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An Ontology Centric Architecture For Mediating Interactions In Semantic Web-Based E-Commerce Environments

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AN ONTOLOGY CENTRIC ARCHITECTURE FOR MEDIATING INTERACTIONS IN SEMANTIC WEB-BASED E-COMMERCE ENVIRONMENTS

A dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy at Virginia Commonwealth University

by

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Abstract

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Information freely generated, widely distributed and openly interpreted is a rich source of creative energy in the digital age that we live in. As we move further into this irrevocable relationship with self-growing and actively proliferating information spaces, we are also finding ourselves overwhelmed, disheartened and powerless in the presence of so much information. We are at a point where, without domain familiarity or expert guidance, sifting through the copious volumes of information to find relevance quickly turns into a mundane task often requiring enormous patience. The realization of

accomplishment soon turns into a matter of extensive cognitive load, serendipity or just plain luck. This dissertation describes a theoretical framework to analyze user interactions based on mental representations in a medium where the nature of the problem-solving task emphasizes the interaction between internal task representation and the external problem domain. The framework is established by relating to work in behavioral science, sociology, cognitive science and knowledge engineering, particularly Herbert Simon's (1957; 1989) notion of satisficing on bounded rationality and Schön's (1983) reflective model. Mental representations mediate situated actions in our constrained digital environment and provide the opportunity for completing a task. Since assistive aids to guide situated actions reduce complexity in the task environment (Vessey 1991; Pirolli et al. 1999), the framework is used as the foundation for developing mediating structures to express the internal, external and mental representations. Interaction aids superimposed on mediating structures that model thought and action will help to guide the "perpetual novice" (Borgman 1996) through the vast digital information spaces by orchestrating better cognitive fit between the task environment and the task solution.

This dissertation presents an ontology centric architecture for mediating interactions in a semantic web based e-commerce environment. The Design Science approach is applied for this purpose. The potential of the framework as a functional model is illustrated by using it to model the hierarchy of tasks in a consumer decision-making process as it applies in an e-commerce setting. Ontologies are used to express the perceptual operations on the external task environment, the intuitive operations on the internal task representation, and the constraint satisfaction and situated actions conforming to reasoning from the cognitive fit. It is maintained that actions themselves cannot be enforced, but when the meaning from mental imagery and the task environment are brought into coordination, it leads to situated actions that change the present situation into one closer to what is desired. To test the usability of the ontologies we use the Web Ontology Language (OWL) to express the semantics of the three representations. We also use OWL to validate the knowledge representations and to make rule-based logical inferences on the ontological semantics. An e-commerce application was also developed to show how effective guidance can be provided by constructing semantically rich target pages from the knowledge manifested in the ontologies.

CHAPTER 1 Introduction

1.1 Prologue

Whether in personal or professional life, we regularly interact with information spaces, just as we interact with physical objects. Our behavior in today's information rich environment extends across geographical distances and time zones, and is driven mostly by the need to fulfill some desire for knowledge.

This dissertation is not about radical new innovations intended to change the way we interact with information spaces. It is, in many ways, about applying what we know about human cognitive processes – the way we interpret information from external environments and process it internally for purposes of problem-solving, reasoning and decision-making tasks (Zhang 1997).

Digital domains exist on the Internet in different forms serving different purposes ranging from e-commerce store-fronts to digital libraries. As store-houses of information, the content on these sites provide a space that is information rich on features, service and goods (Ranganathan et al. 2002). Visitors to these information spaces rely on navigational aids to find (hyperlinks, menu structures, keyword search, etc.) the information content of interest and to evaluate (feedback forms, reviews, ranking, testimonials, etc.) their relevance. Users almost often have uniquely different information needs. You might search the Amazon (www.amazon.com) website to find the book reviews on J.K. Rawling's last book, *Harry Potter and the Deathly Hallows*, while a person completely unknown to you might be using the extensive drill-down capabilities of PriceLine (www.priceline.com) in an attempt to determine the specifications and best price of a certain brand of LCD high definition TV before Superbowl Sunday. Ironically, it is the navigational aids that provision effective information search and enhance the consumer experience. But, they are almost always passive facilitators.

There is no shortage of information on the World Wide Web today. In our efforts to find what we need on the web, we often end up playing the guessing game of making the right choice from a finite set of juxtaposed options (links, search results, etc.). The passive navigational aids are often not adept in leading the user in the right direction nor are they designed to reflect the cognitive process of the individual user who ultimately uses them. Since browsing information spaces involve cognitive actions of the user, it is only natural to assume that navigational aids should be in agreement to address and adjust this fact in an efficient way. What is needed is a facilitator, a sort of car salesman-type assistant that can help the user in finding information in the most convenient and quickest possible manner.

Interaction with public information spaces can fundamentally be viewed as social in nature - objects shared and used anonymously or collaboratively, feedback and testimonials intended to help other individuals, conflicts that emerge as interpretations or environments that are forced on others, our own expertise, training, social and cultural upbringing defining the patterns of activity. Even communication issues such as ambiguity, incompleteness, and loss of sense of context that we encounter in a digital space are just the same as we face them in social settings (Wexelblat 1999). Furthermore, the unquestionable proof for this simile also lies in the evolution and ever increasing popularity of social network websites such as Myspace (www.myspace.com) and Facebook (www.facebook.com), and their more structured version, the blogs (Java et al. 2006). Social networking websites and blogs have evoked great interest in sociological and anthropological research due to their unique ability to quickly influence public opinion by inducing information flow among individuals connected through the Internet irrespective of their anonymity, attitude and behavior (Hill et al. 2002).

We encounter different types of situations, which we can refer to as *task environments* (Newell et al. 1972). The activities of individuals in these task environments are situated in the social and physical setting in which they occur (Klahr et al. 1989, p:288; Newell et al. 1972). This applies to both physical and digital worlds, where consciously or subconsciously we engage, interact and converse with the environment before directing an action. Information processing models have failed to adequately address this *situated character* of activity (Suchman 1987). For effective interaction with the environment, an individual's knowledge structure must incorporate detailed understanding of the structural features of the environment (Klahr et al. 1989). Unfortunately, this becomes a far-fetched expectation, especially for the novices, or in instances where representations fail to provide any form of guidance on the decision to act.

In some sense, the complexity of the problem is analogous to the metaphor of Simon's ant on the beach (1996) used to illustrate observed behavior of a decision maker.

While the goal of the ant may be to reach some distant food, the path is long, winding and complex. How often do we ourselves find taking such twisty winded roads, as we search for specific information on the web? How often do we culminate with unsatisfactory results in addition to the opportunity cost of the time spent? Simon (1996) argues that the complexity of the environment rather than the complexity of the mechanism governs the actions of the decision maker. However, the complexity of the external environment is not the only input or stimulus that determines a person's ability to successfully (or optimally) complete a task. The situated actions are also driven by the internal representation of the task (Khatri et al. 2006; Shaft et al. 2006; Vessey 1991; Zhang et al. 1994). Problem-solving involves human thinking that is governed by arranging simple information processes into orderly, complex, sequences that are responsive to and adaptive to the task environment where clues are extracted from the environment as the sequences unfold (Newell et al. 1972; Simon 1996). In other words, the activities of an individual in a task environment involve processing of information distributed across the internal mind as well as the external environment.

The role of information perceived from external representations and the information retrieved from internal representations and the interwoven relationship between them that leads to a decision to act is not a radical new way of thinking in this world. In this dissertation we limit ourselves to the digital realm, but use valuable insights drawn from disciplines such as Behavioral Science, Sociology, Cognitive Science, Marketing, Knowledge Engineering and Design Science. We attempt to use innovative techniques to develop an artifact intended for use in digital domains based on proven behavioral and organizational theories from related disciplines. By using a Design Science approach, the artifact developed will attempt to discover user intentions and serve as a facilitator to guide a user through digital information space. The resulting artifact will provide intellectual and computational tools that will help extend the boundaries of human problem-solving and organizational capabilities (Hevner et al. 2004).

As with any endeavor of this nature, it is necessary to characterize the research problem clearly, define the scope of research focus, and describe how and where the contributions will be purposeful. The rest of this chapter addresses these aspects and concludes with a roadmap to the overall structure of the dissertation.

1.2 Motivation for the research

Navigating the complex information space is a major source of cognitive overhead for users in digital domains (Dhillon 2000). For all practical reasons, an information space should therefore be designed with the intent of treating any user as a novice. Ideally, a person can benefit from an expert whose body of knowledge and familiarity with the space can be used as a guiding force to drive navigation (Wexelblat 1999). To clarify this simple notion, assume that a customer is searching for a book titled *Phonemic awareness using Songs and Rhymes* at one of the nearby retail outlets of a large upscale bookstore like Barnes and Nobles. By leveraging the advantage of vast warehouses across the country, such stores have the capacity to stock huge volumes of books across different categories like Children, Computing & Internet, Education & Teaching, Game Books, Music Books, or Self Improvement, just to name a few. The specific book could fall into any of these sections. And probably the best course of action to find the book is to seek help from the friendly customer service person at the help desk. However, if the same customer were to look for the book on the website of the book store (www.barnesandnobles.com), he will resort to external aids such as detailed layout maps or drill-down menus that model the information structure to independently gain knowledge about the space. But, without the anticipatory nature of the personal interactive guidance available from the expert at the help desk, he is left in the dark, independently acting and seeking "cognition in the wild" (Hutchins 1995) merely relying on passive navigational aids.

Given that navigation can easily turn into a huge mental exercise, it is quite surprising that so many of our navigational activities are in fact successful. To navigate the information space more effectively, it is essential that semantic attributes that reflect the situated character of activity, the internal representation of the task and the spatial attributes of the external representations are combined (Dhillon 2000; Suchman 1987; Zhang et al. 1994). The result is a cognitive information model catered to the needs of the relentless expert or the infrequent novice augmented with contextual navigational aids specific to the information space. Creating a cognition based model will allow the creation and maintenance of a dynamic information processing structure that can facilitate better interaction with the information space by providing spatial cues (layout, image placement, length of text, window size, navigation icons, etc.), which are coupled to the semantic inferences based on relevance and meaning of individual user action. The system will continually seek to apply existing knowledge to create newer cognitive models with every step of the situated action.

For tasks that require processing of information available from the environment, transformations are required to form the mental representation of the task (Vessey 1991). The extended cognitive fit theory suggests that the internal representation of the problem domain and the external problem representation are two integral factors that drive the transformation required to create the mental representation of task solution (Shaft et al. 2006). Here, the internal representations are the knowledge structures in the problem solver's mind and the external representations are the knowledge and structures in the environment. Furthermore, the extended cognitive fit model suggests that it is the cognitive fit between the internal and external representations combined with the interactions between them that contribute to the development of mental representations for task solution (Khatri et al. 2006; Shaft 2006). The distributed model of cognitive fit has been applied and studied in the context of various domains such as Geospatial-temporal applications and software modification tasks. However, it is important to point out one fundamental commonality that stands out in the application areas where the theory has been tested. That is, the mental representation of the problem solver is based on interpretations of explicitly stated tasks or clearly narrated problem statements. The task definition however, does not always need to be explicit for a user in a digital space. A strong argument for this is made later in the dissertation (refer Chapter 3).

The extended cognitive fit model provides a preliminary footing to develop a framework suitable for the web incorporating mental model representations. With a little astute thought and objective use of knowledge from other disciplines, information structures can be developed to help orient a user towards a finely determined subset in the space within the very large range of possibilities in the vast information space. For the customer still searching for the book on the website of the bookstore, this implies the fortitude of using proactive spatial aids and navigation cues that are consistent with the semantics of buyer behavior and the patterns of interaction with the adaptive information bearing medium. Keeping in mind the well-recognized limitations of passive navigational aids and coordination mechanisms, the presence of active facilitators could moderate interventions in a way, as Schön (1983) says, that would orient action to change the present situation into one closer to what is desired.

For the sake of clarity, consider the classic consumer decision-making process as it applies in an e-commerce setting. The decision-making process is a time consuming effort that can be characterized as a sequence of five stages. They are need recognition, alternative search, alternative evaluation, purchase decision and post-purchase evaluation (Engel et al. 1995). Every stage in the buyer behavior involves different cognitive tasks, reasoning, and decision-making challenges that reside in the consumer's mind rather than being explicitly stated. The structure of this task hierarchy is dependent on the objective, and will also be different and unique depending on the user. The objective may be a simple exploratory exercise (learn how the 3:2 pulldown ratio enhances picture quality on a 1080i progressive scan television) or it could be the completion of an intended purchase (buy the J.K.Rawling's *Harry Potter and the Deathly Hallows* based on convincing reader reviews that you just finished reading). No matter how simple or complex the objective is, the user at each stage, creates a mental representation of the task solution based on the internal representation of the task and the perception of the external domain representation. A cognitive fit shows agreement, which in turn reasons to action that moves the user to the next task in the hierarchy. At each stage of the task, if the representational properties of the perceptual and intuitive operations can be identified, the user can then be presented with cues that are likely to provide more accurate guidance resulting in better problem-solving performance. Since the representational properties for individual users will be contextual, we need a flexible means to express the differences and isomorphic similarities (Zhang et al. 1994). Finally, the expressive power of ontologies can be used to conceptualize the representational properties in a machine-readable format.

1.3 Research questions

Another factual parallel can be drawn between the characteristics and limitations of the current state of web spaces and medical drugs. The accepted practice for prescribing drugs throughout the history of modern medicine is simple - specific medicines for specific symptoms with variation in doses based on vital signs (temperature, pulse rate, blood pressure, respiratory rate, etc.) taken by health professionals to assess the basic body functions. This also turns out to be the major stumbling block in drug effectiveness because a single drug approach is incapable of addressing differences in genetic make up and variations in disease genes (Collins 2006). Today we face similar problem in the information age. There is an abundance of information; however, the makeup of our information need is different. Just as we are headed in the direction of tailored medicines customized to our individual genetic maps, what we need is information structures that can be tailored to our unique needs.

To pursue this vision, we need a way to relate individual information needs to the complex external representation and the internal task representation. The interplay between them creates the mental representation of the task solution. Furthermore, a cognitive fit helps reduce the gap between the internal and external representations. The extended cognitive fit model (Shaft et al. 2006) purports this view but tested against a specific and relatively static type of external representation and explicitly stated goal representations. A theory is as strong as its assumptions. We make a strong case (refer to Chapter 3) that a user's interaction in a digital space may or may not be tied to an explicitly stated task. An important question that must therefore be addressed is, what cognitive information model is best suited to depict the user dynamics in digital information spaces. Specifically, we focus on rethinking the extended cognitive fit model by using an instantiation of an e-commerce setting.

This naturally leads to more complex questions. What would be an appropriate computational means to express the internal, external and mental models to test the applicability of cognitive fit in an e-commerce setting? We cannot even comprehend testing the applicability of cognitive fit unless we have a means to express these three representations. Ontologies have recently amassed rapidly growing adulations as the preferred formal means to express shared conceptualizations. Therefore, the research question is whether ontologies can effectively be used to express these three representations. Ontology development is in itself, an iterative process where the researcher studies the domain to understand the contextual knowledge that must be represented. The relations and constraints that must be modeled are then defined. If available ontologies can be extended, then test cases must be used to verify their utilities. Otherwise new ontologies have to be developed. Finally, if the developed ontologies do not pass the test cases, then the researcher must re-evaluate his or her comprehension of the domain and repeat the steps (Chen 2004). Once the ontologies have been developed, the question is whether the ontologies have true semantic expressive power for effective instantiation and use. The next logical question is, how to implement and validate the representations using an ontology representation language. This dissertation investigates the applicability of ontology for mediating interactions in the context of an e-commerce setting.

1.4 Research objectives

A cognitive information model should offer better performance by enabling higher levels of comprehension and utilization of information. One objective of this research is to build and evaluate a cognitive information model that can also serve as the functional model to rationalize the structure of ontologies. The existing knowledge base of theories and frameworks from related disciplines will be used for this purpose. The other related objective of this study is to build the relevant ontologies using known methodologies, formalisms and validation criteria. The Design Science approach will be adopted for this task. Subsequently, the usability of the ontologies will be tested after the semantics of cognitive fit is described using an ontology language. In the context of semantic web concepts (Berners-Lee et al. 2001), Web Ontology Language (OWL) is widely gaining popularity as the vocabulary language of choice for expressing context representations defined in ontologies (Chen 2004, McGuinness 2003, Thomas et al. 2005). OWL will therefore be used to validate knowledge representations and to make rule-based logical inferences based on context reasoning from ontology semantics. Finally the utility of the constructs will be tested in an e-commerce setting. An implementation architecture capable of reasoning on the ontologies has to be developed for this purpose.

1.5 Significance of this research

We have become dependent on digital information. But the sheer quantity and the non-availability of a contextual information access structure make it an arduous task for both humans and machines to find relevant information (Kuntz 2005). Without familiarity of the domain, sifting through the copious volumes of information to find relevance can easily turn into a mundane task requiring patience and perseverance. A realization of accomplishment can very well turn into a matter of serendipity or just plain luck, synonymous perhaps to the sea faring navigational adventures of the early Europeans in the mid twentieth century. Imagine Christopher Columbus's exuberance or Captain James Cook's delight, if they accidentally fell upon advanced position aids like Global Navigation Satellite Systems (GNSS) instead of relying on the direction of ocean swells, cloud clusters at island locations and other Polynesian methods of navigation. Captain Cook would surely agree that an artifact that enables synthesis of relevance based on context would go a long way towards effective space processing and perception. He would have been thrilled to avoid going in circles (see Figure 1).

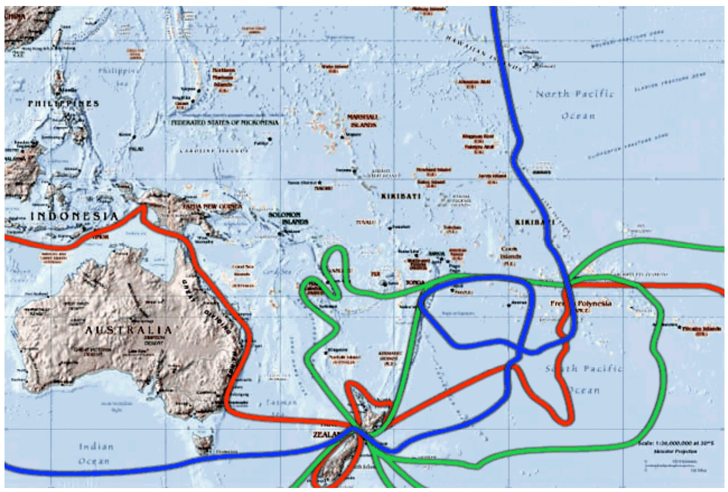

Figure 1. Captain James Cook's South Pacific voyage routes.

Image from wikipedia (http://en.wikipedia.org/wiki/Captain_James_Cook)

This dissertation follows the Design Science paradigm. "Innovations define ideas, practices, technical capabilities and products, through which implementation and use of Information Systems can be effectively and efficiently accomplished" (Hevner et al. 2004). The research presented in this dissertation aims to develop ontologies that can guide situated actions in information spaces. In addition to demonstrating the use of ontologies to describe the external domain and the internal task representation, the research also presents ways by which semantics of cognitive fit can be specified in OWL expressions. The ontologies can be used by domain owners (e-commerce managers, for instance) to improve organization of information, and can be used by the users (consumers) to improve comprehension and navigation through the information spaces (Wexelblat 1999).

Lee (2000) conceptualizes Information Systems (IS) as comprising of a behavioral subsystem and a technological subsystem that are inseparable. Using the concepts of “true” systems thinking Lee explains how technological subsystems transform behavioral subsystems and vice-versa. Changes in one impact the other and attempts to optimize one without considering the behavioral subsystem will only result in suboptimal solutions (see Figure 2).

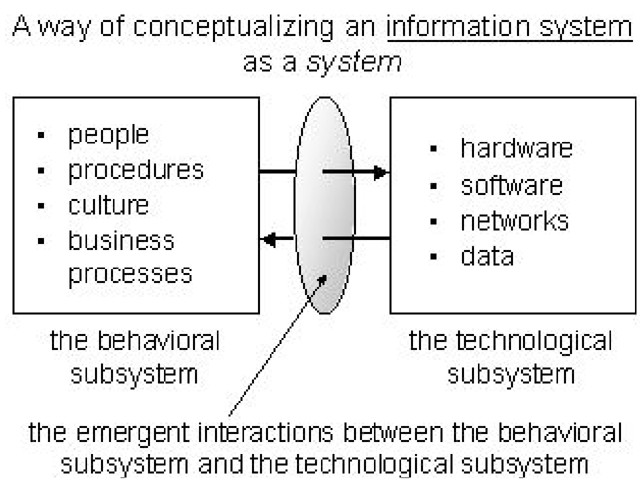

Figure 2. Interaction between technological subsystem and behavioral subsystem.

Adapted from Lee 2000.

Lee (2008) also highlights the impact of technological subsystems on social (organizational) subsystems. Information requirements of the organizational subsystems, for reasons ranging from gaining competitive advantage to improving business processes, necessitate change to technological subsystems. Change to Information Technology imposes new organizational requirements for the organization to satisfy. This leads to a continuous cycle of evolution and change to both technological and social subsystems (see Figure 3).

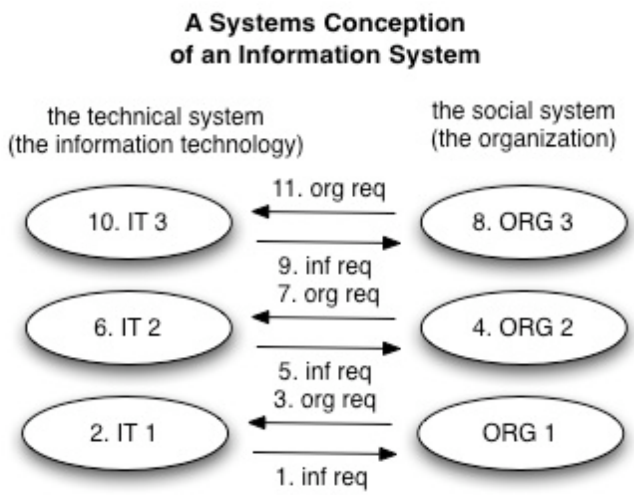

Figure 3. Interaction between technical subsystem and social subsystem.

Adapted from Lee 2008.

As a sociotechnical system that deals with behavioral, technological and social issues, Information Systems thus become a self-evolving group of the three main subsystems that are linked through permeable boundaries and also sustain, interact and change simultaneously.

In this research, we develop a technological subsystem (the design artifact) that dynamically responds to behavioral subsystems (interactions of the user with the design artifact). Sure enough, the implementation requirements of the technological subsystem will impose necessary and requisite changes to the social subsystem (the organization). The changes however, as described by Lee (2000, 2008), are just indispensable aspects of successful IS implementation in any forward looking technologically driven organization. The cognitive information model proposed in this research will offer intellectual opportunities to suggest improvements to existing theories or propose new theories from their development and use. As Hevner et al. (2004) suggests, the goal (artifact) is utility (use of artifact) informed by truth (relevance) and utility will inform theory (rigor).

1.6 Roadmap to the dissertation

The rest of this study is organized as follows. The field of cognitive science has proposed different models to describe the perceptual and intuitive activities during problem-solving, based on different levels of emphasis on the structure and importance of the environment and the person's internal representation of the task. Many are based on diverse assumptions, and some more satisfactory to the context of this research than others. Chapter 2 of this dissertation offers a sneak preview on this important topic. This chapter also discusses definitions of relevant terms as they apply to the research as well as a literature review on the use of ontologies to define terms, concepts and relationships in the domain of discourse. Considering the fact that the study uses buyer behavior in an e-commerce setting as a test case, this chapter also offers insight into the classic consumer decision-making process popularized in the marketing literature.

In Chapter 3, the proposed framework is presented. The chapter describes its use as a methodology and as a functional model. On the methodological side, we illustrate the potential of the framework to analyze the user interaction with the external space. To do this, we use the hierarchy of tasks in a consumer decision-making process as it applies in a typical e-commerce setting. This backdrop is used to develop the ontologies for the internal task representations and external domain representation as well as the derived cognitive fit ontology. This is done in Chapter 4. The implementation architecture to instantiate the artifact in an e-commerce setting is also described in detail in Chapter 4.

On the empirical side, use cases describing consumer decision-making processes are developed to evaluate whether specific predictions made from observed and historic user data is consistent with the derived cognitive fit ontology. The utility of the cognitive information model and the ontologies must be visible by their ability to express the concepts semantically in the selected application domain. The use of cognitive fit ontology to enhance problem-solving performance is evaluated using analytical, testing and descriptive methods. The results are presented in Chapter 5. Finally, Chapter 6 has concluding remarks that recap the dissertation with a rundown on the insights gained, limitations identified and directions for future work.

CHAPTER 2 Prior Research

Navigating the large heterogeneous complex information space is a major cognitive activity for all of us in today's age and time. This chapter presents a review of literature on some of the main ideas that evoke thinking and deeper understanding about theories of action and information foraging activities. These topics spread across different disciplines such as Behavioral Science, Cognitive Science, Design Science, Knowledge Engineering, Marketing and Sociology. Specifically examined are the behavioral aspects of assessing, retrieving and processing information, the role of reflective practice in cognition and the epistemology of satisficing under bounded rationality. In later chapters, we instantiate the framework in the context of an e-commerce setting and build ontologies that specify the conceptualization of cognitive fit. For that reason, this chapter offers relevant background on e-commerce and consumer decision-making process from reviewing literature in the marketing discipline. The Design Science approach for creating the artifact is also presented here. Where it emerges during the walkthrough, this chapter is formatted in such a way to highlight the definition of key terms as they arise in the context of this research.

2.1 Foraging for information

Activities associated with assessing, seeking and handling information sources is characterized as information foraging (Pirolli et al. 1995). Foraging for information is an activity undertaken to find information by making optimal use of the available knowledge required to support a decision-making task. Almost always, the search is an adaptive cognitive activity that is based on internalized user goals and contextualized to the source of information. A cytogeneticist searching the genomic library for a match on a detected chromosome aberration or the house electrician looking to verify a specific safe installation code in the National Electrical Code handbook are examples that demonstrate information foraging. Users in the information space need help to find their way to the correct information. They may need help to understand what they have found to complete the decision task. Information foraging is thus contextualized exploration combined with exploitations (Wexelblat 1999).

Exploratory search can take many forms and is aided by a variety of methods (Fox et al. 2006). Kuntz (2005) summarizes three broad categories for indexing and systematic access to stored information. The systematics-based approach hierarchically catalogues content based on topic, author, date, etc. to create a navigable structure. This approach, borrowed from librarianship, is too rigid and requires a high degree of pre-editing before use. Conventional full-text search on the other hand is a highly popular approach, as it makes no assumptions regarding structure and semantic relationships of terms. But queries that are too generic will retrieve inordinate volumes of results even with advanced modern retrieval systems such as Google. The approach that is currently gaining strong momentum is the one that aims to retrieve information based on the semantic relevance of the content (Berners-Lee et al. 2006). Information foraging substantiated on semantics is possible when knowledge spaces are enhanced with ontologies and knowledge structures are created as a semantic web (Berners-Lee et al. 2006; Ding et al. 2002; Kalfoglou et al. 2003; Uschold et al. 1996). The task of enhancing the content with semantic vocabulary can be arduous and requires extensive human input. However, benefits present themselves as high quality outcomes from knowledge queries since results produced are based on matches against ontological terminology.

Literature reviews show many different techniques for user-centered semantics based information foraging. Vector space models, Latent Semantic Indexing (Letsche et al. 1997), Probabilistic Relevance Models (Kuntz 2005; Wang 2006), Artificial Neural Networks (Lin 1997), Lexical Chaining based on linguistic factors (Green 1998) and Pathfinder Network Scaling (Chen 1999) are some examples. Utilities such as spatial co-citation maps (Chen 1999), Fisheye View (Janecek et al. 2002), Spatial Paradigm for Information Retrieval and Exploration (SPIRE) (Hetzler et al. 1998), etc. are also often attached to these methods to provide visualization of the semantic structures.

Of course, the information content in the digital spaces is constantly undergoing change. Organizations add new information, change existing information, or remove stale information. The underlying linking structures, layout maps, drill-down menus and other navigational aids designed to help the user, also change to reflect the transformations on the information space. To an extent, domain owners and experts may rely on their body of knowledge or expertise to circumvent these changes to the information models, whereas a novice or an unskilled person will be easily loose hope in the face of transition. We regularly observe this around ourselves – the ease with which an expert programmer can switch Interactive Development Environment (IDE) to work with different programming languages being an example of the former; the elderly refusing to upgrade operating systems on their computers or use cell phone based text messaging are examples of the latter. Such is the necessity to adjust to the changing digital environment, it is rumored that major search engines like Google and Yahoo incur huge computational overheads to ensure that their PageRank vectors reflect this constant fluctuation in the information content available online.

2.2 Satisficing on bounded rationality

The issue of finding information of relevance naturally leads to Herbert Simon's notion of *satificing* based on bounded rationality (Newell et al. 1972; Simon 1957). Simon (1957, 1996) points out that we are limited in our abilities to determine all probabilities of outcomes, let alone evaluate all possible alternatives of a decision process with a high degree of precision. Under this bounded rationality, Simon states that we are forced to make decisions not by "maximizing" but by satisfying and sufficing; in other words, "satisficing." In a digital world, what this implies is that a user foraging for information has to make decisions based on the knowledge he has mustered up to that point in time. There is the high possibility that the individual never even came across a critical piece of important information resulting in a less than optimal decision. The information foraging theory is complementary to this notion (Pirolli et al. 1999). It seeks to understand how strategies and technologies for information seeking, gathering and consumption adapt to the flux of information in the environment (Pirolli et al. 1999). Information foraging theory draws from the optimal foraging theory in biology by using the metaphor of organisms adapting their dietary choices, habitats, food sharing, etc. to environmental problems and changing constraints (Pirolli et al. 1999). Whales move to ocean bodies richer in plankton, wolf packs forage for prey in a constrained nocturnal bustle, exotic pet parrots are picky eaters and emperor penguins walk months in extreme winter weather to bring food home to their babies. We observe similar social behaviors even within the bounds of the constrained digital world; moving between information spaces, making observations, filtering information, reciprocating favors through feedbacks and sharing information. Our hunt for information is sustained through a form of adaptive exploration using available knowledge, extracting the relevant information from the external space and internally assessing the expected value of an action. Juxtaposed somewhere in there is our desire for speed and accuracy with which information is retrieved and used.

Since cognitive behavior for the completion of a task can be viewed as governed by bounded rationality and shaped by constraints in the external environment, the need to furnish information pertinent to the context suddenly seems strikingly important. In other words, the perception drawn from external ecology and the internal representation of the problem task mediates the formation of a mental model that determines the rationale for behavior. An alternative view would be, that a satisficing action is less than optimal when the external environment and internal representation negatively mediates the mental model of the user's problem task. Personal bias, ability to look-ahead and learned knowledge are all factors that can influence the situated action ultimately rendered by the user (Zhang 1997).

2.3 Technical rationality model and reflective practice

Schön (1983) uses the model of technical rationality to explain the way traditional practitioners rely on experience and expertise to take action in a situation. Their familiarity with the theories, concepts, framework, instruments and analytical methods help them find effective solution to immediate problem task. Professionals in the field of medicine, architecture, engineering and town planning are examples of such experts who follow the technical rationality model. But not all users of the information space are professionals, nor is it reasonable to expect everyone to master every information domain. As Schön (1983) points out, most real-world situations are characterized by complexity, uncertainty, instability, uniqueness and value conflicts. Technical rationality model fails to account for the practical competence in "divergent" situations (Schön 1983, p:49). For a novice it is often the case that the skill is not so much needed in solving the problem as it is in finding the initial problem details, relevant features and guiding cues (Wexelblat 1999). It is no surprise that Agatha Christie and Arthur Conan Doyle continue to delight readers simply through their astute description of the details of a murder mystery that solves the case rather than the mastery of trained police officials. Whereas the technical rationality model isolates the practitioner from the confusing world of everyday operations, the reflection-in-action gives prominence to implicit patterns of thought and action based on tacit knowledge and a feel for what is being dealt with (Schön 1983; Wexelblat, 1999). For the expert, thought exists before action; for a "reflective practitioner" the knowing is in the action (Schön 1983, p: 49). Consequently, for the "perpetual novice" (Borgman 1996) treading through the vast expanses of digital information, a dynamic information structure that models thought and action as coexisting complementing entities will be more useful than a rigid technically oriented structure suited for experts.

2.4 Task environments, external representation and internal representation

Information in internal representations is retrieved from memory by cognitive activity consistent with the task environment. The cues in external representations can help trigger the retrieval processes (Zhang et al. 1994; Zhang 1997).

For the context of this research, we use Zhang's (1997) definition of external representation.

> *External representation are the knowledge and structure in the environment, as physical symbols, objects, or dimension (e.g., written symbols, beads of abacuses, dimensions of graph, etc.), and as external rules, constraints, or relations embedded in physical configurations (e.g., spatial relations of written digits, visual and spatial layouts of diagrams, physical constraints in abacuses, etc.)*

For a long distance runner searching an online store for athletic shoes with a specific pronation characteristic and arch support, the e-commerce storefront represents the external environment. The visuals, hyperlinks, navigational menus and other interactive aids are the symbols and objects in this space whereas, the payment options, discount specials and shipping restrictions form the rules and constraints embedded in that space. Searching for shoes with common shapes and inspecting them side-by-side activate the perceptual operations of the customer.

External representations are not just inputs and stimuli, but they also serve as memory aids and provide information that can be directly perceived and used without the need for explicit interpretation or formulation (Newell et al. 1972; Zhang et al. 1994). Zhang suggests that they aid the users' perceptual processing by limiting abstraction and by supporting reflective thought. External representations anchor cognitive behavior and are intrinsic to many cognitive tasks that guide, constrain and even determine such behavior. These spaces may have variant or invariant information that can be perceived without the mediation of deliberate inferences or computations (Zhang et al. 1994).

We also luxuriously borrow Zhangs' (1997) definition of internal representation for the purpose of this research.

> *Internal Representations are the knowledge and structure in memory, as propositions, productions, schemas, neural networks, or other forms. They are the meaning of individual symbols (e.g., the numerical value of the arbitrary symbol*

"7" is seven), the addition and multiplication tables, arithmetic procedures, etc., which have to be retrieved from memory.

Internalization is more than just an internal conversation (Hutchins 1995, p: 312). The internal representations are what enable intuitive operations (Kahneman 2003), such as interpreting the meaning of pie-charts and scatter diagrams, predicting market trends, musing the rich taste of an Australian red wine or simply judging the relative magnitude of numbers on an ordinal scale. The scatter plots, stock charts and rack of imported wines at the wine store are themselves external representations that help to shape the internal interpretations.

For every running shoe that is evaluated by the athlete in the online store, the internal representation of the buyers' expectations is influenced by the intuitive reasoning about the properties of the artifact described in the e-commerce space.

The behavior in a task environment involves dynamic processing of information perceived from the external representations and those retrieved form the internal representations (Shaft et al. 2006; Zhang 1997). Shaft (2006) points out that the cognitive fit between the internal and external representations and the interaction between them, as well as the problem-solving task, contribute to the development of mental representations for the task solution. This view draws from the Theory of Cognitive Fit (Vessey 1991) which states that performance (measured along the dimensions of accuracy and speed) will be enhanced when there is a cognitive fit (match) between the information emphasized in the problem representation and that required by the problem-solving task.

Reaching consent on the correct shoes to buy prior to the purchase is an outcome of creating a mental model that is a match between the athlete's internal representation and the perception from the external environment. The cognitive fit leads to the action of committing his payment details on the website.

A human behaves in a number of different classes of situations, which Newell et al. refers to as "task environments" (1972, p:3). Literature reviews provide no explicit definition of the characteristics of a task nor is there a clearly articulated theory of task. There are however, many ways in which task has been categorized. Newell et al. (1972) classifies task into elementary tasks and higher-level decision-making tasks. Elementary tasks are simple operations centered around acquisitioning or evaluating information. Acquisitioning is exploitation of information to take action. Evaluation is exploring to find information that will best suit the solution. Decision-making tasks are complex higher level tasks that may be decomposed into subtasks and normally involve both exploration and exploitation of information (Vessey 1991). This research uses Newell et al.'s (1972, p:55) interpretation of task environment to bring together the interplay of external representations and internal representations.

> *Task environment as an environment coupled with a goal, problem or task – the one for which the motivation of the subject is assumed. It is the task that defines a point of view about an environment, and that, in fact, allows an environment to be delimited.*

Of course, there could be several goals in the environment; however, that complication is deliberately avoided here for the sake of simplicity. As Newell et al. (1972) points out, a complete theory of task environment will have to be comprehensive to cover all known human knowledge such as natural science, fine arts, games, genetics, etc. Such an effort will be stretching our imagination far beyond any form of reality and is at best left as research interests to the disciplines of psychology and behavioral sciences.

2.5 Cognition

Cognitive science is an immensely studied area that inevitably contents itself by creating models of unobservable processes to explain observable human behavior. The discipline is vast and deeply researched. Different approaches have been adopted to study cognition; the socio-historical approach, the situated cognition approach and studies on diagrammatic reasoning are some of them (Zhang et al. 1994). The goal of this section is only to present a superficial view of rudimentary ideas pertinent to this research and fundamental to the human cognitive system. We do this with the caution of treading thin ice and by no means, does this study aim to extend the knowledge base of this highly interesting field of science.

Human beings are complex adaptive systems continuously exploiting information from the surrounding environment for the process of coordinating actions and interactions based on social context (Hutchins 1995). Individual task performances in the context and constraints of the outside world involve mental work that brings together the internal representation of the task and the external representation of the problem space. Processing information is thus a cognitive activity in a context, where context is not just the conditions of the external environment, but a wider dynamic space in which the mental models of the individual also play an important part.

Understanding information means being able to apply it to all the tasks for which it is relevant (Simon 1989, p:441). People process information differently. Researchers for example, go the extra length to remove personal bias from experimental situation whereas practitioners use their own opinions to make organizational decisions. Paintings of Salvador Dali or Jackson Pollock invoke completely different interpretations in different people (See Figure 4). Hutchins (1995) befittingly refers to this naturally occurring culturally constituted human activity as the "cognition in the wild." Many different factors constitute the ability of a task performer to process information acquired from the environment. Among them, the role of memory, the lines of communication with the external environment and the mental activity of modeling the task in context are recurring topics in most cognitive science literature (Hutchins 1995; Kahneman 2003; Newell et al. 1972; Simon 1989; Tversky et al. 1981; Zhang 1997).

Sociology classifies memory as social memory, community memory and collective remembering (Middleton et al. 2001). Wenger (1986) proposed the Transactive Memory Theory based on the idea that members in a group benefit from each other's knowledge and expertise. When there is a shared understanding of who knows what, the individual members themselves sometimes serve as memory aids to each other (Wenger 1986). Hutchins (1995) argues that memory is a product of social and cultural dynamics and is not done on its own. Context plays a dominant role in a person's ability to remember, recall and forget. History rich objects, conversations, landmarks, signposts, etc. are all different forms of triggers that provide additional memory support. They have important roles serving as guides, comforts, reminders and teachers (Wexelblat, 1999). A shopper's grocery list, an attorney's sticky notes, browser bookmarks, calendar notifications, or our own injury marks and scars that attach us to a story in our past, are examples of subtle, yet robust memory structures that we encounter in our day-to-day lives. Even habits, such as leaving office keys with house keys, to some extent are preserved over lengthy periods of time to serve as effective memory aids. Consequently, the role of memory and external memory aids in information retrieval systems is an important one that cannot be ignored (Komlodia 2007).

Figure 4. Galatée aux Sphères (Salvador Dali, 1952)

Human progress in mastering matter at smaller and smaller dimensions.

(At display at the Monastery on Rapture island.)

Psychology and Computers Science to an extent, treat individual memory as sensory memory, short-term memory and long-term memory (Newell et al. 1972; Simon 1989). Sensory memory is the buffer for stimuli received through the sensory channels whereas short-term memory is a scratch pad with limited capacity. Long-term memory, as the name suggests, stores information over a length of time. Studies have shown that experts tend to develop better memory mechanisms to facilitate retrieval of information stored in long-term memory than novices (Klahr et al. 1989). Newell and Simon (1972) demonstrated this by observing the behavior of grandmasters over a chessboard. Their studies point out that familiarity with the problem domain and ability to anticipate intermediate knowledge states of the solution algorithms helps experts better anticipate future information needs. These factors facilitate higher performance in information retrieval from long-term memory for an expert compared to a novice working in the same problem space. Klahr et al. (1989, p:254) quotes Staszewski's analysis about how experts create and effectively use such information retrieval structures. He suggests that the experts can recognize and code problems and sub-problems into organized semantic networks using unique and easily accessible memory codes in their long-term memory. Their deep understanding and knowledge help them to create strong associations linking problems to their semantic networks, thereby substituting retrieval for computation as a means of solving certain problems. Recognizing such patterns help experts to select and use efficient processing strategies. In comparison, a trainee's strategic use of his retrieval structure is often a direct reflection of knowledge about the task environment stored in the short-term memory.

For the purpose of this research memory is treated as existing in the midst of an ongoing exchange between the intuitive operations on internal task representation and the perception operations on the external environment. We are not concerned with the abstract processes of memory as much as we are with the factors that influence intuitive judgment such as bias, look-ahead capabilities and learned knowledge and the perceptual processing of information from the outside world conducted sequentially or in parallel.

The practice of navigation is in many ways about following instructions, whether the instructions come from within us or from others. It is the internalization of external representational instructions. There certainly are cognitive costs involved with internalizing information. Two major ones are errors and misinterpretations. Reduction in errors and misinterpretation will lead to better efficiency and time saving, which for a unskilled person or a novice will be impossible without the right instructions or navigational aids to guide action. A solution to the problem is to design mediating artifact that can be used by both novice and experts with particular structure features that can be exploited by simple interaction strategies to produce useful coordination (Hutchins, 1995, p:296).

2.6 Theory of Cognitive Fit

Problem-solving is the result of assigning cognitive meaning to the task environment based on interaction between internal image of the external world inclusive of all known constraints and the problem-solving task. Cognitive science literature generously agrees with this view of problem-solving although there are differing opinions in the levels of involvement of internal and external representations. Some view external representations as mere inputs and stimuli to the internal mind (Newell et al. 1972), while others share the feeling that the environment is highly structured and information rich, and therefore sufficient for perception and action (Gibson 1966). A more recent approach describes cognitive activity as distributed across the internal human mind, external artifacts, space and time (Hutchins 1995; Tversky and Kahneman 1981; Zhang 1997). This view argues that cognitive tasks are neither internal nor external, but distributed across both representations (Zhang 1997). Vessey (1991) proposed the theory of cognitive fit to suggest that performance (measured along the objective dimensions of accuracy, time and interpretation accuracy) on a task will be enhanced when there is cognitive fit between information emphasized in the problem representation and that required by the type of problem-solving task. This model is shown in Figure 5.

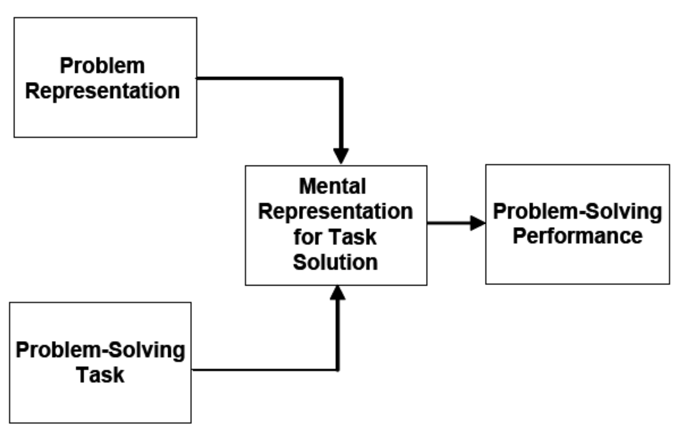

Figure 5. General problem-solving model

Adapted from Vessey 1991.

The theory of cognitive fit was based on the information-processing model suggested by Newell et al. (1972). Zhang and Normal (1994) elaborated on the distinction of internal representation from mental representation and presented a framework for the distributed model of cognition where internal and external representations are two inseparable parts (Zhang et al. 1997). Shaft and Vessey (2006) modified the theory of cognitive fit to include this distinction and proposed the extended cognitive fit model. According to this model, the cognitive fit between the internal and external representations, and the interactions between them, as well as the problem-solving task contribute to the development of the mental representation for task solution. This is shown in Figure 6. However, this model does not explicate the nature of interaction between the internal and external representations.

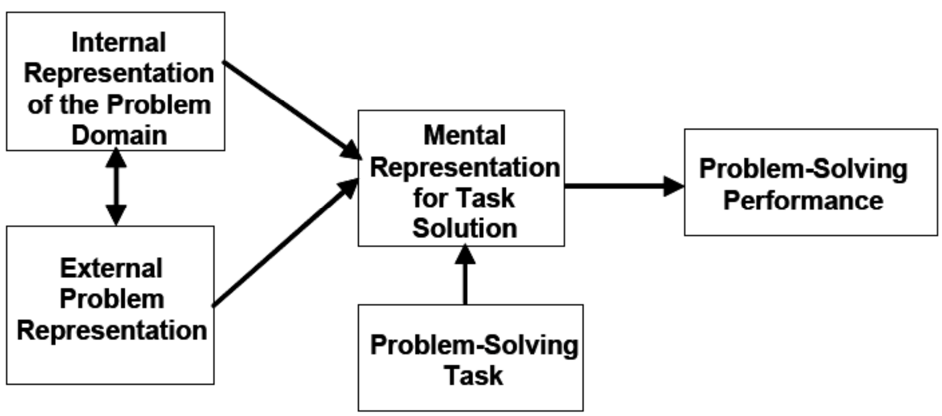

Figure 6. Extended Cognitive Fit Model

Adapted from Shaft et al. 2006.

Mental representations mediate situated actions in the environment that provides the opportunity for completing a task. Mental representation creates meaning that is formed when the person develops an internal image of the external world that includes aspects of the problem-solving task. Creating mediating structures of information that can be superimposed on this model can help guide the user through the vast digital information spaces by orchestrating better cognitive fit between the task environment and the task solution (Hutchins 1995). A system like this, consisting of the task performer, their internal representations, the mediating information structures and the external world, can settle into a solution that satisfies the constraints quicker than a system without mediating structures. The constraint satisfaction and the ensuing situated action reasons from the cognitive fit. Clearly, the action themselves cannot be enforced, because they are taken by the user on the environment and involve dynamics of the external space and the mental imagery of the user about the task solution. In any case, when the meaning of the mental imagery, the action and the task environment are brought into coordination, it leads to better performance.

2.7 Artifact in Design Science

Schön (1983) quotes Simon and others suggesting that all occupations engaged in transforming actual situations to preferred situations are concerned with design (p: 77). Design paradigms have their roots in engineering (Simon 1996) and Design Science is fundamentally a problem-solving exercise (Hevner et al. 2004). Schön notes that a good design process involves a conversation with the materials of a situation. The conversation is reflective in nature where the designer reflects-in-action to construe the problem and strategizes on action in response to a situational back-talk (Schön 1983, p:79). The importance of design is well documented in Information Systems (IS) literature (Bensabat et al. 1999; March et al. 1995; Glass 1999; Orlikowski et al. 2001). Design is elusive yet fascinating; difficult to master, yet vital (Glass 1999). The process is experimental, artistic, innovative and cognitive, all at the same time.

Technology is pervasive and invasive. In the current civilization, we as sophisticated human beings use Information Technology (IT) artifacts in all walks of life whether it is a business domain, such as finance, marketing, accounting or human resources, or it is some other non-business area such as medicine, governments, biology or the armed forces. March et al. (1995) presents a two dimensional framework for IT research that ties the products of Design Science with the laws of Natural Science with which to characterize phenomena. This is shown in **Figure 7**. The first dimension is based on creating the Design Science artifacts – constructs, models, methods and instantiations. The second dimension is the natural science activities that justify and build theories by evaluating the artifacts. The real value of this framework is the fact that it recognizes the distinction between research outputs and research activities.

A review of IS literature shows numerous conceptualizations of information technology, some that consider only representations and instantiations, and others placing emphasis on the role of people and organization. Orlikowski et al. (2001) reviewed close to two hundred articles published in *Information Systems Research* journal and identified 14 distinctive conceptualizations of information technology spread across five clusters of classification. The classification clusters identified are Nominal view, Computational view, Tool view, Proxy view and Ensemble view. Based on this excellent effort, their findings expose the ongoing trend among IS researchers to focus attention on theoretical exercises under the assumption that IT artifacts are relatively stable, discrete, independent and fixed. Studies on organizational context in which some technology, usually unspecified, is used, or causality of variations on a dependent variable through the presumable effects of technology are classics examples of this form of IS research (Orlikowski et al. 2001). The outcome of the study is vocalized as the need for IS research to engage more seriously in its core subject matter – the IT artifact (Orlikowski et al. 2001).

	RESEARCH ACTIVITIES				
		BUILD	**EVALUATE**	**THEORIZE**	**JUSTIFY**
	CONSTRUCTS				
RESEARCH OUTPUT	**MODEL**				
	METHOD				
	INSTANTIATION				

Figure 7. Research Framework in Information Technology
Adapted from March et al. 1995.

Weber (1987) voiced similar opinions for phenomenal changes almost a decade prior to the study done by Orlikowski. He called for a new paradigm in IS research that can explain the behavior of discrete artifacts through instantiations and representations. Since IS depicts behavioral aspects and technological aspects as two sides of the same coin (Lee 2000), the relevance of understanding how and why IT works is just as important as the rigors of methodology development and theory testing. Hevner et al. (2004) positions an IT artifact somewhere in the middle of this spectrum where technological and behavioral aspects are the two extremes. For the purpose of this research, we orient ourselves with the definition of IT artifact used by Hevner et al. (2004) that draws from March et al. (1995).

> *IT artifacts are broadly defined as constructs (vocabulary and symbols), models (abstractions and representations), methods (algorithms and practices), and instantiations (implemented and prototype systems).*

This is especially important since the research methodology adopted for this dissertation aims to construct, model and instantiate the necessary methods for representing the internal, external and cognitive states of a user in an information space. Considering that such artifacts are rarely full-blown information systems ready for primetime (Hevner et al. 2004), the definition is a good match for this research as the current scope precludes theorizing on social and organizational implications. Concerns of that nature will be the focus of future theory building studies. Such studies will also ensure the *rigor* requirement of IS research to theorize and justify the applicability and generalizability of the artifact.

Using the framework (shown in **Figure 7**), March et al. (1995) opines that Design Science research builds and evaluates constructs, models, methods and instantiations. Building the artifact demonstrates feasibility whereas evaluating the artifact determines progress and contributes to the foundation of knowledge bases. The two other processes, theorize and justify, are the focus of behavioral research in IS. We use the following definitions for the four outputs of Design Science research. For the purpose of this research, we quote March et al. (1995) to describe a construct.

> *Constructs form the vocabulary of a domain. They form the specialized language and shared knowledge of a discipline or sub-discipline.*

Constructs provide a language to describe the problems within a domain and to specify the solutions (Schön 1983; Hevner et al. 2004). Kuhn (1996) has demonstrated the notion of a paradigm based on the ability to create well-formed logical structures from the existence of an agreed upon set of constructs for a domain. The constructs can be formalized using ontologies consisting of classes (concepts), relations, functions, axioms and instances (Gruber 1993). Ontology Web Language (OWL) is an example of a markup language for expressing construct formalisms.

To depict the meaning of a model, we refer back to March et al. (1995).

> *A model is a set of propositions or statements expressing relationships among constructs.*

A model aims to represent the real world, which includes the problem space and solution statements. Entity-Relationship Diagrams, Use-Cases, and Activity-Flow Diagrams are examples of models used for describing information requirements and problem definitions of an information space. Simply put, a model is a representation of how things are. It aims to capture the structure of reality in order to be a useful representation (March et al. 1995). To be useful a model has to be comprehensive, clear, accurate, detailed, factual and specific in nature.

Methods define processes (Hevner et al. 2004). To define a method, we use the following statement from March et al. (1995).

A method is a set of steps (an algorithm or guideline) used to perform a task.

Methods are facilitators for solving problems. They can take different forms such as mathematical algorithms, natural language processing, data structure or programming language functions. The underlying constructs and models usually influence methods. For example, given the data modeling formalism in an OWL document (the construct) used to describe a business process flow (the model), a specific primitive (method) can be implemented to execute state transitions of a pre-defined variable (Thomas et al. 2005). Design Science artifacts can produce methodologies rich in tools and methods required for gathering, analyzing and transforming data to generate a viable solution to the problem defined in the model.

Instantiations validate the effectiveness of the proposed constructs, models or methods. We again follow the definition used by March et al. (1995).

An instantiation is the realization of an artifact in its environment.

By operationalizing the constructs, models and methods, instantiation helps to assess the suitability, feasibility and effectiveness of an artifact for its intended purpose. Prototype building and beta testing with focus groups are commonly undertaken activities to evaluate instantiations. The outcomes also enable researchers to understand the effects of the artifact on users and further refine the constructs, models and methods.

As technology evolves into new application areas, innovation creates IT artifacts with technical capabilities intended to solve known problems uniquely and solved problems more efficiently (Hevner et al. 2004). Design Science builds the IT artifacts, whereas behavioral science studies its implementation to develop theories that can predict or explain a certain phenomenon from its use. Figure 8 shows the conceptual framework proposed by Hevner et al. (2004) that combines Behavioral Science and Design Science paradigms in IS research. The constructs, models, methods and instantiations of the IT artifact contributes to the foundations of the knowledge base. Relevance accompanies building and evaluating the artifact. Rigor follows by theorizing and justifying the effectiveness of the artifact and their implications to the people and organizations that utilize them.

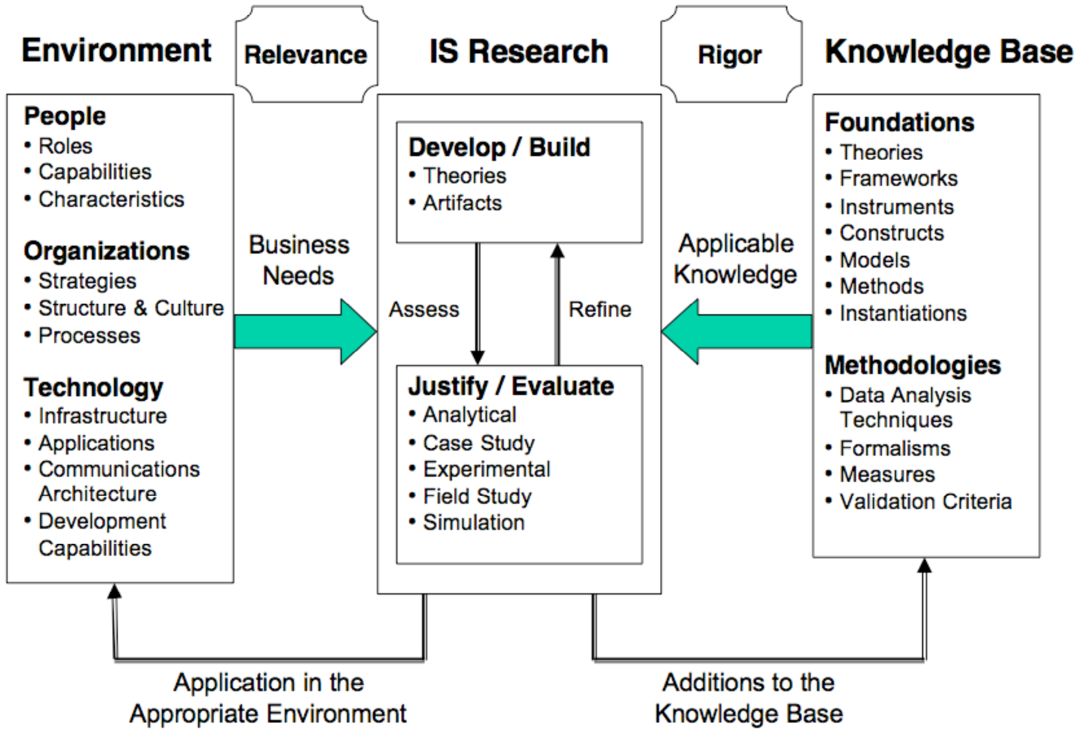

Figure 8. Information Systems Research Framework

Adapted from Hevner et al. 2004.

2.8 Ontologies

Design Science research in Information Systems is the study of artifacts as they adapt to changing environments and underlying information components (Weber 1987). The value of information and the relevance of information sources in a digital space are assessed in relation to the task environment of the user. The task may be choosing a graduate school, reorganizing a stock investment portfolio or looking up friends on a social network website. The cognitive structure of information processing and reflective actions is, in a large part, dependent on the knowledge available from the problem space. Almost always, an urge for additional knowledge emerges in order to better define goals, reflective conversations and actions, heuristics, etc (Schön 1983; Suchman 1987). Consequently, the value of information nestles in the improvements on external representations that cradle the context of the task environment. A context is not just the information that describes the user or his task environment, but is the whole situation that is relevant to the user, his intentions, desires, and beliefs (Dey 2000). We use Dey's (2000) interpretation of context for this study.

> *Context is any information that can be used to characterize the situation of an entity. An entity is a person, or object that is considered relevant to the interaction between a user and an application, including the user and the application themselves.*

To share an understanding of context information, research has shown the benefits of using a common vocabulary that describes the basic concepts in a domain and relations among them (Berners-Lee et al. 2006; Ding et al. 2002; Kalfoglou et al. 2003; McGuinness 2001). Ontologies have become popular in the knowledge engineering community as a means of explicitly representing context information in a format that can be understood by humans and processable by machines. Many different definitions of ontologies have been proposed in knowledge engineering literature. The term "ontology" as borrowed from the field of Philosophy meaning "a systematic account of existence"

(Gruber 1993). One of the first definitions of ontology describes it as “the basic terms and relations comprising the vocabulary of a topic area as well as the rules for combining terms and relations to define extensions to the vocabulary” (Gómez-Pérez et al. 2004 p:6). This research uses Gruber’s (1993) definition of ontology expanded and explained by Studer et al (1998, p:185).

> *An ontology is a formal, explicit specification of a shared conceptualization. Conceptualization refers to an abstract model of some phenomenon in the world by having identified the relevant concepts of that phenomenon. Explicit means that the type of concepts used, and the constraints on their use are explicitly defined. Formal refers to the fact that the ontology should be machine-readable. Shared reflects the notion that an ontology captures consensual knowledge, that is, it is not private of some individual, but accepted by a group.*

A more modest explanation of an ontology is that, it is a formal explicit description of concepts in a domain of discourse (or classes), properties of each class describing various features and attributes of the class, and restrictions on properties (Noy et al. 2001).

With the explosive growth of the World Wide Web it has become increasingly difficult to identify, access and return information specific to the user’s needs. Ontology has emerged as an attractive sub-discipline in the field of Knowledge Engineering to enable uniform representation of data and their relationships with a domain of interest. Berners Lee et al. (2001) portrayed the semantic web model as an extension of the web from its current form, with enhanced capabilities made possible through explicit representation of the semantics underlying the data on which software agents can carry out sophisticated goal-oriented tasks (Embley, 2004). As a key element for the successful implementation of the semantic web model, ontology enables content-based access, interoperability and communication at a level that was unattainable in the traditional hyper-text markup based web environment. By using ontology as the primary structuring model for information presented on the web, information foraging activities can retrieve facts more effectively and conveniently because of the semantically shared understanding of the underlying structure. Conceptual terms can be used for finding query matches based on domain knowledge instead of the traditional approach of matching on strings and substrings as per operational knowledge.

Ontologies thus act as a mediator between information structures presented to a user in the digital space and contextual domain knowledge. Concepts expressed through the ontological terms acquire their exact semantic meaning when situated in a context. That means, any Information System subscribing to the same ontology can speak the same language in different ways depending on the context (Firat et al. 2004). This is made possible by creating semantic objects (instantiations) from the ontology where the variations due to context are represented in the attribute values of the objects (Firat et al. 2004). However, to support seamless communication based on semantics, equivalence between meanings has to be established based on varying contexts. Research in the areas of ontology mapping and reasoning based on ontological heterogeneities have gained significant attention in the recent past to address these concerns (Ding 2000, Firat et al. 2002).

Ontologies have seen application in many areas ranging from its use in organizing multimedia files for distributed collaborative filtering (Wang 2006) to use in personalization and recommendation systems as well as in collaborative knowledge acquisition (Van der Aalst et al. 2003; Kuntz 2005) and Geographic Information Systems (Visser et al. 2002). To summarize, ontologies seek to represent a model of the world where contextual variation is a reality and concepts are reflections of this reality (Foy et al. 2001). Limitations, on the other hand, in the use of ontologies include extensive manual intervention to create ontologies and the context axioms.

Ontologies expressed using the semantic language OWL can provide context representation and reasoning, knowledge sharing, and meta-language definitions (Chen 2004). OWL is developed as part of the Semantic Web initiatives from W3C and has evolved as the popular open standard for semantic knowledge representation. In striking contrast to the limitations of markup languages such as HTML to serve only as presentation tags, OWL language is a web language that can be used by computer applications to process information content based on semantic inferences (McGuinness 2003). As a knowledge representation language for defining and instantiating ontologies, OWL describes classes, relations between classes, properties of attributes in a class and restrictions on properties using normative RDF/XML format. The web ontology document will be referred to as *ontology documents* for the purpose of this research.

Even though we have seen a recent shift from HTML to XML and its translations (such as XSLT) to assist with the machine processing of web documents, it is not a desirable option for expressing shared domain conceptualizations. XML is a nice mechanism to declare simple data structure within web documents, but lacks expressive capabilities essential for realizing the semantic web vision of Berners-Lee et al. (2001). The semantic web is more than just pages and links. It is about relationships between things. It does not matter whether or not one thing is part of another or simply related to taxonomically or otherwise. In its simplest form, it is a way of describing things in a way that is logically decipherable by computers. So the statement "the only constant is change" can be inferred to be the same as "change is the only constant." Another good example that highlights the lack of computing "smartness" is the language translation applications on the web. Semantic inabilities result in interesting translations. For example "this island is botanically impossible" in English (with due respect to Martel 2001) translates to the equivalent of "this island is impossible botany" in French!

Where as XML and HTML places emphasis on syntax, ontologies are about conveying semantics. Languages like OWL use RDF/XML markups to make logical statements from which computers can make inferences. For instance, an ontology document may contain OWL expressions that specify

(Manoj) lives in zip (23221)

(Manoj) has a (Ducati Motorcycle)

[Manoj's] (Ducati Motorcyle) is in (Good) Condition

The document when placed on a web server becomes accessible by its uniform resource locator (URI), just as any other html page or other resource on the web. The statements can be linked to "things" in parenthesis in another ontology document that states

(Ducati Motorcycle) is from (Italy)

(Ducati Motorcycle) is a (Motorcycle)

When different knowledge bases (ontology documents) are linked in this manner, the resulting knowledge structures remain connected although easily broken down. Computers can still make logical inferences no matter how complex the structures or what it is about. This is different from centralized databases with millions of records or other websites that are spiced up with html meta-tags and xml tags. Meaningful information can be retrieved when there is a way to semantically tie the concepts together. With the lack of expressiveness, there has to be an awful lot more syntax to make structures logically decipherable by computers.

2.9 E-commerce

In this research, we develop a framework and study its use as a methodology and as a functional model. To do this, we consider the task environment of a characteristic consumer in an e-commerce setting. Specifically, we look at the hierarchy of tasks in the consumer decision-making process to judge the effectiveness of using ontologies to represent external environment, internal task representation and the resulting cognitive fit. We choose the e-commerce setting as the representative external information space because of its unquestionable ubiquity, futher proliferation and unparalleled consumer dependence in the future.

In the last decade, the worldwide e-commerce has experienced remarkable growth with a matching increase in online consumer spending. It is reported that ecommerce worldwide reached a high of $1.3 trillion in 2003 (Mahmood et al. 2004). Needless to say, e-commerce has turned into an important business phenomenon that has attracted the interest of researchers, practitioners and the public alike. Researchers have specifically examined different e-commerce websites to identify how companies are using the web for interaction with customers. One study of Fortune 500 companies found that 95% use web sites to provide information on their products and services, and nearly 25% do some form of electronic transactions (Liu 1997). These segmented percentages must be much higher today. Forster Research estimates a continued growth in advertising and marketing investment for online commerce from around $14.7 billion in 2005 to about $26 billion by 2010 in the US alone (Elkin 2006). Relatively cheaper computer hardware and software, higher network bandwidth and new technologies like XML and AJAX, makes it easier for firms to deliver dynamic web content catered towards developing better supplier relationships. Disseminating real time information to the customers also becomes easier. We have seen a trend among all popular brick and mortar firms leveraging online channels to add more choices, offer better flexibility and provide cost saving to consumers.

The e-commerce market is classified into two main types: business-to-business

(B2B) and business-to-consumer (B2C) (Kauffman et al. 2001; Subramani et al. 2001). Subramani et al. (2000) makes a distinction between the two by stating that a B2B initiative focuses on strategic IT investment decisions that enhance relationships between customers and suppliers and requires multiple firms. In a revision definition later, the authors added additional variables (Customer Type, Firm Type, Product Type, Innovativeness and Governance) to differentiate between B2C and B2C (Subramani et al. 2002). Based on this revision, B2B are those where e-commerce initiatives involve electronic exchange between two or more business entities; whereas, B2C relationships seek to generate benefits for at least one business entity or an individual consumer. We do recognize that both B2B and B2C are either a unilateral initiative or a joint initiative involving alliances or partnerships among multiple business firms. For this dissertation we limit ourselves to considering only B2C commerce where benefits promised to the individual customer are more in focus than multiple participants. Research initiatives in B2B tend to focus on improvements in processes and systems that enable flow of information between the partnering organizations (Gebauer et al. 2002).

E-commerce has brought to light the inadequacies of conventional business models in elucidating business techniques for the web. Design Science can play a role in the process of designing, prototyping and building systems which enable those business techniques pertinent to the characteristics of the Internet medium that differentiates it from the familiar climate of traditional business environments. Riggins (1999) identifies three different criteria for value creation of an e-commerce system – efficiency improvement, effectiveness enhancement and strategic purpose. He also suggests five dimensions along which firms compete online: By using various modes of "interaction", firms compete over both "time" and "distance" to provide some "product or service" to their customers through a chain of "relations" (Riggins 1999). He uses these two perspectives to create the Ecommerce Value Grid that lists 15 different areas where web-based commerce can be used to add value for their customers.

Advancements in technology have, without doubt, enabled e-commerce to adopt new and innovative approaches to Internet marketing, retail transactions, knowledge distribution and other support activities (Applegate et al. 1996; Kardaras et al. 2000). This fast pace of growth has caused many businesses to overlook key aspects of design principles for the success of e-commerce systems.

2.10 Consumer decision-making

A main focus of this study is to use the decision-making process in an e-commerce environment as the test case for developing ontologies to describe the internal, external and mental representations of the consumer. In this section we provide a review of literature from the Marketing discipline to identify accepted theories of consumer decision-making applicable for this purpose.

Buyer Behavior Theory has its origins in the Marketing literature of the 1960s and 1970s. Howard (1963) first published a theory of consumer choice in his book *Marketing Management: Analysis and Planning*, the revised version of which was later published as the Theory of Buyer Behavior (Howard and Sheth 1972). In 1973, Engel and Blackwell proposed another theory of consumer buying behavior in their book *Consumer Behavior* (referred ed. 1995). Finally, Bettman (1979) also published a widely cited information processing theory of consumer choices. These theories have contributed significantly to our current view and understanding of the consumer decision-making process. Brief summaries of these theories are presented below.

Howard and Sheth (1972) proposed their theory of buyer behavior as a systems model consisting of an input, a processing and an output component (shown in Figure 9). The inputs are factors that affect the initiation of the shopping process. The processing component includes behaviors and stimuli that affect decision-making and learning. The output component is represented by a set of variables that attempt to capture the impact that the process had on the consumer and the observable behaviors of the shopping experience.

Bettman (1979) presents the information processing theory of consumer choice as an iterative model consisting of six components: processing capacity, motivation, attention, information acquisition, decision processes, and consumption and learning processes. He argues that a consumer may jump between stages at any time as a result of receiving new or contradicting information and that the iterative nature of the process is made up of a series of choices at each of the phases.

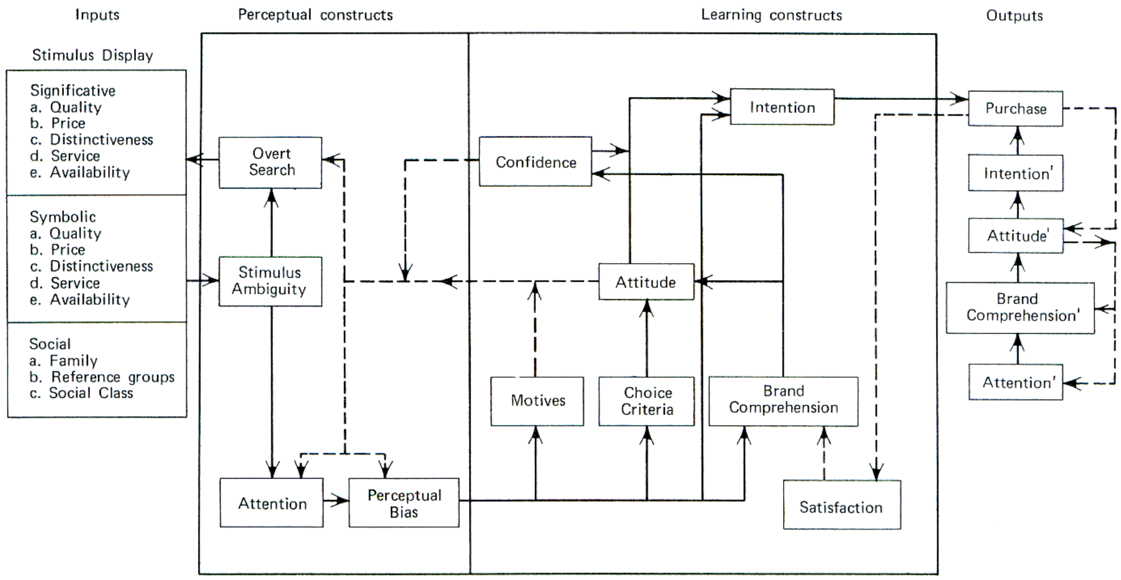

Figure 9. Buyer Behavior Model

Adapted from Howard et al. 1972.

Engell and Blackwell (1995) models consumer decision-making process using five phases (**Error! Reference source not found.**). They are need recognition, information search, alternative evaluation, purchase decision and post-purchase evaluation. Similar to Howard et al. (1972) and Bettman (1979), this model also accounts for the impact of environmental factors and the effects of learning on an individual's behavior.

The models of all three researchers show many similarities. Therefore, we have to wonder if it is just coincidence or if consumers are equally predicable in the patterns of their buyer behavior. All of the models begin with the consumer's realization that they have a need which requires a purchase to satisfy. All models emphasize the role of information search, both internal (memory models) and external (environmental scrutiny).

Finally, there is the decision-process, which represents the outcome (purchase decision, completion of transaction or just learning). From the point of view of a researcher, the similarities represent confirmation of truth, which in turn can inform design. Utility from design will inform and justify the theory (Hevner et al. 2004).

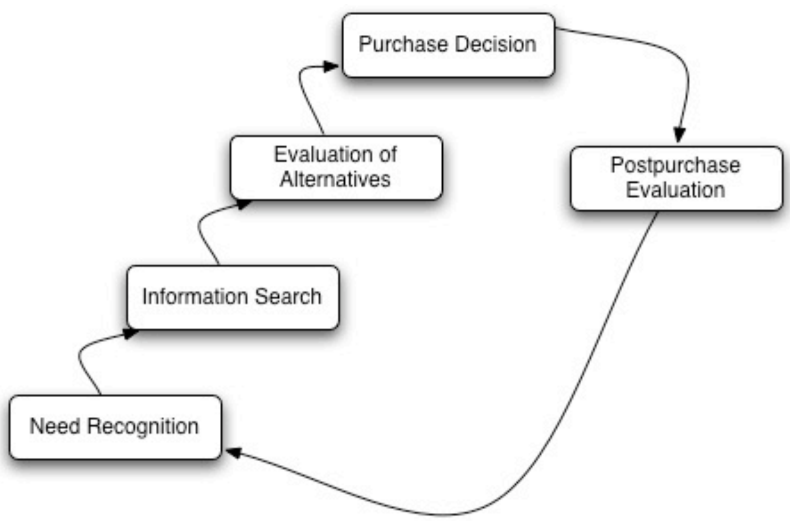

Figure 10. Consumer Decision-Making Model

Adapted from Engell et al. 1995.

For the purpose of this research, we use the model proposed by Engell et al. (1995) for two reasons. It is simple enough to describe the consumer's decision-making process, and it is comprehensive enough to cover all aspects of his or her decision. However, it is rarely the case that a consumer commits to a purchase at every visit to an e-commerce website. In this study we consider a medley of situations, where a person might simply be seeking information, akin to *exploration* or using information to reinforce and confirm a purchase, a form of *exploitation* or both. Whether it is exploration or exploitation, the mediating information structures should be one that enables him to complete the task effectively and efficiently.

2.11 Summary

Our goal in this chapter was to highlight topics relevant to this research. It is by no means comprehensive, but should offer the reader a clear picture of the disciplines from where the principles and ideas are borrowed and how they are interwoven to create the fabric of the research framework proposed in the next chapter.

CHAPTER 3 Research Methods

This chapter attempts to portray a coherent description of the organizing framework that forms the foundation of this study. It explores the connection between existing theories that lay the groundwork for building the artifact using Design Science principles. The discussion should also serve as a glide path to verify the logical consistency of existing theories and assessing ways in which new theory may be developed.

3.1 Chasing the train

There is an unspoken call for help guilelessly characterized by the volume of information available electronically. We are in a phase of the digital age, where there is rapid rate of change in information, functionalities and interfaces of information spaces. Even the computer savvy is faced with the challenge of constantly having to update their skills. In fact, it is fair to assume that a significant number of users of digital spaces do not find technology intrinsically interesting but rather an unavoidable medium born out of the necessity to find requisite information. As Borgman (1996) describes it, there is a need for designing systems that are usable by the "perpetual novice."

To perform a task, we process the information perceived from external representations and the information retrieved from internal representations in an interwoven, integrative and dynamic manner. The resulting mental representations mediate situated actions necessary for completing the task. As Schön (1983) would agree, the question, "How ought I to act *in this information space*?" quickly turns into a scientific one. The appropriate means, as Schön suggests, have to be selected by applying the relevant scientific theory. Theories of social action and cognitive science discussed in the previous chapter show that, creating a mediating structure of information based on the cognitive fit between the internal task representation and the external problem representation may lead to better task completion performance. The framework described in this chapter intends to provide us with the ability to analyze user interaction with the external space and to think prospectively about relevant design issues in building mediating structure of information represented as ontologies. The mediating structures will help to proactively examine the contextual nature of the task to be performed and to customize the problem-solving aids (tools, navigational aids, menu structures, etc.) required to perform the task. The theoretical basis of this effort originates from the notion suggested by Vessey (1991) that complexity in the task environment will be effectively reduced when problem-solving problem aids support task strategies (methods and processes) required to perform the task.

3.2 Developing the framework

The extended cognitive fit model (see Figure 6) makes the argument that when the decision maker's mental representation of the problem (software comprehension) and their mental representation of the task (the software modification task) match, problem-solving performance is likely to be more accurate and quicker than it would otherwise be (Shaft et al. 2006). This model has been applied in many areas such as performance evaluation in software comprehension and modification tasks (Shaft et al. 2006), testing the usefulness of geospatio-temporal annotations for schema comprehension (Khatri et al. 2006), etc. Utility of the model is also evident for managerial decision-making, market analysis, and resource management as well as for generating contextual maps like the "fisheye" (Janecek et al. 2002) and spatial co-citation maps (Chen 1999).

A closer analysis however, reveals the need to reconceptualize the boundaries of the extended cognitive fit model and its generalizability for assessing its use in a digital information space. As Feynman (1998) might cheerfully say, "So we have a theory, and we do not know whether its right or wrong, but we do know that it is a little wrong or at least incomplete." Three significant deliberations are worthy of discussion in this regard. First, the study of software maintenance and modification is used to test the theory by varying the cognitive fit to create the dual-task interference roles of match and mismatch. The external problem representation here is the comprehension of the software that helps to create the mental representation of the software based on the clearly specified software modification task. In a digital space the external representation can be any information space of choice depending on the information foraging requirements of the user. There is little to hold back a user from switching to another "information patch" if the expected gains from the current information space is lower than the expected gains in a new information patch (Pirolli et al. 1999).

Second, the mental representation of the task solution and the cognitive requirements are expounded in relation to a software modification task that is distinctly and unambiguously stated to a group of IT professionals. For a user acquisitioning and evaluating information in the digital space, the task may be explicit or implicit. It is explicit if the inquiry is well defined. It is implicit in nature if there is a need to investigate and learn. Completion of explicit tasks is easy to determine (authorizing an online payment of a utility bill), but the completion (or near completion) of an implicit task is a subjective judgment (literature search to write a research paper). Above all, in a digital domain, each user possibly constructs a different mental model for structurally similar problems (isomorphs as suggested by Zhang {1997}). Extended cognitive fit model (Shaft et al. 2006) is catered towards an explicitly defined task. It does not apply to subjective individual tasks that are unique and vary from person to person.

Finally, the extended cognitive fit model emphasizes the interaction between the internal representation of the problem domain and the external problem representation as well as the problem-solving task (see Figure 6). The model offers no detailed interpretation of the nature of these interactions or the influence of intuition and reasoning (Tversky et al. 1981). Herbert Simon's notion of satisficing on bounded rationality and Schön's reflective model (refer Chapter 2) can offer some rudimentary insights into the balancing act between thought and situated action that is lacking in the extended cognitive fit model. If nothing else, the inclusion of these philosophical positions can enhance the effectiveness of the model to express user intentions in a given information space.

This is certainly not a diatribe on the extended cognitive fit model, but a debatable concern about the suitability and predictive power of the model given the difference in circumstances of the user behavior and the nature of the digital information spaces. The selection of a specific information space and the representational bounds (context) within that external space is shaped by the problem-solving task at hand, whether implicit or imposed. For instance, it is reasonable to assume that a person looking for watches will not be spending time in the sock section of an online clothing store. On the same note, the task environment is an important catalyst that defines the internal representation of the problem-solving task. Together they influence the mental representation of the task solution. This notion is portrayed in Figure 11.

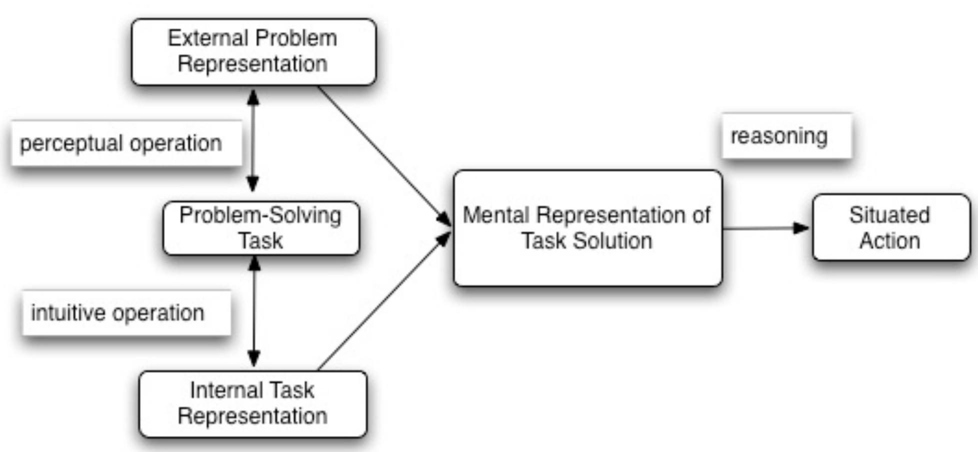

Figure 11. The Cognitive Information Model

To provide clarity to this postulate, let us look at the consumer decision-making process in an e-commerce environment. The decision-making process is a higher level decision task that can be decomposed into elementary subtasks at each of the six stages (refer Chapter 2). The mental representations of the task solution themselves quite possibly will be different from person to person even for isomorphic subtasks. Cognitive fit in this context implies that the internal representation of the subtask matches contextual problem representation perceived from the environment. Intuitive operations on the internal environment combined with the perceptual operations on the external environment help to find new and unexpected meanings and to direct responses to such discoveries. To use Schön's jargon, this "reflective conversation" with the situation guides the response leading to the next subtask in the consumer decision-making process.

Argyris and Schön (1992) proposed a general framework to describe personal and interpersonal actions using theories of action that exist as espoused theories and theories-in-use. The answer to how a person would behave under certain circumstances is his or her espoused theory of action for that situation. Theories that actually govern an individual's action become his or her theories-in-use, which may match (congruent) or may not match (incongruent) his or her espoused theories. Theories-in-use are the person's operational theories of action and distinguishable from the espoused theories that are used to justify his or her action. As a unit of description for the knowledge that describes action, theories of action explain the distinction between espoused theories and theories-in-use, the relationship between theory of action and the behavioral world, and the dynamics of

Schön's concept of reflection-in-action (1983) through which theories-in-use are instantiated, developed and often modified.

Theories of action uphold the viewpoint that the individual may or may not be aware of the incompatibility between their espoused theory and theory-in-use. However, the framework deliberates that all human being (and not just professionals) reflect on actions to maintain competence and continuity toward what they sense as necessary to complete a task. As human behavior is in itself a consequence of the theories of action of the individual, it can be used to explain, predict and to some extent, control the behavior of the person. Since the completion of a task in the task environment involves a sequence of actions undertaken by the user, a theory of practice can also be specified which consists of a set of theories of action that yield satisficing outcomes under set boundaries of action and within acceptable bounds of governing variables and constraints (Argyris et al. 1992).

In the duality of our existence as a social and rational animal, Simon (1957) states that there are theories portraying a high degree of rationality at one end of the spectrum and on the other end of the spectrum, there are theories depicting high levels of motions and emotions in our social behavior. Simon notes the need for a "theory of action" that appropriate provisions for both the rational and social aspects of human behavior. Schön (1983) followed with the notion of the "reflective practitioner" where thought and action based on tacit, newly discovered and learned knowledge is more commonly the type of intervention used by a practitioner to satisfice their interaction with a situation during the course of everyday activities. We borrow these ideas of information processing (Simon 1957; 1989), reflection-in-action (Schön 1983) and the theories in practice (Argyris et al.

1992) to express the interpretation of situated actions as shown in Figure 12. Schön specifically subsumes the role of the situation's talk-back in assisting practitioners to reflect on the construction of problems and strategies implicit in their actions (p:79). The model presented here extends Schon's viewpoint to include the way clients - the users of e-commerce applications (in addition to professionals) construct particular descriptions from which their interpretations and actions would ensue.

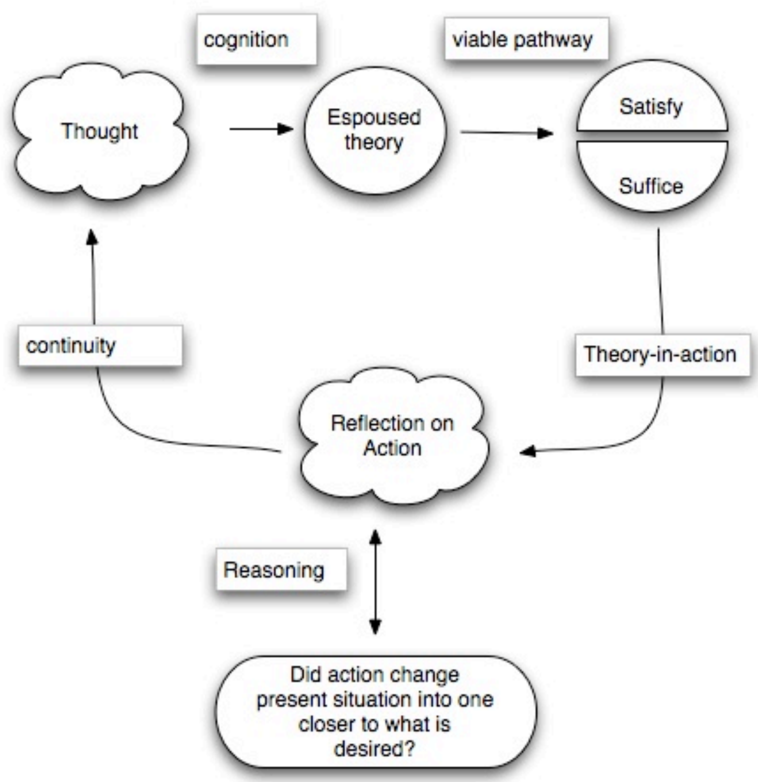

Figure 12. Combining Theory of Action and Reflective Practice

Assistive navigational aids that we currently use in the information rich digital spaces are mostly passive facilitators such as hyperlinks, drop-down menus and keyword searches. Although literature review shows many propositions that consider the use of semantics for information search and discovery, none of them consider the cognitive processes of the user in the task environment.

In a consumer decision-making process, the stimuli for thought may be triggered in many ways. It could be the juicy big burger commercial that makes a person run for the car keys or the much-awaited release announcement of the ultra thin solar powered laptop with widescreen LCD. The action that follows is situated in context (finding car keys or applying for an equity loan to buy the expensive laptop), rationally bounded (assuming that there is gas in the car or that equity loans are allowed to purchase environmentally friendly computers) and is in pursuit of a viable pathway to satisfice. The intuitive operations on internal representation influence the rational and emotional behavior (quenching hunger being satisfying and the justifiable need to conform with changes in computing as sufficing) and hold an equally important position with the automated operations of perception (Kahneman 2003). Even though satisficing may seem at odds with expectations of optimality and high levels of aspiration, research has shown that satisficing better characterizes descriptions of activity among real users in the real world, given the natural limits imposed by resource bounds and imperfect information (Pirolli et al. 1999). Pirolli and Card (1999) use the example of hill climbing to make this argument and comment that satisficing is a form of localized optimization especially when creating implicit models for use in information foraging activities.

Intuitive operations are slower, effortful, more likely to be consciously monitored or deliberately governed (Kahneman 2003). Information from the internal representation is retrieved by intuitive processes (Zhang 1997). Our ability to determine the magnitude of numerical values, mentally add or subtract numbers and categorize ordinal values are all examples of intuitive operations on internal representations. Intuitive operations are associated with poor performance in novices, but may generate powerful, accurate, spontaneous responses in experts (a master chess player does not see the same board that a novice sees) (Newell et al. 1972; Kahmeman 2003). They create an intrinsic view of the task in context. Zhang (997) lists three main factors that influences operations on the internal representations. They are lookahead, biases and learned knowledge. Lookahead is the ability to evaluate all possible alternatives before selecting an action. How many times have you been to a restaurant and flipped through the entire menu before deciding on a certain food selection? In a digital environment, the potential for use of complete lookahead is possible but not always practical. A search on Google (http://www.google.com) for "restaurant menu" returns a measly 43,300,000 hits! Learning occurs from past experiences or from performing a task more than once. Learning also has a direct impact on the decision on action. You know the time of your favorite television show because you have watched it in the past. You can call out your favorite flavor at an ice cream shop because you have savored it many times before. When information structures are sufficiently unambiguous, a learned sequence of actions may take precedence without conscious intervention (Hutchins 1995). You can literally get to the news website that you have bookmarked and visit every morning as if you were blindfolded. When ambiguity arises or when snags are encountered, the motor activity may follow cues by remembering and relating past experiences in the semantic medium. When the semantic medium becomes insufficient to produce new states, explicit lexical representation can bring coordination with the semantic medium to produce meaningful actions (Hutchins 1995, p:309). A bias influences action on the basis of information retrieved from internal representation (personal choice, prejudice, experience, brand loyalty, etc.) or from information gathered from external representations (recommendations, learned knowledge, reviews, etc.). Recommending a movie that has your favorite actor or buying your favorite perfume fixated with distillates of giant squid found in a sperm whale's stomach are all examples of actions influenced by bias.

External representation provides a holistic view of the domain in context of the task and is processed by perceptual mechanisms, which is, of course, internal (Zhang 1997). In the digital information space, the perceptual operations may be sequential or parallel on the spatial representation of the information space. A physician browsing through the electronic medical archive for reference publications on somatoform disorders is a sequential process. However, comparing the colors of t-shirts side-by-side is a parallel operation on the isomorphic task. The information available from the external representation itself may be constrained by the preceding actions that lead to the current patch of information space and by the embedded rules in that space. The activity flow associated with the subtasks of selecting a category from the "Diagnostics and Statistical Manual of Mental Disorders" or checking availability of a t-shirt size are all testimonials to that fact. Perceptual operations also have direct impact on lookahead capabilities. When complete lookahead is impractical, as is the case with most information rich digital space today, we rely on percepts or biases to help narrow the decision on action in hopes of leading to a situation closer to what is desired (Schön 1983, Zhang 1997).

All in all, the thought process, the action to satisfice along a viable pathway and the reflection on action together creates a form of continuity that can be expected to hold across the evolution and progression of the cognitive process for task completion. It is interesting to notice comparable resemblance observed from the Darwinian point of view, where properties of interaction with a system is a product of evolution, and behaviors are consistent with the logic that "continuity must hold" (Margolis 1987, p:26). Whereas, the external representations enable perceptual operations, the internal representations activate intuitive processes (Zhang 1997). The interplay between the intuitive and perceptual operations creates the mental representation of the task solution. This is cognitive fit.

3.3 Ontologies and the framework

To operationalize the internal, external and mental representations as computational models, we can use ontologies. Ontologies are used to provide explicit and bounded specifications of shared conceptualizations. The relevance of ontologies in their representational capacity is gaining popularity and support in practice and in academic research across numerous disciplines. Ontologies are being used to model user dimensions such as personal preferences and interest (Dominik et al. 2005), organizational environments (Fox et al. 1997), workflow systems (Thomas et al. 2005), biological functions (Rosse et al. 2003) and social factors such as cognition, goals and actions (Thomas et al. 2003).

One of the main objectives of this study is to build the ontologies to represent the different states of thought, action and reflection that manifest themselves from the current state of the internal and external representations. There is really no single way to model a domain using an ontology (Foy et al. 2001). To provide a frame of reference for this research and to form a basis from which to generalize at a later stage, we start with the perspective of the consumer decision-making model in an e-commerce environment. Three different ontologies are developed to test the applicability of cognitive fit in this scenario. We call the ontology for internal task representation the "User Ontology" since the task representation is contextual to an individual user and should therefore allow for variations in interpretation and nuances in meaning pertaining to that particular person. The external problem representation is the problem domain or the information space in context and is referred as the "Domain Ontology". Lastly, the mental representation of the task solution is the "Cognitive Fit Ontology."

Ontology development is an iterate process and requires the researcher to gain a thorough understanding of the problem domain before contextual knowledge can be expressed as axioms, often in the form of first order logic statements (Firat et al. 2004; Fox et al. 1997). It is common practice in the discipline to verify the suitability of existing ontologies by testing against well-defined use cases (Chen 2004; Firat et al. 2004). Available ontologies can also be extended or new ontologies can be created. For developing User Ontology and Domain Ontology, we examine the suitability of existing ontology models such as the Generic User Model Ontology (Dominik et al. 2005) and the Organization ontology for modeling enterprises (Fox et al. 1997) respectively. Concepts in the ontology should be a close representation of the objects and their relationship with the domain of interest (Foy et al. 2001). Intuitive on internal representations and perceptual operations on external environment are modeled in the ontologies using a combination of concepts and properties. Concepts in this ontology include the classes, individuals and their state values, various forms of *object* and *datatype* properties, and axioms in the form of closure statements defined in the ontology and rule language expressions (refer web reference on Protégé Editor; web reference on SWRL).

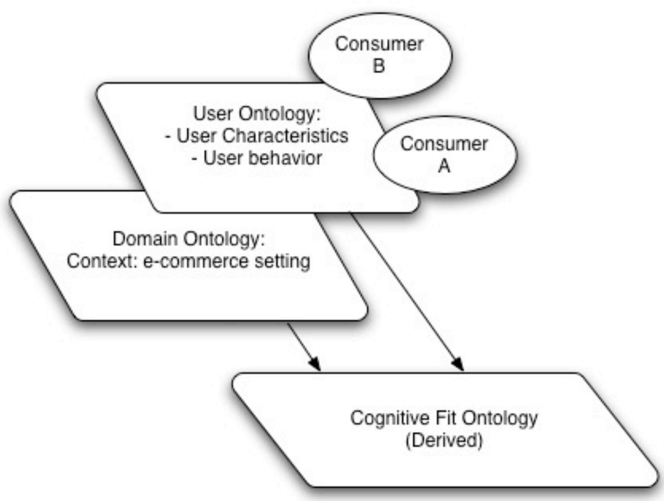

Figure 13. Ontology Mapping from the Cognitive Information Model

In an e-commerce environment, potentially every user has a different goal. The goals can also be isomorphic in nature, for which each user possibly constructs a different mental model (see Figure 13). Here, the Domain Ontology is the e-commerce space and the User Ontology is the internal task representation that takes into consideration the contextual variations of individual task environment (Consumer A and B in Figure 13). The Cognitive Fit Ontology is the recognition of the differences in individual task and the information needs specific to the task. The hierarchy of concepts described in the Cognitive Fit Ontology consists of vocabulary that articulates the semantics of asserted and inferred mapping between the User Ontology and the Domain Ontology based on observable user interaction with the digital space. The rules for assertions and inferences are implicitly stated in the ontology as "necessary and sufficient conditions" as well as explicitly defined using SWRL based descriptive logic statements.

Many different methodologies have been proposed for ontology mapping (see Kalfoglou et al. 2003 for a detailed review). Generally adopted mapping approaches usually start by treating ontologies as a signature-axiom pair, O = (S,A), where S is the ontological signature that describes the vocabulary and A is the set of axioms that specify the intended interpretation of the vocabulary (Firat et al. 2004; Ding et al. 2002; Kalfoglou et al. 2003). While ontology mapping is the task of relating vocabularies in such a way that logic expressions modeled as mathematical structures account for how the source ontological signatures and axioms can be mapped (Kalfoglou et al. 2003), the dynamic nature of updates necessary to model cognitive fit makes the use of traditional conversion functions unsuited for representing the current and reasoned user actions in the information space. To preserve the references of component terms and the truth of assertions in the domain where actions are carried out we therefore use close axioms within ontologies and SWRL/SQWRL rules (refer web reference on on SWRL) as a means for updating ontology individual properties.

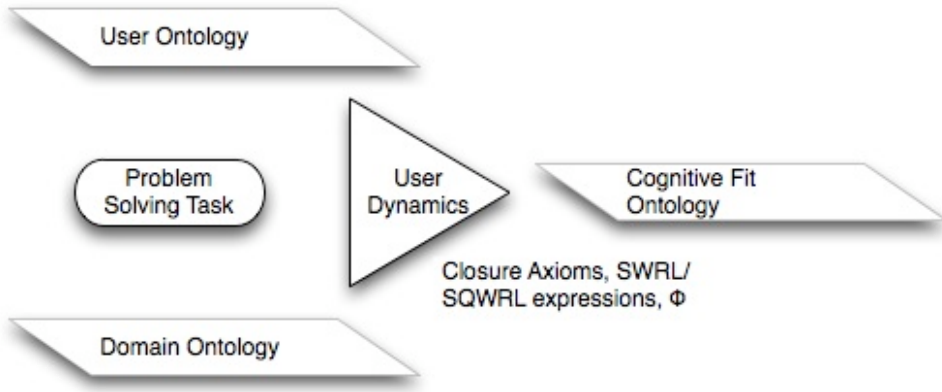

Figure 14. Ontology assertions using ontology axioms

For the consumer in the e-commerce environment, the ontology mapping will link local variations in individual user actions (described in the User Ontology) with the task environment (Domain Ontology). The resulting cognitive fit then seeks to align the interpreted user context with specific segments of the domain ontology. The objective is to represent the outcomes of thought, action and reflection in action that will help to change the present situation to one closer to the desired state. Specific user behaviors attributable to espoused theories of action (Argyris et al. 1992) are used for this purpose and stated using SWRL rules. In general, a SWRL rule Φ, is the mapping from knowledge base and the known fact list to semantic expression in first order descriptive logic (Figure 14). If Φ preserves the truth of assertion for the given domain, an expert system can be used to reclassify and assert individuals into a hierarchy of “Reasoned State” and “Current State” concepts defined in the Cognitive Fit Ontology. The SWRL rule can also be used to tag the next predicted consumer decision-making phase and the information space of consequence.

The "Reasoned State" will guide (or misguide) the user to the next sub-task in the consumer decision-making process. Since assistive aids to guide situated actions will reduce complexity in the task environment (Vessey 1991; Pirolli et al. 1999), determining the context and the subtask of a given user from the Cognitive Fit Ontology will allow the creation of active representations in the form of symbols, site maps, adaptive navigational structures and interactive tools. By including the known characteristics of situated activity when creating the knowledge representations, the asserted individuals in the ontology will be sufficiently informed with a general knowledge about the consumer decision-making process and specific knowledge about domain orientation.

Returning to Simon's analogy of the ant on the beach (1996), it is equivalent to suggesting that the Cognitive Fit Ontology will serve the ant a satisficing knowledge structure about the beach that is harmonious with the intuitive reasoning and observed perceptive activities. By including the known characteristics of situated activity when creating the knowledge representations, the ant should now be sufficiently informed to take future actions by using its own general knowledge about the task and specific knowledge about the beach. Clearly there may be incongruence between the espoused theory and theories-in-use (Argyris et al. 1992), but higher effectiveness is attained if the actions lead to desired results in the shortest possible time.

3.4 Applying the framework

Design is the search process to discover an effective solution to a problem. The effectiveness of the solution is dependent on the knowledge of the application domain (e.g., problem recognition, requirements and constraints) and the solution domain (e.g., techniques, tools, etc.) (Hevner et al. 2004). Whether the purpose is exploration or exploitation, the ultimate goal of information-seeking processes is to locate and use the correct information to solve a problem (Komlodi et al. 2007). In information rich digital spaces we often find ourselves being the "perpetual novice" (Borgman 1996) and we sustain actions under constraints such as the limitations of our own mind and complexities of the environment whose abstract structures are almost always unknown. To support novel discovery and use of information under such constraints, the format of representation has proven influence on the information that is perceived and the processes that are activated (Zhang 1997). Zhang (1997) refers to this as the "representational determinism." Our own history is copiously spotted with numerous examples of representational determinism. Examples include the fallacies of Ptolemy's geocentric theory leading to the heliocentric view of Copernicus and the Arab numerical system replacing the Greek number system due to the obvious representative limitations of the latter in large number calculations. A noteworthy point that bubbles to the surface is that, unless we are equipped with active representational forms and tools, it is imperative that in today's digital world, portions of the environment will remain unexplored and critical information will remain undiscovered. The tools we use for interaction with the space must therefore be portable, easy to use and access, persistent, contextual and aware of new, old and updated information (Komlodi et al. 2007).

Problem-solving is the utilization of available means to reach desired ends while satisfying the laws that exist in the environment (Simon 1996). The cognitive information model we propose in this dissertation helps to create mediating structures (ontologies) by coordinating the internal representation of the task and the external problem domain where actions are carried out. The coordination of the internal procedures (semantic, lexical and/or motor) and the external world where the actions are carried out is a simultaneous process (Hutchins 1995, p:304). The mediating structures will serve as useful foundations to build visual tools and spatial layouts that provide dynamic contextual interaction assistance for end-users.

A corollary to the ontology development effort is that, if the mediating structures are truly effective, we should be able to instantiate the ontologies in any ontology expression language. Validation of the ontologies developed in this study takes two forms. It is the completeness of semantics for interpreting user context and the problem domain. It is also the test of expressive capabilities of context representation that can be operationalized in ontology expression languages. For this study, we use Web Ontology Language, OWL to instantiate the ontologies. OWL is preferred because it offers proven declarative support for structured knowledge representation (Berners-Lee et al. 2001; Chen 2004, Thomas et al. 2005) and rule-based logical inference from ontology semantics as evidenced by its use in many prominent research initiatives (Berners-Lee et al. 2001; Chen 2004; McGuinness 2003). A potential point of contention that may arise from the discussion so far is the conflict between satisficing and optimizing. Following Pirolli et al.'s (1999) argument that satisficing is a form of localized optimization, the belief upheld for this research is that, at its worst, the framework will be satisficing. At its best it could very well be optimizing.

3.5 Summary

This chapter presents the theoretical basis and highlights concerns in comparable theories that make it relevant to developing a new framework. It also establishes this framework in terms of existing theoretical work, particularly Herbert Simon's notion of satisficing on bounded rationality and Schön's reflective model. We also justify weighing in the role of problem-solving task to emphasize the interaction between internal and external representations. The importance of understanding the intuitive and perceptive operations and their co-dependence on the problem-solving task is presented. Finally, the rationale for developing mediating structures using ontologies is also presented. Considering the scientific progress made in the field of Information Systems, it is intriguing to notice that few researches have envisioned the possibility and practicality of building systems by their ability to accommodate the bounded rationality (time constraints, lack of complete information, memory capacity, etc.) in which we normally operate. In a limited form, this is precisely what this research aims to satisfy. The next chapter will cover the implementation and use of the three ontologies in digital information spaces.

CHAPTER 4 Architecture Design

Given the theory and framework of the preceding chapters, there are several application areas where the model could be tested. Some obvious possibilities include electronic commerce, digital libraries, virtual museums, organizational knowledge stores, large database repositories and help desk systems. Each of these beckon a unique way of arranging information that will be least challenging for the user to explore and exploit. For this dissertation we focus on the role of consumer buyer behavior as it applies to the problem of navigating an e-commerce store. Just as light is easily broken down into its component colors when viewed through a glass prism, different constituent issues exist for this task that need to be individually addressed. From the perspective of developing ontologies, the main challenge is to model the conceptualizations that will express the semantics of cognitive fit between the users' internal representations and their interactions with the external environment. From a business owners' perspective, we have to consider the problem of how to semantically present spatial information and visual cues. The domain owner may also have vested interest in using the knowledge base to analyze activities that have direct implications to the business such as predicting demand, generating revenue, identifying profit margin opportunities and calculating re-shelving intervals on high volume products. From a system architect's perspective, we look at the implementation tools that will provide reasoning and inference capabilities and techniques to mediate contextual updates to the user interface through ontology assertions and queries. And finally, from a consumer's point of view, we look at how the model can provide assistance that will result in a richer, more productive and individualized experience regardless of whether the user is a novice, an expert or somewhere in between.

Different tasks, isomorphic or not, create different internal representational structures. To allow for this contextual variation, semantic "objects" and their attributes are represented as semantic "individuals" and their "properties" in the ontology. Figure 15 illustrates a simple schema of an e-commerce system, together with contextual variations in the tasks of the users. For the given e-commerce system, a user in Context A may wish to buy a television with the latest technology costing less than five hundred dollars. Another user in Context B might be simply exploring the digital space for information on the best way to configure and setup a home theatre system. Their problem-solving tasks are different and so are their mental representations of the task solution. While Context A involves exploration and exploitation of information available from the external representation, Context B is characteristically just explorative in nature. A cognitive fit is a match between the information emphasized in the external representation to the internal representation of the task solution (Shaft et al. 2006, Zhang 1997). Ensuing activities are contextually situated (Schön 1983) and rationally bounded on the internalized goals of satisficing in the constraints of the domain (Simon 1957; 1989).

As there are no generally accepted naming convention for defining ontology concepts or relationships among the concepts and their instantiations, this dissertation adopts the nomenclature used by Protégé Knowledge Acquisition System (Protégé 2007) developed and supported by Stanford Center for Biomedical Informatics Research at the Stanford University School of Medicine.

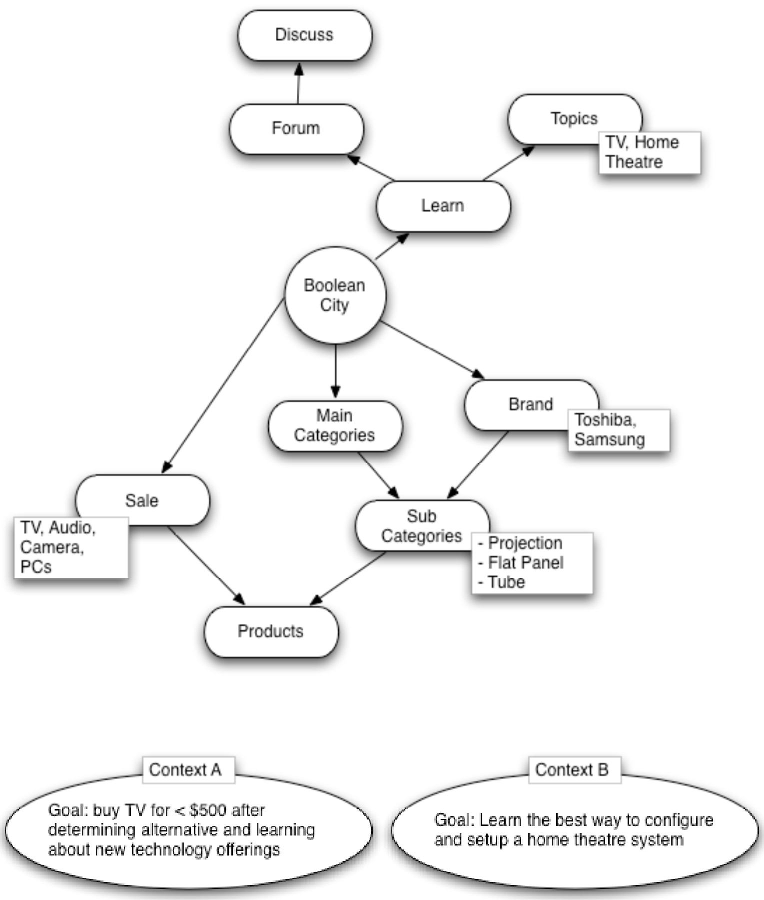

Figure 15. Problem-solving tasks and context variations in an e-commerce system

The Protégé project is a free open source ontology editor and knowledge-base framework based on Java programming language and supports ontology modeling in different formats including RDF(S), OWL and XML Schema. This dissertation adopts the nomenclature standards used by the Stanford team since ontology development for this research is done using Protégé (version 3.4 Build 110). The Protégé software provides a modular knowledge management environment for specifying and assembling ontologies and for modeling problem-solving methods that implement procedural strategies for solving ontology tasks (Eriksson et al. 1995).

The rest of this chapter details the principled construction of the component ontologies, the implementation architecture for reasoning and rule executions, and the generation of the e-commerce application software mediated by ontologies and informed by the rule engine.

4.1 Ontology design

Ontology development is an iterative modeling activity undertaken by the knowledge engineer who first identifies the distinctions of the application area for which it is built. The initiative has to be motivated by the kind of tasks envisioned as served by the knowledge base. Ontologies help to keep the knowledge model separate from the application logic of the problem-solving methods (Musan 1998, van Heijst et al. 1995). The separation allows easy knowledge sharing, documentation and reuse in other application domains.

To develop the necessary ontologies for this research, the focus is turned to the interplay between the external environment (the e-commerce setting) and the internal task (the consumer decision-making process) from which the cognitive fit of situated activity in the task environment is inferred. To gain a thorough understanding of the task environment, a detailed analysis of two popular e-commerce websites on the Internet was conducted. Experts in the discipline of Marketing Management and Knowledge Engineering participated in this analysis to discuss the underlying structural model and the behavioral conceptualization shaped from the interactions with the websites. This was used as a roadmap to identify and evaluate existing ontologies to determine whether or not they can be reused or extended for this research. General User Model Ontology (Dominik et al. 2005), Shared Action Ontology (Metzinger et al. 2003), Organizational Environments (Fox et al. 1997), Cognition, Goals and Actions (Thomas et al. 2003), Workflow Systems (Thomas et al. 2005), and the Person Ontology in the SOUPA Domain (Chen 2004) are some of the ontologies that were extensively evaluated for this purpose. Given the unique nature of the research problem, it was determined that the semantic expressiveness of examined ontologies was not useful in their existing form or extensible for this study. The analytical exercise was fruitful however in helping identify several useful semantic vocabularies applicable to model our concept of the Domain, User and Cognitive Fit specifications. We started with a rough first pass at the ontologies, which was revised, refined and conditioned progressively for anticipated applicability and extensibility. Further discussion with experts helped to fill in details as realistic as possible. Literature review of related work (refer Chapter 2) used for developing the Cognitive Information Model (described in Chapter 3) also provided useful insights into expressive vocabulary used in this ontological engineering exercise. Additionally, repetitive evaluation against applications, problem-solving methods and ontology query simulations further helped debug the ontologies and identify weaknesses. A recurring point of discussion was the topic of deciding how to enrich the ontologoies with the correct logical axioms, class definitions and value partitions that accurately characterize the conceptualizations. The choice of concept names used in the ontology is thus the outcome of a collective acumen guided by the goals of the overlaying application – that being to serve rich contextual navigational assistance for exploring and exploiting information in an e-commerce storefront. Although changes to the base ontology were rare once the knowledge experts agreed on the final design choice, fine adjustments were made throughout the application development process as iterative testing revealed minor weaknesses and concerns. The three upper ontologies are described in detail in the following sections.

4.1.1 Domain Ontology

To capture knowledge about the e-commerce domain and to reason over the ontology using descriptive logic, we use the expressiveness of the ontology web language, OWL. Choosing from the three species of OWL languages (OWL-Lite, OWL-DL and OWL-Full) was steered by the level of automated reasoning expected from the ontologies. OWL-DL was chosen as the expressive language for the ontologies, since current implementation of reasoner engines does not guarantee decidability (Buchheit et al. 1993, Donini et al. 1997) or computational completeness of complex inference problems (Stoilos et al. 2006) when used with the more powerful OWL-Full language.

The Protégé development environment defines three main components for an ontology - *Individuals, Properties* and *Classes* (Horridge et al. 2004). Individuals are objects or instances of a concept in the domain of interest mainly differentiated by the value of their attributes. Properties are relations on individuals and can have single (*functional*) or multiple values. They can also be *transitive* (with or without inverse links) or *symmetric*. As a concrete representation of concepts in the domain on interest, OWL classes are a set of conditions that must be satisfied by individuals in order for them to be a member of the class. Classes in the ontology define the semantic expectations for the instances (Musan 1998) whose definitions are specified by the knowledge engineer or the domain expert. The Protégé system used to model the ontologies automatically generates the resulting ontology document using RDF/XML as the normative syntax for the underlying OWL knowledge representation language.

Figure 16 shows a snap shot of the concept terminology and the class hierarchy for the Domain Ontology. The Domain Ontology encompasses representational vocabulary that expresses the semantics of the task environment - the e-commerce setting. The taxonomic structure depicts the classification of concepts starting with the most generic categorization of items on sale through the e-commerce store. The categories and sub-categories are modeled as per the analysis of the popular e-commerce websites on the Internet. *Theme* differentiates between products and services available from the e-commerce site by using the concepts *MainListing* and *ServiceListing*. *MainListing* groups all major categories of products such as Televisions and Video, Audio, Computers, Cameras, mp3 players, accessories, etc. *ServiceListing* may include Repair, Installation, Financing Programs and other service rendered by the business. For the sake of simplicity *TV* and its related *DiscussionForm* under *TVAndVideo* category are the only listings specified in the OWL document used in this research.

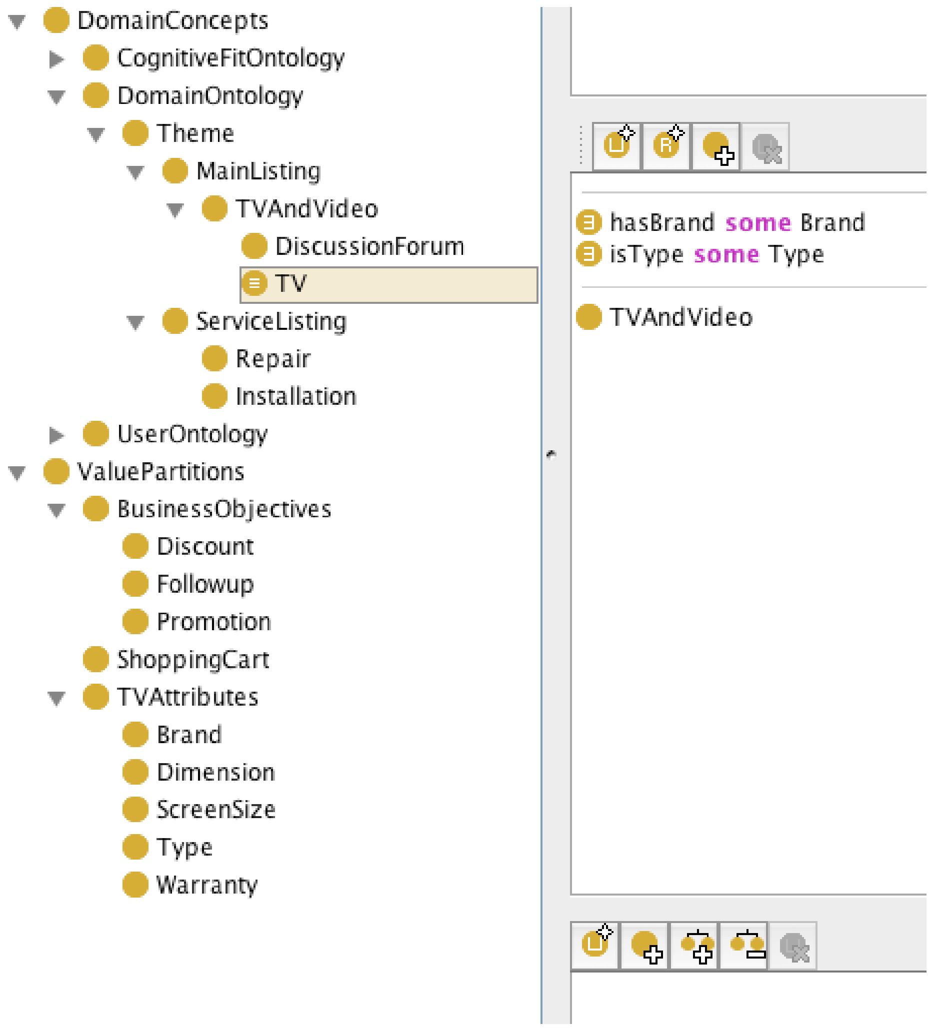

Figure 16. Snapshot of Domain Ontology in the Protégé Ontology Editor

ValuePartitions are design patterns in ontology engineering used to refine class descriptions (Foy et al. 2001). They add sub quality to an upper domain concept. For example, the child classes of *TVAttributes* which are *Brand*, *Dimension*, *ScreenSize*, *Type* and *Warranty* are concepts relegated to cover the parent quality of the class *TV*. Although additional attributes may be necessary to complete the description of a television, this was not done for the sake of simplicity. They may be easily included in the ontology as accompanying sibling classes and value partitions under *TVAttributes*.

OWL Individuals instantiated for the value partitions become fillers for the instantiation of a television item property. For example, Philips, Samsung and Vizio are possible instantiations of the class *Brand*, whereas instantiations of *Type* are used to characterize a television item such as LCD, Plasma or Tube. Two *necessary and sufficient* conditions are assigned for the class *TV* to provide closure on individuals that are asserted as instances of this class. They are

hasBrand some Brand

isType some Type

Existential Quantifier (∃) on the *object* property *hasBrand* specifies the existence of at least one necessary relationship along this property of a television item to an individual of the class *Brand*. Existential Quantifier (∃) on the *object* property *isType* specifies the existence of at least one necessary relationship along this property of a television item to an individual of the class *Type*. Since reasoning in OWL-DL is based on Open World Assumptions (OWA) (Baader et al. 2003, Haarslev et al. 2007), closure axioms for *ScreenSize*, *Dimension*, *Price*, *Discount*, and *Promotion* are not explicitly stated as necessary and sufficient conditions as their corresponding *data* properties *hasScreenSize*, *hasDimension*, *hasPrice*, *discountSale* and *promotionSale* may not be trivially satisfied. Whereas object oriented programming relies on Closed World Assumption (CWA) that are trivially satisfied, in the realm of Open World reasoning, there is the possibility that additional unknown fillers for the *allValuesFrom* Universal Quantifier (∀) that were not specified in the ontology may also exist. It should also be noted that all object and data properties for the television specification are defined as *functional* to ensure singularity in the class relationships.

Ontology classes to trace activities with direct implication to the business owner are also defined as part of the Domain Ontology. *Discount*, *Promotion*, *Followup* classes serve the sales and marketing objectives by using the knowledge base to assert consumer interest in products on discounted sales, promotion items, or to tag a post purchase follow-up tactic intended to reduce cognitive dissonance. Use cases described in the next chapter demonstrate the role of *BusinessObjectives* value partitions in an e-commerce application. Contextual cues such as product highlighting and differing menu structures are rendered on the user interface screen as per any agreement reasoned between identified user activity in the information space and the cognitive fit with the task environment.

The user interface of the e-commerce application uses the shared representation of the Domain Ontology to create the external environment on which the user interacts and converses before directing an action. The Domain Ontology defines a precise and consistent knowledge model and is least susceptible to periodic change. If the knowledge engineer should modify that ontology, then changes will affect components of the user interface.

4.1.2 User Ontology

On the other hand, the User Ontology is a description of the consumer buyer behavior model and reflects the position of the customer's behavior in the digital space based on situational influences that direct their action. To understand a customer's behavior in the e-commerce space, we must understand the customer's intent, the current information patch that the customer is responding to and the behavioral situation in which the response is occurring (Lim et al. 1997). Whereupon the intuitive operations on internal task representations produce the consumers' choice-response action, the User Ontology describes the temporary decision-making states of the individual that triggered their need to explore or exploit information during a purchase involvement. By aligning these temporary states to the phases in the buyer behavior model, we can fairly accurately map the current situational characteristic to their decision-making action. This in turn helps to reason the next phase in the buyer behavior model and to anticipate the next response in the external environment. A snapshot of the taxonomy of classes in the User Ontology is shown in Figure 17.

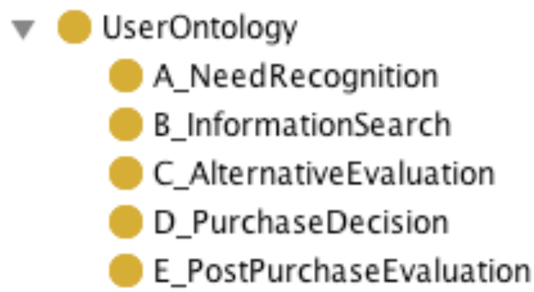

Figure 17. Snapshot of User Ontology in Protégé Ontology Editor

The interaction of a specific consumer in the e-commerce environment is translated into specific instantiations of the classes in the User Ontology. Assuming that satisficing is localized optimization within the constraints of domain bounds and complete (or partial) information, a *behaviorState* data property is used to characterize the current and reasoned phase of the consumer in the buyer behavior model. The *domain* for this functional property is the union of all User Ontology classes (since the customer can be in one or more buyer behavior phase at any given time) and the slot filler (*range*) for the property is defined as *String* literal with *current, reasoned*, and *ambiguous* as the allowed values. Figure 18 shows this partial ontology that defines *behaviorState* in OWL. Use cases that exemplify the application of this data property are provided in the next chapter.

As pointed out earlier, intuitive operation on internal task representation is slow and effortful and is influenced by bias, look-ahead and learned knowledge (refer Chapter 2). The *current* slot filler value of *behaviorState* is used to impart expressiveness over learned knowledge, as asserted from observable trails left behind by user actions (satisficing) in the e-commerce application interface. The *reasoned* value favors the next desired state in the consumer decision-making process as inferred from the current behavior state. Ontology properties used to describe the role of bias and look-ahead is managed in the Cognitive Fit Ontology and duly explained in the next section.

```
<owl:FunctionalProperty rdf:ID="behaviorState">
  <rdfs:domain>
    <owl:Class>
      <owl:unionOf rdf:parseType="Collection">
        <owl:Class rdf:about="#A_NeedRecognition"/>
        <owl:Class rdf:about="#B_InformationSearch"/>
        <owl:Class rdf:about="#C_AlternativeEvaluation"/>
        <owl:Class rdf:about="#D_PurchaseDecision"/>
        <owl:Class rdf:about="#E_PostPurchaseEvaluation"/>
      </owl:unionOf>
    </owl:Class>
  </rdfs:domain>
  <rdfs:range>
    <owl:DataRange>
      <owl:oneOf rdf:parseType="Resource">
        <rdf:first rdf:datatype="http://www.w3.org/2001/XMLSchema#string"
        >current</rdf:first>
        <rdf:rest rdf:parseType="Resource">
          <rdf:first rdf:datatype="http://www.w3.org/2001/XMLSchema#string"
          >reasoned</rdf:first>
          <rdf:rest rdf:parseType="Resource">
            <rdf:first rdf:datatype="http://www.w3.org/2001/XMLSchema#string"
            >ambiguous</rdf:first>
            <rdf:rest rdf:resource="http://www.w3.org/1999/02/22-rdf-syntax-ns#nil"/>
          </rdf:rest>
        </rdf:rest>
      </owl:oneOf>
    </owl:DataRange>
  </rdfs:range>
  <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#DatatypeProperty"/>
</owl:FunctionalProperty>
```

Figure 18. Ontology Definition of *behaviorState* in OWL

Modeling these operations into the ontology is a daunting task simply due to the nature of the definition of task environment. For example, an elementary task such as an individual viewing the detailed specification of a particular television may be interpreted as an information acquisition exercise (classifiable as an OWL instantiation of *B_InformationSearch* in the User Ontology) or as evaluation of information (classifiable as an OWL instantiation of *C_AlternativeEvaluation* in the User Ontology). To address this particular challenge, a rule set of possibilities is conceived using description logic based SWRL language. A detailed analysis on SWRL is provided in subsequent sections of this chapter.

4.1.3 Cognitive Fit Ontology

Information pickup involves the exercise of cognitive skills. The Cognitive Information Model was developed to elucidate the problem representations best suited to support a certain type of task by identifying a match – a cognitive fit, between the information emphasized in the external environment and that required by the type of problem-solving task under consideration. In other words, matching presentation of information to internal task representation leads to formulation of consistent mental representations of task solution.

To model the internal task representation of the information space in the ontology, we define *Intent.* The concept *Intent* establishes the state of the person's mental representation that directs an action toward a specific objective. A finite set of actions possible in the e-commerce domain is defined as subconcepts of *Intent*. They are *AddToCart*, *Checkout*, *CompareItems*, *ViewDiscussionForum*, *ViewItem* and *ViewListing*. Additional classes can be added to model other user intent in the information space depending on the type of information space and the problem-solving tasks. Two other main classes are defined in this ontology structure – *CurrentState* and *ReasonedState*. *CurrentState* maintains current situational knowledge about the user and his external environment. *CurrentNode* is the current point or the spot in the external space. It maybe a landmark used by the person to orient his or her position. It could be a point to return for additional information. The intent of the user identified by tracing the person's known interaction with the problem domain asserts reference to that specific individual instantiation of the *Intent* subclass also as an individual of class *CurrentNode*. The expert system shell performs this assertion by matching semantic rules from the rule set. The user activity is also the basis for asserting OWL individuals of the concept *CurrentPhase*. Covering axioms in the ontology and SWRL semantic rules developed by the owner of the data sources in conjunction with domain experts and ontology designers confer reasoning about the consumer decision-making phase based on recognizable user interactions. For example, a consumer adding a product to the shopping cart qualifies to trigger the semantic rule for which the intent of the user action creates an *AddToCart* individual reference under class *CurrentNode*. The rule also infers the current decision phase of the consumer as a purchase decision activity and translates this new knowledge into a fact by establishing an OWL individual reference from class *D_PurchaseDecision* to class *CurrentPhase*. The execution of rules is explained in more detail in the "implementation blueprint" of this chapter. A snapshot of the Cognitive Fit Ontology as viewed in the Protégé Ontology Editor is shown in Figure 19.

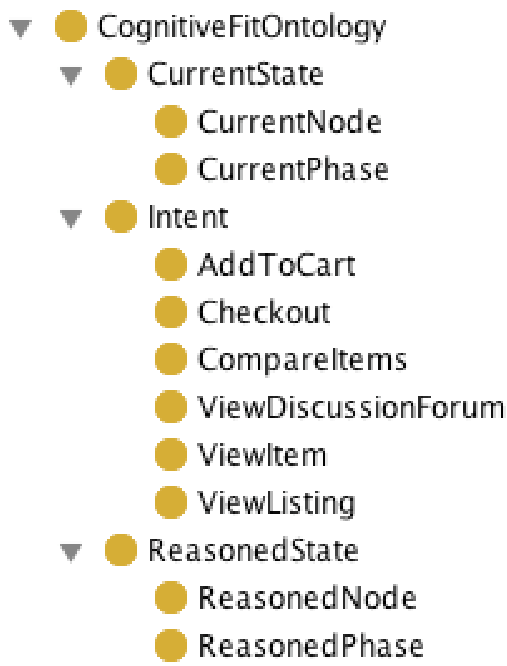

Figure 19. Snapshot of Cognitive Fit Ontology in Protégé Ontology Editor

Whether it is the first visit of a confused novice or an experienced user revisiting the e-commerce site, the design philosophy of the Cognitive Fit Ontology is to maintain contextual differences between visitors so that semantically rich target pages with varying document content may be returned to the end user. An expert may rely on learned knowledge (from past or repeated experience) and prior familiarity with the information space to navigate the storefront. A novice, on the contrary, will benefit from assistive aids that suggest "How I ought to act?" in the information space. Covering axioms in the form of first-order logical axioms make assignment of contextuality possible by delegating the desired machine state information (of the e-commerce domain space) and behavior state (decisions making phase of the consumer) to the *ReasonedState* of the Cognitive Fit ontology.

```
<owl:DatatypeProperty rdf:ID="machineState">
  <rdfs:range>
    <owl:DataRange>
      <owl:oneOf rdf:parseType="Resource">
        <rdf:rest rdf:parseType="Resource">
          <rdf:first rdf:datatype="http://www.w3.org/2001/XMLSchema#string"
          >current</rdf:first>
          <rdf:rest rdf:parseType="Resource">
            <rdf:rest rdf:resource="http://www.w3.org/1999/02/22-rdf-syntax-ns#nil"/>
            <rdf:first rdf:datatype="http://www.w3.org/2001/XMLSchema#string"
            >unbound</rdf:first>
          </rdf:rest>
        </rdf:rest>
        <rdf:first rdf:datatype="http://www.w3.org/2001/XMLSchema#string"
        >reasoned</rdf:first>
      </owl:oneOf>
    </owl:DataRange>
  </rdfs:range>
  <rdfs:domain>
    <owl:Class>
      <owl:unionOf rdf:parseType="Collection">
        <owl:Class rdf:about="#ViewItem"/>
        <owl:Class rdf:about="#AddToCart"/>
        <owl:Class rdf:about="#Checkout"/>
        <owl:Class rdf:about="#ViewListing"/>
        <owl:Class rdf:about="#ViewDiscussionForum"/>
        <owl:Class rdf:about="#CompareItems"/>
      </owl:unionOf>
    </owl:Class>
  </rdfs:domain>
  <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string"
  >domain is union of all classes. it is not inherited.</rdfs:comment>
</owl:DatatypeProperty>
```

Figure 20. Ontology definition of *machineState* in OWL

The combination of properties of the inferred OWL individuals classified as instances of *ReasonedNode* and *ReasonedPhase* is then used to present contextually different document updates on the e-commerce site. For instance, once the costumer has added a product to the shopping cart (which corresponds to a *purchase decision*), the SWRL rules triggered by the rule engine will delegate post purchase evaluation as the next desired behavior state. This occurs if the predetermined axioms agreed by domain owners and implemented as rules by the ontology designer entail the display of a discussion forum of useful tips on the product as a means to reduce post-purchase cognitive dissonance. Under this circumstance, the *machineState* data property is correspondingly updated to infuse the display of *ViewDiscussionForum* OWL concept as the next desired contour of reality. Figure 20 shows this partial ontology definition of *machineState* in OWL.

The *domain* for the *machineState* functional property is the union of all subclasses of class *Intent* (since the asserted or inferred intend of the customer is an instance of any of these classes). The slot filler (*range*) for the property is defined as *String* literal with *current*, *reasoned* and *ambiguous* as the allowed values. Use cases to demonstrate the applicability of this data type property is provided in the next chapter. The *current* slot filler value is used to establish expressiveness about the situated action that was carried out by the user and the *reasoned* filler value favors the next desired intend as inferred from the current machine state of the user interface. A slot value *ambiguous* maintains truth about the *machineState* that can neither be inferred nor be asserted, perhaps due to existence of casual conditions such as the first visit to the e-commerce space or access from a directly hyperlinked location in another domain space.

```
<owl:DatatypeProperty rdf:ID="hasUserPreference">
  <rdf:type rdf:resource="&owl;FunctionalProperty"/>
  <rdfs:domain>
    <owl:Class>
      <owl:unionOf rdf:parseType="Collection">
        <owl:Class rdf:about="#Promotion"/>
        <owl:Class rdf:about="#ScreenSize"/>
        <owl:Class rdf:about="#Type"/>
      </owl:unionOf>
    </owl:Class>
  </rdfs:domain>
  <rdfs:range>
    <owl:DataRange>
      <owl:oneOf>
        <rdf:List>
          <rdf:first rdf:datatype="&xsd;string">biased</rdf:first>
          <rdf:rest>
            <rdf:List>
              <rdf:first rdf:datatype="&xsd;string">unbiased</rdf:first>
              <rdf:rest rdf:resource="&rdf;nil"/>
            </rdf:List>
          </rdf:rest>
        </rdf:List>
      </owl:oneOf>
    </owl:DataRange>
  </rdfs:range>
</owl:DatatypeProperty>
```

Figure 21. Ontology definition of *hasUserPreference* in OWL

To personify the influence of bias on individual preferences, a functional data property *hasUserPreference* is delegated in the ontology. The slot filler (*range*) for this functional property is a *String* literal with *biased* and *unbiased* as allowed values. Figure 21 shows the partial ontology for the *hasUserPreference* property. The *domain* for this property is described as the union of all classes (the selection of a television item may be biased by the user preference on a certain *Type* of tv or by *ScreenSize* or the person may be exploring items that are only on *Promotion* sales) that have influence on the intuitive operations on the internal task representation.

Unless a consumer in the e-commerce environment is making an impulse purchase, we know from our own experiences that we rely on factors such as personal choices, brand royalty, product reviews and opinions of other customers to reduce ambiguity and to retrieve information from the internal and external representations. To accommodate the influence of look-ahead capabilities in the evaluation of alternatives the *object* property *compareSelectedItems* is defined in the ontology. The *range* for this property is the union of all product categories listed on the e-commerce storefront and the *domain* describes the intent of the user to evaluate alternatives (subclass *CompareItems* of class *Intent*) before directing an informed action. The partial OWL ontology that describes this property definition is shown in Figure 22. The *object* property *range* only includes the *#TV* as the *rdf:resource* since we restrict ourselves to the listing of television items for the purpose of this research. Additional categories and products can be easily added to the list as necessary using the Protégé Ontology Editor.

```
<owl:ObjectProperty rdf:ID="compareSelectedItems">
   <rdfs:domain rdf:resource="#CompareItems"/>
   <rdfs:range rdf:resource="#TV"/>
</owl:ObjectProperty>
```

Figure 22. Ontology definition of *compareSelectedItems* in OWL

In a sort of Darwinian way of evolution, the property values of individuals instantiated in the subclasses of Cognitive Fit Ontology change contextually over time from the Domain Ontology and the User Ontology. The emerging knowledge is used to garnish a viable pathway reasoned with a certain degree of continuity restricted only by the domain constraints of the external environment and the inferred accuracy of the internal task representation. Noting that an expert practitioner may rely on repeated experience and a body of knowledge (Schön 1983) unavailable to the "perpetual novice" ((Borgman 1996), truism of observed interactions expressed in the Cognitive Fit Ontology serves as the guiding force that drives the presentation of spatial cues with a certain restricted richness and continuity currently unattainable from the use of passive facilitators.

4.2 Implementation blueprint

To articulate the implementation of the framework the following engineering issues are addressed in this section - (i) the deployment and administration of assertion, inference and reasoning engines, (ii) interaction between the user interface and the elements of navigation and (iii) the role of SWRL rules and SQWRL queries on the ontologies. Other related issues and daunting challenges that became apparent during the development and implementation of the model are addressed in the limitation sections of this chapter.

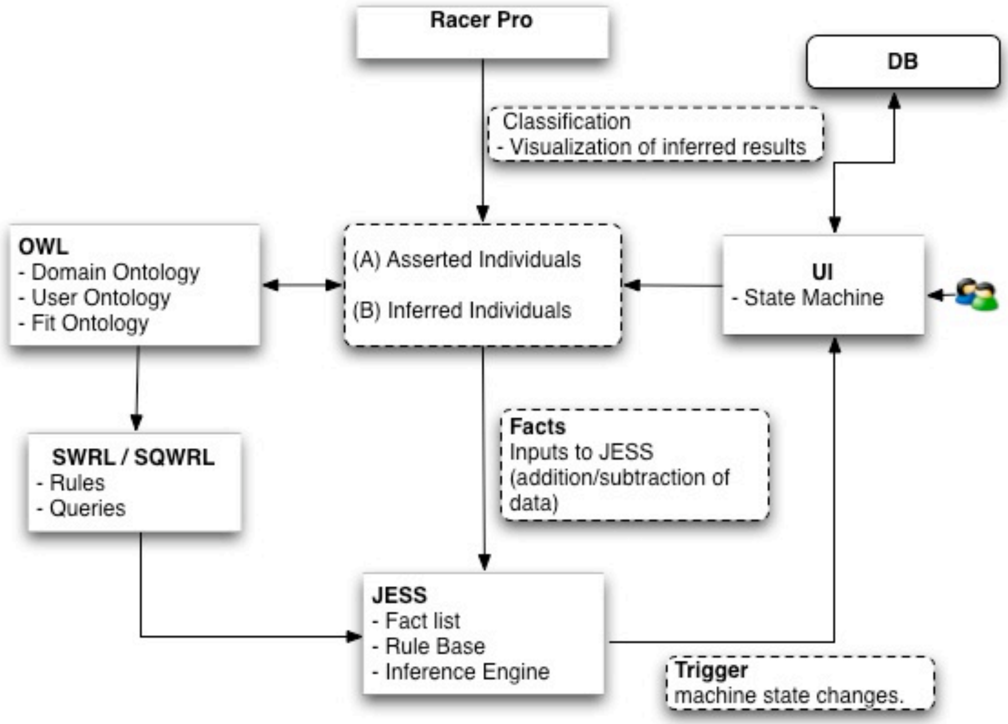

Figure 23. Implementation Architecture

Central to the implementation architecture are the three ontologies upon which context assertion, instantiation and reasoning are performed. The functional implementation architecture shown in Figure 23 consists of four main components – (i) the knowledge representation consisting of the fact list and the rule base, (ii) a reasoning system to compute subsumption relationships between classes (classification hierarchy) and to detect ontology inconsistencies, (iii) a rule based expert system (inference engine) for deductive (forward chaining) and inductive (backward-chaining) reasoning and (iv) the graphical interface where the state changes are presented to the end user.

4.2.1 Assertions, inferences and reasoning

Once the concepts and relationships among concepts have been captured in the ontology, they can be used to guide the execution of rules that drive updates to the software components of the e-commerce user interface. For purposes of automating the presentation of the information structure in the e-commerce space, business rules are developed to assert the user interaction with the information space and to control or influence the behavior of the consumer. Interaction procedure and buyer behavior logic is too dynamic to effectively manage as application code. The rules of interaction established by the domain owner and constructed by the knowledge engineer using SWRL is used by an expert system shell to reason about OWL individuals that are semantically asserted as instances of OWL classes based on trails that explain the interactions of the user with the application interface. We use Jess as the rule engine for this purpose. Jess (Jess 2008) uses an enhanced form of Rete Algorithm (Forgy 1982) to reason using declarative rules on the knowledge available from ontologies. To reason deductively (forward chaining) from available data and inference rules, the Jess engine searches the rule base until it finds a rule for which the antecedent (body) of the rule is known to be true (Peuschel et. al 1992). If the facts in the knowledge base support all of the closure conditions for the rule antecedent, the consequent is inferred and new information is added to the knowledge base. For inductive reasoning (backward chaining) the Jess rule engine starts with the list of goals and works backwards from the consequent (head) to the antecedent of the rule (Peuschel et. al 1992). If available information meets all consequent criteria, then the goal is inferred to be true. The rules defined in the knowledge are primarily forward chaining since they run in response to the arrival of new knowledge updates as a result of events triggered by the action of the user on the application interface.

Different functional and operational responses are elicited as a result of the rule execution by the Jess expert system. Inputs on the user interface become facts in the fact list. The rule engine matches facts in the fact base with rules in the rule base to decide what rules to execute and when. The pattern matcher of the Jess inference engine is responsible for executing the rules and for updating the working memory with new knowledge. While the SWRL rule set rarely changes, the rule consequent may reclassify asserted OWL individuals, adding newly inferred property value for individuals or updating the association between two individuals that are related. The heuristics is repeated and new knowledge is progressively added to the fact base. Support for translating SWRL rules into Jess rules is provided by the Protégé editor API with the Jess plugin. Enabling the SWRLJessTab in Protégé Editor (O'Connor et al. 2005, SWRL 2007) provided the visual interface used to build the SWRL rules and to test the inference capabilities of the rules.

To validate the consistency and integrity of the ontology, a reasoner engine is used. Racer Pro is a commercial knowledge management system (Racer Pro 2008) that provides facilities for reasoning services on multiple T-boxes (ontologies) and A-Boxes (instances). The Racer system implements a highly optimized tableau calculus for algebraic reasoning based on the logical semantics of *SHIQ* (Horrocks et al. 2003). It is a DIG (Description Logic Implementers Group) compliant reasoner whose key tasks include automated concept subsumption reasoning (Haarslev et al. 2007) and detecting concept inconsistencies (Horrocks et al. 2000) in the ontology. These validation operations and consistency checks are performed repeatedly to ensure that the assertions and individual inferences from the firing of SWRL rules by the expert system do not compromise the concept integrity due to conflicts with the closure axioms defined in the ontology. Racer Pro also provides a TCP based interface for easy command interaction and query accessibility from java based applications. A time-limited fully functional version of the software was used in this research.

Different checks and balances are employed in the architecture to guarantee computational completeness, decidability and automated reasoning (Baader et al. 2003, Horrocks 2002) on the ontology. First and foremost, care is taken to ensure that the sub-language used to express the ontology remains as OWL-DL. For this reason *hasValue* restriction, ∋ with individuals as *filler* values is avoided in the ontology structure, as this form of usage alters the ontology sub-language into OWL-Full upon which classification is not *complete* with current reasoners (Horridge et al. 2004). Additionally, Open World Assumptions are very difficult to implement with individuals (as property values) due to decidability limitations. Care is taken during the ontology modeling exercise and in the SWRL rule development process to reduce the chance of reasoner causing unexpected results (Haarslev et al. 2007, Horridge et al. 2004) due to axiom conflicts. Finally, OWL does not support the concept of variables. Since deriving conditional statements from A-Boxes is implicitly closed world assumed and requires reference to instances that are not known before execution, reification could have been used to extend OWL-DL (Wagner et al. 2004). Ontology classes can be created for reified relations and this approach have been used in the past in ontologies like Ontoclean/DOLCE (Gangemi et al. 2002), Sowa and

GALEN (Baker et al. 1999). However reification would result in high levels of class repetition especially in upper level ontologies. We therefore chose to use individuals (*statically* defined) to maintain state change information that are subsequently updated through SWRL rules instead of reification of additional concepts. Validation using Racer Pro helps to identify any anomalies that may arise during the state changes. The reasoner thus plays a critical role in ensuring that the conceptualization remains amenable and compatible for the realistic and successful execution of the underlying java application code that drives updates on the user interface. They serve to preserve the references of the component terms in the ontology and to certify the assertions of truth in the domain where the user interactions are carried out.

4.2.2 SWRL rules and SQWRL queries

The SWRL rules externalize the espoused theories of user action in specific situations. The Semantic Web Rule Language (SWRL) is based on a combination of OWL-DL and OWL lite sub-languages with the Unary/Binary RuleML sub-language. They extend OWL axioms to include Horn-like rule syntax (Horrocks et al. 2003, Golbreich 2004). SWRL rules can use the same vocabulary from the OWL ontology thus allowing easy syntactic and semantic interoperability between the two. Different types of rules can be expressed using SWRL – forward and backward chaining rules for chaining ontology properties, reasoning rules for expert systems and even query rules complex queries on the knowledge base (Horrocks et al. 2003). The SWRL Tab widget (SWRL

2007) offers a draft implementation of SWRL with a bridge between Racer Pro and Jess for reasoning with SWRL rules on the OWL ontologies (Horrocks et al. 2003, O'Connor et al. 2005). Even though the SWRL Tab itself has no inference capabilities, it provides the knowledge engineer with a rule development environment to conveniently edit the rules, test their execution using Jess rule engine and load them to and from the OWL knowledge base.

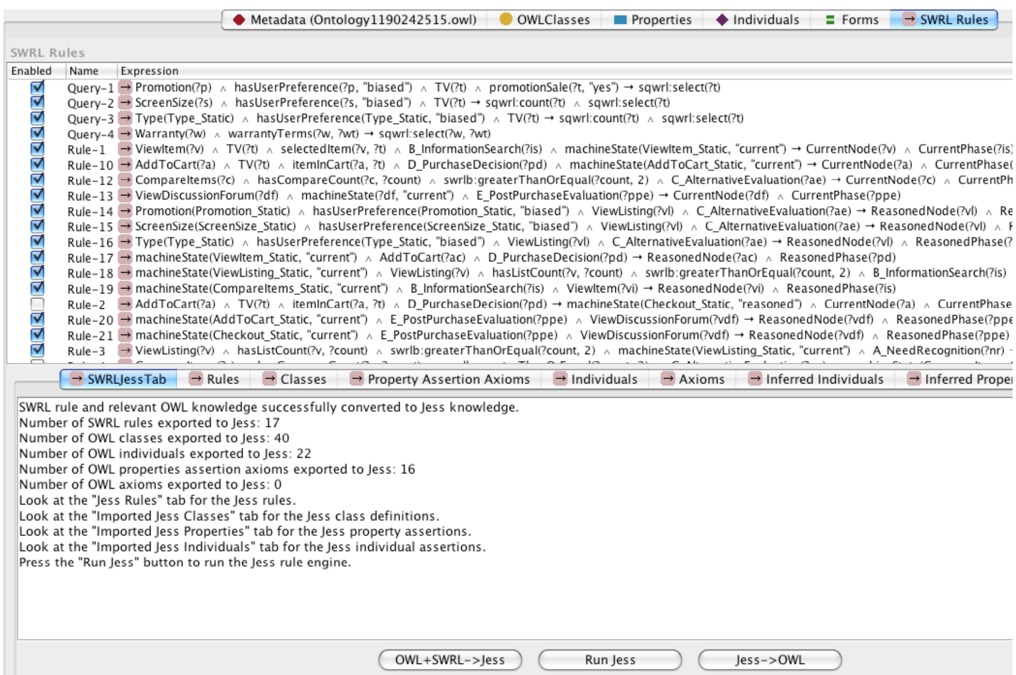

Figure 24. Screenshot showing SWRL Rule Tab with Jess controls

Additionally, the SWRLJessTab plugin within the SWRL Tab widget provides an API-level interaction mechanism that allows developers to access the rule engine functions. For seamless interoperation, the SWRL factory API implementation allows Jess to interoperate with SWRL by representing OWL individuals as Jess facts, translating SWRL rules into Jess rules, and by performing inference using the rules on the facts and transferring the results to the OWL knowledge base (O'Connor et al. 2005). A screenshot of the SWRL Rule Tab is shown in Figure 24.

A SWRL rule consists of an antecedent (*body*) and a consequent (*head*) expressed in Horn-like structures using OWL concepts. Given a set of rules (expressed in SWRL) and a set of facts (individuals of ontology concepts), any compatible rule engine (such as Jess) can perform forward chaining and backward chaining to reason about OWL individuals and to infer new knowledge from existing facts. For varying task environments encountered in the external problem space, a different set of rules construct different contextual mental representations. At the level of rule representation, the same set of rules can be distributed differently across different internal and external representations. In other words, the inferred differences or isomorphic similarities of the problem-solving tasks trigger the execution of a different set of SWRL rules. As long as these variations are represented in the state information of OWL individuals, Jess expert system shell can perform inference to create new facts and use the new knowledge for further inference. When the inference process is completed, the facts are transferred to the OWL knowledge base and the reasoner is called to perform a consistency check of the knowledge base. To demonstrate this, consider the following SWRL rule:

AddToCart(?a) ∧ TV(?t) ∧ itemInCart(?a, ?t) ∧ D_PurchaseDecision(?pd)
→ machineState(Checkout_Static,"reasoned") ∧ CurrentNode(?a)
∧ CurrentPhase(?pd) ∧ behaviorState(D_PurchaseDecision_Static, "current")

The Cognitive Fit Ontology describes the match between individual problem-solving tasks and the user's specific information needs. The rules for asserting *CurrentState* and *ReasonedState* concepts of the Cognitive Fit Ontology are triggered by Jess with every situated action taken by the consumer on the user interface. The rule engine triggers the above rule when the antecedent (the consumer adding an item to the shopping cart) condition is encountered (a situated action implying a purchase decision) on the user interface. The rule consequent reclassifies the ontology instances (infer OWL individual of *AddToCart* class as an OWL individual of CurrentNode and *D_PurchaseDecision* as the *CurrentPhase*) and updates the behavior state properties of OWL individuals of relevant User Ontology sub-classes to represent this task (the *behaviorState* property of *D_PurchaseDecision_Static* OWL individual is made *current*). The rule also updates the machine state (change *machineState* property of *Checkout_Static* OWL individual to *reasoned*) with the newly inferred knowledge.

Capabilities of core built-ins for mathematical and string operations are used in the SWRL rule below to update the *ReasonedState* when the customer's action was asserted as the intent to view a listing of items or compare selected items.

machineState(ViewListing_Static,"current") ∧ ViewListing(?v)
∧ hasListCount(?v,?count) ∧ swrlb:greaterThanOrEqual(?count, 2)
∧ B_InformationSearch(?is) ∧ViewItem(?vi)
→ ReasonedNode(?vi) ∧ ReasonedPhase(?is)

This rule is fired when the antecedent (the consumer selecting more than one item to compare) condition is encountered (a situated action implying information search) on the user interface. The rule consequent appropriately reclassifies the ontology instances by inferring *B_InformationSearch* as the *ReasonedPhase* and the OWL individual filler of the *selectedItem* property of the *ViewItem* class as the *ReasonedNode*.

Queries on OWL ontology are performed using Semantic Query-Enhanced Web Rule Language, SQWRL. Once the SWRL Tab is activated and the most recent *swrl.owl* ontology is imported using the metadata tab in the Protégé Editor, SQL-like queries can be executed on any known OWL individuals in the ontology. Operations supported in the current implementation of SQWRL include basic queries to extract information using property values and OWL individuals of classes, counting, aggregation operations, grouping, create ordered results, perform distinct select and operations to examine the structure of OWL ontologies using built-in T-Box and A-Box query libraries (SQWRL 2007). For example, an instance where SQWRL is used in the implementation is when the user interface relies on the SQWRLQueryAPI factory to discover items pertaining to a recognized user bias, such as an interest in LCD televisions or those on promotion sale. For example, consider the following SQWRL query rule:

Promotion(?p) ∧ hasUserPreference(?p, "biased")
∧ TV(?t) ∧ promotionSale(?t, "yes")
→ sqwrl:count(?t) ∧ sqwrl:select(?t)

The SQWRL rule shown above will count and select specific televisions based on the inferred user preference for viewing televisions based on *promotionSale*. The query results are then programmatically loaded to a data structure outside the ontology and displayed on the user interface. Although the results of the query built-ins cannot be written back into the knowledge base, they are powerful mediators that can be used to retrieve information quickly and efficiently from the ontologies. Appendix 1 shows a listing of all SWRL rules and SQWRL queries used for the Cognitive Information Model.

4.2.3 User interface and elements of navigation

As described in the preceding sections, the combination of ontologies, Jess rule engine and Racer Pro reasoner serves as a form of semantic machine that gathers contextual inferences about the consumer's behavior in the e-commerce space. The User Ontology serves to externalize the buyer behavior decision-making process and the Domain Ontology contents the situated action of the user in the external environment. In the digital realm, it becomes feasible to capture the semantic relevance of the situated actions since interactions leave traces of intent as the person sifts from node to node in the domain space. Facts in the Cognitive Fit Ontology are constantly refined by the interwoven relationship between the user's internal representation of the problem-solving task and the external problem representation. Knowledge manifested in the cognitive fit ontology is then used to further organize and furnish information to the consumer in the form of rich spatial cues and contextual navigational aids. The heuristics is repeated to create a logical pathway that guides the person from one context node to the next. At a more granular level of the application code, any action on the UI triggers invokes the following sequence of operations in the underlying implementation architecture:

- Java application code uses SWRLRuleEngineBridge API methods to reset the bridge, rule engine and cache copy of the knowledge base.
- The bridge factory is initialized with the OWLModel of the ontology.
- SWRL rules, SQWRL queries and OWL knowledge is imported into the bridge.
- Jess loads rules and facts from the bridge and infers new knowledge.
- SQWRL queries are executed to retrieve semantically relevant facts from the knowledge base.
- New knowledge is written to the cache and the bridge is reset.
- Consistency of the ontology is checked with Racer Pro.
- UI is updated with new information and contextual navigational cues.

The schema of this sequence of events is shown in Figure 25. The above heuristics gives an indication of when the rule engine triggers the execution of appropriate rule sequence and how information content is contextually updated on the main display panel of the application.

Looking at a particular running example of a consumer's decision-making process will help to illustrate the elements of navigation. The use case will help to highlight the semantic relevance of navigational assistance facilitated by the underlying architecture. We also use the example as a guiding metaphor to explain the design details of the user interface.

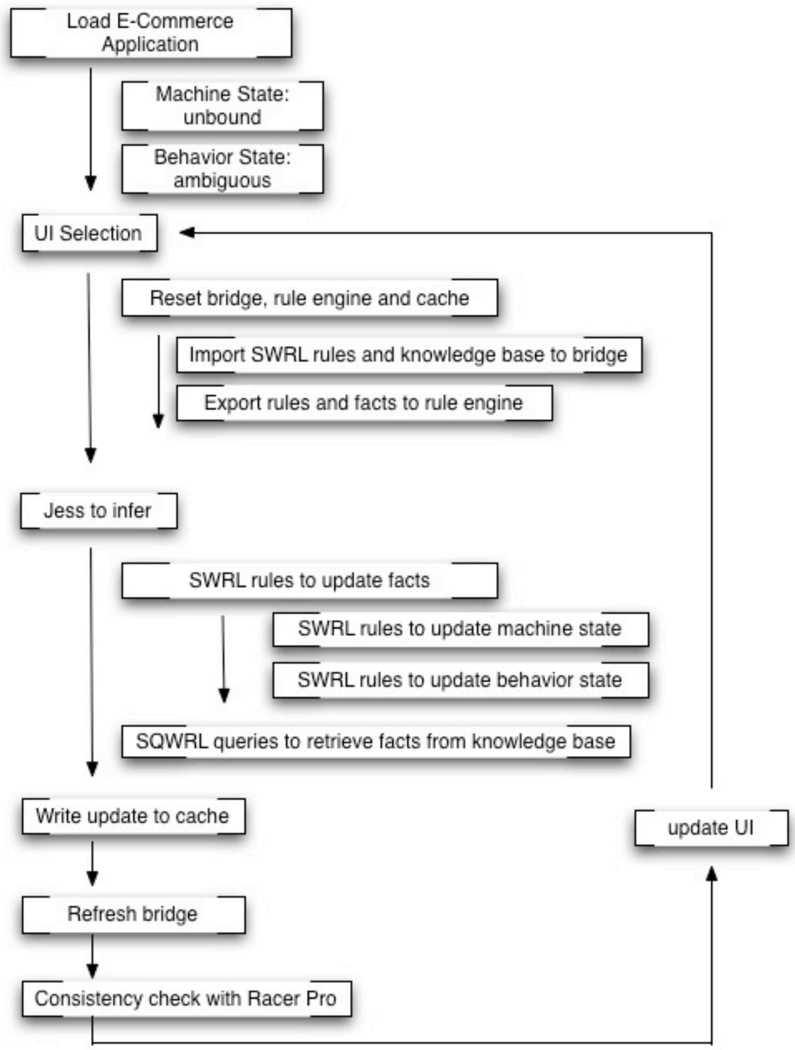

Figure 25. Operating sequence of events in the architecture

Let us assume that Dr. Little just finished his home renovation project and is now looking to replace his television with a new LCD high definition television. Having established his desire to purchase the right television (*need recognition phase*) from the stock options he just cashed out, he visits the e-commerce storefront. As the application starts up, a window with three main components – a *JTree* model view of the Domain Ontology, the main display panel and an "Ontology State" button, is loaded on the computer screen. The modular user interface (UI) for the application (Figure 26) was built using java programming language and mimics the classic functionalities of a commercial e-commerce application. A good UI design should allow both a novice and expert to move through the information space quickly without memorizing the steps. For the purpose of demonstration, the category listing often seen on e-commerce websites (such as TV, Computers, Cameras, etc.) is replaced by the java *JTree* control model representation where the viewable nodes are rendered directly from the hierarchy of concepts defined in the Domain Ontology. Categorization of products is a form of taxonomical scheme that arrange information in a super-type/subtype structure. The use of *JTree* control was justified as it provisions easy awareness about the Domain Ontology among the subjects of the study as well as enable the person to browse the product categories with relative ease. The main panel of the application presents contextual information based on user actions and navigational cues to the consumer. The "Ontology State" button elicits a quick and easy view of the current state of knowledge base including inferred facts, and reasoned machine states and behavior states.

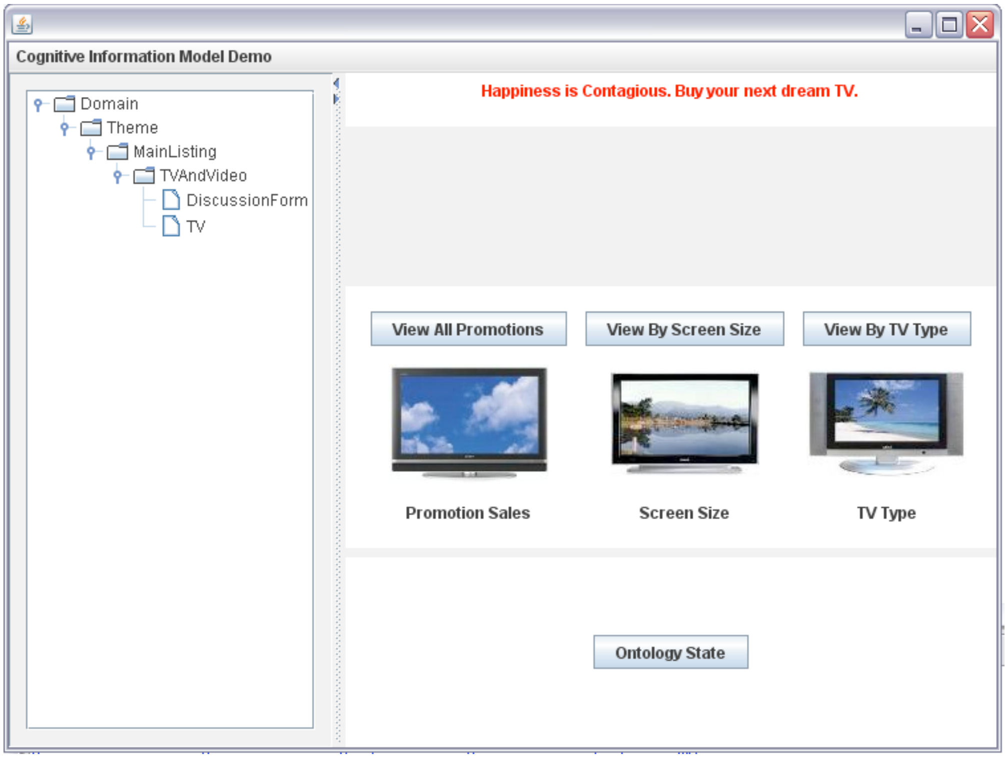

Figure 26. User Interface for the e-commerce application

The UI environment allows Dr. Little to browse all televisions stored in the knowledge base by screen size, type or by promotion sales further establishing his *need recognition phase* in the buyer decision-making model.

Based on the user preference asserted by the rule engine, Dr. Little is then presented with an interface screen customized with assistive aids specific to the recognized buyer behavior phase. The screen is dynamically and contextually created to emphasize related facts (highlight screen size details if the consumer opted to view television based on screen size) with explicit lexical representations (customized link text) and navigational aids that will lead to the next associated information patch in the domain space. If Dr. Little chose to view all televisions on promotion sale, the information and the cues presented are semantically befitting to the inferred bias so as to reduce ambiguity and to increase accuracy in the succeeding actions. The resulting screen is shown in Figure 27**.** The summary of active facts in the knowledge base displayed when the "Ontology State" button is clicked is shown in Figure 28.

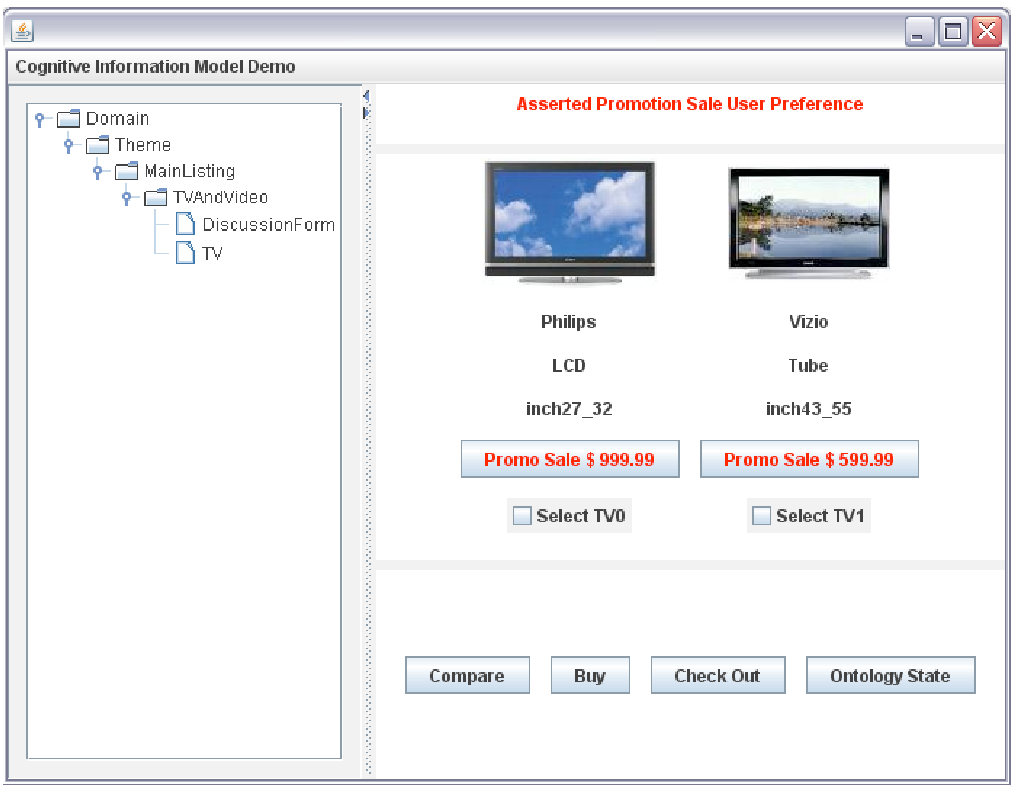

Figure 27. Screenshot resulting from inferred *Bias* on *PromotionSale*

Notwithstanding an *in-and-out* type of visit to the e-commerce store (all too common on the web), the interface then presents the user with options to compare items (*alternative evaluation phase*) or to explore details (*information search phase*) of a specific item. The user can select these links to visit target screens that are also contextually enriched and similarly constructed by using the heuristics mentioned before, albeit using a set of different facts and rules. The SWRL rules help the heuristics to extract *sequentiality* (Wexelblat 1999) for the experience and to present enhancements that emphasize information on the screen.

Business Objectives:
- *- Promotion_Static.userPreference = biased*

TV Attributes:
- *-ScreenSize_Static.userPreference = unbiased*
- *-Type_Static.userPreference = unbiased*

Fit Ontology:

Intent:
- *-AddToCart.machineState = unbound*
- *-ViewListing_Static.machineState = current*
- *-ViewITem.machineState = reasoned*
- *-CompareItems.machineState = unbound*
- *-ViewDiscussionForm.machineState = unbound*

CurrentState:
- *-CurrentNode (1)*
- *-CurrentPhase (2)*
- *-A_NeedRecognition_Static*

ReasonsedState:
- *-ReasonedNode(2)*
- *-ViewItem_Static*
- *-ReasonedPhase(2)*
- *-B_InformationSearch_Static*

UserOntology:
- *-NeedRecognition.behaviorState = [current]*
- *-InformationSearch.behaviorState=[reasoned]*
- *-AlternativeEvaluation.behaviorState=[ambiguous]*
- *-PurchaseDecision.behaviorState=[ambiguous]*
- *-PostPurchaseEvaluation.behaviorState = [ambiguous]*

Figure 28. Inferred facts in knowledge base from user action

As Dr. Little moves through the different phases of the buyer decision-making model, the intuitive operations (such as lookahead capabilities for comparing item screen, better learned knowledge from product information screen) and perceptual operations (parallel or sequential listing as a function of item count) enhances cognitive fit between information accentuated in the problem space and that required by the problem-solving task.

Assuming that Dr. Little exhibits behavior on the user interface that is proxemic (Hall 1990) to *alternative evaluation* (by choosing the televisions he wishes to compare), the SQWRL rule retrieves the count and the items selected from the knowledge base. The SWRL rule sets the *ReasonedPhase* as *B_InformationSearch* while also changing the *machineState* of *CompareItems_Static* to *current*. Items that are selected from this screen (Figure 27) become fillers for the *SelectedItem* property of the static OWL individual under *ViewItem* intent. The UI of the e-commerce application displays the selected items with emphasis on navigational links that will allow the user to view additional details of each television. If Dr. Little chooses to view more details of a specific television such as the product description or specifications, the layout of the ensuing screen is updated to feature meaningful information pertaining to the affirmation of the previously reasoned behavior phase of *information search*. The SWRL rule execution further marks *purchase decision* as the *ReasonedPhase* and *Add To Cart* as the reasoned intent. The screenshot in Figure 29 depicts this scenario.

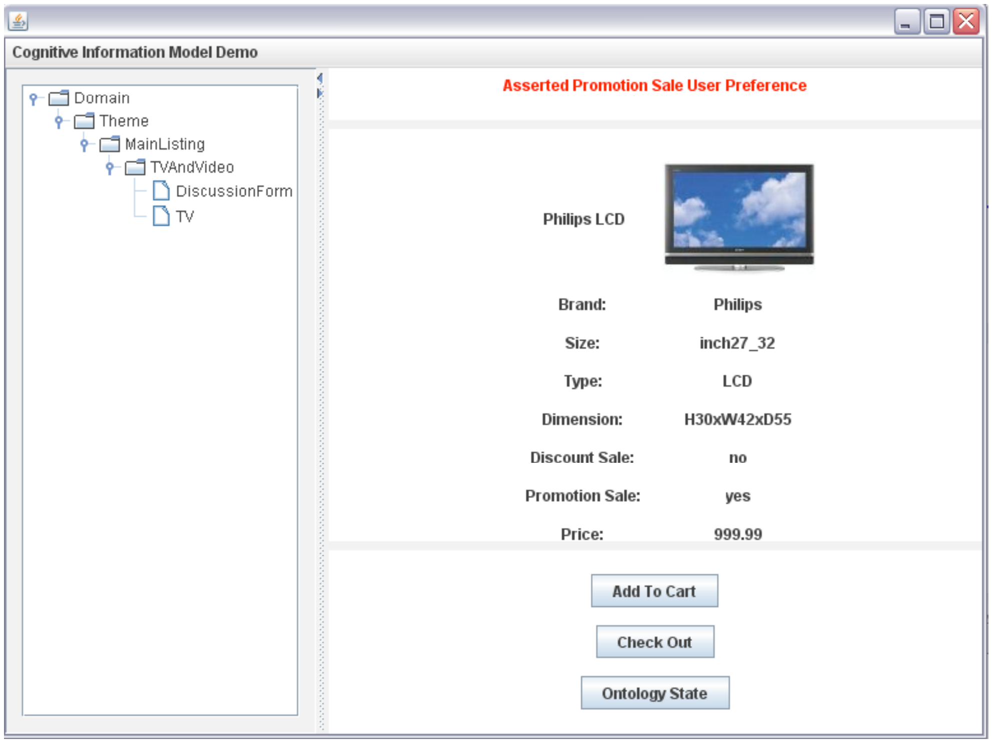

Figure 29. Screenshot following inferred *Information Search* behavior phase

The screen transition that follows correspondingly lean towards persuading a *purchase decision* (emphasis on the *Add to Cart* and *Check Out* buttons) due to the ontological closeness of this reasoned phase to the current phase of *information search*.

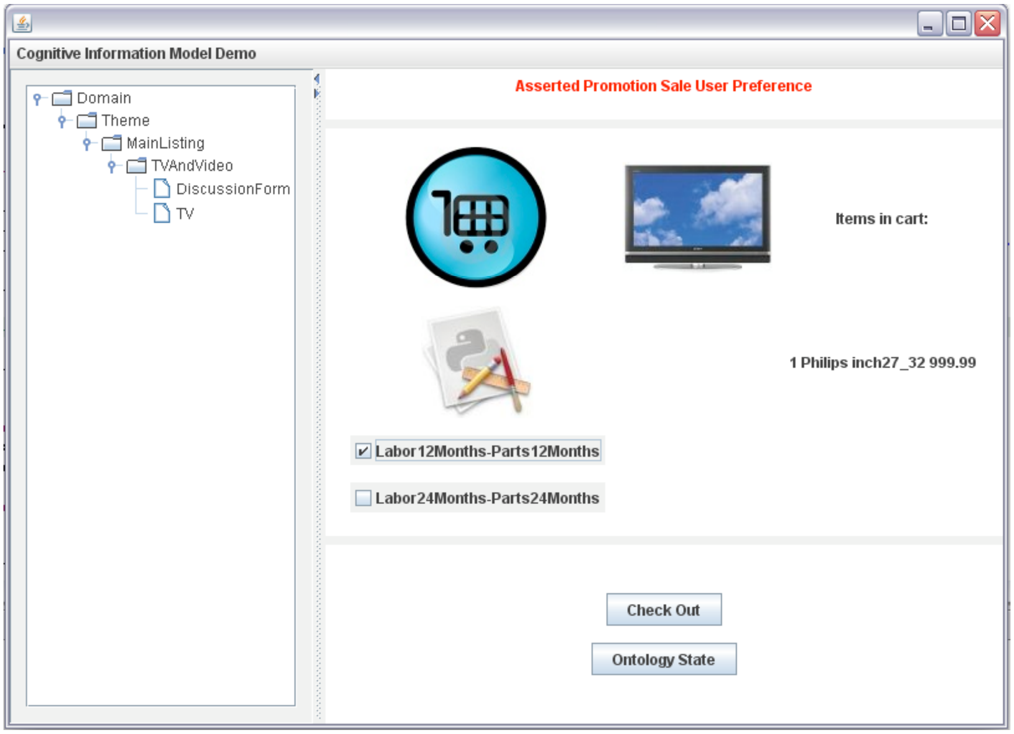

Figure 30. Screenshot following inferred *Purchase Decision* behavior phase

If Dr. Little did in fact add a specific television to the cart, he is presented with warranty options that are specific to the television in the shopping cart. The action executes rules to tag the *behaviorState* of *D_PurchaseDecision_Static* OWL individual as *current* and infers *post purchase evaluation* as the next immediate phase in the buyer behavior. The resulting screen is shown in Figure 30. Completing checkout indicates conformance to *post purchase evaluation* as the reasoned phase. Discussion forum topics befitting the purchased television item are then displayed on the screen. This follows from the triggering of rules that reflect the previously agreed upon course of action intended to reduced cognitive dissonance. Figure 31 displays this interface update of the application.

The *Followup* concept in value partitions of the ontology also marks the consumer for prospective business potentials for promotional correspondence in the future.

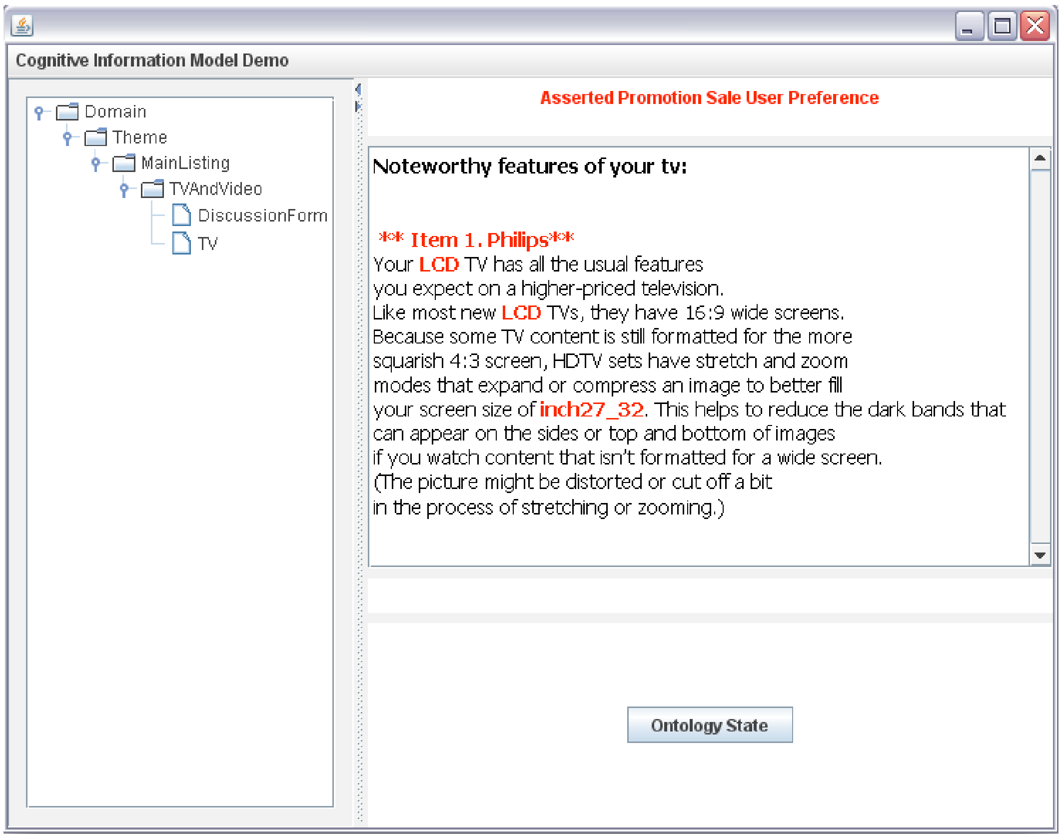

Figure 31. Screenshot following inferred *Post Purchase Evaluation*

In comparison to fixed designs of traditional e-commerce websites, a user navigating down a path using this type of interface design is presented with alternatives that are distinctive and dynamic resulting from, what Schön (1983) would call, "interactive conversations with the situation."

The main focus of the application interface is to provide a contextually rich representation of the external environment that will lead towards better problem-solving performance, irrespective of whether the consumer is a new customer or an experienced user. By coordinating a fit between the internal task representation and the external stimuli, the use of anticipatory navigational aids will help any user to learn about the information space as well as strengthen their intentions and beliefs. Of course, experienced users tend to have less trouble navigating the space mainly by trusting their familiarity with the domain. However, a new customer may quickly feel lost or discouraged in the plethora of information spread over the entire external environment. There is no doubt that a user's attitude, values, personality, culture, etc. are all driving factors that influence their behavior. Nevertheless, in today's world where interaction with the digital realm is more social than ever before, it is imperative that domain owners offer viable navigational tools that in part or whole reflect individual differences in varying user contexts.

Last but not least, the software development for the e-commerce application was undertaken with the goal of allowing future ontology updates to propagate throughout the system components with minimal software changes. Detailed attention is also given to ensure that all custom java classes are generic in their implementation, scalable to accommodate knowledge base changes and well documented to allow easy feature enhancements as may become necessary in the future. If the knowledge engineer updates the knowledge base, no major reprogramming of the existing software components is necessary. The application developer only has to substitute the new java class definitions (with the updated getter/setter methods for property binding) for the old ones and use their functionality in the application code. The OWL java classes themselves can be generated easily using the "Protégé-OWL Java Code Generator" of the Protégé knowledge editor software.

4.3 Implementation issues

Here we describe the major difficulties and inherent shortcoming of the different components in the architecture that were revealed during the realization and testing of application scenarios. Most of the issues faced during the development of the ontologies and its use in the software are attributable to the limitations of the reasoner and the rule engine in its current state to make inferences on the open world assumptions of OWL constructs. Different external resources provided numerous insights and ideas for workarounds and suggestions of improvements in the overall design process. Prominent resources that were consulted include proceeding papers from popular knowledge modeling conferences, semantic web workshops and most importantly, the highly motivated and niche community of users that actively participate on the protégé mailing list maintained by the Biomedical Informatics Research wing at the Stanford University School of Medicine. As innovation and standardization continues in the field of semantic web, it is imperative that in the foreseeable future, rational solutions will evolve to address the majority of the concerns faced in this Design Science research initiative.

OWL woes:

Modeling woes with OWL stretches across a plethora of topics starting from the choice of OWL sub-language to befuddling concept design options, reasoner limitations on certain axiom types and extending to addressing innocent misconceptions among developers with background in other programming paradigms.

OWL-DL is the more palatable and ubiquitous of all the three OWL sub-languages since the use of DL constructs to create explicit closure axioms that allow computational decidability and reasoning. However, there are numerous restrictions on the expressiveness possible using OWL-DL axioms. First, conditional statements are not supported in the current specification of OWL implementation. Secondly, the degree of detail expected in the characterization of the domain concepts determines the choice of OWL sub-language. Clearly, a highly detailed ontology (requiring the use of a richer language like OWL-Full) will get closer to specifying all intended conceptualizations and thereby establish better utility of the domain knowledge. But OWL-Full compromises on decidability and makes it impossible for currently available reasoners to classify the ontologies correctly. A reasonable and practical tradeoff is to use OWL-DL sub-language instead and to stick with DL-safe rules. Ontology closure axioms with relations to OWL instances should still be avoided within OWL-DL, which would otherwise make the ontology OWL-Full. However, the use of DL-safe rules in the ontology to assure decidability comes at the price of inference power by reasoners and rule engines (Liem et al. 2007). Last but not least, modeling woes are further aggravated by the lack of support for variables in the OWL sub-languages.

OWL individuals themselves are not distinct in OWL unless they are explicitly declared as different. This adds limiting consequences due to Open World Reasoning since the reasoner cannot correctly count separate individuals, as there are chances that those individuals might actually be the same. This makes it practically impossible to satisfy maximum cardinality restrictions by counting property filler values. The only work around to address this issue is to carefully state *disjointness* and to make explicit assertions on maximum cardinality, although this approach beats the purpose of defined concepts and reasoning. Minimum cardinality restrictions may however, be satisfied.

From a developer's perspective it is also important to realize that properties in the ontology are not inherited the way that may be expected. For instance, stating that a property has a *domain* for a particular class *Theme*, does not imply that the property has a *domain* that includes all subclasses of *Theme* even though the Protégé Ontology Editor tool may give that impression. To manage reification (Wagner et al. 2004) that would otherwise create high levels of class repetition in the ontology, we adopt an approach similar to that used for representing N-ary relationships (Noy et al. 2006). Statically defined OWL individuals are used to maintain state information on a relationship that is subsequently updated through SWRL rules. In other words, we use instances of relationships rather than statements about such instances. This approach allows us to make additional arbitrary assertions about those relationships.

Finally, there is the granularity problem of deciding between the use of OWL concepts and instances during the ontology development process (Kotowski 2007). When modeling real world scenarios such as the e-commerce domain or the buyer behavior model, it is often unclear whether certain realism should be represented as a concept or as an instance. A case in point is the *Brand* of a television, which can be either of the two. Although the problem is more ubiquitous among biological ontologies and geographical ontologies (Kotowski 2007), it can be a source of confusion depending on what the ontology developer means and how the application developer perceives them to be used. To address this issue, the philosophy followed in this modeling exercise was to identify scenarios (*Intent* in the Cognitive Fit Ontology, the five phases of the User Ontology, etc.) and use them to model the ontology fragments. Properties are used only where minimally essential relationships between the ontology fragments are to be defined. SWRL rules are used for other complex conditional expressions and in consequent firing scenarios.

SWRL / SQWRL trouble:

One of the main issues that can plague the knowledge developer is deciding whether to write a DL statement within the ontology or to use a SWRL rule. SWRL rules are essentially just another form of formally sound OWL-DL axioms. The commonly used approach in the knowledge-modeling world is to therefore to take the SWRL approach when DL expressivity is not sufficient. However, OWL-DL reasoning currently has significantly greater tool support than SWRL and DL reasoners can perform subsumption, inference and class membership testing more efficiently than the more general SWRL rule system. Academically it can also be argued that SWRL offers comparatively minimal inference support, whereas the specialized, restricted and variable-free DL rule syntax enables better reasoning and decidability. The latter also ensures that the user stays within the bounds of computationally feasible ontology structures.

To heighten the hardship, SWRL (and OWL) supports only monotonic (McCarthy 1980, Noy et al. 2002) inferences. *Negation as failure* (NAF) is not supported in SWRL (OWL supports classic negation but not NAF) as it leads to non-monotonicity (Bry et al. 2005, McCarthy 1980, SWRL 2007). NAF is contrary to open world assumption thus making it harder to prove negatives with universal statements rather than just finding an existing positive statement that is true. As a result, a SWRL rule,

Promotion(?p) ∧ ¬ hasUserPreference(?p, "biased") ∧ TV(?t)
∧ hasScreenSize(?t, "inch43-inch55") → viewItem(?t)

to display the television by *ScreenSize* if the user preference is not *promotion* will be indecipherable to the reasoner. To work-around the monotonic restrictions and to overcome the difficulties of NAF, a commonly used approach is to build an OWL class that satisfies the desired properties (or their negation) and have the reasoner trigger a SWRL rule to assert the variable OWL individual as an instance of that class.

Whether we use DL-safe axioms or SWRL or both, SQWRL is the preferred query language to retrieve knowledge from the ontology. But the current implementation of SQWRL within Protégé Knowledge Editor will not allow queries to be executed on reasoner-inferred knowledge. To execute SQWRL queries on updated OWL facts, the heuristics shown in Figure 32 is used. This approach is computationally costly and slower to complete due to persistent disk access requirements. Future release of Protégé Editor will support SQWRL query on Jess or Pellet inferred knowledge, which should significantly reduce code execution overhead.

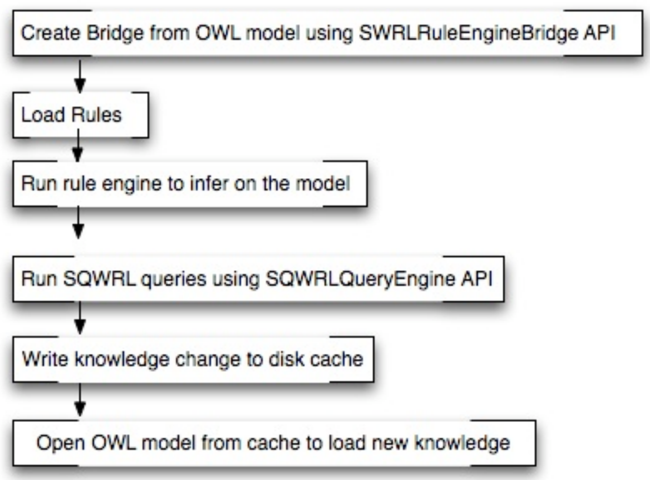

Figure 32. SQWRL rule execution heuristics

By design SWRL rules can only be used to add information. It cannot remove or retract information from the ontology. For example, if a SWRL rule is used to modify the property of an OWL individual, the new value can only be added (along with existing values). If the property is *functional* then the reasoner will throw an exception although SWRLJessTab will not report this anomaly. Attempting to programmatically access the new value is not feasible either, as the order of selection from the available values is logically irrelevant as far as the reasoner is concerned. *Disjunction* operations also present problems with SWRL, but there are easier work arounds (SWRL 2007). The heuristics in

Figure 32 are used to address these concerns as well. It also serves to infer knowledge monotonically from the ontologies by using caching as a mechanism to store interim knowledge states of the ontology.

Finally, SQWRL provides no way of accessing the information gained from query execution. So query results cannot be written back to the ontology. For instance, SQWRL is not allowed to insert the results of computed sum of *ShoppingCart* prices back to the ontology as such an operation will invalidate OWL's open world assumption and lead to non-monotonicity. A future version of SQWRL is expected to support forms of disjunction and NAF in queries only (but not for inference) since semantic issues of negation and disjunctions are not as severe for simple queries (SQWRL 2007).

Reasoning agony:

Reasoning and decidability for practical applications comes at the sacrifice of limiting ontology structures to DL-safe rules upon which classification is assured with current reasoner engines. During reasoning the reasoner is in full control of generating new concepts and those new concepts are generated using the formal model underlying OWL-DL. The reasoner has no control (or understanding) of what happens inside the SWRL/SQWRL rule set. If the rules were to create new OWL entities as a side effect of execution, potentially the ontology sub-language would become OWL-full where upon further decidability will be lost. The validation logic built into the application code to recognize such exceptions are costly and results in a noticeable delay between the UI screen transitions.

As previously mentioned, SWRL rules are effectively OWL axioms and care should be taken to make certain that they do not conflict with closure axioms defined in the ontology. Current implementation of SWRL Rule Engine Bridge will not check for such conflicts. This is a significant limitation in the current implementation of the bridge API whereby it fails to represent all OWL axioms when transferring knowledge from the OWL ontology to the bridge (exceptions are the basic class and property axioms such as *rdfs:subClassOf* and *rdfs:subPropertyOf*, and the axioms *owl:sameAs*, *owl:differentFrom*, *owl:allDifferent*, *owl:equivalentClass*, and *owl:equivalentProperty*) (SWRL 2007). The result is that the inference mechanisms do not know about the remaining OWL axioms. Accordingly, checking for conflicts between SWRL rule and OWL axioms are left to the knowledge engineer and can quickly escalate into a huge labor intense responsibility.

Pellet is an open source alternative to Jess rule engine that has the capability to consider all OWL axioms during the rule execution and signal an error in case of conflicts. Pellet can also handle DL-safe SWRL rules without explicit swrl.owl and swrlb.owl imports. But there is no support for Pellet in the current release of Protégé and will not be available until the next version release. Although hybrid approaches have been proposed (Golbreich et al. 2005, Liem et al. 2007) to combine different reasoning paradigms, exchanging conclusions between rule engine and DL reasoner by running them simultaneously still remains far from reality.

The knowledge engineer should also keep in mind that developing the rule set can be an arduous process requiring considerable time, particularly in domains with numerous rule dependencies. The rule development and testing can turn out to be a cumbersome process because there is no easy way to predict the rule firing sequence. SWRL rules are logical statements about the ontology and by the nature of their formalism they are neither procedural nor sequential. If the rule engine determines that the antecedents are satisfied, the consequent will be asserted. For the domain expert, a comforting relief will come from the use of the SWRLJessTab visual editor in Protégé that can assist with syntax checking on the SWRL rules and perform inference testing with the built-in plug-in for Jess (O'Connor et al. 2005, SWRL 2007). *Rule grouping* is still not possible and the core SWRL built-in library does not yet support *list* operations. These are highly desirable features and may become available in the future implementation of the Protégé knowledge management environment.

UI tribulations:

Unfortunately, there is also no easy way to distinguish between asserted and inferred information resulting from rule execution. Finding the *delta of change* between the old and new knowledge programmatically after running Jess requires repeated disk writes as part of the heuristics shown in Figure 32. Clearly this is not an optimal solution, but remains the only option until API (presumably SWRLJessBridge and others) improvements become available. In the interim, the above mentioned heuristics serve as a practical solution to identify the consumer's decision-making phase, analyze facts for currency and constraint satisfaction, and to reason new facts by coordinating known user behavior with facts from the external task environment.

Another significant challenge comes from working with the changing state of ontology standards, tools and reasoning capabilities. And that is the daunting task of building the artifact with version control and interoperability management of the different architectural components. While improvements are certainly welcomed changes to the overall advancement of the available techniques, collaboration and coordination needs between the knowledge designer and the application developer forces adherence to a common grounding that is probably a version or two behind the current full/beta versions of the software components. To better deal with this issue, the ontology model and application code in this design experiment was fashioned to be modular thereby allowing individual components to evolve on their own and still endorse a high degree of transparency between changing versions.

4.4 Summary

This chapter explained how meaningful direction could be provided to users in their information foraging activities on an e-commerce storefront. To effectively navigate the information space, semantic and spatial attributes have to be combined. And different people use different mental representations to create and maintain their working model of the problem-solving task (Dillon 2000). Domain owners should recognize these differences in the design and engineering of their web presence. Whether it is an online electronic store or a virtual museum displaying popular contemporary art, each embody a unique challenge of presenting information in a particular way. The contemporary art expert may display effortless information pickup in the virtual museum but will benefit from additional visual and lexical stimuli to walk through an electronic store. Problem-solving support therefore requires careful understanding of the aptitude and capacities of the user and apprehension of their contextual surrounding (Heil 1983).

This chapter described the ontology development process and detailed the role of each internal component of the implementation architecture. An e-commerce application was used to show how effective guidance can be provided by constructing semantically rich target pages and by reducing ambiguity in the navigational efforts. Difficulties encountered due to limitations in the current state of art of semantic technologies were also elaborated in this chapter.

CHAPTER 5 Evaluation

In the previous chapter we explained the design of the ontologies and demonstrated the feasibility of mediating assistance that it can provide. Constructing an e-commerce application encompassing semantic web techniques was an important and necessary first step towards providing a "proof of construction" (Nunamaker 1991). Once feasibility is demonstrated by instantiating the system in the selected domain of interest, subsequent research focus can be directed towards improvements in the artifact or the process. But first, the artifact has to be evaluated for its effectiveness and completeness in satisfying the requirements and constraints of the problem it was meant to solve (Hevner et al. 2004). Evaluation also helps reveal other weaknesses that can nurture constructive feedbacks for future improvements.

Hevner et al. (2004) suggest several methods to evaluate designs. Since the selection of evaluation method must appropriately match the designed artifact, this research uses three out of the five approaches suggested by Hevner et al. (2004). The methods used here are analytical, testing and descriptive approaches. Architectural analysis (analytical) is used to test the ontologies against truth of assertions in the domain and to study the artifact for its dynamic qualities and replicability of outcomes. Functional and structural testing was an ongoing built-in function stretched over the entire development lifecycle of the artifact. Informed discussions with ontology experts and detailed case scenarios were used to demonstrate the purpose of the ontologies and to assess the utility of the implementation architecture. Open interviews with domain experts (descriptive) in the field of e-commerce marketing helped the researcher to validate the rule sets for different (or isomorphic) task environments encountered by a user in an e-commerce setting. Informed arguments were a valuable source of feedback for continuing improvement and reinforced the effectiveness of the ontological concepts that embody the theoretical constructs. Regular meetings with knowledge engineering experts also helped to evaluate the quality, utility and efficacy of the designed artifact. The rest of this chapter discusses all three of these approach in more detail and offer deeper insight into the essence of this research project.

5.1 Evaluation methods

Developing the ontologies and the concept definitions therein was a complex iterative process. The terminal version of the knowledge base was a result of fulfilling subjective tradeoffs and objective goals. Subjective decisions called for the judgment of the knowledge designer regarding the degree of detail in the characterization of concepts. There were also the objective goals of how best the application can benefit from their use. Since there exists no commonly used methodology to address these potentially conflicting objectives, the design aspirations for the ontologies propositioned for this research were targeted at capturing as much essence of the problem relevance as possible.

The design and implementation of the artifact is in itself an experiment from which we learn about the nature of the problem, its utility in a given environment and possible solutions (Hevner et al. 2004). Descriptive evaluation was used for judging the quality of the constructs, utility of the model and usability of the artifact instantiation. Architectural Analysis (analytical) and testing (functional and structural) were also used as additional methods for evaluating the models, methods and artifact instantiation. The evaluation methods used in this research are summarized in Figure 33.

Artifact	Evaluation Method
Constructs	Descriptive (Scenarios, Informed Arguments, Detailed Discussions)
Model	Descriptive (Scenarios, Informed Arguments, Theoretical foundations from knowledge base) Testing (Functional)
Methods	Testing (Functional and Structural) Analytical (Architectural Analysis)
Instantiation	Descripive (Scenarios, Detailed Discussions) Analytical (Architectural Analysis)

Figure 33. Design Evaluation Methods

5.1.1 Descriptive

Scenarios describe specific interactions of a user (in this case, the consumer) with the system (the e-commerce environment) in the natural language form of the domain expert and devoid of all technical jargon. They help to better understand the problem domain and the changes that the application should achieve in the changing context of specific users in the information space. Scenarios are concrete and flexible building blocks that entail creation of use cases that reflect realistic and diverse situations (Atwood 2002, Carroll 2000, Guindon 1990, Kazman et al. 1996). In this research, we reply on a scenario-based design approach (Carroll 2000) to build and evaluate the finer details of the artifact constructs (concept vocabulary), model (the Cognitive Information Model) and instantiation (the e-commerce application). The use of scenarios helped us to recognize and capture generalizations in the ontology at a comfortable level of detail. The scenarios themselves were co-authored under the supervision of experts in the discipline of Marketing Management and Knowledge Engineering.

A collection of scenarios form use cases. They describe a sequence of events when taken together leads to the completion of a stated objective. An example is the narrative described in the previous chapter of Dr. Little on a quest to find the correct television set that matches his price and performance expectations. Use cases helped the researcher to better understand both the problem domain and the context of specific users in the information space (Turner 1998) because they are closest to stories about practices observable on e-commerce storefronts. Use case description of process flows validated the domain conceptualization expressed in the ontolgoies.

There are really no widely accepted formal ontology evaluation methods and only initial attempts have been made so far (Weinberger et al. 2003). Active involvement of domain experts is the most sought after method for verifying correctness of the ontologoies and for finding improvements (Edgington 2005). Open interviews of participants and regular reviews by domain experts who raise informal and formal competency questions are commonly used quality validation approaches in AI applications that rely on case-based reasoning, natural language processing and rule based expert systems (Edgington et al. 2005, Gruninger et al. 1995). We relied on similar methods for the descriptive evaluation of the artifact constructs. The primary focus of the domain experts was the verification of conceptual coverage and validity of conceptualization stated in the knowledge base. Verification centered on consistency, clarity, coherence, generality and minimal bias in the internal features of the knowledge base. The validation criteria focused on the completeness, competence and granularity of the ontological vocabulary (Weinberger et al. 2003) in describing the consumer buyer behavior in an e-commerce domain. Periodic discussions with the experts and informed arguments ensured that upper level ontologies and value partitions are accurate representations of real world concepts. Competence was further demonstrated by the OWL implementation of the ontologies and by manifesting its utility in an e-commerce setting. Expert guidance and oversight also helped to verify and categorize SWRL rule antecedents and consequents for multiple use cases. The SWRL/SQWRL rule sets were evaluated by matching function to individual scenarios.

5.1.2 Testing

Testing in an important technique for assessing the quality of the design artifact. In addition to evaluating whether the artifact satisfies the specified requirements (verification), testing also helps detect errors, defects and failure of any system components (validation) during its use. Although in practice there is no single generally accepted testing method, the two basic forms of testing that are commonly used in software engineering are functional (black box) testing and structural (white box) testing (Fischer 2007). The artifacts of this research were tested using both approaches.

Functional (or black box) testing focuses mainly on the outputs generated by a system in response to selected inputs and execution conditions. They validate the behavioral and functional aspects of the system against the stated software specifications without taking any implementation details into account (Fischer 2007). We started with the development of test cases traceable from desirable use cases that specify the behavior of the system. Test cases analyze functional specifications, software constraints and help debug unidentified anomalies in uses cases. Test cases were run repeatedly to users experienced in ontologies and semantic web techniques. They generated the anticipated results or sequence of events, thus satisfying desirable relevance, feasibility and repeatability (Chen 2004, Edgington et al. 2005, Williams et al. 2007). A sample list of test cases that model the scenario of Dr. Little's decision-making processes in the e-commerce setting is described later in this chapter.

Structural (or white box) testing is the close analysis of the internal structure of the system design including the logic of the software code. White box testing may be conducted as unit tests, integration tests and regression tests (Beydeda et al. 2001, Williams et al. 2007). Experts prudently and diabolically reviewed the artifact methods, statements, rule conditions and decision logic to ensure that most independent paths in the software were tested with at least one set of processing scenarios.

Unit testing is the lowest level of testing for software units or groups of related code components. The application programmer repeatedly performed this test during the development phases of the knowledge base and the e-commerce application. *JUnit* testing features built into the software development platform were used to attain very high percentage of statement and branch coverage in the application code. Full coverage was not accomplished because of the inherent complexity of the problem space leads to NP-completeness and the unlikelihood of completion in polynomial time. Validation using coverage criteria (Beydeda et al. 2001) demonstrated the structural integrity of the application in binding the knowledge base and the data dependent rule sets to the reasoner engine and the expert system shell.

Integration testing was used to verify the interaction between the different components of the implementation architecture. They helped uncover integration issues and ambiguities. One such instance was identifying the difference in results depending on how Jess was used in the architecture. Jess results from direct reasoning on OWL documents were found to be different from the facts inferred when used within the SWRLJessTab plugin for Protégé Editor. The origin of this problem was attributable to the incomplete implementation of Jess in the SWRLJessTab plugin. The misleading perception presented by the Ontology editor would not have been identified had it not been for integration testing conducted on the implementation architecture.

To ensure that modifications to the rule sets and ontologies did not cause any unintended side effects in the e-commerce application, regression testing (Williams et al. 2003) was performed as an ongoing process throughout the development lifecycle of the software.

5.1.3 Analytical method

The brainstorming sessions during descriptive testing and the architectural evaluation using black-box and white-box testing fall under the bigger umbrella of Architectural Analysis. Architectural Analysis was effectively and extensively used in all stages of the life cycle of the system development process. It characterizes artifacts at a high level of abstractions making the analysis, design and construction of complex systems intellectually traceable (Richardson et al. 1996, Stafford et al. 2001). It also serves as an effective vehicle by which system evaluators can reason functionality satisfaction criteria of a system right from the conception and development to the deployment and evolution. Architectural analysis helps to uncover design defects, component compatibility issues (static analysis) and communication behavior between the components (dynamic analysis) (Richardson et al. 1996). All of these were critical factors for this study that had to be taken into consideration given the avant-garde artifact and the premature stage of third party software components that were used in this research project.

Software Architecture Analysis Method (SAAM) is a canonical method for the architectural analysis and evaluation of software systems where scenarios are used to illuminate the properties of an artifact. Numerous industrial and academic studies, ranging from multimedia conference applications to air traffic control systems, have used SAAM for the architectural analysis of design artifacts (Kazman et al. 1996). Figure 34 shows the different steps in SAAM. Its usefulness manifests in the evaluation of the fitness of the architecture with the intended use of the artifact (Kazman et al. 1994; 1996).

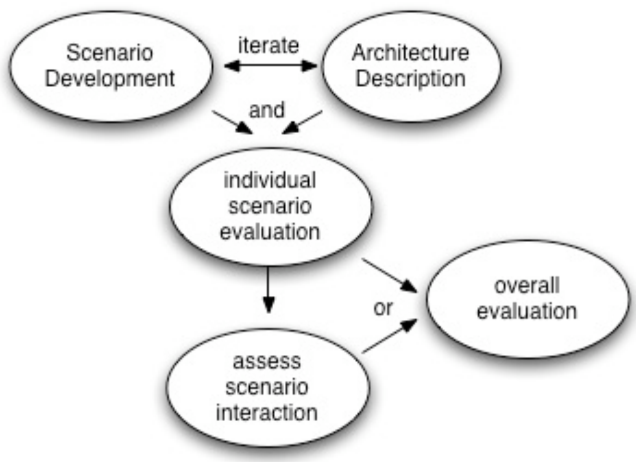

Figure 34. Software Architecture Analysis Method (SAAM), Kazman et al. 1996

Carrying out scenario-based architectural analysis helped the research process in two ways. The benefits were people-oriented and process-oriented. It helped to develop a disciplined focus among the knowledge engineers during the development and verification processes of the ontologies and the implementation architecture. Open communication among designers helped to share a system-level thinking and noteworthy outcomes accrued in the form of agreement between common syntactic and semantic notations. Extended communication on specific problem areas and cumulative efforts between the researcher and the experts in the generation of documented use cases helped to critically evaluate construct alternatives and confer reasoned tradeoffs (Kazman et al. 1996) of desired qualities in the ontologies. One such example was determining the desired level of granularity in the expressiveness of the ontologies. Another example was the general consensus on choosing OWL-DL over OWL-Full by electing on reasoning capability of the inference engine over expressivity. From a process point of view, SAAM helped the evaluators to comprehend implications of specific design choices as well as analyze the artifact for its system-level qualities (performance, scalability and reliability). For instance, emphasis on the fidelity (consistency, clarity, coherence, generality and minimal bias) of the ontologies was compatible with the belief that the chosen level of precision would minimize reasoner errors and avoid costly misrepresentations in the e-commerce application user interface during the course of a consumer's buyer behavior cycle. Another notable quality observation that became apparent is the delay between updates on the user interface following situated user actions. This noticeable delay is attributable to the complexity of the implementation environment and the current state of architectural components that made it necessary to contrive computationally costly workarounds.

5.2 Summary of cases for evaluation

Once the concepts were modeled and OWL individuals created, SWRL/SQWRL rules were drafted in the SWRL Tab widget of the Protégé Ontology Editor. RacerPro performed consistency check and classification testing on the knowledge base while the

JESS expert system shell executed SWRL/SQWRL rules as necessary. This section lists the cases that were used for evaluation.

Case # 1: Using the menu to browse to Televisions listing infers Need recognition.

Explanation:

When TVandVideo theme is the selected category from the MainListing, CurrentNode is set as ViewListing, and CurrentPhase is set to A_NeedRecognition.

Action:

Browse category to TVAndVideo theme of the MainListing.

Rule execution:

ViewListing(?v) ∧ hasListCount(?v, ?count) ∧ swrlb:greaterThanOrEqual(?count, 2) ∧ machineState(ViewListing_Static, "current") ∧ A_NeedRecognition(?nr)
→ CurrentNode(?v) ∧ CurrentPhase(?nr)

UI Outcome:

Television categories are listed for selection by Promotion, Screen Size or TVType.

Associated Ontology Fragment	**Asserted Conditions**	**Asserted Individuals (Properties)**	**Inferred Individuals (Properties)**
Domain - MainListing – TVAndVideo - TV	isSequential some TV	TVListing_Static isSequential TV_1 TV_2 TV_3	
UserOntology - A_NeedRecognition		A_NeedRecognition_Static (behaviorState: ambiguous)	C_AlternativeEvaluation_Static (behaviorState: reasoned)
CognitiveFitOntology - CurrentPhase			A_NeedRecognition
CognitiveFitOntology - CurrentNode			ViewListing_Static (machineState: unbound)

Case # 2: View Televisions based on promotion as user preference.

Explanation:

When promotion sales option is selected, all televisions on promotion sales are displayed. ReasonedNode is set as ViewListing, and ReasonedPhase is made C_AlternativeEvaluation with a user bias tagged for promotion sales.

Action:

Browse category to TVAndVideo theme of the MainListing.

Rule execution:

Promotion(Promotion_Static) ∧ hasUserPreference(Promotion_Static, "biased") ∧
ViewListing(?vl) ∧ C_AlternativeEvaluation(?ae)
→ ReasonedNode(?vl) ∧ ReasonedPhase(?ae)

Promotion(?p) ∧ hasUserPreference(?p, "biased") ∧
TV(?t) ∧ promotionSale(?t, "yes") → sqwrl:select(?t)

UI Outcome:

Televisions are listed by promotion with relevant details highlighted. User bias is recognized.

Associated Ontology Fragment	**Asserted Conditions**	**Asserted Individuals (Properties)**	**Inferred Individuals (Properties)**
DomainOntology ValuePartitions BusinessObjective – Promotion	isSequential some TV	TVListing_Static isSequential TV_1 TV_3	Promotion_Static (hasUserPreference: biased)s
UserOntology - A_NeedRecognition		A_NeedRecognition_Static (behaviorState: current)	
CognitiveFitOntology -CurrentNode		ViewListing_Static (hasListCount: 2) (machineState: current)	
CognitiveFitOntology			C_AlternativeEvaluation

- ReasonedPhase			(behaviorState: reasoned)
CognitiveFitOntology - ReasonedNode			ViewListing_Static (machineState: unbound)

Case # 3: Comparing items infer alternative evaluation.

Explanation:

When two or more televisions are selected for comparison, C_AlternativeEvaluation is the current phase and CompareItems is the current node. ReasonedPhase is set as B_InformationSearch and ReasonedNode is made ViewItem.

Action:

Select two televisions to compare and click the Compare button.

Rule execution:

CompareItems(?c) ∧ hasCompareCount(?c, ?count) ∧
swrlb:greaterThanOrEqual(?count, 2) ∧ C_AlternativeEvaluation(?ae) →
machineState(CompareItems_Static, "reasoned") ∧ CurrentNode(?c) ∧
CurrentPhase(?ae) ∧ behaviorState(C_AlternativeEvaluation_Static, "current")

machineState(CompareItems_Static, "current") ∧ B_InformationSearch(?is) ∧
ViewItem(?vi) → ReasonedNode(?vi) ∧ ReasonedPhase(?is)

UI Outcome:

Televisions that are on promotion and selected for comparison are displayed with emphasis on the details of individual items.

Associated Ontology Fragment	Asserted Conditions	Asserted Individuals (Properties)	Inferred Individuals (Properties)
DomainOntology - MainListing –	isSequential some TV	TVListing_Static isSequential	

TVAndVideo – TV		TV_1 TV_3	
UserOntology - C_AlternativeEvaluation	hasUserPreference: biased	C_AlternativeEvaluation_ Static (behaviorState: current)	
CognitiveFitOntology - CurrentNode		TVListing_Static (hasListCount: 2) (machineState: bound)	
CognitiveFitOntology - ReasonedPhase			B_InformationSearch (behaviorState: reasoned)
CognitiveFitOntology - ReasonedNode			ViewItem_Static (machineState: reasoned)

Case #4: Viewing specifications of a television infers information search.

Explanation:

When the button highlighted with the user preference is clicked, a detailed specification of the selected television is presented to the user. To cater to the business objective of selling the television to the customer, D_PurchaseDecision is the set as the reasoned phase with AddToCart as the reasoned node.

Action:

Button clicked to view detailed specifications of a particular television.

Rule execution:

machineState(ViewItem_Static, "current") ∧ AddToCart(?ac)
∧ D_PurchaseDecision(?pd) → ReasonedNode(?ac) ∧ ReasonedPhase(?pd)

UI Outcome:

Specifications of the selected television are displayed with emphasis on influencing a purchase decision.

Associated Ontology Fragment	Asserted Conditions	Asserted Individuals (Properties)	Inferred Individuals (Properties)
Domain - MainListing – TVAndVideo - TV		TV_3	
UserOntology - B_InformationSearch	hasUserPreference: biased	B_InformationSearch_Static (behaviorState: current)	
CognitiveFitOntology - CurrentNode		ViewItem_Static (machineState: current)	
CognitiveFitOntology - ReasonedPhase			D_PurchaseDecision (behaviorState: reasoned)
CognitiveFitOntology - ReasonedNode			AddToCart_Static (machineState: reasoned)

Case #5: Adding item to cart is Purchase Decision.

Explanation:

When a television is added to the shopping cart, the user is presented with warranty options specific to the television. E_PostPurchaseEvaluation becomes the reasoned phase. Checkout option is also displayed.

Action:

TV_3 added to the shopping cart.

Rule execution:

AddToCart(?a) ∧ TV(?t) ∧ itemInCart(?a, ?t) ∧ D_PurchaseDecision(?pd)
→ machineState(Checkout_Static, "reasoned") ∧ CurrentNode(?a) ∧
CurrentPhase(?pd) ∧ behaviorState(D_PurchaseDecision_Static, "current")

machineState(AddToCart_Static, "current") ∧ E_PostPurchaseEvaluation(?ppe) ∧
ViewDiscussionForum(?vdf) → ReasonedNode(?vdf) ∧ ReasonedPhase(?ppe)

UI Outcome:

Items in the shopping cart are displayed. Warranty options are presented for the selected television along with the option to complete check out.

Associated Ontology Fragment	Asserted Conditions	Asserted Individuals (Properties)	Inferred Individuals (Properties)
Domain - MainListing – TVAndVideo - TV		TV_3	
UserOntology - D_PurchaseDecision	hasUserPreference: biased	D_PurchaseDecision_Static (behaviorState: current)	
CognitiveFitOntology - CurrentNode		AddToCart_Static (machineState: current)	
CognitiveFitOntology - ReasonedPhase			D_PostPurchaseEvaluation (behaviorState: reasoned)
CognitiveFitOntology - ReasonedNode			ViewDiscussionForum_Static (machineState: reasoned)

Case #6: Checkout elicits the business objective of reducing cognitive dissonance.

Explanation:

When the checkout button is clicked, E_PostPurchaseEvaluation becomes the current phase. To confirm with the business objective of reducing cognitive dissonance, a discussion forum page specific to the type of television that was purchased is displayed. Machine state and behavior states are reset from the application.

Action:

Warranty Plan_1 is selected and the checkout button is clicked to complete the purchase of the television.

Rule execution:

AddToCart(?a) ∧ selectedWarrantyPlan(?a, ?wp) ∧ D_PurchaseDecision(?pd)
→ machineState(Checkout_Static, "reasoned") ∧ CurrentNode(?a) ∧
CurrentPhase(?pd) ∧ behaviorState(D_PurchaseDecision_Static, "current")

```
// reset ontology states programmatically
com.demo.CIMOntology.resetUserPreferenceBiasProperty();
```

```
com.demo.CIMOntology.resetUserOntologyBehaviorStateProperty();
com.demo.CIMOntology.resetFitOntologyMachineStateProperty();
```

UI Outcome:

Discussion forum page specific to the purchased television is displayed.

Associated Ontology Fragment	**Asserted Conditions**	**Asserted Individuals (Properties)**	**Inferred Individuals (Properties)**
Domain - MainListing – TVAndVideo - TV ValuePartition - Warranty		TV_3 Plan_1	Plan_1 (WarrantyTerms: Labor12Months- Parts12Months)
UserOntology - E_PostPurchaseEvaluation	hasUserPreference: biased	E_PostPurchaseEvaluation_Static (behaviorState: current)	
CognitiveFitOntology - CurrentNode		ViewDiscussionForum_Static (machineState: current)	
CognitiveFitOntology - ReasonedPhase			behaviorState: ambiguous
CognitiveFitOntology - ReasonedNode			machineState: ambiguous

5.3 Implications and lessons learned

This research study has numerous implications that are summarized in this section. The significance of the findings and the results of the research are important because they nurture creative momentum for future work. This section will act as a vehicle to highlight some of the lessons learned from this dissertation. The lessons learned should serve the purpose of assisting researchers and practitioners in conducting informed research and development in the area of semantic web applications.

While the original vision of the semantic web is flamboyant and inspiring, it has yet to takeoff in a grant fashion. The main detriment from a knowledge engineer's viewpoint is arguably the lack of a standardized ontology development methodology. Several initiatives are in progress to address these concerns but the efforts are mostly fragmented. While some propose methodologies without having a specific problem to solve, others focus on engineering specific ontologies without concern to existing ones. Numerous tools also exist to assist knowledge engineers through the development process, each with their own version naming conventions and methods. Without a unified endeavor to standardize the ontology engineering processes the suitability of particular tools and languages will remain inconsistent with the myriad methodologies and the problems that they are intended to solve. These deficiencies place huge challenges on researchers and practitioners. Left with no options, building applications centered on semantic web concepts can be laborious and gradual due to extensive dependence on the support of different Descriptive Logic Implementation Group (DIG) communities, subjective rational and collaborative overhead.

Another issue that has plagued the adoption of semantic web is the issue of annotating all domain information in RDF or OWL to make them machine processable. Currently there are no tools that would perform the annotation automatically. The propensity is then to ask what reasons the domain owners really have to invest labor, time and money into such arduous tasks. Are there real benefits in building systems that understand semantics? If the goal is to improve consumer online experiences, will the solutions be better than existing tools based on historical trends and statistical frequency analysis? The answer really depends on the purpose of the individual application. If what we are looking for in such a system can be summarized to spending less time searching for relevance (accuracy), spending less time looking at concepts that do not matter (speed) or spending less time explaining what we want (interpretational precision), then a solution that understands semantics can be beneficial. The complexity of such systems will be higher and may not be fully error free. However, demonstrating practical implementations with a well-defined business focus and consumer satisfaction objective will play a vital role in persuading adoption of semantic solutions outside of academic exercises. This dissertation succeeded in providing that initial stimulus.

As a knowledge engineer, one of the key aspects to bear in mind when modeling ontologies are the trappings of open world assumptions on which inferences are corroborated by the reasoner systems. This philosophical underpinning is drastically different from the value testing, type checking, or conditional clause assessments of closed world assumptions that most application developers are familiar with. The inferences and assertions from the underlying reasoning system will spring surprises unless the ontology modeler changes the way of thinking.

The design aspirations in this dissertation deliberately ruled out the inclusion of individual identity in the constructs. This decision is in harmony with the novelty and purpose of the artifact itself. A novice's knowledge may be spotty in the subject-matter domain and possibly consists of just a superficial understanding of the external space and concepts (Klahr et al. 1989). An expert, on the other hand, can rely on past experience and domain familiarity to optimally forage for information within the constraints of the space

(Pirolli et al. 1995). The sustained design objective of the artifact developed here was to provide mediation capabilities that are transparent to the end user irrespective of the individual's experience level with the domain.

This work has shown how the artifact can be applied to address three specific issues in an e-commerce domain. For information users, it offers an activity-based representation of the domain space to facilitate richer, more productive and individualized experiences. For information designers, the design concerns that should be addressed to conceptualize buyer behavior were highlighted. We showed how the decision-making process could be modeled as ontologies. We also explained how domain owners could use the knowledge base to analyze user activities that have direct implications on business objectives. We applied popular theories from behavioral science, sociology, cognitive science and knowledge engineering to develop the artifact used within the specified context. The theoretical model was implemented to demonstrate how navigational guidance could be predicted and presented to the end user by identifying the cognitive fit of the mental representation of the task solution to the problem task. Use cases describing real world phenomenon were compiled from scenarios to evaluate the artifact. As stories of experts and novices interacting with the digital space, the use cases portrayed reflective practice, adaptive cognitive activity and satisficing actions under bounded rationality.

5.4 Summary

In this chapter the evaluation of the artifact design, construction, implementation and instantiation was described. This research endeavor converged many complex issues relating to the mechanism of interpreting, understanding and learning about the structure of human adaptations in an external information-bearing environment. The locus of activity was that of coordinating the interplay between the intuitive and perceptual operations and facilitating a cognitive fit between the internal and external task representations. The evaluation primarily focused on assessing the artifact for suitability, feasibility and effectiveness of its intended purpose. Scenario-based evaluation tested soundness of the functional model in portraying the hierarchy of tasks in the consumer decision-making process. It helped to verify that the observed and predicted outcomes were consistent across multiple use cases. It also informed the researcher about limitations of the implementation observable at the user interface level of the e-commerce application. Refining the implementation with updated versions of third party software components are planned as future enhancements. The role of Architectural Analysis cannot be emphasized enough. Continuous analysis and evaluation was an on-going iterative process that truly helped to transform the problem task and the solution approach into implemental design artifacts. Architectural Analysis was an effective evaluation approach that combined hands-on design with critical analysis and reflections resulting in a thorough assessment of the design artifacts developed in this research initiative.

CHAPTER 6 Conclusion

Ultimately the merits of any dissertation is endorsed by the insights and results conditioned from the central thesis. As Hevner et al. (2004) states, the critical role of design-science research is in identifying undeveloped capabilities that will expand IS into new realms not previously believed to be amenable. Constructing the artifact and instantiating it in a research setting is just the first step prior to actual adoption and use in real systems (Nunamaker et al. 1991). This dissertation alleviated concerns about the ability to "construct" and elucidated realistic insights about its effectiveness in addressing the research problem. From the discussions in the preceding chapters, it can be concluded with assurance that an ontology centric architecture for mediating interactions has the potential for effectively mediating interactions in an e-commerce setting.

The rest of this chapter will summarize the essence of this research and point out the limitations of this study. Opportunities for improvements that are conduits for future research initiatives will also be outlined.

6.1 Essence of the research

Problem Relevance: We live in an age of information overload. Sifting for relevant information is more of a problem now than ever before. Since browsing information spaces involves cognitive actions of the user, active navigational aids that are aware of contextual variations in a user's problem-solving task, their decision-making process and adaptations will be a useful supplement for better problem-solving performance. What we currently lack in digital domains are information structures that are tailored to the uniqueness of our individual needs. Assistive aids should be proactive (rather than reactive) and should reinforce the situated actions of a user in finding information conveniently and quickly (refer Chapter 1). The need becomes even more justifiable as the stunning popularity and use of public digital spaces such as e-commerce storefronts, social networking websites, digital archives and virtual libraries will only have a wider reach and growing importance in the future.

Research Rigor: The research presented in this dissertation has theoretical foundation in the fields of Cognitive Science, Knowledge Engineering, Marketing Management and Design Science. The Distributed Model of Cognition (Zhang et al. 1994), the Extended Cognitive Fit Model (Shaft et al. 2006), Schön's Reflective Model (1983) and Simon's notion of satisficing on bounded rationality (1996) form the underlying formalisms upon which the proposed Cognitive Information model is established (refer Chapter 2, 3). The research thus draws from a popular, clearly defined and well-tested base of literature and knowledge. The foundation has proven validity in many related research areas and disciplines. They embellish the prescriptions for designing ontologies that characterize the cognitive fit of consumers' buyer behavior and their context in an information space. The model proposed in this research was methodologically verified for the representational strength of its constituent ontological constructs and empirically validated by building an instantiation.

Design as a Search Process: Design Science research starts with the representation of the problem and its simplified conceptualizations (Hevner et al. 2004). For tasks that require interactions with the external environment, the individual's reflective action (Schön 1983) is influenced by the interaction between the external and internal representations and by the processing of information available from them (Zhang 1997). This cognitive behavior is also directed by constraint satisfaction and by the notion of satisficing on bounded rationality (Simon 1957; 1989). Furthermore, in an e-commerce setting, the mental apparatus of performing an action is directed through a sequence of states that can be ascertained by the five phases of the consumer buyer behavior model (Engel et al. 1995). For each type of task, the situated actions (and the sequence of states) are repeated more or less consistently due to the nature of the influence of intuitive operations on internal task representations and perceptual operations on external problem representations (Hutchins 1995, Kahneman 2003). The ontological constructs express this conceptualization and the rule base is consistent with the predetermined sequence of situated actions (refer chapter 3, 4).

Design as an Artifact: The three definitive ontologies model the external environment, the buyer behavior model and the cognitive fit. The ontologies together with their integral vocabulary, logical axioms and rule sets are the *constructs* of the artifact. A *model*, the Cognitive Information Model was proposed and *methods* were developed to implement the design architecture. Test cases operationalized through the e-commerce application form the artifact *instantiation*. Assertions on the ontology are effected using SWRL rules triggered by Jess Expert System Shell. SQWRL is used for querying the ontologies. The Racer Pro reasoner performs ontology validation following knowledge base updates. The implementation illustrates the "proof of construction" (Nunamaker et al. 1991) of an ontology centric architecture for mediating interactions in semantic web-based e-commerce environment (refer Chapter 4). Theory building naturally emerges as the next phase of the artifact design.

Design Evaluation: The problem definition explicitly stated the attributes desirable of the artifact prior to its conceptualization (refer Chapter 1). Descriptive, testing and analytical approaches were used to evaluate the resulting artifact. Justification of specific design choices were explicated and the implementation was tested for usability using combinations of scenarios that reflected buyer decision-making test cases. This further validated the utility of ontologies in mediating interactions in digital information spaces. The virtues and limitations of the constructs as well as the capabilities and constraints of the model were also described in detail (refer Chapter 4, 5). The model has not been tested in an actual environment or observed in a real world operational setting. Å real world e-commerce site instantiation and a controlled experiment to subjectively gauge the user's perception of the tool and objectively measure the effects on problem-solving performance will be the focus of future research objectives.

Research Contributions: The successful design and implementation was in itself a scientific study of the artifact. This dissertation propositioned a model to analyze user interactions in digital domains and it demonstrated an end-to-end functional model to test the utility of semantic web techniques in an e-commerce setting. Aptly speaking, the main research contributions are the artifacts themselves – constructs (the ontologies), model (the Cognitive Information Model), methods (the implementation architecture) and the instantiation (the e-commerce application). The technical details and design principles presented in this research will positively make it easier for technical researchers and practitioners to replicate this work with minimal effort. The uniqueness of the artifact and its novelty will help IT managers to add new capabilities to existing digital domains. Domain owners will find utility from superior organization and taxonomical classification of information. Consumers will muster better comprehension of the problem space and benefit from improved navigation through the information space. For behavioral researchers, this research offers an excellent opportunity to validate (or falsify) new theories associated with the use of the artifact in an e-commerce or other similar contexts. Articulating the design principles on which the Cognitive Information Model is proposed can serve as the basis for hypotheses testing for future theory building exercises. This will further enhance the knowledge base and advance our understanding of how to best use ontologies for effective user navigation in digital information spaces. An agenda for addressing these issues are discussed in Chapter 6.

Research Communication: This research provides relevant and useful information for managerial audiences as well as researchers. Related work in the future will focus on targeting journal publications so that practitioners can understand the application of the artifact. It will also provide researchers with opportunities to undertake theory building and justification endeavors. This in turn will help to extend the knowledge base.

6.2 Limitations of the study

IT artifacts are not merely objects, but designed, constructed and used by people whose assumptions, interests and values are embedded into its constituent components (Orlikowski et al. 2001). As such, this research focused on the two main activities to address the two main questions fundamentally relevant to Design Science - does it work? and, how well does it work? (March et al. 1995). To answer the first question, the feasibility of construction of the artifact was demonstrated. We drew upon use case instantiations of real world phenomena, black-box and white-box testing, and architectural analysis to evaluate the fidelity, completeness, robustness and level of detail of the artifact. But additional work still remains. Demonstrating utility is only one part of the scientific cycle. Theory building has to follow so that utility can inform truth.

6.2.1 Theoretical enhancements

The Cognitive Information Model is strongly grounded on reputed theories in related disciplines. We hypothesized that the model was sufficiently strong to serve as a concrete guideline to depict the formation of mental representations of task solutions and to anticipate the consequences of their decisions in the task environment. But of course, no such model is ever completely perfect, nor can it comprehensively cover all realisms of cognition that govern the nature of interactions between the internal and external task representations. To develop the model proposed in this study, we resorted to well-established literature to identify the finite set of factors that influence the intuitive operations and perceptual operations. The model clearly does not include all known factors that influence problem-solving performance. For example, the role of illusion or curiosity is not included. Illusions arise from inconsistencies between perception and reality (Margolis 1987). Outside of curiosity, which is inherently difficult to the model, illusion is believed to be the major cause of backtracking during the navigation process (Margolis 1987). Other factors that are sidelined from the model include the effects of memory, idiosyncrasies and unique mannerisms. Since SWRL rules essentially reflect the espoused theories of action, concerns may be raised over how changes could be made to the rule base to accommodate variations observed in user's theories of action. The dilemmas of inconsistency (progressive incompatibility of governing variables of the theory-in-use) and effectiveness (deterioration of rule sequence reaching a point at which the SWRL rules fail or fall outside allowed bounds) (Argyris et al. 1992) can be addressed by monitoring utility of the artifact over a period of time. Adjusting the rule base for corrections is possible but will require manual intervention followed by additional regression testing. Certainly we do not believe that the model is restrictive in any form due to these limitations. At its worst, it still closely mimics what we know about cognitive information processing.

Another area where the model can be beneficial is to identify linkages to theories from Human Computer Interaction (HCI). The methodologies from HCI will help the researcher to better understand the needs and limitation of specific user interface design choice. The desirable properties can then be formally included in the ontologies to further enrich them.

6.2.2 Artifact improvements

The choice of ontological idioms and logical axioms describing the character of consumer buyer behavior was a pragmatic matter distilled from extensive literature research, observations and repeated consultation with domain experts. Although our study proved that the ontological vocabulary is a consistent, coherent and competitive representation of the Cognitive Information Model, there are additional aspects of the ontology that can be improved upon. While some of the improvement will have to be based on feedbacks from real world model testing, more upper level ontologies and value partitions may be added to the ontologies for greater conceptual coverage and completeness. For convenience reasons, the current version of the domain ontology specifies only one category of products under the main listing of items on the e-commerce storefront. Appending supplementary categories will aid a more thorough quality validation of the knowledge base and the rule set. Additional value partitions may also be used to further refine the sub-qualities of the upper domain concepts. Testing with a more elaborate ontology specification will help to evaluate the scalability of the methods, constructs and instantiations of the artifact. These improvements will definitely be favorable additions in the future but will require a high degree of editorial work by the knowledge engineer.

There are also functional limitations in the way SWRL and SQWRL rule sets were implemented. Under the current available implementation of SWRL built-ins, it is almost next to impossible to write rules for complex relations involving temporal predicates under monotonicity constraints. A possible workaround is to timestamp every change of value of a property (Matheus, 2005). However, writing SWRL rules to reason through historic time variant values will be a daunting task. Time related variables are hence not treated in any part of the current study. Similarly, there is also no remedy for dealing with uncertainty in the current implementation of SWRL built-ins and hence not considered in the construction of the artifact.

Subtle limitations in the exposition of the knowledge base become apparent based on the manner in which the SWRL Rule Bridge Engine treats OWL axioms (refer to Chapter 4). Since the rule engine may not consider all OWL axioms during the inference process, a heavier emphasis is placed on the use of the safer SWRL rules over OWL axioms. A desirable solution will be to transfer all OWL axioms to the bridge and then pass them to an alternate target rule engine/reasoner such as Pellet. But dealing with all OWL axioms in rule engine is non-trial and plug-in support for Pellet within Protégé Knowledge Editor is currently available only in the beta version of the software. Future implementations of the architecture should target the use of some hybrid approaches that combine different reasoning paradigms (O'Connor et al. 2005) or upgrade to the latest versions of software components currently used in the implementation architecture.

Another issue worthy of mentioning is the performance concerns related to the implementation architecture. The observable delay in rendering user interface updates on the e-commerce application is attributable to computational complexity of the implementation architecture. Notable factors being the marshalling and de-marshalling of SWRL/SQWRL built-ins by the rule engine, costly invocation of bridge API from the application with every step of user interaction and the requisite reasoner validation of knowledge base updates following SWRL inferences. Investigating alternative ways to tweak the rule sets and the OWL axioms maybe worthy of pursuit if the overall performance in terms of lower computational overhead and higher speed can be attained.

Last but not least, the artifact design considerations ruled out the inclusion of personal identify in its constructs. It would be interesting to study how the notion of identity along with its prominent elements such as personal history, search history and authentication credentials impact the overall utility of the artifact. Users may have privacy or “spoofing” concerns (which are already present in our daily interactions with the Internet); but at the same time the identity concepts may help to revive lost information, recall forgotten activities (Wexelblat 1994) or retrace actions that were trivially dismissed in the past.

6.2.3 Theory building and evaluation

Prior to generalizing on the effectiveness and utility of the artifact, a controlled experiment has to be conducted in a real world setting with random selection (for external validity) and assignment (for internal validity) of participants to the experimental and control groups. Subjective measures of the experiment will be designed to gauge the end user's ability to exploit the tool, the efficiency in doing so and his or her perception of the experience. Objective measures will focus on problem-solving performance measured along the dual metrics of accuracy and time. Rigorous evaluation of the empirical evidence will help to discover the truth from which theories may emerge. Left as it is, contributions to the knowledge base will be deprived of the manifestations of truth - the source for further development and refinement of the artifact. Currently this remains unfulfilled in the scope of this research project.

The study looked at buyer behavior in an e-commerce setting using the Consumer Decision-Making Model by Engell et al. (1995). A substantial portion of the knowledge base and the rule set are based on the differences and isomorphic similarities (Zhang et al. 1994) abstracted by the use cases centered on this one model. It may be beneficial to build and compare alternate representations derived from other competing theories of consumer buyer behavior. Such an effort will aid further evaluation of the representational efficiency of the constructs proposed in this research. It may also facilitate the identification of additional factors that affect cognitive behavior in digital spaces and related information processing mechanisms carried out in problem-solving tasks.

Additionally, comparison to other similar artifacts was not used as one of the formal evaluation method. This really cannot be a criticism of the work because there is simply no known artifact that directly addresses the same research problem. The closest we got to semantically supported information foraging techniques were the fish-eye view models, patina maps, Latent Semantic Indexing, Spatial co-citation maps and the Spatial Paradigm for Information Retrieval and Exploration (refer Chapter 2). They are mostly passive facilitators relying on interaction history analyzed from server logs, client side cookies or persistent session data.

Finally, use case evaluation did not reveal the effects of the artifact over an extended period of use. It would be interesting to get insights on unnoticed or other hidden behavioral changes outside of the canned use case scenarios. Longitudinal tests will be useful for that purpose. It can also be applied to test the effects of specific features and functions over time and provide feedback for future improvements.

6.3 Epilogue

The list of limitations and associated improvements discussed in the previous section was not intended to diminish the contributions of this dissertation. On the contrary, it offers great opportunities for further investigation. The artifact described in this dissertation is only the "beginning" of innovation fostered by information gathered from other disciplines, insights gained through active discussions where ideas are not just accumulated by any knowledge expert but openly shared and most importantly, the curiosity of the mind.

The real value of this research stems from the strength of the applied theoretical base. The benefits will reveal themselves as more specialized tools evolve from the proposed artifact. Target application areas range from e-commerce domains, digital libraries and virtual museums to organizational knowledge stores, large database repositories and even help desk systems. Combined with the newer web presentation tools such as Windows Presentation Framework, Asynchronous JavaScript And XML or Adobe Flex ActionScript, we can finally envision the prospects of molding semantically informed digital information spaces adorned with jaw-dropping interface designs. After all, to see the patterns in a fractal complexity, we have to take a step back and gain perspective. With this dissertation the initial step has been taken towards understanding knowledge structures that empower consumers with a sense of comfort and accomplishment as they tread through the increasingly turbulent and chaotic world of digital information.

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APPENDIX A

RELEVANT SWRL RULES AND SQWRL QUERIES

SWRL / SQWRL	Rule
Query-1	Promotion(?p) ∧ hasUserPreference(?p, "biased") ∧ TV(?t) ∧ promotionSale(?t, "yes") → sqwrl:count(?t) ∧ sqwrl:select(?t)
Query-2	ScreenSize(?s) ∧ hasUserPreference(?s, "biased") ∧ TV(?t) → sqwrl:count(?t) ∧ sqwrl:select(?t)
Query-3	Type(Type_Static) ∧ hasUserPreference(Type_Static, "biased") ∧ TV(?t) → sqwrl:count(?t) ∧ sqwrl:select(?t)
Query-4	Warranty(?w) ∧ warrantyTerms(?w, ?wt) → sqwrl:select(?w, ?wt)
Rule-1	ViewItem(?v) ∧ TV(?t) ∧ selectedItem(?v, ?t) ∧ B_InformationSearch(?is) ∧ machineState(ViewItem_Static, "current") → CurrentNode(?v) ∧ CurrentPhase(?is)
Rule-2	AddToCart(?a) ∧ TV(?t) ∧ itemInCart(?a, ?t) ∧ D_PurchaseDecision(?pd) → machineState(Checkout_Static, "reasoned") ∧ CurrentNode(?a) ∧ CurrentPhase(?pd) ∧ behaviorState(D_PurchaseDecision_Static, "current")
Rule-3	ViewListing(?v) ∧ hasListCount(?v, ?count) ∧ swrlb:greaterThanOrEqual(?count, 2) ∧ machineState(ViewListing_Static, "current") ∧ A_NeedRecognition(?nr) → CurrentNode(?v) ∧ CurrentPhase(?nr)
Rule-4	CompareItems(?c) ∧ hasCompareCount(?c, ?count) ∧ swrlb:greaterThanOrEqual(?count, 2) ∧ C_AlternativeEvaluation(?ae) → machineState(CompareItems_Static, "reasoned") ∧ CurrentNode(?c) ∧ CurrentPhase(?ae) ∧ behaviorState(C_AlternativeEvaluation_Static, "current")
Rule-5	AddToCart(?a) ∧ selectedWarrantyPlan(?a, ?wp) ∧ D_PurchaseDecision(?pd) → machineState(Checkout_Static, "reasoned") ∧ CurrentNode(?a) ∧ CurrentPhase(?pd) ∧ behaviorState(D_PurchaseDecision_Static, "current")
Rule-6	TV(?t) ∧ promotionSale(?t, "yes") ∧ itemInCart(AddToCart_Static, ?t) → Promotion(?t)
Rule-7	TV(?t) ∧ discountSale(?t, "10 Percent") ∧ itemInCart(AddToCart_Static, ?t) → Discount(?t)
Rule-10	AddToCart(?a) ∧ TV(?t) ∧ itemInCart(?a, ?t) ∧ D_PurchaseDecision(?pd) ∧ machineState(AddToCart_Static, "current") → CurrentNode(?a) ∧ CurrentPhase(?pd)
Rule-12	CompareItems(?c) ∧ hasCompareCount(?c, ?count) ∧ swrlb:greaterThanOrEqual(?count,

	2) ∧ C_AlternativeEvaluation(?ae) → CurrentNode(?c) ∧ CurrentPhase(?ae)
Rule-13	ViewDiscussionForum(?df) ∧ machineState(?df, "current") ∧ E_PostPurchaseEvaluation(?ppe) → CurrentNode(?df) ∧ CurrentPhase(?ppe)
Rule-14	Promotion(Promotion_Static) ∧ hasUserPreference(Promotion_Static, "biased") ∧ ViewListing(?vl) ∧ C_AlternativeEvaluation(?ae) → ReasonedNode(?vl) ∧ ReasonedPhase(?ae)
Rule-15	ScreenSize(ScreenSize_Static) ∧ hasUserPreference(ScreenSize_Static, "biased") ∧ ViewListing(?vl) ∧ C_AlternativeEvaluation(?ae) → ReasonedNode(?vl) ∧ ReasonedPhase(?ae)
Rule-16	Type(Type_Static) ∧ hasUserPreference(Type_Static, "biased") ∧ ViewListing(?vl) ∧ C_AlternativeEvaluation(?ae) → ReasonedNode(?vl) ∧ ReasonedPhase(?ae)
Rule-17	machineState(ViewItem_Static, "current") ∧ AddToCart(?ac) ∧ D_PurchaseDecision(?pd) → ReasonedNode(?ac) ∧ ReasonedPhase(?pd)
Rule-18	machineState(ViewListing_Static, "current") ∧ ViewListing(?v) ∧ hasListCount(?v, ?count) ∧ swrlb:greaterThanOrEqual(?count, 2) ∧ B_InformationSearch(?is) ∧ ViewItem(?vi) → ReasonedNode(?vi) ∧ ReasonedPhase(?is)
Rule-19	machineState(CompareItems_Static, "current") ∧ B_InformationSearch(?is) ∧ ViewItem(?vi) → ReasonedNode(?vi) ∧ ReasonedPhase(?is)
Rule-20	machineState(AddToCart_Static, "current") ∧ E_PostPurchaseEvaluation(?ppe) ∧ ViewDiscussionForum(?vdf) → ReasonedNode(?vdf) ∧ ReasonedPhase(?ppe)
Rule-21	machineState(Checkout_Static, "current") ∧ E_PostPurchaseEvaluation(?ppe) ∧ ViewDiscussionForum(?vdf) → ReasonedNode(?vdf) ∧ ReasonedPhase(?ppe)

VITA

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Prior to his doctoral studies, Manoj earned a Master of Science in Information Systems and a Master of Business Administration from the Virginia Commonwealth University, Richmond, Virginia.

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