Fall 12-21-2010

Formalizing a Conceptual Framework of Work Domain Knowledge

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Dissertation

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11/24/2010

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A
Dissertation
Presented to the Faculty of
The University of Texas
Health Science Center at Houston
School of Biomedical Informatics
in Partial Fulfillment
of the Requirements

for the Degree of

Doctor of Philosophy

by

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Dedication Page

To my family with thanks for a lifetime of love and support

Abstract

Background: The failure rate of health information systems is high, partially due to fragmented, incomplete, or incorrect identification and description of specific and critical domain requirements. In order to systematically transform the requirements of work into real information system, an explicit conceptual framework is essential to summarize the work requirements and guide system design. Recently, Butler, Zhang, and colleagues proposed a conceptual framework called Work Domain Ontology (WDO) to formally represent users' work. This WDO approach has been successfully demonstrated in a real world design project on aircraft scheduling. However, as a top level conceptual framework, this WDO has not defined an explicit and well specified schema (WDOS) , and it does not have a generalizable and operationalized procedure that can be easily applied to develop WDO. Moreover, WDO has not been developed for any concrete healthcare domain. These limitations hinder the utility of WDO in real world information system in general and in health information system in particular.

Objective: The objective of this research is to formalize the WDOS, operationalize a procedure to develop WDO, and evaluate WDO approach using Self-Nutrition Management (SNM) work domain.

Method: Concept analysis was implemented to formalize WDOS. Focus group interview was conducted to capture concepts in SNM work domain. Ontology engineering methods were adopted to model SNM WDO. Part of the concepts under the primary goal "staying healthy" for SNM were selected and transformed into a semi-structured survey to evaluate the acceptance, explicitness, completeness, consistency, experience dependency of SNM WDO.

Result: Four concepts, "goal, operation, object and constraint", were identified and formally modeled in WDOS with definitions and attributes. 72 SNM WDO concepts under primary goal were selected and transformed into semi-structured survey questions. The evaluation indicated that the major concepts of SNM WDO were accepted by 41 overweight subjects. SNM WDO is generally independent of user domain experience but partially dependent on SNM application experience. 23 of 41 paired concepts had significant correlations. Two concepts were identified as ambiguous concepts. 8 extra concepts were recommended towards the completeness of SNM WDO.

Conclusion: The preliminary WDOS is ready with an operationalized procedure. SNM WDO has been developed to guide future SNM application design. This research is an essential step towards Work-Centered Design (WCD).

Acknowledgements

Over the five and half years at the School of Biomedical Informatics, University of Texas at Houston, I have benefited from many people during my graduate studies, and this dissertation would not have come to fruition without the guidance of my committee, and the help and support from my friends and family.

First of all, I would like to express my deep gratitude to my advisor, Dr. Jiajie Zhang, for the inspiration, the guidance, and the encouragements he has shown along the way. He has had the greatest influence on my academic life. My appreciation also goes to my committee members, Drs. Todd R. Johnson, Kim Dunn, Crag W. Johnson, Amy Franklin and Muhammad F. Walji for their valuable comments and suggestions which have contributed to improving this dissertation. I would also like to extend my thanks to Dr. James P. Turley, who has been helpful during various stages of my studies.

There is no way to measure the help, support, and kindness from my fellow students and friends, with whom the interactions have contributed greatly to my study. My special thanks go to Drs. Yang Gong, ChuanTao Jiang and Leeyean Wong.

Last but not the least, I consider myself fortunate to be extremely blessed with my beloved family. None of this would have been possible without the love and support from my family. My very special thanks go to my mother, Yuling Guo, who has dedicated everything to my life. I am also hugely indebted to my wife Chuzhi Yin. She has always been on my side, supporting and cheering me up with love and care.

Finally, I appreciate the financial support from Dr. Jiajie Zhang that funded the research discussed in this dissertation.

Table of Contents

List of Figures

List of Tables

Vita, Publications and Field of Study

PhD in Health Informatics, University of Texas	2005.9-2010.12
MSc in Medical Informatics, Erasmus University Rotterdam, the Netherlands	2003.8-2004.7
MD in Clinical Medicine, Medical College, Southeast University China	1998.8-2003.7

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Field of Study

Health Informatics

Introduction

According to 2009 Standish CHAOS report regarding over 15,000 nationwide software projects, 44% of the projects were challenged by overdue, over budget, or did not meet promised functionality, 24% of the projects were canceled or never used (Standish Group, 2009). The failure rate is even greater for healthcare projects such as Electronic Health Records (EHR) due to the domain complexity (Kaplan & Shaw, 2002) (Zhang J. , 2005) (Sittig, Kuperman, & Fiskio, 1999) (Berg, 2001). Further survey revealed that 61% of these failures happened in the requirement analysis and design stages in information system lifecycle (Mcmanus & Wood-Harper, 2004). The issue to systematically address the essential requirements of users' daily work and seamlessly turn these requirements into a successful design remains a challenge (Goddard, 2007).

Why Study Usefulness Conceptual Modeling in Health Care System Design?

A successful system design from a problem space to its solution space requires the system to be both useful and usable (Helander, Landauer, & Prabhu, 1997) (Zhang & Butler, UFuRT: A work-centered framework and process for design and evaluation of information systems, 2007). Usefulness means that the system can actually help people accomplish their work in valuable ways (Helander, Landauer, & Prabhu, 1997). Usefulness is essential because it is invariant with respect to work context, application technology, or cognitive architecture. If the implemented system does not meet usefulness requirement, the technology adopted in the system will fail, regardless of its large collection of functionalities, fancy and cutting-age features, and purely technical merits (Zhang & Bulter, Design models for interactive problem-solving: context & ontology, representation & routines., 2009).

Three coordinated steps are necessary to transform usefulness from requirement to final information system: 1) acquisition of requirement, 2) specification of requirement, 3) and implementation of requirement. Among these three steps, a conceptual framework is essential to assist the specification of work domain and guide usefulness design and implementation around the work domain. Recently, Butler, Zhang, and colleagues proposed WDO as a new conceptual framework to model work. WDO is defined as "an explicit, abstract, implementation-independent description of essential requirements of work." (Butler, Zhang, Esposito, Bahrami, Hebron, & Kieras, 2007). However, three existing limitations hinder the promotion of WDO in information system design: 1) WDOS has not been explicitly and formally identified and described. 2) The operationalized procedure has not been created to apply WDOS to a specific domain. 3) A concrete demonstration of WDO in a real clinical domain has not been developed.

Theoretical Background

The research motivation here primarily arises from distributed cognition that reveals the necessity to identify work distributed across human minds (internal), external cognitive artifacts (external), groups of people, and across space and time (Hutchins, 1996). The concepts of WDOS are selected from classic economics view of production. The essential principle regarding how to study a system derives from general system theory. Ontology engineering methods provide concrete step-by-step processes to develop a WDO.

Goal of Study

The purpose of this study included three parts: 1) to formalize the WDOS; 2) to operationalize a procedure to develop WDO; 3) to evaluate WDO approach using a concrete domain. SNM was selected as the applied domain.

The contribution of this study can be summarized into three levels. At the theoretical level, an explicit WDOS will be defined to support the future development of WDO in different work domains. At the practical level, a major contribution will be to demonstrate the operational procedure how SNM WDO is developed. At the clinical level, SNM WDO will be helpful for the future development of SNM applications. The fundamental contribution of this research will facilitate and support WCD.

Organizations of Dissertation

The dissertation is organized as follows. Chapter 1 provides a review of the literature regarding previous researches towards usefulness. Chapter 2 provides the theoretical analysis for the conceptualization of WDO. Chapter 3 provides a detailed description of current limitation of SNM in obesity management. Chapter 4 delineates the preliminary study of WDO in time management domain. Chapter 5 depicts experimental designs and the procedure for acquiring data. Chapter 6 contains a summary of the data collected, the statistical methods employed to analyze the data, and the major results obtained. Chapter 7 is intended to be a discussion section which includes significant findings and their implications, and an acknowledgement of the limitations of the study as well as suggestions for future research. Finally, Chapter 8 offers concluding comments.

Chapter 1: Towards Usefulness: A Review of the Literature

This chapter reviews the pertinent literature on critical situation in information system failure, definition of usefulness, and factors affecting usefulness in information system lifecycle. It provides the basic motivation and current challenges for developing a WDOS towards work centered design.

1.1 Critical Situation in Information System Failure

According to the 2009 Standish CHAOS report regarding over 15,000 nationwide software projects, 44% of the projects were challenged by overdue, over budget, or failure to meet promised functionality while 24% of the projects were canceled or never used (Standish Group, 2009). The failure rate is even greater for larger projects such as Electronic Health Records (EHR) due to the extra domain complexity (Kaplan & Shaw, 2002) (Zhang J. , 2005) (Sittig, Kuperman, & Fiskio, 1999) (Berg, 2001). Further survey revealed that 61% of these failures happened in the requirement analysis and design stages in the information system lifecycle (Mcmanus & Wood-Harper, 2004). In terms of cost-benefit, the estimation (Bias & Mayhew, 1994) indicates that the late correction of requirement errors could cost up to 200 times as much as correction during such requirement engineering stage. The issue to systematically address users' essential requirements of their daily work and seamlessly turn these requirements into a successful design remains a critical challenge (Constantine & Lockwood, 1999).

1.2 What Is Usefulness?

Generally, a successful information system needs to address two aspects: usefulness and usability. Usefulness means that the system can actually help people accomplish their work in valuable ways (Molich, Jeffries, & Dumas, 2007) (Landauer, 1995). Usability means that the system can meet subjective satisfaction in terms of ease of use and learning. The "usefulness" aspect corresponds to the intrinsic difficulty of the system while “usability” corresponds to the extrinsic difficulty of the system (Zhang J. , 2005).

Usefulness is essential because it is invariant with respect to work context, application technology, or cognitive architecture. Many applications have failed because of the lack of usefulness, even though their user interfaces were well developed (Goransson, Lind, Pettersson, Sandblad, & Schwalbe, 1987) (Wright & Fields, 2000). In fact, if the functionality of an application is not useful, its user interface is irrelevant. Without articulating usefulness requirements, important tasks are being overlooked and systems are being designed without needed features and facilities. As a result, users make frequent requests for changes that delay delivery and drive up costs. Conversely, if functionality is chosen effectively, then even poor user interface might be acceptable to users.

1.3 Factors Affecting Usefulness during Information System Lifecycle

Three coordinated steps are necessary to transform usefulness from requirement to end information system: 1) acquisition of requirement, 2) specification of requirement, and 3) implementation of requirement. In acquisition of requirement, the analyst focuses on helping the client formulate the requirement explicitly and precisely using observation, survey, interview, and case study etc. In specification of requirement, the analyst focuses on representing the requirements according to an abstract conceptual framework (Meyer, 1985). In implementation of requirement, the analyst focuses on developing real system to reflect requirement addressed in the acquisition step. Any wrong step will cause problems of system quality, such as incompleteness, contradictions, ambiguities, noises, forward references, or over-specifications (Roman, 1985). Factors related with acquisition of requirement have been well studied in ethnographic studies, such as the strengths and limitations of interview, survey, observation; or even detailed factors, such as methods to develop leading or probing questions, methods to distinguish superficial answers to each question, and methods to integrate data from disparate sources, i.e. interviews, observations, videotape, artifacts, and surveys. Factors related with implementation of requirement have been well discussed in human machine interaction, such as small form factors, data dimension and data scale in representation analysis, working memory, selective attention in interaction analysis (Zhang & Butler, UFuRT: A work-centered framework and process for design and evaluation of information systems, 2007). Factors related with the specification of requirement can be generally divided into two parts: 1) conceptualization of the specification which requires an explicit conceptual framework to summarize the specification of work domain and guide implementation of requirement in information system; and 2) the operational procedure to develop such a conceptualization which ensures the quality of the concept framework. These two factors are still under discussions as delineated in 1.4.

1.4 Specification of Work Domain

The promotion of employing abstract models to solve concrete problems has been discussed since 1970. Rather than representing the literal actions of users or the concrete objects they manipulate, these conceptual models represent abstractions out of which work is composed and from which supporting systems will be constructed (Van Lamsweerde, 2009). A successful abstracted conceptual model hides details and ignores information selectively. The modeling concepts are grouped into language units. A language unit consists of a collection of tightly coupled modeling concepts that provide users with the power to represent aspects of the system under study according to a particular paradigm or formalism from the abstract to the concrete. Consequently, it will expose the focus explicitly and is easier to construct than the complex reality they represent and assist communication between analysts, designers and end-users.

Modeling is often the most efficient way to quickly build an understanding of a problem and map out the speediest resolution. The process to build a conceptual model is less costly and time-consuming than building the real information system. Therefore, it will help the analyst to identify problems in the earlier stage (Constantine & Lockwood, 1999) (Van Lamsweerde, 2009). The future system development will be created, fashioned, executed, or constructed according to the models. In addition, Lubus proposed that the specification of requirement should be as formal as possible. Formal conceptual framework will support sharing common understanding of the structure of knowledge among people precisely, and enable requirement reuse, which makes explicit domain assumption.

1.5 Strength and Limitations of Previous Approaches

A couple of previous approaches have been developed to serve the above purposes. These approaches generally included one or more schemas and their development procedures. The domain specific models can be further developed by extending these schemas. Use Case (UC), hierarchical task analysis (HTA), Work Breakdown Structure (WBS) and GOMS are four of the widely used approaches.

1.5.1 UC

UC was proposed by Jacobson in 1992 (Jacobson, Christerson, Jonsson, & Övergaard, 1992) (Jacobson, Booch, & Rumbaugh, The Unified Software Development Process, 1999) within a graphic notation language called Unified Modeling Language. UC works on a description of a system's behavior as it responds to a request that originates from outside of that system. Each UC model describes how an actor will interact with the system to achieve a specific goal. The core components of UC conceptual framework are actor, system, overall goal, cases, and the associations between users and cases. Actor means the initiator of the interaction. System refers to an artifact which the actor will interact with. Case describes how the actor will interact with the system to achieve a specific goal. UC is a mature model to capture user (person or organization) proffered interaction requirements. Certain object-oriented methodologies encourage the construction of use cases as scenarios of user activities related to the software system.

However, there are several problems with UC models. Firstly, UC model is almost always written as the overwhelming focus of an information system. UC model is thus an example of a product-oriented paradigm, which gives too much priority to the software, and too little priority to the end-users' work or life processes (Helander, Landauer, & Prabhu, 1997). Secondly, each UC model is a definition of user actions by system designers: its words carry a connotation of end-user focus and work analysis, but the substance is in fact centered on software features that may or may not be related to end-user needs. The problem is then to make effective user participation an integral part of UC model and its related development. Thirdly, the conceptual framework of UC is unable to express non-interaction requirements, such as mental work independent on any system or non-functional requirements such as platform, performance, timing, or safety-critical aspects.

1.5.2 HTA

HTA was proposed by Annett and Duncan in 1967 (Annett & Duncan, 1967). HTA has been used for a range of applications, including interface design and evaluation, allocation of function, job aid design, error prediction, and workload assessment. Although it is difficult to pinpoint all of the possible factors that could have led to the development of HTA, some of the main features are likely to include: the breakdown of tasks into their elements, the questioning of human performance in systems, a need to understand both physical and cognitive activities, a desire to represent the analysis in a graphical manner, and a need for an underpinning theory of human behavior (Stanton, 2004).

HTA has three governing principles. In the first principle, HTA is proposed as a means of describing a system in terms of its goals. In the second principle, HTA is proposed as a means of breaking down sub operations in a hierarchy. The sub-operations are described in terms of sub-goals, i.e. in order to satisfy the goal in the hierarchy its immediate sub-goals have to be satisfied, and so on. The final principle states that there is a hierarchical relationship between the goals and sub-goals and there are rules to guide the sequence that the sub-goals are attained.

However, a couple of limitations still exist in the implementation of HTA.

1. Ambiguous definitions lead to inconsistent models: the term "task" can be defined as the complete performance of a given procedure; or the totality of effort to design and/or build a given thing, to monitor and/or control a given system; or to diagnose or solve a given problem; or a small sub-element such as a particular movement or measurement. (Helander, Landauer, & Prabhu, 1997). Due to the ambiguous definitions, task modeler may elaborate goals on top of task hierarchy and talk about operation in the lower part of the task hierarchy.

2. No boundary or stop point for decomposition: one of the most difficult features of task analysis is to know exactly when to stop the analysis (Annett J. , Duncan, Stammes, & Gray, 1971). The criterion for stopping the analysis is determined by satisfying the probability (P) of failure multiplied (x) by the cost of failure(c) to an acceptable level, known as the PXC rule (Stammers & Astley, 1987). However, it is not easy to estimate these values and urge task analysts not to pursue re-description unless it is absolutely necessary (Stammers & Astley, 1987).

3. Hierarchy structure can only express the relationship of progressive decomposition. It is not sufficient to express other relationships between tasks, for example, parallel relationship between tasks. A richer expressiveness of relationships between tasks is still needed.

1.5.3 GOMS

The other widely used method is GOMS analysis, which was proposed by Card, Moran, and Newell in 1983 (Card, Moran, & Newell, 1983) and further modified by Kieras in 1994 (Kieras & John, 1994) and in 2004 (Kieras D. , 2004). As the acronym represents, GOMS schema includes four concepts: goal, operator, methods, and selection rules. Goals are what the user intends to accomplish. Operators are actions that are performed to get to the goals. Methods are sequences of operators that accomplish a goal. Selection rules describes alternative path to accomplish one single goal using different methods (Kieras D. , 2004).

GOMS is advantageous at studying a user's interaction with a computer to its elementary actions such as physical, cognitive or perceptual actions. A GOMS model is a representation of the knowledge "how to do it" that is required by a system in order to get the goal accomplished. GOMS models can predict the procedural aspects of usability regarding the amount, consistency, and efficiency of the procedures that users must follow. However, GOMS modeling does not represent the complete understanding working content, such as the required resources of the work, flexible expressiveness of the relationships between operations.

1.5.4 WBS

The concept of WBS was developed with the Program Evaluation and Review Technique (PERT) in the United States Department of Defense. PERT was introduced by the U.S. Navy in 1957 to support the development of its Polaris missile program (Norman, Brotherton, & Fried, 2008). WBS is a hierarchical structure, which shows a subdivision of effort required to achieve an objective; for example a program, project, and contract (Wysocki, 2006).

A couple of terms are used in WBS. The first term is activity, which is simply a chunk of work. The second term is task. Activities are turned to tasks at some level in the hierarchy. A task is a smaller chunk of work. Another term is work package, which is a complete description of how the tasks that make up an activity will actually be done. It includes a description of the what, who, when, and how of the work. The process to break down work into a hierarchy of activities, tasks, and work packages is called decomposition, which is level based. The goal statement is defined as a Level 0 activity in the WBS. The next level, Level 1, is a decomposition of the Level 0 activity into a set of activities defined as Level 1 activities. These Level 1 activities are major chunks of work. When the work associated with each Level 1 activity is complete, Level 0 activity thus completed. As a general rule, when an activity at Level n is decomposed into a set of activities at Level n + 1 and the work associated with those activities is complete, the activity at Level n, from which they were defined, is complete.

The six characteristics that an activity must possess to be called a task are as follows: 1) Status/completion is measurable. 2) The activity is bounded. 3) The activity has a deliverable objective. 4) Time and cost are easily estimated. 5) Activity duration is within acceptable limits. 6) Work assignments are independent. If the activity does not possess all six of these characteristics, decompose the activity and check again at that next lower level of decomposition. As soon as an activity possesses the six characteristics, there is no need to further decompose. As soon as every activity in the WBS possesses these six characteristics, the WBS is defined as complete.

The limitations of WBS approach are, 1) the difference between three concepts, activity and a task are not clearly defined. 2) Decomposition has restricted expressiveness power. The boundary of WBS analysis is not clear due to the ambiguous concept definitions.

1.5.5 Summary

The limitations of current approaches can be summarized as below:

1. Limited view of work domain system: the conceptual framework over specifies the system with technical details, like use case. Such an over-specification may limit the view and proper design of a work centered system.
2. Ambiguous concepts: The core concepts are ambiguously defined without definitive attributes. The intension and extension are thus not clear which cause problems for the operationalization of the concepts. As a result, two users may start the requirement specification based on same conceptual model, but ending in two discrepant models.
3. Lack of expressiveness power beside decomposition: The limitation cannot reflect the complexity in a work domain.
4. No explicit study of resources used in the work: Incomplete elaboration of objects may cause indirect manipulation or affordance in later representation analysis.
5. No specific boundary: Neither of above methods explicitly separates the user's essential requirements (what need to be included in a work domain) from the implementation detail (how a work domain is implemented). Without such clear dissociation, the mixed outputs from these methods are still unable to precisely address the usefulness requirements.

6. Interoperability: Since each model uses different concepts, the result will be completely different. The interoperability towards complicated system design is still an issue.

In view of the above limitations, a new conceptual framework is still needed with improved expressiveness power and clear operational procedure (Kavakli & Loucopoulos, 2005).

Chapter 2: Theoretical Foundation

This chapter reviews the theories upon which this study is laid out in more details.

2.1 The impact of Distributed Cognition on Information System Design

Tracing back to 1970, the major principle for information system design is machine-centered (Norman D. A., The Design of Future Things, 2009). Machine-centered designers compare users to machines and point out the limitations of human: human is distractible, have learning curve and will be tired for long time task. Due to these limitations, machine-centered designer emphasizes the need of technologies over those of users. They force users into a supportive and adaptive mode to perform redundant tasks without considering users' primary skills and experiences. The classic thoughts came from Frederick Winslow Taylor's monograph (Taylor, 1911) in which Taylor proposes to decompose corporate operation into simple, standardized, executable piece by piece actions and insert human as accessory machine in the stream line to repeat the same action day after day to improve the performance of the whole streamline. Under this condition, workers do not need to understand the principle or get special training to repeat the simple action. Such a system thereby cannot tailor to user specific requirement. Machine-centered design is very commonly rejected by most end users.

The growth of distributed cognition theory changed the understanding of interactions between people and technologies fundamentally (Hollan, Hutchins, & Kirsh, 2000). An earlier and classic example of distributed cognition is Hutchins' research on the navigation work domain of naval ships, Hutchins described how the "robust" and "redundant" knowledge distributed across people and instruments on a ship enabled the complex task of piloting the ship. He called the shipboard team a "flexible organic tissue" that responds to potential breakdown in one part of the tissue by the rapid response of another part of the tissue. This example indicates that, cognitive activities are distributed across human minds (internal), external cognitive artifacts (external), groups of people, and across space and time (Hutchins, 1996) (Zhang & Patel, Distributed cognition, representation and affordance, 2006).

According to the theory of distributed cognition, Norman criticized machine-centered design and proposed user-centered design. The objective of user-centered design is to design a system tailored and tested for the users' own perspectives and needs. User-centered design takes extensive attention of users' characteristics and user preference of the interface interaction. It proposed to involve users in the whole process of system development, typically during requirement gathering and usability testing. Methodologies for user-centered design have been widely discussed and adopted, such as talking with users, visiting customer locations, observing users working, video-typing users' work, learning about the work organization, having user to think aloud, etc.

Although user-centered design has led to many successful user-friendly products in many industries, it is still not able to address the complexity of work beyond individuals. No matter how well the capabilities of an individual in a system (whether a person or an instrument) are studied, it is still impossible to understand work domain without looking at the system as a whole. It is therefore essential to study work at the systems level rather than the level of the individual to encompass interactions among groups of people and with resources and materials in the environment.

In order to better reveal system complexity and reflect such a complexity in information system design, WCD is proposed by Butler, Zhang, and colleagues. "Work-centered" emphasizes the focus of system design on the quality of the work collaboratively performed by the distributed system composed of machines and human users. In order to support work-center design, a new conceptual framework called WDO to represent users' requirements of the work is under study. The preliminary definition of WDO is that "WDO is an explicit, abstract, implementation-independent description of essential requirements of work". Iterative processes on the formalization and operationalization of WDO are critical for the future adoption of WCD.

2.2 Classic Economics Theory about Production

The earliest view of "work" derives from the term "production" in economics. According to what Smith defined in *The Wealth of Nations*, "Consumption is the sole end and purpose of all production". In this way, the unique purpose of production is decomposed and distributed among different work domains. A company or organization may develop a mission statement accordingly to guide the organization structure, operation and resource management. The mission statement can be further decomposed into role based goals according to the organization structure.

Nearly one century later, Marx in his book *Das Capital* introduced a series of "Factors of Production". The three factors of production include labor, the subjects of labor and the instruments of labor. More specifically, labor refers to the physical and mental activities applied to satisfy certain requirements. Marx also points out: the subjects of labor are the subjects that labor is utilized to make changes on, during the endeavor of work. The subjects of labor could not only be the natural resources such as trees, minerals and oil, but also be processed products such as chemicals and cotton yarn. The instruments of labor include all kinds of tools required during work, such as facilities, equipment, etc. These three factors are essential to production independent of social style, organization type, and environment context. Marx also pointed out that the labor has to interact with the subject and object of labor in order to deliver the output of work. Without such an interaction constraint, these three factors can only be potential factors of production. Such a constraint is a precondition to the existence of production.

Based on the theory of “production”, a work domain can be viewed with four meaningful concepts: goal, operation, object, and constraint. Goal derives from the purposes of production. Operation and object have roots from factors of production. Constraints address the mandatory associations among goal, operation and objects. The preliminary framework of these four concepts is that, operations are performed on the objects under the constraints to achieve goals.

2.3 General System Theory

General system theory (Von Bertalanffy, 1969) is a trans-disciplinary approach that studies general principles of any system. The theory and methodology can be applied to all types of system studies in different fields. General system theory provides guidance from four aspects which are described below.

2.3.1 Proving Feasibility for System Abstraction

General system presents the existence of isomorphism. In reality, there are phenomenon with different, specific and concrete implementations in technology; but models, conceptualization and principles are general among these technology implementations. Certain aspects, corresponding abstractions, procedures and conceptual models can be extracted and applied to different phenomena in the same domain. Any system is built upon order, interrelation, and balance among parts as a means of maintaining the smooth functioning of the whole. This statement indicates that, it is possible to develop a WDO which is generalizable to summarize different implementations of the same work domain system.

General system theory also provides the formulation and derivation of those principles from other system study which are valid and reusable for the investigation of any new system. For example, a system in general system theory must meet two conditions: 1) has a set of independent elements; 2) and that these elements strand interrelations.

2.3.2 Providing Methodology Guidance for System Study

General system theory also discussed various methodologies to study systems. Compartment theory is introduced to divide system into subunits with certain boundary conditions between which transport processes take place. Set theory is presented to study different collections of objects. Graph theory is discussed to present system complexity concerning structural or topologic properties of systems, rather than quantitative relations. Net theory is summarized to construct connections with compartment, set, graph, etc. theories and is applied to various system studies, i.e. nervous network. Such a discussion provides guidance to how to study work domain system.

2.3.3 Motivating an Ontology to Represent System Infrastructure

General system theory states that it is essential to develop a system ontology to understand not only the elements but their interrelations to reveal what is meant by "system". Further study about how systems are realized at the various levels of the world of observation can be constructed based on system ontology.

2.4 Ontology Engineering

An ontology is an explicit specification of shared conceptualization (Gruber, 1993). Explicit means each concept in ontology should be without ambiguity. Shared means that an ontology captures consensual knowledge that is accepted by a group of users. Conceptualization refers to an abstract model of some phenomenon in the world by having identified the relevant concepts of that phenomenon (Cruber, 1991). An Ontology Web Language (OWL) has been studied and accepted as a worldwide standard to represent ontology. OWL supports four features: 1) Reusability and interoperability: an OWL model can be shared among different user groups or applications on the web. 2) Flexibility: the classes and relationships defined in OWL can be easily expanded and dynamically modified. 3) Consistency and quality checking across models: the improper structure, such as dead loop, broken relationships and conflict overlapping between Superclass and Subclass, is hard to identify in complex system, but easy to detect from OWL. 4) Reasoning: OWL has rich expressivity supported by automated reasoning tools (Newell, 1982). In one sentence, OWL can perfectly hold system infrastructure, the output of set theory, graph theory and net theory as discussed in the general system theory.

Recently, there has been an explosion of interest in ontologies to represent human centered-design (Smith & Becker, 1997) (Dardenne, Van Lamsweerde, & Fickas, 1993) (Zave, 1982) (Rubing, Noy, & Musen, 2006) in order to maximize the value of human knowledge in system design (Smith & Becker, 1997). One of the most popular ontology engineering methods is Uschold and King's method that has been promoted by W3C as a standard (Uschold, 1996) (Gomez-Perez, Corcho, & Fernandez-Lopez, 2003). Uschold and King's method is presented as presented in Figure 1:

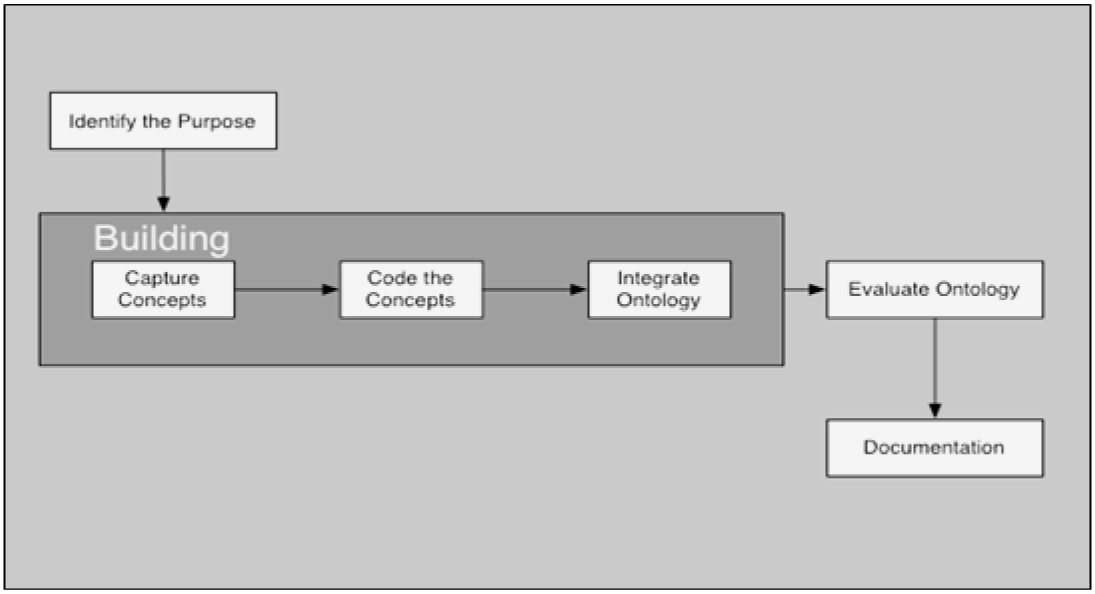

Figure 1. This diagram presents the six steps in the Uschold and King's method.

Process 1: To identify the purpose and scope. The purpose of this step is to clarify why the ontology is being built, what its intended uses are and what is the scope.

Process 2: To build the ontology. This process can be broken down into three steps.

2.1: Capture concepts: The purpose of this step is to identify key concepts and relationships between concepts in the interested domain with precise and unambiguous definitions for such concepts and relationships. Three strategies can be used for this step: bottom-up, top-down, and middle-out. 1) The bottom-up strategy proposes to identify first the most specific concepts and then generalize them in to more abstract concepts. 2) With the top-down strategy, the most abstract concepts are identified first and then specialized into more specific concepts. 3) The middle-out strategy recommends to identify first the core of basic terms, and then specify or generalize upper or below concepts as required.

2.2: Code the concepts: this step involves two sub-steps: 1) Committing to basic terms that will be used to specify the ontology. 2) Writing the code: this step includes two activities: a) creating name conversions such as using uppercase or lowercase letters to name the terms; b) inserting concepts to OWL model according to name conversions.

2.3: Integrate ontologies: this is optional process which refers to whether and how to integrate existing ontologies with current ontology.

Process 3: to evaluate ontology. Broadly speaking, the ontology evaluation approaches can be classified into following four categories: 1) Golden standard approach: the evaluation is based on comparing the ontology with a “golden standard” (which itself maybe an ontology (Maedche & Staab, 2002)). 2) Data driven approach: the evaluation is based on comparing ontology with a source of data regarding the domain coverage (Brewster, 2004). 3) Human expert approach: the evaluation is based on human assessment how well the ontology meets a set of predefined criteria, standards, requirements, etc. (Lozano-Tello & GÓMEZ-PÉREZ, 2004) 4) Application based approach: the evaluation uses the ontology in an application and evaluates some aspects of the application (Porzel & Malaka, 2004). The selection of evaluation approach usually depends on the type and the purpose of the ontology.

Process 4: to document. In this step, a tutorial will be written to explain the purpose, scope and components of the ontology. A glossary of terms, concept taxonomies, relation, instance, as well as attributes for instance and class will be included in the tutorial as well.

2.5 Summary

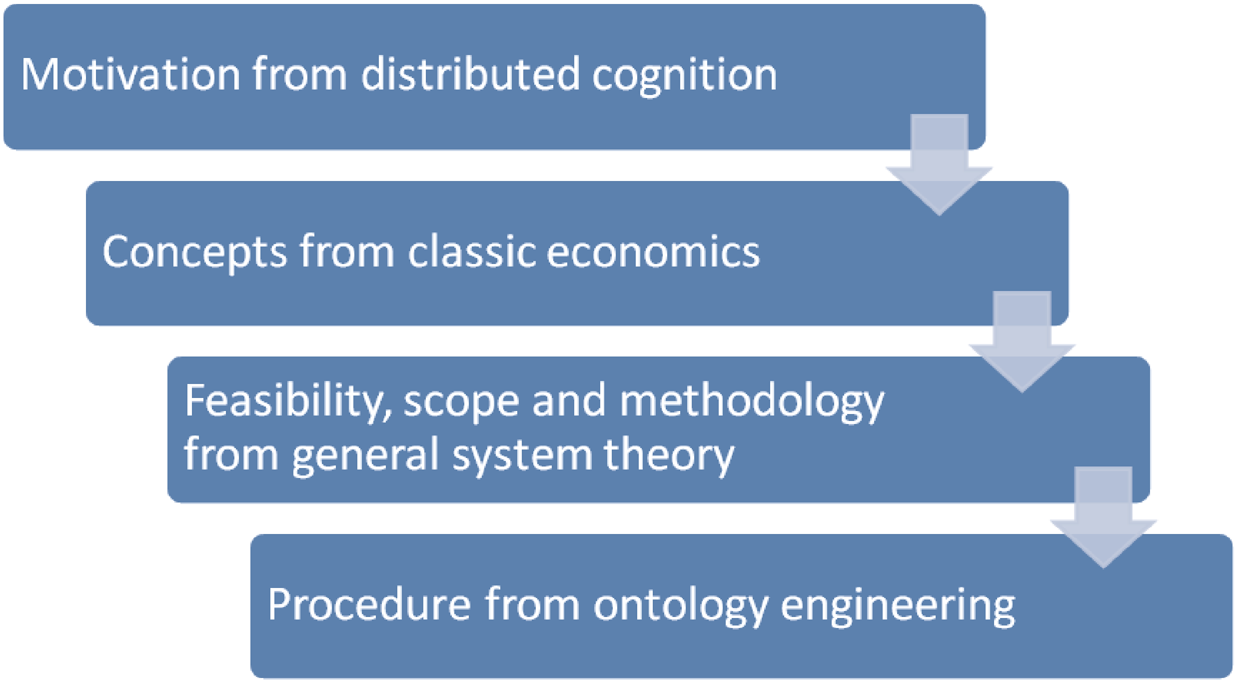

Figure 2. This figure presents the theoretical diagram for this research.

The theoretical foundation of this research is presented in Figure 2. This research is motivated by distributed cognition to build a formal WDOS to support the articulation of work domain knowledge. The concepts of WDOS derive from classical economics. General system theory provides general guidance of system analysis, such as basic rules in a system and various methodologies to study a system. Ontology engineering provides applicable engineering method towards the development of WDO.

Chapter 3: SNM and SNM Applications

This chapter presents the prevalence of obesity, multiple intervention approaches to solving obesity problems and the current status of SNM applications. Based on the literature review on existing problems in SNM, SNM was selected as the study work domain.

Obesity is among the leading preventable causes of death worldwide, and obesity increases the risk of mental and physical conditions such as diabetes, high blood pressure, high blood cholesterol, etc. (Ogden, Carroll, Curtin, McDowell, Tabak, & Flegal, 2006). In 2001, the US Surgeon General declared an obesity epidemic, reporting that approximately 300,000 US deaths a year are associated with obesity and overweight (US Surgeon General, 2001). The obesity rates have doubled from 1980 to 2002, and the age-adjusted prevalence of obesity was 33.8% in 2007-2008 (Flegal, Carroll, Ogden, & Curtin, 2010).

Both genetic and environmental factors contribute to obesity, and therapeutic lifestyle change such as dieting and physical exercise is the primary approach to control obesity, with anti-obesity medications, weight loss programs and surgery as supplements. In order to change lifestyle, behavior interventions, such as SNM, are fundamentally linked to successful weight loss (Quinn, Goka, & Richardson, 2003). SNM is defined as recognizing the occurrence of a behavior, i.e. eating and drinking, and recording it (Korotitsch & Nelson-Gray, 1999). By SNM, the patient is able to review and adjust the food categories and amounts, therefore better control of the outcomes from the patient's efforts (Burke, et al., 2005). SNM has been shown to be an effective method to motivate adherence to a healthy diet (Atienza, King, Oliveira, Ahn, & Gardner, 2008).

SNM has two formats: the traditional paper-and-pencil format and the innovative electronic format. The traditional paper-and-pencil format has inherent limitations in recording everyday diet (Yon, Johnson, Harvey-Berino, & Gold, 2006). On the one hand, patients back fill the diaries, which make the data less reliable because of recall bias. On the other hand, patients need to find out and calculate the nutrition values for each meal, which could be very time-consuming and reduces the adherence to recording (Stone, Shiffman, Schwartz, Broderick, & Hufford, 2002). The introduction of hand-held personal digital assistance (PDA) has been shown to improve the quality and timeliness of the SNM (K. Glanz, 2006) .

However, over 100 applications have been developed and widely promoted, but the feedback from end users is still negative (Yon, Johnson, Harvey-Berino, & Gold, 2006). There are four steps needed to achieve the long time goal by using SNM applications: 1) improving the SNM application usefulness; 2) promoting SNM adoption; 3) changing patient behavior; 4) resulting in positive clinical outcomes.

This research is focused on the usefulness improvement of SNM application, which is the first and essential step towards final clinical outcomes. In this research, we investigated overweight users' SNM requirement by modeling a SNM WDO. The SNM WDO can be used to guide the future development of new SNM applications.

Chapter 4: Preliminary Study: WDO of Time Management Domain

This chapter presents a preliminary study that was conducted to assess the feasibility of WDO approach.

We have carried out our preliminary study in two steps: 1) implementing WDO, UC, GOMS approaches to analyze time management domain; 2) comparing the difference among the three conceptual frameworks.

Since time management is a very common daily activity, we selected time management domain as the applied domain for this preliminary study. Five domain experts discussed their daily activities in the time management domain. Based on the discussion, we implemented WDO, UC, and GOMS approaches.

4.1 Implementing WDO, UC, GOMS Approaches to Analyze Time management domain

4.1.1 WDO Approach

According to the basic components of WDO, we identified goals, operations, objects and constraints of the time management domain. The top-level goal is to manage time. From the top-level goal, four sub goals were enumerated to be: 1) aware of the arrival of an instant; 2) aware of current time; 3) aware of the elapsed time; 4) aware of the stop instant of an interval. Upon the sub goals, the corresponding operations were enumerated to: 1) inform users the arriving of an instant; 2) inform users of the current instant; 3) inform users of the elapsed interval; 4) inform users of the stop instant of an interval. We identified three major objects: instant represents an absolute point of time; interval represents a period of time; duration, the subclass of interval, represents a specific interval with a start instant and a stop instant. The constraints between operations and objects were also explicitly stated in the WDO: for example, the first operation "inform users of the arrival of an instant" required the object "instant". Once the goal is defined, the operation should be generic and directly targeting at the goal independently of the implementation detail, for example, the end user can either use a device or ask a friend to acquire the object.

4.1.2 UC Approach

We have also implemented the UC approach according to the developing processes of UC as mentioned in Larry's book (Constantine & Lockwood, 1999). In UC, the designer has to assume that there is a system to interact with. The analyst then has to define the goal of the work before enumerating cases. We took "aware of the stop instant of an interval" as the goal. The operation in WDO "inform users of the arrival of an instant" was transformed into an explicit action as essential case "count down duration". The case was further addressed as: 1) set duration 2) start counting 3) get stop message 4) cancel counting. In this example, the case "cancel counting" is not directly applicable towards the user's goal. It is an additional case due to the implementation detail of the system. Also, objects and constraints were not addressed in this UC model.

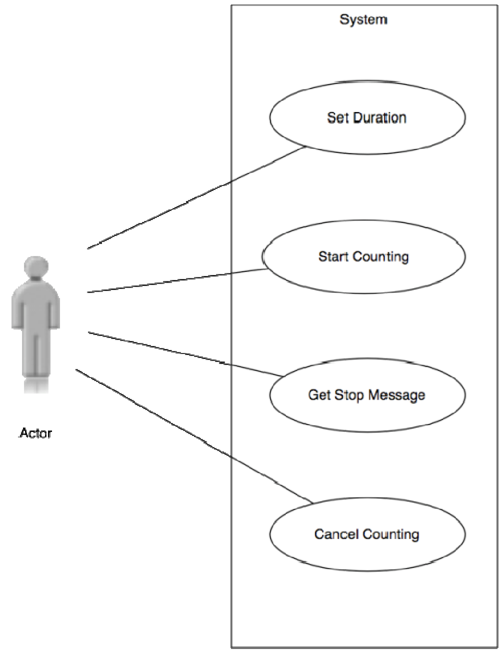

Figure 3. This diagram displays the UC of “count down duration”. The human icon on the left side represents an actor. The frame on the right side represents a system. The ellipses represent all supported cases. The lines represent the association between the user and cases.

4.1.3 GOMS Approach

According to the Kieras’s tutorial (Kieras & John, 1994) of GOMS analysis, we also implemented GOMS analysis. We still took “aware of the stop instant of an interval” as the goal. Since GOMS requires the assignment of a specific interface to study the keystroke level interaction, we used the interfaces of regular watch and timer to demonstrate the processes. On top of below two tables, the goal of GOMS is presented. Below that, the numbers of sequential steps are enumerated on the left. The explanation of each step is documented as narrative in the middle. The analysis of cognitive distribution is presented on the right side in which “internal” means internal process of the brain; “external” means external process of the interaction with device.

Table 1. This table displays the result of GOMS analysis to accomplish the goal "aware of the stop instant of an interval" using watch.

Method for accomplishing goal of setting duration (Watch)		
Step	**Step description**	**Cognitive distribution**
1	Think of duration	internal
2	Retrieve current time	external
3	Decide the start time	internal
4	Calculate the stop time by adding duration to the start time	internal
5	Remember stop time	internal
6	Return with goal accomplished	
Method for accomplishing goal of starting counting		
1	Observe the needle passing the start time	external
2	Aware the start time has been passed	internal
3	Return with goal accomplished	
Method for accomplishing goal of stopping counting		
1	Observe the needle passing the stop time	external
2	Aware of the expiration	internal
3	Return with goal accomplished	

Table 2. This table displays the result of GOMS analysis to accomplish the goal "aware of the stop instant of an interval" using timer

Method for accomplishing goal of setting duration (Timer)		
Step	**Step description**	**Cognitive distribution**
1	Think of duration	internal
2	Key in duration	external
3	Return with goal accomplished	
Method for accomplishing goal of starting counting		
1	Click the start button	internal
2	Return with goal accomplished	
Method for accomplishing goal of stopping counting		
1	Receive the alert from timer	external
2	Aware of the expiration	internal
3	Return with goal accomplished	

From these two tables, we can see that it takes 12 steps to accomplish the goal using watch, but takes only 8 steps to accomplish the same goal using timer. Comparing the results of GOMS analysis between watch and timer, the designer will be able to address that using a watch needs more steps than using a timer. These extra steps will cause redundant cognitive workload. As such, a timer is more efficient to accomplish this goal.

4.2 Comparing the Difference among Three Conceptual Frameworks

Two Subject Matter Experts (SMEs) validated the results of three approaches and identified the differences among WDO, UC and GOMS as presented in Table 3.

Table 3. This table displays the differences among WDO, UC, GOMS conceptual frameworks. “Yes” means all parts of the feature are covered by the approach. “No” means none of the feature is covered by the approach. “Partial” means some parts of the feature are covered by the approach.

Features	UC	GOMS	WDO
Identify goals	Yes	Yes	Yes
Identify top level operations	Yes	Yes	Yes
Identify objects	No	No	Yes
Identify constraints between operations	Partial	Partial	Yes
Identify constraints between objects	No	No	Yes
Identify constraints between operations and objects	No	No	Yes
Describe the intrinsic complexity of work	Partial	Partial	Yes
Separate work context from intrinsic nature of work	No	No	Yes

Chapter 5: Experimental Design

Based on the theoretical analyses presented in the previous chapters, this chapter presents my proposed hypotheses and the experimental design for my studies.

The purpose of this study is to formalize WDOS and develop an operationalized procedure to apply WDOS to SNM domain. Since the purpose of WDO has been well described in the previous chapters, we divided our experimental design into three parts according to process 2 and 3 mentioned in the Uschold and King's method: 1) capture concepts 2) code the concepts, and 3) evaluate ontology. The whole dissertation will serve as the documentation of the ontology.

5.1 Capture Concepts

Top-down strategy was selected as the major method for concept capturing. According to the top-down strategy, the most abstract concepts are identified at first and then specialized into more specific concepts. Consequently, two steps are involved: 1) Capture domain independent concepts to build WDOS; and 2) Capture specific concepts in SNM domain to populate a SNM WDO.

5.1.1 Capture Domain Independent Concepts to Build WDOS

The purpose of this session is to formally define WDOS to guide future WDO development. WDOS includes the definition, and attributes of the four concepts which are goal, operation, object, and constraint. Walker and Avant's 8-step concept analysis (Walker & Avant, 1994) (5.1.1.1 to 5.1.1.1.8) was used to formalize WDOS.

5.1.1.1 Select the Core Concepts as Targets of This Study

In order to select concepts to reflect the work domain, we examined core concepts of WDOS from preliminary research studies, literature review, and limitations of previous concept definitions.

5.1.1.2 Determine the Aims or Purpose of the Analysis

According to previous chapters, the purpose of our study is to clarify the meaning of existing concepts in WDOS and develop an operationalized procedure.

5.1.1.3 Identify All Uses of the Concept

In this step, we identified as many uses of the concept as we could find. The uses were retrieved from thesauruses, colleagues, and available domain literature. Extensive reading in many different sources was implemented. This review of literature provided support to validate ultimate choices of the defining attributes. After enumeration, the decision to use all the usages of the concept or pertinent to one aspect of the concept was made.

5.1.1.4 Determine the Defining Attributes

In order to identify the broadest insight into the concept, we examined many different instances of a concept through literature review. During literature view, iterative group discussions were hosted to identify characteristics of the concept that appeared repeatedly. The list of characteristics, called defining or critical attributes, were identified in this study.

5.1.1.5 Identify a Model Case

A model case is a “real life” example of the use of the concept that includes all of the critical attributes of the concept. This is absolutely sure an instance of the concept. In this study, we identified a model case for each core concept.

5.1.1.6 Identify Other Cases

Similar case is a model case but in a different domain. Borderline case is a case sharing attributes, but not containing all of the critical attributes of the model case. Related cases are in some way connected with model case but with no critical attributes. Contrary case is a clear example of "not the concept". Invented cases are constructed using ideas outside of real experience. We also examined other possible cases through literature review and group discussions with SMEs.

5.1.1.7 Identify Antecedents and Consequences

Antecedents are events or incidents that must occur prior to the occurrence of the concept. Consequences are those events or incidents that occur as a result of the occurrence of the concept. We examined possible antecedents and consequences through literature review and group discussions.

5.1.1.8 Define Empirical Referents

Empirical referents are classes or categories of actual phenomena that by their existence or presence demonstrate the occurrence of the concept itself. The finals step is to determine the empirical referents for the critical attributes. Referents are observable, measurable, and testable and are used to assess the concept. Empirical referents were examined in this study by literature review and group discussions with SMEs.

5.1.2 Capture Specific Concepts in SNM Domain to Populate SNM WDO.

The purpose of SNM WDO is to gather data to represent the essential requirement of SNM users' work in line with the definition of goal, operation, object and constraint. The most commonly used method of gathering data is to interview people who work in the domain. The

SNM domain concepts were captured via focus group interview. The orientation of users' cognitive constructions, values, beliefs and behaviors were identified in focus group interview to better understand the shared knowledge of the SNM users (Spradley, 1979) (Niles, 1994).

Focus group interview design: Taking the preliminary WDOS as the target, three kinds of questions were mainly used in the interview: descriptive, structural, and contrast. Descriptive questions focus on collecting a sample of the subjects' opinions in free text, for example, "Could you please describe your daily nutrition management behavior?" Structural questions focus on discovering the basic units in the user's knowledge, for example, "What else can you think of as an operation besides reviewing intake history?" Contrast questions focus on providing the meaning of various terms in the subject's language, for example, "What do you mean by rating food?" The questions were organized in a goal-oriented way with three sessions. The questions in first session were related with goals. When the goal was well discussed, the questions in the second session of operation were asked to discuss the operations related with previous goals. When the operations were well discussed, the questions in third session were asked to discuss the objects related with previous operations. Questions about the constraints were asked during these three sessions. Probing questions were asked to uncover details about specific pieces of information and understand whether these pieces of information not mentioned were optional or simply overlooked. The interview questionnaire was reviewed and approved by three SMEs.

Subjects: Most current SNM applications are targeting overweight population (BMI value >25). Because the expected subjects have a great deal to share about the topic or have had intense or lengthy experiences with the topic of discussion, a small group design with 4-6 subjects is acceptable (Kreuger, 1988). As such, five subjects were recruited from the overweight population from a convenience sample of healthcare professionals working in the medical center.

Setting: A closed lab was used as the site for data collection. An audio recorder was used to record the interview process.

5.2 Code the Concepts

This step involved two sub-steps: 1) commit to basic terms that will be used to specify the ontology; and 2) write the code.

5.2.1 Commit to Basic Terms that Will Be Used to Specify the Ontology.

The recorded audio was played sentence by sentence during transcription. Microsoft OneNote was used to transcribe the output of the focus group interview into text. A double check was implemented by playing the audio from beginning to the end and reading the text at the meantime.

The NVivo software was used for qualitative data analysis. A new project was created in NVivo with the transcribed text as the source file. NVivo software supports three kinds of coding. Descriptive coding is the process of identifying information that describes the cases in a project. This process relates both to the coding of information as cases and the creation of attributes to classify them. Topic coding is the process of assigning references within the data to the topics, categories or concepts they relate to. Analytical coding is the process of interpreting and reflecting the meaning of the data so as to arrive at new ideas and categories. This process entails gathering material that should be rethought and reviewed given your growing understanding of the categories in your data. Both topic coding and analytical coding are used in this research in order to group concepts under four topics “goal, operation, object, constraint”.

5.2.2 Write the Code

The name conventions for each concept were decided in this step about using uppercase or lowercase letters to name the terms. After that, concepts was be inserted into OWL model using Topbraid composer, an ontology modeler, according to name conversion. Firstly, WDOS was built up as an OWL file based on the result of 5.1.1 concept analysis. When the four sets were ready, we created a new SNM WDO file, imported WDOS and transferred the coding results from 5.1.2 into the new file.

5.3 Evaluate Ontology

There are six criteria that we want to address in the evaluation process. 1) Acceptance: which means that concepts in SNM WDO should represent major users' option of SNM work. 2) Completeness: which means that all valid concepts should be included. 3) Consistency: which means that the relationship between concepts should be adhere without any conflict. 4) Explicitness: which means that each concept should only represent one meaning without ambiguity. 5) Experience dependency: since SNM WDO represents the common knowledge, concepts in SNM WDO should be independent of users' domain experience or even specific, users' application experience. 6) Goal priority dependency: the modeling approach is goal-oriented; we would like to know if SNM WDO will be dependent on goal priority.

According to Uscold and King's method regarding ontology evaluation, human expert approach was selected to evaluate SNM WDO. There are multiple ways to extract human expert opinions. Semi-structured survey was selected because surveys are often good follow-on methods to interviews when it is important to get information from a wide range of informants. After distilling WDO concepts from interviews, we would like to see whether the interpretations hold up with a larger sample by surveying a larger, more diverse group.

5.3.1 Research Hypotheses

The above six criteria were transformed into sevenquestions below:

Q1: What is the acceptance rate of SNM WDO by users?

Q2: Does SNM experience affect SNM WDO in general?

Q3: Does SNM App experience affect SNM WDO in general?

Q4: Is WDO dependent on primary goal?

Q5: Is the correlation between two concepts in WDO consistent?

Q6: Is there any ambiguous concept in WDO?

Q7: Is there any new concept we did not address in the focus group interview?

5.3.2 Survey Design

Per the suggestion from Niles, a survey usually should be filled in within 10-15 minutes with around 90-100 questions. Any survey longer than that makes subjects less focused which reduces the quality of the responses, such as low response rate or incompleteness (Niles, 1994). Based on that, a semi-structured survey was designed to address the above questions. The whole survey design process includes three steps:

1 Concept selection: In order to control the length of the survey, only the primary goal "staying healthy" and its related sub goals, operations and objects, were selected. Firstly, we selected the primary goal "staying healthy". Based on the constraint "hasSubGoal", we enumerated all sub goals. Thereafter, we retrieved the operation via the constraint "requireOperation". If there were still lower level operations, we enumerated all operations based

on the constraint “hasSubOperation”. For each operation, we retrieved the objects via the constraint “requireObject”. Since we had more than 100 constraints, in order to control the length of the survey, we did not enumerate all constraints. For each type of constraint, we picked up a typical example of the constraint, and created a question based on the example. For example, the constraint “generateObject” was transformed into such a question: Do you think an activity may create new information? For example, taking blood glucose test will generate blood glucose lab result.

2 Concept transformations: For each concept we selected above, we created one question in the Likert scale. For example: How strongly do you agree that a primary goal of Self-Nutrition applications is to assist people to Stay Healthy? (Primary goal – stay healthy). The answer could be from 1. Strongly agree; 2. Agree; 3. Neutral; 4. Disagree; 5. Strongly disagree. In this way, each question represents a concept in SNM WDO. After such a transformation, we had 4 questions regarding goals, 31 questions regarding operations, 28 questions regarding objects, and 9 questions regarding constraints.

3 Adding open end questions: Besides the above questions, one question was created as independent variable regarding goal priority dependency “How strongly do you agree that a primary goal of Self-Nutrition applications is to assist people to Stay Healthy?” Two more questions were created regarding user experience with the SNM domain or SNM applications serving as independent variables. We also created 9 open-ended questions to allow users to express their own opinions in free text. For completeness: we used the question “What else can you think of as a related concept?” For explicitness, we used the question “Do you think any answer to the above questions is ambiguous? If yes, please write it done in text field below.” The evaluation survey was electronically developed using SurveyMonkey with password protection.

The correlations between two concepts were implicitly designed. Ideally, if the subjects strongly agree to “staying healthy” as the primary goal, they should also strongly agree to the sub goal of “staying healthy”, which is “having a stay healthy plan”.

Survey content validity: To be considered valid, the measurement should accurately describe what a concept was defined in SNM domain. In other words, the survey should adequately sample the most important observable competencies of a given concept. Two approaches were adopted to ensure content validity. 1) Three SMEs in concept modeling and survey design domain inspected the whole survey design process. The survey was modified accordingly to improve the relevance and clarity of each question. 2) Pilot test: the survey was administered to five users. Feedbacks from these users were considered for survey modification.

Survey internal consistency reliability: The single measurement instrument was administered to a group of human subjects on one occasion to estimate reliability. The reliability of the instrument can be judged by estimating how well the items that reflect the same construct yield similar results. In this research, the concern was about how consistent the answers are for different questions for the same survey within the measure. There are a wide variety of internal consistency measures that can be used. Cronbach’s Alpha was selected for this study.

Subjects: 41 overweight subjects were recruited from a convenience sample of healthcare professionals working in the medical center.

Setting: A closed lab was used for data collection. Users were requested to fill in the survey using a computer in the lab.

Chapter 6: Data Collection and Analysis

This chapter depicts issues related to the collection of data, experimental procedure, and presents the statistical considerations.

6.1 Capture Concepts

6.1.1 Capture Domain Independent Core Concepts to Build WDOS

6.1.1.1 Select the Core Concepts as Targets of WDOS

The decision of concept selection was made upon three reasons: 1) According to classical economics, goal, operation, object, constraint are key factors to describe work. 2) According to the frequency, these concepts are commonly used in the previous requirement engineering models. Goal is used five times in UC, GOMS, WBS, cognitive work analysis, and seven stage of action model. Operation and its synonyms, such as task, operator, activity etc., are used six times in UC, GOMS, WBS, cognitive work analysis, seven stages of action model and Object Action model. Object is used once in object action model. Constraint is used twice in WBS and cognitive work analysis. 3) According to the preliminary study of time management WDO, we demonstrated a scenario in which four concepts were required to describe the scenario. Therefore, goal, operation, object and constraint were selected as our targets for further analysis.

6.1.1.2 Determine the Aims of the Analysis

The aim of this analysis is to explicitly define the above four concepts to create a WDOS. This clarification will assist the future operationalization of the concepts for the development of domain specific WDO.

6.1.1.3 *Identify Uses of the Concept*

The previous uses of these four concepts were majorly identified via literature review and SME group discussions. GOMS, UC, WBS, object action interface model, cognitive work analysis, and seven stages of action model were studied.

Previous Uses of Goal

The definitions of goal vary in different ways. Kieras (Card, Moran, & Newell, 1983) (Kieras & John, 1994) stated that goals in the GOMS model are what the user intends to accomplish. Norman in the seven stage action model (Norman & Draper, User Centered System Design: New Perspectives on Human-Computer Interaction, 1986) stated that the goal is translated in an intention to do some action. Wysocki in WBS (Wysocki, 2006) defined that goal is an objective the system under consideration should achieve. Vicente, the founder of cognitive work analysis (Vicente, 1999) defined that goal is a state to be achieved or maintained by an actor at a particular time. Goals are attributes of actors.

Keller separated goals into functional and non-functional goals (Keller, Kahn, & Panara, 1990). Functional goals describe the services that the system is expected to deliver whereas non-functional goals refer to expected system qualities such as security, safety, performance, usability, flexibility, customizability, interoperability, and so forth (Keller, Kahn, & Panara, 1990). Mylopoulos stated that there is a clear distinction between soft and hard goals. Soft goals means the satisfaction of the goal cannot be established in a clear-cut sense (Mylopoulos, Chung, & Nixon, 1992); and hard goals means that satisfaction can be established through verification techniques, or measurable (Wysocki, 2006). Based on state-oriented definition, Dardenne (Dardenne, Van Lamsweerde, & Fickas, 1993) classified goal into three types according to the start and end states: achievement, maintenance and avoidance. An achievement goal is satisfied when a target condition is attained. A maintenance goal is satisfied as long as its target condition remains true. An avoidance goal is satisfied for as long as its target condition remains false. This state-driven classification originates from the methodology in Artificial Intelligence.

Previous Uses of Operation

Literature review indicated that many synonyms from different models share the same or similar definition of operation. Vicente called it “task” and defined it as an action that can and should be performed by one or more actors to achieve a particular goal (Vicente, 1999). Kieras called it “operator” and defined that operators are actions that are performed to get to the goal (Card, Moran, & Newell, 1983). Jacobus in his use case model (Jacobson, Christerson, Jonsson, & Övergaard, 1992) called it “case” and defined it as a description regarding how the actor will interact with the system to achieve a specific goal. Wysocki called it “activity” and defined it as a chunk of work.

Axel proposed that the top level operation is directed by operationalizing lowest level sub goal. Jocabus and Vicente separated operations into machine operation and human operation. Zhang separated operations into two categories: implementation independent operation and implementation dependent operation. Implementation independent operation is operation that the work domain needs to do to achieve the goal, for example, finding a patient name. Implementation dependent operations refers to how sub operations implement the operation, for example, if a physician want to find a patient name, the physician may click search button and read the text on an EHR interface. The physician can talk with the patient directly, or ask a nurse to do that. Implementation independent operations are generalizable for all hospitals which reflect the intrinsic difficulty of the work. Therefore, the identification of implementation-independent operation is reusable. Implementation dependent operations are highly dependent on the environment setting, context, and hospital routine policy, etc. Each hospital may implement the operation in different ways. Wysocki stated that implementation dependent operations are also useful because it enables one to estimate the duration of the work, determine the required resources, and schedule the work. Kieras specifically restricted operation to key-stoke level to study human machine interactions.

Previous Uses of Object

Shneiderman in his object-action model (Shneiderman & Plaisant, 2005) defined object as a basic concept of computer related objects like files, buttons, dialog box etc. This definition is too restricted for interface study only. Newell pointed out that, for abstract object, the classification of object is based on the intrinsic nature of the object; for concrete object, the classification of object is based on the intrinsic nature and external appearance (Newell, 1982). Objects can not only be referring to physical objects in classic economics, such as paper, pencils, calculators and computers, but also to mental objects (Norman & Draper, User Centered System Design: New Perspectives on Human-Computer Interaction, 1986), such as arithmetic, logic and language representing information structures rather than physical properties. Mental objects also include procedures and routines, such as mnemonics for remembering or methods for performing tasks (Norman & Draper, User Centered System Design: New Perspectives on Human-Computer Interaction, 1986). The common objects in a clinical work domain are text (such as SOAP, progress note, manuscript), graphics, figure annotation, high resolution image from X-Ray, CT, number from lab result, heart sound, oral debriefing, and full-motion video of the whole operation (Zhu M. D., 2006).

Previous Uses of Constraint

WBS took the definition of constraint originally from the book "Theory of constraint" (Goldratt, 1999), in which constraint is defined as anything that prevents the system from achieving more of its goal. In cognitive work analysis, constraint is defined as a relationship between or limits on, behavior. Constraint removes degrees of freedom. In information theory, constraint is defined as a degree of statistical dependence between or among variables. In artificial intelligence, constraint is defined as a condition that a solution to an optimization problem must satisfy.

Based on the descriptive limitation of the work, WBS approached divided constraint into money constraint, resource constraint and time constraint.

Based on distributed cognition, constraint can be divided into internal constraint or external constraint. Internal constraint (also known as cognitive constraint) refers to work demands associated with worker cognitive characteristics. External constraint (also known as environment constraint) refers to work demands associated with factors that are external to the worker, e.g. physical or social reality. Apparently, there are overlaps between the above classifications, i.e. a time constraint may also be an environmental constraint.

6.1.1.4 Determine the Defining Attributes

Attributes of Goal Discussed in Previous Approaches

Axel suggested that each goal should have a unique name. Bulter stated that there are two states for one goal, start state and end state (Butler, Zhang, Esposito, Bahrami, Hebron, & Kieras, 2007). Axel (van Lamsweerde, 2009) stated that, there is a priority attribute among multiple goals, for example, if there are multiple organ failure in one patient, the goal to save the most deadly organ will be the first priority.

Attributes of Operation Discussed in Previous Approaches

Wysocki suggested that each operation should have a unique name and ID. Vicente argued that operation requires an actor or operator to implement. Vicente stated that the operation can be done either by a machine or a human. In order to prevent complicated analysis of human characters which is the major assignment from behavior science, Marken suggested that the basic assumption behind each model is that human are adaptive and goal-oriented agents (Marken, 1986).

Attributes of Object Discussed in Previous Approaches

There is no unique classification or attributes of objects in current foundation ontology which is created to model the things in the world, such as CYC, Galen, and GFO, etc. For concrete object (Uschold, 1996), numeric attributes should be used to describe its external forms, such as weight, shape, color of an apple.

Attributes of Constraint Discussed in Previous Approaches

Constraint requires a name and ID to uniquely identify each of them. In cognitive work analysis, constraint has a clear object serving as the purpose of the constraint, a subject as target to impose effect, for example, a specific behavior. Constraint attributes in information theory can take other forms: (1) it can be fixed numbers, which might, for example, set the mean values or ranges of the variables: (2) iy can be functional relations between two or more variables.

6.1.1.5 Identify a Model Case

To achieve the goal "aware of BMI value", the users need to know the objects (weight value, height value, gender, BMI formula, ideal BMI range) and the operations on these objects, such as identifying weight value, identifying height value, identifying gender, identifying BMI formula, calculating BMI value, checking BMI value in BMI range under the constraint that, "Calculating BMI value" "is dependent on operation" "filling in weight value, height value, gender into BMI formula".

6.1.1.6 Identify Other Cases

A similar case is identified in drug prescription domain. For example, to achieve the goal of generating a drug prescription, the physicians need to know the Objects (drug name, pharmacological incompatibility, direction, availability in the store, etc.) and the Operations on these objects, i.e. "aware of the dosage for underweight patient" is under the constraint that "underweight patient should not consume the entire pill".

6.1.1.7 Identify Antecedents and Consequences

No antecedent and consequence was identified for these four concepts via literature review and SME discussions.

6.1.1.8 Define Empirical Referents

Timer, stop watch and watch served as the empirical referent for time management WDO. Public accessible applications in iPhone App store (Apple, Inc., 2010), such as lose weight, restaurant, served as empirical referents for the SNM WDO.

6.1.2 Capture Specific Concepts in SNM Domain to Populate a SNM WDO

The experiments were conducted in 2010. Approval to conduct this study was obtained from the Institutional Review Board (IRB), Committee for the Protection of Human Subjects at the University of Texas Health Science Center at Houston (Appendix A).

Five subjects were selected from graduate schools within the Texas Medical Center. Subjects were recruited through face to face presentation. These subjects were recruited (ages 18 years and older) regardless of ethnicity and gender.

Recruited subjects were required to read the IRB approved consent form, in which the purpose, potential risks, benefits, and the amount of compensation were indicated. The primary investigator addressed the subjects' concerns and questions about the experiment. When there were no further questions, the subjects signed the consent forms. All subject information was then coded using a study accession number. There was no direct identifiable link between the data collected and the subjects.

Data collection was conducted in a private cubicle within the Cognitive Informatics Laboratory located at the School of Biomedical informatics, University of Texas Health Science Center at Houston. The total duration was one hour and twenty minutes.

Each subject was given a 10-dollar grocery gift card as compensation for his/her participation in this research. No subjects withdrew from this research. Audio-recorded interview data were played and transcribed into text using Microsoft OneNote. Double check was implemented by playing the audio from beginning to the end and validating the transcribed text.

6.2 Code the Concepts

6.2.1 Commit to Basic Terms that Will Be Used to Specify the Ontology

We created a new project in NVivo and saved the transcribed text as the source file. Analytical coding was majorly used to interpret data. Interview transcript was read and re-read to identify the core concepts. Concepts were aggregated into four sets： goal, operation, object, constraint. The results were reviewed, discussed, modified, and approved by three SMEs.

6.2.2 Write the Code

An OWL file was created in Topbraid composer when the above four sets were identified. The name space of the OWL file was created using the string "http:// www.uthouston.edu/sbmi/WorkCenteredDesign/WDOS". Camelback naming convention was selected to guide the code written process (van Lamsweerde, 2009). As defined in Camelback, 1) no spaces or punctuation is allowed in the concept name. 2) Minimal dashes and underscores should be used in the concept name. 3) Name should be short but descriptive. Each class name should start with the upper case. Each property name should start with a lower case letter and subsequent first letters was capitalized. The modeling process also followed top-down strategy.

Construct WDOS

In this step, concept name, definition, attributes, and relationships were created using ontology terms.

Construct *owl:Class*

Four classes called goal, operation, object, constraint were created as *owl:Class* in the OWL serving as the "set". Each two classes were set with *owl:disjoint* property which means an instance cannot be under more than one of these four classes.

Construct *owl:Property*

owl:DatatypeProperty was used to hold attributes of four core concepts identified in concept analysis. *owl:hasName*, *owl:hasID*, *owl:hasStartState* and *owl: hasEndState* have been created under *owl:DatatypeProperty as attributes of the core concepts.*

owl:ObjectProperty was used to hold constraints. The domain and range with the primitives *rdfs:domain* and *rdfs:range* were explicitly used to set the source and target of a constraint. For example, the constraint "goal may have sub-goals" has been created as owl: *owl:TransitiveProperty* with *owl:domain* goal and *owl:range* goal.

Any property that can be classified under other property was created as sub-property using the primitive *rdfs:subPropertyOf*.

Construct OWL Value Constraints

One built-in OWL value constraint was also used in this study: *owl:someValuesFrom*

The value constraint *owl:someValuesFrom* is a built-in OWL property that links a restriction class to a class description or a data range. A restriction containing an *owl:someValuesFrom* constraint describes a class of all individuals for which at least one value of the property concerned is an instance of the class description or a data value in the data range. For example, the statement regarding possible competition between goals "favorite foods are taken in a weekly base" and "staying healthy" was modeled as *"StayingHealthy" "hasCompetingGoal" "owl:someValuesFrom" "FavoriteFoodsAreTakenInA_WeeklyBase"*.

Populate SNM WDO

Since the output of the focus group interview is plain text narrative, the output from NVivo is not formal enough for ontology modeling. The process to populate SNM WDO is still analytical and upon group discussions with SMEs.

A new OWL file called "SNMWDO" was created with the name space "http:// www.uthouston.edu/sbmi/WorkCenteredDesign/SNMWDO".

WDOS was imported into SNM WDO serving as the top level schema. All concepts identified in the four sets were validated and imported to populate SNM WDO.

We first constructed goals and the attributes of goal. We then set the constraints between goal and sub goal. For example, we created subclass "StayingHealthy" and subclass "HavingA_StayingHealthyPlan". We then created a constraint called "requireSubGoalHavingA_StayingHealthyPlan" and set its domain as "StayingHealthy" and its range as "HavingA_StayingHealthyPlan".

After that, we created operations and the attributes of operation. We then connected the lowest level sub goal and operation using the constraint between goal and operation "requireOperation". For example, the goal "AwareOfBMI_Value" "requireOperation IdentifyBMI_Fomula" "IdentifyBMI_Fomula". We then set the constraints between operations.

After that, we constructed objects and the attributes of object. We then connected operation and object using the constraints between operation and object "requiresObject" or "generateObject", i.e. the operation, "IdentifyHeight" "requiresObjectHeightValue" "HeightValue". We then set the constraints between objects.

The consistency check was implemented using ontology reasoning engineer. No item was identified in Topbraid composer error log.

6.3 Evaluate Ontology

This session depicts issues related to the collection of survey data, experimental procedure, and presents the statistical considerations. The experiments were conducted in 2010. Approval to conduct this study was obtained from the Institutional Review Board (IRB), Committee for the Protection of Human Subjects at the University of Texas Health Science Center at Houston (Appendix A).

6.3.1 Survey Data Collection

This study solicited a purposeful sample of 41 subjects from graduate schools within the Texas Medical Center. Subjects were recruited through face to face presentation. These subjects were recruited (ages 18 years and older) regardless of ethnicity and gender.

Data collection was conducted in a private cubicle within the Cognitive Informatics Laboratory located at the School of Biomedical informatics, University of Texas Health Science Center at Houston. All experimental materials were presented to the subjects using a Dell Latitude XT2 laptop computer with an identical screen resolution.

Recruited subjects were required to read the IRB approved consent form, in which the purpose, potential risks, benefits, and the amount of compensation were indicated. The primary investigator addressed the subjects' concerns and questions about the experiment. When there were no further questions, the subjects signed the consent forms.

All subject information was then coded using a study accession number. There was no direct identifiable link between the data collected and the subjects. They were told to feel free to ask any question during the data entry process. Subjects were informed that it was allowable to take a break during data entry process.

On average, each subject took less than 22 minutes, including breaks, to complete the entire experiment. Each subject was given a 10-dollar grocery gift card as compensation for his/her participation in this research. No subjects withdrew from this research. Data were transferred and combined into a single Excel sheet from SurveyMonkey. Data were then clustered and sorted for each research question in separated Excel sheets and loaded in SPSS.

6.3.2 Survey Data Analysis

Descriptive analysis of subjects' demographic information

Descriptive analysis was used to analyze subjects' demographic information, such as age, gender, race, etc.

Survey Internal consistency reliability

Cronbach's Alpha was used to test internal consistency reliability. Four tests were executed upon the questions under four subscales.

Q1: What is the acceptance rate of SNM WDO by users?

Concepts related survey questions are divided into four subscales: goal subscale, operation subscale, object subscale and constraint subscale. For each subject, we summed the total score of all questions in one subscale and divided the score by total number of questions in that subscale. This step provided us an average score for each of the four subscales: GO for goal subscale, OP for operation subscale, OB for object subscale, CO for constraint subscale.

This question was answered by one sample *t* test globally using the four average scores of the groups of questions regarding goal, operation, object and constraint, and locally using individual Likert scale question.

Hypothesis: For each subscale or individual Likert scale question, H_0: μ Average score = 3 (neutral). Two tailed *t* statistics tested the hypotheses at the α = .05 significance level.

Q2: Does SNM experience affect SNM WDO in general?

This question was answered globally by the Puri-Sen *L* test, one-way nonparametric multivariate analysis (MANOVA), and locally by the Mann Whitney *U* test, One-way nonparametric univariate analysis.

In order to generate global statement, all concepts related questions are divided into four subscales: goal subscale, operation subscale, object subscale, constraint subscale. For each subject, we summed the total score of every question in one subscale and rank the score. As a result, we created the rank of the total score of all goal related questions, RGO; the rank of total score of all operation related questions, ROP; the rank of the total score of all object related questions, ROB; the rank of total score of all constraint related questions, RCO.

Puri-Sen *L* test

Hypothesis: H_0: μ Domain Experience = μNo Domain Experience. Puri-Sen *L* statistic tested the hypothesis at the α = .05 significance level.

Independent variable: Domain Experience versus No Domain Experience (categorical variable)

Dependent variables for global multivariate Puri-Sen *L* test: RGO, ROP, ROB, RCO

Formula: *L*=Pillai's Trace * (total number of records-1), Degree of freedom (*df*) = total groups of independent variable-1.

Mann-Whitney *U* test

Hypothesis: H_0: μ Domain Experience = μNo Domain Experience. Mann-Whitney *U* statistic tested the hypothesis at the α = .05 significance level.

Independent variable: Domain Experience versus No Domain Experience (categorical variable)

Dependent variables for local univariate Mann-Whitney U test: the Likert scale rating response to each question (ordinal variable).

Q3: Does SNM App experience affect SNM WDO in general?

This question was answered globally by the Puri-Sen L test, one-way nonparametric multivariate analysis (MANOVA), and locally by the Mann Whitney U test, One-way nonparametric univariate analysis.

Puri-Sen *L* test

Hypothesis: H_0: μ App Experience = μNo App Experience. Puri-Sen *L* statistic tested the hypothesis at the α = .05 significance level.

Independent variable: App Experience versus No App experience (categorical variable).

Dependent variables for global multivariate Puri-Sen *L* test: RGO, ROP, ROB, RCO.

Formula: *L* = Pillai's Trace * (total number of records-1), Degree of freedom (*df*) = total groups of independent variable-1.

Mann-Whitney *U* test

Hypotheses: H_0: μ App Experience = μNo App Experience. Mann-Whitney *U* statistic tested the hypothesis at the α = .05 significance level.

Independent variable: App Experience versus No App experience (categorical variable).

Dependent variables for local univariate Mann-Whitney *U* test: the Likert scale rating response to each question (ordinal variable).

Q4: Is the WDO dependent on subject primary goal?

Since 39 subjects selected “staying healthy” as the primary goal, 2 subjects did not. The very small sample size of 2 for the second group is inadequate for a meaningful statistical testing. This question will be addressed in the future study.

Q5: Is the Correlations between Two Concepts in WDO Consistent?

Pearson correlation matrix was calculated. After that, we picked up meaningful correlations based on our research design. Pearson correlation value between 0.1 and 0.3 will be considered as small size. Pearson correlation value between 0.3 and 0.5 will be considered as moderate size. Pearson correlation value above 0.5 will be considered as large size (Cohen, 1992).

Q6: Is There Any Ambiguous Concept in WDO?

The answers of these questions were presented in free text. All text were integrated into one new source file and saved in previous NVivo project. Topic coding was used to assign the data to four topics: goal, operation, object and constraint.

Q7: Is There Any New Concept We Did Not Address in Focus Group Interview?

The answers of these questions were presented in free text. All text were integrated into one source file and saved in previous NVivo project. Topic coding was used to assign the data to four topics: goal, operation, object and constraint.

Chapter 7: Results and Discussion

This chapter summarizes the results of this study and discusses the significance, limitation, and future impact of this study.

7.1 Result for goal 1: Formalize the WDOS

The core concepts for WDOS were identified in this study: goal, operation, object, constraint. The attributes of these concepts were identified. The first draft of WDOS was created as a sharable ontology file. The future development of domain specific WDO can be done by importing and extending WDOS.

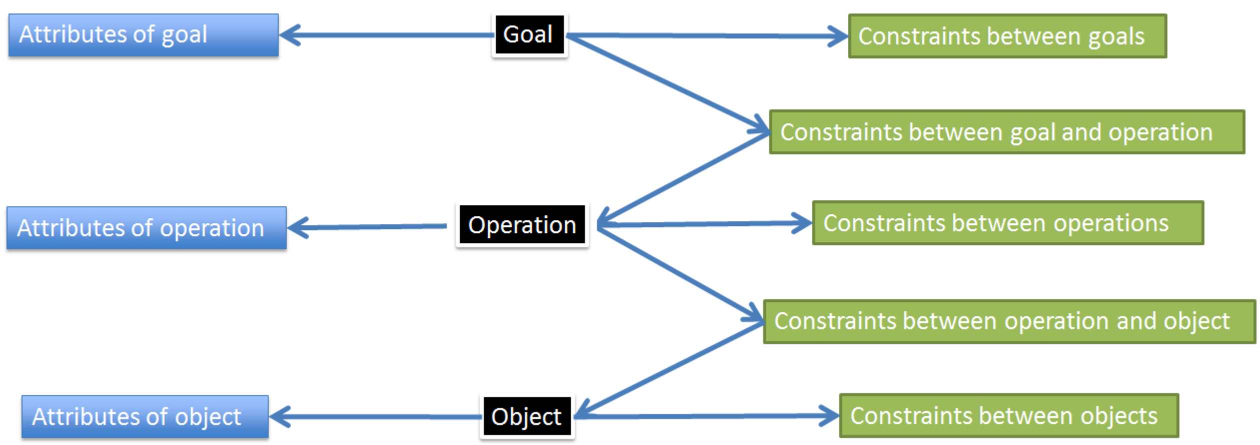

Figure 4. WDOS identified in this study.

7.1.1 Definitions of goal, operation, object and constraint

Definition of Goal in WDO

Goal is the objective some efforts in the work domain want to achieve. Goal answers the essential question why a work domain exists.

Definition of Operation in WDO

Operation is a necessary action generating effort towards goal. Operation answers the question what the major activities are in the work domain.

Definition of Object in WDO

Object is an entity toward which an operation is directed. Object answers the resource requirement for the work domain.

Definition of Constraint in WDO

Constraint is a relationship between two concepts which defines an explicit condition the work domain must satisfy. Constraint answers internal connection among work domain concepts.

7.1.2 Attributes of goal, operation, object and constraint

Attributes of Goal in WDO

hasID: this attribute defines the unique identifier of a goal in a work domain.

hasName: this attribute defines the unique name of a goal in a work domain.

Attributes of Operation in WDO

hasID: this attribute defines the unique identifier of an operation in a work domain.

hasName: this attribute defines the unique name of an operation in a work domain.

hasStartState: the start state indicates the state when operation has not been implemented.

hasEndState: the end state indicates the state or outcome when an operation has been implemented.

Attributes of Object in WDO

hasID: this attribute defines the unique identifier of an object in a work domain.

hasName: this attribute defines the unique name of an object in a work domain.

Attributes of Constraint in WDO

hasID: this attribute defines the unique identifier of an object in a work domain.

hasName: this attribute defines the unique name of an object in a work domain.

hasSource: the source is the initializer of the constraint in a work domain.

hasTarget: the target is the receiver of the constraint in a work domain, i.e. the constraint "requireOperation" has source "goal" and target "operation".

7.2 Result for goal 2: operationalize a procedure to develop WDO

Based on the theoretical foundation, we customized ontology engineering and created an operationalized procedure to develop domain specific WDO: 1) Conduct focus group interview to capture domain specific concepts from domain participants. 2) Construct ontology modeling by importing WDOS and populating the model using goal-oriented strategy. 3) Conduct semi-structured survey to validate the quality of WDO according to the six criteria mentioned above.

7.3 Result for goal 3: evaluate WDO approach using a concrete domain

The concrete SNM WDO was developed, evaluated and modified using data collected from focus group interview and semi-structured survey.

Result of Focus Group Interview

Descriptive analysis of subjects' demographic information

Of the 5 human subjects, 2 are female, 3 are male. All subjects are Asians with an average age at 27.5.

NVivo analytic coding result

Fourteen goals were identified. Among them, five were identified as top level goals by all subjects: "Staying healthy", "favorite foods are taken in a weekly base", "Aware of new food knowledge", "expense is controlled properly", and "Aware of food information shared by friends". Only female subjects strongly agreed that the goal "Private information is protected" was needed to be achieved as top level goal. "Staying healthy" was agreed as the primary goal based on the consensus among 5 subjects. There was no consensus regarding the priority rank for the other five top level goals. Seven sub goals were discussed as well, i.e. “having a staying healthy plan” is a sub goal of “staying healthy”.

Forty-six operations were identified. Among them, “monitor body status”, “monitor nutrition balance”, “monitor energy consumption via exercise” were most frequently proposed, responded and accepted by all users. Other operations, such as “identify guidance regarding exercise type and time”, “identify BMI” were also widely discussed. The operations related with “Private information is protected”, such as “identify private information”, “set up protection approaches” were only proposed and agreed by two female subjects.

Sixty-eight objects were identified. Among them, “nutrition fact”, “body status measurements”, “exercise type” are widely discussed with instantiations, such as “potassium”, “weight scale”, “yoga”, etc.

Twelve constraints were identified. The constraints were implicitly discussed during the focus group interview. The constraints between goal and sub goal “requires sub goal”, between goal and operation “requires operation”, between operation and object “requires object” were accepted based on the consensus among 5 subjects. The possible competition between goals “favorite foods are taken in a weekly base” and “staying healthy” was discussed. The dependency between operations, such as “calculate BMI” is dependent on “identify weight value”, was discussed as well.

Results of Semi-Structured Survey

Descriptive analysis of subjects' demographic information

Of the 41 subjects, there are 17 males and 24 females. 1 subject is under the age of 25, 22 subjects are between the age of 25 and 34, 15 subjects are between the age of 35 and 44, and 3 subjects are older than 45 years old. Among the subjects, 5 are Hispanic, 29 are Asians, 3 are Caucasians, and 4 are African Americans.

Survey internal consistency reliability

The questionnaire has high reliabilities ranging from 0.743 to 0.961. For the three questions related with goal, Cronbach's alpha is 0.743. For the 31 questions related with operation, Cronbach's alpha is 0.961. For 28 questions related with objects, Cronbach's alpha is 0.956. For 9 questions related with constraints, Cronbach's alpha is 0.887.

Q1: What is the acceptance rate of SNM WDO by users?

One-sample *t* test result:

Table 4 One-sample *t* test result 1

	N	Mean	Std. Deviation	Std. Error Mean
AVG GO	41	4.1768	.72294	.1129
AVG OP	41	4.1589299	.48092	.0751
AVG OB	41	4.2195121	.49284	.0769
AVG CO	41	4.1436314	.65557	.1023

The means of four subscales in table 4 are all above four, which indicates general agreement between 4 (agree) and 5 (strongly agree) in Likert scale.

Table 5 One-sample *t* test result 2

	Test Value = 3						
	T	*Df*	*Sig. (2-tailed)*	*Standardized Effect Size*	*Mean Difference*	*95% Confidence Interval of the Difference*	
						Lower	*Upper*
AVG GO	10.423	40	$P < .001$	1.6278	1.1768	.9486	1.4050
AVG OP	15.430	40	$P < .001$	2.4101	1.1589	1.0071	1.3107
AVG OB	15.844	40	$P < .001$	2.4747	1.2195	1.0639	1.3750
AVG CO	11.170	40	$P < .001$	1.7441	1.1436	.9367	1.3505

Global tests: All Table 4 subscale means significantly exceeded 3 ($p < 0.001$). The standardized effect sizes indicate strong agreements with goal, operation, object, constraint subscale questions.

Local tests: Among the one-sample *t* tests on each of the 72 Likert scale items, the mean significantly exceeded 3 ($p < 0.001$), with one exception $p = 0.008$ (see Appendix E). The standardized effect sizes indicate strong agreement with each SNM question.

Q2: Does SNM experience affect SNM WDO in general?

Puri-Sen *L* Test Result: $L= 0.064*(41-1) =2.56$, $df= 1$. The critical value of Chi-square with df = 1 at .05 level is 3.84. 2.56 < 3.84. The difference between experienced and inexperienced groups regarding agreement with the four subscales of concepts in SNM WDO are not statistically significant ($\alpha =.05$).

Mann-Whitney *U* Test Result: We found that except for "food location" ($p = .025$) concept item, there were no significant ($\alpha =.05$) differences between these two groups in individual Mann-Whitney U test.

Q3: Does SNM App experience affect SNM WDO in general?

Puri-Sen *L* Test Result: *L*= 0.128*(41-1) =5.12. *df* = 1. We checked Chi-square table and retrieved the value 3.84. When $p = 0.05$, 5.12 > 3.84, this significant (α =.05), reject H_0. There is significant difference between the groups with App experience and without App experience in SNM WDO. In order to further probe the research hypothesis, we conducted Mann-Whitney *U* test to see if there is significant difference among individual questions.

Mann-Whitney *U* Test Result: We found that except for the object "historical weight trend" (p = .036) and the constraint between operation and object "operation may generate new information" (p = .027), there is no difference between these two groups.

Q5: Is the correlation between two concepts in WDO consistent?

Pearson Correlation Result:

3 pairs were identified based on the constraint "requireSubGoal" between goal and sub-goal. Among the 3 pairs, there is no significant correlation.

19 pairs were identified based on the constraint "requireOperation" between sub goal and operation. Among the 19 pairs, 10 pairs have moderate size correlations; 3 pairs have large size correlations see appendix K.

3 pairs were identified based on the constraint "hasSubOperation" between operation and sub operation. Among the 3 pairs, 1 pair has large size correlation; 1 pair has moderate size correlation.

16 pairs were identified based on the constraint "requireObject" and "generateObject" between operation and object. Among the 16 pairs, 5 pairs have moderate size correlation; 3 pairs have large size correlation.

Q6: Is there any ambiguous concept in WDO?

Based on the collected data from semi-structured survey, one subject reported BMI was ambiguous. However during test, two subjects asked us about the concept “food location” which was further clarified with examples, such as “restaurant” and “grocery store”. Human subjects were satisfied with the explanation.

Q7: Is There Any New Concept We Did Not Address in Focus Group Interview?

The concepts below were identified for the possible expansion of SNM WDO.

Goal: “aware of applicable medication” was mentioned by one subject.

Object: “bone density”, “applicable medication”, “waist size” were mentioned by one subject.

Sub operation: “monitor waist size” “isSubOperationOf” “monitor body status” was mentioned by one subject.

Object: “cholesterol level” was mentioned by five human subjects. “Blood pressure”, “percentage of muscle mass and water” and “food combination” were proposed by one subject.

7.4 Discussion

We divided our discussions into three parts: 1) the impact of this research towards future WCD; 2) the limitations of this study; and 3) future work.

7.4.1 The Impact of This Research towards WCD

Initial Step towards the Clarification of WDOS

WDO is a projection of the work and how the concepts of work are related to one another. It bridges the gap between work domain knowledge analysis and usefulness implementation in information system. Comparing with previous approaches, the ambiguous definition issue has been solved. Critical attributes of the concepts in WDOS have been proposed. This research initialized the WDOS as the groundwork for future clarification and expansion of core concepts in WDOS. This dissertation provides the definition of WDOS and operational tutorial for the future implementation of work domain analysis in other domains by expanding WDOS.

Towards WDO Reuse

Software reuse has been widely discussed (Van Lamsweerde, 2009) (Jacobson, Booch, & Rumbaugh, The Unified Software Development Process, 1999). However, domain specific software products are rarely reused (Newell, 1982) due to the complexity of work, specific environment setting, workflow, organization issues, etc. Currently, we have over 300 EHR vendors and over 1000 EHR products if taking into account different versions of EMR products (List of EMR software vendors, 2010). The repetitive software reengineering processes are consuming tremendous resources with little efforts by reinventing similar functions among all EMR to meet work requirements. A generalizable WDO will be reusable among all software projects dedicated to the same work domain, therefore partially reduce unnecessary waste of software engineering resources.

7.4.2 The Limitations of This Research

Focus group interview can provide details of the research domain, but is subject to problems of bias and small samples. Such bias can come from individual personality in the working style or memory failures to recall work domain knowledge. For example, if the work is important but not frequently implemented, it may not be recalled. Semi-structured survey also carries limitations. Subjects may not spend as much time answering a survey as they will in an interview, so the amount of data collected per informant will necessarily be less.

Statistic consideration: While small studies can provide results quickly, they do not normally yield reliable or precise estimates. The main problem with small studies is interpretation of results, in particular confidence intervals and *p* values. The lack of statistical significance does not mean there is no effect. Small studies may produce false-positive or false-negative results, or over-estimate the magnitude of an association. Therefore, we cannot make definitive conclusions from Puri-Sen *L* test, Mann-Whitney *U* test and Pearson correlation test at this moment due to the small sample size, i.e. In order to draw definitive conclusion for Q2 and Q3 using Mann-Whitney *U* test, 368 records are needed for two tailed hypothesis with effect size 0.3, *p* value 0.05 and power 0.8 (Erdfelder, Faul, & Buchner, 1996). Data collected in this study will be used to design larger confirmatory studies in the future.

7.4.3 Future Work

The future work aims to improve the WDOS and its operationalized procedure towards WCD.

Model Prospect

Further studies of WDO in different work domains are still needed to validate and expand the WDOS, i.e. studying the further classifications of four core concepts and the enumeration of all possible constraints. During survey data analysis, we proposed a boundary between implementation dependent and independent operation by evaluating deviation of acceptance. The significant deviation of acceptance may indicate that the concept already touched the variant implementation details. A second round of survey may be used to test this hypothesis in the future.

OWL supports first-order logic based reasoning. How to take advantage of the reasoning feature to discover unknown work domain knowledge will be an interesting research question in the future.

A complex system may have loose coupling constraint or unknown dynamics between concepts in a work domain, such as an open system (Von Bertalanffy, 1969). At this time being, we did not meet expressiveness limitation of first-order logic because of the small scale of this study. When WDO approach is implemented in a large scale research, the expressiveness power may be further discussed by comparing the new modeling requirements with first-order logic supported expressions.

Engineering Prospect

Current operational procedure of WDO is still lab-intensive and time-consuming. Single survey usually cannot cover all concepts in one work domain. Ways to improve the efficiency of this method are still needed to be addressed.

Since this is a small size study, other ontology engineering methods are still needed to be tested, such as ontology alignment, synthesis, aggregation, etc.

Usefulness Prospect

Apparently, the next research question is about how to take advantages of WDO specification to realize usefulness in the final implementation. Upon UFuRT framework (Zhang & Butler, UFuRT: A work-centered framework and process for design and evaluation of information systems, 2007), one way is to further decompose implementation-independent operation into implementation-dependent operation. Operation allocation analysis can then be implemented to allocate proper operations to participants or artifacts in the distributed work domain. Operation related objects can then be identified. A representation analysis can be implemented afterwards to study how to represent these objects. Meaningful interactions can then be generated to actually help people accomplish their work in valuable ways. Further research in these directions will be very promising to close the loop of usefulness study.

Chapter 8: Summary and Conclusion

A successful system design from a problem space to its solution space requires the system to be both useful and usable. Usefulness means that the system can actually help people accomplish their work in valuable ways. In order to achieve usefulness, it is essential to model the work in the specification of requirement to summarize data from acquisition of requirement and guide the implementation of requirement. The objective of this research is to formalize the WDOS, operationalize a procedure to develop WDO, and evaluate WDO approach using a concrete domain.

This research is motivated by distributed cognition to build a formal WDOS to support the articulation of work domain knowledge. The concepts of WDOS derive from classical economics. General system theory provides general guidance of system analysis, such as basic rules in a system and various methodologies to study a system. Ontology engineering provides applicable engineering method towards the development of WDO.

Four concepts, "goal, operation, object and constraint", were identified and formally modeled in WDOS with definitions and attributes. Data from focus group interview were used to populate SNM WDO. 72 concepts under primary goal "staying healthy" in SNM WDO were selected and transformed into semi-structured survey questions. The evaluation indicated that the major concepts of SNM WDO were accepted by overweight human subjects. SNM WDO is generally independent of user domain experience but partially dependent on SNM application experience. 23 of 41 paired concepts have significant correlation. Two concepts were identified as ambiguous concepts. 8 concepts were recommended towards the completeness of SNM WDO.

The preliminary WDOS is ready with an operationalized procedure. This research is an initial step towards the clarification of WDOS.

Future WDO development in different WDO can start by importing and expanding WDOS using the operationalized procedure demonstrated in this study. The continuing study includes: 1) implementing WDO in more domains to validate and refine WDOS, 2) identifying innovative usages of WDO, such as quality control, decision support, interface design, etc.

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Appendix A: CPHS Approval

THE UNIVERSITY *of* TEXAS
HEALTH SCIENCE CENTER AT HOUSTON

The Committee for the Protection of Human Subjects
Office of Research Support Committees

6410 Fannin, Suite 1100
Houston, TX 77030

Dr. Jiajie Zhang
UT-H - SHIS - Health Informatics

NOTICE OF APPROVAL TO BEGIN RESEARCH March 04, 2009

HSC-SHIS-09-0047 - Formalizing a Conceptual Framework of Work Domain Knowledge

PROVISIONS: This approval relates to the research to be conducted under the above referenced title and/or to any associated materials considered by the Committee for the Protection of Human Subjects, e.g. study documents, informed consent, etc.

APPROVED: By Expedited Review and Approval

REVIEW DATE: 3/4/2009

APPROVAL DATE: 3/4/2009

EXPIRATION DATE: 2/28/2010

CHAIRPERSON: Anne Dougherty, MD

Subject to any provisions noted above, you may now begin this research.

CHANGES: The principal investigator (PI) must receive approval from the CPHS before initiating any changes, including those required by the sponsor, which would affect human subjects, e.g. changes in methods or procedures, numbers or kinds of human subjects, or revisions to the informed consent document or procedures. The addition of co-investigators must also receive approval from the CPHS. **ALL PROTOCOL REVISIONS MUST BE SUBMITTED TO THE SPONSOR OF THE RESEARCH.**

INFORMED CONSENT: When Informed consent is required, it must be obtained by the PI or designee(s), using the format and procedures approved by the CPHS. The PI is responsible to instruct the designee in the methods approved by the CPHS for the consent process. The individual obtaining informed consent must also sign the consent document. Please note that only copies of the stamped approved informed consent form can be used when obtaining consent.

HEALTH INSURANCE PORTABILITY and ACCOUNTABILITY ACT (HIPAA):
The study must meet all HIPAA research requirements. For compliance guidelines see details on the Committee for the Protection of Human Subjects website at:
http://www.uth.tmc.edu/ut_general/research_acad_aff/orsc/cphs/guidelines/hipaa.htm

UNANTICIPATED RISK OR HARM, OR ADVERSE DRUG REACTIONS: The PI will immediately inform the CPHS of any unanticipated problems involving risks to subjects or others, of any serious harm to subjects, and of any adverse drug reactions.

RECORDS: The PI will maintain adequate records, including signed consent and HIPAA documents if required, in a manner that ensures subject confidentiality.

Appendix B: Consent Form

Formalizing a Conceptual Framework of Work Domain Ontology

INFORMED CONSENT FOR RESEARCH STUDY

INVITATION TO TAKE PART

You are being invited to take part in a research project called, Formalizing a Conceptual Framework of Work Domain Knowledge conducted by Dr Jiajie Zhang and his research staff. Your decision to take part is voluntary and you may refuse to take part, or choose to stop taking part, at any time. You may refuse to answer any questions asked or written on any forms. This research project has been reviewed by the Committee for the Protection of Human Subjects (CPHS) of The University of Texas Health Science Center at Houston as Protocol Number HSC-SHIS-09-0047.

QUESTIONS:

Dr. Jiajie Zhang and his research staff will be glad to answer any questions regarding the study at any time at 713-500-3922.

DESCRIPTION OF RESEARCH

The purpose of this study is to learn the daily activities of nutrition management software users through an improved informed consent process and develop a conceptual model to describe these activities. We will gather information from nutrition management software users, and design and test a new prototype of nutrition management software.

PROCEDURES

During this study there are no right or wrong actions or answers. As a part of the study you will do one or more of the following. (1) Interview. In the interview, we will ask you a series of questions in the following categories: advantages and disadvantages of using nutrition management software, areas that need improvement, etc. An audio recording of the interview may be made to help data gathering. (2) Survey. You may also be asked to fill out survey questions about your thoughts of the information provided during the informed consent process. (3) Evaluate a new prototype of nutrition management software. You will first be asked to fill out an evaluation survey by rating the usefulness of each interface of the prototype. Your interaction with the prototype will be observed and you maybe asked to think aloud as you interact with the prototype.

TIME COMMITMENT

The experiment will take about 60 minutes.

RISKS

There will be no physical risk or discomfort for you. The data will only be handled by the investigators on the project. After the data collection of each session, the data will be stored in a locked box. After each analysis of the data, they will be placed back in the locked box. The investigators will translate the data from the audio files or notes into a password protected computer, kept in a locked office. This computer will not be used by anyone other than study personnel. No identifiers of the people in the study will be kept in the transcribed data. The data (audio and notes) will be immediately destroyed after the work is completed. The computer files will also be destroyed after the study is completed. If you agree to be in this study, all information will be anonymous. When and if this study is reported, only anonymous data will be presented.

BENEFITS

You will receive no direct benefit from being in this study; however, your taking part may help us develop better healthcare software engineering process in the future.

ALTERNATIVES

You have the choice of not being in this study.

STUDY WITHDRAWAL

You can withdraw from this study at anytime for any reason by calling Dr. Jiajie Zhang at 713-500-3922.

IN CASE OF INJURY

If you suffer any injury as a result of taking part in this research study, please understand that nothing has been arranged to provide free treatment of the injury or any other type of payment. However, all needed facilities, emergency treatment and professional services will be available to you, just as they are to the community in general. You should report any injury to Dr. Jiajie Zhang at (713) 500-3922 and to the Committee for the Protection of Human Subjects at (713) 500-7943. You will not give up any of your legal rights by signing this consent form.

CONFIDENTIALITY

You will not be personally identified in any reports or publications that may result from this study. Any personal information about you that is gathered during this study will remain confidential to every extent of the law.

COSTS, REIMBURSEMENT, AND COMPENSATION

You will receive $10.00 for you taking part in this study.   No other compensation will be given.

SIGNATURES:

Taking part in this study is your choice. If you sign this form it means that you wish to take part in this research study. Sign below only if you understand the information given to you about the research and choose to take part. Make sure that any questions have been answered and that you understand the study. If you have any questions or concerns about your rights as a research subject, call the Committee for the Protection of Human Subjects at (713)500-7943. If you decide to take part in this research study, a copy of this signed consent form will be given to you.

____
Printed Name of Subject

____________________________________   __________________
Signature of Subject   Date/Time

____
Printed Name of Individual Obtaining Consent

____________________________________   __________________
Signature of Individual Obtaining Consent   Date/Time

IRB NUMBER: HSC-SHIS-09-0047
IRB APPROVAL DATE: 7/26/2010
IRB EXPIRATION DATE: 11/30/2010

CPHS STATEMENT:

This study (HSC-SHIS-09-0047) has been reviewed by the Committee for the Protection of Human Subjects (CPHS) of the University of Texas Health Science Center at Houston. For any questions about research subject's rights, or to report a research-related injury, call the CPHS at (713) 500-7943.

Appendix C: CPHS Renew Approval

THE UNIVERSITY *of* TEXAS
HEALTH SCIENCE CENTER AT HOUSTON

The Committee for the Protection of Human Subjects
Office of Research Support Committees

6410 Fannin, Suite 1100
Houston, TX 77030

Jiajie Zhang, PhD
UT-H - SHIS - Health Informatics

NOTICE OF CONTINUING REVIEW APPROVAL December 17, 2009

HSC-SHIS-09-0047 - *Formalizing a Conceptual Framework of Work Domain Knowledge*

PI: Jiajie Zhang, PhD

PROVISOS: Provide CPHS a copy of the human subject's education certificate for Min Zhu by faxing the document to 713-500-7951.

Unless otherwise noted, this approval relates to the research to be conducted under the above referenced title and/or to any associated materials considered at this meeting, e.g. study documents, informed consents, etc.

NOTE: If this study meets the federal registration requirements and this is an investigator-initiated study, or if the PI is the study sponsor or holds the IND/IDE applicable to this study, and no one else has registered this trial on the national registry, you are required to register this trial on the national registry at www.clinicaltrials.gov in order to publish results in any of the key peer-reviewed journals. For further information contact Gena Monroe at 713-500-7903.

APPROVED: By Expedited Review and Approval

REVIEW DATE: December 15, 2009

APPROVAL DATE: December 17, 2009 **EXPIRATION DATE**: 11/30/2010

CHAIRPERSON: Anne Dougherty, M.D.

Upon review, the CPHS finds that this research is being conducted in accord with its guidelines and with the methods agreed upon by the principal investigator (PI) and approved by the Committee. This approval, subject to any listed provisions and contingent upon compliance with the following stipulations, will expire as noted above:

CHANGES: The PI must receive approval from the CPHS before initiating any changes, including those required by the sponsor, which would affect human subjects, e.g. changes in methods or procedures, numbers or kinds of human subjects, or revisions to the informed consent document or procedures. The addition of co-investigators must also receive approval from the CPHS. ALL PROTOCOL REVISIONS MUST BE SUBMITTED TO THE SPONSOR OF THE RESEARCH.

INFORMED CONSENT: Informed consent must be obtained by the PI or designee(s), using the format and procedures approved by the CPHS. The PI is responsible to instruct the designee in the methods approved by the CPHS for the consent process. The individual obtaining informed consent must also sign the consent document. Attached is the approved and validated informed consent form. You must discard all previous informed consent documents being used and replace them with this stamped validated version. **Please note that only copies of the appropriately dated, stamped approved informed consent form can be used when obtaining consent.**

UNANTICIPATED RISK OR HARM, OR ADVERSE DRUG REACTIONS: The PI will immediately inform the CPHS of any unanticipated problems involving risks to subjects or others, of any serious harm to subjects, and of any adverse drug reactions.

RECORDS: The PI will maintain adequate records, including signed consent documents if required, in a manner which ensures subject confidentiality.

Appendix D: WDO Coding Protocol

Work domain ontology is an explicit, abstract, implementation-independent description of essential requirements of work composed of four components: goals, operations, objects and constraints. Goal is the objective some efforts in the work domain want to achieve. Goal answers the essential question why a work domain exists. Operation is defined as a necessary action towards a sub goal achieved by one or multiple agents independently of the technique. Operation defines the activity components of the work. Object is defined as an entity in which thought or operation is directed. Constraint is a relationship between two concepts which defines an explicit condition the work domain must satisfy. Constraint answers internal connection among work domain concepts. The relationships among these components are: operations are performed on the objects under the constraints to achieve a goal**.**

Example: to achieve the goal of generating a drug prescription, we need to know the objects (drug name, pharmacological incompatibility, direction, availability in the store, etc.) and the operations on these objects, such as finding the dosage for underweight patient under the constraint that underweight patient should not consume the entire pill.

Coding processes: A code is a name or label that assigns meaning to a segment of related data. The NVIVO software for qualitative data analysis will be used to assist coding of the data. We expect the final product of the analysis to include a detailed description of the goals operations, constraints, and objects in Self-Nutrition Management domain.

1. Text transcript of focus group interview will be available before coding.
2. One coder will go through the transcript and make sure there is no ambiguous concept in the text.
3. The coder will read and re-read to code following concepts.
    a. Goal
    b. Operation
    c. Object
    d. Constraint between goals
    e. Constraint between goal and operation
    f. Constraint between operations
    g. Constraint between operation and object
    h. Constraint between objects
4. A coding book will be developed and applied to the entire data set.
5. Codes with common linkages will be aggregated into categories.
6. Categories will be aggregated into themes according to commonalities.
7. Themes and patterns will be identified and developed through data reduction and iterations of data display and depict linkages.
8. Discussion with Subject Mater Experts will be used to refine the codes.

Appendix E: Effect Size of One-Sample *t* Test

Effect size of each question was manually calculated as below.

	Test Value = 3							
	t	df	Sig. (2-tailed)	Standardized Effect Size	Mean Difference	95% Confidence Interval of the Difference		Std. Deviation
						Lower	Upper	
V3	3.622	40	.001	0.565591245	.854	.38	1.33	1.509
V4	13.375	40	.000	2.08882725	1.610	1.37	1.85	.771
V5	8.227	40	.000	1.284872082	1.293	.98	1.61	1.006
V6	5.453	40	.000	0.851627858	.951	.60	1.30	1.117
V7	9.717	40	.000	1.517589789	1.171	.93	1.41	.771
V8	6.820	40	.000	1.065120644	.951	.67	1.23	.893
V9	4.996	40	.000	0.780260103	.756	.45	1.06	.969
V10	3.576	40	.001	0.558434082	.585	.25	.92	1.048
V11	2.808	40	.008	0.438489972	.439	.12	.76	1.001
V12	5.632	40	.000	0.879525532	.756	.48	1.03	.860
V13	9.964	40	.000	1.556064526	1.244	.99	1.50	.799
V14	6.569	40	.000	1.025978352	1.000	.69	1.31	.975
V25	12.175	40	.000	1.901425588	1.293	1.08	1.51	.680
V26	10.694	40	.000	1.670058719	1.317	1.07	1.57	.789
V27	7.833	40	.000	1.223379127	1.073	.80	1.35	.877
V28	9.262	40	.000	1.446496253	1.146	.90	1.40	.792
V29	8.914	40	.000	1.392141986	1.146	.89	1.41	.823
V30	18.571	40	.000	2.900369864	1.585	1.41	1.76	.547
V31	7.923	40	.000	1.237417566	1.171	.87	1.47	.946
V32	10.288	40	.000	1.606723071	1.317	1.06	1.58	.820
V33	8.345	40	.000	1.303299608	1.049	.79	1.30	.805
V34	11.566	40	.000	1.806235168	1.293	1.07	1.52	.716
V35	10.579	40	.000	1.652140892	1.293	1.05	1.54	.782
V36	8.041	40	.000	1.255722022	1.049	.79	1.31	.835
V51	11.151	40	.000	1.741527786	1.317	1.08	1.56	.756
V52	9.370	40	.000	1.463309045	1.268	.99	1.54	.867
V53	10.063	40	.000	1.571649811	1.268	1.01	1.52	.807
V54	19.489	40	.000	3.043620327	1.537	1.38	1.70	.505
V55	14.525	40	.000	2.268392022	1.439	1.24	1.64	.634
V56	9.167	40	.000	1.431642528	1.220	.95	1.49	.852
V57	6.027	40	.000	0.941228582	.976	.65	1.30	1.037
V58	11.566	40	.000	1.806235168	1.293	1.07	1.52	.716
V59	9.872	40	.000	1.541822543	1.220	.97	1.47	.791
V60	13.092	40	.000	2.044553156	1.341	1.13	1.55	.656

V61	15.338	40	.000	2.395344851	1.415	1.23	1.60	.591
V15	18.571	40	.000	2.900369864	1.585	1.41	1.76	.547
V16	18.571	40	.000	2.900369864	1.585	1.41	1.76	.547
V17	12.397	40	.000	1.936091954	1.439	1.20	1.67	.743
V18	8.322	40	.000	1.299602649	1.146	.87	1.42	.882
V19	6.681	40	.000	1.043334295	.976	.68	1.27	.935
V20	7.987	40	.000	1.247411646	1.024	.77	1.28	.821
V21	11.793	40	.000	1.841794325	1.341	1.11	1.57	.728
V22	9.073	40	.000	1.416914773	1.268	.99	1.55	.895
V23	6.569	40	.000	1.025978352	1.000	.69	1.31	.975
V24	8.101	40	.000	1.26517249	1.073	.81	1.34	.848
V37	14.337	40	.000	2.239128191	1.512	1.30	1.73	.675
V38	9.599	40	.000	1.49904605	1.317	1.04	1.59	.879
V39	9.076	40	.000	1.417375339	1.195	.93	1.46	.843
V40	10.595	40	.000	1.654665554	1.122	.91	1.34	.678
V41	7.293	40	.000	1.138910671	.951	.69	1.21	.835
V42	7.607	40	.000	1.188011091	.976	.72	1.23	.821
V43	13.361	40	.000	2.086638582	1.390	1.18	1.60	.666
V44	10.172	40	.000	1.58854318	1.293	1.04	1.55	.814
V45	8.041	40	.000	1.255722022	1.049	.79	1.31	.835
V46	9.698	40	.000	1.514580952	1.268	1.00	1.53	.837
V47	7.149	40	.000	1.11651801	1.122	.80	1.44	1.005
V48	14.344	40	.000	2.240150449	1.415	1.22	1.61	.631
V49	14.106	40	.000	2.20301322	1.488	1.27	1.70	.675
V50	9.925	40	.000	1.55008665	1.317	1.05	1.59	.850
V62	5.723	40	.000	0.893770851	.805	.52	1.09	.901
V63	13.092	40	.000	2.044553156	1.341	1.13	1.55	.656
V64	3.660	40	.001	0.57159061	.585	.26	.91	1.024
V65	16.836	40	.000	2.629384643	1.561	1.37	1.75	.594
V66	7.394	40	.000	1.154700538	1.000	.73	1.27	.866
V67	6.819	40	.000	1.065025987	1.122	.79	1.45	1.053
V68	10.008	40	.000	1.562998271	1.488	1.19	1.79	.952
V69	8.066	40	.000	1.259754854	1.146	.86	1.43	.910
V70	5.461	40	.000	0.852934501	.878	.55	1.20	1.029
V71	7.833	40	.000	1.223379127	1.073	.80	1.35	.877
V72	10.694	40	.000	1.670058719	1.317	1.07	1.57	.789
V73	7.607	40	.000	1.188011091	.976	.72	1.23	.821
V74	11.039	40	.000	1.72404452	1.293	1.06	1.53	.750

Appendix F: Focus Group Interview Questionnaire

Thank you for participating in the study. As part of this project, we are developing an application that records food intake and exercise. The goal is to create an application that allows individuals to capture their own habits. This application is used for what we call self-nutrition management. Self-nutrition management includes things like daily food choices, the amount and type of exercise as well as individual physical characteristics such as age, height, weight, and health status. To develop this application, we would like to hear suggestions about how you might use this tool and its features.

1. Do you think self-nutrition management is important for you?
2. If yes, why is it important?
3. If not, why?
4. Are you currently using any system for self-nutrition management?

[Allowing free response]

5. If you were to use a self-nutrition management system, what would your primary goal be?
6. What would your secondary goal be?

{Probe – depending on response to above a limited range of 7 or 9 may be asked}

From your responses there are multiple kinds of goals mentioned –*such as achievements (goals with an end point- i.e. earning a diploma, learning to drive, climbing a mountain) and others that are dynamic or - long term (goals without an clear endpoint but rather long term –i.e. working as a doctor.)*

7. What are the achievement goals (such as climbing everest), you might set for yourself?
8. What are the sub-goals you might need to hit before achieving the ultimate goal?

9. What are the more dynamic goals or long term you might like to achieve?
10. What are the sub-goals you might need to hit before achieving the ultimate goal?
11. For each of above goal, could you please tell us what you will do to achieve your goal?
12. Could you describe your daily activities including sitting at desk, watching TV for amount of time and any multi-tasking?
13. What activities will you do to reach your goals?
14. What will you need to do each activity? If I want to write a note, I need a pen and a piece of paper?
15. What the percentages of your daily meals come from home-cooking, convenience foods, fast-food restaurant or sit down restaurant?

Appendix G: Semi-Structured Survey

This semi-structured survey was printed by SurveyMonkey. The layout is slightly different from the web version.

Self-Nutrition Goals and Ways to Achieve Them

1. Introduction to Self-Nutrition management

Many people are interested in using current technology such as iPhone applications to manage health care information. Some of these systems are used to help people manage their food/calorie intake, exercise, and nutrition balance. We call such systems Self-Nutrition Management Applications. The purpose of this page is to collect general feedbacks regarding your personal experiences and goals of self-nutrition management.

*** 1. Do you have any experience with Self-Nutrition Management?**

- ○ No
- ○ less than 1 year
- ○ 1 to 2 years
- ○ more than 2 years

*** 2. Do you have any experience with Self-Nutrition Managment Applications, for example, Lose Weight, Restaurant, BMI Calculator from iPhone app store?**

- ○ No
- ○ less than 1 year
- ○ 1 to 2 years
- ○ more than 2 years

*** 3. Below are a list of goals that others have listed as reasons for using a Self-Nutrition Management Application. Please select the reasons why you might want to use such an application.**

- ☐ To save money by offering tips for food shopping
- ☐ To help me explore and enjoy food by understanding its nutritional value
- ☐ To create a social experience by sharing information with friends
- ☐ To stay healthy by maintaining a healthy exercise and food intake balance
- ☐ To create a private food diary that is readily available but secure
- ☐ To explore new foods and understand how they fit in my current diet

Other goals (please specify)

Self-Nutrition Goals and Ways to Achieve Them

* 4. How strongly do you agree that a primary goal of Self-Nutrition applications is to assist people to Stay Healthy?

- 1. Strongly disagree
- 2. Disagree
- 3. Neither agree nor disagree
- 4. Agree
- 5. Strongly agree

5. Do you think any answer of the above questions is ambiguous in this page? If yes, please write it done in below text field

Self-Nutrition Goals and Ways to Achieve Them

2. Questions about Self-Nutrition Management plan

Previously, we discussed your personal experiences and goals of Self-Nutrition management. In this page, we will ask you questions from three prospectives: 1) Self-Nutrition management plans related with your goals; 2) the activities related with your Self-Nutrition management plan; 3) the information you want to process for your plan.

*** 1. Below are three kinds of management plans that can be part of a goal to stay healthy. Please select how strongly you agree/disagree that this plan components are part of staying healthy?**

	1. Strongly disagree	2. Disagree	3. Neither agree nor disagree	4. Agree	5. Strongly agree
a. Have a plan to balance nutrition and exercise	○	○	○	○	○
b. Having a plan for ideal weight	○	○	○	○	○
c. Having a plan that leads to an ideal body shape	○	○	○	○	○

Other plan (please specify)

*** 2. To create an overall plan to stay healthy, what activities do you need to do?**

	1. Strongly disagree	2. Disagree	3. Neither agree nor disagree	4. Agree	5. Strongly agree
a.Identify the risks of improper nutrition balance	○	○	○	○	○
b.Identify your daily budget of calories and needed exercise	○	○	○	○	○
c.Calculate (or add) calories burned through exercise	○	○	○	○	○
d.Calculate (or report) calories remaining in daily budget	○	○	○	○	○
e.Identify how much budget is still available	○	○	○	○	○
f.Determine a time interval for your plan	○	○	○	○	○
g.Determine intake/exercise in your plan	○	○	○	○	○
h.Modify the plan according to changing circumstance (a big meal, extra exercise etc)	○	○	○	○	○

Others (please specify)

Self-Nutrition Goals and Ways to Achieve Them

*** 3. When creating a Self-Nutrition management plan, certain pieces of information can be made readily available to users. Please select how strongly the listed information concerning your current state of health belong in a system to help you stay healthy.**

	1. Strongly disagree	2. Disagree	3. Neither agree nor disagree	4. Agree	5. Strongly agree
Required exercise					
Planned exercise					
Ideal weight					
Ideal Blood glucose					
Ideal Calorie budget					
Historical weight trend					
Current Weight					
Current Body Mass Index (BMI)					
Current Blood Glucose Level					
Historical Weight trend					

What else do you want to be aware of ?

*** 4. Body Mass Index (BMI) is a key statistical measure of body weight based on a person's weight and height. Please indicate the degree to which the following components would be part of a BMI management plan.**

	1. Strongly disagree	2. Disagree	3. Neither agree nor disagree	4. Agree	5. Strongly agree
Understand what BMI is					
Understand how to calculate BMI					
Set a time interval for achieving ideal BMI					
Calculate BMI					
Compare your current BMI with Ideal BMI					

5. Do you think any answer of the above questions is ambiguous in this page? If yes, please write it done in below text field

Self-Nutrition Goals and Ways to Achieve Them

3. Questions about awareness of body status

During the Self-Nutrition management, you may want to be aware of your body status. In this page, we will ask you two types of questions: 1) major activities related with your body status; 2) the information you want to process regarding your body status.

*** 1. What steps do you need to take to understand your current body status and ideal body status?**

	1. Strongly disagree	2. Disagree	3. Neither agree nor disagree	4. Agree	5. Strongly agree
Measure current weight	◯	◯	◯	◯	◯
Measure current height	◯	◯	◯	◯	◯
Calculate BMI	◯	◯	◯	◯	◯
Measure Blood Glucose	◯	◯	◯	◯	◯
Identify Ideal Weight	◯	◯	◯	◯	◯
Identify Ideal BMI	◯	◯	◯	◯	◯
Identify ideal Blood Glucose	◯	◯	◯	◯	◯

Others (please specify)

*** 2. Please select how strongly the listed information concerning your current state of health belong in an application to help you stay healthy.**

	1. Strongly disagree	2. Disagree	3. Neither agree nor disagree	4. Agree	5. Strongly agree
Current Weight	◯	◯	◯	◯	◯
Current Body Mass Index (BMI)	◯	◯	◯	◯	◯
Current Blood Glucose Level	◯	◯	◯	◯	◯
Historical Weight trend	◯	◯	◯	◯	◯
Historical BMI	◯	◯	◯	◯	◯
Historical Blood Glucose Levels	◯	◯	◯	◯	◯
Ideal Weight	◯	◯	◯	◯	◯
Ideal BMI	◯	◯	◯	◯	◯
Ideal Glucose	◯	◯	◯	◯	◯

What else do you want to be aware of ?

Self-Nutrition Goals and Ways to Achieve Them

3. Do you think any answer of the above questions is ambiguous in this page? If yes, please write it done in below text field

Self-Nutrition Goals and Ways to Achieve Them

4. Questions about exercise managment

During the Self-Nutrition management, you may want to manage your exercise. In this page, we will ask you two types of questions: 1) major activities related with your exercise; 2) the information you want to process regarding your exercise.

*** 1. Exercise is part of staying healthy. Please select the degree to which the listed details concerning exercise would benefit a self-nutrition plan to stay healthy.**

	1. Strongly disagree	2. Disagree	3. Neither agree nor disagree	4. Agree	5. Strongly agree
a.Needed Calories to Be Burned for Current Goals	○	○	○	○	○
b.Calories that have been burned daily	○	○	○	○	○
c.Suggested Duration of Exercise to Meet Goals	○	○	○	○	○
d.Suggestions for Types of Exercise to Meet Goals	○	○	○	○	○
e.Suggestions for Different exercises based on previous activities	○	○	○	○	○

*** 2. To determine what exercise/how much exercise you need to complete, which of the following steps will you need to do?**

	1. Strongly disagree	2. Disagree	3. Neither agree nor disagree	4. Agree	5. Strongly agree
understand the calorie you need	○	○	○	○	○
understand the calorie you need to consume	○	○	○	○	○
understand the calorie you have burned	○	○	○	○	○
Measure weight	○	○	○	○	○
obtain weight value	○	○	○	○	○
calculate BMI	○	○	○	○	○
Measure blood glucose	○	○	○	○	○
identify ideal weight	○	○	○	○	○
identify ideal BMI	○	○	○	○	○

Other operation (please specify)

3. Do you think any answer of the above questions is ambiguous in this page? If yes, please write it done in below text field

Self-Nutrition Goals and Ways to Achieve Them

5. Questions about intake management

During the Self-Nutrition management, you may want to manage your intake. In this page, we will ask you two types of questions: 1) major activities related with your intake management; 2) the information you want to process regarding your intake.

*** 1. To manage your nutrition intake, which of the following steps do you need to follow?**

	1. Strongly disagree	2. Disagree	3. Neither agree nor disagree	4. Agree	5. Strongly agree
Identify components of the food you are eating (sometimes difficult when eating out)	○	○	○	○	○
Identify food nutrition facts (calories, grams of fat, sodium)	○	○	○	○	○

Others (please specify)

*** 2. Please select how strongly the listed information concerning food facts in an application to help you stay healthy.**

	1. Strongly disagree	2. Disagree	3. Neither agree nor disagree	4. Agree	5. Strongly agree
Food name	○	○	○	○	○
Food category	○	○	○	○	○
Food location	○	○	○	○	○
Food nutrition facts	○	○	○	○	○

Others (please specify)

3. Do you think any concept is ambiguous in this page? If yes, please write it done in below text field

Self-Nutrition Goals and Ways to Achieve Them

6. Questions about relationships between two ideas

In this page, we are going to ask you questions about the relationship between two ideas. Please rate the question based on the relationship and use the example as a guide.

*** 1. Do you think a goal may have sub goals? For example, the goal 'aware of ideal body status' have sub goal 'aware of ideal BMI' and 'aware of ideal weight'?**

- 1. Strongly disagree
- 2. Disagree
- 3. Neither agree nor disagree
- 4. Agree
- 5. Strongly agree

*** 2. Do you think two goals may be competing with each other? for example, you may want to eat your favorite food, however, the calorie the favorite food carries maybe against your calorie budget. In other word, the goal 'enjoy favorite food' may be competing with the goal 'stay healthy'.**

- 1. Strongly disagree
- 2. Disagree
- 3. Neither agree nor disagree
- 4. Agree
- 5. Strongly agree

*** 3. Do you think a goal requires activities to achieve it? for example, in order to be aware of body status, you may want to measure weight.**

- 1. Strongly disagree
- 2. Disagree
- 3. Neither agree nor disagree
- 4. Agree
- 5. Strongly agree

Self-Nutrition Goals and Ways to Achieve Them

*** 4. Do you think that an activity supports a goal? For example, the operation 'measure weight' supports the goal 'aware of body status'.**

- 1. Strongly disagree
- 2. Disagree
- 3. Neither agree nor disagree
- 4. Agree
- 5. Strongly agree

*** 5. Do you think an activity can be decomposed into sub-activities? For example， in order to set up BMI plan, you may need to retrieve the range of BMI and select a value from the range.**

- 1. Strongly disagree
- 2. Disagree
- 3. Neither agree nor disagree
- 4. Agree
- 5. Strongly agree

*** 6. Do you think an activity may create new information? for example, taking blood glucose test will generate blood glucose lab result.**

- 1. Strongly disagree
- 2. Disagree
- 3. Neither agree nor disagree
- 4. Agree
- 5. Strongly agree

*** 7. Do you think an activity may require information? for example, in order to calculate BMI, you may need height, weight of one person.**

- 1. Strongly disagree
- 2. Disagree
- 3. Neither agree nor disagree
- 4. Agree
- 5. Strongly agree

Self-Nutrition Goals and Ways to Achieve Them

* 8. Do you think an object can be decomposed into sub-objects? For example, pizza has a topping.

- 1. Strongly disagree
- 2. Disagree
- 3. Neither agree nor disagree
- 4. Agree
- 5. Strongly agree

* 9. Do you think an object can be classified into a group? For example, Apple is a fruit.

- 1. Strongly disagree
- 2. Disagree
- 3. Neither agree nor disagree
- 4. Agree
- 5. Strongly agree

10. Do you think any answer of the above questions is ambiguous in this page? If yes, please write it done in below text field