Knowledge Management Tutorial: An Editorial Overview

Antony Satyadas, *Senior Member, IEEE*, Umesh Harigopal, *Member, IEEE*, and Nathalie P. Cassaigne, *Senior Member, IEEE*

***Abstract*—We present a tutorial on knowledge management (KM) and a roadmap of this special issue around the knowledge life cycle. Knowledge management is a discipline that provides strategy, process, and technology to share and leverage information and expertise that will increase our level of understanding, to more effectively solve problems, and make decisions. We address three key views: 1) codification: tacit and explicit knowledge types; 2) various knowledge environments; and 3) cognitive aspects, followed by detailed descriptions of features and technology, and how this capability is being leveraged in forward looking organizations.**

***Index Terms*—Agents, collaboration, communities, e-learning, knowledge management (KM), maturity model, neural networks (NNs), portal, social capital.**

I. Introduction

KNOWLEDGE is "awareness or familiarity" gained by experience [1]. According to Davenport and Prusak [19], "knowledge derives from minds at work." It is the fluid mix of framed experience, values, contextual and actionable information, and expert insight that provides a framework for evaluating and incorporating new experiences and information. Oxford Dictionary's definition of knowledge is "awareness or familiarity gained by experience." Another way to define knowledge is as actionable information. The term "actionable" is used more in a pragmatic sense; not in the sense that one always takes actions based on knowledge.

"X know/has Q knowledge about Y" or

"X know Q how to Z"

where X is a human/machine, Z is typically a verb (decide, solve problem, etc.), and Q is a relative quantifier.

Metrics can be leveraged around the quality, validity, completeness, etc., of knowledge.

Generally as knowledge increases (through learning—really a lower level construct, collaboration, observation) our understanding increases. Thus, there could be X who perceives knowledge as information since X has not gained a sufficiently deep understanding or because it is not yet actionable. This does not mean that knowledge is an object. It will be shown in the upcoming sections how both thematic and categorical knowledge is dynamic, but how the notion of explicit knowledge, in the tacit and explicit view of knowledge, introduces a storage aspect.

Knowledge management (KM) is a discipline that provides strategy, process, and technology to share and leverage information and expertise that will increase our level of understanding to more effectively solve problems and make decisions [1]. KM initiatives have originated from diverse domains such as organizational effectiveness, business management, cognitive science, psychology, philosophy, and leveraging computation. The key here is effectiveness.

Companies such as Texas Instruments have initiated KM projects through quality, reengineering, and best practice projects. Coca Cola and Monsanto have taken the organizational learning route. Accenture and IBM approached this from the e-business technology side, General Motors and the U.S. Army through decision-making projects, and Skandia via accounting related initiatives [19].

More recently, knowledge-enabled customer relationship management (CRM), supply chain management (SCM), enterprise performance management (EPM), and enterprise resource planning (ERP) system vendors have started to incorporate KM capabilities in their solutions [21], [18]. Typical business drivers are as follows:

- capture, store, and retrieve reusable intellectual assets [32], [33];
- the need to quickly find actionable information;
- the need for a better way to leverage the existing creativity within the organization, thereby increasing the rate of innovation;
- decrease in time-to competency; increase in effectiveness and productivity;
- measure and track value and flow of information;
- the ability to determine who is the expert and communicate;
- the need to build highly effective virtual teams and reduce cycle times, as well as better customer relationships;
- the need for a better way to share information and knowledge across organizational boundaries and the ability to rapidly respond to queries or crisis;
- the need to retain the knowledge of experts who are retiring.

There are three key views:

1) environments that nurture and support the evolution of knowledge through its life cycle;
2) cognitive representations of knowledge that really refer to human perception [71];
3) codification that captures the ability to represent knowledge in a tangible form (see Fig. 1).

Manuscript received June 1, 2001; revised October 1, 2001. The ServPrice Project was supported by the EPSRC Grant GR/L40380/01.

A. Satyadas is with IBM Corporation, Cambridge, MA 02142 USA (e-mail: antony_satyadas@us.ibm.com).

U. Harigopal is with J. P. Morgan Chase & Co., New York, NY 10260 USA (e-mail: umesh.harigopal@jpmorgan.com).

N. P. Cassaigne is with the Department of Computaton Dtg., University of Manchester Institute of Science and Technology, Manchester, U.K. (e-mail: n.cassaigne@co.umist.ac.uk).

Publisher Item Identifier S 1094-6977(01)11255-1.

1094–6977/01$10.00 © 2001 IEEE

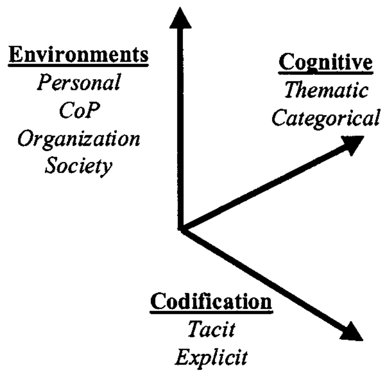

Fig. 1. Knowledge views.

A good example of the cognitive representation is the notion of thematic and categorical knowledge kept in balance by self-regulation [10]. Tacit knowledge can be leveraged through people–people interaction using asynchronous and synchronous collaboration capability [11], [37] as well as through knowledge of affinity of experts to topics. Explicit knowledge is typically captured using innovative techniques such as storytelling [31], rationalized using taxonomy generation technologies and the like, and leveraged through portals that provide a window into the application and content in organizations.

This paper is organized as a tutorial. We will first discuss some of the challenges and required strategies in KM. This will be followed by a deep dive into knowledge environments. The 4-phase knowledge life cycle and the synergy between knowledge and learning solutions and how it nurtures social capital will be explored. Contributions made by the papers in this special issue will be highlighted here. KM features and technologies is the next topic, followed by discussions on "cognizant e-business," the role of computational intelligence, and a methodology for adopting KM, metrics/tracking, security/privacy, and standards. We conclude with a discussion on open problems.

II. Challenges and Strategy

What are the challenges in managing knowledge? Stochastic variability, and the inherently incomplete, imprecise, often asymmetric, and local nature of knowledge along with the transformation management dimension, including trust, and culture contribute to the challenges. Content, people, and systems (applications, infrastructure) with the associated smartness are critical components. Challenges in content include:

a) sheer volume and size;
b) storage—file types and formats, associated standards;
c) inconsistent meta-data;
d) inconsistent meta-data;
e) inconsistent meta-data;
f) multiple languages;
g) dynamic nature in terms of value, updates, and relevance;
h) accuracy and speed of retrieval.

[41]. Additional challenges include serendipity, innovation, navigation, search, and visualization. Challenges in the "people" aspect include the following factors:

a) expertise is subjective;
b) affinity is contextual;
c) real-time access;
d) dynamic relationships and contexts [1].

Strategies for KM should take into consideration these challenges. Key guidelines include

1) leveraging a maturity model [1];
2) emphasis on transformation management recognizing the fact that the technology play is only around 30% [2];
3) addressing knowledge and learning capabilities as part of business processes [21];
4) nurturing communities of practice (CoP) as the knowledge environment that promotes social capital [8];
5) the ability to unearth tacit and explicit knowledge gaps and recommend corrective action [27];
6) emphasis on effectiveness versus efficiencies [39], [40];
7) leveraging complexity [38] and adaptive enterprise guidelines [9];
8) distinguishing between information and KM requirements and capabilities [57];
9) a system view toward return on investment (ROI) and total cost of ownership (TCO) measurements.

In our experience, successful KM strategies depend on top-down and bottom-up stakeholder consent, significant attention to specific organization culture, and addressing this as a whole, in conjunction with the business and learning strategy of the organization.

III. Knowledge Environments

Studies indicate that the knowledge life cycle activities occur in knowledge environments, which are personal, CoP, inter-/intra organization, and society [1].

A. Personal

The focus here is on speedy research, projects, focused conversations, fast comprehension (summary, structure, notation), and personalization around relevant content, filters, and target writing. This requires infrastructure capabilities such as portals, productivity tools, and CoP single sign-on, and personal virtual workspaces.

B. Communities of Practice (CoP)

Research studies [25], [15] indicate that CoP promote voluntary participation and sharing with no formal reporting relationships. The members are not bound by time, deliverables, or who does what. The focus is on ongoing issues. Key requirements include access, membership in multiple CoP, performance, store search and retrieve across multiple CoP, and the ability to mine the knowledge present in these CoP.

C. Inter-/Intra-Organization and Society

At the inter-/intra-organizational level, requirements point toward knowledge networks that connect multiple CoP, teamrooms, intellectual capital management (ICM) systems [32], [33], and virtual workspaces for problem resolution and projects [1].

The society level distinction includes a) public and b) relationship (customer, partner, and vendor) focused.

IV. Knowledge Management Life Cycle

Researchers including Harigopal and Satyadas [1], [57] have been addressing KM technology requirements across its life cycle. We will highlight the key capabilities in this section and also use this to provide a roadmap of the papers in this special issue.

The work of Cross *et al.* contributes to the knowledge creation and sharing aspects of the life cycle. They assess the influence of social context in the form of task (e.g., unit, functional, hierarchical, task interdependence, spatial proximity), and social structural factors (e.g., influence—relations of relative power, trust, friendship, gender) on the choice of the person to go and seek information (based on benefits such as meta-knowledge, problem reformulation, validation of plans or solutions, and legitimation from contact with a respected person), in an organizational setting, using social network analytic methods [quadratic assignment procedure (QAP) used to compute Pearson correlations and multiple regressions].

Harigopal and Satyadas [57] present the cognizant enterprise maturity model (CEMM) that can be used to:

1) calibrate;
2) conduct capability assessment (determine where the organization is currently in terms of their ability to successfully execute KM and related projects);
3) achieve maturity advancement: execute the required steps to move from one level to the other.

The current version of the key maturity areas (KMA) in CEMM focuses primarily on technology. The key process areas (KPA) of people CMM leveraged in CEMM address the culture and transition management aspects. SW-CMM addresses process capability around software development. They leverage fuzzy multicriteria group decision making capabilities to compute relevancy measures for the KMAs [57], [64], [68].

A. Create

New knowledge is created from available knowledge and information via innovative and creative processes. The human processes that produce new knowledge can be individual efforts or collaborative sessions—brainstorming sessions, active research, and serendipity during information retrieval, or day-to-day practice. System-assisted knowledge discovery processes find new patterns in existing information during data or text mining [5], [47]–[50], which could be stored as new knowledge back into the KM system. These steps create explicit knowledge, whereas tacit knowledge is created and honed over a period of time and practice.

Rajagopalan and Isken present the results of their studies using real data from a large tertiary care hospital; how different data preparation methods impact the quality of knowledge discovered (in the form of IF THEN rules) using two data mining techniques: Kohonen's self-organizing map [unsupervised neural network (NN)]and K-means clustering.

Ma *et al.* recognizes E. Coli promoters in DNA sequences (a binary classification problem), by applying a combination of:

1) Bayesian maximum *a posteriori* expectation-maximization algorithm to locate the binding sites of the promoter sequences;
2) aligning the promoters with respect to their binding sites and transcriptional start sites and identify features (35 with high information contents) and represent them based on an orthogonal encoding method;
3) training a fully connected, one hidden layer, artificial neural network (ANN) using a scaled conjugate gradient algorithm to recognize the promoters;
4) evaluating performance using three measures: precision, specificity, and sensitivity.

B. Capture

Explicit knowledge can be captured as it is created and implicit knowledge can be elicited from the sources using questionnaires, interviews, or leveraging a collaborative environment. Knowledge thus gathered can be represented using schemes such as semantic networks, scripts, expert systems, etc. Tacit knowledge, on the other hand, cannot be captured at this stage of the knowledge life cycle but can only be identified as existing in a particular expert's mind. The discovery and availability of such an expert can be codified as a knowledge source [11], [37].

Decision making under constraints and uncertainties poses significant challenges in prediction. In the case of predictive and reactive train scheduling, Isaai and Cassaigne apply KM techniques to transform the tacit knowledge of experts responsible for operational decision making into the explicit knowledge usable for enhancing tactical and operational decision making.

Maluf and Tran [58] address the multidomain data aggregation challenges due to semantic inconsistencies and heterogeneity of representation using "domain algebra" and demonstrate the use of articulation rules to link declarative interfaces (CORBA IDL is used) using a "Mediator" software component. Intersection, union, and difference are the operations applied in this paper. The Mediator is a first-order logic production system built using the CLIPS expert systems tool with the associated pattern matching algorithm, and B-tree indexes. This paper addresses the explicit knowledge dissemination/sharing and organization aspects of the KM lifecycle and the knowledge interoperability challenge.

C. Organize

Information and knowledge captured during the knowledge synthesis processes need to be organized by an appropriate taxonomy for ease of retrieval. A knowledge map (semantic map, taxonomy, topic map, etc.) in addition to aiding the retrieval process helps in human comprehension of the scope and boundaries of available knowledge.

Polikar *et al.* presents

1) an "incremental learning" algorithm [that leverages an ensemble of classifiers (using adaptive boosting algorithm) for later aggregation using a weighted majority voting procedure] for ANN pattern classifiers;
2) results of applying it to several benchmark data (optical digits database, vehicle silhouette database, concentric circles database, gas sensing dataset) as well as real-life tasks;
3) a theoretical upper-error bound.

D. Disseminate/Share

Knowledge created, captured, and organized is ready for distribution via multiple delivery channels. Dissemination includes "pushing" knowledge to its users and users "pulling" the knowledge they need. The range of push mechanisms includes information and knowledge portals, intelligent agents, and recommendation systems. Search engines, knowledge map browsers, and adaptive/inferential information retrieval mechanisms aid users in knowledge pull activities. Proven knowledge that has been used and leveraged upon regularly could be transformed into courses that can be distributed via learning initiatives within the organization [3], [16].

Chen *et al.* presents a domain visualization method capable of providing explicit connections between latent domain knowledge and mainstream domain knowledge. Results are on two cases: 1) growth of Pathfinder network applications and 2) the missing link between two diseases: BSE in cattle and CJD in humans—based on Prion theory. A spiral two-citation-step approach, and generalized similarity analysis techniques are used. KM relies on taxonomies and visual navigation/search of these taxonomies to promote organization and discovery of knowledge. Applications of intelligent agents [76] are required in all stages of managing knowledge, especially during automatic knowledge organization and retrieval. Such agents will interact with the knowledge worker to understand user interest/expertise and present relevant information as well as interact with other knowledge agents in the enterprise to assemble knowledge maps and discover connections. As industry standards evolve around Web services and UDDI, agents will need the autonomy (adjustable by human intervention) to negotiate transactions on behalf of a business or a person.

Hexmoor's paper presents formalism for deriving the autonomy of an agent in the presence of cooperating agents using a belief-desire-intention model. The subsequent stages of utilizing the determined autonomy in utility analysis and selection of an action are also presented. Given the social capital implications of leveraging KM, and the related aspects of culture and change, robust agent models can help us significantly in understanding and providing immediate business value.

V. Features and Technologies

Nine core feature categories for KM and their associated technology enables have been identified:

1) **content:** create, store, deliver, value, manage—aggregate, filter, mine, taxonomy;
2) **portal:** single-signon, integrate, portlets, user interface, personalize, pervasive, search, navigation, context;
3) **collaboration:** synchronous such as instant chat, emeeting, virtual agent, phone, web; asynchronous such as virtual workspace, email [4];
4) **learning:** just-in-time, self-paced, instructor led, learner led, collaborative, face to face [42];
5) **social capital** [8];
6) **expertise:** awareness, affinity value, locate;
7) **communities** [25];
8) **business intelligence:** datawarehouse, analytics;
9) **business integration:** process, application integration, and data aggregation.

Life Cycle	Structured	Unstructured	Tacit
Create Synthesize	Data Mining Modeling	Text Mining Inferential Search Collaboration	Collaboration Awareness Practice
Capture Store	Data Warehouses Workflow	Doc. Repositories Communications Mgmt. Recorded Collaboration	Expert Profiles Story Telling
Organize Integrate	Data Aggregation Integrate structured and unstructured indexing.	Taxonomies Quantitative Mining Highlighting Summarization	Integrated Expert and Knowledge Taxonomies
Disseminate	Ad-Hoc Reports OLAP Personalization	Portals, Personalization Content Mgmt. Collaborative Filtering	Expertise Location
	Intelligent Infrastructure	e-Learning	Smart Agents

Fig. 2. Technology enablers.

Technologies that support these features can be spread across the four knowledge life cycle phases and the types of knowledge, as shown in Fig. 2. Note that structured and unstructured knowledge belongs to the category of explicit knowledge. We will focus on the following specific technologies:

1) hybrid expert systems;
2) personalization—includes profiling and customization;
3) taxonomies/search/knowledge discovery;
4) knowledge metrics;
5) knowledge visualization.

A. Hybrid Expert Systems

Core requirement is to capture the knowledge of experts and translate them into rules and reasoning processes to aid in decision support. Rules range from simple and rigid to complex and vague. Approaches include computational intelligence, case-based reasoning, storytelling, and leveraging CoP [43]–[45], [80].

B. Personalization

Tacit knowledge by definition cannot be captured in a document or knowledge base. Auto and dynamic profiling enables the capture of clues, strengthened by taxonomies; behavioral analysis using logs and clickstream information; mining unstructured data generated using email; memos; documents; and expertise location/profiling. Profiling is the key capability required for personalization (services that match user's tacit and explicit preferences). Examples of these services include headlines, home pages, push mail, banners, mail campaign, discount on related object, and channel choice. Profiling also assists in customization that gives the end user flexibility to choose layout and functional objects.

C. Taxonomies, Search, and Knowledge Discovery

Taxonomy is defined as a set of ordered groups or categories. Measurable benefits of taxonomy include:

1) effective information reuse;
2) better organization and improved quality of information;
3) full text search.

Ontology is an explicit specification of a conceptualization. Conceptualization is the formal structure of reality as perceived and organized by an agent, independent of the vocabulary used and

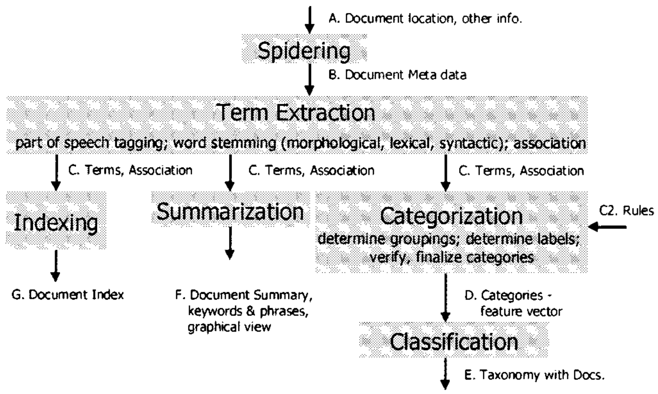

Fig. 3. Taxonomy generation.

the actual occurrence of a specific situation [53]. Recent efforts in the area of "semantic web" [77], [78] portray interesting possibilities in adding smartness through meaning and relationships.

With approximatley 80% of corporate data being unstructured (in emails and documents), classifying these against suitable categories helps to create mental models of information (see Fig. 3). It also helps to navigate and search this information, thereby promoting innovation and knowledge discovery through a very dynamic, interactive, and iterative experience. Text mining [50] is the core technology with related capabilities such as clustering based on vector math, support vector machines (SVMs) [61], [62], rule-based, catalog-by-example, examining document structure, vertical vocabularies, machine learning, pattern analysis [63], term extraction, summarization [48], categorization, indexing, similarity measures, classification, and natural language processing [52], [60].

Challenges in this area include

1) **processing:** right training set; incremental delta only versus real-time; new categories; automation versus manual tagging; performance implications versus currency; and scalability;
2) **multicategorization:** vertical taxonomies, personalization, aggregation, rationalization, and import/export;
3) **syntactic:** number of documents per category; number of subcategories per category; depth (three levels?);
4) **semantic:** choosing the appropriate criteria;
5) **learning:** generalization versus memorization.

Key metrics include accuracy (number of tokens that represent a topic), precision, recall, granularity, coherency (every taxonomy level more specific than its parent), well-formedness, relevance, availability (what if the document gets deleted), and maintenance.

The emerging area of digital rights management including copyright protection (encryption, tracking, digital watermarks), distribution, usage of, and payment (metering) for digital content, bring together multiple channels and take organization of knowledge to new levels of maturity [75].

Searching capabilities include multiterm free text search, refinement within a category, "find more like this," document ranking, thesaurus, filtered document search, Boolean and extended syntax, and expert syntax. Systems that link taxonomy to expertise and CoP can leverage these searching capabilities to generate valuable query results. Federated searching capabilities can be extended to address structured and unstructured information searches with appropriate query result consolidation.

D. Knowledge Metrics

The value of knowledge is a key factor in measuring its timeliness and relevance. The value of knowledge changes based on the context of a decision-making or a problem solving process. This value can only be inferred from knowledge, its consumption, the social capital, and the context.

E. Knowledge Visualization

Knowledge visualization techniques go beyond taxonomies, maps, and being able to determine where the action is in a CoP or a chat room, to incorporating time sensitive relevance, relationships, and the ability to apply diverse personalized metaphors.

VI. Knowledge and Learning

Knowledge and learning is like the yin and the yang [1]. Pedagogy options include learner centric, instructor centric, problem-based learning, and communities. The implications of being a "learning organization" have been studied in detail by several researchers [10], [16], [26], [27], [30], [36]. IBM uses a four-tier learning model [42] that allows for just-in-time (e.g., Webinars), self-paced (e.g., CBT, simulations), collaborative (e.g., virtual classrooms), and face to face (e.g., instructor led in class training) learning. The content ranges from FAQs, virtual help desk dialogs, presentations, catalogs, expert systems, advanced search results, syndicated content, email, navigation output, synchronous and asynchronous collaboration results, and webinars, to structured course material. The challenge here is in being able to capture nuggets of new knowledge and making it available for the learner to leverage based on the appropriate learning model and pedagogy. Standards play a key role in winning this challenge.

VII. CoP Nurtures Social Capital

Social capital is the value created by maintaining and sustaining inter-/intra-organizational relationships [2], [8]. As discussed earlier, studies indicate that CoP nurtures social capital. Key metrics include connections (ties between people, the ability to evaluate, identify, and contact experts), relations (interpersonal dynamics including network, trust, and the ability to share knowledge), context, causality reliable and complete content, and the ability to be adaptive [9], [38]. Several organizations have started to report their social capital in addition to their financials to their shareholders.

VIII. Cognizant E-Business

Cyberspace economy is imposing unique demands on strategies for leveraging KM capabilities in the e-business. The observed dynamics of the dot coms, the changing profile of a knowledge worker, and the pervasive and distributed nature of the marketplace present an emerging paradigm: the cognizant enterprise [21], [57]. Cognizant means mindful, knowledgeable, perceptive, or conscious. It promotes leveraging shared knowledge exchanges with increasing smartness, and driving creativity by nurturing communities conducive for tacit–tacit exchanges. The competitive edge would then be maintained by how well the workers are able to apply the knowledge. The emphasis shifts to their ability to maintain real options and make just-in-time decisions. There are Nno surprises here, considering the traits of a sense and respond organization, an adaptive, self-organizing, and organic enterprise. The challenge shifts from transforming the nonshare mindsets to employee/partner pervasive self-enablement: nothing but a combination of categorical and ongoing learning.

The cognizant enterprise is a live community of the minds, nimble in execution. The workforce is virtual and the level of automation is a direct function of the domain/industry. Employee loyalty is defined separately. Critical success factors include the ability to make decisions amidst uncertainty and imprecision.

Identified knowledge environments sets the stage for evolving more effective business innovation, business integration, and intelligent infrastructure capabilities. Key characteristics include the following:

1) effective relationships drive transactions;
2) multicross-channel, client agnostic;
3) pervasive, open standards, self-enablement, frameworks;
4) self-organizing [design for change: $d = f(c)$];
5) knowledge, learning, and thought flows [79];
6) leveraging business integration, business innovation, and smart business process modeling, and adaptability.

Identified touch points for KM processes, technology, and products to augment e-business capabilities include business rules, business processes, personalization, adaptive marketing, knowledge-base, catalogs, CoP, portals, problem resolution, and decision making. Vertical solutions are industry specific. Market adaptive pricing technology from KSS is a good example of leveraging core knowledge and applying it to telecommunication, petroleum, and retailing domains [54], [69].

Another example is the elicitation, representation, and processing of tacit knowledge from sales and marketing teams through a hybrid system (ServPrice) with the objective to optimize profit in bidding situations. On average it was demonstrated that a 10.5% increase in profit could be obtained while retaining the same possibility of winning a bid as with the original prices. Similarly on average a 49% increase in the likelihood of winning a bid could be obtained compared to control cases while retaining the same or greater profit. As shown by these results, a successful elicitation of tacit knowledge has the potential to bring substantial improvement in the overall bidding performance and profitability of a company [69], [70].

IX. Computational Intelligence

Computational intelligence techniques include hybrids of soft computing capabilities such as fuzzy systems, ANNs, evolutionary algorithms (EAs), and chaos theory. KM solutions leverage these techniques for addressing learning, search, prediction, evaluation, control, and reasoning challenges. Pattern recognition (categorization, classification) [63], semantic analysis, software agents, and causal reasoning are critical. Popular techniques include k-means fuzzy clustering, self-organizing maps [59], [60], Hopfield, SVM [62], feed forward ANNs with back-propagation, Hebbian learning, and other types of ANNs [41], [46], [56].

ANNs are brain-inspired connectionist models that consist of many similar linear and nonlinear computational elements connected in complex patterns. The simple computational elements, also known as neurons, when associated in complex patterns, have the ability to perform tasks such as memory recall, pattern recognition, and learning [46].

A fuzzy system uses a mathematical framework that comprises of fuzzy logic, fuzzy set theory, approximate reasoning, and possibility theory to represent uncertain or imprecise data and/or information and logically reason with it to generate linguistic and numerical outputs. It provides a nonlinear/linear input–output variable mapping using a set of linguistic rules and the associated decision logic [65].

EAs are numerical global optimization techniques rooted in the mechanism of natural search and selection process associated with evolution and natural genetics. Options include genetic algorithms (GAs), evolutionary strategies, genetic programming, and evolutionary programming [43]. All of these methods are probabilistic in nature and exhibit global search capabilities (guided random technique category), thus making them attractive for almost all areas of human activity. Other categories include calculus-based and enumerative technique such as dynamic programming. EA can handle all search spaces including nonsmooth, multimodal, and discontinuous spaces and can identify multiple optimal solutions.

Learning is a process of inferring from repeated experiences. Neural learning is data driven (both supervised and unsupervised), and is driven by the weight modification activity, based on an appropriate learning algorithm. It also provides a framework for representing the knowledge. EA uses probabilistic transition rules to search from a population of coded parameter values. This simultaneous sampling of the search space, the notion of mating fitter individuals to bring up new generations, and the dual strategy of exploration and exploitation assists in obtaining near-optimal solutions. The objective is to benefit from the exploratory nature of EA and the corrective nature of NNs. The NN search space is usually infinite, multidimensional, and multimodal [72].

Evolutionary fuzzy modeling (EFM) combines the implicit and explicit imprecision and uncertainty management capabilities of fuzzy systems (fuzzy set theory, fuzzy logic, expert systems, possibility theory) with the evolutionary learning and global optimization capabilities of EAs to evolve reliable and robust models. Unique features of EFMs include their ability to evolve multiple models, inherent parallelism, exception handling, simplicity, cost-effectiveness, and their ability to combine qualitative and quantitative knowledge in the learning and inference phases [43].

Evolutionary neuro-modeling (ENM) combines the representation and nonlinear representation, and the corrective learning strengths of NNs with the searching capabilities of EAs/GAs. The evolutionary learning options for ENM may be divided into the following categories:

1) architecture;
2) weights;
3) connections (topology);
4) input variable selection;
5) semantics.

Complexity manifests itself in different ways, between order and chaos. Chaos theory is one way of studying complexity. Complex chaotic systems are characterized by their flavor of randomness (identifiable using the Hurst's exponent), dimensions, scaling, attractors, Lyapunov exponent (sensitivity to initial conditions), and entropy. They are nonlinear, deterministic, and dynamic. Complex systems, which have strange attractors and a positive Lyapunov exponent, are said to be chaotic [73], [74]. Researchers such as Stacey [38] place self-organizing interaction, with its intrinsic capacity to produce emergent coherence, at the center of the knowledge creating process in organizations.

X. Methodology

How can one go about executing KM projects in an organization? We provide some basic guidelines that can help in this effort. The starting point is to establish the strategy and business case. Leverage a tool such as CEMM to assess the maturity level of the organization and determine the gaps that needs to be covered. This typically includes core information management capabilities. The organizational culture and trust will drive activities around transformation management. Ensure that the right executive sponsorship is available and focus on low hanging fruits to generate quick proof-points. For many organizations, the growth path requires nurturing of key CoP. Social capital generation needs to be supplemented with appropriate technology and enablement.

Do not be too ambitious about metrics. Start small and ensure that what is measured can be tracked. Technology solutions take the path of proof-of-concept, pilot, and then production rollout. There are quite a few support sites available to make informed choices of tools and systems integrators [34]. An iterative and incremental approach is required to successfully deliver KM projects. Methodologies such as OMG's model-driven architecture [58] can be leveraged to implement KM projects.

A. Roles and Responsibilities

The roles will be dependent on business needs, enterprise strategy, and the organizational scope of the KM initiative. A task group would be comprised of chief knowledge officer (CKO), chief learning officer (CLO), KM evangelists, CIO, CTO, CFO, the program manager, and the chief knowledge architect (CKA). The program manager and CKA lead the program office, which oversees all KM projects. Note that one of the C-level executives in the task group would also be the sponsor.

The functional subgroups in each KM project team would be around needs assessment, transformation (business process reengineering and metrics measurement and tracking, social awareness and cultural change), and technology (business analysis, architecture—tools evaluation, analysis and design; and development). Members of each KM project team may include line-of-business sponsors, user representatives, technical and process architects, a project manager, and various specialists.

XI. Metrics, Gotchas

Metrics should be treated at multiple levels. At one level, it is all about increase quality, customer satisfaction, loyalty, and retention, reduced risk, operating costs, and time spent during training, number of new patents, products, and ideas. At the micro level, metrics includes relevancy, precision, and recall [1]. Practitioners have studied and documented typical gotchas [19]. This includes

- lack of user update due to insufficient communication;
- everyday use not integrated into normal working practice;
- lack of time to learn on system (too complicated);
- lack of training, poor planning, and inadequate resources;
- users could not see personal benefits;
- senior management was not behind it; lack of accountability;
- unsuccessful due to technical problems;
- lack of strategy;
- failure to connect with real business issues;
- lack of outcome and process measures;
- "one size fits all" approach.

Critical success factors [19] include the following:

- a knowledge-oriented culture.;
- technical and organizational infrastructure;
- senior management support;
- a link to economics or industry value;
- a modicum of process orientation;
- clarity of vision and language;
- nontrivial motivational aids;
- some level of knowledge structure;
- multiple channels for knowledge world.

XII. Security and Privacy

Identifying and locating experts, knowing what organizations and I know, and knowledge sharing has significant security and privacy implications. Organizations that form virtual teams with multiple contracting partners/vendors have distinct challenges around knowledge sharing. Concerns around intellectual capital in a highly competitive environment need to be balanced with social capital benefits. While profiling promotes automation, obtaining authorization before making newly discovered expertise in public is one of the many strategies employed by KM software companies.

XIII. Standards

Standards play a significant role across the KM capabilities. This includes agent communication, meta-data representation, business integration, interoperability, multichannel and cross-channel success, portals, and advanced collaboration.

Currently mature/emerging standards include web-based delivery and integration such as W3C (XML, XSL), OMG (CORBA, UML), J2EE, communications (T.120, H.323, WAP), knowledge representation and transfer (KQML), content (RDF, ContentML), web services (UDDI, SOAP, WSDL), e-learning (AICC, SCORM), and workflow (WfML).

Standardization is required in the areas of document management interfaces, knowledge nuggets, smart components, and knowledge environments.

XIV. Open Problems

We will discuss some open problems around the knowledge life cycle.

Knowledge Creation: Most of the open problems in artificial intelligence are applicable here. This includes the Chinese room argument (understanding versus imitation, appearance versus reality: John Searle, 1980, 1992), Rapaport's Korean Room (1998), Turing test (Alan Turing, 1950), Horgan-Tienson (against symbolic AI), Rychlak's exclusive OR argument, Penrose's revival of Gödel argument, and Dreyfus's challenge [51]. Researchers have been debating over behavioral characteristics such as reactivity, sequentiality, routineness, and trial-and-error adaptation, and cognitive characteristics such as dichotomy of the implicit and the explicit (closely related to symbolic versus subsymbolic processing, conceptual versus subconceptual processing, and conscious versus unconscious), bottom-up learning, synergistic interaction, and modularity (Sun [71]). The CLARION model proposed by Sun [71] focuses on the interaction of implicit and explicit processes in human cognition. Approaches include reinforcement learning (bottom level), rule and plan extraction at the top level, development of modular structures using spatial partitioning, and development of modular structures using temporal segmentation [71].

Knowledge Capturing: Tacit knowledge capture continues to be an open problem, even with the recent advances around innovative methods such as story telling and TKIM [11]–[31].

Knowledge Organization: The key open problem here is knowledge representation using a universal language that may allow multiple channel and experience support [47].

Knowledge Dissemination: The grand challenge is knowing what to deliver to whom using what mode when and how quickly. There is the associated challenge of how informal knowledge nuggets can be optimized for learning and how the new knowledge discoveries can be automatically converted to valuable learning objects.

ACKNOWLEDGMENT

The authors would like to thank M. G. Singh for motivating them to co-edit this special issue on knowledge management.

REFERENCES

[1] U. Harigopal and A. Satyadas, "Fundamentals of knowledge management," in *IEEE Tutorial*, Boston, MA, Oct. 2001.
[2] D. Cohen and L. Prusak, *Good Company How Social Capital Makes Organizations Work*. Boston, MA: Harvard Business School Press, 2001.
[3] R. Cross and S. Israelit, *Strategic Learning in a Knowledge Economy*. London, U.K.: Butterworth Heinemann, 2000.
[4] D. E. Smith, *Knowledge, Groupware and the Internet*. London, U.K.: Butterworth Heinemann, 2000.
[5] U. Fayyad *et al.*, *Advances in Knowledge Discovery and Data Mining*. Menlo Park, CA: AAAI, 1996.
[6] B. Hackett, *Beyond Knowledge Management: New Way to Work and Learn*. New York: Conference Board, 2000.
[7] J. Leibowitz, *Building Organizational Intelligence: A Knowledge Management Primer*. Boca Raton, FL: CRC, 2000.
[8] E. L. Lesser, *Knowledge and Social Capital*. London, U.K.: Butterworth Heinemann, 2000.
[9] S. H. Haeckel, *Adaptive Enterprise*. Boston, MA: Harvard Business School Press, 1999.
[10] A. Iran-Nejad, Guest Editor, *J. Mind Behavior*, vol. 21, no. 1, 2, 2000.
[11] R. J. Sternberg *et al.*, *Practical Intelligence in Everyday Life*. Cambridge, U.K.: Cambridge Univ. Press, 2000.
[12] J. S. Brown and P. Duguid, "Balancing act: How to capture knowledge without killing it," *Harv. Bus. Rev.*, May–June 2000.
[13] I. Nonaka, "The knowledge-creating company," *Harv. Bus. Rev.*, Nov.–Dec. 1991.
[14] S. E. Prokesch, "Unleashing the power of learning," *Harv. Bus. Rev.*, Sept.–Oct. 1997.
[15] E. C. Wenger and W. M. Snyder, "Communities of practice: The organizational frontier," *Harv. Bus. Rev.*, Jan.–Feb. 2000.
[16] D. E. Garvin, "Building a learning organization," *Harv. Bus. Rev.*, July–Aug. 1993.
[17] D. Krackhardt and J. R. Hanson, "Informal networks: The company behind the chart," *Harv. Bus. Rev.*, July–Aug. 1993.
[18] A. Tiwana, *The Essential Guide to Knowledge Management*. Englewood Cliffs, NJ: Prentice-Hall, 2001.
[19] T. H. Davenport and L. Prusak, *Working Knowledge*. Boston, MA: Harvard Business School Press, 1998.
[20] H. Rollett. (2001) Knowledge management bibliography. [Online]. Available: http://www2.iicm.edu/herwig/kmbib.html.
[21] A. Satyadas and U. Harigopal, "Cognizant e-business solutions: Leading the next e-business wave with knowledge management", White Paper, 2001.
[22] M. H. Zack, "Developing a knowledge strategy," *Calif. Manage. Rev.*, vol. 41, pp. 125–145, 1999.
[23] T. H. Davenport, D. D. D. Long, and M. C. Beers, "Successful knowledge management projects," *Sloan Manage. Rev.*, vol. 39, no. 2, pp. 43–57, 1998.
[24] N. M. Dixon, *Common Knowledge: How Companies Thrive by Sharing What They Know*. Boston, MA: HBS, 2000.
[25] E. Wenger, *Communities of Practice: Learning, Meaning, and Identity*. Boston, MA: Cambridge Univ. Press, 1999.
[26] P. M. Senge and A. Kleiner, Eds., *The Dance of Change: Mastering the Twelve Challenges to Change in a Learning Organization*. New York: Doubleday, 1999.
[27] J. Pfeffer and R. I. Sutton, *The Knowing–Doing Gap: How Smart Companies Turn Knowledge Into Action*. Boston, MA: HBS, 2000.
[28] C. Hubert, S. Elliott, and C. O'Dell, *Knowledge Management: A Guide for Your Journey to Best-Practice Processes*, TX: Amer. Productivity Quality Cent., 2000.
[29] A. Tiwana, *Knowledge Management Toolkit, The: Practical Techniques for Building a Knowledge Management System*. Englewood Cliffs, NJ: Prentice-Hall, 2000.
[30] G. V. Krogh, K. Ichijo, and I. Nonaka, *Enabling Knowledge Creation: How to Unlock the Mystery of Tacit Knowledge and Release the Power of Innovation*. London, U.K.: Oxford Univ. Press, May 2000.
[31] S. Denning, *The Springboard: How Storytelling Ignites Action in Knowledge-Era Organizations*. London, U.K.: Butterworth-Heinemann, 2000.
[32] C. Ehin, *Unleashing Intellectual Capital*. London, U.K.: Butterworth-Heinemann, 2000.
[33] P. H. Sullivan, *Value Driven Intellectual Capital: How to Convert Intangible Corporate Assets Into Market Value*. New York: Wiley, 2000.
[34] Y. Malhorta. (2001) References in knowledge management. [Online]. Available: http://www.brint.com/km/kmrefs.htm.
[35] G. V. Krogh, K. Ichijo, and I. Nonaka, *Enabling Knowledge Creation: How to Unlock the Mystery of Tacit Knowledge and Release the Power of Innovation*. London, U.K.: Oxford Univ. Press, 2000.
[36] I. Nonaka and T. Nishiguchi, Eds., *Knowledge Emergence: Social, Technical, and Evolutionary Dimensions of Knowledge Creation*. London, U.K.: Oxford Univ. Press, 2001.
[37] P. Baumard, *Tacit Knowledge in Organization*. Thousand Oaks, CA: Corwin, 1999.
[38] R. D. Stacey, *Complex Responsive Processes in Organization: Learning and Knowledge Creation (Complexity and Emergence in Organizations* Routledge, U.K., 2001.
[39] P. F. Drucker, *Management Challenges for the 21st Century*. New York: Harper & Row, 2001.
[40] ——, *Drucker in Harvard Business Review*. Boston, MA: HBS, 2001.
[41] A. Satyadas and U. Harigopal, *Leveraging Computational Intelligence for Knowledge Management: The ANN Value Proposition, Tutorial, Session III*. Washington, DC: IJCNN, 2001.
[42] IBM Mindspan and Knowledge Management Solutions. (2001). [Online]. Available: www.ibm.com/mindspan; www.ibm.com/knowledge.
[43] K. Krishnakumar and A. Satyadas, *Computational Intelligence Tutorial*. Washington, DC: AIAA Professional Development Course, 1997, 1998.
[44] R. Sun, *Integrating Rules and Connectionism for Robust Commonsense Reasoning*. New York: Wiley, 1995.
[45] ——, *Hybrid Neural Systems*. New York: Springer-Verlag, 2000.
[46] C. G. Looney, *Pattern Recognition Using Neural Networks*. London, U.K.: Oxford Univ. Press, 1997.
[47] D. Lenat and R. V. Guha, *Building Large Knowledge-Based Systems*. Reading, MA: Addison-Wesley, 1990.
[48] I. Mani, *Automated Text Summarization*. London, U.K.: Benjamins, 2001.

[49] T. Berners-Lee, J. Hendler, and O. Lassila, "The semantic Web," *Sci. Amer.*, vol. 284, no. 5, pp. 34–43, 2001.
[50] R. Kosala and H. Blockeel, "Web mining research: A survey," in *Proc. ACM SIGKDD*, vol. 2, 2000, pp. 1–15.
[51] H. L. Dreyfus, *What Computers Still Can't Do: A Critique of Artificial Reason*. Cambridge, MA: MIT Press, 1992.
[52] D. Jurafsky and J. H. Martin, *Speech and Language Processing*. Englewood Cliffs, NJ: Prentice-Hall, 2000.
[53] T. R. Gruber, "A translation approach to portable ontologies," *Knowl. Acquisition*, vol. 5, no. 2, pp. 199–220, 1993.
[54] Market Adaptive Pricing., Manchester, UK. [Online]. Available: www.kssg.com.
[55] W. Kloesgen and J. Zytkow, *Handbook of Data Mining and Knowledge Discovery*. London, U.K.: Oxford Univ. Press, 2001.
[56] U. M. Fayyad, G. Piatetsky-Shapiro, and P. Smyth, "From data mining to knowledge discovery: An overview," in *Advances in Knowledge Discovery and Data Mining*. Menlo Park, CA: AAAI, 1996, ch. 1, pp. 1–34.
[57] A. Satyadas and U. Harigopal. (2001) Enterprise knowledge maturity model, half-day workshop. KM World, CA. [Online]. Available: www.kmworld.com.
[58] Common object request broker architecture (CORBA), model driven architecture (MDA).. OMG, MA. [Online]. Available: www.omg.org.
[59] T. Kohonen, S. Kaski, K. Lagus, J. Salojarvi, J. Honkela, V. Paatero, and A. Saarela, "Self organization of a massive document collection," *IEEE Trans. Neural Networks*, vol. 11, May 2000.
[60] T. Honkela, "Self-organizing maps in natural language processing," Ph.D. dissertation, Helsinki Univ. Technol., Helsinki, Finland, 1997.
[61] C. J. C. Burges, "A tutorial on support vector machines for pattern recognition," *Data Mining Knowl. Disc.*, vol. 2, pp. 121–167, 1998.
[62] T. Joachims, "Making large-scale SVM learning practical," in *Advances in Kernal Methods—Support Vector Machine Learning*. Cambridge, MA: MIT Press, 1998.
[63] A. K. Jain, R. P. W. Duin, and J. Mao, "Statistical pattern recognition: A review," *IEEE Trans. Pattern Anal. Machine Intell.*, vol. 22, Jan. 2000.
[64] The NetherlandsM. K. Starr and M. Zeleny, "MCDM-state and future of the arts, multiple criteria decision making," in *Studies in Management Sciences*, M. Zeleny, Ed. Amsterdam: North-Holland, 1977, vol. 6, pp. 5–29.
[65] A. Satyadas, H. C. Chen, A. Iran-Nejad, and B. Chissom, "Intelligence: Exact Computation or Biofunctional Cognition," *Psych. Bul.*, vol. 31, no. 3, pp. 175–178, 1993.
[66] R. Penrose, *Shadows of the Mind*. London, U.K.: Oxford Univ. Press, 1994.
[67] D. J. Chalmers, R. M. French, and D. R. Hofstadter, "High-level perception, representation, and analogy: A critique of artificial intelligence methodology," *J. Experimental Theoretical Artif. Intell.*, pp. 185–212, 1992.
[68] C. Carlsson and R. Fullér, "Fuzzy multiple criteria decision making: Recent developments," *Fuzzy Sets Syst.*, vol. 78, pp. 139–153, 1996.
[69] N. Cassaigne and M. Singh, "Intelligent decision support for the pricing of products and services in competitive markets," *IEEE Trans. Syst., Man, Cybern. C*, vol. 31, pp. 96–106, Feb. 2001.
[70] P. Bussey and N. Cassaigne, "Decision technologies for new bid pricing processes in distribution industries," in Systems Engineering for Business Process Change. New York: Springer-Verlag, to be published.
[71] R. Sun, *Duality of the Mind: A Bottom Up Approach Toward Cognition*, New York: Lawrence Erlbaum, 2001.
[72] K. KrishnaKumar and A. Satyadas, "Evolving multiple fuzzy models and its application to an aircraft control problem," in *Genetic Algorithms in Engineering and Computer Science*, J. Periaux and G. Winter, Eds. New York: Wiley, 1995.
[73] S. A. Kauffman, *The Origins of Order*. London, U.K.: Oxford Univ. Press, 1993.
[74] L. P. Kadanoff, *From Order to Chaos*. Singapore: World Scientific, 1993.
[75] Internet digital rights management.. [Online]. Available: http://www.idrm.org.
[76] P. Maes, Ed., *Designing Autonomous Agents: Theory and Practice From Biology to Engineering and Back*. Cambridge, MA: MIT Press, Mar. 1991.
[77] A. Ankolekar, M. Burstein, J. R. Hobbs, O. Lassila, D. L. Martin, S. A. McIlraith, S. Narayanan, M. Paolucci, T. Payne, K. Sycara, and H. Zeng, "DAML-S: Semantic markup for Web services," in *Proc. Int. Semantic Web Workshop*, 2001.
[78] T. Berners-Lee, J. Hendler, and O. Lassila, "The semantic Web," *Sci. Amer.*, May 2001.
[79] D. F. Halpern, *Thought and Knowledge: An Introduction to Critical Thinking*, New York: Lawrence Erlbaum, 1989.
[80] K. M. Wiig, "Knowledge management: Where did it come from and where will it go," *J. Expert Syst. Applicat.*, vol. 13, no. 1, pp. 1–14, 1997.

Antony Satyadas (S'92–M'98–SM'01) received the B.S. degree in electrical engineering from the College of Engineering, University of Kerala, Trivandrum, India, in 1984 and the M.S. and Ph.D degrees in computer science and cognitice science in from the University of Alabama, Tuscaloosa.

He is currently with IBM Corporation, Cambridge, MA. His 17 years of consulting and research expertise include knowledge management, computational intelligence, smart component architectures, CAD-CAM, and large scale e-business solutions. He has conducted extensive research in cognitive prediction and control using soft computing and has more than 35 publications in books, international journals, and conferences. He has been conducting short course, and workshops/tutorials worldwide in these areas. He has vast experience in leading the evolution of end-to-end solution capabilities for several Fortune 100 companies in diverse industry sectors such as life science, aerospace, automotive, government, financial services, pharmacy, energy, petro-geology, telecommunications, and education. His past experience includes working for Perot Systems, Bellsouth Telecommunications, University of Alabama, OMC Computers, and HCL Computers Ltd., and entreprenurial and standards initiatives in soft computing through Flexible Intelligence Group.

Umesh Harigopal (M'01) received the B.Tech. degree in computer science from Jawaharlal Nehru Technological University, Nehru, India, in 1990 and the M.S. and Ph.D. degrees in computer science from the University of Alabama, Tuscaloosa, in 1993 and 1999, respectively.

He has more than ten years of research and industry experience in the areas of telecommunications, healthcare, network management, B2B collaboration, CRM, and knowledge management. His research and publications are in the areas of KM, ANNs, natural language processing, programming languages, and parallel distributed computing. He has offered courses, tutorials, and conference sessions in related fields. He is currently Vice President of Technology and Architecture at J. P. Morgan Chase & Co., New York, where he recommends strategic technology initiatives for different business areas with the primary focus on digitization and KM.

Nathalie P. Cassaigne (S'97–A'99–SM'01) received the DESS degree in information systems in 1991 and the DEA degree in management sciecne in 1992.

Currently, she is a Lecturer in Decision Technologies at University of Manchester Institute of Science and Technology (UMIST), Manchester, U.K. Prior to joining UMIST, she was head of new business development at Knowledge Support Systems Plc., where she co-specified and co-designed the Intelligent Tactical Decision Support System TelPrice, which won the European IST Award in 1999. This award is sponsored by the European Commission, administered by the European engineering academies (Royal Academy of engineering for U.K.) and is given "for excellence in converting information technology research into innovative products for the marketplace." She has over ten years experience in helping senior executives unlock the personal and corporate benefits by supporting and optimizing strategic and tactical decisions. She has operated in a wide range of organizations in the private and public sectors including telecommunication, manufacturing, aerospace industries, and government.