A Bosch Software Innovations
and MongoDB White Paper

IoT and Big Data

A Joint Whitepaper by Bosch Software Innovations and MongoDB
October 2014

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Bosch Software Innovations and MongoDB collaborate to enable IoT Applications

Bosch Software Innovations – the Bosch Group's software and systems house – and MongoDB – the leading Big Data company – are collaborating to provide a platform for the development of highly scalable applications for the Internet of Things (IoT).

From advanced telematics solutions to smart power tools and appliances to micro-electromechanical sensors – The Bosch Group is at the forefront of the IoT, driving its IoT activities through the Bosch Software Innovations (Bosch SI) unit. MongoDB is the leading database for big data applications, leveraged by thousands of customers for highly scalable real-time applications.

This whitepaper outlines the joint IoT application platform and how customers can benefit from Big Data technology in realizing the Internet of Things vision.

Internet of Things — The Opportunity

Regardless of who you talk to, everybody agrees that the IoT (Internet of Things) will be the next big "thing" (no pun intended): Bosch SI estimates that 6 billion devices will be connected by 2015, Gartner predicts 26 billion connected devices by 2020, topped by Cisco with an estimate of 50 billion also by 2020.

The excitement for IoT is supported by:
▪ Ever shrinking hardware (e.g. Intel's announcement of Edison, the SD-card sized PC board with integrated WiFi)

▪ Ubiquitous connectivity (almost every Telco carrier is now offering dedicated network solutions for Machine-2-Machine as the foundation for IoT)

▪ Rich IoT application platforms (such as the one discussed in this whitepaper)

▪ An increasing amount of IoT applications in many use-cases and industries.

Some of these IoT scenarios are very end-user oriented, e.g. driven by crowd funding and the Maker Movement. Examples include the Pebble smart watch, the innovative Tile product (a "Thing" locator) or the smart Hue light bulbs from Phillips.

However, many IoT examples are more focused on industrial applications, including Fleet Management, Telematics, Smart Metering and Smart Grids, Tele Health, and so on. This whitepaper will focus on three of the most innovative industry domains to illustrate the transformational power of the IoT, and how it can leverage Big Data:

▪ Retail and Logistics
▪ Manufacturing
▪ Mobility.

[1] *http://www.bosch-si.com/newsroom/iots/internet-of-things.html*
http://www.gartner.com/newsroom/id/2636073
http://share.cisco.com/internet-of-things.html

FIGURE 1: Retail and Logistics Use Case

Use case 1: Retail and Logistics

Retail and logistics is one key area where IoT is expected to have a huge impact as an enabling technology. RFID (Radio Frequency Identification) has been used successfully in logistics to track containers, pallets and crates for some time now, primarily in closed loop systems and mostly with high-value goods. The massive investments in IoT technologies are promising to help reduce costs for RFID and similar technologies, eventually making the tracking of goods on an item-level a feasible business case. For retailers, this has many advantages, including inventory accuracy, reduction of administrative overhead, automated customer check-out processes and a reliable anti-theft system.

Other emerging technologies are so-called “beacons”. These beacons are indoor positioning systems, which can interact directly with modern smart phones, e.g. using Bluetooth Low Energy (BLE). A network of in-store beacons can identify the location of a customer in a store and send them push notifications. For example, a user might create a shopping list on their smart phone and share it with the store app. Upon entering the store, the store app will display a map to the customer, which highlights all the products on his shopping list. Every time the customer gets close to a position where a group of products from their shopping list is located, the app will notify them and make a recommendation for a particular brand.

At the check-out point, the system could identify all the products in the shopping cart automatically via RFID, create and confirm an invoice, and use the smart phone to process the payment. The store’s inventory system is automatically updated when the checkout process is complete.

An IoT application supporting this kind of scenario would greatly benefit from using an IoT application middleware, as explained later in this paper. The use of a NoSQL data repository would be of great benefit for storing all kinds of structured, semi-structured and unstructured customer related data, including shopping history and movements through the store. Advanced data analytics algorithms could be used to analyze the customer’s movements and past shopping decisions. This enables the IoT application to generate shopping recommendations that can be pushed to the customer’s smart phone while in the store, or to notify them of special offers – for example if the system detects that the customer is returning to an area in proximity to the store.

Use case 2: manufacturing

“Industry 4.0”, “Smart Factory” and “Industrial Internet” – these are some of the terms used to describe the social and technological revolution that promises to change the current industrial landscape. There are many examples discussed and explored in this area, from leveraging IoT supply chain optimization to the

FIGURE 2: Manufacturing Use Case

modularization of production lines with the help of intelligent products.

One interesting example that we explore here is related to the increasing use of hand-held tools in manufacturing, e.g. for the assembly of automobiles, airplanes, trains and ships. In recent years, these tools have become more powerful (e.g. torque) and are now equipped with long lasting batteries, enabling workers to use them without the limitations of power cables or a fixed connection to an air compressor. This greatly enhances flexibility, but also poses certain challenges from a manufacturing process point of view, which can be addressed by leveraging IoT capabilities.

One of the key IoT concepts is the development of intelligent, connected "edge" devices. One example for such an IoT device is the Bosch Rexroth Nexo, a powerful nut runner which is equipped with an on-board computer and wireless connectivity. The on-board computer supports many aspects of the tightening process, from configuration (e.g. which torque to use) to creating a protocol of the work completed (e.g. which torque was actually measured). In addition, the Nexo features a laser scanner for component identification.

By integrating such an intelligent edge device into the IoT, very powerful services can be developed that can help with supply chain optimization and modularizing the production line. For example, these intelligent tightening tools can now be managed by a central asset management application, which provides different services:

- Basic services could include features like helping to actually locate the equipment in a large production facility
- Geo-fencing concepts can be applied to help ensure only an approved tool with the right specification and configuration can be used on a specific product in a production cell.

The central asset management system can help with optimizing tool maintenance, for example by periodically reading calibration information from the remote tools via the factory WLAN. The asset management application can serve as the bridge between the power tools and the ERP (Enterprise Resource Planning) and MES (Manufacturing Execution System) systems that control the manufacturing process. For example, the asset management system can distribute work orders and configurations to the tools. In addition, the asset management application can document each tightening process by creating inspection lots (e.g. using torque recordings from the tools) and associate them with the BOM (Bill of Material) in the ERP system.

Figure 3: Telematics/Mobility Use Case

Such a production documentation system can benefit hugely from Big Data and NoSQL technologies that allow the aggregation of large volumes of heterogeneous, multi-structured data about the production process, including legacy data from many different systems, in addition to images and film recordings from different production modules. In an age where manufacturers can suffer huge costs from large product recalls, this can be a very powerful tool.

Use case 3: Mobility

Rapid developments in mobility and automation are driving significant transformations across many industries – especially in the creation of new services and customer experiences. Telematics is a prime example of an industry harnessing the power of mobile connectivity and IoT.

While the engine data bus has long served to aggregate sensor events for engine diagnostics or geo-location, each new generation of vehicle is equipped with more sensors to extend services into fuel efficiency, driver safety, theft prevention and more. The availability of these sensors, coupled with the integration of data to back-end enterprise systems via IoT application middleware is creating entirely new business models. For example, auto-makers and car rental companies have introduced new vehicle sharing offerings enabling customers to locate cars using their smartphones, rent them for a short time, and then park and return them anywhere within a defined zone (e.g. DriveNow and Car2Go in Europe and ZipCar in the US). They may partner with local property owners to provide secure parking for the vehicles, and in the case of electric cars, with power companies for the location of charging points.

Consider leasing and car rental companies who are facing multiple challenges today. In a highly competitive market, margins can be improved only through cost savings. At the same time, customer requirements and expectations are increasing. Driven by rising fuel prices and general sustainability efforts, fleet managers expect additional solutions from car leasing companies to help them go green and reduce costs.

Another example is an increased interest in dynamic leasing contracts with flexible mileage and duration terms, offering better flexibility. In a project with a leading leasing provider, Bosch Software Innovations implemented a connected fleet solution addressing many of these challenges and therefore enabling the leasing provider to successfully compete in this market. Leveraging an on-board, built-in unit and remotely connecting this unit with a backend application allows the fleet operator to get real-time information about fleet performance, individual vehicle status, and so on. In the enterprise backoffice systems, this information is consolidated and fed into the relevant backend processes. Established approaches such as Business Process Management (BPM) and Business Rules Management (BRM) provide valuable tools and techniques to enable integration and automation – for example to schedule preventative maintenance and repair. Web-based access to vehicle information can be provided to the individual car lessees. Other mobility providers, such as gas station operators, are also integrated into the enterprise processes.

IoT Foundation: Asset and Event Management

As we could see from the three examples above, the IoT can enable a wide range of different applications. However, almost all of these IoT use cases share a common set of requirements. The goal of Bosch SI is to offer a generic application platform for the IoT which addresses these common requirements. Of course, flexible and scalable data management is one of the key requirements, and Bosch SI is leveraging MongoDB as the central data management technology.

Before looking at some of the benefits of this

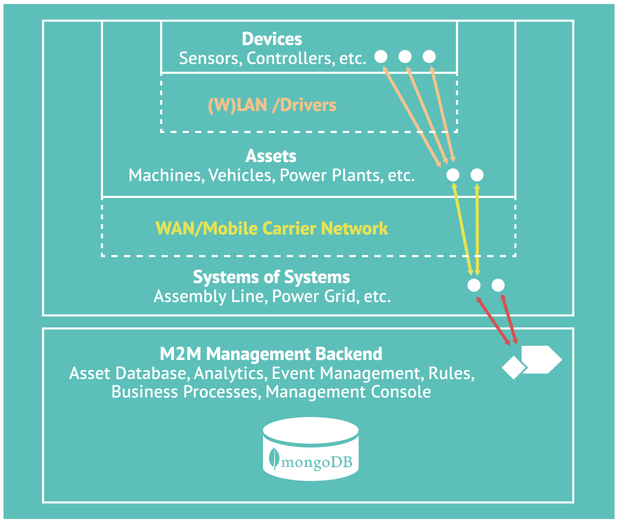

Figure 4: Asset Hierarchy in Bosch SI's IoT Platform

approach, the following section will provide a more general description of how the Bosch SI application platform is enabling IoT applications. This will help in understanding how these applications can benefit from the NoSQL and Big Data technologies provided by MongoDB.

If we look at the three use cases described above, we can see that there are two central entities in industrial IoT applications:

- Assets: Most industrial IoT applications are built around some kind of physical asset. The types of assets can vary greatly, from shopping carts to hand-held power tools to large trucks.
- Events: Managing events generated by the assets is critical to most industrial IoT applications. These events can range from technical events like a machine failure to a customer's expression of a buying interest in a retail application.

In order to efficiently manage different types of assets and events, the Bosch SI platform has a built-in mechanism for creating hierarchies of assets and the events that need to be communicated between these different hierarchies. The three hierarchy levels supported are:

- Devices: Devices are typically small, self-contained hardware elements like sensors, controllers, etc.
- Assets: An asset is typically a larger, more powerful entity, like a machine, a vehicle, or a power plant. An asset can connect to multiple devices through a local network, using specialized software drivers for different types of devices. The asset typically connects to the backend via a mobile carrier network (GSM, EDGE) or via a direct Internet connection .
- Systems of Systems: Multiple assets can be grouped together to form what is called a System-of-Systems, e.g. an assembly line consisting of multiple machines, a power grid consisting of multiple power plants, etc.

The benefit of using well-defined hierarchies of assets in an IoT application is that the underlying application platform can provide many required features out-of-the-box, regardless of the specific type of asset. These features include:

- Asset Communication: The Bosch SI platform enables efficient communication between the different hierarchy levels, including events sent from remote assets to the backend, as well as operations initiated from the backend and sent to and executed by the remote assets.
- Management Backend: The Management Backend provided by Bosch SI includes a central asset database, data analytics, secure event management, business rules execution, business process execution, and a management console for technical asset administrators.

From a data management point of view, the IoT application platform must manage two distinct types of data in the backend:

- Asset Instances and Hierarchy: Each asset becomes an individual entry in the central asset database, including information about its position in the asset hierarchy, as well as additional attributes and properties. The information about the asset hierarchy is critical in order to enable efficient communication with all assets.
- Events related to individual Assets: Each asset entry contains a complete recording of all events related to the asset, including technical events (e.g. failure notifications, etc.), as well as business events (e.g. a vehicle is crossing a geo-fence).

Asset and Event data is imposing huge challenges on the data management strategies for IoT applications. Some of these challenges include:

- Data Volumes: Depending on time intervals and numbers of assets, data volumes for the event history can become overwhelmingly large. Imagine 10 Million smart meters submitting a meter

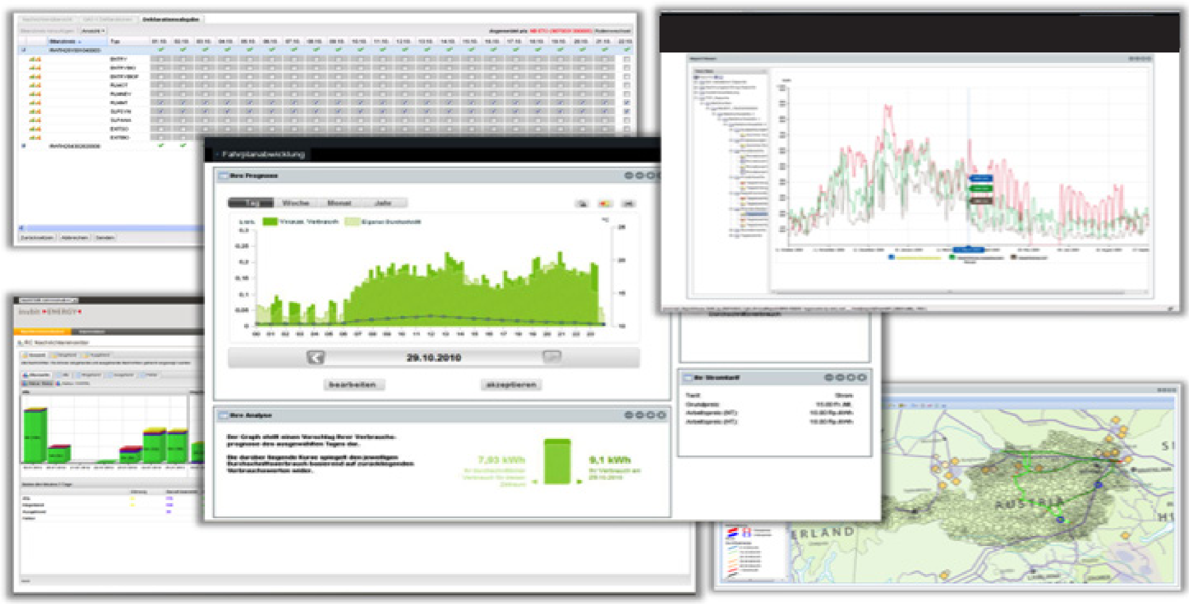

FIGURE 5: Examples for Asset and Event Data from Bosch SI platform

reading every 15 minutes for 20 years

- Data Schemas: In addition to structured data such as meter readings, many IoT applications also have to deal with semi-structured and un-structured data. For example, an event might include additional information such as a digital image taken to document the event, or an un-structured reading in an unknown technical format submitted by a specialized sensor.
- Data Schema Evolution: Especially in large IoT deployments it will be impossible to ensure that all assets in the field will always have the same configurations or versions of hardware and/or software. Consequently, the data management solution must be able to handle different versions of asset and event data in parallel.

To finish the discussion of asset and event management as the foundation for IoT applications, let's take a look at how an application must be able to support the analysis of individual events, as well as the correlation between different events.

Figure 6 provides an example. The asset management platform contains information about the different system entities, in this example a machine consisting of two components, A and B.

The IoT platform is recording a time series for a given attribute of component B, e.g. engine temperature. If the temperature exceeds a certain threshold, a "temperature out of range" event is submitted. The operator would now shut down the machine. A more detailed analysis might actually reveal the following: Machine component A had a spike in the time series for a critical attribute of component A. This spike might have been above the norm, but within an acceptable range. However, time correlation of the two events reveals that this spike in the behavior of component A might be the root cause for the failure of component B.

This is a good example for the type of real-time data analysis for asset and event data in an IoT application which must be provided by the underlying data management platform.

Big Data: 5 Key Capabilities for IoT

Some of the basic asset and event management capabilities described above can already be found in established M2M application platforms. M2M – or Machine2Machine – is seen by many in the industry as the predecessor of the IoT. However, the evolution from M2M to the IoT is not only a question of adding more devices.

From a recent report from Machina Research, an analyst firm specializing on M2M, IoT and Big Data: "The significance of the Internet of Things is not that more and more devices, people and systems are 'connected' with one another. It is that the data generated from these 'things' is shared, processed,

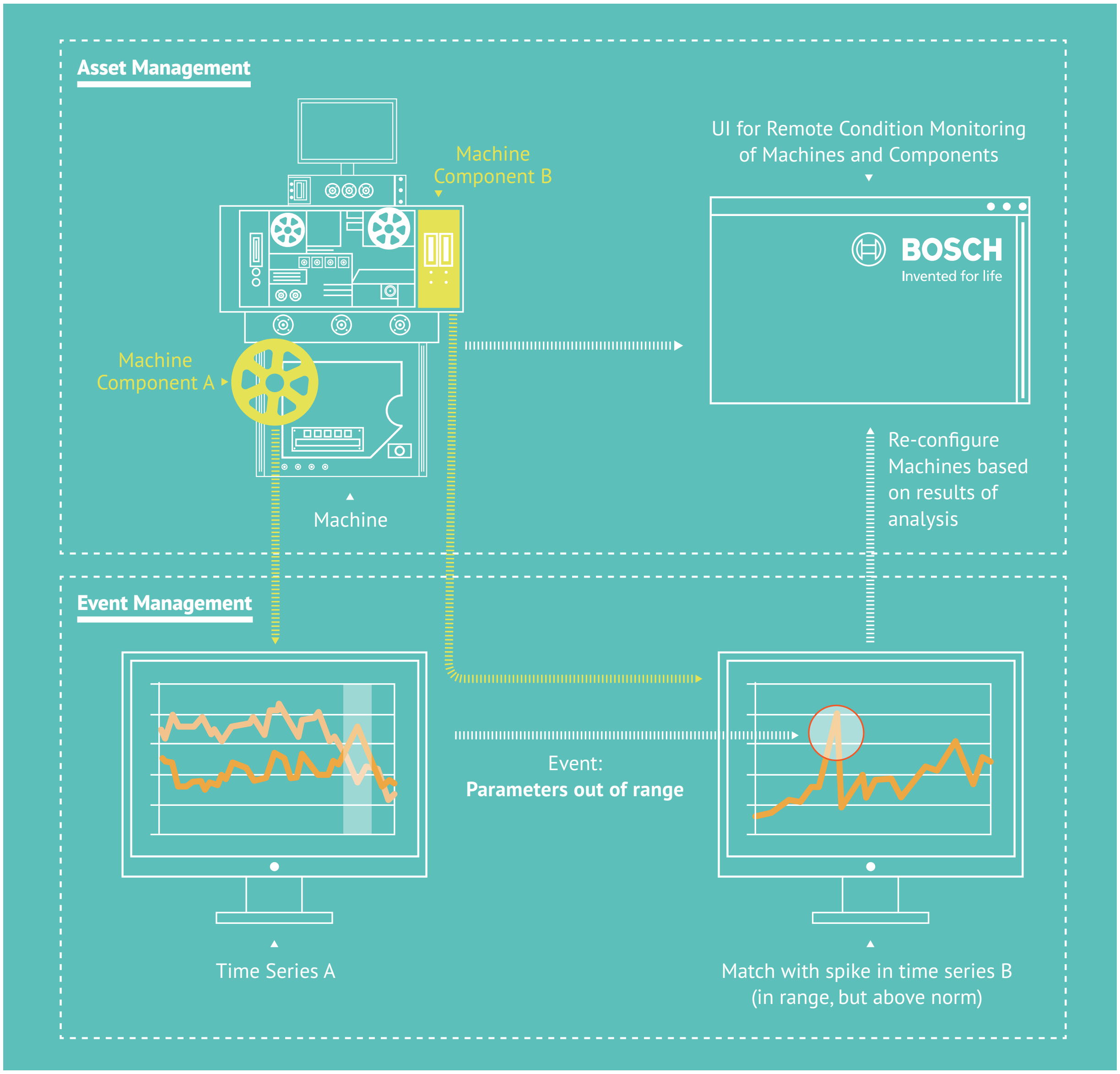

FIGURE 6: Event Correlation

analysed and acted upon through new and innovative applications, applying completely new analysis methods and within significantly altered timeframes. The Internet of Things will drive Big Data, providing more information, from many different sources, in real-time, and allow us to gain completely new perspectives on the environments around us."

Machine to Machine (M2M) applications are well established in a range of industrial applications, they are typically characterized by managing well defined data sets from specific classes of device, encoded in vertically integrated technology stacks designed to enable monitoring and alerts.

The evolution from M2M to IoT fundamentally changes these characteristics. Data needs to be aggregated from multiple, disparate devices in addition to data from other physical assets and even from enterprise systems. The data arrives at higher speeds, in greater volumes and variability of structure. The data must be analyzed in real time to deliver richer applications enabling enhanced operational insight - examples of which are included in the following section of the whitepaper. The arrival of IoT places new demands on all components of the technology stack – and especially in the underlying databases used to store, manage, process and analyze the data.

To learn more about the challenges of IoT data storage, download the Machina Research report "Why

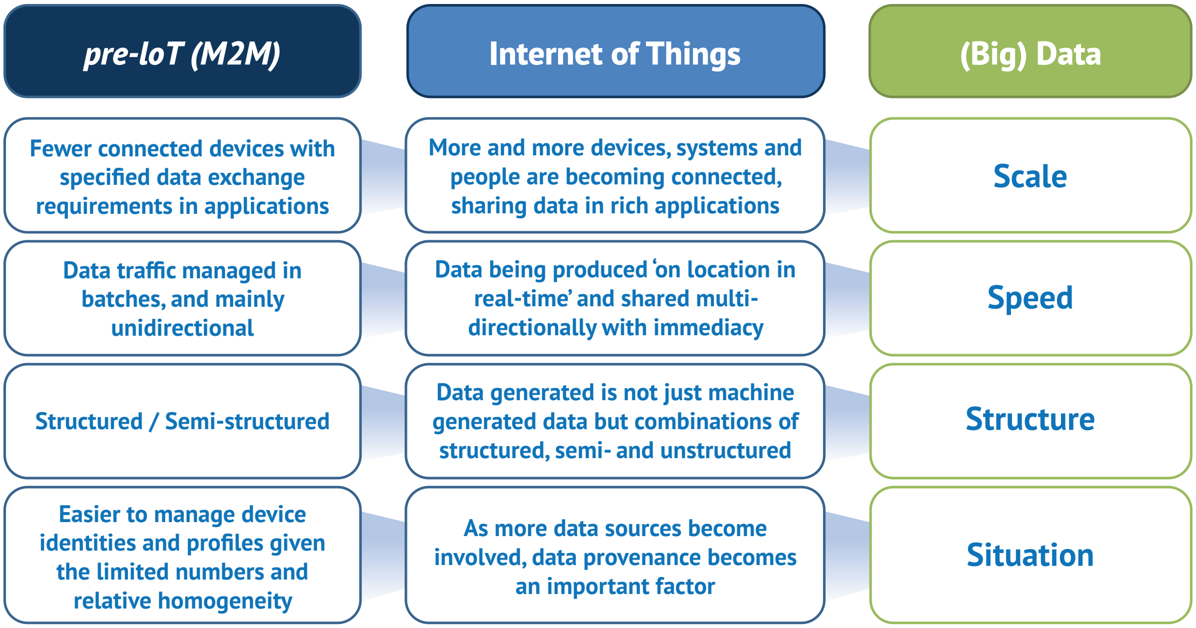

FIGURE 7: The Relationship Between M2M, IoT and Big Data [Source: Machina Research, 2014]

NoSQL databases are needed for the Internet of Things" http://www.mongodb.com/lp/download/machina-research

Based on our own research and experience, we have identified the following 5 key capabilities for data management in IoT:

1. Creating rich, functional applications: Data management must support the development of functionally rich applications with complex data and algorithms, with fast time to market and at low cost.
2. Unlocking Business Agility: The ability to support many new and frequently changing business requirements, causing fast and continuous evolution of the underlying data model.
3. Enabling a Single Point of Truth & Business Convergence: Aggregate multiple views of related data from multiple systems into one consistent version of the data.
4. Real-Time Operational Insight: Support both operational as well as analytical applications from the same data source
5. Enterprise-Grade Platform: Provide highly scalable, cloud-based, robust and secure applications

In the following, we will discuss each of these 5 key capabilities in context of our IoT business use cases.

1: Creating Rich, functional applications

Today's applications now incorporate a wide variety of data, bringing structured, semi-structured and unstructured data together to yield deeper operational insight into all areas of the business:

- Retail: "farm-to-fork" initiatives and increasing regulatory requirements to prove food lineage require the addition of sensors to generate audit trails tracking food production and transportation through the supply chain.
- Manufacturing: Capturing time-series, event based sensor data directly from the production line enables manufacturers to detect when processes are exceeding predefined tolerances and quickly take corrective action to avoid product wastage.
- Telematics and Mobility: The engine data bus is already established as a standard in luxury cars and trucks, consolidating individual events from sensors for engine diagnostics. The addition of new sensors enables richer applications and an increasing amount of data is being pushed back to central servers, enabling a fleet management company to start building new asset management applications that compare drivers and vehicles

```
{
  vehicle_id: '123abc'
  vehicle_driver: 'Miller',
  base: 'London',
  tracking: [
    { timestamp: '2014-01-17-12:00:00',
    location: [51.123,-0.232],
    speed: 55, ...},
    { timestamp: '2014-01-17-12:15:00',
    location: [51.224,-0.238],
    speed: 5, ...} }
}
```

Figure 8: MongoDB's Intuitive Document Data Model

across their fleet, identifying best — and worst — practices.

The variability of data generated by IoT applications is a far cry from the simple general ledger and address book applications that helped to popularize the relational database. Trying to force-fit database technologies designed decades ago to support these new types of applications inhibits agility and drives up cost and complexity.

Semi-structured and unstructured data does not lend itself to be stored and processed in the rigid row and column format imposed by relational databases, and cannot be fully harnessed for analytics if stored in BLOBS or flat files. Organizations must therefore embrace database technologies that provide the flexibility to model, store, process and analyze new complex data types typical in sensor based applications.

flexible data model: json documents

Complex data types typical in IoT applications can be modeled and represented more efficiently using JSON (JavaScript Object Notation) documents, rather than tables. MongoDB stores JSON documents in a binary representation called BSON (Binary JSON). BSON encoding extends the popular JSON representation to include additional data types.

With sub-documents and arrays, JSON documents also align with the data structure of objects at the application level. This makes it easy for developers to map the information model of the device or asset to its associated document in the database.

In contrast, trying to map the same object representation of the data to the tabular representation of an RDBMS slows down development. Adding Object Relational Mappers (ORMs) can create additional complexity by reducing the flexibility to evolve schemas and to optimize queries to meet new application requirements.

Instead of spending a lot of time dealing with the impedance mismatch between the programming language and the database, the developers must be enabled to focus on creating rich, functional applications.

2: Unlocking Business Agility

IoT is in its infancy. Changes in customer requirements, emerging standards and new use-cases demand flexible and dynamic development methodologies and data storage architecture.

- Retail: Technologies such as NFC and Apple's iBeacon enable retailers to derive as much insight from customer movement around their physical stores as they are used to getting from tracking customer movement around their eCommerce stores. By capturing and visualizing data from these location-based sensors, retailers can build heat maps to optimize the placement of high-margin products.
- Manufacturing: Smart Factory concepts are proposing more flexible assembly lines and support for smaller batch sizes by moving away from centrally controlled systems towards chains of intelligent and more autonomous production modules which interact with each other directly via the products, e.g. using RFID to create a "product memory".
- Telematics and Mobility: Rapid developments in automation and fleet management see each new generation of vehicle bristling with more sensors! Established telematics applications such as geo-location and engine diagnostics are being complemented by new services extending to areas such as fuel efficiency, driver safety, theft prevention and more.

The rapid evolution of IoT applications can be constrained by traditional software development methodologies — for example, the waterfall approach

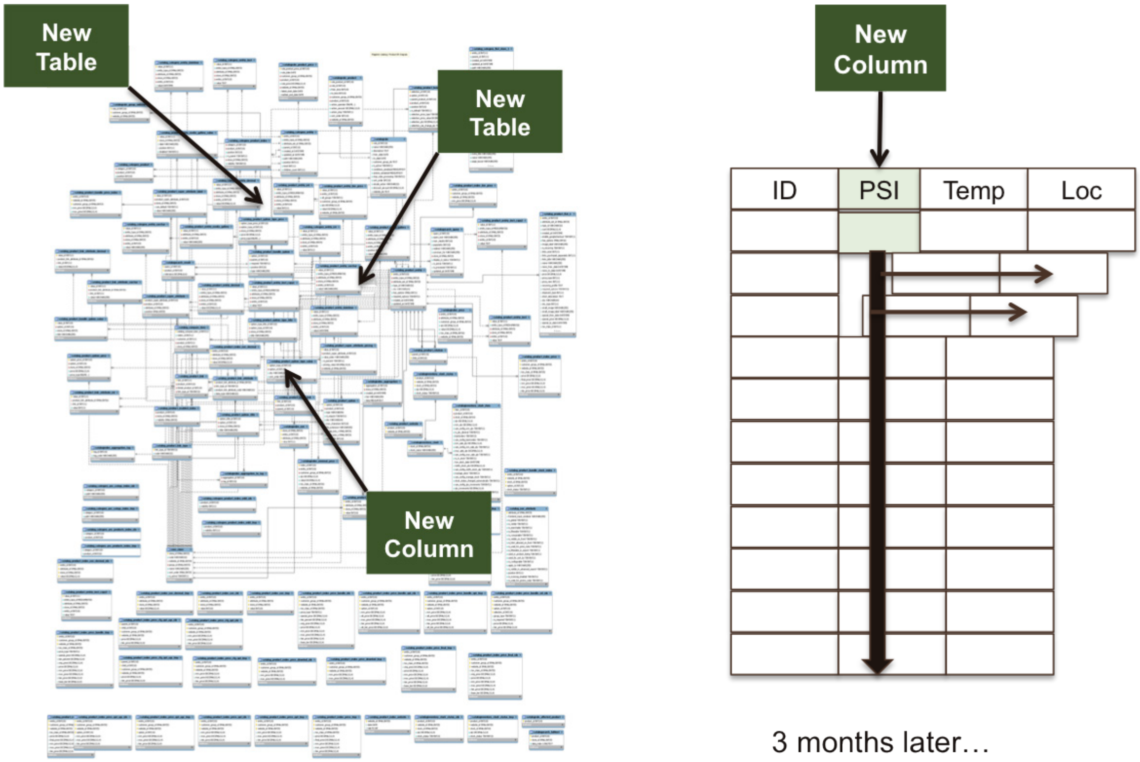

FIGURE 9: Complexity of Building & Maintaining a Single View with a Relational Schema

places enormous dependency on the requirements defined upfront. As illustrated in the examples above, these requirements are simply not known at the start of many projects. Instead, organizations need flexible, iterative development practices to make it easy for teams to respond to new business and market demands, without being held back by rigid data models.

Continuous Integration: Dynamic Database Schema

MongoDB's dynamic schema means that application development and ongoing evolution are straightforward, enabling continuous integration as developers add new features.

MongoDB enables developers to evolve the database schema through iterative and agile methodologies. Developers can start writing code and persist the objects without first pre-defining their structure. Each document (analogous to a row in a relational database) can have its own set of fields. Users can adapt the structure of a document's schema just by adding new fields or deleting existing ones, making it very simple to handle the rapidly changing data generated by fast moving IoT applications.

Contrast this with a traditional relational database — the developer and DBA working on a new project must first start by specifying the database schema, before any code is written. At minimum this will take days; it often takes weeks or months.

These benefits also extend to maintaining the application in production. When using a relational database, an application upgrade may require the DBA to add or modify fields in the database. These changes require planning across development, DBA and operations teams to synchronize application and database upgrades, agreeing on when to schedule the necessary ALTER TABLE operations. As MongoDB allows schemas to evolve dynamically, such an upgrade requires modifying just the application, with typically no action required for MongoDB.

High Productivity Application Development: Native Drivers

One fundamental difference with SQL-based relational databases is that the MongoDB interface is implemented as methods (or functions) within the API of a specific programming language, as opposed to a completely separate language like SQL, making MongoDB simple and natural to use. Developers interact with the database through native libraries that are integrated with their respective environments and code repositories, enabling much higher development productivity as they build new, or update existing, applications.

3: Enabling A Single Point of Truth and Business Convergence

Building a single view of a business entity — whether a physical asset or a customer — can deliver a range of benefits, from improved cross-sell and up-sell to enhanced operational efficiency and reduced costs:

- Retail: Building on the NFC and Beacon example earlier, retailers can instantiate a single view of their customers in real time, converging actual location in the store with their profile, purchase history and loyalty card details in order to deliver timely and targeted promotions.
- Manufacturing: Production line machines contain many discrete components, each with their own sensors. Bringing these together, along with the relevant service history can ensure optimum asset utilization and production line efficiency.
- Telematics / Mobility: Fleet managers can blend views of a vehicle's real time operational performance and diagnostics against asset registers that track service history to optimize preventative maintenance schedules.

Creating this "single point of truth" requires aggregating multiple views of related data distributed across different source systems into one consistent view. Using a relational database, the development and DBA team would first have to undertake lengthy design reviews in order to pre-define a common schema. Subsequent changes to the any of the source schemas would then necessitate associated changes to the single view schema.

MongoDB's dynamic schema and flexible document model do not impose the same constraints, enabling source systems to continuously evolve without impacting the single view needed by the business.

4: Real-Time Operational Insight

IoT applications enable new levels of operational insight and business discovery, but their value can only be fully realized when analysis is delivered in real time — providing the ability to react and respond as processes are in-flight.

- Retail: Inventory is tracked as it moves from shelf to basket while the retailer concurrently performs analytics that attempt to match available supply to predicted demand, adjusting for any deviation automatically through warehouse operations and the supply chain.
- Manufacturing: Sensor data from robotic systems is persisted to the database while analytics work in the background to identify optimizations to the production line.
- Telematics / Mobility: Engine diagnostics is enhanced by writing a continuous stream of sensor data to the database while simultaneously performing analytics comparing current status to historical baseline readings in order to proactively identify deviations and potential faults. For example, changes in oil or engine temperature may indicate the need to perform preventative maintenance.

Many traditional databases support operational applications by capturing structured data as it is generated. They then rely on slow moving batch ETL (Extract Transform Load) processes to replicate the data to the Enterprise Data Warehouse (EDW) where it is blended with semi-and-unstructured data for OLAP (OnLine Analytical Processing). To eliminate the analytics latency that inhibits real time business insight, it is necessary for the database to support both operational and analytical processes across the same data source handling structured, semi-structured and unstructured data.

Running Complex Analytics across Operational Data

MongoDB's replica sets allow live operational data to be written to a primary node before then being replicated transparently to secondary nodes against which analytic processes can be run. This separation of concerns ensures that complex analytical queries do not take computational resource from the operational workload.

With its rich index and query support, including secondary, geospatial and text search indexes, the Aggregation Framework and native MapReduce, MongoDB can run complex ad-hoc or reporting analytics in-place against multi-structured data to deliver real-time operational insight. Integration with many of the leading BI (Business Intelligence) and Analytics tools enables efficient business discovery.

5. Enterprise-Grade Platform

As IoT applications become embedded within the operational fabric of the business, they must deliver the scalability, availability and security demanded by any enterprise application. Business continuity and security are typically governed by strict mandates in every industry vertical. Specific examples include:

- Retail: The recent security breach of 70 million customer accounts at Target contributed to a 46% drop in net profits. The 2011 Playstation network breach at Sony Corporation is estimated to have cost the business over $4.5bn. As IoT applications are integrated into retail operations, they must provide security against attack if other businesses are not to suffer the same costs. Standards such as PCI-DSS and HIPAA (for those retailers selling pharmaceutical products) are also top of mind
- Manufacturing: If a production line were to stop due to an unplanned failure — even for a short period of time — the costs can be significant, including lost production capacity, idle workers and scrapped product. As IoT is at the very heart of many production line systems, continuous availability should be a prime concern.
- Telematics / Mobility: As drivers and fleet management companies come to rely on in-vehicle sensors for engine diagnostics, driver aids and regulatory compliance (i.e. self-certification of driver hours), downtime of IoT systems can cause critical business disruption and heavy costs.

While databases such as MongoDB offer new capabilities for flexible data management and agile development methodologies, they cannot compromise on the enterprise-grade capabilities of traditional relational databases. Using MongoDB organizations can build fault tolerant and secure applications that scale-out on commodity hardware as data volumes generated by sensors continues to explode.

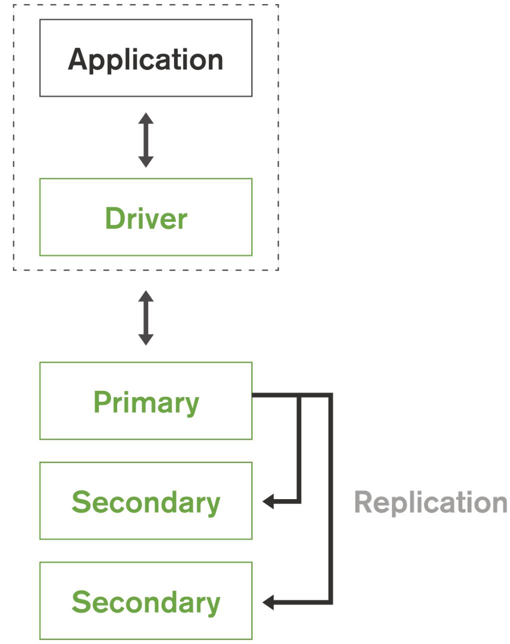

Figure 10: Self Healing MongoDB Clusters

Business Continuity with MongoDB Replica Sets

MongoDB maintains multiple copies of data within replica sets, using native replication to mirror data between replica set members. Replica sets can be deployed both within and across geographically distributed data centers. A replica set is self-healing, eliminating the need for administrators to manually intervene in the event of failure.

The number of members in a MongoDB replica set is configurable, and a larger number of replica members provides increased data durability and protection against database downtime (e.g., in case of multiple machine failures, rack failures, data center failures, or network partitions). Optionally, operations can be configured to write to multiple replica set members before returning to the application, thereby providing functionality that is similar to synchronous replication. Replica sets also provide operational flexibility by providing a way to upgrade hardware and software without requiring the database to go offline.

Defense in Depth Security Architecture

Among the Fortune 500 and Global 500, MongoDB already serves 10 of the top financial services institutions, 10 of the top electronics companies, 10 of the top media and entertainment companies, 10 of the top retailers, 10 of the top telcos, and 6 of the

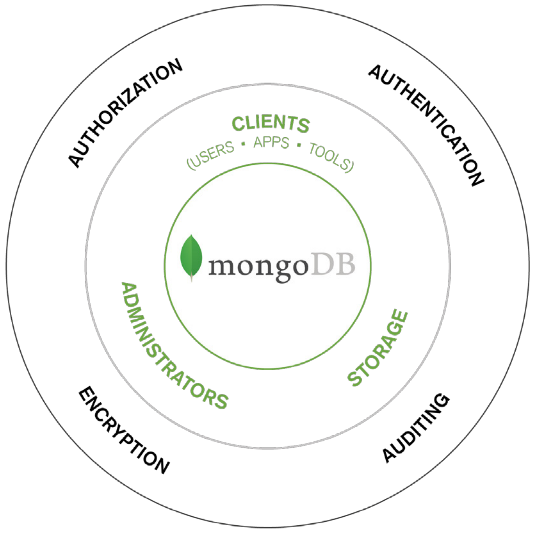

Figure 11: MongoDB Security Architecture: Defend, Detect and Control acess to IoT Data

top healthcare companies, in addition to deployments in government, military and intelligence applications. Security is a top consideration for all of these customers.

MongoDB is architected to provide defense in depth at every layer of the database:

- Authentication can be managed from within the database itself or via integration with external security mechanisms including LDAP, Windows Active Directory, Kerberos and PKI x.509 certificates.
- Authorization can be configured with granular user-defined roles, making it possible to implement a separation of duties between different entities accessing and managing the database. Field-level redaction can be used to manage access to sensitive data at the field level. A single document can therefore contain data with multiple security levels, avoiding the complexity of separating data across distinct databases.

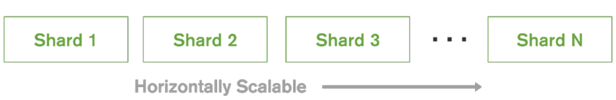

Figure 12: Simple Scaling for Growth of IoT Data

- Auditing captures access and administrative actions to the database, providing a trail for compliance and forensic analysis.
- Encryption, certified to FIPS 140-2, protects data in motion over the network and at rest on disk.

Economic Scaling as Sensor Data Grows

As new sensor-rich devices and assets come online so data volumes can quickly exceed the throughput and capacity requirements of a single server. Relational databases were designed at a time when scaling meant buying larger servers, however most modern applications rely on scaling out by distributing the load across fleets of commodity servers - providing a much lower cost and less complex way of adding capacity.

To try and leverage the flexibility and economics of scale-out computing, developers and DBAs using relational databases spend valuable cycles adding caching layers or building custom database partitioning in their application code and queries — rather than writing new applications.

MongoDB uses a technique called auto-sharding that is transparent to the application, enabling organizations to cost-effectively scale their database across hardware without imposing additional complexity on development teams.

Production-Ready IoT Databases

Over 1,000 organizations rely on commercial products from MongoDB, including startups and more than 30 of the Fortune 100. We offer software and services to make your life easier:

MongoDB Enterprise is the best way to run MongoDB in your data center. It's a finely-tuned package of advanced software, support, certifications, and other services designed for the way you do business.

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Conclusions

Platforms managing data and applications require significantly more flexibility, agility and scalability to meet the requirements of businesses in the Internet of Things. These requirements will be dynamic and constantly changing as the opportunities from integrated sensors and devices, and their data are identified. Businesses will look to gain and maintain competitive advantage from innovative applications, requiring quicker application development, agile data models coupled with enterprise-grade assurances. Bosch SI and MongoDB have worked closely together to create a solution that helps customers addressing these challenges.

About Bosch Software Innovations

Bosch Software Innovations, the Bosch Group's software and systems house, designs, develops, and operates innovative software and system solutions that help customers around the world both in the traditional enterprise environment and in the Internet of Things (IoT). Bosch Software Innovations has locations in Germany (Berlin, Immenstaad, Stuttgart), the United States (Chicago and Palo Alto), Singapore, China (Shanghai), and Australia (Melbourne). More information can be found at www.bosch-si.com.

Contact Bosch Software Innovations

About MongoDB

MongoDB makes development simple and beautiful. For tens of thousands of organizations, MongoDB provides agility and the freedom to scale. Fortune 500 enterprises, startups, hospitals, governments and organizations of all kinds use MongoDB because it is the best database for modern applications. Through simplicity, MongoDB changes what it means to build. Through openness, MongoDB elevates what it means to work with a software company. Please visit www.MongoDB.com to learn more.

Contact MongoDB

mongoDB BOSCH

New York · Palo Alto · Washington, D.C. · London · Dublin · Barcelona · Sydney · Tel Aviv
US 312-368-2500 · EUROPE +49-30-72-61-12-0 · info@bosch-si.com
US 866-237-8815 · INTL +1-650-440-4474 · info@mongodb.com