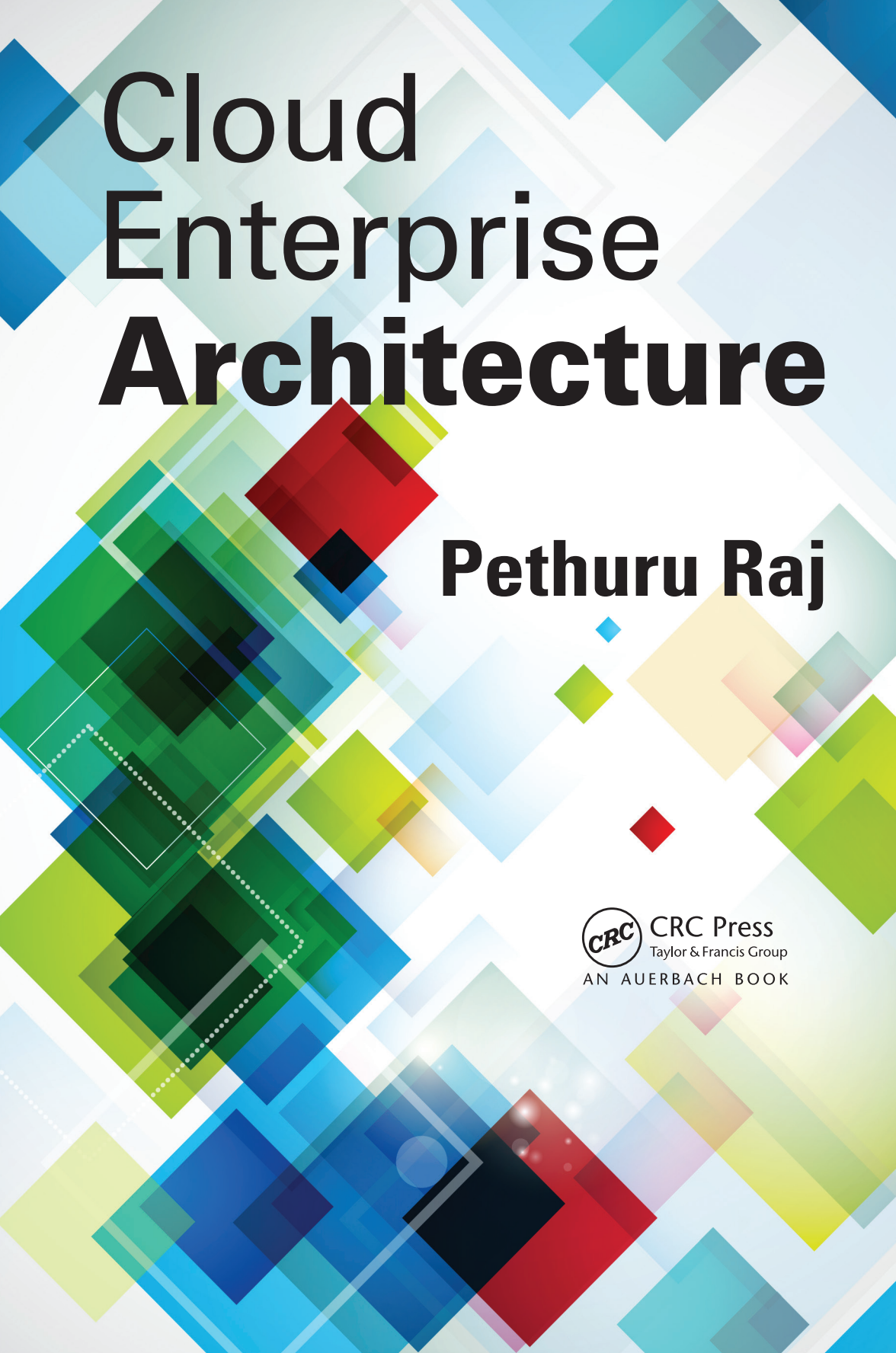
Cloud Enterprise Architecture

Pethuru Raj



CRC Press
Taylor & Francis Group
AN AUERBACH BOOK

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CRC Press
Taylor & Francis Group
Boca Raton London New York

CRC Press is an imprint of the
Taylor & Francis Group, an **informa** business
AN AUERBACH BOOK

CRC Press
Taylor & Francis Group
6000 Broken Sound Parkway NW, Suite 300
Boca Raton, FL 33487-2742

Version Date: 20120831

International Standard Book Number-13: 978-1-4665-0233-8 (eBook - PDF)

This book is dedicated to

my father, Chelliah (late) and my mother, Anna Marial

Contents

Foreword

Cloud computing is becoming a highly attractive paradigm, especially for business organizations, whether small, medium, or large. Reduction in capital and operating costs, agility of services development and deployment, as well as the ability of the cloud environment to allow scalability with respect to the highs and lows of demands of the enterprises' provisions are just some of the promises of this emerging trend. However, in order to achieve the benefits of cloud environments, organizations need to tread carefully and have the appropriate road map for migration to the cloud. Among other things, they need to have the enterprise applications developed in such a way that they are suitable for distributed environments as well as correct and appropriate data, information, and infrastructure architectures—collectively known as enterprise architecture (EA).

A well-established enterprise has a *strategic vision* that gives it future direction and provides guidance toward its *business strategy*. This, in turn, drives the *IT strategy* that helps to develop the EA. This presents an organizing principle that aligns the functional mission of the business with its IT strategy and execution plans. In this respect, there are a number of architectures that need to be taken into consideration, including *data and applications architectures*, *integration architecture*, *technology architecture*, and *management*, *security*, *and governance architectures*. All these need to be in place and correctly implemented.

The aim of this book on "Cloud Enterprise Architecture" is to develop a framework in terms of the aforementioned individual architectures and discuss these in detail in separate chapters. The objective is to align EA with the cloud technologies to provide a true value to the organizations' business strategy. The book presents some welcome "futuristic" ideas as well.

The book describes and presents suggestions as to how an EA can enable an enterprise to quickly adapt to the changing requirements as well as to address the new challenges. It talks about a number of well-accepted application-level architectures, such as those referred to as *service oriented*, *event driven*, *model driven*, *web oriented*, and so on. With respect to the data architectures, the book discusses topics such as parallel and distributed data crunching, as well as the issues of *big data*. IT infrastructures

are discussed in detail with respect to partitioning, provisioning, deprovisioning, automation, and resource sharing. In a cloud environment, which is distributed, the IT infrastructure landscape is totally different and requires novel methodologies for networking and communication. There is a useful discussion about the integration technologies and methodologies in terms of connectivity (e.g., in case of *Cloud Bursting*), interoperability (which is an issue of concern), composition, collaboration, and brokerages. The book has three chapters on management, governance, and security, signifying the huge importance of these aspects in working with cloud environments. Reduced governance controls and security threats due to shared boundaries within the cloud environments (especially in the case of public clouds) are indeed some of the major issues for cloud consumers. This is in spite of the fact that cloud management solutions are being made available by reputable vendors and organizations such as NIST, CSA, and OASIS. These organizations are working toward developing open standards with respect to management, governance, networking, security, interoperability, and so on. The book discusses all the relevant core aspects in this context.

This book is a useful source of information for enterprise architects, managers, and directors of organizations, as well as students and researchers in the fields of cloud computing and EA. It provides a thorough and timely investigation of the convergence of cloud computing, on one hand, and enterprise data, applications, and infrastructure architectures, on the other. It is a welcome addition to the body of existing knowledge in these fields and emerging new technologies.

Zaigham Mahmood
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Dr. Zaigham Mahmood is a reader in applied computing and assistant head of Distributed and Intelligent Systems (DISYS) research group in the School of Computing and Mathematics, University of Derby, UK. He is also an Arcitura.com Certified Cloud Trainer. Dr. Mahmood has organized many conference tracks and workshops. He is an accomplished author with in excess of 75 presentations and articles. His latest book on *Cloud Computing for Enterprise Architectures* appeared in 2011. He is currently editing or authoring six books, including the two on *Cloud Computing: Concepts and Technology* and *Software Engineering frameworks for Cloud Computing Paradigm*.

Preface

The business landscape is in a continuously changing mode with a vast number of digitalization and globalization activities steadily springing forth and spreading. Information technology (IT) is being widely and wholeheartedly recognized as the greatest enabler of business. IT is penetrating deeper, and the dependence of business automation on IT is becoming stronger. There has to be a commendable coupling between business and IT. Markets are becoming extremely competitive and knowledge-driven; investors and executives demand more out of IT investments, and customers demand more pioneering and premium products from business organizations. The world economy is receding and is recessionary, and at best could achieve a rather muted recovery. Win–win partnerships are being established at a furious pace among enterprises to take on the brewing changes and challenges together, and smaller companies are consistently being usurped by larger conglomerates to gain more market and mind shares. Newer and nimbler avenues are being explored, experimented on, and expounded for fresh revenues.

IT budgets are silently being pruned, the innovation mindset is being insisted on among professionals to come out of the current constriction, and entrepreneurial spirits are being appreciated. Product vendors are releasing a plethora of path-breaking and people-centric solutions. Service organizations are proactively and preemptively conceiving and concretizing a battery of novel services to the market to sustain the edge earned. Acquisitions and mergers are being announced very frequently these days to retain the brand value gained. Factors such as productivity, flexibility, simplicity, adaptability, agility, openness, timeliness, and affordability are mandated these days on business operations, outlooks, and outputs. It is absolutely clear that business and IT ought to sail together to put up a unified face in order to decisively and distinctly take on the changing realities in the marketplace. The awareness, association, and alignment between business and IT are becoming stronger, deeper, and thicker.

In this very delicate and difficult scene, experts and evangelists insist on an integrated and insightful approach for tightly coupling business and IT. That is, business and IT alliance has become indispensable. Suppose a corporation wants to introduce a new product into its portfolio; there is,

therefore, a need to define additional business processes, hire extra personnel, change the supporting applications, and augment the technical infrastructure to support the additional load. This new initiative could also lead to changes in the organizational structure. Fruitfully leveraging IT advancements to shape business automation, augmentation, and acceleration is a tedious and time-consuming task, and hence needs a lot of brainstorming, strategizing, and planning.

IT capabilities need to be weighed objectively, and the resulting knowledge has to be deposited safely for future access and articulation. Executives need to be in a position to quickly make informed and appropriate decisions. All these mandate that there has to be an integrated vision and mission in place to make business IT-aware and IT business-centric. Without such a synchronization mechanism in place, business may not profit from the series of innovations and improvisations happening in the hot IT domain and discipline. Business and IT strategies need to be intertwined in order to be relevant in the changing marketplace. This harmonization is able to pour out a stream of fresh possibilities and newer opportunities.

It is a widely recognized fact that enterprise architecture (EA) is the most efficient and effective way for perfectly attaining the business and IT alignment. EA has become the tool of choice for architects in order to establish the direct and decisive linkage between business and IT. EA is an enterprise-scale approach and instrument for accomplishing the beneficial integration between business and IT. Precisely speaking, EA is a coherent set of principles, methods, and models that is used in the design and realization of the enterprise's organizational structure, business processes, information systems, and infrastructures.

In recent years, a few business-driven technologies have emerged and evolved. Service oriented architecture (SOA) is the most notorious architectural pattern and is being projected as a promising and powerful design paradigm with a great potential for producing mission-critical, dynamic, adaptive, and enterprise-class applications. The much-published service thinking has the intrinsic capability of impacting the whole enterprise copiously. Not only service-based system engineering but also the goals of business integration, enterprise composition, and legacy modernization are being effortlessly fulfilled with the power of the service idea.

Another concept sweeping the entire IT industry is the cloud theme. While the service paradigm targets the arenas of software design and development, the much-debated, deliberated, and discoursed cloud idea assists exceedingly well in software deployment, delivery, and management. That

is, the massive and mesmerizing adoption and adaptation of SOA and cloud computing greatly and gently could simplify and streamline the full-fledged and fail-safe implementation of the ideas and ideals of EA. In order words, SOA and cloud are the leading EA-enablement technologies. They are assisting and affecting the EA field immeasurably and incredibly. This book is all about articulating the distinctive, transformative, and augmentative capabilities of cloud computing on EA.

We write about the venerable mission of precisely and concisely presenting the impacts and implications of the evolving enigmatic cloud concepts on the EA. We have detailed the development of flexible and futuristic EA, how cloud meets, mingles with and molds EA, and how the convergence of cloud with EA is to bring bigger turnarounds and makeovers on small, medium, and large-scale enterprises. There are architectural frameworks such as TOGAF for facilitating the design of next-generation EA.

In this book, we have visualized all the noteworthy shifts due to the blending of cloud concepts with the traditional EA and written about the cloud-instigated enterprise integration, security, and management architectures. The first chapter is all about the salient and spectacular contributions of a number of powerful and potential technologies including the service and the cloud paradigms, for establishing smart enterprises. Leading IT players are extensively advertising and articulating smart enterprise technologies these days. Business intelligence, service orientation, mobility, machine-to-machine (M2M) integration, cloud, big data, and in-memory computing models are being prescribed as the fulfilling and failsafe mechanisms and methods for the forthcoming era of smart businesses.

The second and third chapters describe the transitions that the business and IT domains are going through with the stability and maturity of cloud concepts. The various limitations of IT and the glut of underutilized and unutilized IT infrastructures have laid the foundation for the breakthrough cloud idea, and this praiseworthy advancement in the IT field has resulted in a series of delectable and decisive ramifications on the business side. Several business models have been unearthed and published since then, and global enterprises (small, medium, and large) have instantly jumped on the cloud bandwagon in order to reap all the indicated and instinctive advantages of the cloud movement.

The fourth chapter describes what EA is, how EA enables enterprises to be adaptive to meet business changes and challenges, how EA guides the goal of attaining and retaining a tight alignment between business and IT,

and so on. This chapter explains several promising and potential architectural frameworks, platforms, and tools for facilitating the design of EA in a systematic and simplified manner. With the seamless amalgamation of cloud concepts into an enterprise, the traditional EA is bound to be expansively modified to absorb and accommodate the cloud idea. We have named the resultant concept cloud enterprise architecture (CEA).

The fifth chapter is on cloud application architecture (CAA). Cloud business architecture (CBA) has to be taken toward its logical and physical conclusion using a suite of application, data, and technology architectures. In this chapter, we have talked about some of the prominent and dominant application-level architectures such as service-oriented architecture (SOA), event-driven architecture (EDA), model-driven architecture (MDA), service component architecture (SCA), mesh architecture, web-oriented architecture (WOA), and so on. There are processes, practices, patterns, products, and platforms for constructing service-oriented cloud applications (SOCAs) or cloud-based service applications (CBSAs).

In the sixth chapter, we describe cloud data architecture (CDA). Exquisite and elegant data models and schemas are very important for next-generation cloud enterprises. As clouds are being revitalized for accomplishing bigger and better things and requirements, such as for parallel and distributed data-crunching tasks to perform behavioral analytics, quick and cost-effective investigation of process and data-intensive applications, real-time business intelligence needs, and so on, the relevance of CDA is climbing sharply. Increasingly, nonrelational databases are built and posited in clouds to perform a plethora of emerging necessities. Clouds are being positioned for big data computing, which is being recognized as the futuristic computing model. New types of databases are emerging for cloud environments and cloud storage is a new shining domain. All of these clearly illustrate the power and value addition of CDA.

In the seventh chapter, we talk about cloud technology architecture (CTA). IT infrastructures are in transition phase. In fact, underutilized and unutilized computing machines are collected from different locations, consolidated and centralized in one place to provide optimal and managed resource provisioning, monitoring, and management services. IT infrastructures are steadily virtualized to be decomposed and composed as the situation warrants. Partitioning, provisioning, and deprovisioning are fully automated to enable resource sharing. With the addition of a series of novel mechanisms, resource availability is guaranteed in any circumstance. Elasticity is being ensured through the runtime creation

of new cloud resources and once the job is over, all the resources can be put back. That is, runtime expansion and contraction is being realistically and readily provided to users. Self-service is one of the key differentiators of cloud infrastructures. A number of automated software solutions are introduced into any cloud environment in order to fulfill a number of manual operations that are becoming completely automated. Capacity planning is a vital research topic to achieve dynamic capacity planning. Load balancing, job scheduling, and so on are programmatically automated by competent software solutions. Cloud governance is another prospectus for cloud researchers.

In the eighth chapter, we discuss cloud integration architecture (CIA). As there are convincing reports from reputed and renowned market watchers and analysts on the huge market for cloud brokerages (CBs) with the increased migration, deployment, and delivery of services and applications by third-party clouds, the factors such as cloud connectivity, interoperability, integration, composition, and collaboration have gained immense traction. There is a range of broker software in order to establish linkage between different, distributed, and decentralized clouds (private, public, and hybrid). Cloud service aggregation, intermediation, arbitration, dissemination, mashups, and so on are some of the new-generation processes that ultimately lead to sophisticated and smart composite services, which in turn enable building and supplying cloud-based, people-centric services. Next-generation supply chain involves a kind of need-based integration of diverse and geographically distributed cloud services.

In the ninth chapter, we concentrate on the significance of cloud management architecture (CMA). With the unprecedented adoption of cloud computing, effective management, and governance of cloud resources (servers, virtual machines [VMs], applications, networks, services, and data) are paramount in order to readily get what was preached and pronounced earlier. Creation of new VMs and their optimized usage go a long way in realizing the stated business benefits out of the cloud idea. Every interaction happening in a cloud environment has to be closely monitored and acted upon. There are management platforms for cloud infrastructures emerging and evolving at a fast pace. Infrastructure software solutions providers, IT powerhouses, and behemoths are working overtime for producing standards-based cloud management software. Corporates and service organizations are buying, installing, and invoking an appropriate cloud management solution in their green and lean cloud centers to support and sustain business operations.

The tenth chapter is exclusively allocated to supply all the security information so that a well-intended security strategy is in place in order to ward off any kind of internal or external security threats, vulnerabilities, and risks. As widely reported, the security aspect is the main stumbling block for the glorified cloud movement. Providers and researchers are working in unison in order to arrive at and articulate wider kinds of security solutions (software as well as hardware). The cloud security architecture (CSA) leads to effective security strategy that in turn boosts the sliding and shrinking confidence of people.

The eleventh chapter explains the need for governance mechanisms for cloud environments wherein a variety of IT resources roam. We have supplied details regarding how policy comes handy in automatically enforcing only authorized interactions among cloud components.

The final chapter is about key onboarding services. This chapter explains all the mandatory requirements before adopting the cloud idea. The migration methodology is described in detail for the benefit of the reader. There is a set of best practices for arriving at a modernization and migration plan for any enterprise pondering the ways and means of switching over to the cloud infrastructures. There are innumerable legacy as well as modernized IT applications, platforms, and infrastructures. The main motto of this chapter lies in the pragmatic empowerment of them to be cloud-ready so that the target and task of cloud onboarding is smoothly nurtured and nourished.

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Acknowledgments

First of all, I give all the glory and honor to our Lord and Savior Jesus Christ.

I express my sincere gratitude to John Wyzalek, Senior Acquisitions Editor, for immensely helping me from the conceptualization to the completion stage of this book. The publishing teams at CRC Press: Jennifer Stair, Project Editor and Full Service Coordinator and Leah Wohl-Pollack, Project Coordinator, diacriTech, USA, have been very prompt in this book project. Thanks a lot.

I need to remember my supervisors Prof. Ponnammal Natarajan, Anna University, Chennai, India; Prof. Priti Shankar (very recently passed away), CSA Department, Indian Institute of Science, Bangalore, India; Prof. Naohiro Ishii, Department of Intelligence and Computer Science, Nagoya Institute of Technology, Japan; and Prof. Kazuo Iwama, School of Informatics, Kyoto University, Japan, for shaping my research life. I express my sincere and heartfelt gratitude to Thomas Erl, the world's top-selling SOA author for granting me a number of memorable opportunities to write book chapters for his exemplary books.

From the bottom of my heart, I thank Yamini Ravishankar, MS student, Department of Electrical and Computer Engineering, George Mason University, Fairfax, Virginia, USA, for proofreading all the chapters very passionately. She came up with a number of valuable comments and corrections (syntax, structure, and semantics) for all the chapters.

I recognize the fruitful association with Prof. V. Vaidhyanathan, Prof. John Bosco Balaguru, Prof. Amirtharajan, and Prof. V. Venkatesh, the School of Computing, SASTRA University, Tamil Nadu, India, over the years. I also respect the close interactions with Prof. M. Nachamai, Prof. Ashok Immanuel, Prof. Sumitra Binu, and Prof. Peter Augustine, Department of Computer Science, Christ University, Bangalore, India.

I have to profoundly recognize Dr. Thandavan Settu (MD, Global Applied Materials, Ltd.) and his family for their unfailing love, affection, and care. I also extend my thanks to Daniel David, the Director, Celeste Engineering, Bangalore, India, for all the rewarding time spent together. I am extremely grateful to Mrs. Rani Robert from the United States for her weekly call, exhortations, and prayer. I recollect the unflinching support

rendered by Dr. Mohanavadivu Periasamy, the CEO, Scientific Research Invision, Canada, and Dr. Devasia Kurian, the CEO, astTECS Solutions, Bangalore, India.

I would expressly like to thank my wife, Sweetlin Reena, and sons Darren Samuel and Darresh Bernie, for their perseverance as I have undertaken the tremendous and tedious challenge of putting this book together. I thank my brothers' and sisters' families for all their steadfast support extended to me during this long and arduous life journey. I thank Pastor George, Shalom Church, Naganathapura, Bangalore, for his earnest prayers.

I thank all the readers.

Author

Having obtained the competitive UGC research fellowship, I successfully obtained a PhD from Anna University, Chennai, India. Then, I obtained a CSIR fellowship to work as a postdoctoral researcher in the Department of Computer Science and Automation (CSA), Indian Institute of Science (IISc), Bangalore. Thereafter, I was granted a couple of international fellowships (JSPS and JST) to work as a research scientist for 3 years in two leading Japanese universities. I worked as a lead architect in the corporate research (CR) division of Robert Bosch, India, for 1.5 years.

I have gained more than 12 years of IT industry experience. Primarily, I have contributed as a technical architect for 8 years and as a software product architect for 4 years. Currently, I am working as an enterprise architecture (EA) consultant, focusing exclusively and extensively on EA-inspired business transformation capabilities. My ultimate aim here is to provide technology advisory services to worldwide organizations and business enterprises to enable a smooth transition to be smarter in their operations, offerings, and outputs, by articulating and empowering them to adopt, adapt, and apply proven, potential, and promising technologies, enabling and empowering architectural styles, infrastructure consolidation, and process optimization methods.

I have acquired good knowledge on some emerging technologies such as cloud computing, service-oriented architecture (SOA), event-driven architecture (EDA), and enterprise architecture (EA). Also, I have gleaned reusable knowledge in big data computing and Hadoop, real-time and real-world cloud analytics, machine-to-machine (M2M) integration/cyber physical systems (CPS), high-performance system design, and the development methods of smartphone applications. I have made use of the opportunities that came my way to focus on a few business domains, including telecommunication, retail, government, energy, and health care.

I have contributed book chapters for a number of technology books that were edited by internationally acclaimed professors and published by leading publishing houses.

CEA Book Audience and Key Takeaways

Enterprise architecture (EA) has been an important ingredient for any growing enterprise to support and sustain its ordained journey toward the envisioned target. EA's capabilities and contributions are paramount and pioneering for smoothening and streamlining the rough and tough route. EA brings out a holistic and shared view of the current business and IT landscapes. EA insightfully facilitates in unearthing the right and relevant nuances and niceties for effectively planning, controlling, strengthening, and innovating the business transition process and path toward its future and envisaged state. The other prominent advantage is to establish a tighter alignment and association between IT and business. That is, all kinds of business changes and challenges can be instantly and intelligently taken care of if the underlying IT resources, products, and processes are appropriately business aware and aligned. Precisely speaking, EA directly contributes to business agility, autonomy, and affordability. EA's success delightfully determines the success of a business.

Further, EA extracts and exposes business-critical and actionable information to business executives and visionaries to cognitively contemplate and justify tactical and strategic decisions. The decisions, being sound and sharp, enable and empower chief executives to plunge into the initiation and implementation mode straight away. The informed and timely analysis and actions will ultimately prove to be disruptive, inventive, and transformative for the whole enterprise to trek along to reach greater heights in less time. Further, EA participates in realizing an implementable road map for intelligently exploiting IT architectural building blocks, platforms, and infrastructures to achieve business augmentation and transformation with ease. There are several core and peripheral technologies emerging in order to realize the goals, methods, and processes of EA. Some have vanished with the speed they arrived and some are persisting with sheer power. Service orientation (SO) and cloud computing are the top two technologies showing immense potential and promise in tackling a variety of prickling and perpetual IT challenges. Also, these are

very generic enterprise-scale technologies and hence are associated with EA. This extended technology ecosystem significantly elevates EA's role and responsibility in reaching the illuminated milestones of worldwide EA-adopted enterprises.

Cloud Computing—It is a well-received and recognized fact that the cloud paradigm has brought in a bevy of innovations for the IT discipline. The cloud technology, being a composite concept, has gained a lot of attention and drawn appreciable attraction from industry professionals and academicians these days. A number of pioneering and game-changing technologies (virtualization, consolidation, federation, service-oriented architecture [SOA], grid, utility, on-demand and autonomic computing models, dynamic resource provisioning, software as a service [SaaS], ambient communication, etc.) are intelligently combined, converged, and clustered together to lay the flexible and futuristic foundation for the forthcoming knowledge-driven and cloud-based service era. The much-discoursed and deliberated cloud technology has brought in a series of favorable and facilitating impacts on the enterprise IT.

Other prominent disciplines receiving effusive power and value from the pioneering and penetrating cloud idea are Web 2.0 (social computing) and Enterprise 2.0. Not only enterprises but also corporations, governments, and cities are keen to leverage the distinctive characteristics of the brewing cloud style to be highly automated, real time, and dynamic in their assignments. In a nutshell, the disruptive and transformative cloud paradigm promises sharp and significant increases in business dynamism, augmentation, and acceleration.

The Convergence of EA and Cloud Computing—In the past, we have moved from monolithic systems to multitiered architectures. As the service-orientation concepts become pervasive and popular, the enterprise IT is fully embracing them in order to be nimble and supple in their operations, offerings, and outlooks. Now, with the massive adoption of the path-breaking cloud idea, enterprises are steadily and smartly transforming themselves into on-demand, lean, instant-on, and adaptive organizations. The cloud, being an enterprise-class technology, can quite naturally merge and mingle with EA in preparing and providing advanced capabilities and capacities to global enterprises in precisely and perfectly anticipating volatile business needs and varying customer leanings. This acquired and extracted knowledge in turn leads to readying the underlying IT systems for proactively and preemptively conceiving, constructing, and delivering versatile and premium services. And this combination of EA and the

cloud paradigm is definitely bound to result in a series of game-changing revolutions for enterprises. That is, the incredible cloud paradigm, in sync with EA, is collectively capable of producing remarkable results in taking business entities to the next level. It is overwhelmingly clear that with the right kind of cloud technologies, strategies, and methodologies, all kinds of nonfunctional (quality of service [QoS]) attributes can be effortlessly and speedily realized in cloud enterprises.

In this book, we discuss the great implications of the cloud paradigm on EA. We dig deeper to extract and elucidate the perceptible and positive changes that will affect EA design, governance, strategy, management, and sustenance. We envision and explain what kinds of desired transformations each of the architectural blocks of EA undergoes in the light of this strategically significant convergence.

The Audience—This is primarily for enterprise architects, cloud evangelists and enthusiasts, and cloud application and service architects. Further on, cloud center administrators, cloud business executives, managers, and analysts will find this book informative and inspiring while formulating appropriate mechanisms and schemes for sound modernization and migration of traditional applications to cloud infrastructures and platforms.

The EA tool vendors can benefit a lot from this book in identifying, understanding, and justifying the new cloud-induced features and functionalities to be attached in their products for the forthcoming cloud era. As there are several unique concerns and challenges (performance, scalability, dependability, availability, security, controllability, visibility, etc.) at the cusp of this distinct convergence, university students and scholars are set to gain a lot from this book.

The Key Takeaways—We give a modern overview of EA in the context of the surging popularity of cloud computing. We have reserved separate chapters for each of the contributing architectures (business, information, application, integration, security, and technology) of EA to vividly illustrate the current and impending implications of the cloud theme on each of them. We have included a full-fledged chapter on the enterprise cloud. In addition to these, the future is for federated clouds and the vision is to establish the intercloud. Considering these developments, we have incorporated a chapter on cloud integration and composition architecture. Also, a chapter on cloud security architecture has been added. A comprehensive strategy chapter is introduced for enterprise architects and business executives to ponder and plan for the cloud-inspired transformations.

1

Cloud-Enabled Smart Enterprises!

INTRODUCTION

Enterprises are steadily and strategically undergoing a number of noteworthy transformations due to constant and consistent shifts occurring in many of the business-related aspects. Enterprises are increasingly information technology (IT)-driven and solely and squarely depend on the IT improvisations and innovations to surge ahead in meeting the varying and vast needs of their customers, clients, and consumers. The association and alignment between business and IT is tending to be tighter. That means any shift in the IT domain and discipline has immediate and intrinsic impacts and bearings on business operations, outlooks, and offerings. Newer and nimbler technologies are emerging and evolving; business processes are being integrated and innovated; new products, platforms, patterns, practices, and procedures are being unearthed; and so on.

In the past, businesses were forced to leverage and manage with whatever technologies were available at that point in time, but today the widespread scenario is quite contrary. That is, we come across a deluge of business-centric technologies these days. In other words, the gap between IT and business is being eliminated, and therefore IT is more tuned and turned toward business. Recent technologies are more business enabling and empowering. Any change or challenge within a business situation gets immediately noticed and attended to with the smart usage and leverage of these business-aware technologies.

Apart from these constructive and contributive technologies, flexible and futuristic architectures, epoch-making business models, facilitating frameworks, and proven methodologies are being frequently unfolded to prop up the envisaged business mission and subsequent strategy making, as well as their best-in-class realization. Business augmentation, acceleration, and

automation are being closely linked up with the simplicity, success, and sensitivity of information and communication technologies. Process engineering has become another active area of focus for IT professionals. Service orientation (SO) has become the most common architectural principle, paradigm, and pattern for designing and delivering enterprise-scale applications.

Composition is the most pragmatic and purposeful idea propelling the whole IT world today. Composites are emerging as the amenable, affable, and affordable building blocks for next-generation IT systems. Composite processes, interfaces, services, and applications are the ultimate result of the composition process. Composition containers, techniques, tools, languages, and standards are flourishing. IT infrastructures are going through a series of far-reaching transitions. We read and use the well-consolidated, centralized and converged, virtualized, automated, and sharable infrastructures very frequently. Standards-compliant and open platforms for application design, development, debugging, deployment, and delivery are hitting the market. Management and governance modules are increasingly produced and marketed in order to moderate the rising application complexity.

Multitenancy is a highly talked-about feature being inherently incorporated in IT servers, applications, platforms, databases, and services. Due to the extreme heterogeneity and multiplicity, the value and demand for multifaceted middleware backbones, containers, engines, hubs, buses, and fabrics is on the climb. That is, the reflective middleware is being made available for simplifying and streamlining the rough and tough integration, intermediation, aggregation, and arbitration requirements among application components in highly heterogeneous and complex IT environments. Other contributive components include software frameworks, design patterns and metrics, best practices based on experiences, and key guidelines out of expertise gained. These components individually as well as collectively are aiming to speed up and strengthen enterprise IT so that it can be furiously fast, supple, and sound in meeting next-generation business requirements.

THE BREWING IT TRENDS & TECHNOLOGIES

- **The Technology Space**—There is a cornucopia of disruptive, transformative, and innovative technologies (Computing, Connectivity, Miniaturization, Sensing, Actuation, Perception, Analyses, Knowledge Engineering, etc.).

- **The Process Space**—With new kinds of services, applications, data, infrastructures, and devices joining mainstream IT, fresh process consolidation, orchestration, governance, and management mechanisms are emerging. Process excellence is the ultimate aim.
- **Infrastructure Space**—Infrastructure consolidation, convergence, centralization, federation, and automation and sharing methods clearly indicate the infrastructure trends in computing and communication disciplines. Physical infrastructures become virtual infrastructures.
  - **System Infrastructure.**
  - **Application Infrastructure**—Integration Backbones, Broker Middleware.
- **Architecture Space**—Service-oriented architecture (SOA), event-driven architecture (EDA), model-driven architecture (MDA), and so on, are the leading architectural patterns.
- **The Device Space** is fast evolving (slim and sleek, handy and trendy, mobile, wearable, implantable, portable, etc.). Everyday machines are tied to one another as well as to the Web.

There are a number of spectacular shifts in the hot and happening IT space. Transformative, augmentative, and disruptive technologies are emerging and evolving steadily. In this section, we will discuss some of the pioneering and prominent technologies sweeping the IT discipline.

Miniaturization technologies are well received across the IT industry. Every hardware component is shrinking, whereas its power, usage, and value are on the climb. From the age-old mainframe era to today's personal and professional tablets, palmtops, and laptops, the aspect of miniaturization has been gaining a lot of traction and attraction. We read about invisible, disappearing, infinitesimal, and calm modules, tags, labels, stickers, chips, and pads collectively forming highly pervasive and persuasive computers, communicators, sensors, and actuators. Slim and sleek handy and trendy handhelds, wearables, implantables, portables, nomadic and wireless devices, industry machines, medical instruments, consumer electronics, web and information appliances, kitchen utensils, displays, gadgets, and gizmos are very dominant and prominent in our daily work and walk environments. Nanotechnology, system-on-a-chip (SoC), microelectromechanical systems (MEMS), and so on, are some of the eye-capturing and elegant miniaturization technologies.

Integration technologies are clearly occupying a top position. All kinds of siloed, legacy, closed, inflexible, and monolithic systems are accordingly

modernized and made interoperable in order to create integrated IT environments. Business integration has been a challenging affair for IT service and solution providers due to the multiplicity of heterogeneity-induced complex systems. There are industry-strength and open standards being specified by agencies and consortiums. There are standards-compliant brokers, middleware, hubs (enterprise application integration [EAI]), fabrics, buses (enterprise service bus [ESB]), data services and composites, enterprise information integration (EII), and so on for simplifying and streamlining the diverse, distributed, and decentralized IT applications, services, and databases. Integration is the base for intermediation, aggregation, composition, collaboration, and so on among software components, networks, systems, and finally, environments.

Composition technologies are becoming popular due to the demand for creating business-aware and -aligned composites. In the recent past, mashups (business, information, and user interface) have been domineering. Orchestration and choreography are the popular mechanisms and schemes for ensuring real-world and real-time composites. In the sensor world, fusion is the buzzword; in short, composition technologies are penetrating into diverse fields. In a smart home environment, multiple sensors (heat, humidity, gas, fire, etc.) combine well to arrive at accurate and real-time information for remote, analytical, decision-enabling, and actuating IT systems to ponder about the next course of action in time.

Collaboration technologies are very popular with the heightened needs for several kinds of collaborative applications and services. Leading IT product vendors are showing extreme interest in producing and presenting a variety of collaboration suites for everyday use. E-mail, chat, and messaging are the well-known and ubiquitous types of collaboration software.

Recently, some of the underutilized technologies such as virtualization, federation, and automation have been gaining the upper hand in the IT space. In fact, the much-published Gartner report ranks virtualization as the leading technology. It is clear that virtual machines (VMs) have brought in drastic and desired changes on IT infrastructures. With the unprecedented usage of hypervisors, higher utilization, portability, interoperability, autonomy, and elasticity of IT infrastructural components are being easily ensured. Notably, there is a virtualization-sponsored segregation among software and hardware modules. That means any number and type of software could run on virtualized systems. Decomposition and composition are the main techniques empowering the value and power of virtualization. Considering the strategic significance, every kind of infrastructure is being meticulously virtualized in order to be shared across. There are hypervisors

for large-scale systems and microvisors for resource-constrained devices. Creating and managing the scores of VMs out of physical servers is being simplified and presented as a viable and long-term solution for the ills confronting the expensive yet underutilized and unutilized IT infrastructures. In short, dependencies are being decimated toward a boundary-less information flow. Light coupling and decoupling are being insisted on for the future in order to bring in tightness between business and IT.

It is possible to run multiple applications sharing one physical machine or storage device to increase utilization rates, or to allocate multiple machines and storage devices to one application to increase its performance. In other words, the one-to-one dependencies between applications and their underlying platforms are removed. This hidden capability provides unprecedented flexibility in meeting service-level agreements (SLAs). IT optimization, resource utilization, and sharing are strongly growing with the materialization of virtualization and automated resource provisioning techniques. Other notable developments in the IT field include consolidation, centralization, and convergence. The combination and clustering of technologies scintillatingly induce newer and nimbler innovations and improvisations.

Connectivity technologies are the most pervasive and penetrating technologies these days. There are wireline as well as wireless communication technologies for networks of different sizes, scopes, and structures. There are generic as well as special-purpose networks such as body area networks (BANs), personal area networks (PANs), local area networks (LANs), metro area networks (MANs), and wide area networks (WANs). Worldwide consortiums and bodies are being formed to arrive at open and implementable communication standards that insist on specific protocols and technologies for certain scenes and situations. With embedded devices joining the mainstream IT space, there is a cornucopia of new communication protocols. The connectivity space is a very interesting and inspiring story for the globally as well as locally connected world. In the communication landscape, there are several buzzwords such as ambient, autonomic, and unified communication. The transition is from anywhere, anytime communication to everywhere, every-time communication. With the larger device space set to grow and glow exponentially, machine-to-machine (M2M) communication needs to thrive to facilitate the people-centric and premium services that must be delivered to the right users at the right time, in the right quantity, and at the right place.

Computing technologies are really inspirational and instrumental for the IT world. Leading IT players and pundits have brought out scores of

computing paradigms with the ultimate objective of automating people's ubiquitous information and service access. Further on, with their maturity, financial transactions, commercial and business activities, and decision enablement are being greatly simplified and smoothened. That is, slowly yet steadily, personal as well as professional requirements, processes, and tasks are becoming fully automated with the embracement of computing technologies and infrastructures.

In the recent past, there has been a greater awareness and awakening on fulfilling the hard-to-crack nonfunctional requirements (quality of service [QoS] attributes) such as scalability, high performance and assurance, availability, security, dependability, affordability, amenability, consumability, and so on of the IT solutions, systems, networks, and environments. Since the beginning of the IT age, mainframe computers have been extremely powerful and capable of accomplishing billions of transactions per day without any slowdown and breakdown. Today's powerful and technologically advanced server machines cannot compete with the age-old mainframes in the QoS attributes. However, due to mainframes' rigidity and conservativeness, there came a host of delectable and dexterous transformations in the IT landscape.

Without an iota of doubt, the distributed computing model has definitely changed the structure and scope of enterprise IT. There is a myriad of flourishing distributed architectures and approaches such as the client-server and multitier methods. The indomitable web is the cool and catalytic paradigm fully subscribing to the distributed architecture. Through the redundancy of IT resources, high availability, accessibility, scalability, fault-tolerance, and other needs of IT applications are being realized quite easily and elegantly. Further on, peer-to-peer (P2P), cluster, and grid computing models could ensure high availability, performance, and scalability of various types of IT resources. Parallel, multicore, super, and petaflop computing models are fulfilling the high-throughput goals.

Mobile computing enables all kinds of wireless, nomadic, implantable portable, and mobile devices to achieve anywhere, anytime, computing. Besides, there are pervasive and ubiquitous computing concepts materializing for context-aware and cognition-enabled applications. Autonomic, on-demand, and utility computing styles are primarily to make computing a social utility. Real-time computing is for real-time applications.

For environmental sustainability, the idea of green computing is gaining widespread reception and recognition these days. Data centers and server farms comprising a deluge of varied and vast IT infrastructures and resources are drawing a huge amount of energy, which is unfortunately

becoming scarce and expensive. The colossal IT centers are also dissipating a lot of heat into our living environment. Thus, it is absolutely clear that IT is one of the major culprits for environmental degradation. On the other hand, professionals and professors are overwhelmingly in unison on the overall view that IT-based technological advancements come in handy in effective energy preservation. That is, the emergence of IT-based energy harvesting and conservation technologies and methodologies is widely being given a warm welcome. For example, smart monitoring and metering of the electric grid and its subsystems (named as smart grid) is emerging as the frontrunner for energy efficiency in the energy-starved world. Thus, green computing is all about a bevy of computing techniques, tips, and tools for ensuring and enabling greener environments.

Biology-inspired computing models are fast emerging as a way out for solving computationally and intellectually challenging business, social, and scientific problems in our everyday lives. High-data and process-intensive applications are being tackled through a series of interdisciplinary efforts. DNA computing, quantum computing, optical computing, and so on are some of the maturing models creating waves and buzzes in the struggling IT industry.

Service computing is definitely a paradigm shift in the IT industry. Hordes of modernization, transformation, and optimization tasks are being readily achieved with the perfect and pragmatic usage of amazing service concepts. Every entity and element in IT is being expressed and exposed as a service. This clearly signals the vision of "IT as a Service" being established and sustained. In subsequent chapters, there will be detailed descriptions on this highly successful, sizzling, and succulent paradigm. This service enablement will ultimately land in the era of shared and virtual computing.

Smart computing is the latest in the annals of the expanding and enchanting computing world. Data-to-information transition is being sped up with a spate of path-breaking schemes and mechanisms. Subsequently, knowledge extraction and engineering disciplines are going through a slew of positive and progressive shifts with the rise of robust and resilient technologies in the fields of artificial intelligence, ambient intelligence (AmI), and swarm intelligence. There has been continuous empowerment of IT infrastructures, processes, and applications to be anticipative, adaptive, and articulate in their operations, offerings, and outlooks. The self-awareness and surroundings awareness go a long way in deriving and deploying next-generation IT solutions. The perfect and precise understanding of the changing needs of users enables advanced and adroit IT systems to be proactive, preemptive, and prompt to conceive and deliver multifaceted applications and services to users.

Situation awareness is zooming ahead with the voluminous production of miniaturized sensors and actuators. Mesh network technologies and topologies are substantially contributing to heterogeneous, wireless, and smart sensors to form ad hoc networks in order to gather, glean, and gain actionable and accurate insights about the users' movement, mood, and needs in a particular place. This extracted knowledge base enables cyber systems to fulfill both the mental as well as the physical needs in time with accuracy and alacrity. Thus, the noun "smartness" is pervasive, penetrative, and persuasive. Today, every tangible thing is being attached with this adjective "smart." For example, we come across advertisements such as smart hotel, home, hostel, hospital, and so on very frequently.

TREKKING TOWARD THE SMART WORLD

According to IT visionaries and luminaries, there will be a seamless and spontaneous merger of everyday technologies to create a kind of technology cluster and cloud to fulfill our personal as well as professional requirements insightfully, instantly, and instinctively. That is, there comes the possibility of merging our minds with machines. This shift is to enforce and empower a series of newer possibilities and opportunities. Learning will be an everywhere and all-time affair because we will have intimate and real-time access to the world's information assets and knowledge base using our accompanying electronic gizmos, and on the other side, we will also have an unfailing backup of our brains on massive-scale digital storages. Massive research endeavors and efforts are concertedly put into these seemingly magical and mesmerizing technology themes, which will let us beneficially connect our nervous systems to computers.

The next 20 years will see more influential innovations toward making our lives exciting, eerie, and exotic. Disruptive and transformative technologies with smart synchronization with a galaxy of precisely procuring, intelligently processing, perfectly perceiving, and instantaneously performing technologies will emerge to realize a wider variety of revolutionary and knowledge-driven applications and services that lead to making our daily environments insightful, interactive, and informative. Auto-identification tags digitally carrying our personal profile and preferences will map, mingle, mesh, and mash up with other contributing elements and entities in our personal as well as professional environments toward

the realization of not only our information and transaction services but also our physical needs. The trickling trend is to enable seamless linkage between the physical and the cyber worlds. Sensors and actuators are the eyes and ears of next-generation IT.

Our daily articles, utensils, tools, and products can be transformed into smart objects and artifacts by attaching them with infinitesimal, invisible yet intelligent computers, communicators, codes, chips, controllers, sensors, tags, stickers, displays, and so on. That is, ordinary items become extraordinary. For example, our coffee cups, dinner plates, medicinal tablets, clothes, and other common, casual, and cheap things will be empowered to act smart in their interpretations and interactions with other entities in the vicinity, with remote IT systems, and with their owners. The overall process is highlighted here. First, all the tangible, worthy, and everyday things in our personal, professional, and social environments need to be quietly and quickly transitioned into sentient and digital artifacts. Secondly, they should be able to find and bind with one another seamlessly and spontaneously. In other words, the first is instrumentation and the second is service enablement. That is, every single entity becomes a service consuming, brokering, and/or providing element. The service enablement empowers them to talk through messaging. From there, the digitalized or smart objects and devices could compose and collaborate to be contributive and constructive for crafting sophisticated and situation-aware IT solutions. Service integration (direct or indirect) leads to adaptive and aware services. Outwardly, the service-exposing devices are strengthened to form resourceful and multipurpose device ensembles that are cognitive and context aware; ultimately, smart environments get formed and sustained.

This kind of fascinating, fabulous integration among all kinds of everyday things, such as implantable, mobile, wearable, handheld, portable, fixed and nomadic devices, kitchen vessels, medicine cabinets, manufacturing machines, vehicles on the move, robots, and consumer electronics at the ground level with local as well as distant IT applications (Web 1.0 [simple web], Web 2.0 [social web], Web 3.0 [semantic web], Web 4.0 [smart web], enterprise, and cloud-based software as a service [SaaS], etc.) will result in the Internet of Things (IoTs). Hence, there is no doubt that future generations will experience and realize complete and compact technology-sponsored and splurged living. The impacts and implications of information and communication technology (ICT) in our lives become bigger, deeper, brighter, yet calmer as days go by. The technology-inspired precision and perfection will be common, yet decisive and decision enabling. The disciplines such as

AmI, smart environments, ubiquitous computing, and cyber-physical systems (CPSs) are in one or another way related to the vision of IoT.

Today, everything is being given the adjective "smart." Leading IT players are brimming with confidence to make everything smart. Implementation technologies, methodologies, processes, infrastructures, middleware, best practices, key guidelines, evaluation metrics, and other enabling architectures, frameworks, utilities, widgets, and so on are being trimmed and tuned toward the goal of establishing the smart world. The stability, maturity, adaptability, affordability, and dependability of technologies are being critically reviewed and revisited through a host of transnational initiatives by IT professors, pundits, and professionals. Even enterprises are not left out, and there is a deluge of dissertations and deliberations on smart enterprises. In the ensuing sections, we will discuss the conspicuous contributions of cloud computing in designing, developing, and deploying smart enterprises.

REVISITING THE ENTERPRISE JOURNEY

Every enterprise is started with a clear-cut vision, realization strategy, implementation roadmap, constructive and contributive processes, people with sufficient education, experience and expertise, and so on. However, the ultimate success of all the endeavors and efforts solely and squarely depends on the underlying IT environment. In short, information technologies have a direct and distinct bearing on how enterprises are being run and managed in accordance with the varying expectations of their stakeholders. In the beginning, business was IT-driven, that is, businesses had been established and supported with the available technologies of those days. Therefore, the gap between IT realities and business sentiments was wider. However, today the scene is dramatically different. With the unearthing of business-aware and -aligned technologies, there is a closer and tighter alignment between business and IT. The distinct advantage due to this twist and turn is that any business change and challenge can be immediately taken care of in a positive manner by the enterprise IT. Precisely speaking, the strength and sustainability of technologies decides the success of enterprises.

Primarily, the nonfunctional attributes such as agility, sensitivity, responsiveness, autonomy, and adaptivity of enterprise computing are being strongly insisted upon by enterprise owners. Thus, the vision is to strategize, craft, and operate an optimal IT infrastructure that can

support business agility, adaptivity, affordability, efficiency, and continuity. Visionaries and experts, through their illustrious and industrious experiences and expertise, have formulated the following traits and tenets for the next-generation IT ecosystem:

- Simplified, synchronized, and smart IT
- Sensitive, responsive, and real-time IT
- Converged, dynamic, on-demand, and autonomic IT

A few proprietary as well as standardized approaches to achieve the core objectives have been proposed by leading industry players as follows:

Dynamic Enterprises

Fujitsu's Triole (http://www.fujitsu.com/global/services/solutions/triole/index.html) is one such initiative for building and maintaining dynamic IT capability. Triole is a compelling architecture and product strategy to support and streamline complicated IT operations and management. It is a learned and refined process to create industrialized IT infrastructure. It is all about the optimal management of IT infrastructures and services through the two core technologies: virtualization and automation.

- Virtualization—As has been known for a long time, virtualization is all about flexibility. This is achieved by creating an additional layer for bringing in the desired flexibility among various IT resources in the stack. This new layer is for cleanly and clearly separating the prickling and perpetual concerns such as the inhibiting dependencies and deficiencies. In layman's terms, virtualization separates IT applications and data from their dedicated runtimes, which in turn leverage operating systems, processors, memory, and storage. The idea is to negate the traditional style of different applications running in different infrastructures. In other words, a single IT infrastructure can host, deliver, and manage a variety of diverse applications. Infrastructures are accordingly partitioned, provisioned, and even pooled to run different IT services and applications effectively. Virtualization enables IT infrastructures to adapt quickly to changing business requirements as software and hardware are elegantly segregated. Pooling encourages efficient utilization of resources; thereby, virtualization proves to be a highly impactful and insightful technology.

- Automation—Pundits and professionals encourage compact automation in place of manual operations as enunciated by IBM's autonomic computing concept. IT systems and platforms will be empowered to be autonomic in their diagnostics and decisions. This not only enhances the efficiency and affordability but also ensures continuity even in the midst of any unexpected outages and disasters.

Adaptive Enterprises

The white paper authored by Kerry Main, senior solutions architect, HP Canada, quotes the famous statement of Charles Darwin that "it is not the strongest of the species that survives nor the most intelligent, but the most responsive to change."

In an adaptive enterprise, business and IT are synchronized well to capitalize on all kinds of changes (business and technology). IT breaks away from the inflexible, closed, and silo-like systems of the past to create open and forward-looking systems that deliver more value and vigor to the business. The major gains being achieved by an adaptive enterprise include adding partners to supply chain system in hours rather than weeks or months, doubling the pace of product introduction without sacrificing the quality attributes, shifting IT investment from infrastructure maintenance to core competencies, and so on. The inherent capabilities of an adaptive enterprise include heightened business availability and continuity, enhanced IT consolidation and simplified services management, dynamic collaboration to maximize productivity through sharing and optimal utilization of IT resources, and so on.

According to SAP reports, this vision stands on business model innovations that can be pursued along three dimensions: customer-centric innovation, supply-chain-centric innovation, and organizational process innovation. It is argued that there is unmatched growth power based on business model innovation. It is difficult for competitors to reproduce the business model innovation. New business models are much harder for other companies and corporations to imitate since they are dependent on organization-specific competencies. The key gains include the facilitation of changes while retaining the successful business models, empowerment of people toward new realities, establishment of collaboration among all the constituents and participants, inspiration for cross-functional thinking in order to spur innovation, focused indulgence on process innovation, exploration and experimentation of newer avenues for fresh revenues, and so on.