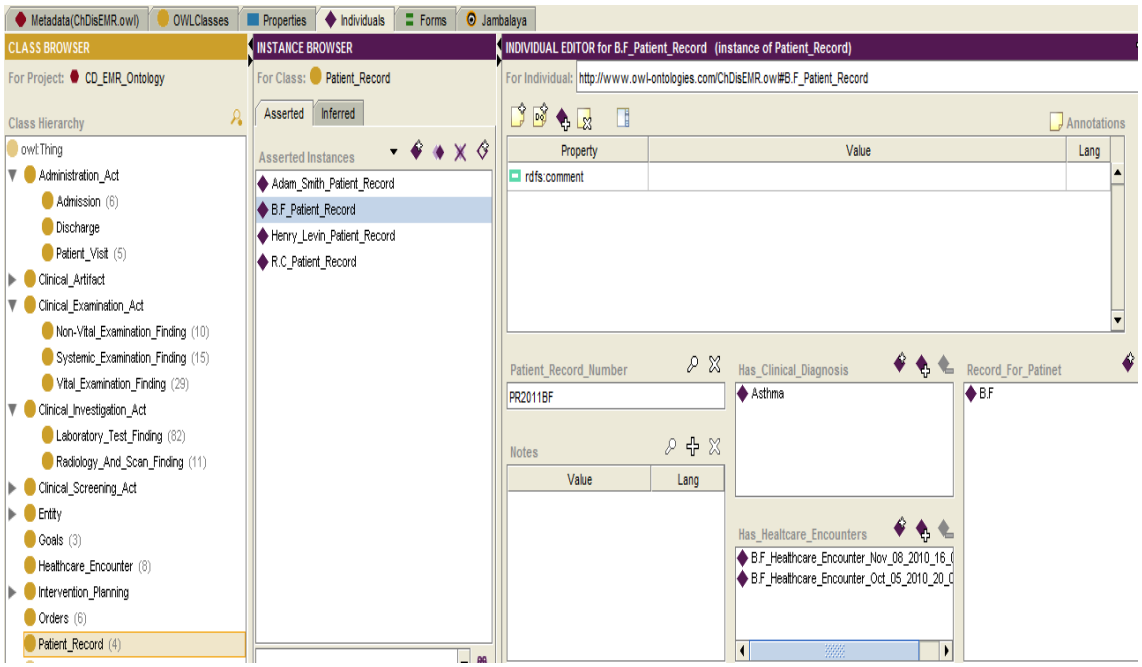


Figure5-11 Patient Record of B.F in CD-EMR Ontology

Table 5-7 Instantiation of B.F Medical Record

Class	Instances	Properties		Values
		Object Properties	Data-type Properties	
Patient Record	B.F_Patient_ Record	Has_Clinical_ Diagnosis		Asthma
		Has_Healthcare _ Encounters		B.F_Healthcare_Encounter_Oct_05_2010_20_00_00
				B.F_Healthcare_Encounter_Nov_08_2010_16_00_00
		Record_For_ Patient		B.F
			Patient_Record_ Number	PR2011BF
			Notes	

As mentioned above, the patient record of B.F consists of visits which were on Oct 05 2010, and Nov 08 2010. The first visit was in emergency and non-scheduled visit and the second was a scheduled follow-up. Each visit is captured in CD-EMR Ontology as healthcare encounters. During the first healthcare encounter patient examination was performed, patient history and sign and symptoms were recorded, investigations were performed to determine patient's state, and treatment was provided to stabilize patient's condition. The record of first healthcare encounter is shown in Figure 5-12 and the details are presented in Table 5-8.

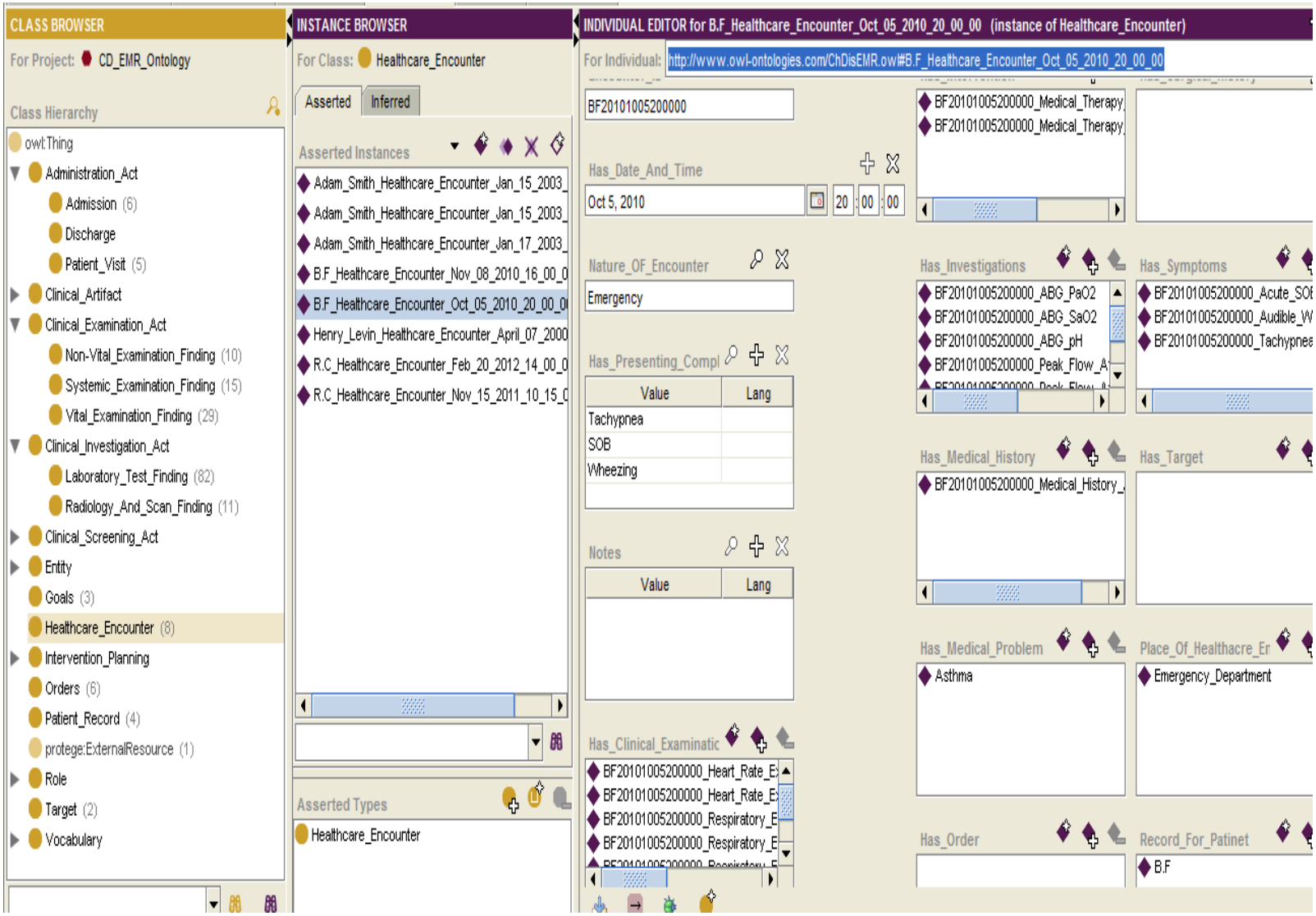


Figure 5-12 Instantiation of B.F Healthcare encounter on Oct 05th, 2010, at 8:00 pm

Table 5-8 Details of instantiation of B.F Healthcare encounter on Oct 05th, 2010, at 8:00 pm

Class	***Instances***	***Properties***				
		Object Properties			***Data-type Properties***	***Values Of Data_types***
		Property	***Value (Individual Of Other classes)***	***Individual of class***		
Healthcare_Encounter	B.F_Healthcare_Encounter_Oct_05_2010_20_00_00	Has_Medical_Problem	Asthma		Has_Date_And_Time	Oct_05_2010_20_00_00
		Has_Symptoms	BF20101005200000_Acute_SOB (Shortness of breath acute in nature SNOMED CT Code 267036007)	Symptom_Finding		
			BF20101005200000_Audible_Wheezing (Audible Wheezing SNOMED CT Code 56018004)	Symptom_Finding		
			BF20101005200000_Tachypnea (Tachypnea	Symptom_Finding		

			SNOMED CT Code 271823003)			
		Has_Medical_ History	BF20101005200000_Medical_ History_Asthma (medical history of asthma Treatment taken: Cromolyn Sodium, Ventolin SNOMED CT Code 84100007)	Medical_History_S creening		
		Has_Clinical Examination	BF20101005200000_Heart_R ate_Examination (Results: 110 per minute SNOMED CT Code364075005)	Clinical_Examinati on_ Act: (Vital_Examination _ Finding)	Has_Encount er_ID	Oct 5, 2010
			BF20101005200000_Respirat ory_Rate_Examination (Results: 40 per minute Note: Respiratory rate shows signs of accessory muscle use SNOMED CT Code: 86290005)	Clinical_Examinati on_ Act: (Vital_Examination _ Finding)		
			BF20101005200000_Respirat ory_Examination_ Auscultation	Clinical_Examinati on_ Act:		

			(Audible sound abnormal: Inspiratory and expiratory wheez Notes: Patient is also coughing up a small amount of white sputum SNOMED CT Code: 52653008)	(Systemic_Examination_ Finding)		
			BF20101005200000_Respiratory_Examination_Auscultation_After_1st_Aerosol_Treatment (Audible sound abnormal: Weezing Notes: Auscultation revealed loud expiratory wheezing and better airflow SNOMED CT Code: 52653008)	Clinical_Examination_ Act: (Systemic_Examination_ Finding)		
			BF20101005200000_Respiratory_Examination_Auscultation_After_2nd_Aerosol_	Clinical_Examination_ Act:		

			Treatment (Results shows improvement after therapy SNOMED CT Code: 52653008)	(Systemic_Examination_ Finding)		
			BF20101005200000_Respiratory_Rate_Examination_After_2nd_Aerosol_Treatment (Results: 24 per minute SNOMED CT Code: 86290005)	Clinical_Examination_Act: (Vital_ Examination_ Finding)		
			BF20101005200000_Heart_Rate_Examination_After_2nd_Aerosol_Treatment (Results: 108 per minute SNOMED CT Code364075005)	Clinical_Examination_Act: (Vital_ Examination_ Finding)		
		Has_ Investigations	BF20101005200000_ABG_PaO2 (Test Result: 70) BF20101005200000_ABG_ PaCO2 (Test Result value: 27)	Clinical_Investigation_Act (Laboratory Exam)	Nature_Of_ Encounter	Emergency Visit

			BF20101005200000_ABG_SaO2 (Test Result value: 93%) BF20101005200000_ABG_pH (Test Result value: 7.5) BF20101005200000_Peak_Flow_Before_First_Aerosol_Treatment (Test Result value: 125) BF20101005200000_Peak_Flow_After_First_Aerosol_Treatment (Test Result value: 250) BF20101005200000_Peak_Flow_Before_Second_Aerosol_Treatment (Test Result value: 230) BF20101005200000_Peak_Flow_After_Second_Aerosol_Treatment (Test Result value: 360)			

		Has_ Intervention	BF20101005200000_Medical_ Therapy_First_Aerosol_Treat ment (**Medication Name**: Albuterol Dose: 0.5 cc **Route**: Inhalation (Nebulization) **Therapy_Instruction**: Nebulize the patient with 0.5 cc Albuterol with 3.0 cc Normal saline for 10 minutes **Medical_Equipment_Used** Nebulizer) BF20101005200000_Medical_ Therapy_Second_Aerosol_Tre atment (**Medication Name**: Albuterol Dose: 0.5 cc **Route**: Inhalation (Nebulization) **Therapy_Instruction**: Nebulize the patient with 0.5 cc Albuterol with 3.0 cc	Intervention_Planni ng Medical_Therapy		

			Normal saline for 10 minutes **Medical_Equipment_Used** Nebulizer **Notes**: Symptoms resolved and patient was given prescription for inhaled steroids to be used with current home meds) B.F_Patient_Education_To_Use_Inhaler_Oct_05_2010	Patient_Education		
		Has_Order	BF20101005200000_Prescription (**Medication Name**: Cromolyn Sodium, Ventolin, Steroid **Instruction**: Inhaled steroid using inhaler Continue regular medication)	Order Order		
		Place_Of_Healthcare_Encounter	Emergency Department	Material_Entity		
		Record_For_Patient	B.F (Name: B.F	Patient		

			Age: 37 years Gender: Female Race: Black)			
		Scheduled_Next _ Visit	BF20101005200000_Follow-up_Visit (Date and time of next schedules visit: Nov 8, 2010, 16:00:00 Has_Description: Follow-up after 4 weeks even if the patient is feeling perfectly fine If symptoms get worse than visit Emergency)	Patient_Visit		

According to the instructions the patient B.F visited the doctor's office after 4 weeks for a follow-up visit. During the follow up visit patient examination was performed and the findings of exam were recorded in the class *Clinical_Examination_Act.* The patient was advised to continue the current medications and use inhaled steroids as needed; this information is recorded in the class *Order* as *Prescription.* The next scheduled visit after 6 weeks is captured through the instance of class *Patient_Visit*. The instantiation is shown in Figure 5-13 and the details are presented in Table 5-9.

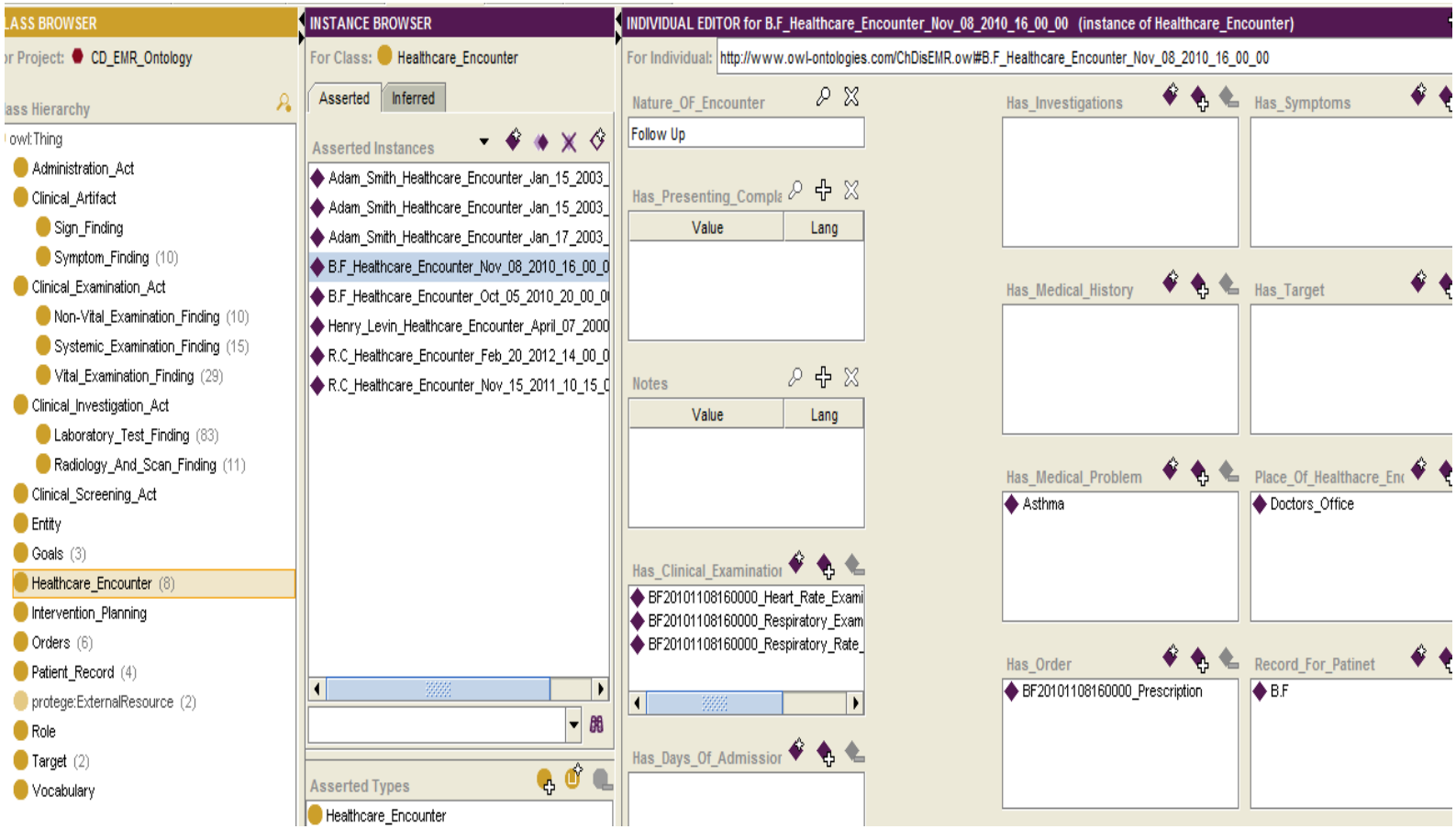


Figure 5-13 Instantiation of B.F Healthcare encounter on Nov 08th, 2010, at 4:00 pm

Table 5-9 Details of instantiation of B.F Healthcare encounter on Nov 08th, 2010, at 4:00 pm

Class	***Instances***	***Properties***				
		Object Properties			***Data-type Properties***	***Values Of Data_types***
		Property	***Value (Individual Of Other classes)***	***Individual of class***		
Healthcare_ Encounter	B.F_Healthcare_Encounter_Nov_08_2010_16_00_00	Has_Medical_ Problem	Asthma	Medical_Problems	Has_Date_ And_Time	Nov_08_2010_16_00_00
		Has_Clinical Examination	BF20101108160000_Heart_Rate_Examination (Results: 82 per minute SNOMED CT Code364075005)	Clinical_Examination_ Act: (Vital_Examination_ Finding)	Has_Encounter_ID	BF20101108160000
			BF20101108160000_Respiratory_Rate_Examination (Results: 22 per minute SNOMED CT Code: 86290005)	Clinical_Examination_ Act: (Vital_Examination_ Finding)		
			BF20101108160000_Respiratory_Examination_Auscultation (Audible sound normal: Clear breath sound	Clinical_Examination_ Act: (Systemic_Exami		

			Notes: Clear breath sound with improved air flow SNOMED CT Code: 52653008)	nation_ Finding)		
		Has_Orders	BF20101108160000_Prescription (Medication Name: Cromolyn Sodium, Ventolin, Steroid Instruction: Continue current medications Continue Inhaled Steroid SOS)			
		Place_Of_Healthcare_Encounter	Doctor's office	Material_Entity	Nature_Of_ Encounter	Follow-up visit
		Record_For_Patient	B.F (Name: B.F Age: 37 years Gender: Female Race: Black)	Patient		
		Scheduled_Next_ Visit	BF20101005200000_Follow-up_Visit (Date and time of next schedules visit: Dec 20, 2010, 14:00:00	Patient_Visit		

5.6.3 MEDICAL RECORD [115,116,117]

Patient: Laura Jane

Age: 56 years

Ethnicity: African-American

Occupation: Clerical job for a transportation company

Marital Status: Married

Gender: Female

Clinical Diagnosis: Diabetes Type 2

Presenting Complaints:

- Headache
- Pedal edema

History:

- Stopped smoking at the age of 46 years
- No alcohol consumption
- Three pregnancies with no complications
- Father had hypertension and coronary bypass surgery and died of a stroke at the age of 65 years.
- Mother had diabetes mellitus type II and died of heart attack at the age of 50 years.
- Three siblings; one died of a massive myocardial infarction at the age of 35 years.
- No medications, except for multivitamins and occasional Tylenol for headache and muscle aches.

Examinations:

Weight: 192 lbs.
Height: 5' 4"
BMI: 33

Vitals:

- Blood Pressure :Normal: 126/78 mmHg
- Heart Rate: 80 per minute
- Respiratory Rate: 18 per minute
- Temperature: Normal

Non-Vital Exam:

- **Anemia: Negative**
- **Thyroid: Normal**
- **JVP: Normal**
- **Lymph node: Not palpable**
- **Edema: Pedal edema (2+** bipedal edema)

Cardiovascular condition:
within normal limits

Eye Exam:
Normal

Respiratory Exam:
Normal

Labs:

Glucose Monitoring

A1C: 8.1%

Fasting: 200 mg/dl

Lipid Profile

Total: 215 mg/dL

LDL: 135 mg/dL

HDL: 53 mg/dL

Triglycerides: 130

Kidney Profile

Creatinine: 0.9 mg/dL

Microalbuminuria: none

Liver Function

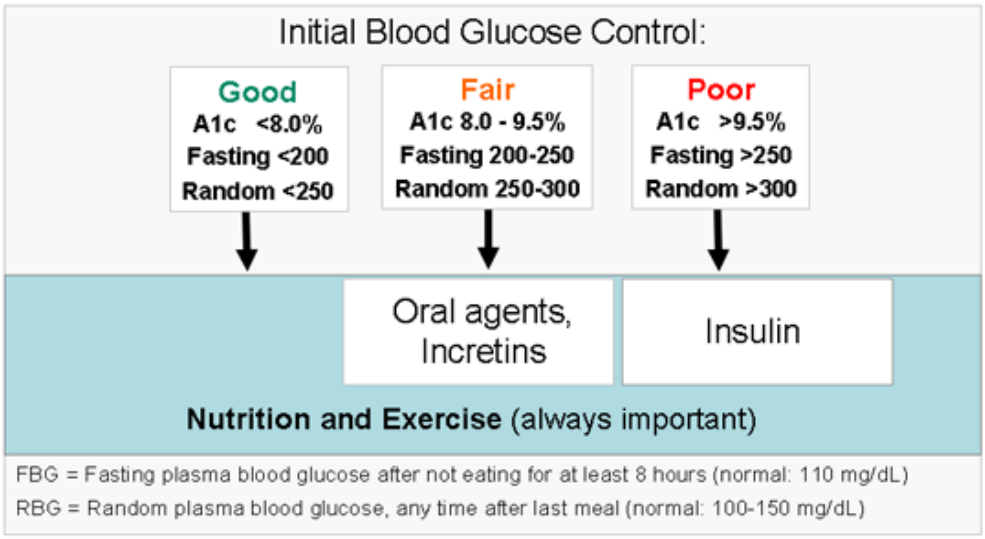
ALT: normal

AST: normal

Treatment Plan:

She should receive instruction on nutrition (diet plan) and exercise (lifestyle), and should receive an antihyperglycemic agent to lower her blood glucose.

Table 5-10 Initial Control of Diabetes Taken From [115]



Management and Care Planning:

- After the meeting of the patient with a diabetes educator for one hour, the patient is judged to be capable of self-management. She will further receive 10-15 more hours of diabetes education.
- Goals of A1c less than 7% and/or mean plasma glucose less than 130 mg/dL are set, to be achieved within 4 months. The patient signs a contract.
- Goal: Lose weight.
- Start metformin 250 mg bid, a 1200 calorie meal plan, and self-monitoring of blood glucose twice a day. The patient is taught how to use the averaging function of the blood glucose meter.
- Patient received written instructions that in 2 weeks, if her average blood glucose is above 130 mg/dL, she should increase the dose of metformin to 250 mg tid. Two weeks after that, if her average blood glucose remains over 130 mg/dL, she can change metformin dose to a maximum of 500 mg, bid.
- Introduction of diabetes meal plan. Follow meal plan of Canadian Diabetes Association: http://www.diabetes.ca/diabetes-and-you/nutrition/meal-planning-guide/
- Adapt healthy lifestyle : Follow Healthy Lifestyle Resource of Canadian Diabetes Association: http://www.diabetes.ca/diabetes-and-you/nutrition/healthy-lifestyle/

Follow-Up: Return in 10 weeks for evaluation.

Assessment after 10 Weeks:

Examination:

BP: 130/80 mmHg

Heart Rate: 82 per minute

Respiratory Rate: 20 per minute

Temperature: Normal

No pedal edema

Goal Results:

A1C reduced to 7.4%

Weight: lost 5 pounds

Meal planning: Partially followed meal plan.

Life style: Lifestyle changed according to the guideline which resulted in weight loss.

Management Plan:

- Although the patient has made progress, she seems to have stabilized at a blood glucose level of 160 mg/dL
- The metformin dose is increased to 500 mg tid
- The patient is instructed to self-increase the dose of metformin to 1000 mg bid if her average blood glucose values remain above 130 mg/dL
- Goals:
    - Goals of A1c less than 7%
    - Continue meal plan according to the guideline
    - Continue physical activity and healthy lifestyle
- Record RBS and FBS using blood glucose meter.

- Self-Management: Perform foot examination for edema and numbness.

Follow-Up: Schedule patient for follow-up visit in 8 weeks.

Patient Assessment, Week 18

Examination:

BP: 125/80 mmHg

Heart Rate: 80 per minute

Respiratory Rate: 22 per minute

Temperature: Normal

No pedal edema

Goal Results:

A1C reduced to 7.2%

Weight: lost 2 more pounds

Patient has stabilized at a blood glucose level of 160 mg/dL. The higher metformin dose did not yield any additional efficacy.

Meal planning: Meal planning is hard for the patient but she has changed her eating habits. She has continued to lose weight, although the progress (one pound per month) is slow.

Self-Management: No pedal edema or numbness recorded.

Follow-up: After 16 weeks.

Table 5-11 Instantiation of Medical Record of Laura Jane in CD-EMR ontology, CPR ontology and HL-7 RIM

Patient Record	**CD-EMR Ontology**	**CPR Ontology**	**HL-7 V3**
Laura Jane	Patient	Patient	Role
Age: 56 years **Ethnicity**: African-American **Occupation**: Clerical job for a transportation company **Marital Status**: Married **Gender**: Female	Patient (Patient Information)	N/A	Data-types Properties
Diabetes Type 2	Clinical Diagnosis	Clinical Diagnosis	Entity
Headache Pedal edema	Presenting Complaints	N/A	N/A
Stopped Smoking at the age of 46 years No alcohol consumption 3 pregnancies with no complications	Personal History	N/A	N/A
Father had hypertension and coronary bypass surgery and died of a stroke at the age of 65 years.	Family History	N/A	N/A

Mother had diabetes mellitus type 2 and died of heart attack at the age of 50 years. 3 siblings; one died of a massive myocardial infarction the age of 35 years.			
No medications, except for multivitamins and occasional Tylenol for headache and muscle aches.	Medical History (Drug History)	Medical History	N/A
Blood Pressure :Normal: 126/78 mmHg Heart Rate: 80 per minute Respiratory Rate: 18 per minute Temperature: Normal	Vital Examination Finding	Vital Sign	Act
Weight**:** 192 lbs. Height: 5' 4" BMI: 33 Anemia: Negative	Non-Vitals Examination Finding	Clinical Examination	Act

Thyroid: Normal JVP: Normal Lymph node: Not palpable Edema: Pedal edema (2+ bipedal edema)			
Cardiovascular condition: within normal limits Eye Exam: Normal Respiratory Exam: Normal	Systemic Examination Finding	Clinical Examination	Act
Glucose Monitoring A1C: 8.1% Fasting: 200 mg/dl Lipid Profile Total: 215 mg/dL LDL: 135 mg/dL HDL: 53 mg/dL Triglycerides: 130 Kidney Profile Creatinine: 0.9 mg/dL Microalbuminuria: none Liver Function	Laboratory Test Finding	Laboratory Test	N/A

ALT: normal AST: normal			
Meeting with a diabetes educator. She will receive 10-15 more hours of diabetes education. The patient is taught how to use the averaging function of the blood glucose meter.	Patient Education	N/A	N/A
Goals of A1c less than 7% Goal: Lose weight	Goal	N/A	N/A
Metformin 250 mg bid	Medical Therapy	Medical Therapy	Entity
Patient received written instructions that in 2 weeks, if her average blood glucose is above 130 mg/dL, she should increase the dose of metformin to 250 mg tid. Two weeks after that, if her average blood glucose remains over 130 mg/dL, she can change metformin	Prescription Instruction	N/A	N/A

dose to a maximum of 500 mg, bid.			
Introduction of diabetes meal plan 1200 calorie meal plan Adapt healthy lifestyle	Lifestyle Modification	N/A	N/A
Self-monitoring of blood glucose twice a day	Self-Management Support	N/A	N/A
Return in 10 weeks for evaluation	Patient Visit (Follow-up)	N/A	N/A
Assessment after 10 Weeks	Healthcare encounter	N/A	N/A
BP: 130/80 mmHg Heart Rate: 82 per minute Respiratory Rate: 20 per minute Temperature: Normal	Vital Examination Finding	Vital Sign	Act
No pedal edema	Non-Vital Examination Finding	Clinical Examination	Act
A1C reduced to 7.4% Weight: lost 5 pounds Meal planning: Partially followed meal plan.	Goal Results	N/A	N/A

Life style: Lifestyle changed according to the guideline which resulted in weight loss			
Metformin dose is increased to 500 mg tid	Medical Therapy	Medical Therapy	Entity
The patient is instructed to self-increase the dose of metformin to 1000 mg bid if her average blood glucose values remain above 130 mg/dL	Prescription Instruction	N/A	N/A
Goals of A1c less than 7% Continue meal plan according to the guideline Continue physical activity and healthy lifestyle	Goal	N/A	N/A
Record RBS and FBS using Glucometer	Order	N/A	Act
Perform foot examination for edema and numbness	Self-Management Support	N/A	N/A
Schedule patient for	Patient Visit	N/A	N/A

follow-up visit in 8 weeks	(Follow-Up)		
Patient Assessment, Week 18	Healthcare Encounter	N/A	N/A
BP: 125/80 mmHg Heart Rate: 80 per minute Respiratory Rate: 22 per minute Temperature: Normal	Vital Examination Finding	Vital Sign	Act
No pedal edema	Non-Vital Examination Finding	Clinical Examination	Act
A1C reduced to 7.2% Weight: lost 2 more pounds Patient has stabilized at a blood glucose level of 160 mg/dL. The higher metformin dose did not yield any additional efficacy. Meal planning: Meal planning is hard for the patient but she has	Goal Results	N/A	N/A

changed her eating habits. She has continued to lose weight, although the progress (one pound per month) is slow. Self-Management: No pedal edema or numbness recorded.			
Follow-up after 16 weeks	Patient Visit (Follow-Up)	N/A	N/A

The medical record of the patient Laura Jane has been instantiated in CD-EMR ontology, CPR Ontology and HL7 V3. It has been observed that most of the patient information that is common between acute and chronic diseases management is captured in both – CD-EMR Ontology and CPR Ontology– models. This information includes patient examination, laboratory tests, and medical therapy. HL7 version 3 also covered this information through its classes and data-type attributes. The information that is related to the longitudinal nature of the care process of CDM is only captured through CD-EMR ontology. The notion of patient education, lifestyle modification, self-management support, goal setting and evaluation of patient state by reviewing goal results are all captured by CD-EMR ontology. This shows that the CPR Ontology and HL7 V3 are deficient in concepts that are necessary to capture the longitudinal care process of CDM. On the other hand, the structure and design of CD-EMR ontology possesses all the necessary concepts of CDM, and can handle the information generated during the longitudinal care process of CDM.

5.6.4 INSTANTIATION RESULTS

We have instantiated two medical records in CD-EMR Ontology and one medical record in all three models for validation. Each record has two episodes. During instantiations our ontology has captured the follow-up which are scheduled healthcare encounters as well as emergency visits which are unscheduled encounters. CD-EMR Ontology also captured the heterogeneous patient data in a systemic manner. The patient specific information such as lab results and examination findings are tagged with encounter ID, date and time of healthcare encounter. The tagging of patient specific information in the CD-EMR Ontology makes the information within the record (a) easily queryable, (b) searchable, and (c) prevents the input of redundant information. This information is stored in a systemic manner in the patient specific module of CD-EMR Ontology and can be easily retrievable at the point of care for decision making purposes. The Knowledge module provides the generic knowledge such as lab test name, signs and symptoms name, name of clinical examination, and SNOMED CT code, to the patient specific module. As we have developed our model in OWL DL we have successfully used the functionality of restrictions for example, we have specified the value of SNOMED CT code to the class Clinical_*Screening_Act* , for history taking, in patient specific module, Figure 5-14. Besides the patient specific information in records, our ontology also provides the references ranges for the lab tests and the vital examinations such as temperature, heart rate/pulse and respiratory examinations. In our ontology we make use of RDF comments and provide the charts and the recommended ranges for the lab tests along with the complete information of the source in the knowledge module of CD-EMR Ontology Figure5-15. The instantiation of patient record in the CD-EMR Ontology further validate the strength of the ontology framework and the depth of the captured knowledge.

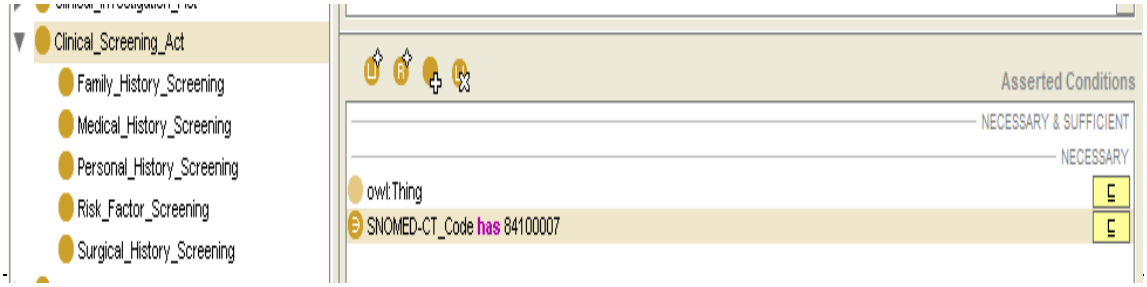
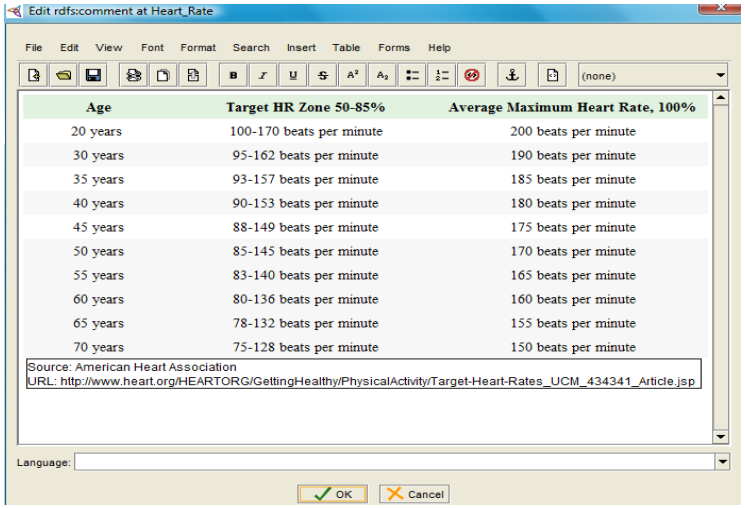
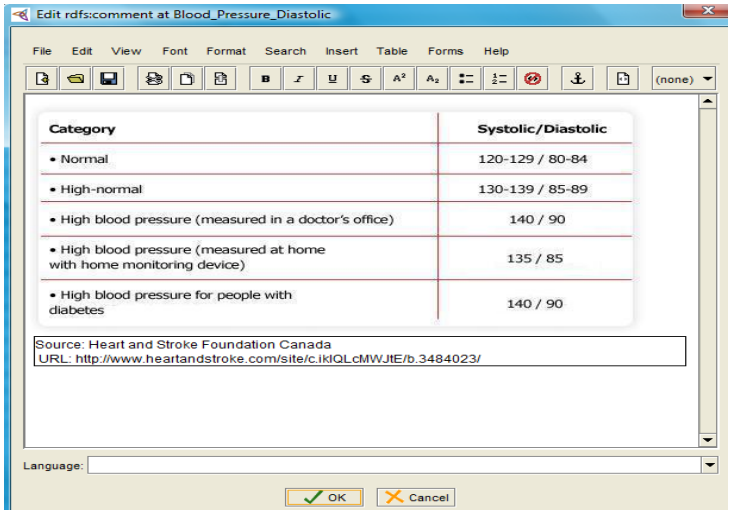


Figure5-14 SNOMED CT Code restriction for class *Clinical_Screening_Act* in CD-EMR Ontology





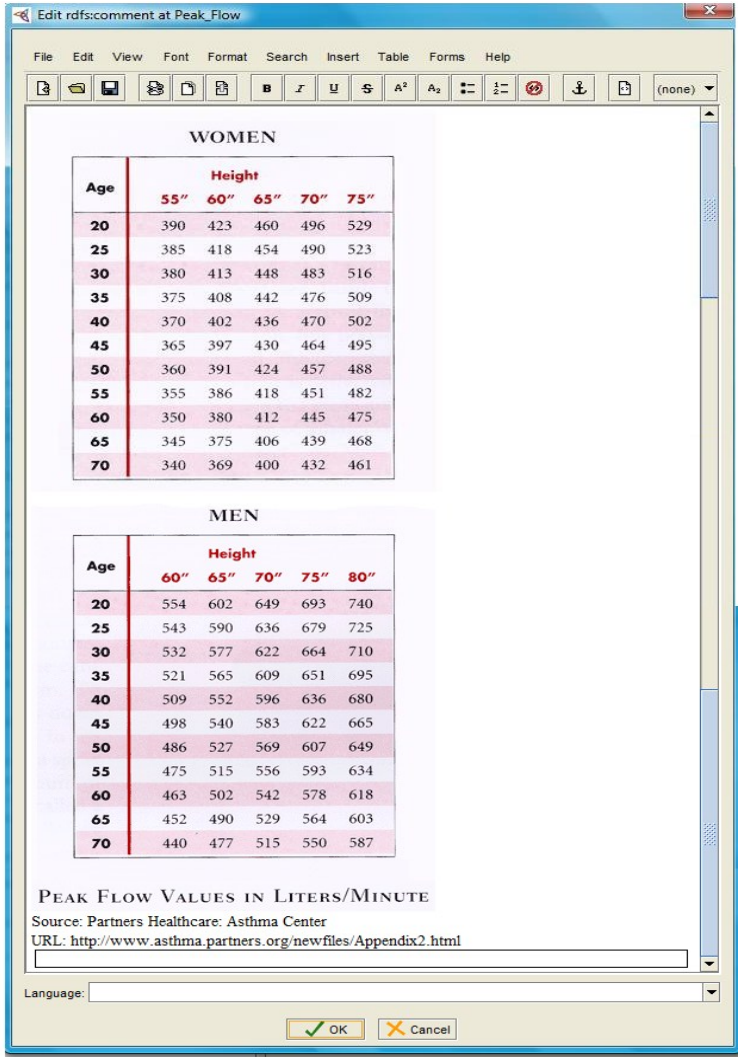
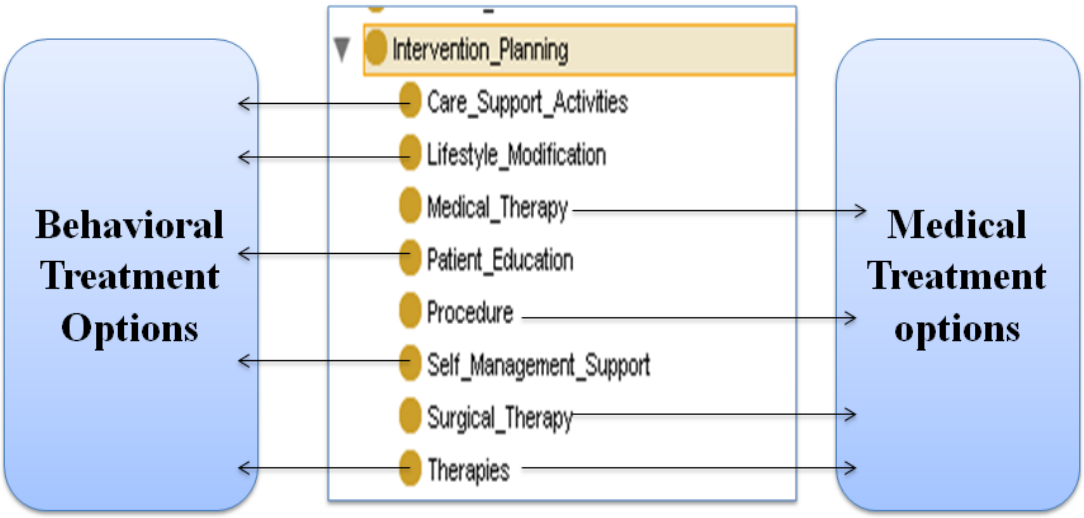


Figure 5-15 Examples of references ranges for Blood pressure, Heart Rate, and Peak Flow along with the source. Captured in CD-EMR Ontology as RDF Comments in Knowledge Module

5.7 EXPRESSIVITY OF CD-EMR ONTOLOGY

We have developed the CD-EMR ontology by using the concepts from CCM, CPR Ontology, and HL7 V3. As mentioned earlier in Chapter 2, CPR ontology provides a comprehensive ontological framework to capture patient information. Due to the fact that CPR ontology was developed using POMR standard, it supports information generated during acute care. CPR ontology can capture information related to lab results, clinical examinations, sign and symptoms and medical treatment through its classes *cpr:clinical_investigation_act, cpr:clinical-examination, cpr:sign-finding, cpr:symptom-finding,* and *cpr:medical-therapy* respectively. HL-7 V3 is a messaging standard and provides top level concepts such as Act, Role, and Entity through the classes of RIM. During the development of CD-EMR Ontology we have used above mentioned concepts in our ontology to capture the patient information regarding the care elements which are common between acute and chronic care. Beside these concepts, we have incorporated the CD-EMR Ontology with classes and properties to support the holistic care process of CDM. For example the classe *Intervention_Planning* of CD-EMR ontology has eight subclasses as shown in Figure 5-16.



5-16 Sub-classes of Class *Intervention_Planning* showing Behavioral and Medical Treatment Options

Three of the sub-classes provide the conventional medical options which are *Medical_Therapy*, *Surgical_Therapy* and *Procedure*. These sub-classes capture the

information related to medical treatments, drugs, surgical interventions, and various types of procedures. The sub-classes *Lifestyle_Modification*, *Patient_Education*, *Self_Management_Support,* and *Care_Support_Activities* capture the behavioral aspects of CDM, and involvement of community resources and services needed beside the medical treatment of the pathology to deal with the notion of impact and stigma of chronic diseases. The sub-class therapy supports both medical and behavioral options by capturing information related to various types of therapies such as physiotherapy which is a medical option, and psychological, behavioral, spiritual and music therapy which are behavioral options. Beside these subclasses, the classes *Goal* and *Target* help in setting different goal and specific target for the patients to achieve active involvement of patient in the care process. Along with these classes CD-EMR ontology also possesses attributes such as *Patient_Compliance, Patient_Counseling, Evaluation_of _Lifestyle,* and *Dietary_Intake,* which capture various aspects, such as impacts of chronic diseases beside the pathology.

We have seen the CPR ontology only provides the concepts that cover the medical options of treatment process and lack the concepts necessary to capture the behavioral aspects and longitudinal process of CDM. Therefore, CPR Ontology does not support the longitudinal and holistic nature of CDM. Despite comprehensiveness, the lack these concepts and properties resulted in under-utilization and limited expressivity of this model. The CD- EMR Ontology is developed by (a) combining the elements from the standard models –CCM, CPR ontology and HL-7 v3 –, and (b) the incorporation of core concepts of CDM. Therefore, the structure of CD-EMR provides a framework to capture (a) patient information regarding the care elements which are common between acute and chronic care, such as lab results, examination findings, and medical treatment, and (b) longitudinal, patient-centric and holistic nature of CDM. The CD-EMR Ontology represents the merge point of these standard models which results in increased usability and enhanced expressivity of the CD-EMR Ontology. Due to the sharing of concepts from these standard models CD-EMR Ontology provides a comprehensive ontological framework which is capable to capture acute diseases, emergency conditions as well as the holistic care process of CDM.

5.8 DISCUSSION

The formalization and implementation of CD-EMR Ontology have been successfully completed. During this phase of our research, we first transformed the conceptual model of CDM into the formal model of CD-EMR and then implemented it as CD-EMR Ontology. Prior to formalization and implementation phases, selection of a standard model was done and we selected OWL Ontology as our model for formalization and implementation. Model formalization and implementation was done in light of the selected standard models (CCM, CPR, and HL7RIM). Ontology engineering was successfully done and the product was achieved as CD-EMR Ontology. During model implementation (Ontology engineering), the quality of the outcome was tested for any inconsistencies and any flaw in the taxonomy using the Pellet Reasoner even before instantiation. The instantiation of clinical scenarios further validates the captured knowledge and data handling of heterogeneous patient information. At this stage we have successfully formalized the conceptual model of CDM into formal model of CD-EMR and ontology engineering provides us with the outcome in the form of CD-EMR Ontology. In the subsequent chapter we will discuss the evaluation of our CD-EMR Ontology in detail.

5.9 CONCLUSION

Our main aim was to develop a semantically interoperable knowledge model of EMR for CDM. We adapted the knowledge management approach [81] and developed the conceptual model of CDM. In this part of our research, we have formalized the conceptual model and successfully implemented it in the form of CD-EMR Ontology. During the model formalization and implementation phases we have successfully integrated the CD-EMR Model and ontology with the CPR Ontology and HL7 RIM. This integration is achieved by reusing the components of these standard models in the developmental process. Therefore, we believe that the structure and design of CD-EMR Ontology (a) can supports the massive information which is generated during the longitudinal care process of CMD, (b) can face the technical challenges that accompany the patient data from heterogeneous sources, and (c) can provide a portal for systemic data storage and retrieval in a semantically interoperable fashion. This strong structure and functionalities of the CD-EMR ontology is due to the fact that it inherited the

concepts from the above mentioned standard models. After development of CD-EMR Ontology we have validated the ontology by instantiating clinical scenarios which further prove the sound structure of CD-EMR ontology on practical grounds.

CHAPTER 6: ONTOLOGY EVALUATION

6.1 INTRODUCTION

After the development and validation of CD-EMR ontology, we now have a knowledge-based and semantically interoperable EMR system, in the form of CD-EMR ontology, which can support the heterogeneous data and longitudinal care process of Chronic Disease Management (CDM). The need is to evaluate the CD-EMR ontology against different criteria such as coverage of a particular domain, complexity and the granularity of the domain, model richness, consistency and completeness of the ontology, and semantic interoperability [112]. In order to evaluate our CD-EMR ontology we have devised a multi-step evaluation schema which is discussed in the subsequent sections of this chapter.

6.2 SCHEMA FOR ONTOLOGY EVALUATION

We have designed a two step schema to perform a comprehensive evaluation of CD-EMR Ontology both technically and on a knowledge basis. This multi-step approach allows us to evaluate different aspect of our ontology. The step of our evaluation are (a) to evaluate the structure of ontology and the consistency, (b) to evaluate the captured knowledge i.e. the model richness and knowledge depth, and (c) to evaluate the semantic interoperability. The evaluation schema is shown in Figure 6-1 and explained below.

(a) *Step 1:* In this step of evaluation we will evaluate the structure and compliance of CD-EMR ontology with the ontological principle described by Bodenreider et al [96]. The consistency among the classes is evaluated by using Pellet reasoner. This step allows us to evaluate the logical structure and inconsistencies in the ontological framework.

(b) *Step 2:* In this step we will evaluate the model richness of CD-EMR Ontology by instantiating clinical scenarios (use cases) of chronic disease patient. The concept of evaluation of ontology by use cases is not new, it well recognised in the field of ontology engineering and semantic web [112]. This step allows us to evaluate how CD-EMR Ontology handles (a) the complexity and granularity of domain, (b) the heterogeneous data and patient information, and

(c) the longitudinal care process of Chronic Disease Management. Moreover in this step, we will evaluate the functionality of semantic interoperability by instantiating an HL7 V3 based clinical scenario. This allows us to evaluate whether the CD-EMR Ontology is compliant with HL7 V3 and semantically interoperable.

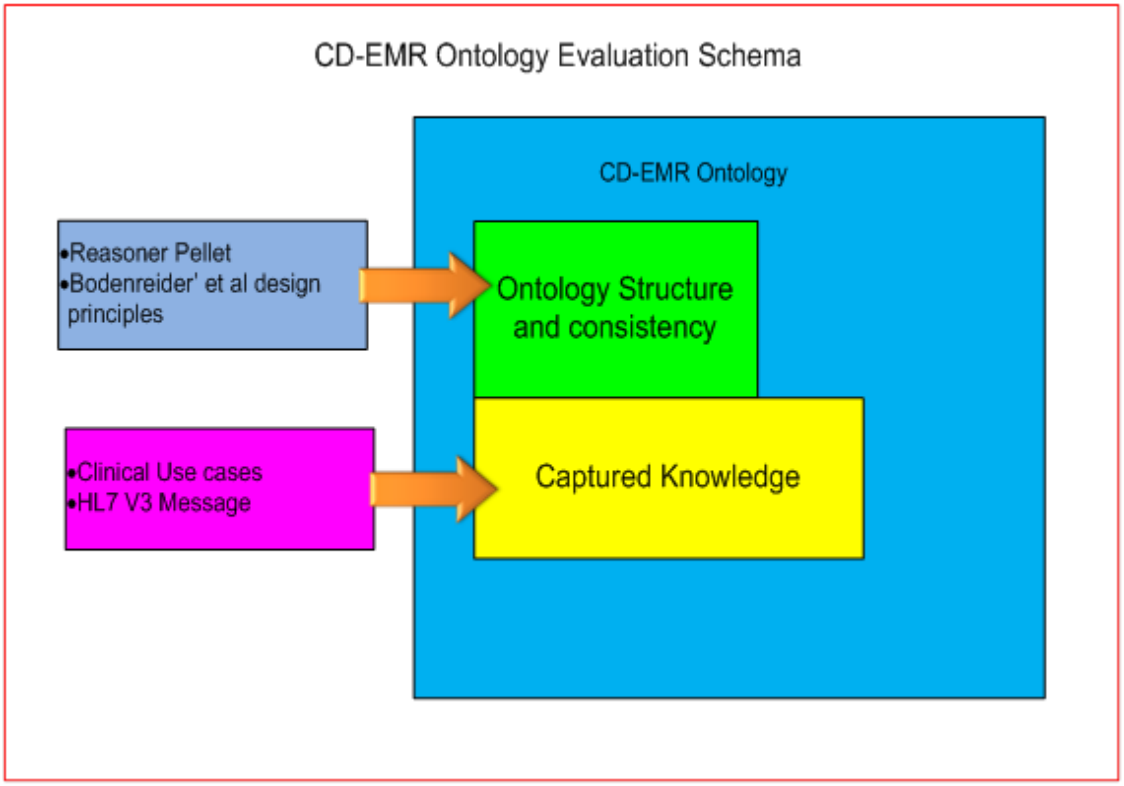


Figure 6-1 Evaluation schema of CD-EMR Ontology

6.2.1 STEP 1 ONTOLOGY EVALUATION

In this step we have evaluated our CD-EMR Ontology using Pellet and the seven design principles proposed by Bordenreider et al [96]. The details are explained below.

EVALUATION OF CONSISTENCY AND TAXONOMY BY PELLET REASONER: In the first phase of evaluation we have evaluated the logical consistency and taxonomy by using Pelett reasoner. The rationale to use the Pellett reasoner is, (a) Pellett is an OWL–DL reasoner and we have developed our

ontology in OWL-DL, and (b) we have developed our ontology using Protégé, and Protégé has a plug-in for Pellett reasoner. The results of Pellett reasoner show no logical inconsistencies or improper classification of taxonomy in our CD-EMR Ontology.

EVALUATION OF ONTOLOGY COMPLIANCE WITH DESIGN PRINCIPLES

We have evaluated the compliance of CD-EMR Ontology against the seven design principles proposed by Bordenreider et al [96] for medical ontologies. Bodenreider Principles [96] are more development-oriented rather than theory-oriented and these principles are defined for the quality assurance of the ontology. For these aforementioned reasons we have evaluated the compliance of our ontology with these principles. These principles include [95].

1. "Each hierarchy must have a single root.
2. Each class (except for the root) must have at least one parent.
3. Non-leaf classes must have at least two children.
4. Each child must be different from its parent and siblings must be different from one another.
5. Each child must have all its parent properties
6. No cycles are allowed in an IS-A hierarchy.
7. All attributes of a parent class must either be inherited by each child or refined in the child" [95]

Since we have used Protégé to develop our ontology, out of seven principles three of them were enforced by Protégé. In other words, Protégé does not allow violating the three principles and assures they are met. During evaluation we found that our CD-EMR Ontology is fully compliant with the remaining ones.

6.2.2 STEP 2: ONTOLOGY EVALUATION

In this step we have evaluated our CD-EMR Ontology by instantiating clinical scenarios of chronic diseases and HL7 message. This step validates the captured knowledge and comprehensiveness of the CD-EMR Ontology.

The clinical scenarios used for evaluation are the published clinical cases. The first clinical scenario was published in 'The new England journal of Medicine' [113] and the second medical record is an HL7 v3 message proposed by HL7 Continuity of Care Record work group [114]. We will first present the case summary and then discus the instantiation of the clinical scenario in the CD-EMR Ontology.

6.2.2.1 CLINICAL SCENARIO I

CASE SUMMARY

"A.D a 79-year-old man was admitted to the hospital because of occlusion at a vascular access site in the right forearm for hemodialysis and worsening intermittent claudication. Two days before the admission, he returned to the hospital from a hemodialysis facility because of poor flow from an arteriovenous fistula. After assessment, he was sent home with an appointment at the hospital two days later for a study with radiographic contrast agent and another hemodialysis session.

Patient has a history of hypertension and coronary artery disease, and he had had an acute anterior myocardial infarction six years before this admission, for which he had received tissue plasminogen activator (alteplase); atheroemboli complicated the procedure, and intermittent claudication in both legs and end-stage renal disease developed. After four years of peritoneal dialysis (two years before the current admission), hemodialysis was initiated. Coronary-artery bypass grafting was performed three months after the infarction occurred, because there was three-vessel coronary disease.

At the time of the patient's admission, the temperature was 37°C, the pulse was 75 beats per minute, and the respiratory rate was 20 breaths per minute. The blood pressure was 120/70 mm Hg. The patient weighed 82 kg. No rash or lymphadenopathy was found." [113].

Patient was admitted for 7 days in the hospital, during the admission several tests were performed, examinations were done and treatments were given to the patient. The details of each day are mentioned in the subsequent parts of this chapter.

Instantiation in CD-EMR Ontology

The medical record of A.D consists of three episodes and covers three different types of healthcare encounters. The first was a scheduled visit to receive haemodialysis. During this visit a complication (i.e. poor blood flow from A/V fistula), led to a referral to the hospital for A/V fistula examination, which was the second healthcare encounter. During the hospital visit, after examination of the A/V fistula the patient was scheduled to visit the hospital after two days for a study with a radiographic contrast agent and another haemodialysis session, which constituted the third healthcare encounter. During the third healthcare encounter, the patient was admitted to the hospital and the admission continued for 7 days. At the time of admission, patient history was taken, sign and symptoms were recorded, examination and investigations were performed, and treatment was given to the patient. Each admission day has been captured as a part of the third healthcare encounter. Figure 6-2 shows the medical record of A.D with the encounters and patient record number. Table 6-1 presents the instantiation.

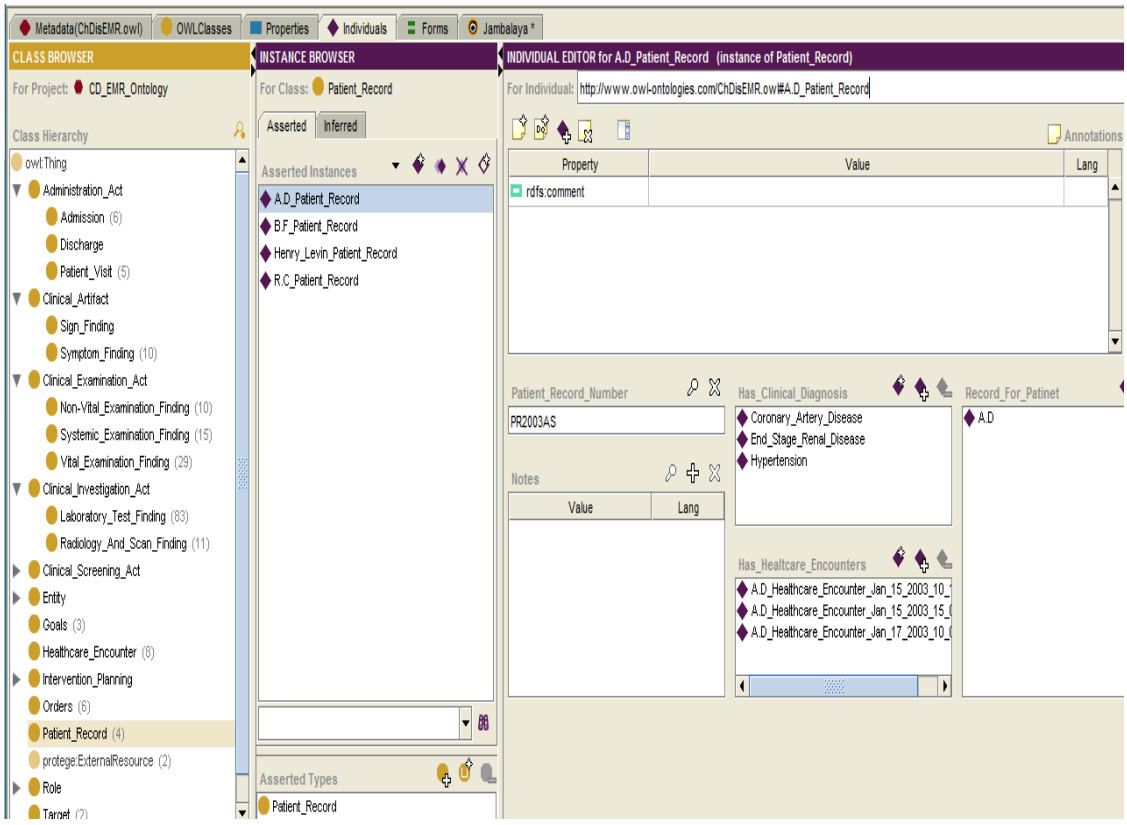


Figure 6-2 Patient Record of A.D in CD-EMR Ontology

Table 6-1 Instantiation of B.F Medical Record

Class	Instances	Properties		Values
		Object Properties	Data-type Properties	
Patient Record	A.D_Patient_ Record	Has_Clinical_ Diagnosis		Coronary artery disease End stage renal disease Hypertension
		Has_Healthcare_ Encounters		A.D_Healthcare_Encounter_Jan_15_2003_10_15_ 40

				A.D_Healthcare_Encounter_Jan_15_2003_15_00_45
				A.D_Healthcare_Encounter_Jan_17_2003_10_00_00
		Record_For_Patient		B.F
			Patient_Record_Number	PR2003AD
			Notes	

Instantiation of A.D Healthcare Encounter on Jan 15th 2003, at 10:15:40am

The first healthcare encounter of A.D is to receive hemodialysis at a hemodialysis facility. During this encounter, due to the complication of an occlusion at a vascular access site which caused poor flow from an arteriovenous fistula, the patient was referred to the hospital for assessment of A/V fistula. It is captured in CD-EMR Ontology as shown in Figure 6-3 and details are presented in Table 6-2.

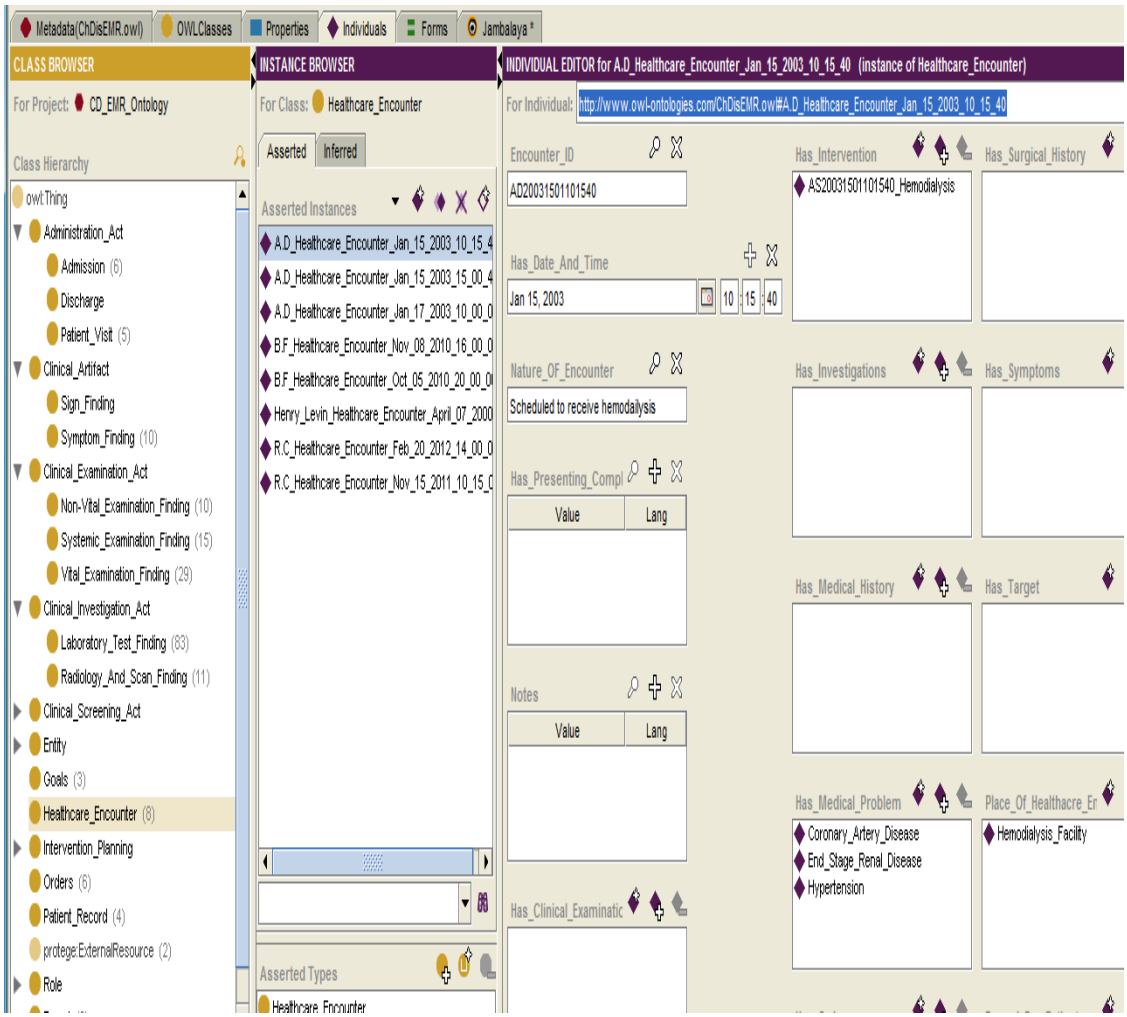


Figure 6-3 Instantiation of A.D Healthcare Encounter on Jan 15th 2003, at 10:15:40am

Table 6-2 Details of instantiation of A.D Healthcare Encounter on Jan 15th 2003, at 10:15:40am

Class	***Instances***	***Properties***				
		Object Properties			***Data-type Properties***	***Values Of Data_types***
		Property	***Value (Individual Of Other classes)***	***Individual of class***		
Healthcare_ Encounter	A.D_Healthcare_Encounter_Jan_15_2003_10_15_40	Has_Medical_Problem	Coronary_Artery_Disease End_Stage_Renal_Disease Hypertension		Has_Date_And_Time	Jan 15, 2003 10:15:40 am
		Has_Intervention	AS20031501101540_Hemodialysis Name of procedure: Hemodialysis Complication: • Poor flow from an arteriovenous fistula • Occlusion at a vascular access site	Procedure	Has_Encounter_ID	AD20031501101540
		Place_Of_Healthcare_Encounter	Hemodialysis_Facility	Material_Entity	Nature_Of_Encounter	Scheduled to receive hemodailysis
		Record_For_Patient	A.D (Name: A.D Age: 79 years Gender: Male)	Patient		
		Scheduled_Next	AD20031501101540_Referral_Vis	Patient_Visit		

		_ Visit	it (Date and time of next schedules visit: Jan 15, 2003, 15:00:00 Visit Type: Scheduled Nature of encounter: Referred to Hospital for assessment of AV fistula Description: Due to poor flow from an arteriovenous fistula patient is reffered to hospital for assessment)			

Instantiation of A.D Healthcare Encounter on Jan 15th 2003, at 3:00:45pm

In the second healthcare encounter (which was a referral visit) the patient visited the hospital and after assessment, the patient was sent home with another appointment at the hospital after two days for a study with a radiographic contrast agent and another heamodialysis session. It is captured in CD-EMR Ontology as shown in Figure 6-4 and details are presented in Table 6-3.

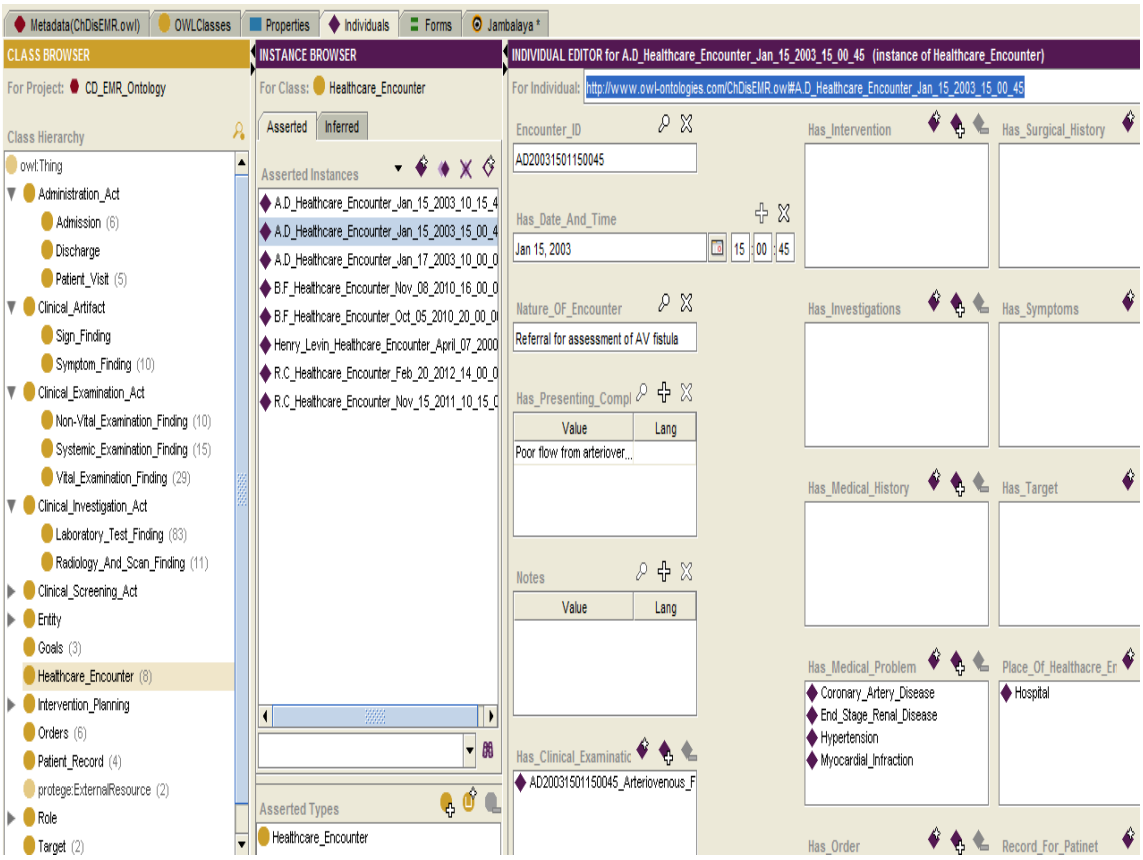


Figure 6-4 Instantiation of A.D Healthcare Encounter on Jan 15th 2003, at 3:00:45pm

Table 6-3 Details Instantiation of A.D Healthcare Encounter on Jan 15th 2003, at 3:00:45pm

Class	***Instances***	***Properties***				
		Object Properties			***Data-type Properties***	***Values Of Data_types***
		Property	***Value (Individual Of Other classes)***	***Individual of class***		
Healthcare_ Encounter	A.D_Healthcare_Encounter_Jan_15_2003_15_00_45	Has_Medical_ Problem	Coronary_Artery_Disease End_Stage_Renal_Disease Hypertension		Has_Date_And _Time	Jan 15, 2003 15:00:45
		Has_Clinical_Examination	AD20031501150045_Arteriovenous_Fistula_Examination Name of examination : Arteriovenous_Fistula_Examination Site of examination: Arteriovenous Fistula	Non-Vital_Examination	Has_Encounter _ID	AD20031501150045
		Place_Of_Healthcare_Encounter	Hospital	Material_Entity	Nature_Of_ Encounter	Referral for assessment of AV fistula
		Record_For_Patient	A.D (Name: A.D Age: 79 years	Patient		

			Gender: Male)			
		Scheduled_Next_ Visit	AD20031501150045_Follow_up_Visit (Date and time of next schedules visit: Jan 17, 2003, 10:00:00 Visit Type: Scheduled Nature of encounter: Follow-up for assessment of AV fistula Description: Radiological study of AV fistula	Patient_Visit		

Instantiation of A.D Healthcare Encounter on Jan 15th 2003, at 3:00:45pm (Admission Day 1)

In the third healthcare encounter the patient visited the hospital after two days. The patient was admitted to the hospital because of an occlusion at a vascular access site in the right forearm for hemodialysis and worsening intermittent claudication. This encounter is captured as the first day of admission. During this visit, patient's medical history about hypertension, MI, paroxysmal atrial fibrillation, ventricular tachycardia, and peptic ulcer disease was captured in *Medical_History_Sereening*. The surgical history about coronary artery bypass surgery and left upper lobectomy was captured in *Surgical_History_Screening*. Clinical examination vitals, non-vitals and systemic examination are captured through *Clinic_Examination_Act.* Clinical investigations are captured through *Clinic_Investigation_Act*, symptoms are recorded in *Symptoms_Finding*, and the treatments were recorded through the sub-classes of class *Intervention_Planning*. The record of the first day is shown in Figure 6-5 and the details of instantiation of day one are presented in Table 6-4.

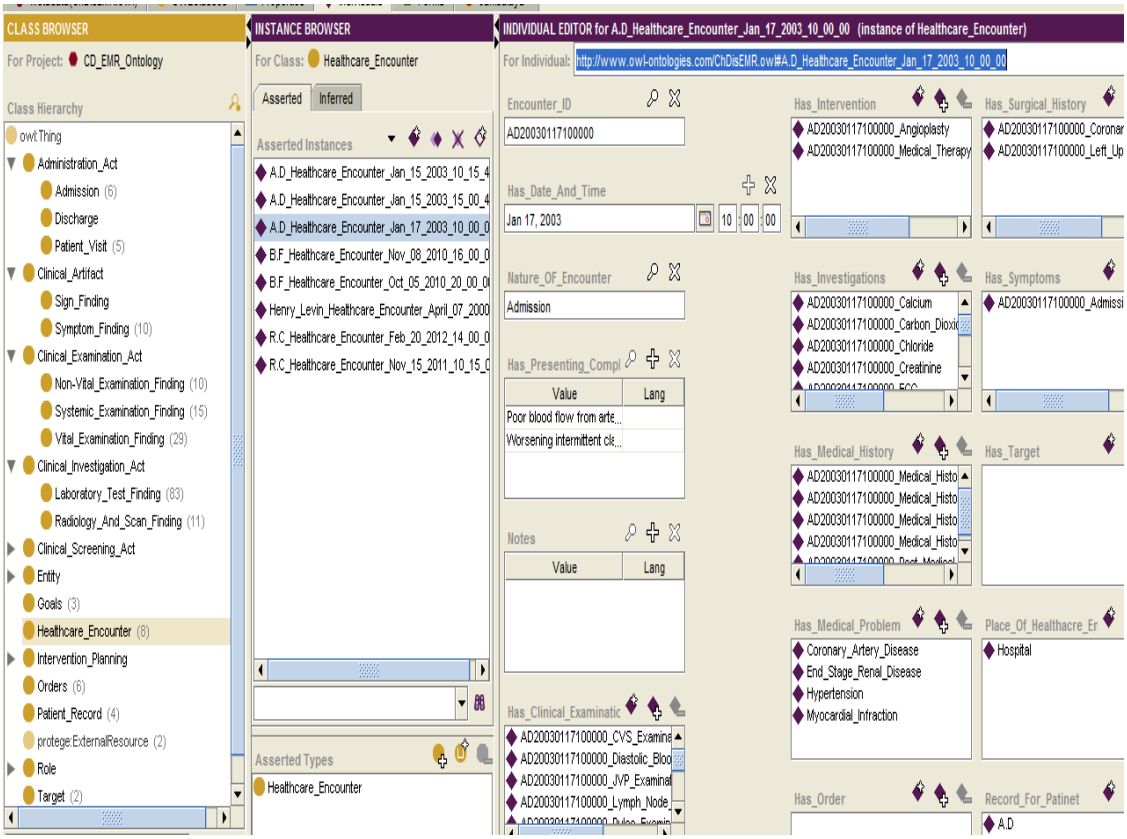


Figure 6-5 Instantiation of A.D Healthcare Encounter on Jan 17, 2003, at 10:00 am

Table 6-4 Details Instantiation of A.D Healthcare Encounter on Jan 17, 2003, at 10: 00 am

Class	***Instances***	***Properties***				
		Object Properties			***Data-type Properties***	***Values Of Data_types***
		Property	***Value (Individual Of Other classes)***	***Individual of class***		
Healthcare_ Encounter	A.D_Healthcare_Encounter_Jan_17_2003_10_00_00	Has_Medical_ Problem	Coronary Artery disease End Stage Renal Disease Hypertension	Medical_Problems	Encounter_ID	AD20030117100000
		Has_Symptoms	AD20030117100000_Admission_Day_1_Claudication (Has_Symptom : Claudication Location: Both legs Quality: Intermittent Severity: Worsing SNOMED CT Code: 275520000)	Symptoms_Finding		
		Has_Medical_ History	AD20030117100000_Medical_History_Acute_MI (Has_Disease: Acute Myocardial Infraction Any_Complication: • Intermittent claudication in both legs	Medical_History_ Screening	Has_Date_And_Time	Jan 17, 2003 10: 00 am

			• End-stage renal disease • Artheroemboli Has_Duration: 6 years (Acute anterior MI six years before this admission) Treatment_Taken: Alteplase SNOMED CT Code: 84100007)			
			AD20030117100000_Medical_History_Coronary_Artery_Disease (Has_Disease: Coronary Artery disease SNOMED CT Code: 84100007)	Medical_History_Screening		
			AD20030117100000_Medical_History_Hypertension (Has_Disease: Hypertension SNOMED CT Code: 84100007)	Medical_History_Screening		
			AD20030117100000_Medical_History_Peritonial_Dislysis (Has_Disease: End Stage Renal Disease Treatment_Given: Peritonial Dislysis	Medical_History_Screening	Has_Presenting_Complaints	Poor blood flow from arteriovenous fistula Worsening intermittent

			Has_Duration: 4 years SNOMED CT Code: 84100007)			claudication
			AD20030117100000_Past_ Medical_History (Has_Disease: • Paroxysmal Atrial Fibrillation • Peptic Ulcer • Ventricular Tachycardia SNOMED CT Code: 84100007)	Medical_History_ Screening		
		Has_ Personal_ History	AD20030117100000_Personal_ History_Smoking_And_Alcohol (Addiction: No Smoking: True No. of cigarettes per day: Up to 2 packs per day he had discontinued smoking several years before admission because of chronic obstructive pulmonary disease and bronchospasm. Alcohol Intake: True No of Drinks: Not Specified	Personal_History_ Screening	Nature_Of_ Encounter	Addmission

			The patient drink little alcohol SNOMED CT Code: 84100007 229819007 (Smoking) 160573003 (Alcohol Intake))			
		Has_ Surgical_ History	AD20030117100000_Coronary_ Artery_Bypass_Grafting (Surgical Procedure performed: Coronary Artery Bypass Grafting Has Disease: MI SNOMED CT Code: 84100007)	Surgical_ History _Screening		
			AD20030117100000_Left_Upper_Lobectomy (Surgical Procedure performed: Left Upper Lobectomy Reason for surgery: Left upper lobectomy for cancer Nature of surgery: Therapeutic SNOMED CT Code: 84100007)	Surgical_ History _Screening		
		Has_Clinical Examination	AD20030117100000_Temperature_Examination (Name of Examination: Temperature Examination	Clinical_ Examination_ Act: (Vital_Examination_		

			Result: 37 degree C SNOMED CT Code: 164300005)	Finding)		
			AD20030117100000_Pulse_Examination (Name of Examination: Pulse, Heart Rate Examination Rate: 75 beats per minutes Result: Normal SNOMED CT Code: 364075005)	Clinical_ Examination_ Act: (Vital_Examination_ Finding)		
			AD20030117100000_Respiratory_Rate_Examination (Name of Examination: Respiratory Rate Rate: 20 breaths per minutes Result: Normal SNOMED CT Code: 86290005)	Clinical_ Examination_ Act: (Vital_Examination_ Finding)		
			AD20030117100000_Systolic_Blood_Pressure_Examination (Name of Examination: Systolic Blood Pressure Result: 120 mmHg SNOMED CT Code:	Clinical_ Examination_ Act: (Vital_Examination_ Finding)		

			271649006)			
			AD20030117100000_Diastolic_Blood_Pressure_Examination (Name of Examination: Systolic Blood Pressure Result: 70 mmHg SNOMED CT Code: 271650006)	Clinical_Examination_Act: (Vital_Examination_Finding)		
			AD20030117100000_JVP_Examination (Name of Examination: Jugular venous pressure (JVP) Examination Examination Finding Normal : 5cm of blood Result: Normal SNOMED CT Code: 274283008)	Clinical_Examination_Act: (Non-Vital_Examination_Finding)		
			AD20030117100000_Lymph_Node_Examination (Name of Examination: Lymph Node Examination Examination Finding Normal: No lymphadenopathy	Clinical_Examination_Act: (Non-Vital_Examination_Finding)		

			Result: Normal)			
			AD20030117100000_Weight_Examination (Name of Examination Weigh Examination Result: 82 kg SNOMED CT Code: 162763007)	Clinical_ Examination_ Act: (Vital_Examination_ Finding)		
			AD20030117100000_Respiratory_Examination (Name of Examination: Respiratory Examination Audible Sound Abnormal: Diffuse expiratory wheezes in both lungs SNOMED CT Code:52653008)	Clinical_ Examination_ Act: (Systemic_Examination_ Finding)		
			AD20030117100000_CVS_Examination (Name of Examination: CVS Examination Examination Finding Normal: • Carotid Pulse Normal without burit	Clinical_ Examination_ Act: (Systemic_Examination_ Finding)		

			• Hands well perfused • Pulse in arm normal and without burit Examination Finding Abnormal: • Arteriovenous fistula thrombosed • Dorsalis Pedis pulse absent bilaterally • Popliteal pulse absent bilaterally • Femoral pulse absent bilaterally Audible Sound Abnormal: Grade 1 systolic cardiac murmur was present along the left sternal border SNOMED CT Code: 364066008)			
		Has_Clinical Investigation	AD20030117100000_Calcium Lab test Name: Calcium	Laboratory_Test_ Finding		

			Result Value: 7.8 Unit of measurement: mg/dl			
			AD20030117100000_Carbon_Dioxide (Lab test Name: Carbon dioxide Result Value: 12.8 Unit of measurement: mmol/liter)	Laboratory_Test_Finding		
			AD20030117100000_Chloride (Lab test Name: Chloride Result Value: 100 Unit of measurement: mmol/liter)	Laboratory_Test_Finding		
			AD20030117100000_Creatinine (Lab test Name: Serum Creatinine Result Value: 14.4 Unit of measurement: mg/dl)	Laboratory_Test_Finding		
			AD20030117100000_Hematocrit (Lab test Name: Hematocrit Result Value: 28.9 Unit of measurement: Percent (%))	Laboratory_Test_Finding		

			AD20030117100000_Mean_corpuscular_volume (Lab test Name: Mean corpuscular volume Result Value: 98 Unit of measurement: fl)	Laboratory_Test_Finding		
			AD20030117100000_Partial-thromboplastin_time (Lab test Name: Partial-thromboplastin time Result Value: 25.5 Unit of measurement: seconds)	Laboratory_Test_Finding		
			AD20030117100000_Phosphorus (Lab test Name: Phosphorus Result Value: 9.5 Unit of measurement: mg/dl)	Laboratory_Test_Finding		
			AD20030117100000_Platelet_Count (Lab test Name: Platelet Count Result Value: 240,000 Unit of measurement: per mm 3)	Laboratory_Test_Finding		
			AD20030117100000_Potassium (Lab test Name: Potassium	Laboratory_Test_Finding		

			Result Value: 6.7 Unit of measurement: mmol/liter)			
			AD20030117100000_Prothrombin_International_Normalized_Ratio (Lab test Name: Prothrombin International Normalized Ratio Result Value: 2.5)	Laboratory_Test_ Finding		
			AD20030117100000_Sodium (Lab test Name: Sodium Result Value: 136 Unit of measurement: mmol/liter)	Laboratory_Test_ Finding		
			AD20030117100000_Urea_Nitrogen (Lab test Name: Blood Urea Nitrogen Result Value: 94 Unit of measurement: mg/dl)	Laboratory_Test_ Finding		
			AD20030117100000_White-Cell_Count (Lab test Name: White-Cell Count	Laboratory_Test_ Finding		

			Result Value: 7500 Unit of measurement: per mm3)			
			AD20030117100000_ECG (Name of Scan: ECG/(EKG) Normal Finding: Normal Rhythm Abnormal Finding: • ST-segment depressions • Poor R-wave progression Nature of scan: Diagnostic	Radiology_And_Scan_Finding		
			AD20030117100000_Fistulograph (Name of Scan: Fistulograph Abnormal Finding: Multiple areas of severe thrombosis within the right-forearm graft. Nature of scan: Diagnostic	Radiology_And_Scan_Finding		
		Has_Interventions	AD20030117100000_Medical_Therapy_Admission_Day_1 Medication Name: • Acetaminophen • Docusate Sodium • Metoprolol	Medical_Therapy		

			• Oxycodone • Simvastatin Medical Equipment Used: Inhaler			
			AD20030117100000_Angioplasty Name of surgical procedure: Angioplasty Notes: Several attempts at angioplasty produced satisfactory flow	Surgical_Therapy		
		Place_Of_Healthcare_Encounter	Hospital	Material_Entity		
		Record_For_Patient	A.D (Name: A.D Age: 79 years Gender: Male)	Patient		

Instantiation of A.D Admission Day 2 Jan 18, 2003

During the second day of admission patient developed chest pain which is captured as symptom finding in the CD-EMR Ontology and Digoxin was given to the patient which is captured as medical therapy via *Has_Intervention*. Clinical investigation performed during second day of admission includes Urea Nitrogen, , Serum Creatinine and Potassium are recorded through *Laboratory_Examination_Finding*. Trans-thoracic cardiac U/S and an intravenous digital subtraction angiogram of the aortic–pelvic region were recorded through *Radiology_and_Scan_Finding*. All these clinical investigations are captured via object property *Has_Investigations* as shown in Figure 6-6. Besides recording the findings of angiogram our ontology has also recorded the image of angiogram using RDF comment as shown in Figure 6-7. The record of second day is shown in Figure 6-6 and the details of instantiation of day two are presented in Table 6-5.

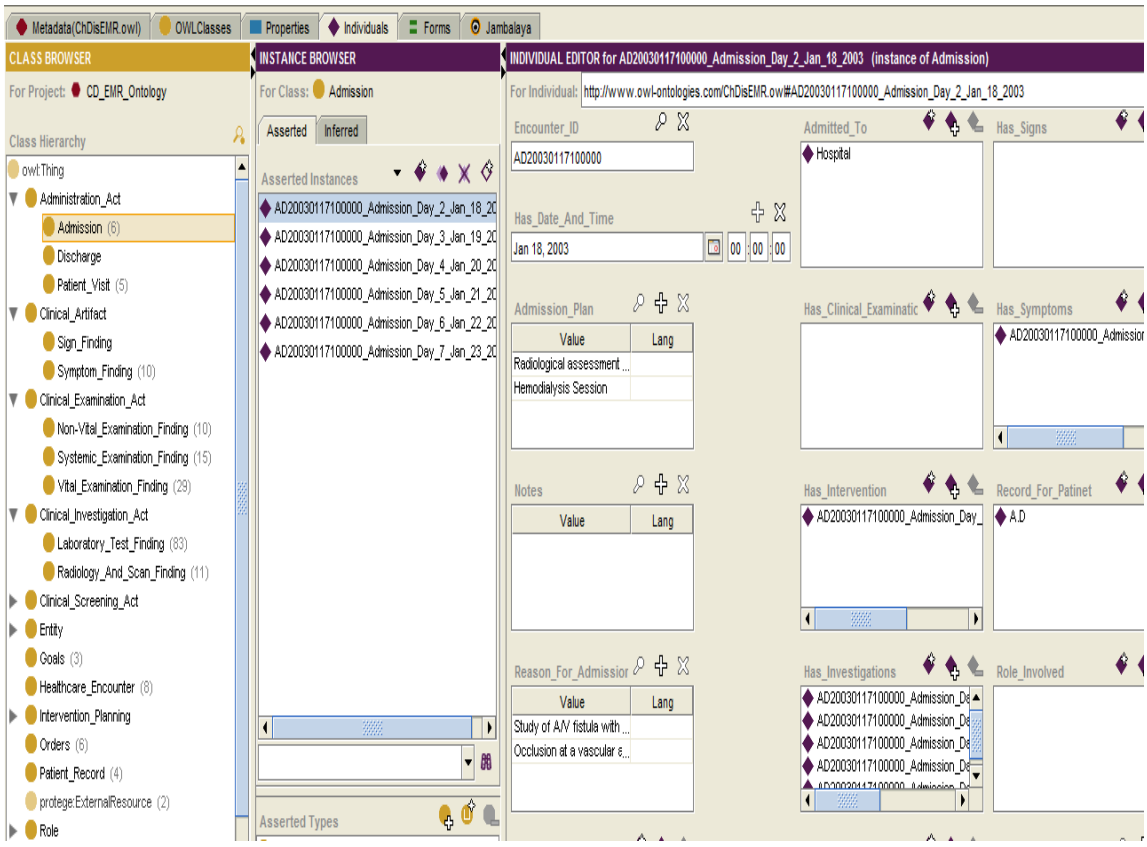


Figure 6-6 Instantiation of A.D Admission Day 2 Jan 18, 2003

Figure 6-7 Admission day 2 image of angiogram captured via RDF comment in CD-EMR Ontology.

Image taken from [113]

Table 6-5 Details of Instantiation of A.D Admission Day 2 Jan 18, 2003

Class	***Instances***	***Properties***				
		Object Properties			***Data-type Properties***	***Values Of Data_types***
		Property	***Value (Individual Of Other classes)***	***Individual of class***		
Admission	AD20030117100000_Admission_Day_2_Jan_18_2003	Admitted_To	Hospital	Material_Entity	Encounter_ID	AD20030117100000
		Has_Symptoms	AD20030117100000_Admission_Day_2_Chest_Pain (Has_Symptom : Chest_Pain Location: Chest Associated Symptom: Atrial fibrillation SNOMED CT Code: 29857009)	Symptoms_Finding	Has_Date_And_Time	Jan 18, 2003
		Has_Clinical Investigation	AD20030117100000_Admission_Day_2_Creatinine (Lab test Name: Serum Creatinine Result Value: 10.1 Unit of measurement: mg/dl)	Laboratory_Test_Finding	Admission_Plan	Radiological assessment of A/V fistula Hemodialysis Session
			AD20030117100000_Admission_Day_2_Potassium (Lab test Name: Potassium	Laboratory_Test_Finding		

			Result Value: 4.9 Unit of measurement: mmol/liter)			
			AD20030117100000_Admission_Day_2_Urea_Nitrogen (Lab test Name: Blood Urea Nitrogen Result Value: 51 Unit of measurement: mg/dl)	Laboratory_Test_Finding		
			AD20030117100000_Admission_Day_2_Angiogram (Name of Scan: Angiogram Normal Finding: • Common and external iliac arteries were patent bilaterally. • Common femoral arteries were patent bilaterally. • Right deep and superficial femoral arteries were patent bilaterally Abnormal Finding: • Diffuse atherosclerotic disease throughout the	Radiology_And_Scan_Finding	Reason_For_Admission	Occlusion at a vascular access site (A/V Fistula) in the right forearm for haemodialysis Study of A/V fistula with radiographic contrast agent and another hemodialysis

			aortoiliac system Poor R-wave progression • Occlusion of the left superficial femoral artery at its origin, with reconstitution distally by the deep femoral artery Nature of scan: Diagnostic with contrast Note: Intravenous digitalsubtraction angiogram of the aortic–pelvic region			session.
			AD20030117100000_Admission_Day_2_Transthoracic_cardiac_ultrasonograph (Name of Scan: Transthoracic cardiac ultrasonography Normal Finding: • Estimated ejection fraction was 59 percent • Left ventricle of normal size and normal systolic function	Radiology_And_Scan_Finding		

			Abnormal Finding: • Akinetic areas at the anterior apex and midportion, along with shallow aneurysmal bulging • Segmental left ventricular dysfunction Nature of scan: Diagnostic			
		Has_Interventions	AD20030117100000_Admission_Day_2_Medical_Therapy_Digoxin Medication Name: Digoxin Drug Strength: 0.75 mg Route: Intravenous Notes: After administration of Digoxin the rhythm reverted to normal overnight	Medical_Therapy		
		Record_For_Patient	A.D (Name: A.D Age: 79 years Gender: Male)	Patient		

Instantiation of A.D Admission Day 3 Jan 19, 2003

During the third day of admission patient developed nausea and vomiting which is captured as symptom findings in the CD-EMR Ontology and Kayexalate was given to the patient which is captured as medical therapy via Has_Intervention. Clinical examinations performed on the third day include JVP 7cm of blood recorded through *Non-Vital_Examination_Finding*, respiratory examination of wheeze recorded through *Systemic_Examination_Finding* and are captured via *Has_Clinical_Examination* . Clinical investigation performed during the third day of admission includes Hematocrit, Prothrombin international normalized ratio, Urea nitrogen, Creatinine, Protein, Albumin, Potassium, Creatine kinase, Creatine kinase isoenzymes, Creatine kinase isoenzyme index, Troponin T, and Stool Test are captured through *Laboratory_Examination_Finding* and X-Ray Chest through *Radiology_and_Scan_Finding* via *Has_Investigations.* The record of third day is shown in Figure 6-8 and the details of instantiation of day three are presented in Table 6-6.

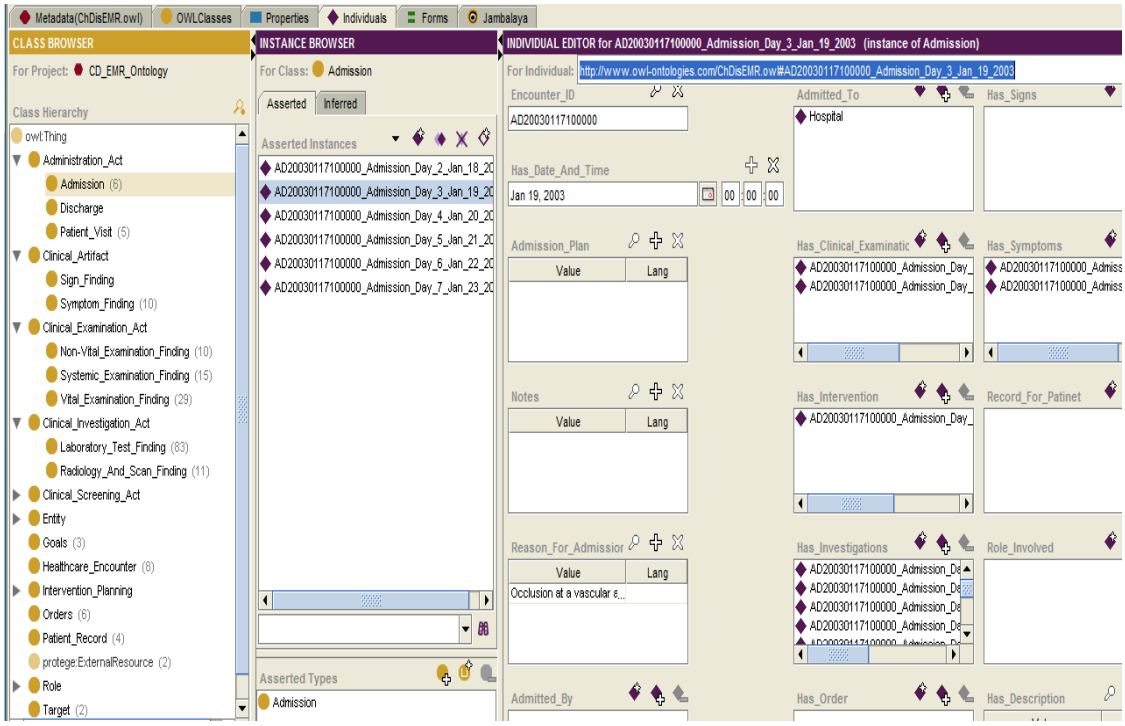


Figure 6-8 Instantiation of A.D Admission Day 3 Jan 19, 2003

Table 6-6 Details of Instantiation of A.D Admission Day 3 Jan 19, 2003

Class	***Instances***	***Properties***				
		Object Properties			***Data-type Properties***	***Values Of Data_types***
		Property	***Value (Individual Of Other classes)***	***Individual of class***		
Admission	AD20030117100000_Admission_Day_3_Jan_19_2003	Admitted_To	Hospital	Material_Entity	Encounter_ID	AD20030117100000
		Has_Symptoms	AD20030117100000_Admission_Day_3_Nausea (Has_Symptom : Nausea Associated Symptom: Vomiting, No abdominal pain SNOMED CT Code: 422587007)	Symptoms_Finding	Has_Date_And_Time	Jan_19_2003
			AD20030117100000_Admission_Day_3_Vomiting (Has_Symptom : Vomiting Associated Symptom: Nausea, No abdominal pain SNOMED CT Code: 422400008)	Symptoms_Finding	Admission_Plan	Radiological assessment of A/V fistula Hemodialysis Session
		Has_Clinical Examination	AD20030117100000_Admission_Day_3_JVP_Examination (Name of Examination: Jugular venous pressure (JVP)	Clinical_Examination_Act: (Non-Vital_Examinati	Reason_For_Admission	Occlusion at a vascular access site (A/V Fistula) in the

			Examination Examination Finding Normal : 7cm of blood Result: Normal SNOMED CT Code: 274283008)	on_ Finding)		right forearm for haemodialysis Study of A/V fistula with radiographic contrast agent and another hemodialysis session.
			AD20030117100000_Admission_ Day_3_Respiratory_Examination (Name of Examination: Respiratory Examination Audible Sound Abnormal: Wheeze SNOMED CT Code:52653008)	Clinical_ Examination_ Act: (Systemic_Examination_ Finding)		
		Has_Clinical Investigation	AD20030117100000_Admission_ Day_3_Albumin (Lab test Name: Albumin Result Value: 2.9 Unit of measurement: g/dl)	Laboratory_Test_ Finding		
			AD20030117100000_Admission_ Day_3_Creatinine (Lab test Name: Serum Creatinine Result Value: 13.6 Unit of measurement: mg/dl)	Laboratory_Test_ Finding		
			AD20030117100000_Admission_ Day_3_Hematocrit	Laboratory_Test_ Finding		

			(Lab test Name: Hematocrit Result Value: 28.7 Unit of measurement: Percent (%))			
			AD20030117100000_Admission_Day_3_Creatine_Kinase_Isoenzymes (Lab test Name: Creatine Kinase Isoenzymes Result Value: 48.4 Unit of measurement: ng/ml)	Laboratory_Test_ Finding		
			AD20030117100000_Admission_Day_3_Creatine_Kinase_Isoenzyme_Index (Lab test Name: Creatine Kinase Isoenzyme Index Result Value: 9.7 Unit of measurement: percent(%))	Laboratory_Test_ Finding		
			AD20030117100000_Admission_Day_3_Protein (Lab test Name: Protein Result Value: 6.1 Unit of measurement: mg/dl)	Laboratory_Test_ Finding		
			AD20030117100000_Admission_	Laboratory_Test		

			Day_3_Creatine_Kinase (Lab test Name: Creatine Kinase Result Value: 501 Unit of measurement: U/liter)	_ Finding		
			AD20030117100000_Admission_ Day_3_Potassium (Lab test Name: Potassium Result Value: 4.9 Unit of measurement: mmol/liter)	Laboratory_Test _ Finding		
			AD20030117100000_Admission_ Day_3_Prothrombin_International _Normalized_Ratio (Lab test Name: Prothrombin International Normalized Ratio Result Value: 2.2)	Laboratory_Test _ Finding		
			AD20030117100000_Admission_ Day_3_Stool_Test (Lab test Name: Stool Test Result Value: Occult blood in stool sample)	Laboratory_Test _ Finding		
			AD20030117100000_Admission_ Day_3_Urea_Nitrogen (Lab test Name: Blood Urea Nitrogen	Laboratory_Test _ Finding		

			Result Value: 62 Unit of measurement: mg/dl)			
			AD20030117100000_Admission_Day_3_Troponine-T (Lab test Name: Troponine-T Result Value: 2.46 Unit of measurement: ng/ml)	Laboratory_Test_ Finding		
			AD20030117100000_Admission_Day_3_Radiograph_Chest (Name of Scan: Radiograph Chest Normal Finding: • Normal cardiac silhouette • No pneumonia Abnormal Finding: • The pulmonary vascularity was mildly prominent . • Mild linear atelectasis or scarring in the middle and lower zones of the right lung Nature of scan: Diagnostic SNOMED CT Code: 56350004)	Radiology_And_Scan_Finding		
		Has_Interventio	AD20030117100000_Admission_	Medical_Therap		

		ns	Day_3_Medical_Therapy_Kayexalate Medication Name: 1. Polystyrene Sulfonate 2. Sorbitol Drug Srength: 60 mg (each) Dose: BID Therapy Instruction: Two oral doses of sodium polystyrene sulfonate in sorbitol (Kayexalate, 60 g each) Schedule: One dose in afternoon Other dose at night	y		
		Record_For_Patient	A.D (Name: A.D Age: 79 years Gender: Male)	Patient		

Instantiation of A.D Admission Day 4 Jan 20, 2003

During the fourth day of admission patient's abdominal examination was performed by a gastroentologist. On examination abdomen was found non tender with normal bowel sound, so the endoscopy was delayed. This finding was recorded in CD-EMR Ontology as *Systemic_Examination_Finding* and captured via *Has_Clinical_Examination*. On the fourth day the patient received heamodialysis and blood transfusion, which are recorded in the ontology as procedures and captured via *Has_Intervention.* Clinical investigation performed during the fourth day of admission includes Hematocrit, Urea nitrogen, Creatinine, Potassium, Creatine kinase, Creatine kinase isoenzymes, Creatine kinase isoenzyme index, Troponin T, Iron, Iron-binding capacity, Ferritin, and Digoxin are captured through *Laboratory_Examination_Finding,* and X-Ray chest and abdomen are recorded through *Radiology_and_Scan_Finding.* All these clinical investigations are captured via object property *Has_Investigations* as shown in Figure 6-9. Beside recording the findings of X-Ray Abdomen our ontology has also recorded the image of X-Ray Abdomen using RDF Comment as shown in Figure 6-10. The record of fourth day is shown in Figure 6-9 and the details of instantiation of day four are presented in Table 6-7.

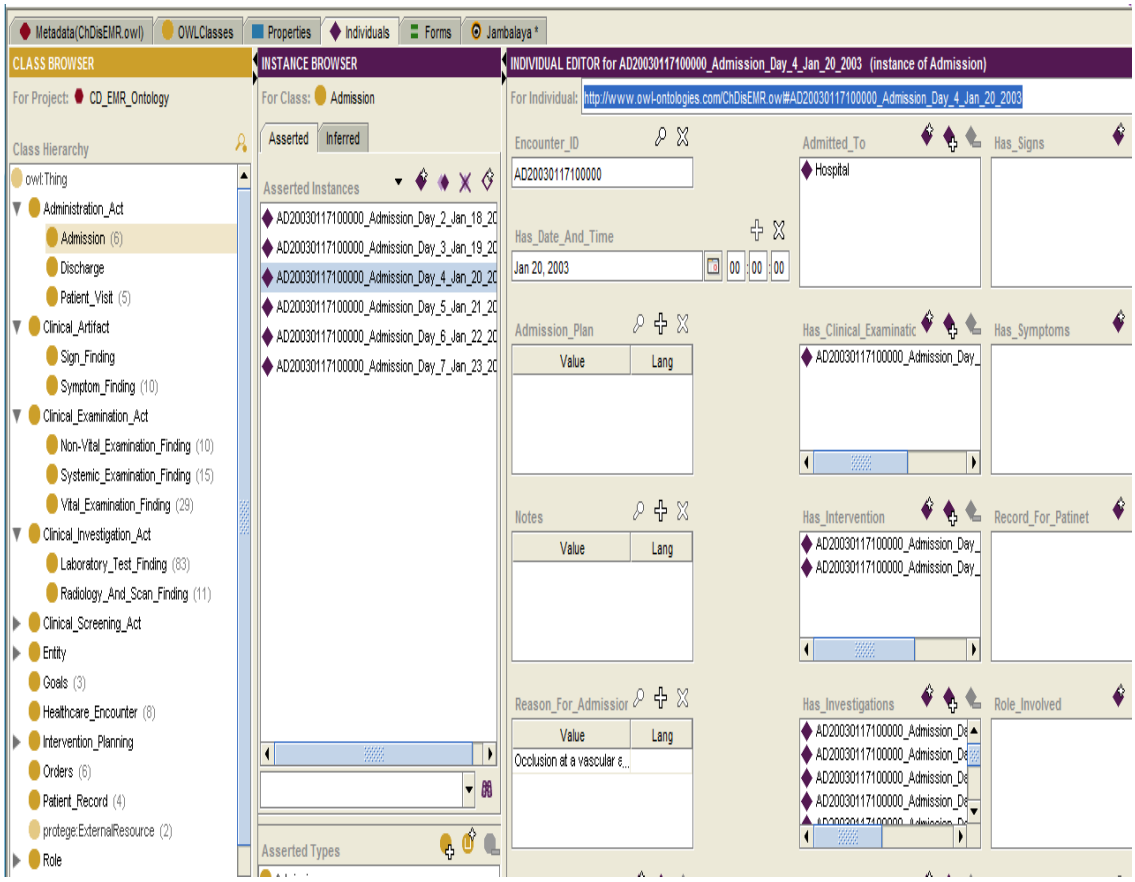


Figure 6-9 Instantiation of A.D Admission Day 4 Jan 20, 2003

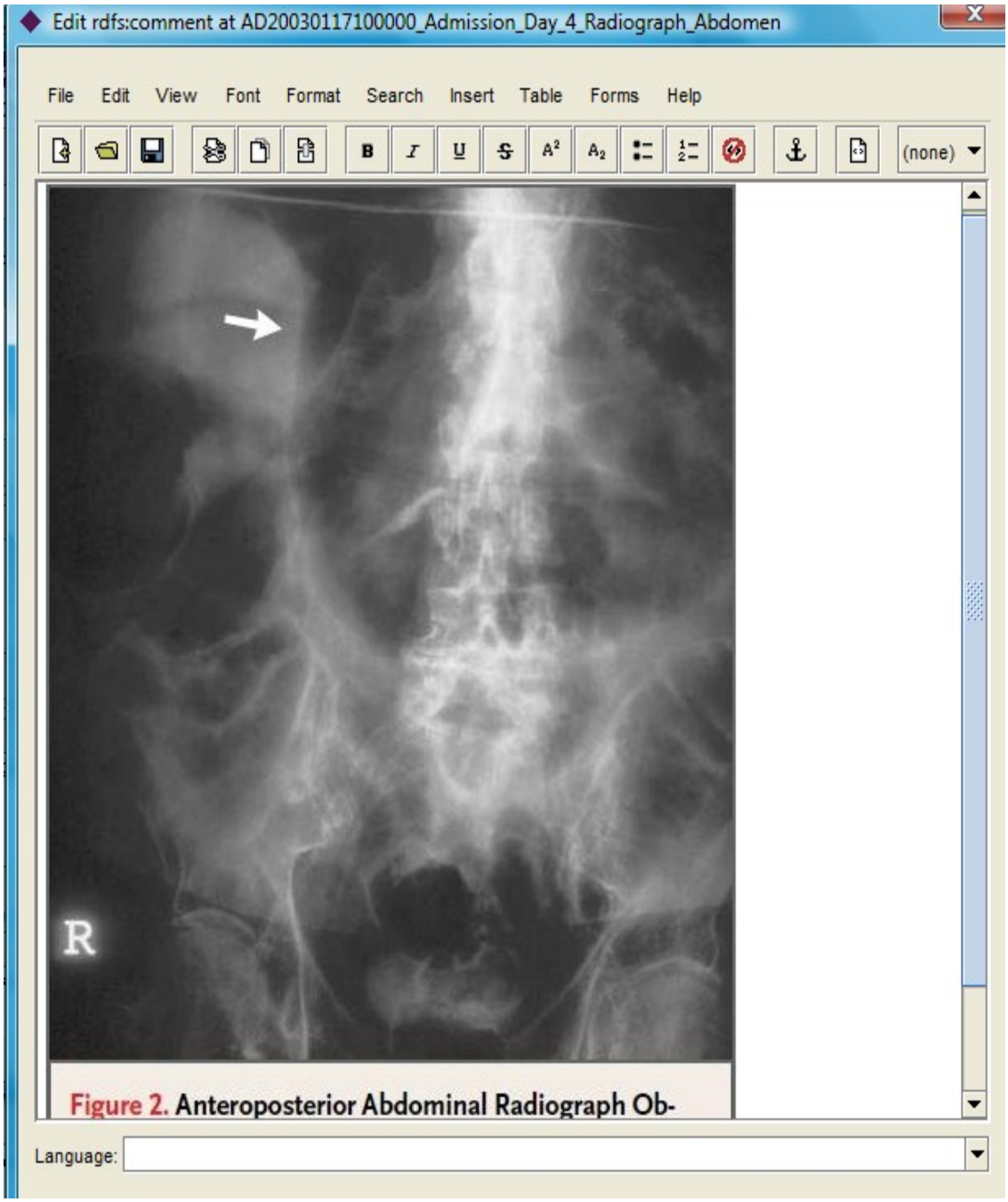


Figure 6-10 Admission day 4 image of X-Ray Abdomen captured via RDF comment in CD- EMR Ontology.

Image taken from [113]

Table 6-7 Details of Instantiation of A.D Admission Day 4 Jan 20, 2003

Class	***Instances***	***Properties***				
		Object Properties			***Data-type Properties***	***Values Of Data_types***
		Property	***Value (Individual Of Other classes)***	***Individual of class***		
Admission	AD20030117100000_Admission_Day_4_Jan_20_2003	Admitted_To	Hospital	Material_Entity	Encounter_ID	AD20030117100000
					Has_Date_And_Time	Jan_20_2003
					Admission_Plan	Radiological assessment of A/V fistula Hemodialysis Session
		Has_Clinical Examination	AD20030117100000_Admission_Day_4_Abdominal_Examination (**Name of Examination**: Abdominal Examination **Site Of Examination**: Abdomen **Audible Sound Normal**: Normal bowel sounds	Clinical_ Examination_ Act: (Systemic_Examination_ Finding)	Reason_For_ Admission	Occlusion at a vascular access site (A/V Fistula) in the right forearm for haemodialysis Study of A/V fistula with

			Tenderness: No Tenderness **Performed By**: Gastroentologist **Note**: Delay endoscopic examination)			radiographic contrast agent and another hemodialysis session.
		Has_Clinical Investigation	AD20030117100000_Admission_Day_4_Digoxin (Lab test Name: Digoxin Result Value: 2.9 Unit of measurement: g/dl)	Laboratory_Test_Finding		
			AD20030117100000_Admission_Day_4_Creatinine (Lab test Name: Serum Creatinine Result Value: 1.9 Unit of measurement: ng/ml)	Laboratory_Test_Finding		
			AD20030117100000_Admission_Day_4_Hematocrit (Lab test Name: Hematocrit Result Value: 26.4	Laboratory_Test_Finding		

			Unit of measurement: Percent (%))			
			AD20030117100000_Admission _Day_4_Creatine_Kinase_Isoen zymes (Lab test Name: Creatine Kinase Isoenzymes Result Value: 32.6 Unit of measurement: ng/ml)	Laboratory_Test_ Finding		
			AD20030117100000_Admission _Day_4_Creatine_Kinase_Isoen zyme_Index (Lab test Name: Creatine Kinase Isoenzyme Index Result Value: 7.3 Unit of measurement: percent(%))	Laboratory_Test_ Finding		
			AD20030117100000_Admission _Day_4_Feritin (Lab test Name: Feritin Result Value: 584 Unit of measurement: ng/ml)	Laboratory_Test_ Finding		
			AD20030117100000_Admission _Day_4_Creatine_Kinase	Laboratory_Test_ Finding		

			(Lab test Name: Creatine Kinase Result Value: 444 Unit of measurement: U/liter)			
			AD20030117100000_Admission _Day_4_Potassium (Lab test Name: Potassium Result Value: 5.3 Unit of measurement: mmol/liter)	Laboratory_Test_ Finding		
			AD20030117100000_Admission _Day_4_Iron (Lab test Name: Iron Result Value: 25 Unit of measurement : ug/dl)	Laboratory_Test_ Finding		
			AD20030117100000_Admission _Day_4_Iron_Binding_Capacity (Lab test Name: Iron Binding Capacity Result Value: 176 Unit of measurement : ug/dl)	Laboratory_Test_ Finding		
			AD20030117100000_Admission _Day_4_Urea_Nitrogen (Lab test Name: Blood Urea Nitrogen	Laboratory_Test_ Finding		

			Result Value: 64 Unit of measurement: mg/dl)			
			AD20030117100000_Admission _Day_4_Troponine-T (Lab test Name: Troponine-T Result Value: 3.72 Unit of measurement: ng/ml)	Laboratory_Test_ Finding		
			AD20030117100000_Admission _Day_4_Radiograph_Chest (Name of Scan: Radiograph Chest Normal Finding: • No subphrenic gas • Clear lungs Nature of scan: Diagnostic SNOMED CT Code: 56350004)	Radiology_And_ Scan_Finding		
			AD20030117100000_Admission _Day_4_Radiograph_Abdomen Normal Finding: No asymmetry to suggest obstruction	Radiology_And_ Scan_Finding		

			Abnormal Finding: Marked dilatation of both large and small bowel loops, consistent with ileus Notes: Outlines of the organs on imaging were unremarkable. Nature of scan: Diagnostic			
		Has_Interventions	AD20030117100000_Admission_Day_4_Blood_Transfusion **(Name of procedure**: Blood Transfusion **Notes**: Transfusion of 2 units of packed red cells)	Procedure		
			AD20030117100000_Admission_Day_4_Hemodialysis **(Name of procedure**: Hemodialysis **Notes:** Resume hemodialysis)	Procedure		
		Record_For_Patient	A.D (Name: A.D Age: 79 years Gender: Male)	Patient		

Instantiation of A.D Admission Day 5, Jan 21, 2003

During the fifth day of admission patient developed adnominal distension which is not associated with abdominal pain and there was no chest pain and fever. This information is captured as *Symptom_Finding* via *Has-Symptoms* in the CD-EMR Ontology and Heparin was given to the patient which is captured as medical therapy via *Has_Intervention*. Clinical examination of respiratory system reveals bilateral wheeze and abdominal examination reveals diminished bowel sounds, mild rebound tenderness, and a diffusely tender abdomen on gentle palpation. These findings were recorded in CD-EMR Ontology as *Systemic_Examination_Finding* and captured via *Has_Clinical_Examination.* Clinical investigation performed during the fifth day of admission includes Hematocrit, Urea nitrogen, Creatinine, and Potassium are captured through *Laboratory_Examination_Finding* and CT scan of the abdomen and pelvis and CT angiographic study of the mesentery are recorded through *Radiology_and_Scan_Finding* via *Has_Investigations* as shown in Figure 6- 11 Besides recording the findings of the CT scan of the abdomen and pelvis, our ontology has also recorded the image of the CT scan of the abdomen and pelvis using RDF Comment as shown in Figure 6- 12. The record of fifth day is shown in Figure 6- 11 and the details of instantiation of day five are presented in Table 6- 8.

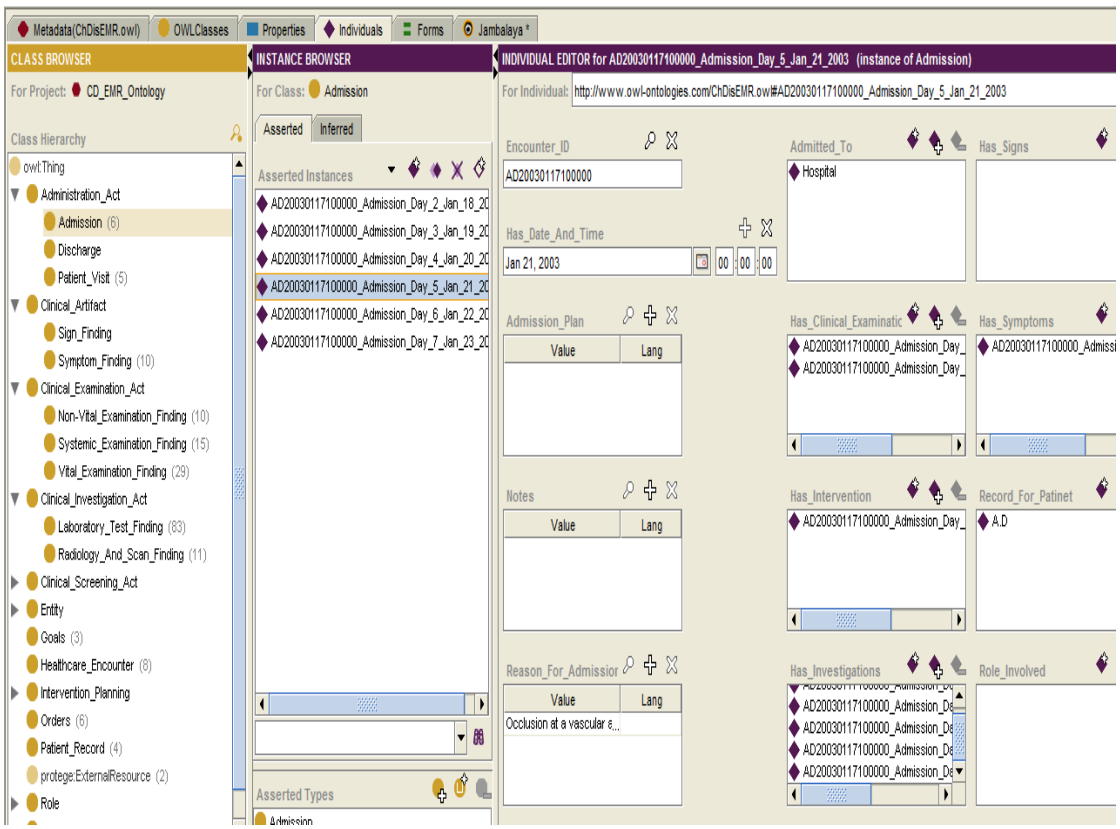


Figure 6- 11 Instantiation of A.D Admission Day 5, Jan 21, 2003

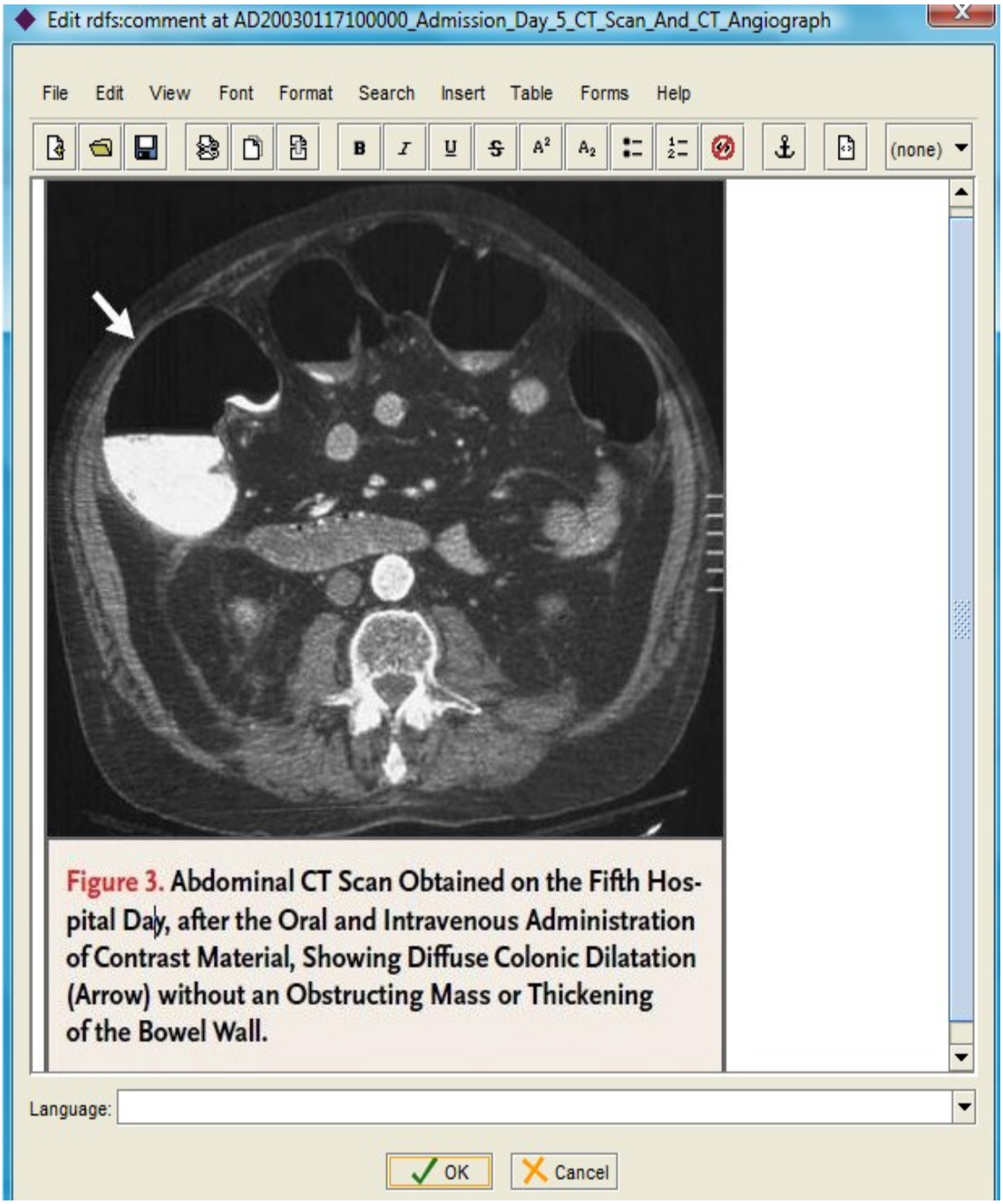


Figure 6-12 Admission day 5 image of Abdominal CT Scan captured via RDF comment in CD- EMR Ontology. Image taken from [113]

Table 6-8 Details of Instantiation of A.D Admission Day 5, Jan 21, 2003

Class	***Instances***	***Properties***				
		Object Properties			***Data-type Properties***	***Values Of Data_types***
		Property	***Value (Individual Of Other classes)***	***Individual of class***		
Admission	AD20030117100000_Admission_Day_5_Jan_21_2003	Admitted_To	Hospital	Material_Entity	Encounter_ID	AD20030117100000
		Has_Symptoms	AD20030117100000_Admission_Day_5_Abdominal_Distension (Has_Symptom : Abdominal Distension Associated Symptom: • Afebrile, • No Abdominal pain • No chest pain SNOMED CT Code: 162068007)	Symptoms_Finding	Has_Date_And_Time	Jan_21_2003
					Admission_ Plan	Radiological assessment of A/V fistula Hemodialysis Session
		Has_Clinical Examination	AD20030117100000_Admission_Day_5_Abdominal_Examination (**Name of Examination**:	Clinical_ Examination_ Act: (Systemic_Examination_ Finding)	Reason_For_ Admission	Occlusion at a vascular access site (A/V Fistula) in the right

			Abdominal Examination **Audible Sound Abnormal**: Diminished bowel sounds **Examination Finding Abnormal**: Bowel sounds are diminished **Tenderness**: Mild rebound tenderness positive Diffusely tender on gentle palpation **SNOMED CT Code**: 271911005)			forearm for haemodialysis Study of A/V fistula with radiographic contrast agent and another hemodialysis session.
			AD20030117100000_Admission_Day_5_Respiratory_Examination (**Name of Examination**: Respiratory Examination **Audible Sound Abnormal**: Wheeze **Examination Finding Normal:** No crackles **Examination Finding Abnormal:**	Clinical_ Examination_ Act: (Systemic_Examination_ Finding)		

			Bilateral Wheeze SNOMED CT Code:52653008)			
		Has_Clinical Investigation	AD20030117100000_Admission_Day_5_Creatinine (Lab test Name: Serum Creatinine Result Value: 10.1 Unit of measurement: mg/dl)	Laboratory_Test_Finding		
			AD20030117100000_Admission_Day_5_Hematocrit (Lab test Name: Hematocrit Result Value: 30.4 Unit of measurement: Percent (%))	Laboratory_Test_Finding		
			AD20030117100000_Admission_Day_5_Potassium (Lab test Name: Potassium Result Value: 3.7 Unit of measurement: mmol/liter)	Laboratory_Test_Finding		

			AD20030117100000_Admission_Day_5_Urea_Nitrogen (Lab test Name: Blood Urea Nitrogen Result Value: 38 Unit of measurement: mg/dl)	Laboratory_Test_Finding		
			AD20030117100000_Admission_Day_5_CT_Scan_And_CT_Angiograph (Name of Scan: CT Scan And CT Angiograph Normal Finding: • No evidence of obstruction • Superior mesenteric artery contained contrast material and revealed no proximal stenosis • No free intraperitoneal air, bowel-wall thickening, or	Radiology_And_Scan_Finding		

			intestinal pneumatosis Abnormal Finding: • Dilated right and transverse colon • Small amount of fluid in the paracolic gutter, adjacent to a distended cecum with a maximal diameter of 7 cm Nature of scan: Diagnostic with contrast)			
		Has_Interventions	AD20030117100000_Admission_Day_5_Medical_Therapy_Heparin Medication Name: Heparin	Medical_Therapy		
		Record_For_Patient	A.D (Name: A.D Age: 79 years Gender: Male)	Patient		

Instantiation of A.D Admission Day 6, Jan 22, 2003

During the sixth day of admission the patient developed adnominal pain which is associated with abdominal distension and tenderness. This information is captured as *Symptom_Finding* via *Has-Symptoms* in the CD-EMR Ontology. Patient received heamodialysis which is recorded as Procedure via *Has_Intervention.* On the sixth day of admission patient was ordered for N/G tube insertion and Sigmoidoscopy. The patient was unwilling to receive these treatments. This information is captured though the data types attribute *Patient_Compliance* and in this case patient was not complaint to the treatment options. Then no oral intake was permitted to the patient, this was covered as an *NPO_Order* in CD-EMR Ontology. Clinical investigation performed during sixth day of admission includes Hematocrit, White-cell count, Prothrombin time, Partial-thromboplastin time, Urea nitrogen, Creatinine, Potassium, Creatine kinase isoenzymes, and Troponine T are captured through *Laboratory_Examination_Finding* and X-Ray abdomen is recorded through *Radiology_and_Scan_Finding* via *Has_Investigations.* The record of the sixth day is shown in Figure 6-13 and the details of instantiation of day six are presented in Table 6-9.

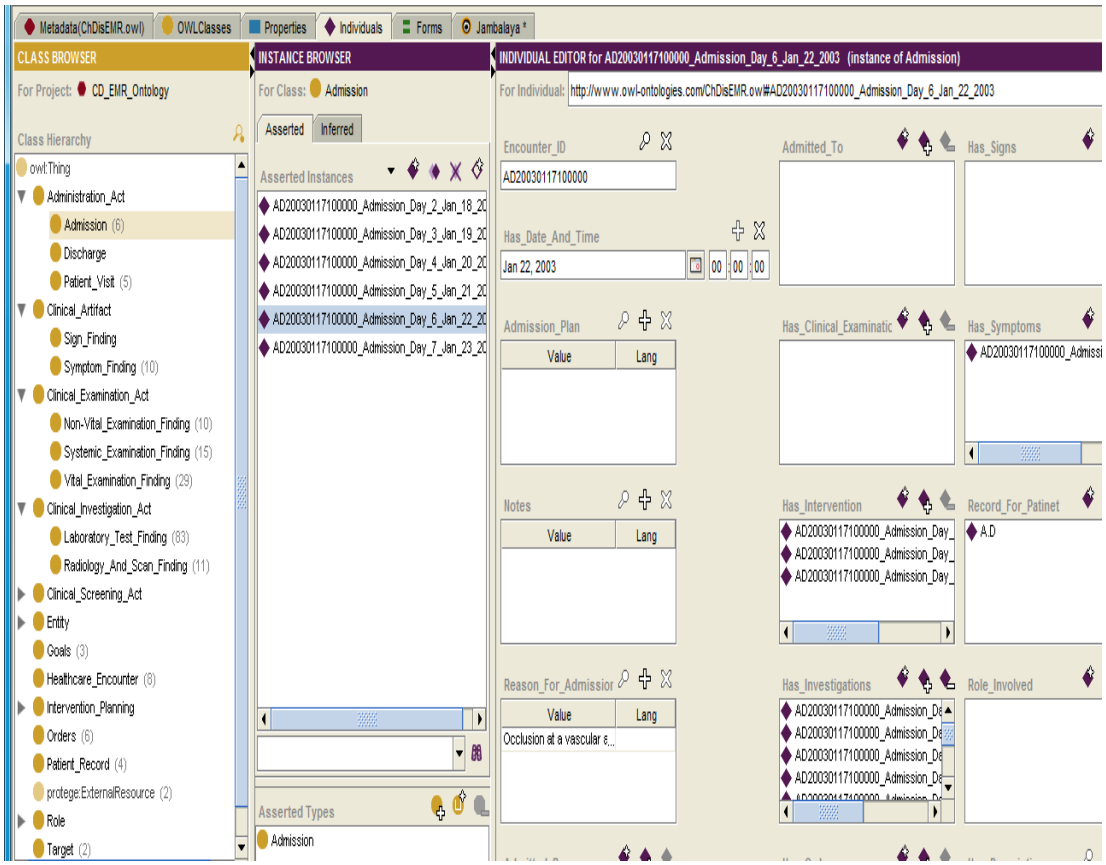


Figure 6-13 Instantiation of A.D Admission Day 6, Jan 22, 2003

Table 6-9 Details of Instantiation of A.D Admission Day 6, Jan 22, 2003

Class	***Instances***	***Properties***				
		Object Properties			***Data-type Properties***	***Values Of Data_types***
		Property	***Value (Individual Of Other classes)***	***Individual of class***		
Admission	AD20030117100000_Admission_Day_6_Jan_22_2003	Admitted_To	Hospital	Material_Entity	Encounter_ID	AD20030117100000
		Has_Symptoms	AD20030117100000_Admission_Day_6_Abdominal_Pain (Has_Symptom : Abdominal pain Associated Symptom: • Abdominal Distension • Tenderness SNOMED CT Code: 21522001)	Symptoms_Finding	Has_Date_And_Time	Jan_22_2003
					Admission_ Plan	Radiological assessment of A/V fistula Hemodialysis Session
		Has_Clinical Investigation	AD20030117100000_Admission_Day_6_Creatinine (Lab test Name: Serum Creatinine Result Value: 11.9 Unit of measurement: mg/dl)	Laboratory_Test_ Finding	Reason_For_ Admission	Occlusion at a vascular access site (A/V Fistula) in the right forearm for

			AD20030117100000_Admission_Day_6_Hematocrit (Lab test Name: Hematocrit Result Value: 30.3 Unit of measurement: Percent (%))	Laboratory_Test_Finding		haemodialysis Study of A/V fistula with radiographic contrast agent and another hemodialysis session.
			AD20030117100000_Admission_Day_6_Creatine_Kinase_Isoenzymes (Lab test Name: Creatine Kinase Isoenzymes Result Value: 7.2 Unit of measurement: ng/ml)	Laboratory_Test_Finding		
			AD20030117100000_Admission_Day_6_White-Cell_Count (Lab test Name: White-Cell Count Result Value: 12000 Unit of measurement: per mm3)	Laboratory_Test_Finding		
			AD20030117100000_Admission_Day_6_Potassium (Lab test Name: Potassium Result Value: 3.9 Unit of measurement:	Laboratory_Test_Finding		

			mmol/liter)			
			AD20030117100000_Admission_Day_6_Prothrombin_Time (Lab test Name: Prothrombin Time Ratio Result Value: 17.6 Unit of measurement: seconds)	Laboratory_Test_ Finding		
			AD20030117100000_Admission_Day_6_Partial-thromboplastin_Time (Lab test Name: Partial-thromboplastin Time Result Value: 64.8 Unit of measurement: seconds)	Laboratory_Test_ Finding		
			AD20030117100000_Admission_Day_6_Urea_Nitrogen (Lab test Name: Blood Urea Nitrogen Result Value: 47 Unit of measurement: mg/dl)	Laboratory_Test_ Finding		
			AD20030117100000_Admission_Day_6_Troponine-T (Lab test Name: Troponine-T Result Value: 6.66	Laboratory_Test_ Finding		

			Unit of measurement: ng/ml)			
			AD20030117100000_Admission_Day_6_Radiograph_Abdomen (Name of Scan: Radiograph Abdomen) Abnormal Finding: • Considerable gas throughout the colon • Dilated cecum • Paucity of gas in the small bowel Notes: • Performed in supine and upright positions. • Paucity of gas in the small bowel, which was believed to have resulted from colonic ileus rather than from bowel obstruction Nature of scan: Diagnostic)	Radiology_And_Scan_Finding		

		Has_Interventions	AD20030117100000_Admission_Day_6_Hemodialysis Name of procedure: Hemodialysis Notes: Hemodialysis was performed on day 6th of admission	Procedure		
			AD20030117100000_Admission_Day_6_Nasogastric_Tube_Insertion Name of procedure: Nasogastric Tube Insertion Medical Equipment used: N/G Tube Patient Compliance: The patient was unwilling to have a nasogastric tube placed	Procedure		
			AD20030117100000_Admission_Day_6_Sigmoidoscopy	Procedure		

			Name of procedure: Sigmoidoscopy Medical Equipment used: Sigmoidoscope Patient Compliance: The patient was unwilling to undergo flexible sigmoidoscopy Reason for procedure: Diagnostic Procedure			
		Has_Order	NPO_Order Instruction: • No oral intake permitted • Keep patient NPO	Order		
		Record_For_Patient	A.D (Name: A.D Age: 79 years Gender: Male)	Patient		

Instantiation of A.D Admission Day 7 Jan 23, 2003

During the seventh day of admission patient had adnominal pain which is associated with abdominal distension, tenderness and diarrheal stools. This information is captured as *Symptom_Finding* via *Has-Symptoms* in the CD-EMR Ontology. Clinical examination includes temperature examination (38.6 degree C) and examination of the abdomen, which reveals infrequent bowel sounds, tenderness and distension; this is recorded in CD-EMR Ontology as *Vital_Examination_Finding* and *Systemic_Examination_Finding* respectively. It is captured in the record of day seven via *Has_Clinical_Examination.* Clinical investigation performed during the seventh day of admission includes Hematocrit, White-cell count, Neutrophils, Platelet count, Mean corpuscular volume, Prothrombin time, Partial-thromboplastin time, Urea nitrogen, Creatinine, and Potassium are captured through *Laboratory_Examination_Finding* and abdominal–pelvic CT scan is recorded through *Radiology_and_Scan_Finding* via *Has_Investigations* Figure 6-14. Besides recording the findings of the CT scan of the abdomen and pelvis, our ontology has also recorded the image of CT scan of the abdomen and pelvis using RDF Comment as shown in Figure 6-15. The record of seventh day is shown in Figure 6-16 and the details of instantiation of day seven are presented in Table 6-10.

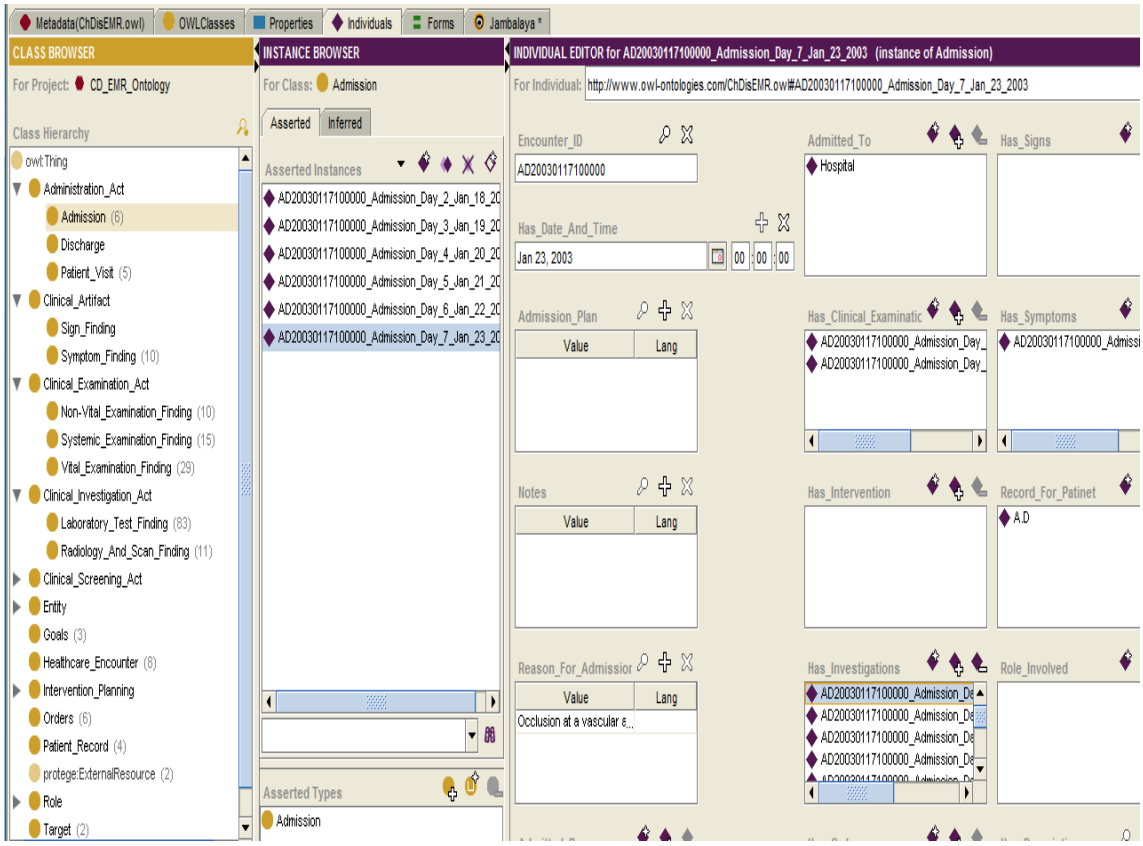


Figure 6-14 Instantiation of A.D Admission Day 7, Jan 23, 2003

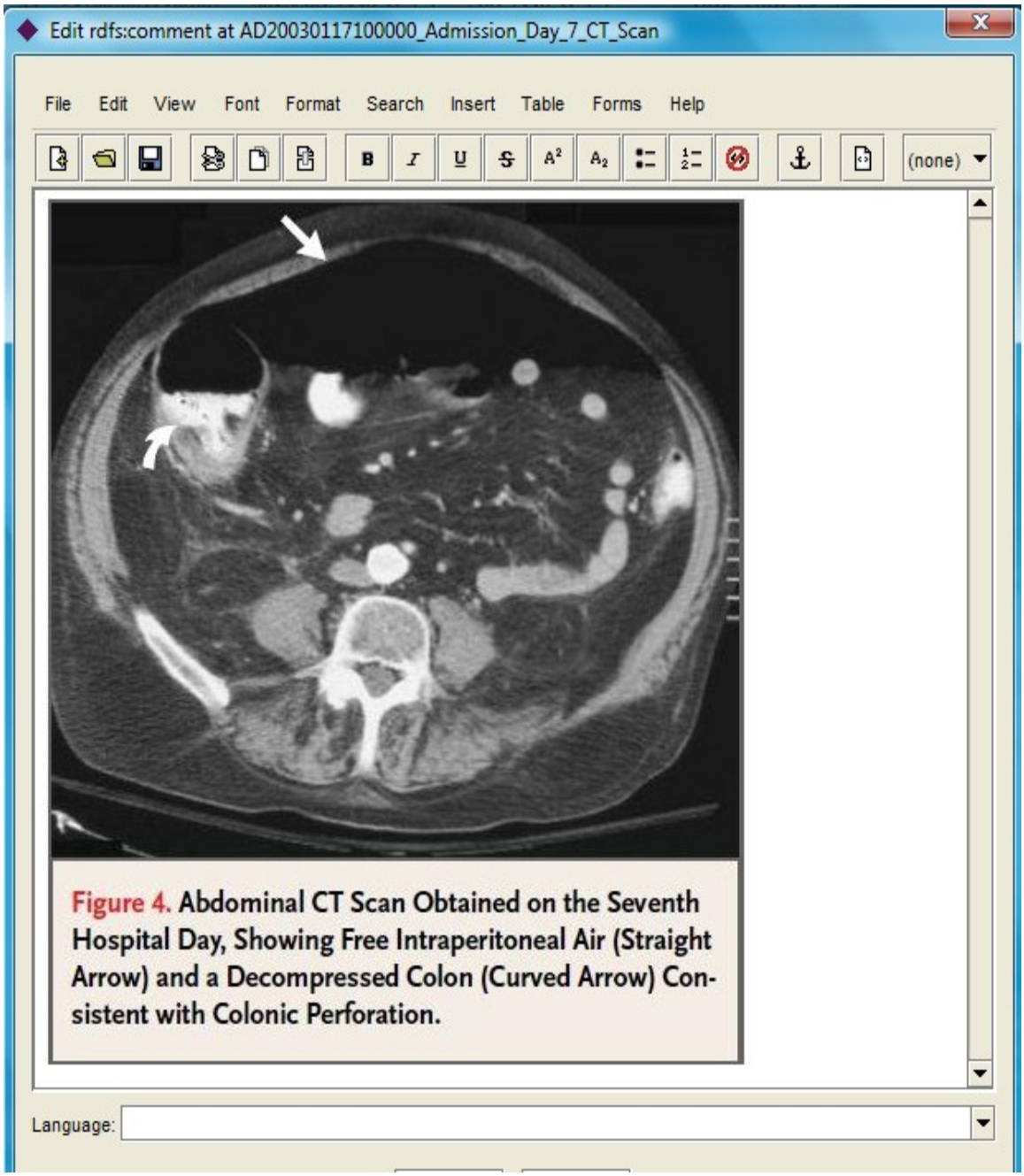


Figure 6-15 Admission day 7 image of CT scan of the abdomen captured via RDF comment in CD- EMR Ontology.

Image taken from [113]

Table 6-10 Details of Instantiation of A.D Admission Day 7, Jan 23, 2003

Class	***Instances***	***Properties***				
		Object Properties			***Data-type Properties***	***Values Of Data_types***
		Property	***Value (Individual Of Other classes)***	***Individual of class***		
Admission	AD20030117100000_Admission_Day_7_Jan_23_2003	Admitted_To	Hospital	Material_Entity	Encounter_ID	AD20030117100000
		Has_Symptoms	AD20030117100000_Admission_Day_7_Abdominal_Pain (Has_Symptom : Abdominal Pain Associated Symptom: • Abdominal Distension • Tender Abdomen • Diarrheal stools SNOMED CT Code: 21522001)	Symptoms_Finding	Has_Date_And_Time	Jan_23_2003
					Admission_ Plan	Radiological assessment of A/V fistula Hemodialysis Session
		Has_Clinical Examination	AD20030117100000_Admission_Day_7_Temperature_Examination (Name of Examination: Temperature Examination Result: 36.8 degree C	Clinical_ Examination_ Act: (Vital_Examination_ Finding)	Reason_For_ Admission	Occlusion at a vascular access site (A/V Fistula) in the right forearm for

			SNOMED CT Code: 164300005)			haemodialysis
			AD20030117100000_Admission_Day_7_Abdominal_Examination (Name of Examination: Abdominal Examination Audible Sound Abnormal: Infrequent bowel sounds Examination Finding Abnormal: Distended abdomen Tenderness: Tenderness positive SNOMED CT Code: 271911005)	Clinical_Examination_Act: (Systemic_Examination_ Finding)		Study of A/V fistula with radiographic contrast agent and another hemodialysis session.
		Has_Clinical Investigation	AD20030117100000_Admission_Day_7_Creatinine (Lab test Name: Serum Creatinine Result Value: 9.0 Unit of measurement: mg/dl)	Laboratory_Test_Finding		
			AD20030117100000_Admission_Day_7_Hematocrit (Lab test Name: Hematocrit Result Value: 33.2 Unit of measurement: Percent (%))	Laboratory_Test_Finding		
			AD20030117100000_Admission_Day_7_White_Cell_Count	Laboratory_Test_Finding		

			(Lab test Name: White Cell Count Result Value: 9000 Unit of measurement: per mm3)			
			AD20030117100000_Admission_ Day_7_Potassium (Lab test Name: Potassium Result Value: 3.6 Unit of measurement: mmol/liter)	Laboratory_Test_ Finding		
			AD20030117100000_Admission_ Day_7_Partial_Thromboplastin_Ti me (Lab test Name: Partial Thromboplastin Time Result Value: 70.7 Unit of measurement: seconds)	Laboratory_Test_ Finding		
			AD20030117100000_Admission_ Day_7_Potassium (Lab test Name: Potassium Result Value: 3.6 Unit of measurement: mmol/liter)	Laboratory_Test_ Finding		
			AD20030117100000_Admission_ Day_7_Prothrombin _Time	Laboratory_Test_ Finding		

			(Lab test Name: Prothrombin Time Result Value: 19.4 Unit of measurement: Seconds)			
			AD20030117100000_Admission_ Day_7_Pletelet (Lab test Name: Pletelet Result Value: 273,000 Unit of measurement : per mm3)	Laboratory_Test_ Finding		
			AD20030117100000_Admission_ Day_7_Urea_Nitrogen (Lab test Name: Blood Urea Nitrogen Result Value: 33 Unit of measurement: mg/dl)	Laboratory_Test_ Finding		
			AD20030117100000_Admission_ Day_7_Neutrophils (Lab test Name: Neutrophils Result Value: 82 Unit of measurement: percent)	Laboratory_Test_ Finding		
			AD20030117100000_Admission_ Day_7_CT_Scan	Radiology_And_ Scan_Finding		

			(Name of Scan: CT Scan Normal Finding: • Sigmoid diverticula were present, without diverticulitis • Oral contrast material flowed to the rectum without extravasation • No site of perforation was identified • Minimal thickening of the ascending colon and cecum Abnormal Finding: • Free intraperitoneal air anteriorly • Smaller air bubbles in the fat and elsewhere in the middle and upper portions of the abdomen Nature of scan: Diagnostic Notes: • Abdominal– pelvic CT			

			Scan • CT Scan with oral and intravenous administration of contrast material			
		Record_For_Patient	A.D (Name: A.D Age: 79 years Gender: Male)	Patient		

6.2.2.2 CLINICAL SCENARIO II

Now we will use a clinical scenario which is written in HL7 V3. This medical scenario was proposed by HL7 Continuity of Care Record work group. Besides evaluation, instantiation of this medical scenario in our CD-EMR Ontology will further strengthen our claim that our ontology is semantically interoperable and is fully compliant with HL7 v3. The case summary is given below and the instantiation is presented in the subsequent part of the chapter.

CASE SUMMARY

Henry Leven the Seventh, a 67 years male patient with DOB Sept 24, 1932, was referred to Good Health Clinic on 7th April, 2000 for further asthma management. Patient is a diagnosed case of Asthma, Hypertension, and Osteoporosis right knee. During that encounter, the responsible clinician Dr Robert Dolin MD, performed the clinical examination including BP, Pulse, temperature, height weight etc; screened patient's medical, surgical, personal and allergy history, and provide medical treatment such as HCTZ, prednisone, Proventil etc. PTF was ordered, prednisone is decreased to 20qOD alternating with 18qOD and patient was advised to visit after 1 week [114].

Instantiation of Henry Leven Patient Record in CD-EMR Ontology

The case of Henry Leven consists of a single referral visit. It is captured in CD-EMR Ontology as the healthcare encounter. The information about the patient such as name, DOB, age is recorded in the class *Patient*. The information about the responsible clinician is recorded in the class *Health_Related_Role*. The information about the place of healthcare encounter is recorded in the class *Material_Entity*. The results of clinical investigations and clinical examinations are recorded using the classes *Clinical_Invetigation_Act* and *Clinical_Examination_Act*. The therapy section of the medical record is maintained in class *Medical_Therapy* and *Procedure*. The order of investigation for next visit is captured in the class order and the next visit in class *Patient_Visit*. The patient record is shown in Figure 6-16 and presented in Table 6-11. The healthcare encounter is shown in Figure 6-17 and the details of encounter are presented in Table 6-12.

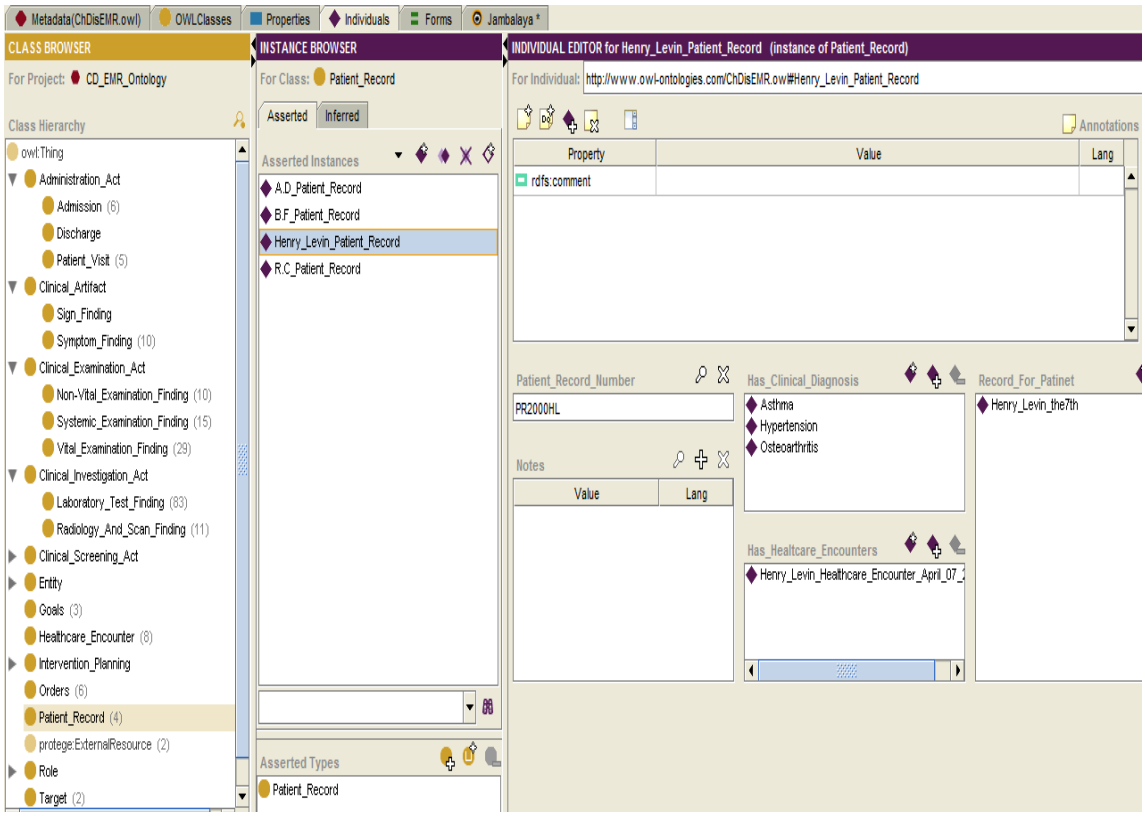


Figure 6-16 Patient Record of Henry Levin the 7th

Table 6-11 Instantiation of Patient Record of Henry Levin the 7th.

Class	Instances	Properties		Values
		Object Properties	Data-type Properties	
Patient Record	Henry_Levin_Patient_Record	Has_Clinical_Diagnosis		Asthma Hypertension Osteoarthritis
		Has_Healthcare_Encounters	Henry_Levin_Healthcare_Encounter_April_	

			07_2000	
		Record_For_Patient		Henry Levin the 7th
			Patient_Record_Number	PR2000HL
			Notes	

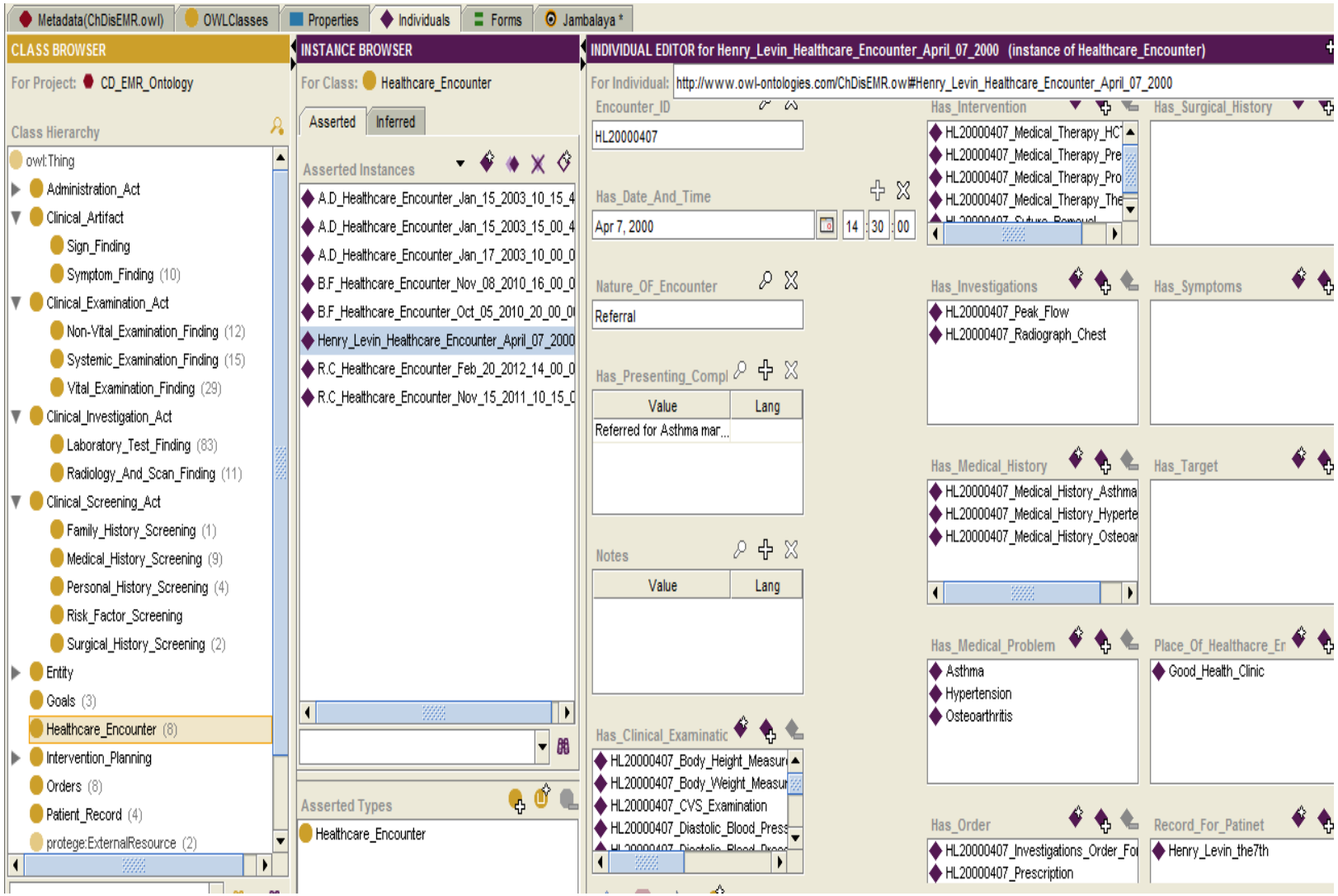


Figure 6-17 Instantiation of Healthcare Encounter of Henry Levin the 7th on April 07 2000

Table 6-12 Details of Instantiation of Healthcare Encounter of Henry Levin the 7th on April 07 2000

Class	***Instances***	***Properties***				
		Object Properties			***Data-type Properties***	***Values Of Data_types***
		Property	***Value (Individual Of Other classes)***	***Individual of class***		
Healthcare_ Encounter	Henry_Levin_Healthcare_Encounter_April_07_2000	Has_Medical_ Problem	Asthma Hypertension Ostearthritis	Medical_Problems	Encounter_ID	HL20000407
		Has_Medical_History	HL20000407_Medical_History_Asthma (Has_Disease: Asthma Age at onset: 18 years Notes: Since 1950 SNOMED CT Code: 84100007)	Medical_History_ Screening	Has_Date_And_Time	April_07_2000
			HL20000407_Medical_History_Hypertension (Has_Disease: Hypertension SNOMED CT Code: 84100007)	Medical_History_ Screening		
			HL20000407_Medical_History_Osteoarthritis (Has_Disease: Osteoarthritis Notes: Osteoarthritis Right knee	Medical_History_ Screening		

			with laterality SNOMED CT Code: 84100007)			
		Has_ Personal_ History	HL20000407_Personal_History_Allergy_And_Adverse_Reaction (Offending_Agent: • Penicillin • Aspirin • Codeine Type of allergic reaction: • Penicillin causes hives • Aspirin causes wheezing • Codeine causes nausea and itching SNOMED CT Code: 84100007)	Personal_History_ Screening	Nature_Of_ Encounter	Referral
			HL20000407_Personal_History_Smoking_And_Alcohol (Alcohol Intake: True No. of drinks: • Less than one per day • Trivial drinker Smoking: True No. Of Cigarettes per day: • Smoke 20 to 30 cig per day	Personal_History_ Screening		

			• Ex heavy cigarette smoker SNOMED CT Code:84100007 229819007 (Smoking) 160573003 (Alcohol Intake)			
		Has_ Family_ History	HL20000407_Family_History_MI (Relationship with patient: Father Has Disease: Myocardial Infraction Age at onset: early 50's Duration of disease: since 1970 Notes: • Father had fetal MI in early 50's • No family history of cancers or diabetes SNOMED CT Code:84100007)	Family_ History _Screening		
		Has_Clinical Examination	HL20000407_Temperature_Examination_Apr_07_2000_14_30_00 (Results: 36.9 C [98.5 F] SNOMED CT Code: 164300005)	Clinical_ Examination_ Act: (Vital_Examination_ Finding)		
			HL20000407_Temperature_Examination_Apr_07_2000_15_30_00 (Results: 36.9 C [98.5 F]	Clinical_ Examination_ Act:		

			SNOMED CT Code: 164300005)	(Vital_Examinati on_ Finding)		
			HL20000407_Respiratory_Rate_ Examination_Apr_07_2000_14_3 0_00 (Results: 16 per minute Notes: Unlabored Breathing SNOMED CT Code: 86290005)	Clinical_ Examination_ Act: (Vital_Examinati on_ Finding)		
			HL20000407_Respiratory_Rate_ Examination_Apr_07_2000_15_3 0_00 (Results: 14 per minute SNOMED CT Code: 86290005)	Clinical_ Examination_ Act: (Vital_Examinati on_ Finding)		
			HL20000407_Pulse_Examination_ Apr_07_2000_14_30_00 (Result: 86 per minutes Rhythm: regular SNOMED CT Code: 364075005)	Clinical_ Examination_ Act: (Vital_Examinati on_ Finding)		
			HL20000407_Pulse_Examination_ Apr_07_2000_15_30_00 (Result: 84 per minutes Rhythm: regular SNOMED CT Code: 364075005)	Clinical_ Examination_ Act: (Vital_Examinati on_ Finding)		
			HL20000407_Systolic_Blood_Pre	Clinical_		

			ssure_Examination_Apr_07_2000 _14_30_00 (Results: 132 mmHg Site of examination: Left Arm Note: Cuff Blood pressure SNOMED CT Code: 271649006)	Examination_ Act: (Vital_Examinati on_ Finding)		
			HL20000407_Systolic_Blood_Pre ssure_Examination_Apr_07_2000 _15_30_00 (Results: 135 mmHg Site of examination: Left Arm Note: Cuff Blood pressure SNOMED CT Code: 271649006)	Clinical_ Examination_ Act: (Vital_Examinati on_ Finding)		
			HL20000407_Diastolic_Blood_Pr essure_Examination__Apr_07_20 00_14_30_00 (Results: 86 mmHg Site of examination: Left Arm Note: Cuff Blood pressure SNOMED CT Code: 271650006)	Clinical_ Examination_ Act: (Vital_Examinati on_ Finding)		
			HL20000407_Diastolic_Blood_Pr essure_Examination__Apr_07_20 00_14_30_00 (Results: 88 mmHg	Clinical_ Examination_ Act: (Vital_Examinati		

			Site of examination: Left Arm Note: Cuff Blood pressure SNOMED CT Code: 271650006)	on_ Finding)		
			HL20000407_Body_Height_Measure_Apr_17_2000_14_30_00 (Results: 1.77 m SNOMED CT Code: 50373000)	Clinical_ Examination_ Act: (Non-Vital_Examination_ Finding)		
			HL20000407_Body_Weight_Measure_Apr_17_2000_14_30_00 (Results: 88 kg (194 lb) SNOMED CT Code: 363808001)	Clinical_ Examination_ Act: (Non-Vital_Examination_ Finding)		
			HL20000407_Skin_Examination_Apr_17_2000_00_00_00 (Examination finding abnormal: Erythematous Rash Site of examination: Palmer surface of left index figure. Results: Erythematous Rash on the palmer surface of left index figure. SNOMED CT Code : 48856004)	Clinical_ Examination_ Act: (Non-Vital_Examination_ Finding)		
			HL20000407_CVS_Examination (Audible sound abnormal: 3rd heart	Clinical_ Examination_		

			sound Examination finding normal: Fourth Heart Sound (S4) Inaudible Examination finding abnormal: Heart murmur SNOMED CT Code: 364066008)	Act: (Systemic_Examination_ Finding)		
			HL20000407_Respiratory_Examination (Audible sound abnormal: Wheezing Examination finding abnormal: Wheeze Site of examination: lungs SNOMED CT Code: 52653008)	Clinical_ Examination_ Act: (Systemic_Examination_ Finding)		
		Has_Clinical Investigation	HL20000407_Peak_Flow (Results: 260 l/m SNOMED CT Code: 313193002)	Laboratory_Test_ Finding		
			HL20000407_Radiograph_Chest (Normal Findings: Clear chest Normal cardiac silhouette Abnormal Findings: Chest Hyper-inflated	Radiology_And_ Scan_Finding		

			SNOMED CT Code: 56350004)			
		Has_Interventions	HL20000407_Medical_Therapy_HCTZ (Medication Name: HCTZ Drug Strength: 25 mg Dose: once a day [qd] Route: Per oral [PO])	Medical_Therapy		
			HL20000407_Medical_Therapy_Prednison (Medication Name: Prednison Drug Strength: 20 mg Dose: once a day [qd] Route: Per oral [PO])	Medical_Therapy		
			HL20000407_Medical_Therapy_Proventil (Medication Name: Proventil Drug Strength: 0.6 units Dose: QID 2 puffs Instruction: Proventil inhaler 2 puffs QID PRN Route: Inhalation	Medical_Therapy		
			HL20000407_Medical_Therapy_Theodur	Medical_Therapy		

			(Medication Name: Theodur Drug Strength: 200 mg Dose: BID Route: Per oral [PO])			
			HL20000407_Suture_Removal (Name of procedure: Suture removal Notes: Suture Removal from left forearm	Procedure		
		Has_Order	HL20000407_Investigations_Order_For_Next_Visit (Has Investigation Name: Pulmonary Function Test Instructions: Complete PTFs with lung volumes)	Order		
			HL20000407_Prescription (Medication_Name: • Hydrocortisone • Predsone Instruction: • Hydrocortisone cream to figure BID. Route :Topical application	Order		

			• Prednisone 20 qOD alternating with 18 qOD. Route: PO			
		Place_Of_Healthcare_Encounter	Good Health Clinic (Has Description: General Internal Medicine Clinic)	Material_Entity		
		Record_For_Patient	Henry_Levin_the7th Name: Henry_Levin_the7th Gender: Male DOB: Sept 24, 1932 Treated By: Robert_Dolin_MD	Patient		
		Scheduled_Next_Visit	HL20000407_Follow_up_Visit (Scheduled Date and time of next visit: Apr 14, 2000 Nature Of Visit: Follow-up Place of healthcare encounter: Good Health Clinic Visit Type: Scheduled Has Description: RTC in 1 week)	Patient_Visit		

6.2.3 RESULTS OF EVALUATION

Results of step I*:* We evaluated our ontology using Pellet for taxonomy and any inconsistency. The results of reasoner show no flaw in taxonomy or any inconsistency in our ontological framework. Besides using the reasoner we have also evaluated the ontological framework against the ontology design principle proposed by Bordenreider et at [96] , and we found that our ontology is compliant with the design principles.

Results of step II. In this step we have instantiated a clinical scenario and an HL7 V3 message in our ontology. The clinical scenario consisting of three episodes and a seven day hospital stay presents a longitudinal patient record. Our ontology captured the longitudinal patient record in a systemic manner. Moreover, we have instantiated an HL7 V3 message in our ontology. During the process of ontology engineering we have used the HL 7 RIM classes and data types attribute in our CD-EMR Ontology, which helped us in successful instantiation of HL7 v3 message.

On the basis of evaluation results we can conclude that our EMR system posses a consistent ontological framework and can maintain longitudinal medical record in a semantically interoperable manner.

6.3 DISCUSSION

In this chapter we have evaluated our CD-EMR Ontology using the designed evaluation schema, in which we have evaluated our ontology (a) against Ontology design principles, (b) technically using reasoner Pellet, and (c) using clinical scenarios to evaluate the captured knowledge. During the evaluation process the CD-EMR Ontology is exposed to diverse and heterogeneous patient data of multiple episodes. These episodes include the scheduled patient visit, such as follow-up visits and referrals, and the ontology also captures the unscheduled and emergency visits. The instantiation results showed that our ontology has successfully captured the heterogeneous patient data from multiple sources, such as laboratory test results; radiology and scan findings; different aspects of patient history, which include medical, surgical, personal and family history; various sign and symptoms; and different types of therapies and procedures. By capturing this information

from multiple healthcare-encounters our ontology successfully maintained the longitudinal medical record. Moreover, the notion of patient centeredness is also captured in the ontology through patient compliance. An example is the case of A.D. The patient was ordered for needed N/G tube insertion and endoscopy, but he refused to receive these treatment options. Then the ontology successfully captured this information through the data-type attribute *Patinet_Compliance*. Then an alternative option was used and an order was given to keep the patient NPO, which is also successfully covered through the class Orders. Beside the successful instantiation of clinical scenarios and captured knowledge, at this stage our ontology cannot provide alerts and reminder and can only be used by system experts. These limitations are discussed in detail in Chapter 7.

6.4 CONCLUSION

A detailed ontology evaluation has been performed, which thoroughly evaluated the CD-MR ontological framework in a multidimensional manner. The designed evaluation schema evaluated the CD-EMR Ontology structurally, functionally, on the basis of captured knowledge, and for semantic interoperability. Results of ontology evaluation have validated our claims: (a) CD-EMR Ontology possess a sound technical structure, (b) CD-EMR Ontology is according to the design principle of Bordenreider et al. [96], (c) CD-EMR Ontology can successfully handle the heterogeneous patient data, and provide a mean for systemic data storage and retrieval, and (d) CD-EMR Ontology serves as an environment which can maintain a longitudinal and patient centric medical record in a semantically interoperable format.

CHAPTER 7: CONCLUSION

7.1 INTRODUCTION

In the previous chapters we have discussed our research work, in which we have outlined our motivations, goals, and objectives to pursue this research. Furthermore, we have discussed the rationale and adapted methodology to develop CD-EMR Ontology, highlighted the different aspects of Chronic Disease Management (CDM) process and captured these processes of CDM in our ontology. We also instantiated a set of use cases and the HL7 v3 message using CD-EMR Ontology and performed the technical evaluation using Pellet and the principles proposed by Bodenreider et al [96]. At the end of successful completion of the developmental processes and evaluation of CD-EMR Ontological framework, we anticipate that our ontology successfully presents an EMR model that is semantically interoperable and supports the longitudinal care process of CDM. It is a well known fact that research is an ongoing phenomenon. Although we have achieved our goals and objectives in this research, still there are certain limitations and future directions for our work. In the subsequent section of this conclusive chapter we will discuss the achievements, limitations, and future directions related to our work.

7.2 ACHIEVEMENTS

We believe that we have achieved the intended goal of our research. The achievements of our research work include (a) CDM Knowledge Model, (b) a well integrated and comprehensive model of EMR for CDM in the form of CD-EMR Ontology, and (c) the achievement of semantic interoperability through CD-EMR Ontology.

(a) CDM Knowledge Model

We have successfully captured the holistic care process of CDM in our conceptual model. The process of CDM is modeled using the empirical and medical knowledge. Our knowledge model represents the various aspects of the care process provided to the patient when the patient enters into the healthcare facility. These aspects are represented as concepts in the knowledge model, including the details of healthcare encounter, patient history, GPE, investigations, multiple

treatment options (both medical and behavioral options), and the longitudinal nature of the care process using the notion of follow-up, referral, or reconsultation. The knowledge model successfully captures the processes, such as workflow and the information flow, when the patient moves across or within healthcare facilities.

(b) Ontological Framework for Chronic Disease Management as CD-EMR ontology.

As the knowledge model successfully captured the holistic care process of CDM, we formalize this model to develop the CD-EMR ontology. The ontology engineering is done using the formal model and the elements from the standard models, which are CPR Ontology, and HL7 RIM. Therefore, the ontological framework is structurally comprehensive and functionally coherent with the standard models, CPR Ontology and HL7 RIM. At each step of development, ranging from conceptual model to CD-EMR Ontology engineering, we validate the evolving prototypes to ensure the comprehensiveness and functionality, and to eliminate the knowledge gaps during modeling and development. The resultant outcome is therefore a comprehensive and well structured knowledge-based ontology framework.

We anticipate that our CD-EMR ontology will be used for systemic data storage and retrieval. The design of CD-EMR ontology is based on advanced knowledge management approaches, specifically semantic web, which accounts for a knowledge-mediated and process-oriented solution for storage of patient information. Therefore, CD-EMR ontology can handle the heterogeneous data of patients with chronic illnesses, and at the same time provides a platform to serve as an EMR for acute, emergency, and co-morbid conditions. The temporal aspect of acute and emergency conditions is captured using the data type attribute “date and time” with the classes and subclasses

of CD-EMR Ontology where necessary. The longitudinal care process is covered by the class *Next_Vist* and the patient centeredness is achieved using the data type attribute *Patient_Compliance* to the treatment. Furthermore, CD-EMR ontology is also integrated with controlled vocabulary such as SNOMED CT.

(c) Semantic Interoperability

It is a well known fact that ontology supports semantic interoperability [112]. Therefore, we have adapted ontology as our model to develop the EMR for CDM. Moreover, we incorporated the CD-EMR Ontology with the data types attribute of HL7 V3 and successfully instantiated HL7 V3 based message (clinical use case). Thus, our ontological framework presents a semantically interoperable environment for systemic data storage and retrieval.

7.3 LIMITATIONS AND FUTURE DIRECTIONS

Despite the fact that we have achieved our intended goals and objectives, our research work still has some limitation which can be addressed in future. These limitations and future directions are discussed below.

(a) Mapping Process

The conceptual mapping among the CDM, CPR and HL7 V3 was performed manually using domain knowledge. It would be worthwhile to apply some pre-existing mapping algorithms and tools to explore the mapping results.

(b) Alerts and reminders

Alerts and reminders are an important functionality of EMR. Although our EMR model has all possible information to generate these alerts and reminders, the need is to integrate this information. We have also proposed the mechanism of generating the alerts and reminders. The mechanism works by comparing two pieces of information or data

elements. For example, our ontology has captured the normal ranges of each investigation through the data type attributes. When the patient data regarding the investigation is entered into the ontology there must be an algorithm or rule-based execution engine to compare the two values and generate an alert if the value of investigation is above or below the normal range, as shown in Figure 7-1. Similarly the alerts can be generated by comparing the captured knowledge in the ontology and the input of patient specific information regarding drug contraindications, allergic or adverse reactions, and route of excretion. Moreover, the similar mechanism can also be used to generate reminders about whether the patient has shown compliance with the treatment regimen given in past or whether the prescribed drug has some addiction potential with the specific patient and some alternate has to be used. Some examples of alerts and reminders are shown in Figure 7-1.

(c) Execution Engine and User interface.

CD-EMR ontology serves as a knowledge base for storing information in a systemic and semantically interoperable manner. It provides the back end schema and information model for electronic data storage. At this stage the CD-EMR ontology can be used by system experts. In order to integrate the information and to achieve a user friendly environment for data entry and retrieval, there is a need to develop an execution engine and friendly User Interface (UI). Developing the execution engine or UI is out of the scope of our research. But we suggest that by using the expertise of a software developer, one can easily develop the execution engine and the UI on the top of our Knowledge base CD-EMR Ontology.

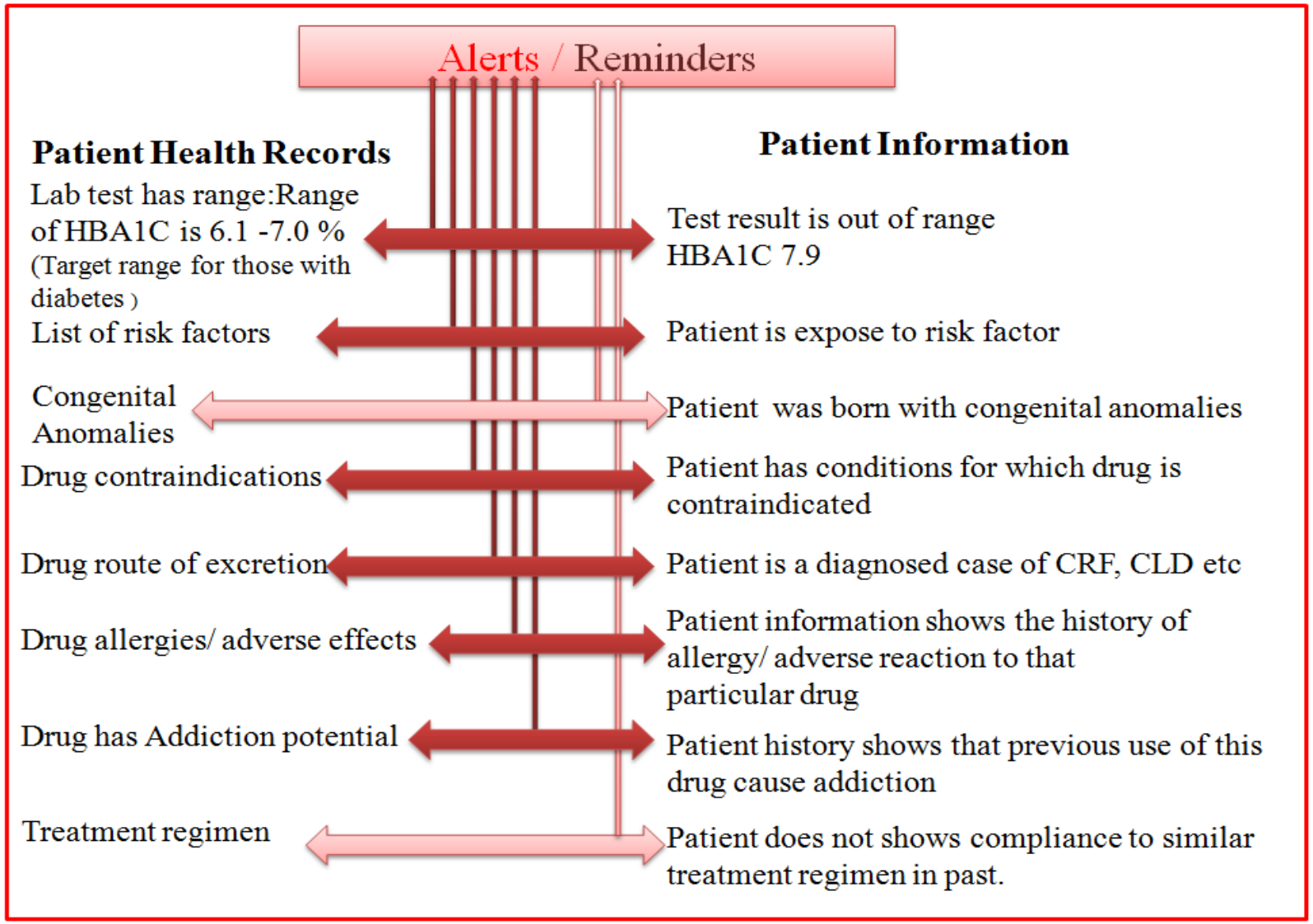


Figure 7-1 Generation of Alerts and Reminders using knowledge form CD-EMR Ontology and patient specific information

7.4 CONCLUSION

The starting point of our research was to explore the process of CDM and then conceptualize it as a model of EMR for chronic disease management. With this simple concept we had entered into the diverse fields of information technology and complex corpus of health care domain in search of a solution. Our journey begins with the extensive review of literature to develop an understanding of the domain. This effort unfolded several diverse aspects of chronic diseases and the processes of CDM, and at the same time helped us in selection of literature sources to abstract the fundamental concepts and core elements of CDM. Using knowledge management approach we had successfully used the abstracted knowledge to develop our conceptual model. After model formalization and implementation we have achieved our research objective which is to develop a comprehensive framework of EMR to support CDM in a semantically interoperable manner.

We believe our CD-EMR ontology provides a patient centric, longitudinal, and semantically interoperable platform to store patient information. The diverse evaluation of CD-EMR ontology further strengthens the claim that CD-EMR ontology is a comprehensive environment and can support the heterogeneous patient information, controlled vocabularies such as SNOMED-CT, and HL7 V3 messages. The intended goal was to cover CDM, but we have used CPR ontology which is based on POMR standard so our ontology can successfully capture the information of acute diseases and co-morbid conditions.

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