The Smarter Planet: Built on Informatics and Cybernetics

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ABSTRACT

IBM's Smarter Planet initiative is a multi-disciplined approach that integrates the key tenets of the IMSCI 2014 (The 8th International Multi-Conference on Society, Cybernetics, and Informatics) conference [1]. Industry has seen a tremendous explosion of data growth. Organizations that dealt with Terabytes (TB) and Petabytes (PB) just a couple of years ago are now faced with the challenge of dealing with Exabytes (EB) of data. An Exabyte is 10^{18} Bytes – a million times a billion bytes! The amount of information available today is truly remarkable; so much that it is considered by many in industry as a new "natural resource." Computing has similarly grown and made major advances. Today's fastest supercomputer is a 33.8 PFLOPS machine (33.8 x 10^{15} floating point operations per second) and applies analytics to predict weather to a degree that was unimaginable ten years ago. The Smarter Planet approach goes beyond the traditional data sources to include a plethora of sensor data (e.g., utility readings, concrete pressure sensors on a bridge, etc.) and applies analytics to provide new Informatics, which in turn can be used to advance new Cybernetics (e.g., Smarter Buildings, Smarter Cities) to address Societal needs in new, innovative ways. [2]

Keywords: Smarter Planet, Informatics, Cybernetics, Advanced Analytics, Big Data, Knowledge Management

1.0 INTRODUCTION

The focus of this paper is on the role of Informatics and Cybernetics [1] in the evolution of IBM's Smarter Planet initiative, and a brief description of the underlying computer (data processing) technology advances Smarter Planet is built on. Whereas a traditional Knowledge Management (KM) system [3] [4] automates the Cybernetics and Informatics that an organization utilizes to run various aspects of its business, one can envision the world as the composition of numerous organizations (governments, industries, academic institutions, and even individuals) working together towards common or inter-related goals and objectives. Advanced Analytics can be applied to increase the effectiveness and efficiency of traditional KM systems. [5]

In a seminal speech to the Council of Foreign Relations, IBM Chairman and CEO Sam Palmisano first noted some grand challenges observed world-wide, as a result of several Global Innovation Outlook (GIO) Summit meetings IBM sponsored with leaders and technologists around the world:

"How much energy we waste: According to published reports, the losses of electrical energy because grid systems are not "smart" range as high as 40 to 70 percent around the world.

How gridlocked our cities are: Congested roadways in the U.S. cost $78 billion annually, in the form of 4.2 billion lost hours and 2.9 billion gallons of wasted gas—and that's not even counting the impact on our air quality.

How inefficient our supply chains are: Consumer product and retail industries lose about $40 billion annually, or 3.5 percent of their sales, due to supply chain inefficiencies.

How antiquated our healthcare system is: In truth, it isn't a "system" at all. It doesn't link from diagnosis, to drug discovery, to healthcare deliverers, to insurers, to employers. Meanwhile, personal expenditures on health now push more than 100 million people worldwide below the poverty line each year.

How our planet's water supply is drying up: Global water usage has increased six-fold since the 1900s, twice the rate of human population growth. According to the Asian Development Bank, one in five people living today lacks access to safe drinking water, and half the world's population does not have adequate sanitation.

And, of course, the crisis in our financial markets: This will be analyzed for decades, but one thing is already clear. Financial institutions spread risk but weren't able to track risk—and that uncertainty, that lack of knowing with precision, undermined confidence." [2]

Recognizing IBM's unique opportunity to provide new leadership and leverage the corporation's 100 years of technical innovation, inventions, and awards [6], Mr Palmisano described IBM's commitment to "building a smarter planet" and the key tenets of the Smarter Planet initiative:

"First, our world is becoming instrumented: The transistor, invented 60 years ago, is the basic building block of the digital age. Now, consider a world in which there are a billion transistors per human, each one costing one ten-millionth of a cent. We'll have that by 2010. There will likely be 4 billion mobile phone subscribers by the end of this year… and 30 billion Radio Frequency Identification tags produced globally within two years. Sensors are being embedded across entire ecosystems—supply-chains, healthcare networks, cities…even natural systems like rivers.

Second, our world is becoming interconnected: Very soon there will be 2 billion people on the Internet. But in an instrumented world, systems and objects can now "speak" to one another, too. Think about the prospect of a trillion connected and intelligent things—cars, appliances, cameras, roadways, pipelines… even pharmaceuticals and livestock. The amount of information produced by the interaction of all those things will be unprecedented.

Third, all things are becoming intelligent: New computing models can handle the proliferation of end-user devices, sensors and actuators and connect them with back-end systems. Combined with advanced analytics, those supercomputers can turn mountains of data into intelligence that can be translated into action, making our systems, processes and infrastructures more efficient, more productive and responsive—in a word, smarter." [2]

This paper describes the innovation and technologies behind the Smarter Planet imitative, which represents a state of the art application of Informatics and Cybernetics fundamentals.

2.0 AUTONOMIC COMPUTING

Enterprise Systems Management (ESM) has evolved over the last forty years, as the size and complexity of systems within organizations have grown. The administration and support of the many system elements (e.g., servers, storage and networks) becomes increasingly challenging as an organization transitions to managing heterogeneous systems across their enterprise. Even today, the majority of our industry struggles to manage system outages, configuration changes, performance tuning, and many other ESM challenges. The Autonomic Computing vision emerged from decades of research and development focused on increasing ESM automation and decreasing the need for human intervention. The term "autonomic" is used to connote the unprecedented level of automation the human body has – i.e., our autonomic nervous systems, which subconsciously governs numerous, complex body functions. For example, our body autonomously measures oxygen levels, body temperature, blood sugar levels, etc. – and then automatically changes respiration, circulation and digestion to dynamically address issues. One doesn't think about increasing one's breathing and circulation when climbing stairs; that's done autonomously by the body in order to control the anomalous exertion being forced on the body.

2.1 TENETS OF AUTONOMIC COMPUTING

Autonomic Computing (AC) has four tenets: Self Configuring, Self Healing, Self Optimizing, and Self Protecting. [7]
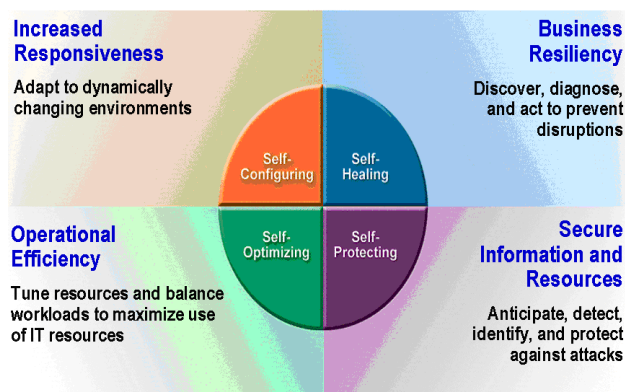

Figure 1: Autonomic Computing Tenets

These tenets, illustrated in the figure above, include the following capabilities:

Self Configuring – Many of today's corporate data centers have a variety of components from a variety of vendors. Installing, configuring, and integrating components is time consuming and error-prone. The AC vision is to automate the configuration of components and systems according to high-level policies; and the rest of the system adjusts automatically.

Self Healing– Determining problems in large, complex systems today can take a team of programmers and system administrators multiple weeks. The AC provides automated detection, diagnosis and resolution to localized software and hardware problems.

Self Optimizing – Today's hardware and software contain hundreds of measurements, diagnostics, alarms, and many more tuning options and parameters. The AC strategy is to continuously seek opportunities to improve performance and efficiency.

Self Protecting – The majority of today's mechanisms for protecting and detecting system attacks and failures are silo'ed and are slowly beginning to use standard security naming conventions. The AC approach is to correlate the information from many disparate protection and detection system elements, to automatically identify and defend against malicious attacks and cascading failures, to provide early warning, and to prevent system-wide failures.

2.2 AUTONOMIC COMPUTING ABSTRACTIONS

A novel aspect of the AC vision is the goal of making decisions that take multiple perspectives into consideration. This can be accomplished with contextual analytics, which provide views of the system elements from various levels of abstraction.
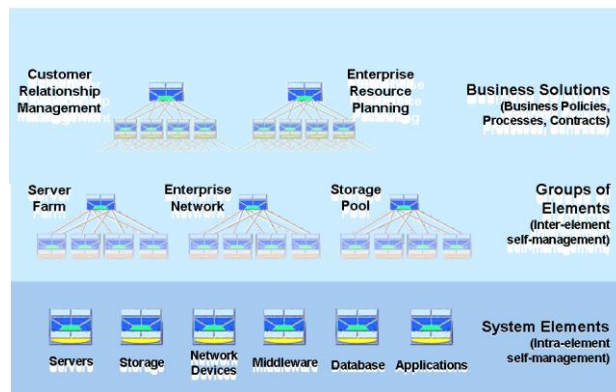

Figure 2: Autonomic Computing Abstraction Levels

Figure 2 illustrates three different views of the same system elements, but with a variety of relationships within different contexts. The lower level abstraction views system elements as a stand-alone entity, and only considers the type of element and vendor specific informatics when diagnosing problems and selecting corrective action. The middle level abstraction looks at the aggregation of similar elements (e.g., a pool of servers) and would extend the diagnostics and problem resolution to consider things such as load balancing, disaster recovery policies, etc.

The top level abstraction takes on a very different perspective. In this example, the top level abstraction places system elements within the context of the corporate missions the system supports. One might place a higher priority on keeping lighter computing loads on mission critical system elements, rather than uniformly spreading computing loads across an enterprise-wide server farm.

2.3 AUTONOMIC COMPUTING CYBERNETICS

The AC design is built on the premise that one must be able to *measure, make a decision, and control* system elements at all of the abstraction levels (as described in the example in Section 2.2). This is called the AC *control loop*. Control loops are designed to provide the self-configuring, self-healing, self-optimizing, and self-protecting capabilities.
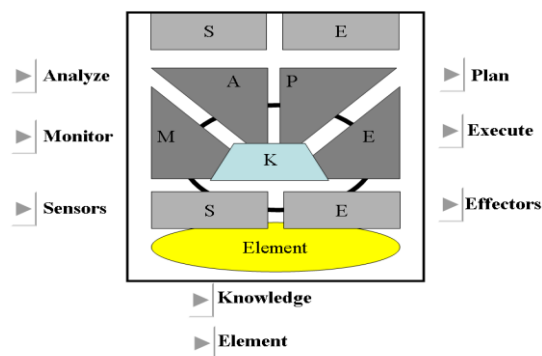

Figure 3: Autonomic Computing Control Loop Component

Figure 3 illustrates the composition of the AC control loop components. The **monitor** sub-component includes mechanisms that collect, aggregate and filter element data (*measures*) from sensors associated with the specific element being controlled. The **analyze** sub-component is made up of mechanisms that model or analyze complex situations within the scope of the control loop. The **plan** sub-component decides the actions needed to achieve the desired goals and objectives. (Note : Analyze and Plan are used to support the "*decide*" phase of the AC control loop.) The decision logic has embedded "act, monitor and learn" functions, which verify the plan successfully solved the problem or achieved the desired outcome. The **execute** sub-component executes the actions planned, supporting the *control* phase of the AC control loop. The **knowledge** sub-component represents the KM associated with the controlled element, and continuously grows as it stores the information that's been measured, analyzed, planned, and executed – and the ensuing results.
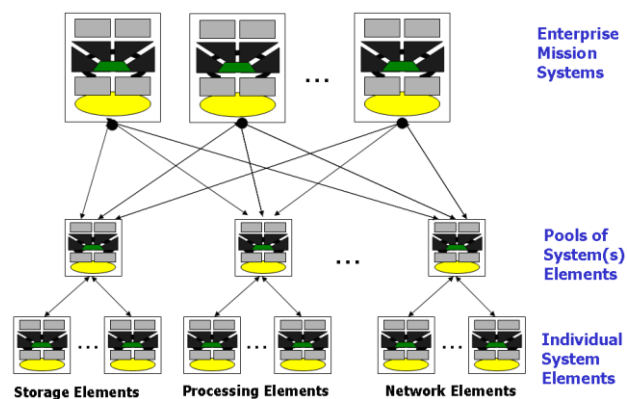

Figure 4: Autonomic Computing Hierarchical Design

Note that the AC control loop structure illustrated in Figure 3 has sensors and effectors at the top and at the bottom. This design provides the ability to manage a single system entity, a pool of entities, or the aggregation of multiple entities -- i.e., in support of the various system levels of abstraction described in Section 2.2 and illustrated in the hierarchical figure above.

It should be noted that AC is not a product. It is a vision that can be implemented at various levels of automation (e.g., self-healing and self-protection), and support many system level abstractions (e.g., resource pools or mission systems). As Information Technology (IT) matures, system elements have improved the information provided through "sensor" interfaces, and have increased the element commands that can be specified through "effector" interfaces to the system element.

3.0 BUILDING A SMARTER PLANET

The authors contend that Autonomic, which focused on enterprise systems management and large data centers, was the technical predecessor to the Smarter Planet initiative. Smarter Planet extends the scope of sensors well beyond the traditional system elements (e.g., servers, storage, networks, etc.) and applies advanced analytics to support a much broader set of informatics, inter-related abstractions (societal areas) and cybernetics. The authors recognize there were numerous other technical and non-technical advances that contributed to the evolving Smarter Planet campaign.

Whereas Autonomic Computing acted on informatics provided from system elements, Smarter Planet's cybernetics approach is to act on informatics from any type of data source – ranging from a utility meter or pressure sensor on a bridge, to mobile devices such as mobile phones and traffic cameras, or even passive micro-chips embedded in a pet or human being.

The Smarter Planet cybernetics is built on three tenets:

1. **Instrumented**: anything with a sensor can be an **Informatics** element. As previously described some sensors are uni-directional (they only provide data, or they simply accept commands). The more useful elements are bi-directional and do both!
2. **Interconnected**: A smarter planet sensor must be interconnected (preferably to the internet, or a hub computer w/ access to the internet), otherwise one loses a tremendous amount of automation by having to include a human in the loop (to read the data and enter it into the system). Some sensors need their data to be converted (e.g., analog to digital, or proprietary representations to industry standard representations).
3. **Intelligent**: And a smarter planet solution is built on intelligent processing (**Cybernetics**) – exploiting advanced analytics to optimize effectiveness and efficiencies from every possible perspective
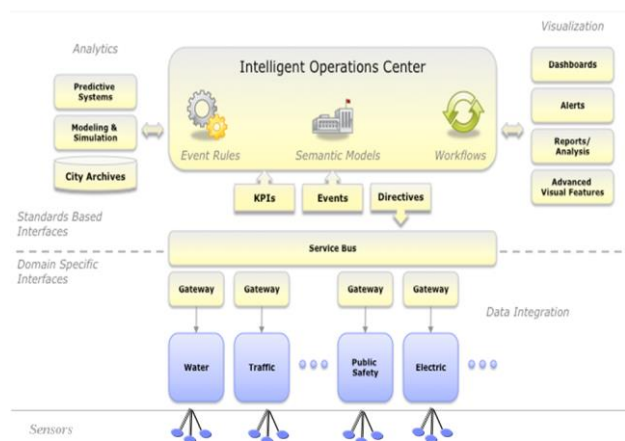

Figure 5: Intelligent Operations Center (IOC)

The Intelligent Operations Center (IOC) is the framework that enables the Smarter Planet to leverage different types of sensors (instrumented sensors and data sources), integrate the sensor data (provide interconnectivity), apply advanced analytics (intelligence) and then define and automate the smarter cybernetics. Like the AC Control Loop Component, it supports the closed-loop cycle to the degree supported by the associated sensor instrumentation.

In the speech Palmisano gave at the Council on Foreign Relations in New York City on November 6, 2008, he discussed IBM's Smarter Planet vision – a new strategic agenda for progress and growth. Palmisano outlined the premise of a smarter planet and the coming of age of a whole new generation of intelligent systems and technologies—more powerful and accessible than ever before.

It provided a way for industries, infrastructures, processes, cities and entire societies to be more productive, efficient, and responsive. Given the data explosion and computing advances of the previous millennium, Palmisano believed there was an opportunity to address the problems and challenges that were gripping the world during 2008. A world capable of making more intelligent decisions—from smarter power grids, to smarter food systems, smarter water, smarter buildings, smarter healthcare, and smarter traffic systems.

Palmisano recognized that everything (including cars, power grids, transportation, phones, etc.) was becoming more instrumented and interconnected. This technology phenomenon produced more volumes, velocity, variety, and veracity (four Vs of Big Data) of information and data being captured than ever before.

By 2010, governments and industries were no longer questioning the Smarter Planet vision nor values – they were looking for knowledge and experience on how to create Smarter Planet solutions. Some of these are included in the figure below.

Figure 6 – Smarter Planet Building Blocks

On January 12, 2010, Sam Palmisano kicked off the new year and decade with a follow-up to the Smarter Planet speech with a new speech called "The Decade of Smart" at the Chatham House in London, England which evolved the Smarter Planet initiative into a multiplatform strategy promoting the way in which IBM technology and know-how helps industry, government, transportation, energy, education, healthcare, cities, and other businesses work smarter and contribute to building a smarter planet. Sections 3.1 and 3.2 describe the more mature "Smarter Buildings" and "Smarter Cities" solutions in more detail.

3.1 SMARTER BUILDINGS

In the U.S., buildings consume 70% of all electricity, up to 50% of which is wasted. Commercial buildings lose as much as 50% of the water that flows into them. By 2025, buildings will be the single largest energy consumers and emitters of greenhouse gasses on our planet. [8] In an attempt to reduced buildings' wasted resources – over the last decade, building owners have installed smart sensors and control systems that can detect and sense various conditions and emit alerts or responses of many disparate systems. These efforts have only lead to minimal costs savings. The challenge for many building owners is how do you collect the Big Data 4V's from the silo information to provide operational and performance improvements in the building. This is a comprehensive effort because most of the building systems (energy, heating, lighting, water, security and other specialized systems) operate independently, through a mix of vendors, and have different protocols and transport mechanisms.

Building managers think and manage buildings along three dimensions: energy, operations, and space. They need to know where are opportunities to save energy; identify operational and/or capital improvements; and ability to optimize utilization of buildings space. The IBM Smarter Building solution solves these building managers' problems by addressing these key challenges: energy and asset management, building operations management, and effective space utilization. The IBM Smarter Building solutions set has the following main areas:

Energy management - energy management is the real-time monitoring of building and data center equipment. It reduces energy consumption and waste over the life cycle of a building and increases facility performance in a sustainable manner.

Operations management - operations management includes asset management and performance, utilization,

availability, and life-cycle management. The portfolio of building assets is optimized through asset visibility and operations management.[8]

As shown in Figure 7 - the IBM Smarter Building solution was built and designed around the elements of *visualization, intelligence, interconnected, instrumented,* and *physical*. These solution capabilities enable building managers to: integrate and optimize the physical and digital infrastructure of buildings; create facilities that are more cost-effective, operationally efficient, productive, safe, secure, and environmentally responsible; gather data, manage assets, monitor sensors, centralized analytics optimization; and distributed control. These Smarter Building solution capabilities will enable the integration of a city's buildings. When interactions between a city and buildings exist, the buildings can contribute to the health of the city. The city as a whole can reduce energy consumption and carbon dioxide (CO_2) emissions by 50–70%, energy usage reduced by up to 40%, maintenance cost 10-30%, and save 30–50% in water usage.
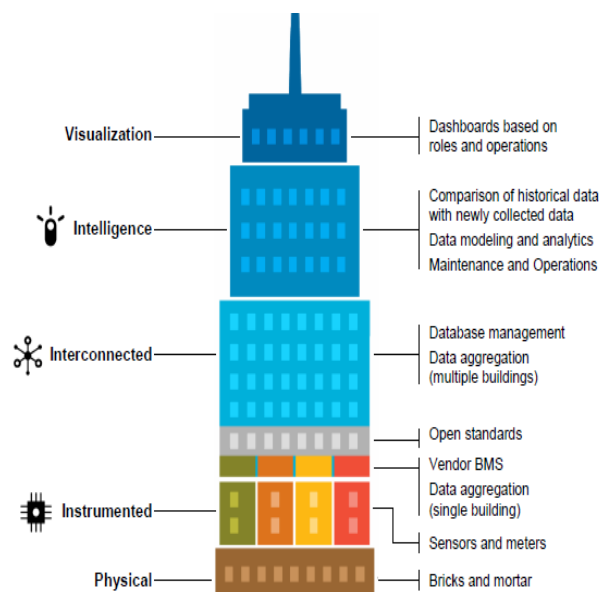

Figure 7 – Smarter Building Architecture Elements

3.2 SMARTER CITIES

Governments and business are faced with shrinking budgets and limited resources but need to meet demanding pressures to improve energy consumption, traffic gridlock, aging infrastructure, healthcare services, financial markets, food production, etc. to spur economic growth and improve quality of life for citizens. Government officials couldn't meet these challenges because most critical information is often stored in disparate systems across disconnected departments, hindering a clear view of the operational picture and increasing the difficulty of coordinating agency efforts. Without a single, integrated view of events, incidents or impending crises, and without the ability to rapidly share information, a city might be unable to effectively deliver services in a sustainable fashion, protect citizens or drive future economic growth. [10]

Government officials and industry involved in city development or federal response services have applied a variety of IOC-based solutions that provide a centralized operations dashboard to help city leaders gain insight into various aspects of city management or federal responses. The centralized operations dashboard spans agencies and enables drill-down capability into underlying agencies, such as emergency management, public safety, social services, transportation, or water. This approach enables cities to manage large complex environments,

communicate more effectively with citizens, understand the state of the city and collaborate between departments. This saves cities money by reducing staff needed to make decisions and by more effectively deploying resources.

These IOC capabilities provide leading cybernetic technologies where systems are involved in a closed signaling loop; that is, where action by the system generates some change in its environment and that change is reflected in that system in some manner (feedback) that triggers a system change. This solution offers integrated data visualization, real-time collaboration and deep analytics that can help city/federal agencies prepare for problems before they arise and coordinate and manage problems as they occur, to enhance the ongoing efficiency of city operations. Executive dashboard capabilities give decision makers a real-time, unified view of operations so they can see who and what resources are needed and available. Cities, federal agencies, and industry can share information instantly across agency lines to accelerate problem response and improve project coordination. [9]

In the past, individual city agencies often focused only on their own operations and were unable to share information with other agencies and departments. The IOC is designed to help multiple agencies and departments share information — such as metrics, events and processes — and collaborate in near-real time, allowing cities to better anticipate and respond to situations while optimizing limited resources.
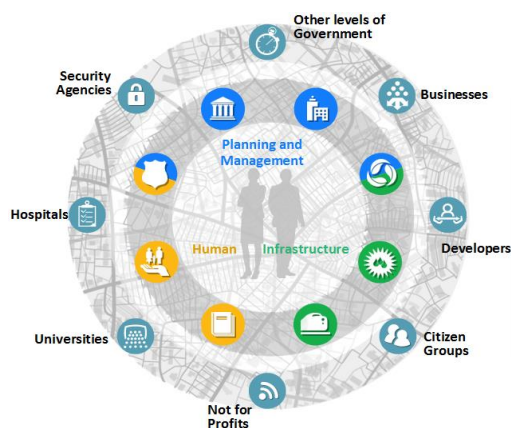

Figure 8 – City Development Management

The IOC framework has been successful implemented in various Smarter Cities world-wide. For instance – the city of Rio de Janeiro teamed with IBM to develop a Smarter City solution – Rio Operations Center that provides city officials with new capabilities to further improve the city's emergency response system, and give citizens access to information that will help them better manage their daily lives. Since opening less than a year ago, the Rio Operations Center has integrated information and processes from across 30 different city agencies into a single operations center that provides a holistic view of how the city is functioning on a 24 by 7 basis. The Operations Center serves as the nerve center for the city, applying analytical models developed by IBM to more effectively predict and coordinate reaction to emergency incidents. [10]

"In Rio de Janeiro, we are applying technology to benefit the population and effectively transitioning to a smarter city," said Mayor of Rio de Janeiro Eduardo Paes. "In addition to using all information available for municipal management, we share that data with the population on mobile devices and social networks, so as to empower

them with initiatives that can contribute to an improved flow of city operations." [10]

Operations officials from across the city now collaborate daily to manage the movement of traffic and public transportation systems, and the efficiency of power and water supplies. The Center also relies on a system pioneered by IBM Research scientists -- a high-resolution weather forecasting and hydrological modeling system for Rio de Janeiro, which can predict heavy rains up to 48 hours in advance. The forecasting system is based on a unified mathematical model of Rio that pulls data from the river basin, topographic surveys, the municipality's historical rainfall logs, and radar feeds. The system predicts rain and possible flash floods, and has also begun to evaluate the effects of weather incidents on other city situations such as city traffic or power outages.

4.0 CONCLUSIONS

We have seen tremendous advances in data processing (computer) technology in the last half century. There were three major technology advancement waves that essentially defined computing in the enterprise. In the 1960s, the advent of the IBM System 360 revolutionized business processes "back office" management – introducing automated systems management. The 1980s transformed the computing power of earlier mainframes to considerably smaller computers, which were ultimately named "personal computers" (PCs). The PC's "client-server" computing model provided employees across the enterprise considerably more autonomy -- e.g., not being required to be connected to the "back-end system" and the versatility that came with new PC applications. And we then saw the birth of the World Wide Web in the 1990s and early 2000s, as the Internet evolved, was commercialized, was a catalyst to the creation of e-Business.

We are likely on the cusp of a fourth wave, which is characterized by the confluence of Big Data, Advanced Analytics, Social Computing, Mobile Computing, and Cloud Computing. This confluence of technologies (sometimes referred to as the Internet of Things) is again transforming the way companies world-wide deliver and consume millions of systems, software and services. The confluence of these technologies is enabling four mega-trends (each with significant societal implications, and advanced capabilities enabling a Smarter Planet):

"**Growing Scale / Lower Barrier of Entry:** A massive expansion in the number of smart devices, sensors, transactions and users of digital technologies is creating huge amounts of structured and unstructured data — while the rise of easy-to-use and affordable programming interfaces is simultaneously lowering the barrier of entry for companies to create applications and services that derive value from this data.

Increasing Complexity / Yet More Consumable: While the volume, variety, velocity, and veracity of data is contributing to the increasing complexity of data management and workloads — creating a greater need for advanced analytics to discover insights — mobile devices have made technology more consumable, creating user demand for interactive tools for visual analytics.

Fast Pace: Change is coming faster than ever — disruptive models for the development and consumption of technology are emerging to penetrate global enterprise ecosystems, resulting in rapid innovation and decreased time-to-value. Open online courses are experiencing exponential growth making education and training more accessible.

Contextual Overload: The proliferation of sensors and devices and the explosive growth in structured and unstructured data are causing information and contextual overload. With the increasing affordability and sophistication of smart devices, new opportunities exist to provide contextually aware and personalized services based on user views, desires, preferences and location, delivered just-in-time." [11]

Technology today is what's enabled the Smarter Planet initiative. One could have conceptually described the value of the many Smarter Planet views in the past; but one could not have had a pragmatic discussion as to how to implement it in the last millennium. The world is flat, connected, and global. The world is evolving at a rapid pace. The World Health Organization (WHO) estimates that the majority of the world population now lives in a city

"Urbanization, the demographic transition from rural to urban, is associated with shifts from an agriculture-based economy to mass industry, technology, and service. For the first time ever, the majority of the world's population lives in a city, and this proportion continues to grow. One hundred years ago, 2 out of every 10 people lived in an urban area. By 1990, less than 40% of the global population lived in a city, but as of 2010, more than half of all people live in an urban area. By 2030, 6 out of every 10 people will live in a city, and by 2050, this proportion will increase to 7 out of 10 people. Currently, around half of all urban dwellers live in cities with between 100 000 - 500 000 people, and fewer than 10% of urban dwellers live in megacities (defined by UN HABITAT as a city with a population of more than 10 million)." [12]

The perdurable world-wide migration from urban settings to cities fuels the need for a Smarter Planet. It is estimated that: Smarter traffic systems can cut gridlock by 20%; and Smarter energy systems can reduce energy waste by 15% or more. The perpetual increase in size and complexities of cities and mega-cities makes it essential for governments to adopt smarter approaches and smarter technology. The industries that have emerged around smarter buildings, and smarter energy (e.g., Energy Service Companies and Energy Management Systems) provide evidence that the world is moving in this direction.

Globally, urban growth peaked in the 1950s, with a population expansion of more than 3% per year. Today, the number of urban residents is growing by nearly 60 million every year. The global urban population is expected to grow roughly 1.5% per year, between 2025-2030. By the middle of the 21st century, the urban population will almost double, increasing from approximately 3.4 billion in 2009 to 6.4 billion in 2050. Almost all urban population growth in the next 30 years will occur in cities of developing countries. Between 1995 and 2005, the urban population of developing countries grew by an average of 1.2 million people per week, or around 165 000 people every day. By the middle of the 21st century, it is estimated that the urban population of these counties will more than double, increasing from 2.5 billion in 2009 to almost 5.2 billion in 2050" [12]

Emerging countries and the rate at which some have grown further validate this confluence of technology; but more importantly, they also present a very interesting opportunity. The cost of "modernizing" a long standing, well established city will notionally cost more than building a smart city "starting from scratch." But starting from scratch is not an option for a city that depends on infrastructure, governance, and the many

other services that would have to be placed on hold during a re-building exercise. The opportunity is there for emerging countries to make intelligent decisions in the design and development of cities – e.g., making early investments in instrumentation, interconnectivity, and ultimately intelligent systems that could help these countries "leap frog" the older technologies and processes that many cities today are in the process of modernizing.

This paper provided a variety of perspectives on the Smarter Planet initiative, the many underlying technologies that make it possible today, and the underlying academic concepts from the field of informatics and cybernetics that have guided its evolution. This paper only discussed a subset of the many industries and "smarter solutions" that have blossomed in the last several years. The next generation of Smarter Planet systems will inevitably exploit other advanced technologies, such as Cognitive Computing [5] Imagine the ability to have a bi-directional discussion with a Smarter Planet system that can reason and adjust itself as it learns from its empirical data and augments the data with human guidance.

ACKNOWLEDGEMENTS

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