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Big Data, CEP and IoT : Redefining Holistic Healthcare Information Systems and Analytics

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***Abstract*— Healthcare industry has been a significant area for innovative application of various technologies over decades. Being an area of social relevance governmental spending on healthcare have always been on the rise over the years. Event Processing (CEP) has been in use for many years for situational awareness and response generation. Computing technologies have played an important role in improvising several aspects of healthcare. Recently emergent technology paradigms of Big Data, Internet of Things (IoT) and Complex Event Processing (CEP) have the potential not only to deal with pain areas of healthcare domain but also to redefine healthcare offerings. This paper aims to lay the groundwork for a healthcare system which builds upon integration of Big Data, CEP and IoT.**

Keywords—Big Data; Internet of Thing; Complex Event Processing; CEP; IoT; Body Sensor Networks; Healthcare

I. INTRODUCTION

The health care industry is extremely big incorporating several sectors that are dedicated to providing health care services and products. Some of these sectors depend significantly on data storage, computing and communication technologies. Healthcare Information Technology (HIT) [16] is "the application of information processing involving both computer hardware and software that deals with the storage, retrieval, sharing, and use of health care information, data, and knowledge for communication and decision making". In recent years a newer sector of Healthcare known as 'Healthcare Informatics' has emerged and started to gain significant popularity. It is a discipline at the intersection of information science, computer science, and healthcare [17]. Healthcare finance and insurance is also another area which relies significantly on computing and communication technologies.

Healthcare information systems have come a long way from being simple patient data management systems, to being repositories of huge volume and variety (blood work reports, diagnosis details, prescription details, scans, x-rays images etc.). Most of this data goes unanalyzed due to its sheer volume and also due to lack of meaningful correlative analytics. Task of analysis all this data becomes even tougher due increasing use of Personal Health Systems (PHS) and Remote Patient Monitoring and Treatment (RMT), Body Area Networks (BAN). Such monitoring devices keep pouring data at a rapid rate and most of this may go unanalyzed.

Healthcare is an area of concern and importance for both developed and developing nations owing to its social relevance. Governments across the world are focusing on all aspects of healthcare like policy changes, legal statures, insurance, funding, and technology overhaul. Patient Protection and Affordable Care Act also popularly known as Obama care is ushering significant changes in US healthcare industry. Hearth insurers are expected to see substantial increase in their cost due to increased risk of covering more people and they cannot legally deny insurance to individuals based on prior health conditions. Affordable care ensures that maximum number of people is covered. This poses as a challenge to hospitals as they will witness increase in patients, which means increasing amount of data to be analyzed.

This paper is organized as follows: Section II discuss about Big Data and its role in Healthcare. Section III details about IoT, its role in future world and how it contributes to healthcare. Section IV provides an overview of CEP and how it is significant in Healthcare information systems and analytics. Section V proposes a holistic system for healthcare informatics. Finally, Section VI gives the conclusion and the step forward.

II. BIG DATA – CRUNCHING HEALTHCARE DATA

The new era of health care will be driven by an explosion in health-related data from a growing range of public and private sources, and can be analysed by increasingly powerful number-crunching computers. This new era is moving from a

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world where illnesses can be treated to one where it can be predicted and can be prevented. Big Data technologies will play a key role in turning this idea into reality. Big Data is a term encompassing the use of techniques to capture, process, analyze and visualize potentially large datasets in a reasonable time frame not accessible to standard IT technologies [1]. It refers to the ability to crunch vast collections of information, analyze it instantly, and draw from it sometimes profoundly surprising conclusions. According to Gartner analyst Doug Laney [2] data growth challenges and opportunities as being three-dimensional, i.e. increasing volume (amount of data), velocity (speed of data in and out), and variety (range of data types and sources). Big data technologies deal with petabytes of records, files, transactional data either arriving as streams or in batches. Rise of disruptive technologies like social and mobile are contributing to increase in unstructured and semi structured data.

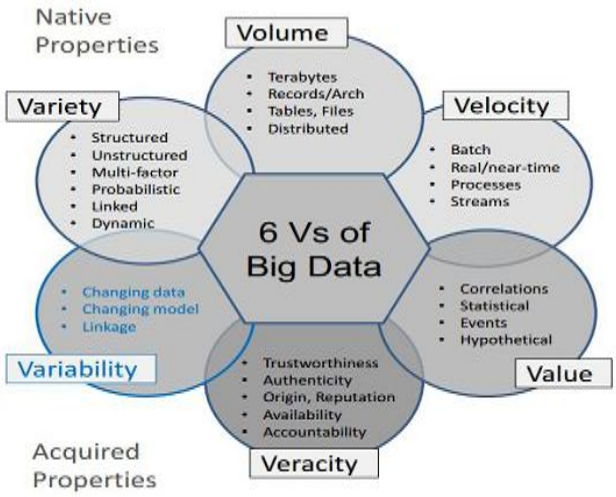

Figure 1: Big Data Properties

Big data technologies have to deal with all these varieties of data. Whereas volume, variety, velocity are the native properties of big data system, it has also three acquired properties of variability (indication of changing nature of data), value(significance based on statistics, hypothesis etc,), and veracity (trustworthiness of data, provenance etc.).

`Big data is an idle fit for dealing with the technology challenges faced by the Health care industry. Increasing public health records with all the new sources of health data generated by wearable sensor devices, Wi-Fi enabled scales, smart phones and low-cost diagnostic kit, could provide a far more accurate picture of individual's health and the treatments they receive. In terms of big data for health care "Volume" refers to the rapidly expanding size of the sets of data being generated in every area of activity in an healthcare enterprise, from revenue, to patient data, to supply and operations. "Variety" includes the diversity of data collected. In a hospital, for instance, data includes patient records containing a variety of information like lab reports, scans, x-rays, prescription details and so on. Beyond diagnosis and treatment related data, all aspects of finance, patient scheduling and workflow, insurance data and medical outcomes etc are also available. Synthesizing and analyzing such disparate elements is challenging on its own. With newer sources of healthcare monitoring devices like personal health monitors, Body Area Networks (BAN) there is significant "Velocity" of incoming healthcare data.

There used to be a time in healthcare industry where more in-patient days translated to more revenue. But now patients are increasingly demanding information about their healthcare options so that they understand their choices and can participate in decisions about their care. Patients are also an important element in keeping healthcare costs down and improving outcomes. Providing patients with accurate and up-to-date information and guidance rather than just data will help them make better decisions and better adherence to treatment programs [4]. As a result of this focus on meaningful information, all healthcare constituents are impacted by big data, which supports analytics that predict how these patients are likely to behave, encourage desirable behavior and minimize less desirable behavior. Report on Big Data Analytics [5] indicates that Big data solutions can help stakeholders personalize care, engage patients, reduce variability and costs, and improve quality of health delivery. Big data analytics can also contribute to providing a rich context to shape many areas of health care like analysis of effects, side-effects of drugs, genome analysis etc.

As populations grow and people live longer, healthcare costs are growing to unsustainable levels. Insights derived by big data analytics can help remove inefficiencies from system. For example, by analysing prescription drugs for specific ailments across the country, Big data analytics can help in saving lots of money if doctors switched from branded to cheaper - but equally effective generic versions of the drug. Big data analytics can aide hospitals in efficient resources management by reducing emergency waiting times, track patient movements, moderate X-ray dosage levels etc. Access to huge amounts of healthcare data coupled with insights provided by big data analytics, it will be possible to develop predictive algorithms that can forecast which demographics are likely to cost the most to treat in future, for conditions like diabetes and asthma. This will enable healthcare providers intervene earlier and redesign their services to cope with the expected massive increase in healthcare demand.There are also certain challenges particular to using big data for healthcare:

Accuracy: Human tendency to understate negative factors, such as smoking and failure to comply with treatment is of concern. People also tend to overstate positive factors, such as exercise. These biases need to be identified and corrected, or passive techniques need to be used in order to acquire data that does not have self-reported bias.

Privacy: People are reluctant to divulge personal information because of concerns about privacy. Providing guarantees for security and privacy, incentives will help to address these concerns.

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Consistency: Standards need to be developed and implemented to promote consistency, increase usefulness and facilitate data usage amongst all the stakeholders involved in various healthcare sectors.
Facility: Mechanisms need to be developed to make it easy for patients to accurately self-report data. This includes evolving passive mobile computing, wearable devices that require no effort. Techniques are needed to get data from healthy people to make the populations truly representative and not biased by the ill in any kind of statistical analysis.
Fragmentation: Healthcare data is significantly fragmented. There is also unwillingness for healthcare participants to share data.

III. INTERNET OF THINGS – INTEGRATED MONITORING OF HEALTH

The Internet of Things (IoT), sometimes referred to as the Internet of Devices or Internet of Everything, is expected to change the world as one sees and perceives it today. Internet of Things (IoT) is a worldwide network of interconnected objects and their virtual representations uniquely addressable based on standard communication protocols. Identified by a unique address, any object including computers, mobile phones, RFID tagged devices, and especially Wireless Sensor Networks (WSN) will be able to dynamically join the network, collaborate, and cooperate efficiently to achieve different tasks. IoT devices gather and share information directly with each other and the cloud, making it possible to collect record and analyze new data streams faster and more accurately [11].

World population is on the raise. Especially in countries like India and China with higher population growth, health care has become one of the largest sectors, both in terms of revenue and employment – and its growth is expected to continue. Estimates project that the current US $40 billion Indian health care industry will grow to US $280 billion by 2020. Such massive systems can effectively handled only by embracing cutting edge technologies. IoT will be key enabler for holistic healthcare environment. The emergence of the IoT, in which devices connect directly to data and to each other, is important in future of healthcare for two reasons:

1. The recent advances in embedded sensors and connectivity technology are allowing devices to connect, anywhere, anytime anyplace to collect record and analyze data that was not accessible before. In healthcare, this means being able to connect and collect patient data on the air over time that can be used to help enable preventive care, allow prompt diagnosis of acute complications and promote understanding of how a meditation is helping improve a patient's parameters.
2. The ability of these smart devices to connect and gather data on their own removes the limitations of human-entered data—automatically obtaining the data that suits doctor's need; at the time and in the way they need it. The automation reduces the risk of error. Fewer errors can mean increased efficiency, lower costs and improvements in quality in just. In healthcare, where human error can literally be the difference between life and death, IoT devices are a boon.

IoT-related healthcare issues today are based on the essential definition of the IoT as a network of devices that connect directly with each other to capture and share vital data through a secure service layer (SSL) that connects to a central command and control server in the cloud. Energy efficiency [7],[10] of sensors will play a major role in the success of this technology. A major concern about sensors is Energy efficiency of these smart devices; various methodologies have been discussed in literature for saving energy in sensor nodes [7].

From the perspective of healthcare, IoT devices can broadly fall in three categories as shown in Figure 2, 3 and 4.

- Personal Monitoring Devices: Wearable blood pressure monitors, thermal sensors, smart pacemakers, movement monitor (posture, gait, step size, step height), EEG nodes, ECG Nodes, pulmonary monitors, diagnostic aides at hospitals.
- Smart Home Devices: Home automation has always been a interesting idea for deployment of sensors. With focus on healthcare, IoT devices at home can monitoring living conditions (temperatures, light etc) at home, keep track of what a person eats (smart fridges). This devices can give better insights for healthcare.
- Environment Monitoring Sensors: These have been around for quite some time for monitoring air quality, temperature, humidity etc in cities. With newer and better sensors smart cities are becoming a reality. Environmental data can help understand spread of ailments like asthma, hypertensions etc which may be attribute to environmental conditions to some degree.

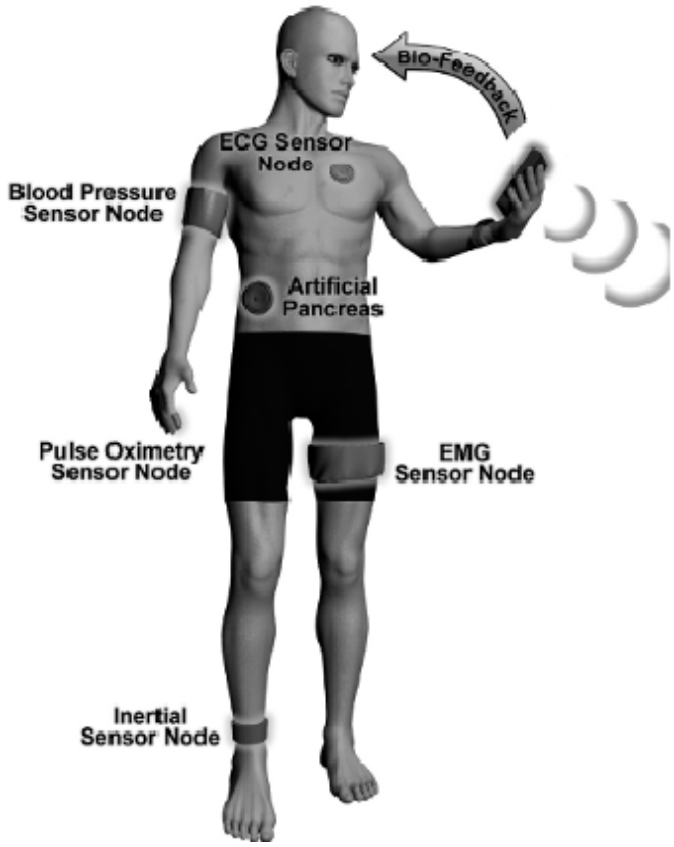

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Figure 2:Personal Monitoring Devices

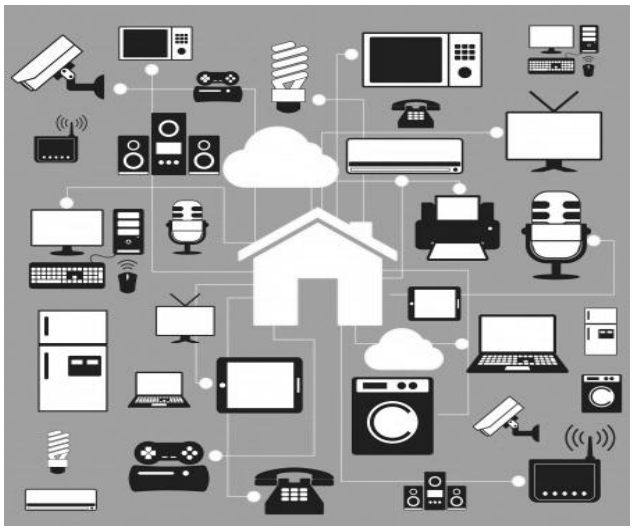

Figure 3: Smart Home Devices

While still an emerging trend, machine-to-machine (M2M) -- and the overall Internet of Things phenomenon -- have

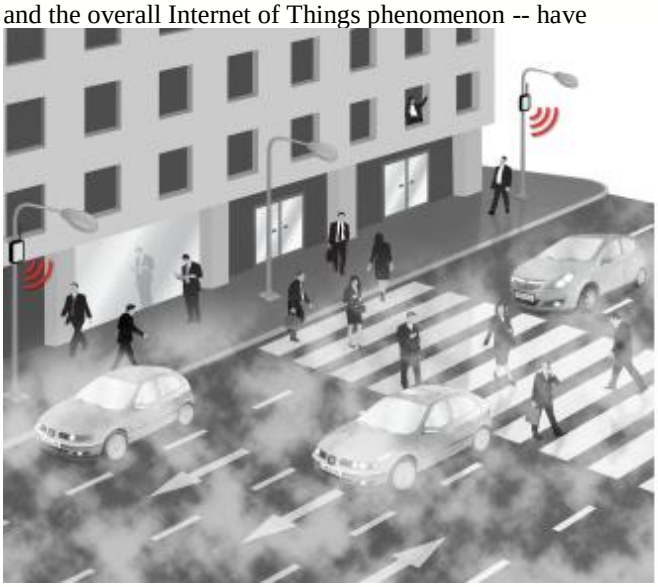

Figure 4: Environment Monitoring Sensors

captured the healthcare industry's attention. The two technologies shared the No. 4 spot on Gartner's 2013 Top 10 Strategic Technology Trends list[12]. Another research firm, Markets and Markets, recently projected the Internet of Things and M2M communications market to grow from $44 billion in 2011 to $290 billion by 2017, representing an estimated CAGR of 30 percent from 2012 to 2017. For solution providers, the technologies represent a way to grow their business, provided they take the right steps and forge the right partnerships. Ability of personal health monitoring devices to communicate instantly with doctors, hospitals, emergency services will redefine the landscape of healthcare industry.

Though a completely viable world of IoT is in near-distant future, some of the ingredients like Wireless Sensor Network (WSN), Body Areas Networks(BAN) are already existent and deeply being explored. Wireless Sensor Network (WSN) refers to a distributed network, consisting of dispersed and autonomous sensing stations. Each sensing station—also known as a sensor node—consists of a computing component, communication component, a power source normally a battery, and some sensors depending upon the application area. Some smart sensors are equipped with an actuator [8]—an electro-mechanical device used to control different components of the system. Wireless Body Sensor Networks (WBSNs) has offered a paradigm shift which can be used for early detection of the different diseases so that health issues can be detected at an early stage. These smart things can collect and analyze the vital sign-related data of patients by deploying different types of bio-medical sensors (for example: body temperature, heartbeat, blood pressure, electrocardiogram (ECG), electro encephalogram (EEG), etc. sensors) for a long period of time, thus reducing the healthcare costs. The bio-medical smart sensor nodes can either be suitably placed on the body or implanted inside the body as depicted in Figure.5. These bio-medical sensor nodes send the sensed information to a coordinator (base station), located on or near the body. The coordinator (base station) is responsible for forwarding the collected information to the sink node. The sink node will send the received data to the health care centre or any other destination.

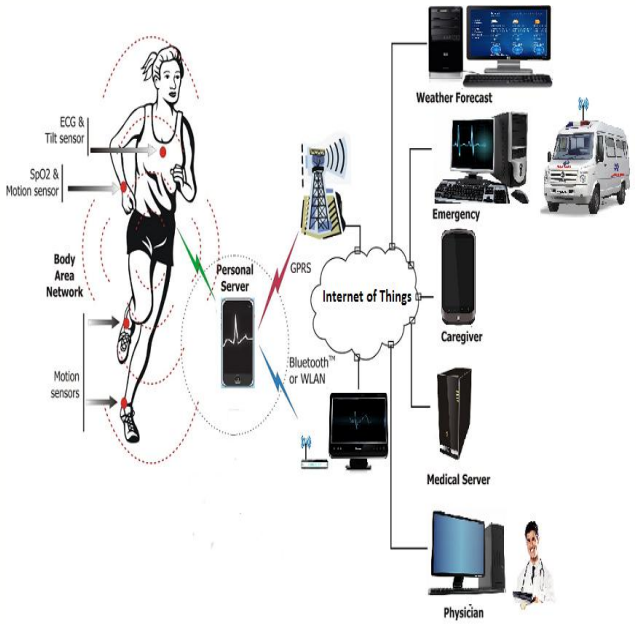

Figure.5.Body Area Network as part of IoT

Benefits IoT in Health Care include:-

- **Clinical care:** Hospitalized patients whose physiological status requires close attention can be constantly monitored using IoT-driven monitoring. This type of health care solution employs sensors to collect comprehensive physiological information and uses gateways and the cloud to analyze and store the information and then send the analyzed data wirelessly to caregivers for further analysis and review. It replaces the process of having a health professional come by at regular intervals to check the patient's vital signs, instead providing a continuous automated flow of information. In this

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way, it simultaneously improves the quality of care through constant attention and lowers the cost of care by eliminating the need for a caregiver to actively engage in data collection and analysis.

- **Ongoing monitoring:** With Internet of Things technology — such as wireless EKG machines , devices for diabetics to track their data, and necklaces or belts that transmit heart rate data — healthcare professionals can collect and store real-time information about their patients, and even be alerted when something is wrong and action is needed. The Internet of Things can transform healthcare from a reaction-based process into an ongoing one.
- **Scaled expertise:** A challenge in healthcare today is that expertise is often limited to an individual or location. For example, a doctor who's an expert in a particular procedure can only be in one place, and with one patient at a time. But the Internet of Things is helping technology evolve to allow for physicians to be able to perform procedures remotely.
- **Remote monitoring:** There are people all over the world whose health may suffer because they don't have ready access to effective health monitoring. But small, powerful wireless solutions connected through the IoT are now making it possible for monitoring to come to these patients instead of vice-versa. These solutions can be used to securely capture patient health data from a variety of sensors, apply complex algorithms to analyze the data and then share it through wireless connectivity with medical professionals who can make appropriate health recommendation .
- **Hospital prevention:** Thanks to ongoing monitoring, Internet of Things technology can also help patients know when a trip to the hospital isn't needed. The devices continually sending health data to doctors can open up the communication and treatment channels so that unnecessary hospital trips are prevented.

IV. COMPLEX EVENT PROCESSING

Complex Event Processing (CEP) technologies have been used for situational awareness and decision making for quite few years. It has regained focus owing to the rising demand for on-the fly processing of events. Growing popularity of Big Data and Internet of Things (IoT) coupled with the need for real-time analytics have fueled the rapid growth of CEP technologies and tools.

The idea of Complex Event Processing (CEP) was first introduced and discussed in detail by Luckham [14]. It is in recent years that CEP has evolved and gained prominence as separate discipline by building upon different technology paradigms like discrete event systems, active databases, Data Stream Management Systems (DSMS), stream reasoning and network management etc. Eckert and Bry [15], defined Complex Event Processing as a technology which encompasses methods, techniques, and tools for processing events while they occur, i.e., in a continuous and timely fashion. According to Luckham [13], CEP consists of principles for processing clouds of events to extract information, together with technologies to implement those principles.

Several CEP engines and frameworks have been proposed and/or developed over past decade and deployed over various domains and problem areas like business process monitoring, healthcare, smart cities, traffic analysis, fraud detection, automation etc. Comprehensive CEP frameworks [18] will be an idle fit for healthcare domain. CEP engines can analyze events and related data which come from various sources (health sensors, environment sensors etc.) in real-time and provide insights for a better healthcare.

CEP can analyses event from personal sensors in correlation with smart home sensor are provides insights which can answers questions pertaining to linkage between personal health, food consumed, quality of lifestyles etc. CEP can also analyzed health changes in correlation with environmental factors like humidity, air quality, temperature etc by subscribing to events from environment monitoring sensors.

Parts of the big data that is of no interest it can be filtered with Complex Event Processing (CEP) as they get into the system and selected data can be compressed by orders of magnitude. One challenge is to define these filters in such a way that they do not discard useful information. Complexities of Big Data associated with the sheer volume can be handled by suitable integration with Complex event processing.

V. HOLISTIC HEALTHCARE

Big Data, CEP and IoT together holds a great potential to change the present scenario of healthcare, starting from drug discovery to remote monitoring of patients, to faster settlement of health insurance, to improved clinical outcomes. The three native properties (volume, variety, velocity) along with the acquired properties (variability, value and veracity) define the key characteristics of big data which are very much suited to healthcare issues. IoT is useful in collecting real time data from patients anytime, anywhere, any place, and easily relates to all the three native properties of big data. Current practice of collecting patient's data at bedside involves writing it down to a paper spreadsheet and then the notes are typed in a data entering finally The data is transmitted to a database server that organizes, indexes, and make it accessible through a database interface and then data is analyzed by doctors, pharmacists etc. It is now clear that there is latency between data gathering, information accessibility and this will grow more as there is increase in volume of data in terms of health databases, clinical data, health insurance data, repositories which can provide better results for better future health care if analyzed properly with the help of complex event processing and big data analytics.

This paper proposes a holistic health care approach for performing complex event processing on the real time data coming from wearable and non wearable sensors whose volume, velocity; variety is huge in terms of storage and processing. The elements and interactions are described below and shown in Figure.6.

IoT Module: Contains the smart elements to extract real time data, transform and load the health data. The data generated from these smarter things is very sensitive and large enough in terms of volume, variety and velocity. So, instead of storing the data in databases for future use, better is to analyze the data at that time only, with the help of Complex Event Processing.

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CEP Module: - CEP will extract real time data from IoT devices as soon as it is generated, and that will be analyzed by applying real time event analytics , and more over CEP can extract the information from the Big data databases on a need basis, which are large enough in terms of volume and byapplying analytics to find the patterns and analyze the data of the patients regarding the past and present health.

Big Data Analytics: - Big data analytics comes into play in order to unlock the value of data, organizations need Inferring knowledge from complex heterogeneous patient sources Leveraging the patient/data correlations in longitudinal records. Understanding unstructured clinical notes in the right context. Efficiently handling large volumes of medical imaging data and extracting potentially useful information and biomarkers. Analyzing genomic data is a computationally

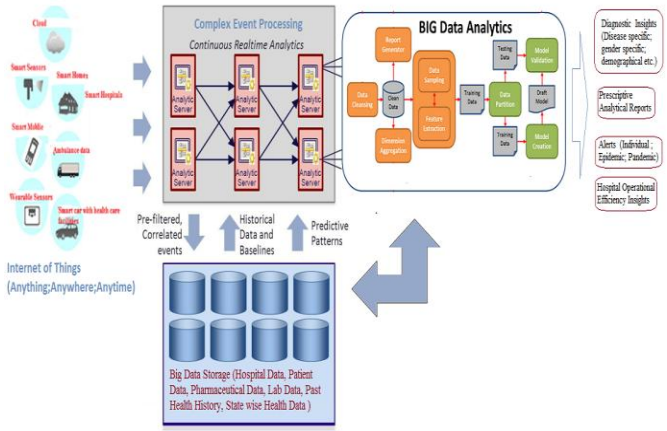

Figure .6. Holistic Healthcare System (Integration of CEP, Big Data, IoT)

intensive task and combining with standard clinical data adds additional layers of complexity. Capturing the patient's behavioral data through several smart sensors; their various social interactions and communications. Take advantage of the massive amounts of data and provide right intervention to the right patient at the right time. Personalized care to the patient Potentiallywill benefit all the components of a healthcare system i.e., provider, payer, patient, and management.

VI. CONCLUSION

Big Data Analytics ,Complex Event Processing and IoT together have extreme potential in solving exsisting and future problem of healthcare industry. Application of these technologies is still in infancy in the healthcare domain. With renewed focus on better healthcare, growth in population , increasing prices, healthcare industry has to embrace cutting edge technoliges like for effective and efficeint functioning. Such application of technology should happen in a integrative manner such as to deliver a complete healthcare solution.

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