Chapter 2.15
Leveraging Knowledge Reuse and System Agility in the Outsourcing Era

Igor Crk
University of Arizona, USA

Dane Sorensen
Raytheon Missile Systems, USA

Amit Mitra
TCS Global Consulting Practice, USA

ABSTRACT

Collaborative work groups that span multiple locations and time zones, or "follow the sun," create a growing demand for creating new technologies and methodologies that enable traditional spatial and temporal separations to be surmounted in an effective and productive manner. The hurdles faced by members of such virtual teams are in three key areas**:** **d**ifferences in concepts and terminologies used by the different teams; differences in understanding the problem domain under consideration; and differences in training, knowledge, and skills that exist across the teams. These reasons provide some of the basis for the delineation of new architectural approaches that can normalize knowledge and provide reusable artifacts in a knowledge repository.

INTRODUCTION

The increasing prevalence of collaborative work groups that span multiple locations and time zones create a growing demand for creating new technologies and methodologies that can enable traditional spatial and temporal separations to be surmounted in an effective and productive manner. In the specific case of information technology (IT), more than 380,000 professionals are currently focused exclusively on export-oriented activities (Aggarwal & Pandey, 2004). The hurdles faced by members of such virtual teams are in three key areas**:** **(i)** differences in concepts and terminologies used by the different teams; (ii) differences in understanding the problem domain under consideration; and (iii) differences in training, knowledge, and skills that exist across the teams (Chang, Dillon, Sommerville, & Wongthongtham, 2006). These reasons provide some of the basis for the delineation of new architectural approaches

that can normalize knowledge and provide reusable artifacts in a knowledge repository.

This article focuses on the issue of providing information systems agility, especially when the work is outsourced from one country (or company) to another or as the work is performed in multiple countries using a hybrid offshoring model such as the 24-Hour Knowledge Factory concept (Gupta, Seshasai, Mukherji, & Ganguly, 2007). This article also deals with the issue of creating an evolving knowledge repository that can be used when systems need to be redesigned or reimplemented.

RELATED WORK

The object management group (OMG) is actively involved in the creation of a heterogeneous distributed object standard. In a departure from modeling standards, such as the common object request broker architecture (CORBA) and the related data distribution service (DDS), OMG moved towards the unified modeling language (UML) and the related standards of meta-object facility (MOF), XML data interchange (XMI), and query views transformation (QVT). The latter standards provide a foundation for the model drive architecture (MDA). In an effort to bring UML and the Semantic Web together, OMG is leading progress toward the ontology definition metamodel.

More specifically, MDA, as related to software engineering, composes a set of guidelines for creating specifications structured as models. In MDA, the functionality is defined using a platform-independent model with a domain-specific language. The domain specific language definition can be translated into platform-specific models by use of a platform definition model (PDM). The ontology definition metamodel is an OMG specification that links common logic and OWL/RDF ontologies with MDA. Common logic being an ISO standard for facilitating the exchange of knowledge and information in computer-based systems, and resource description framework (RDF) and Web ontology language (OWL) being the latest examples of framework and related markup languages for describing resources authored by the World Wide Web Consortium (W3C). OMG and W3C standards are available online at omg.org and w3.org, respectively.

The notion of reuse of knowledge has been previously explored with respect to organizational memory systems. Markus (2001) identified distinct situations in which reuse arose according to the purpose of knowledge reuse and parties involved. The knowledge reuse situations exist among producers who reuse their own knowledge, those who share knowledge, novices seeking expert knowledge, and secondary knowledge miners. The solutions to the problems of meeting the requirements of knowledge storage or retrieval were presented as a combination of incentives and intermediaries.

In the context of allocation of IT resources, O'Leary (2001) conducted a case study of a knowledge management system of a professional service firm concluding that service-wise requirements for knowledge reuse should impact the design of knowledge systems. For example, the studied firm contained three primary service lines: tax, consulting, and audit. Differential reuse, stemming from the relatively low reuse in the consulting service line to high reuse in the tax line, leads to a particular allocation of knowledge bases, software, hardware, and network resources. O'Leary's paper supports earlier work by Vanwelkenhuysen and Mizoguchi (1995), which showed that knowledge reuse has depended on organizational aspects of knowledge systems. Their work suggested dimensions along which ontologies for knowledge reuse may be built, based on workplace-adapted behaviors.

The concept of knowledge reuse and agility is especially relevant to "follow the sun" models, similar in spirit to the 24-Hour Knowledge Factory, and have been attempted by others. Carmel

(1999, pp. 27-32) describes one such project at IBM. In this project, IBM established several offshore centers in a hub-and-spoke model where the Seattle office acted as the hub. Each offshored site was staffed by a phalanx, a mix of skill sets that were replicated across each spoke. Work would be handed out by the Seattle hub; each spoke would accomplish the given task and send the results back to Seattle. This hub-and-spoke model necessitates specialization of the Seattle site. With only one site offering the specialized service, the Seattle site quickly became overwhelmed. The original goal of daily code drops could not be maintained.

Treinen and Miller-Frost (2006) highlight several lessons learned that are echoed in other studies, particularly problems with continuity, misunderstanding and the lag time between cycles of conversation. Cultural differences are also cited as being problematic, especially with respect to various assumptions that were held in lieu of well specified requirements and planning.

Perhaps the most relevant study in respect to the 24-Hour Knowledge Factory, *Follow the Sun: Distributed Extreme Programming Development* (Yap, 2005) describes a globally distributed, round-the-clock software development project. Here, a programming team was distributed across three sites (United States, United Kingdom, and Asia). One of the three sites had prior knowledge of extreme programming. The two remaining sites were coached on extreme programming practices prior to the collaboration. These two sites believed that the first site had an advantage due to its previous knowledge with extreme programming. Individuals from the three sites also met in person, which helped to build confidence about the capabilities of the members of other sites. The team used virtual network computing (VNC) and video conferencing to facilitate communication. Hand-off of project artifacts initially consisted of a daily work summary, but later grew to include knowledge learned and new objectives.

Xiaohu, Bin, Zhijun, and Maddineni (2004) discussed the situation where development teams were dispersed globally, though it seemed that each global unit was still responsible for its own module of the project. The teams did not need to discuss development decisions with each other unless they were related to interfacing or would affect another team. They used the extreme programming method, but because of the global dispersal of teams, they lacked the benefits of customer colocation and participation. They thought the inability to get rapid customer feedback when the customer was in a different location adversely impacted the development of the product and the development time. These issues could easily impact development in a 24-Hour Knowledge Factory setting because customers in one location would thus not be able to interact with all sites.

The above examples highlight the need for an agile knowledge ontology that can more adequately manages the problem of change.

AGILITY AND THE PROBLEM OF CHANGE

Change is difficult, complex, and risky because it usually has unintended side effects. Each decision has many consequences, which in turn have many more. The Y2K problem is a classic example of a seemingly innocuous design decision that snowballed into a worldwide problem. The decision to use a 2-digit representation of the year was originally deemed to be prudent. Later, it was thought to be a problem that would cripple computer systems when their clocks rolled over into the year 2000, since 00 is ambiguous. Ultimately, it cost the world around $600 billion (López-Bassols, 1998) to convert a 2-digit representation of the calendar year to four digits!

Fundamental Computing Technologies

Figure 1 shows the evolution of computing technology as researchers sought to tackle the problem of change and to remain agile though increasingly more complex demands are placed upon the technology.

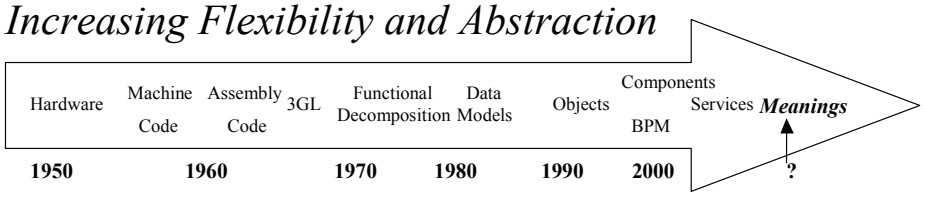
At the far left end of the spectrum lies hardware, originally physically and meticulously programmed to perform relatively simple tasks. Machine code replaced the physical machine programming by the formulation of CPU-specific words, bit patterns corresponding to different commands that can be issued to the machine. Each type of CPU has its own machine code. Similarly, the CPU architecture has a corresponding assembly language. As such, assembly language is not portable and does not increase flexibility, but it does provide the essential abstractions that free the programmer from the tedium of remembering numeric codes or calculating addresses (as was the case when programming was accomplished through machine code). An assembly language is an example of a second-generation language. Third generation languages, denoted by 3GL in Figure 1, finally freed the task of programming from the underlying hardware. This is a much overlooked, but crucial, example of adapting technology to find a solution to the problem of change.

The more recent notion of component-based development (CBD) involves building software systems using prepackaged software components (Ravichandran, 2005). CBD involves reusing application frameworks, which provide the architecture for assembling components into a software system. Components and frameworks may be either developed in-house or externally procured. CBD typically involves using both in-house developed and externally procured software components and frameworks. CBD leverages the emergence of middleware and software objects standards to make software reuse a reality (Ravichandran, 2005). Since CBD encourages the move toward more modular systems built from reusable software artifacts, it was expected to enhance the adaptability, scalability, and maintainability of the resultant software (Szyperski, 1997). CBD requires systems to be architected using a component framework necessitating developers to think through the interrelationships between various elements of an application system at a more granular level at an earlier stage in the development process than in traditional development approaches (Sparling, 2000).

IBM's System/360: The Beginnings of Agile Development

A good example of a business transformation tackling the issues of agility and change through modularity is provided by IBM's System/360 (Amdahl & Blaauw, 2000) in the 1960s (Baldwin & Clark, 2000). The hardwired instruction sets of virtually all computers in the 1950s imposed a high level of interdependence of design parameters. Each computer was designed from scratch and each market niche was matched with

Figure 1.



a different system. Searching for new ways for teams to work together on a project, IBM led the effort to use modularity as a guiding principle. System/360 was the result of that effort. Further, System/360 marks the point at which the industry was transformed from a virtual monopoly to a modular cluster comprised of more than a thousand publicly traded firms and many startups (Fergusson, 2004).

What makes System/360 an important landmark in the agility effort is that it belongs to the first family of computers that was designed with a clear distinction between architecture and implementation. The architecture of each model in the 360 family was introduced as an industry standard, while the system peripherals, such as disk drives, magnetic tape drives, or communication interfaces allowed the customer to configure the system by selecting from this list. With the standardization of the architecture and peripheral interfaces, IBM opened the doors for the commodity component market. With its list of peripherals, System/360 allowed the technology to adapt to a customer's needs. Its backward compatibility tackled the problem of change in its own right, by allowing customers to upgrade and replace their hardware without losing essential capabilities. The ideas of encapsulation of functionality and the standardization of system interfaces inherent in System/360 are critical to understanding the importance of leveraging and reuse of knowledge.

BUSINESS RULES AND THE STRUCTURE OF INFORMATION

Just as was the case with early computer technology decades ago, prior to 3GL in our first example and System/360 in the second, today's business rules are replicated in dissimilar formats in intermingled ways in multiple information systems and business processes. When any rule is changed, a concerted effort must be launched to make modifications in multiple systems. It makes change and innovation complex and error-prone. The framework described in this article attempts to untangle business rules with an ontology derived from the inherent structure of information. By untangling business rules even in complex legacy models and systems, one gains the capability to represent specific elements of business knowledge once, and only once, in a knowledge repository. Using this repository, the specific elements of knowledge can be designed to naturally manifest themselves, in appropriate forms, to suit the idiosyncrasies of different business contexts.

As business processes became more tightly coupled with automation, the lack of agility in information systems became a serious bottleneck to product and process innovation. Frameworks that have attempted to solve this problem include structured programming, reusable code libraries, relational databases, expert systems, object technology, CASE tools, code generators and CAPE tools. They were not very effective partially because they did not adequately address the ripple effects of change; ideally, business rules and knowledge should be represented so that when we change a rule once, corresponding changes should automatically ripple across all the relevant business processes (Mitra & Gupta, 2006).

Knowledge transfer and reuse (Kingston 2002; Myopolous 1998; Van Zyl & Corbett, 2000) attain greater importance in the case of outsourcing. In order to achieve efficiency of resource consumption, we need new approaches to facilitate encapsulation of knowledge and the sharing of such knowledge among the relevant set of workers.

THE FRAMEWORK OF KNOWLEDGE REUSE

While meaning and understanding are abstract notions, they are rooted in the physical world. We learned in chemistry that we can continually

subdivide a substance before reaching a building block, the subdivision of which would disallow us from identifying the substance and knowing its properties. Similarly, to identify the components of knowledge, we must distinguish between assertions whose division will involve no loss of information, and assertions whose division will sacrifice meaning: if an assertion is decomposed into smaller parts and the information lost cannot be recovered by reassembling the pieces. The fundamental rules that cannot be decomposed further without irrecoverable loss of information are called indivisible rules, atomic rules, or irreducible facts (Ross, 1997).

Objects, Relationships, Processes, Events, and Patterns

In the real world, every object conveys information. The information content of physical objects is conveyed to us via one or more of our five senses. Objects are associated with one another. While some associations involve the passage of time, other associations, such as the relative locations of physical objects, are relationships that do not necessarily involve time. These relationships and associations are natural storehouses of information about real world objects. Further, these relationships are objects in their own right.

Processes are artifacts for expressing information about relationships that involve the passage of time (i.e., those that involve before and after effects). As such, the process is not only an association but also an association that describes a causative temporal sequence and passage of time. This is also how the meaning of causality is born: The resources and the processes that create the product are its causes. A process always makes a change or seeks information. Business process engineers use the term *cycle time* to describe the time interval from the beginning of a process to its end. A process, like the event it is derived from, can even be instantaneous or may continue on indefinitely. Processes that do not end, or have no known end, are called sagas. Therefore, a process is a relationship, and also an event, which may be of finite, negligible, or endless duration.

Knowledge involves the recognition of patterns. Patterns involve structure, the concept of similarity, and the ability to distinguish between the components that form a pattern. Claude Shannon developed a quantitative measure for information content (Shannon, 1948). However, he did not describe the structure of information. For that, we must start with the concept and fundamental structure of *Pattern* and measurability in order to build a metamodel of knowledge. The integrated metamodel model of Pattern and measurability (from which the concept of "property" emerges) will enable us to integrate the three components that comprise business knowledge (inference, rules, and processes) into one indivisible whole. The interplay between objects and processes is driven by patterns. Patterns guide the creation of relationships between objects, such as the formation of a team or the modular assignment of duties within a team and across geographically distributed teams. Partnering Employee belonging to one team with that of another is caused by a skill or performance pattern that governs the relevant properties of Employee. As such, the ownership of an artifact under development is shared between Employee objects, which, at a coarser granularity, exist as a unified object we can refer to as a Composite Persona (CP) (Denny et al., 2008).

Perception and Information: Meaning, Measurability, and Format

When an object is a meaning, it is an abstract pattern of information. Its perception is a concrete expression of this meaning, and the same information may be perceived or expressed in many ways. Lacking perceptual information, several expressions or perceptions may all point to the same pattern of information, or meaning. In order to normalize

knowledge, we must separate meaning from its expression. This may be done by augmenting our metamodel to represent entities of pure information that exist beyond physical objects and relationships. This section will introduce three of these objects: domain, unit of measure (UOM), and Format.

Unlike matter or energy, meaning is not located at a particular point in space and time; only its expression is (Verdu, 1998). All physical objects or energy manifested at a particular place at a point in time convey information, and the same meaning can occur in two different artifacts that have no spatial or temporal relationship with each other. They only share meaning (i.e., information content; Baggot, 1992). A single meaning may be characterized by multiple expressions. Differing understandings of concepts, terminology, and definitions are some of the problems that have characterize software developers working in a multisite environment **(Chang et al., 2006).** Unlike a specific material object or a packet of energy that is bound to only a single location at a single point in time, identical information can exist at many different places at several different times. The need to understand the underlying natural structures that connect information to its physical expressions is inherent in the effort to normalize business rules.

Information mediation and expression within the real world is achieved by two metaobjects. One is intangible, emerging from the concept of measurability and deals with the amount of information that is inherent in the meaning being conveyed. The other is tangible; it deals with the format, or physical form, of expression. The format is easier to recognize. It is much harder to recognize the domain of measurability, henceforth referred to simply as domain (Finkbeiner, 1966).

Measurability and Information Content

Through the behavior, or properties, of objects we observe, the information content of reality manifests itself to us. Although these are quite dissimilar qualities of inherently dissimilar objects, such as a person's weight and the volume of juice, both these values are drawn from a domain of information that contains some common behavior. This common behavior, that each value can be quantitatively measured, is inherent in the information being conveyed by the measurement of these values, but not in the objects themselves.

Physical Expression of Domains

Domains convey the concepts of measurability and existence. They are a key constituent of knowledge. There are four fundamental domains that we will consider in this article; two of them convey qualitative information and the other two convey quantitative information, as follows:

- Qualitative domains, containing:
  - Nominal Domains, which convey no information on sequencing, distances, or ratios. They convey only distinctions, distinguishing one object from another or a class from another.
  - Ordinal domains, which convey distinctions between objects and the information on arranging its members in a sequence. Ordinal domains are a pattern of information derived from nominal domains by adding sequencing information. However, ordinal domains posses no information regarding the magnitudes of gaps or ratios between objects (values).
- Quantitative domains:
  - Difference-scaled domains not only express all the information that qualitative domains convey, but also convey magnitudes of difference; they allow for measurement of the magnitude of point-to-point differences in a sequence. This makes difference-scaled domains to be a pattern of information derived from ordinal domains by adding quantitative information on differences between

values in the domain, which makes it a subclass of ordinal domains in the ontology of the meaning of measurability.

- Ratio-scaled domains perform three functions; they assist in the classification and arrangement of objects in a natural sequence, are able to measure the magnitude of differences in properties of objects, and take the ratios of these different properties.

The hierarchy of domains provides the most fundamental kind of knowledge reuse. However, this information is still abstract. In order to give information a physical expression, it must be physically formatted and recorded on some sort of medium. A single piece of information must be recorded on at least one medium, and may be recorded in many different formats.

A symbol is sufficient to physically represent the information conveyed by nominal and ordinal domains. Of course, ordinal domains also carry sequencing information, and it would make sense to map ordinal values to a naturally sequenced set of symbols like digits or letters.

Unlike qualitative domains, quantitative domains need both symbols and units of measure to physically express all the information they carry. This is because they are dense domains (i.e., given a pair of values, regardless of how close they are to each other, it is always possible to find a value in between them). A discrete set of symbols cannot convey all the information in a quantitative domain. However, numbers have this characteristic of being dense. Therefore, it is possible to map values in a dense domain to an arbitrary set of numbers without losing information. These numbers may then be represented by physical symbols such as decimal digits, roman numerals, or binary or octal numbers. There may be many different mappings between values and numbers. For example, age may be expressed in months, years, or days; a person's age will be the same regardless of the number used. To show that different numbers may express the same meaning, we need a unit of measure (UOM). The UOM is the name of the specific map used to express that meaning. Age in years, days, months, and hours are all different UOMs for the elapsed time domain.

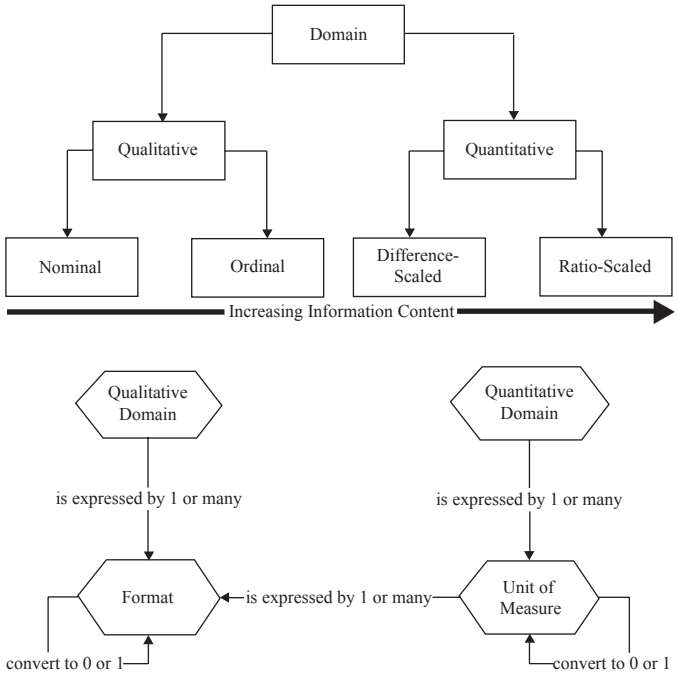
Both the number and UOM must be physically represented by a symbol to physically format the information in a quantitative domain. Indeed, a UOM may be represented by several different symbols. The UOM "dollars," for the money domain, may be represented by the symbol "$" or the text "USD." In general, a dense domain needs a pair of symbols to fully represent the information in it: a symbol for the UOM and a symbol for the number mapped to a value. We will call this pair the full format of the domain.

Domains, UOMs, and Formats are all objects that structure meaning. They are some of the components from which the very concept of knowledge is assembled. The metamodel of knowledge is a model of the meaning of knowledge built from abstract components.

Figure 2 depicts a semantic model. The lower limit (1) on the occurrence of Unit of Measure highlights the fact that each quantitative domain must possess at least one unit of measure. This is because the unit of measure is not optional. A quantitative value cannot be expressed unless a unit of measure can characterize it. The arrow that starts from, and loops back to, Unit of Measure reads "Unit of Measure converts to none or at most 1 Unit of Measure." Conversion rules, such as those for currency conversion or distance conversion, reside in the Metamodel of Knowledge. This relationship provides another example of a metaobject (since relationships are objects too), and demonstrates how a metaobject can facilitate the storage of the full set of conversion rules at a single place.

The conversion rule is restricted to conversion from one UOM to only one other UOM; this constraint is necessary to avoid redundancy and to normalize information. A single conversion

Figure 2. A partial metamodel of domain



rule enables navigation from one UOM to any other arbitrary UOM, by following a daisy chain of conversion rules. The upper bound of one on the conversion relationship in the metamodel also implies that if you add a new UOM to a domain, you have to add only a single conversion rule to convert to any of the other UOMs, and that such information will suffice to enable conversion to every UOM defined for that domain.

Metaobjects, Subtypes, and Inheritance

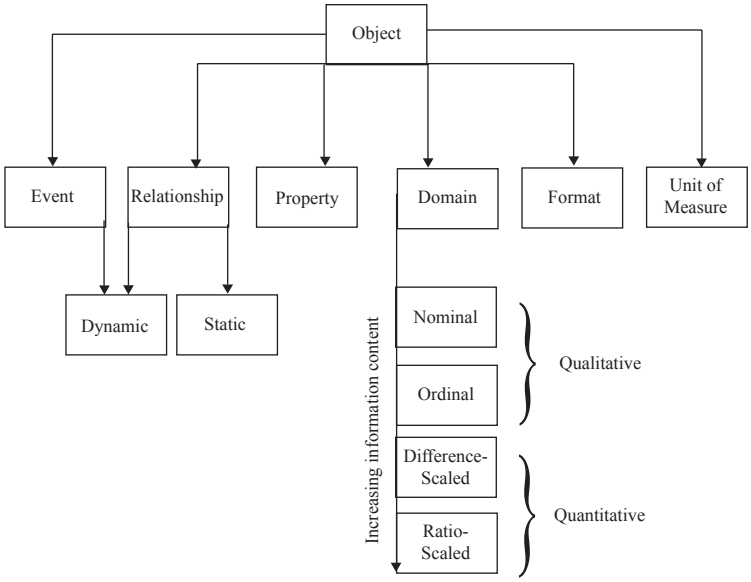
Metaobjects help to normalize real world behavior by normalizing the irreducible facts we discussed earlier. The metaobjects that of interest are object, property, relationship, process, event, domain, unit of measure (UOM), and format. The kinds of atomic rules normalized by each type of metaobject are summarized in Figure 3.

The ontology in Figure 3 organizes objects in a hierarchy of meaning. Lower level objects in the ontology are derived from objects at higher levels by adding information. Figure 3 shows that the meaning of *process* is configured by combining the meanings of *relationship,* an interaction between objects, with the meaning of *event,* the flow of time. This kind of relationship is special. It is called a subtyping relationship and forms the basis of the ontology. Subtyping relationships convey information from higher levels to lower levels of an ontology. The lower level object becomes a special kind of higher level object. Figure 3 shows that ratio scaled domain is a special kind of domain because of the chain of subtyping relationships that lead from Domain to ratio scaled domain via quantitative domain.

The Repository of Meaning

The atomic rule is the most basic building block of knowledge and the ultimate repository of information. It is a rule that cannot be broken into

Figure 3. Basic inventory of metaobjects



smaller, simpler parts without losing some of its meaning. The metaobjects of Figure 3 are the natural repositories of knowledge. They provide the basis of real world meaning. Just as molecules react with molecules in chemical reactions to produce molecules of new substances with different properties from the original reagents, atomic rules may be built from other atomic rules. As we enhance our business positions with product and process innovation, some atomic rules will be reused. These rules are examples of those that can act as reusable components of knowledge. In order to build specialized domains of knowledge, entire structures and configurations may be reused. This is similar to manufacturers creating reusable subassemblies to build machines from ordinary parts. The end product may incorporate many versions and modifications of these reusable subassemblies.

24HrKF: A Practical Application of Knowledge Reuse

Suchan and Hayzak (2001) found that a semantically rich database was useful in creating a shared language and mental models. MultiMind is a collaboration tool under development at the University of Arizona (Denny et al., 2008), aimed at improving upon DiCE (Vin, Chen, & Barzilai, 1993) and other collaborative engineering tools.

A Lifestream database (Freeman & Gelernter, 1996), is a chronologically ordered persistent database, used to collect objects and events relevant to a project. Lifestream incorporates incorporates an algebra that can be coupled to the semantics of project artifacts and knowledge events, allowing substantial opportunity for the automation of mundane tasks and higher level functions. In MultiMind, the Lifestream archives project artifacts and provides configuration management services, in a similar fashion as the Concurrent Versioning System (CVS) or Subversion (SVN) revision control system. In MultiMind, knowledge events are observed and logged into Lifestream. Activities such as reading a message, posting a message, executing a search, or reading a web page, are logged into LifeStream. The correlation of knowledge events with the evolution of project artifacts allows for the reuse of relevant knowledge

between members of a development team. Communication is facilitated by the encapsulation of knowledge as objects which represent interactions with the development environment.

Higher level tasks, such as the visualization of the current state of a project under development or decision facilitation can also be automated. Through MultiMind and its underlying LifeStream, information regarding artifacts and project progress can easily be visualized, identifying the artifacts which required the most maintenance or debugging. This visualization can be used as a guide for business decisions, when queries to MultiMind are filtered to visualize information relevant to a decision.

AN ARCHITECTURE OF KNOWLEDGE

Information systems are built to satisfy business requirements. Sometimes they are undertaken to implement purely technical changes (Smith & Fingar, 2002). Poorly formulated and ill-managed requirements have led to many of the problems that Information Systems projects currently face (Bahill, & Dean, 1999). Our first task, therefore, is to understand the meaning and structure of requirements.

Requirements flow from knowledge. Knowledge is encapsulated in configurations of atomic rules. Knowledge of Information Systems involves configurations of (atomic) rules of business as well as technology. A four-layered hierarchical approach can be used, as depicted in Figure 4.

Table 1 contains brief descriptions of each layer of the architecture of business knowledge, examples of the kinds of policies that may be implemented at the layer, as well as examples of change that may occur in that layer along with examples of the effects of change within a particular layer.

The top business layer helps to assemble components of knowledge into business concepts, such as products, services, markets, regulations, and business practices. Consider a situation where a telephone services provider wishes to integrate cable TV and entertainment media into its business. Such changes in the Business Rules layer will impact business functions and systems functionality, whereas changes to process automation layers alone will impact only availability, timeliness, accuracy, reliability, and presentation of information. Changes in business process automation, in turn, can impose new requirements for performance, reliability and accuracy on technology platforms, which will impact the technology layer.

The level of Business Process Automation is usually changed to leverage information technology or to focus on those processes that create most value while eliminating those of little value. Changes in this layer seldom impact the fundamental business of the firm. For example, the firm could deploy its ordering process on the Web, but not make any fundamental change in the nature of its products, services, or markets. Business Process Automation refers to process innovation and change that leverages information technology.

The technology layer is changed primarily to improve computer performance in terms of speed, cost, reliability, availability or alignment, and support for business process automation.

The fundamental ideas of separating system-specific rules from software implementation, as in the case of 3GL, and separating system architecture and implementation, as in the case of System/360, are even more important today in the context of separating business rules from implementation technologies. The rules related to transporting and presenting the information would belong to the Business Process Automation layers, not the pure business layer. Figure 4 shows that Business Process Automation consists of two layers. The Information Logistics layer is the repository for rules related to the logistics of moving and storing information in files, and the Interface layer is concerned with how this infor-

Figure 4. The architecture of knowledge

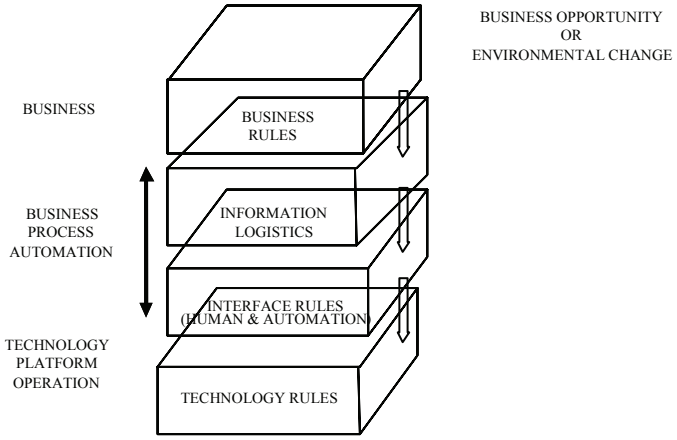


Table 1. Layers of the architecture of knowledge

Layer	Description	Example Policy	Example of Change
Business	Contains assertions about products and services and defines relationships between customers and products or services.	Obtain necessary market freedoms to effectively compete; purchase competitor fixed assets; penetrate untapped markets	Acquisition of new assets necessitates the addition of new relationships between customers and services.
Information Logistics	Contains the repository of rules related to the logistics of storage, transfer, and utilization of business information.	Digital artifacts under development will be stored using a versioning system; artifact access privileges are maintained at a fine granularity	A new employee joins an active team necessitating a change in the rules regarding access to a team-owned artifact.
Interface	Contains the rules for the presentation of business information to human entities.	Access to team-owned objects is controlled by an administrator in close contact with team members; GUI follows Microsoft's Inductive User Interface guidelines.	A new employee joins an active team, necessitating the creation of additional security rules regarding artifact access privileges.
Technology	Contains low-level operational and strategic rules regarding the operation of technology.	Hardware and systems software is standardized through a single reputed vendor.	A change of hardware or systems software vendor necessitates change of legacy software developed for obsolete system.

mation is presented to human operators.

Creating a business knowledge hierarchy such as the one depicted in Figure 4 facilitates the flow of information between the business entities responsible for managing knowledge. Organizing knowledge and information, as described in previous sections, is essential for realizing the flow of information between the layers and creating meaningful and useful relationships between objects within each layer.

Efforts to process and integrate information based on meaning have been made by the W3C consortium, which recommended two modeling standards in 2004: RDF, the Resource Description Framework for metadata, and OWL, the Web ontology language for integrating information. We have seen examples of how some meanings are derived from others by constraining patterns of information they convey to create new meanings. These constrained patterns are subtypes of the meanings they constrain, and every meaning is a polymorphism of the universal object, an unknown pattern in information space that means everything and anything, and conveys nothing. Every object in the inventory of components is a polymorphism of the universal metaobject. RDF and OWL are tailored for the Web and applications of the Semantic Web. Tables 2, 3, and 4 show that the various elements of RDF and OWL as well as their metaobject inventory equivalents, showing that, in effect, the Metaobject Inventory provides a more general framework than either RDF or OWL, and that either of the restricted frameworks are special cases of the types of ontology frame-

Table 2. RDF Classes (retreived from http://www.w3schools.com/rdf/default.asp) and their Metaobject Inventory Equivalents

Element	Class of	Subclass of	Metaobject Inventory Equivalent
Class	All classes		All value
Datatype	All Data types	Class	Domain, Meaning
Resource	All resources	Class	Resource
Container (set of objects)	All Containers	Resource	Aggregate Object
Collection(set membership is restricted by some criteria)	All Collections	Resource	Object Class
Literal	Values of text and numbers	Resource	Subtype of Symbol
List	All Lists	Resource	List of
Property	All Properties	Resource	Property, Feature
Statement	All RDF Statements	Resource	Irreducible fact, rule, atomic rule
Alt	Containers of alternatives	Container	Mutability; Liskov's principle, aggregation of mutable resources
Bag	Unordered containers	Container	Aggregate Object
Seq	Ordered containers	Container	Subtype of Aggregate Object
ContainerMembershipProperty	All Container membership properties	Property	Subtype of Relationship
XMLLiteral	XML literal values	Literal	Subtype of symbol. XML is a subtype of language.

Table 3. RDF properties (retrieved from http://www.w3schools.com/rdf/default.asp) and their metaobject inventory equivalents

Property	Operates on	Produces	Description	Metaobject Inventory Equivalent
Domain	Property	Class	The domain of the resource The domain defines what a property may apply to (operate on).	Domain
Range	Property	Class	The range of the resource. It defines what the property may map to (produce).	co-domain
subPropertyOf	Property	Property	The property of a property	Feature
subClassOf	Class	Class	Subtyping property	Polymorphism
Comment	Resource	Literal	User friendly resource description	Elaboration, description, synonym
Label	Resource	Literal	User friendly resource name	Name, synonym
isDefinedBy	Resource	Resource	Resource definition	Id
seeAlso	Resource	Resource	Additional information about a resource	Elaboration, reference
Member	Resource	Resource	The property of being an instance of a kind of resource	Instance of
First	List	Resource	The property of being the first member of a list	A demiliting role: Lower Limit
Rest	List	List	The second and subsequent members of a list	Subtype of List
Subject	Statement	Resource	The subject of an assertion, i.e., the subject of a resource in an RDF statement	The source of a relationship
predicate	Statement	Resource	Similar to "subject": The predicate of an assertion	Relationship, function
object	Statement	Resource	The object of the resource (in an RDF) Statement	The target of a relationship
value	Resource	Resource	The value of a property	Value
Type	Resource	Class	An instance of a class	Member of a class of classes

works that can be realized through the various polymorphisms of the universal object.

CONCLUSION

In an effort to provide a framework for surmounting the temporal and spatial separations in collaborative, distributed environments, this article presented a framework for knowledge object management that can facilitate reuse of knowledge. The encapsulation of knowledge for distributed environments is also highlighted. The knowledge encapsulation uses a four-tier architecture that facilitates knowledge transfer and reuse, as well as enables better understanding of the problem domain under consideration. Differences in training, knowledge, and skills that exist across the distributed teams can be surmounted by use of a

Table 4. OWL dlasses (retrieved from: http://www.w3.org/TR/owl-ref/) and their metaobject inventory equivalents

Class	Description	Metaobject Inventory Equivalent
AllDifferent	all listed individuals are mutually different	Subtype of Exclusion partition, exclusivity constraint. The concept of distinctions emerges as a polymorphism of the concept of class as information is added o an object/pattern.
allValuesFrom	All values of a property of class X are drawn from class Y (or Y is a description of X)	Domain, Inclusion Set, inclusion partition
Annotation-Property	Describes an annotation. OWL has predefined the following kinds of annotations, and users may add more: • Versioninfo • Label • Comment • Seealso • Isdefinedby OWL DL limits the object of an annotation to data literals, a URI, or individuals (not an exhaustive set of restrictions	Subtypes of Elaboration Version is implicit in temporal objects. Audit properties are implicit in object histories: • The process, person, event, rule, reason and automation that caused a state to change • Time of state change • Who made the change (all the dimensions of process ownership: Responsibility, Authority, Consultation, Work, Facilitation, Information/ knowledge of transition) • When the change was made • The instance of the process that caused the change and the (instances of resources) that were used • Why it was made (the causal chain that led to the process) • How long it took to make the change Label is implicit in synonym, name Comment may be elaboration or reference. The two are distinct in the metamodel of knowledge See also: same remarks as comment. IsDefinedBy may be elaboration, Object ID, or existence dependency. Each is a distinct concept in the metamodel of knowledge
backwardCompatibleWith	The ontology is a prior version of a containing ontology, and is backward compatible with it. All identifiers from the previous version have the same interpretations in the new version.	Part of Relationship between models or structures
cardinality	Describes a class has exactly *N* semantically distinct values of a property (*N* is the value of the cardinality constraint).	Cardinality
Class	Asserts the existence of a class	Object Class
complementOf	Analogous to the Boolean "not" operator. Asserts the existence of a class that consists of individuals that are NOT members of the class it is operating on.	Set negation, Excludes, Exclusion set, Exclusion partition

continued on following page

Table 4. continued

Class	Description	Metaobject Inventory Equivalent
DataRange	Describes a data type by exhaustively enumerating its instances (this construct is not found in RDF or OWL Lite)	Inclusion set, exhaustive partition
DatatypeProperty	Asserts the existence of a property	Feature, relationship with a domain
DeprecatedClass	Indicates that the class has been preserved to ensure backward compatibility and may be phased out in the future. It should not be used in new documents, but has been preserved to make it easier for old data and applications to migrate to the new version	Interpretation. However, the specific OWL interpretation of depreciated class is considered to be a physical implementation of a real life business meaning, outside the scope of a model of knowledge that applies on the plane of pure meanings.
DeprecatedProperty	Similar to depreciated class	See Depreciated Class
differentFrom	Asserts that two individuals are not the same	The concept of distinctions emerging as a polymorphism of the concept of class as information is added o an object/pattern.; subtype of exclusion partition
disjointWith	Asserts that the disjoint classes have no common members	Exclusion partition
distinctMembers	Members are all different from each other	Exclusion Set, List
equivalentClass	The classes have exactly the same set of members. This is subtly different from class equality, which asserts that two or more classes have the same meaning (asserted by the "sameAs" construct). Class equivalence is a constraint that forces members of one class to also belong to another and vice versa.	Mutual inclusion constraint/equality between partitions or objects.
equivalentProperty	Similar to equivalent class: i.e., different properties must have the same values, even if their meanings are different (for instance, the length of a square must equal its width).	Equality constraint
FunctionalProperty	A property that can have only one, unique value. For example, a property that restricts the height to be nonzero is not a functional property because it maps to an infinite number of values for height.	Value of a property, singleton relationship between an object and the domain of a property
hasValue	Links a class to a value, which could be an individual fact or identity, or a data value (see RDF data types)	relationship with a domain
imports	References another OWL ontology. Meanings in the imported ontology become a part of the importing ontology. Each importing reference has a URI that locates the imported ontology. If ontologies import each other, they become identical, and imports are transitive.	Subtype of Composed of. Note that the metamodel of knowledge does not reference URIs. This is an implementation specific to the Web. The Metamodel of Knowledge deals with meanings.

continued on following page

Table 4. continued

Class	Description	Metaobject Inventory Equivalent
incompatible-With	The opposite of backward compatibility. Documents must be changed to comply with the new ontology.	Reinterpretation, Intransitive Relationship, asymmetrical relationships
intersectionOf	Similar to set intersection. Members are common to all intersecting classes.	Subtype of Partition, subtype with multiple parents, set intersection
InverseFunctionalProperty	Inverses must map back to a unique value. Inverse Functional properties cannot be many-to-one or many-to-many mappings	Inverse of an injective or bijective relationship
inverseOf	The inverse relationship (mapping) of a property from the target (result) to the source (argument)	Inverse of
maxCardinality	An upper bound on cardinality (may be "many", i.e., any finite value)	Cardinality constraint:, upper bound on cardinality (subtype of cardinality constraint and upper bound)
minCardinality	A lower bound on cardinality	Cardinality constraint: Lower bound on cardinality (subtype of cardinality constraint and lower bound)
Nothing	The empty set	of the empty set, null value
ObjectProperty	Instances of properties are not single elements, but may be subject-object pairs of property statements, and properties may be subtyped (extended). ObjectProperty asserts the existence and characteristics of properties: • RDF Schema constructs: rdfs:subPropertyOf, rdfs:domain and rdfs:range • relations to other properties: owl:equivalentProperty and owl:inverseOf • global cardinality constraints: owl:FunctionalProperty and owl:InverseFunctionalProperty • logical property characteristics: owl:SymmetricProperty and owl:TransitiveProperty	Property, a generalized constraint, which implies an information payload added to a meaning.
oneOf	The only individuals, no more and no less, that are the instances of the class	members of a class, the property of exhaustivity of a partition
onProperty	Asserts a restriction on a property	constraint on a Feature (makes the feature (object) a subtype of the unconstrained, or less constrained feature (object)
Ontology	An ontology is a resource, so it may be described using OWL and non-OWL ontologies	The concept of deriving subclasses by adding information to parent classes
OntologyProperty	A property of the ontolology in question. See imports.	None, beyond the fact that the ontologoly is an object, which means that it inherits all properties of objects, and adds the property of interpretation

continued on following page

Table 4. continued

Class	Description	Metaobject Inventory Equivalent
priorVersion	Refers to a prior version of an ontology	An instance of Object Property where a relevant instance of ontology Object Class exists, containing a Temporal Succession of concepts. The property of reinterpretation is implicit between versions of an ontology.
Restriction	Restricts or constrains a property. May lead to property equivalence, polymorphisms, value constraints, set operations, etc.	Rule Constraint
sameAs	Asserts that individuals have the same identity. Naming differences are merely synonyms	Set Equality, Identity
someValuesFrom	Asserts that there exists at least one item that satisfies a criterion. Mathematically, it asserts that at least one individual in the domain of the "SomeValuesFrom" operator that maps to the range of that operator.	Subsetting constraint
SymmetricProperty	When a property and its inverse mean the same thing (e.g., if Jane is a relative of John, then John is also a relative of Jane)	Symmetry
Thing	The set of all individuals.	Instance of Object Class
TransitiveProperty	If A is related to B via property P1, and B is related to C via property P2, then A is also related to C via property P1. For example. If a person lives in a house, and the house is located in a town, it may be inferred that the person lives in the town because "Lives in" is transitive with "Located in".	Transitive Relationship
unionOf	Set union. A member may belong to any of the sets in the union to be a member of the resulting set	offset Union, Aggregation
versionInfo	Provides information about the version	Instance of Attribute. Implicit in the concept of the history of a temporal object

common means of discourse about the problem domain under consideration.

For Further Reading

The concepts described here have been utilized and extended in this article to cater specifically to the special needs of offshoring and 24-Hour Knowledge Factory environments. For a detailed discussion of the basic concepts and their wider applications, please refer to the following books by Amit Mitra and Amar Gupta:

- *Agile Systems with Reusable Patterns of Business Knowledge—a Component Based Approach* (Artech House Press, Norwood, Massachusetts)
- *Creating Agile Business Systems with Reusable Knowledge* (Cambridge University Press, Cambridge, England)
- *Knowledge Reuse and Agile Processes—Catalysts for Innovation* (IGI-Global, Hershey, Pennsylvania [in press])

REFERENCES

Aggarwal, A., & Pandey, A. (2004). Offshoring of IT services—Present and future. *Evalueserve.* Retrieved from http://www.evalueserve.com

Amdahl, G. M., Blaauw, G. A., & Brooks, F. P., Jr. (2000). *Architecture of the IBM System/360.* Retrieved November 12, 2007, from http://www.research.ibm.com/journal/rd/441/amdahl.pdf

Baggot, J. (1992). *The meaning of quantum theory.* Oxford University Press.

Bahill, A. T., & Dean, F. (1999). Discovering system requirements. In A. P. Sage & W. B. Rouse (Eds.), *Handbook of systems engineering and management* (pp. 175-220). New York: Wiley.

Baldwin, C. Y., & Clark, K. B. (2000). *Design rules, Vol. 1: The power of modularity.* Cambridge, MA: The MIT Press.

Beck, K. (1999). *Extreme programming explained: Embrace change*. Reading, MA: Addison-Wesley.

Boehm, B. (1988). A spiral model of software development and enhancement. *Computer, 21*(5), 61-72.

Blanchard, E.. (2001). Introduction to networking and data communications. *Commandprompt, Inc.* Retrieved from http://www.w3.org/2004/12/rules-ws/paper/105/

Carmel, E. (1999). *Global software teams: Collaborating across borders and time zones*. Upper Saddle River, NJ: Prentice Hall.

Chang, E., Dillon T. S., Sommerville, I., & Wongthongtham, P. (2006). Ontology-based multi-site software development methodology and tools. *Journal of Systems Architecture, 52*(11).

Coleman, G., & Verbrugge, R. (1998). A quality software process for rapid application development. *Software Quality Journal, 7,* 107-122.

Danait, A. (2005). Agile offshore techniques—A case study. In *Proceedings of the IEEE Agile Conference* **(**pp. 214-217).

Denny, N., Mani, S., Sheshu, R., Swaminathan, M., Samdal, J., & Gupta, A. (in press). Hybrid offshoring: Composite personae and evolving collaboration technologies. *Information Resources Management Journa*.

Fergusson, N. (2004, April 12). Survival of the biggest. *Forbes 2000,* p. 140.

Finkbeiner, D. (1966). *Matrices and linear transformations.* Freeman.

Freeman, E., & Gelertner, D. (1996). Lifestreams: A storage model for personal data. *ACM SIGMOD Record, 25*(1), 80-86.

Gupta, A., & Seshasai, S. (2007). 24-hour knowledge factory: Using Internet technology to leverage spatial and temporal separations. *ACM Transactions on Internet Technology, 7*(3).

Gupta, A., Seshasai, A., Mukherji, S., & Ganguly, A. (2007, April-June). Offshoring: The transition from economic drivers toward strategic global patnership and 24-hour knowledge factory. *Journal of Electronic Commerce in Organizations, 5*(2), 1-23.

Kanka, M. (2001). *A paper on semantics*. Berlin, Germany: Institut für deutsche Sprache und Linguistik.

Kingston, J. (2002). Merging top level ontologies for scientific knowledge management. *Proceedings of the AAAI Workshop on Ontologies and the Semantic Web.* Retrieved from http://www.inf.ed.ac.uk/publications/report /0171.html

Kussmaul, C., Jack, R., & Sponsler, B. (2004). Outsourcing and offshoring with agility: A case study. In C. Zannier et al. (Eds.), *XP/*Agile Universe *2004* (LNCS 3132, pp. 147-154). Springer.

López-Bassols, V. (1998). Y2K. *The OECD Observer***,** 214.

Markus, L. M. (2001). Toward a theory of knowledge reuse: Types of knowledge reuse situations and factors in reuse success. *Journal of Management Information Systems, 18*(1), 57-93.

Mitra, A., & Gupta, A. (2005). *Agile systems with reusable patterns of business knowledge.* Artech House.

Mitra, A., & Gupta, A. (2006). *Creating agile business systems with reusable knowledge*. Cambridge University Press.

Myopolous, J. (1998). Information modeling in the time of revolution. *Information Systems, 23*(3-4).

O'Leary, D. E. (2001). How knowledge reuse informs effective system design and implementation. *IEEE Intelligent Systems, 16*(1), 44-49.

Ravichandran, T. (2005). Organizational assimilation of complex technologies: An empirical study of component-based software development. *IEEE Transactions on Engineering Management, 52*(2)

Ross, R. G. (1997). *The business rule article: Classifying, defining and modeling rules.* Database Research Group.

Smith, H., & Fingar, P. (2002). *The next fifty years.* Retrieved from http://www.darwinmag.com/read/120102/bizproc.html

Sparling, M. (2000). Lessons learned through six years of component-based development. *Communications of the ACM, 43*(10), 47-53.

Suchan, & Hayzak. (2001). The communication characteristics of virtual teams: A case study. *IEEE Transactions on Professional Communication, 44*(3), 174-186.

Szyperski, C. (1997). *Component software: Beyond object-oriented programming.* ACM Press.

Treinen J. J., & Miller-Frost, S. L. (2006). Following the sun: Case studies in global software development. *IBM Systems Journal, 45*(4).

Van Zyl, J., & Corbett, D. (2000). Framework for comparing methods for using or reusing multiple ontologies in an application. In *Proceedings of the Eighth International Conference on Conceptual Structures*.

Vanwelkenhuysen, J., & Mizoguchi, R. (1995). Workplace-adapted behaviors: Lessons learned for knowledge reuse. In *Proceedings of KB&KS* (pp 270-280).

Verdu, S. (1998). *IEEE Transactions on Information Theory, 44*(6).

Vin, H. M., Chen, M.-S., & Barzilai, T. (1993). Collaboration management in DiCE. *The Computer Journal, 36*(1), 87-96.

Xiahou, Y., Bin, X., Zhijun, H., & Maddineni, S. (2004, May). Extreme Programming in global software development. *Canadian Conference on Electrical and Computer Engineering, 4*.

Yap, M. (2005). Follow the sun: Distributed extreme programming environment. In *Proceedings of the IEEE Agile Conference* (pp. 218-224).

This work was previously published in Journal of Information Technology Research, Vol. 1, Issue 2, edited by M. Khosrow-Pour, pp. 1-20, copyright 2008 by IGI Publishing (an imprint of IGI Global).