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Document Title	Added	Issue
A Scalable Multilayer Middleware for Distributed Monitoring and Complex Event Processing for Smart Cities	2018	In this paper, we present a hierarchical, distributed, cloud-based, context-aware architecture for collecting, processing and distributing data in a smart city. The architecture we are proposing has three hierarchical levels, and supports complex event processing (CEP) in several of them. At the lower layer, several mobile objects work as interfaces to sensors and actuators and provide processing capability for local filtering and detection. A second level, consisting of gateways and processing nodes, processes information from its locale and sends the data received from the mobile objects to the storage level using the existing network infrastructure. The highest level provides support for structured storage and queries of the information. Applications outside the platform can collect data through the external interface of the highest level. The system is under development using the InterSCity platform in the upper layer, the ContextNet middleware at the middle layer, and the Mobile-Hub application at the lower layer. It currently collects and processes data on buses running in the City of Rio de Janeiro.
Shapelets and Parallel Coordinates Based Automated Query Generation for Complex Event Processing	2016	Automating the query generation for Complex Event Processing (CEP) has marked its own importance in allowing users to obtain useful insights from data. Existing techniques are both computationally expensive and require extensive domain-specific human interaction. In addressing these issues, we propose a technique that combines both parallel coordinates and shapelets. First, each instance of the multivariate data is represented as a line on a set of parallel coordinates. Then a shapelet-learner algorithm is applied to those lines to extract the relevant shapelets. Afterwards, the identified shapelets are ranked based on their information gain. Next, the shapelets with similar information gain are divided into groups by a shapelet-merger algorithm. The best group for each event is then identified based on the event distribution of the dataset. Then the best group is used to generate the query to detect the complex events. The proposed technique can be applied to both multivariate and multivariate time-series data, and it is computationally and memory efficient. It enables users to focus only on the shapelets with relevant information gains. We demonstrate the utility of the proposed technique using a set of real-world datasets.
A semantic sensor mashup platform for Internet of Things	2018	With the rapid advancement of the Internet of Things (IoT), a number of sensors are constantly deployed and connected to the Web, generating a large amount of real-time streaming data. Such sensor streams may include contextual events, which indicate meaningful information on our environment. For this reason, Web applications which are developed for IoT should embrace sensor streams. Hence, there is a need for a sensor mashup tool to compose multiple sensors for effectively processing sensor streams. However, existing models for sensor mashup do not support complex events included in sensor streams. In this paper, we propose a virtual complex sensor (VCS) model that enables users to combine various existing sensors and formula-based knowledge. In addition, we propose a method of automatically generating multiple VCSs according to a user's configuration. We also provide a graphical user interface for building a VCS mashup and processing complex events. Experimental results on the proposed semantic sensor mashup show that the proposed approach is reasonable and applicable to various IoT application domains.
A Streamlined Approach for Real-Time Data Analytics	2018	Complex and diverse data is continuously being generated every microsecond because of computational intelligence in every field. Leveraging the huge amount of sensory information is a key issue to realize the IoT solutions in many areas. Traditional approaches reported in the literature for ingesting and processing data in real-time become in-efficient sometimes or may result in inadequate results. The faster one can manipulate information from data, the greater the value and cost of operational data become. This paper explains the cost-efficient method of processing and analyzing data in real time along with tools and techniques used for certain applications.
Fog-enabled Event Processing Based on IoT Resource Models	2018	Complex Event Processing (CEP) systems extract interest situations from event flows based on event detection patterns. However, local event processing for distributed Internet of Things (IoT) has not been discussed yet. Besides, it is complex or impossible to discover such patterns in some applications of IoT. In this article, we design a complex event service to process event flows based on IoT resource models, which does not depend on existing patterns, and deals with both discrete events and continuous variables. To improve the CEP performance, local IoT resources are used for local event processing, and a lazy exchange method is designed to realize the collaborated event processing between network edges and a data center. Our evaluation shows that our solution is feasible and effective.
Adaptive Energy-Aware Scheduling of Dynamic Event Analytics Across Edge and Cloud Resources	2018	The growing deployment of sensors as part of Internet of Things (IoT) is generating thousands of event streams. Complex Event Processing (CEP) queries offer a useful paradigm for rapid decision-making over such data sources. While often centralized in the Cloud, the deployment of capable edge devices on the field motivates the need for cooperative event analytics that span Edge and Cloud computing. Here, we identify a novel problem of query placement on edge and Cloud resources for dynamically arriving and departing analytic dataflows. We define this as an optimization problem to minimize the total makespan for all event analytics, while meeting energy and compute constraints of the resources. We propose 4 adaptive heuristics and 3 rebalancing strategies for such dynamic dataflows, and validate them using detailed simulations for 100 - 1000 edge devices and VMs. The results show that our heuristics offer O(seconds) planning time, give a valid and high quality solution in all cases, and reduce the number of query migrations. Furthermore, rebalance strategies when applied in these heuristics have significantly reduced the makespan by around 20 - 25%.
Algorithmic Strategies for Sensing-as-a-Service in the Internet-of-Things Era	2015	The objective of this thesis is to design efficient algorithms and architectures for enabling a Sensing as a Service paradigm in the recent era of Internet-of-things. With the widespread deployment of sensor architectures and sensor-enabled applications all around the globe, our planet today is witnessing an unprecedented instrumentation. The emerging paradigm of Sensing as a Service is replete with many open challenges, starting from systematic sensor deployment, regulated data collection, efficient data aggregation, scalable execution and proper participation. This dissertation aims to address some of these open challenges and attempts to carve a niche proposition by handling these problems from a purely algorithmic perspective. The objective is to examine each of the crucial pieces outlined above in the light of algorithmic design and come up with efficient mechanisms that are both practical and theoretically well-founded. The experiments are planned on real world data and hence, are expected to allow us to examine the efficacy of our proposals in a realistic setting.
Complex event processing for RFID-enabled retail store	2017	Out-of-stock is considered to be a major problem for retailers and suppliers. In this paper, we study the problem of complex event processing in a RFID enabled retail store operation, particularly aiming to provide automated shelf replenishment decisions. We define different event queries to simulate retailer store workflow in the area of backroom (warehouse) and the sales floor over the RFID data streams with item level and case-level tagging. With these queries to detect different levels of objects movement, the retail store can quickly replenish the shelves without long time delays. We utilize a simulated RFID enabled retail store to verify the effectiveness of our method.
A Semantic Publish-Subscribe Architecture for the Internet of Things	2016	This paper presents a publish-subscribe architecture designed to support information level interoperability in smart space applications in the Internet of Things (IoT). The architecture is built on top of a generic SPARQL endpoint where publishers and subscribers use standard SPARQL Updates and Queries. Notifications about events [i.e., changes in the resource description framework (RDF) knowledge base] are expressed in terms of added and removed SPARQL binding results since the previous notification, limiting the network overhead and facilitating notification processing at subscriber side. A novel event detection algorithm, tailored on the IoT specificities (i.e., heterogeneous events need to be detected and continuous updates of few RDF triples dominate with respect to more complex updates), is presented along with the envisioned application design pattern and performance evaluation model. Eventually, a reference implementation is evaluated against a benchmark inspired by a smart city lighting case. The performance evaluation results show the capability to process up to 68k subscriptions/s triggered by simple single-lamp updates and up to 3.8k subscriptions/s triggered by more complex updates (i.e., 10 to 100 lamps).

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Poster Abstract: Real-Time DDoS Detection Based on Complex Event Processing for IoT	2018	With the Internet of Things expansion, there has been an increase in the development of services and applications that use context-aware devices incorporated into smart environments. Those devices produce large quantities of data and demand faster and more precise defense mechanisms. Complex Event Processing (CEP) is an emerging and promising technology that allows real-time analysis of continuous data-steams. In this work, we proposed and developed a DDoS (Distributed Denial of Service) detection system and evaluated its performance running on a Raspberry Pi. The results show that the system can be executed on devices with reduced computational power and that CEP is a viable solution to improve the real-time performance on the detection of DDoS attacks on IoT environments.
Observing the Pulse of a City: A Smart City Framework for Real-time Discovery, Federation, and Aggregation of Data Streams	2019	An increasing number of cities are confronted with challenges resulting from the rapid urbanisation and new demands that a rapidly growing digital economy imposes on current applications and information systems. Smart city applications enable city authorities to monitor, manage and provide plans for public resources and infrastructures in city environments, while offering citizens and businesses to develop and use intelligent services in cities. However, providing such smart city applications gives rise to several issues such as semantic heterogeneity and trustworthiness of data sources, and extracting up-to-date information in real time from large-scale dynamic data streams. In order to address these issues, we propose a novel framework with an efficient semantic data processing pipeline, allowing for real-time observation of the pulse of a city. The proposed framework enables efficient semantic integration of data streams and complex event processing on top of real-time data aggregation and quality analysis in a Semantic Web environment. To evaluate our system, we use real-time sensor observations that have been published via an open platform called Open Data Aarhus by the City of Aarhus. We examine the framework utilising Symbolic Aggregate Approximation to reduce the size of data streams, and perform quality analysis taking into account both single and multiple data streams. We also investigate the optimisation of the semantic data discovery and integration based on the proposed stream quality analysis and data aggregation techniques.
Real-time middleware for cyber-physical event processing	2017	Cyber-physical applications are subject to temporal validity constraints, which must be enforced in addition to traditional QoS requirements such as bounded latency. For many such systems (e.g., automotive and edge computing in the Industrial Internet of Things) it is desirable to enforce such constraints within a common middleware service (e.g., during event processing). In this paper, we introduce CPEP, a new real-time middleware for cyber-physical event processing, with (1) extensible support for complex data processing operations, (2) execution prioritization and sharing, (3) enforcement of absolute time consistency with load shedding, and (4) efficient memory management and concurrent data processing. We present the design, implementation, and empirical evaluation of CPEP and show that it can (1) support complex operations needed by many applications, (2) schedule data processing according to consumers' QoS requirements, (3) enforce temporal validity, and (4) reduce processing delay and improve throughput of temporally valid events.
From Heterogeneous Sensor Networks to Integrated Software Services: Design and Implementation of a Semantic Architecture for the Internet of Things at ARCES@UNIBO	2018	The Internet of Things (IoTs) is growing fast both in terms of number of devices connected and of complexity of deployments and applications. Several research studies analyzing the economical impact of the IoT worldwide identify the interoperability as one of the main boosting factor for its growth, thanks to the possibility to unlock novel commercial opportunities derived from the integration of heterogeneous systems which are currently not interconnected. However, at present, interoperability constitutes a relevant practical issue on any IoT deployments that is composed of sensor platforms mapped on different wireless technologies, network protocols or data formats. The paper addresses such issue, and investigates how to achieve effective data interoperability and data reuse on complex IoT deployments, where multiple users/applications need to consume sensor data produced by heterogeneous sensor networks. We propose a generic three-tier IoT architecture, which decouples the sensor data producers from the sensor data consumers, thanks to the intermediation of a semantic broker which is in charge of translating the sensor data into a shared ontology, and of providing publish-subscribe facilities to the producers/consumers. Then, we describe the real-world implementation of such architecture devised at the Advanced Research Center on Electronic System (ARCES) of the University of Bologna. The actual system collects the data produced by three different sensor networks, integrates them through a SPARQL Event Processing Architecture (SEPA), and supports two frontend applications for the data access, i.e., a web dashboard and an Amazon Alexa voice service.
Demo abstract: Monitoring co-movement of smart objects using accelerometer data	2015	In the Internet of Mobile Things (IoMT) applications dealing with mobile objects may benefit from information if two or more objects are in co-movement, i.e. if they are close to each other and sharing the same movement pattern during some interval of time. In this demo we demonstrate how co-movement can be reliably monitored in a mobile middleware component executing on a smartphone using Complex Event Processing over streams of accelerometer data generated by SensorTags interacting with the smartphone through Bluetooth Low Energy.
Optimal Transmission Policy Derivation for IoNT Flow-guided Nano-sensor Networks	2019	By empowering the IoT with nanoscale communications, thousands of small devices, called nano-nodes, are enabled to monitor complex environments in a nonintrusive way, giving rise to the Internet of Nano-Things (IoNT) paradigm. It is in one of these very complex and critical environments, the human cardiovascular system, where IoNT might stand out. However, the supervision of human health poses significant challenges: firstly, to reduce costs and allow in vivo monitoring nano-sensor networks, the number of deployed nano-routers must be limited, which could cause nano-nodes to undergo long out-of-coverage periods. Lastly, nano-nodes rely on harvested energy from the medium, which severely reduces the number of potential transmissions. To overcome these two problems, smart policies that direct devices on how to proceed with sensed events are crucial. In this line, we propose a generic Markov Decision Process (MDP) model which can be exploited to derive optimal transmission policies that are easily employed by nano-nodes. These policies maximize nano-node throughput and cope with the energy and coverage problems. We have also run a set of simulations to validate our proposal and to compare it to other alternative policies. Results reveal that: (i) our policy systematically outperforms the rest of policies by a large margin; (ii) precision in placing nano-routers and average distance between them strongly affect the nano-network performance. The Python code for the MDP model and simulations has been programmed to be easily adaptable to researchers' needs, making it easier for future IoNT works to add intelligence to the network.
What Is the Internet of Things: An Introduction	2017	This module provides an overview of the Internet of Things technology. The emergence of the paradigm is explored and a range of application areas and challenges are discussed. In particular, we explain the broader implications of networked small devices, and the types of services they can provide. Some implications in the area of personal and information security challenges associated with deployment of Internet of Things and broad adoption of Internet connected small devices and sensor networks are also explored.
Intelligent Checkpointing Strategies for IoT System Management	2017	The Internet of Things (IoT) continues to expand in terms of the number of connected devices. To handle the data produced by those devices, gateways are deployed to collect data, possibly to analyze it, and finally to send it to the cloud or to the end-user to support new services. This process involves complex software that is deployed on those gateways. Moreover, the dynamicity due to new services, mobility, etc., could be corrupted by new events that then require the deployment of software components on additional equipment. Those new events arise in at least two fundamental ways: devices that may change their geographical location; and limitations due to hardware resources and energy consumption. We propose to use autonomic monitoring and control in response to a changing environment in order to manage deployed software with little or no human intervention. A new generic approach is described, based on a semantic model of the system being monitored. Much of the power of the proposed approach is accomplished through a novel use of checkpointing in order to control the software deployed on the gateway.

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Predictable Low-Latency Event Detection With Parallel Complex Event Processing	2015	The tremendous number of sensors and smart objects being deployed in the Internet of Things (IoT) pose the potential for IT systems to detect and react to live-situations. For using this hidden potential, complex event processing (CEP) systems offer means to efficiently detect event patterns (complex events) in the sensor streams and therefore, help in realizing a “distributed intelligence” in the IoT. With the increasing number of data sources and the increasing volume at which data is produced, parallelization of event detection is crucial to limit the time events need to be buffered before they actually can be processed. In this paper, we propose a pattern-sensitive partitioning model for data streams that is capable of achieving a high degree of parallelism in detecting event patterns, which formerly could only consistently be detected in a sequential manner or at a low parallelization degree. Moreover, we propose methods to dynamically adapt the parallelization degree to limit the buffering imposed on event detection in the presence of dynamic changes to the workload. Extensive evaluations of the system behavior show that the proposed partitioning model allows for a high degree of parallelism and that the proposed adaptation methods are able to meet a buffering limit for event detection under high and dynamic workloads.
A Big Data Processing Framework for Self-Healing Internet of Things Applications	2016	In this study, we introduce a big data processing framework that provides self-healing capability in the Internet of Things domain. We discuss the high-level architecture of this framework and its prototype implementation. To identify faulty conditions, we utilize a complex-event processing technique by applying a rule-based pattern-detection algorithm on the events generated real-time. For events, we use a descriptor metadata of the measurements (such as CPU usage, memory usage, bandwidth usage) taken from Internet of Things devices. To understand the usability and effectiveness of the proposed architecture, we test the prototype implementation for performance and scalability under increasing incoming message rates. The results are promising, because its processing overhead is negligible.
Online Decision-Making Using Edge Resources for Content-Driven Stream Processing	2017	The Internet of Things (IoT) describes the emerging paradigm that connects sensors, often located at the edge of the network, to stream processing engines located at the core of the network to enable online data-driven monitoring, management, and control. As IoT applications require increasing volumes of streaming data to be processed by complex workflows in a timely manner, it is becoming important to also leverage resources closer to the edge. Furthermore, the topology of these workflows and where theyare executed is determined not only by application objectives and available resources, but also by the content of the data streams, however, current stream processing engines do not provide this flexibility. In this paper, we present a programming framework that enables applications to specify data-driven, location- and resource-aware processing of data streams. Specifically, it provides abstractions for specifying where and how a data stream is processed based on its content, spatial and temporal characteristics. We also present an implementation of the framework using an event-driven runtime, where events are associatively described. Finally, we demonstrate the effectiveness of the solution by an evaluation of scalability and performance using a disaster response application usecase.
A Microservices Architecture for Reactive and Proactive Fault Tolerance in IoT Systems		599
Multi-Query Optimization for Complex Event Processing in SAP ESP	2017	SAP Event Stream Processor (ESP) platform aims at delivering real-time stream processing and analytics in many time-critical areas such as Capital Markets, Internet of Things (IoT) and Data Center Intelligence. SAP ESP allows users to realize complex event processing (CEP) in the form of pattern queries. In this paper, we present MOTTO - a multi-query optimizer in SAP ESP in order to improve the performance of many concurrent pattern queries. This is motivated by the observations that many real-world applications usually have concurrent pattern queries working on the same data streams, leading to tremendous sharing opportunities among queries. In MOTTO, we leverage three major sharing techniques, namely merge, decomposition and operator transformation sharing, to reduce redundant computation among pattern queries. In addition, MOTTO supports nested pattern queries as well as pattern queries with different window sizes. The experiments demonstrate the efficiency of the MOTTO with real-world application scenarios and sensitivity studies.
Towards human mobility extraction based on social media with Complex Event Processing	2015	Social media has enabled a new breed of soft sensors that enriches the IoT paradigm with new forms of data. The present work introduces a novel approach for personal mobility mining that combines these new data-sources with built-in sensors of a smart-phone in order to timely extract personal mobility pattens by means of the Complex Event Processing (CEP) approach. Unlike previous solutions, the present work profits from both the textual and location data of social-network sites by also dealing with the actual scarcity of geo-tagged documents in those sites. Finally, a preliminary study of the feasibility of our proposal is stated.
A Software Chain Approach to Big Data Stream Processing and Analytics	2015	Big Data Stream processing is among the most important computing trends nowadays. The growing interest on Big Data Stream processing comes from the need of many Internet-based applications that generate huge data streams, whose processing can serve to extract useful analytics and inform for decision making systems. For instance, an IoT-based monitoring systems for a supply-chain, can provide real time data analytics for the business delivery performance. The challenges of processing Big Data Streams reside on coping with real-time processing of an unbounded stream of data, that is, the computing system should be able to compute at high throughput to accommodate the high data stream rate generation in input. Clearly, the higher the data stream rate, the higher should be the throughput to achieve consistency of the processing results (e.g. Preserving the order of events in the data stream). In this paper we show how to map the data stream processing phases (from data generation to final results) to a software chain architecture, which comprises five main components: sensor, extractor, parser, formatter and out putter. We exemplify the approach using the Yahoo!S4 for processing the Big Data Stream from Flight Radar24 global flight monitoring system.
Situation-Aware IoT Service Coordination Using the Event-Driven SOA Paradigm	2016	Internet of Things (IoT) technology demands a complex, lightweight distributed architecture with numerous diverse components, including end devices and applications adapted for specific contexts. This paper proposes a situation-aware IoT services coordination platform based on the event-driven service-oriented architecture (SOA) paradigm. Focus is placed on the design of an event-driven, service-oriented IoT services coordination platform, for which we present a situational event definition language (SEDL), an automaton-based situational event detection algorithm, and a situational event-driven service coordination behavior model, which is based on an extended event-condition-action trigger mechanism. Moreover, we propose a reliable real-time data distribution model to support the effective dispatching sensory data between information providers and consumers, which is based on the grid quorum mechanism to organize those brokers into a grid overlay network to facilitate the asynchronous communication in a large-scale, distributed, and loosely coupled IoT applications environment. We also illustrate the various illustrations for IoT services coordination and alarming disposal process of coal mine safety monitoring and control automation scenarios, and also report the measurement and analysis of the platform's performance.
Production process adaptation to IoT triggered manufacturing resource failure events	2017	Usage of raw data as an asset, from which value can be created to support business and manufacturing decision making, motivated a lot of scientists to explore the challenges on how to exploit this value. Such efforts are concentrated on the framework of “data value chain”, where approaches of architectures and applications aim at equipping enterprises with tools that gather, process and extract knowledge from raw data generated by their internal or external processes. In this context, the present paper deals with the way the production processes in a factory can be adapted to changes that are detected by the processing of raw data which are aggregated by IoT devices installed in the manufacturing environment. The proposed approach introduces a complex system that combines a network of IoT sensors and a high-level multi-agent system that contributes to the vertical integration of all the systems residing in the Enterprise/Factory.

Document Title	Added	Issue
A Coupling System Design Based on the Internet of Things and Intelligent Decision Support System in Industrial Enterprises	2016	Extensive economic development and traditional industrial production processes had caused great waste on human resources and natural energy. In the view of this situation, the paper establishes a coupling information system based on the internet of things and decision support system, expanding the research on the overall framework and design level of the integration system. First, from the macro level, the coupling system is built with the perception layer and decision-making layer as a whole, secondly, starting with complex network theory, the paper makes use of small-world network model to optimize perception layer topology network, finally, as the manufacturing is the core part of perception layer of the industrial enterprises, the technical framework of the active perception of critical events in IOMT based manufacturing process is established, which contributes to providing dynamic monitoring and decision-making to optimize the production process with a new model of support real-time information. Hence, the visual decision knowledge as well as realization of real-time intelligent management can be obtained by the coupling system.
ESCEP: A CEP based on event sharing in Internet of Things	2017	This paper focuses on the research of complex event in the event of overlapping processing problems, put forward a complex event processing engine ESCEP based on event sharing, and the event model is improved. An event linear sequence hash algorithm is used to decompose complex events into several intermediate events, the new event query model is generated according to the event sharing cost algorithm and the event distribution strategy is formulated through the event communication cost algorithm. The prototype system test shows that, the engine is superior to existing engines under the condition of event overlap rate increasing.
Skipping Unused Events to Speed Up Rollback-Recovery in Distributed Data-Parallel CEP	2018	We propose two extensions for a state-of-the-art method of rollback-recovery in distributed CEP (complex event processing). In CEP, an operator network is used to search for patterns in events streams. Sometimes these operators fail and lose their state. Rollback-recovery is a method for dealing with such state losses. The type of rollback-recovery we consider is upstream backup, where the state of a failed operator is recovered by replaying to it the input events that led it to that state. These events are kept in upstream operators' memory buffers, which are trimmed continuously as the downstream operator progresses. The first extension we propose saves memory and speeds up recovery by avoiding to store and retransmit unnecessary events. The second extension makes the base method of upstream backup compatible with data-parallel CEP, allowing that the windows into which operators partition their input be processed in parallel. We evaluated the proposed extensions through experiments that showed a significant reduction in memory usage and recovery time at the expense of a negligible processing overhead during normal operation.
The Internet of Things Enabled Shop Floor Scheduling and Process Control Method Based on Petri Nets	2019	Shop floor scheduling requires consideration of the dynamic, time-varying, and unpredictable natures of the manufacturing environment. A shop floor scheduling/rescheduling method based on Petri net and ant colony optimization (PN-ACO) is proposed given an abnormal event represented by machine breakdown. Because of the difficulty to schedule in the complex and changeable internal and external environment of the shop floor, an Internet-of-Things (IoT)-enabled process control method is proposed, using sensors, RFID, industrial wireless communication, automatic identification, and other technologies to perceive the shop floor field. The value of the mean relative error is 1.77, which illustrates the feasibility and efficiency of the proposed PN-ACO algorithm to solve flexible job shop scheduling problems. To represent operation sequencing information, a schedule timed transition Petri net (TTPN) is proposed which is evolved from the TTPN. On the basis of the mapping mechanism between the Petri net model and the XML, manufacturing resources become autonomous and interactive distributed intelligent manufacturing resources. The experimental results confirm that the proposed method is effective for scheduling and process control of the IoT-enabled shop floor.
Secure and efficient communication in cyber-physical systems through cryptography and complex event processing	2016	The way we view and use technology has changed dramatically over the past decade. We now have smart devices, BigData, cyber-physical systems, internet-of-things and much more. Because technology is so present in the way we communicate and in our day-to-day activities, the need for strong and efficient security systems is extremely poignant. Cyber-physical systems integrate various components and can interact with their surrounding. Their usage in critical applications requires a robust security architecture. While methods like cryptography or steganography can cover aspects such as protecting data and communications, in order to ensure efficiency and the smart usage of resources we need a different approach. Throughout this paper we will describe a method that uses a hierarchical cryptosystem to protect communications within a cyber-physical system combined with complex event processing to optimize the security architecture.
Towards a context-driven platform using IoT and big data technologies for energy efficient buildings	2017	Context-awareness is crucial for leveraging energy-efficient buildings by developing intelligent control approaches in which sensing and actuation tasks are performed according to the contextual changes. This could be done by including the users' actions and behaviours in up-to-date context taking into account the complex interlinked elements, situations, processes, and their dynamics. In this paper, we introduce a holistic platform that integrates recent sensing/actuating and Big data technologies for monitoring and data processing. The main aim is to develop context-driven control approaches whereby energy consumption, production, and storage could be controlled according to actual situations (e.g., occupancy, occupant behaviour patterns, energy production patterns, and weather data). A platform prototype was deployed in our university test site. Experiments have been conducted and preliminary results show the usefulness of this holistic platform for monitoring and data processing in energy efficient buildings.
Opportunistic smart object aggregation based on clustering and event processing	2016	In the envisioned Internet of Things ecosystems, Smart objects are intended to create groups of devices in order to provide higher level services to be leveraged by citizens. However, because of the dynamic nature of such scenarios, the discovery, management and operation of such dynamic coalitions taking into account security and privacy concerns, is a challenging task that has not been properly addressed yet. In this sense, the present proposal devises a novel approach to automatically compose opportunistic aggregations of objects (bubbles) based on Complex Event Processing (CEP) and fuzzy clustering. While the former detects certain events that could give raise to discover new bubbles, the latter allows compose aggrupations of similar objects acting as candidate bubbles. Finally, the application of the proposal in an educational domain is put forward.
Building an IoT Framework for Connected Dairy	2015	Heat stress (HS) causes cows to produce less milk with the same nutritional input, which effectively increases farmers' production costs. The economic toll due to higher-temperature, heat stress is a $1 billion annual problems. Not only in the United States, but also around the globe heat stress causes an adverse impact on dairy productivity. The opportunities, however, for the dairy industry is to electronically monitor cattle temperature and implement appropriate measures so that the impact of HS can be minimized. The U.S. Department of Agriculture estimates nearly $2.4 billion a year in losses from animal illnesses that lead to death can be prevented by electronically checking on cattle's' vital signs. This research paper recommends the most innovative electronic monitor framework, the 'Smart Connected Objects", aka, 'the Internet of Things (IoT)', that enables dairies to minimize the economic impact of HS and, at the same, capture the higher Return on Assets (ROA) & Return on Investment (ROI) by improving operational efficiencies. Happy Cow, more importantly, means happier, more profitable, dairy industry and richer and creamer dairy products. The proposed framework supports both offline and online dairy IoT. This paper presents a prototyping solution design as well as its application and certain experimental results.
A Case Study for Workflow-Based Automation in the Internet of Things	2018	The application of workflow technologies in the context of Internet of Things (IoT) presents a young and vibrant research field. Introducing a dedicated workflow layer on top of typical software architectures to model and execute repetitive tasks among IoT devices, systems and services facilitates the flexibility, reuse, configuration and programming of processes in the IoT. In this work we present the PROtEUS IoT workflow management system (WfMS) and its application for automating typical processes in a Smart Home case study.We conduct various experiments to show the systemâ€™s capabilities and suitability to be used as an IoT WfMS interacting with sensors, actuators, robots, humans and smart objects. PROtEUS integrates components for dynamic service selection, complex event processing, human interactions and self-adaptation, which makes it a WfMS able to cope with new IoT-related challenges.

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Real-Time Manufacturing Machine and System Performance Monitoring Using Internet of Things	2018	This paper introduces a framework to assess the performance of manufacturing systems using hybrid simulation in real time. Continuous and discrete variables of different machines are monitored to analyze performance using a virtual environment running synchronous to plant floor equipment as a reference. Data are extracted from machines using industrial Internet of Things solutions. Productivity and reliability of a physical system are compared in real time with data from a hybrid simulation. The simulation uses discrete-event systems to estimate performance metrics at a system level, and continuous dynamics at a machine level to monitor input and output variables. Simulation outputs are used as a reference to detect abnormal conditions based on deviations of real outputs in different stages of the process. This monitoring method is implemented in a fully automated manufacturing system testbed with robots and CNC machines. Machines are integrated on an Ethernet/IP control network using a programmable logic controller to coordinate actions and transfer data. Results demonstrated the capacity to perform real-time monitoring and capture performance errors within confidence intervals. Note to Practitioners-Estimating expected performance of a manufacturing system processing different parts across multiple machines is a complex problem due to the lack of closed-form equations. Existing solutions focus on monitoring stochastic variables such as production or failure rate, or machine dynamics in separate environments often running asynchronous to the real system. This paper addresses the problem of monitoring and assessing the performance of complex manufacturing systems in real time. The proposed framework uses a real-time hybrid simulation of manufacturing at a machine and system level. The hybrid approach is based on a discrete and continuous model of manufacturing equipment integrated to run synchronously with the real plant floor operation. Data from both the virtual and real environments are merged to assess performance. Deviations from expected values represent an error that can trigger a warning signal to production, maintenance, and/or manufacturing personnel at the plant regarding health and productivity of plant operations.
A supervisory control loop with Prognostics for human-in-the-loop decision support and control applications	2017	This paper presents a novel tandem human-machine cognition approach for human-in-the-loop control of complex business-critical and mission-critical systems and processes that are monitored by Internet-of-Things (IoT) sensor networks and where it is of utmost importance to mitigate and avoid cognitive overload situations for the human operators. The approach is based on a decision making supervisory loop for situation awareness and control combined with a machine learning technique that is especially well suited to this control problem. The goal is to achieve a number of functional requirements: (1) ultra-low false alarm probabilities for all monitored transducers, components, machines, systems, and processes; (2) fastest mathematically possible decisions regarding the incipience or onset of anomalies in noisy process metrics; and (3) the ability to unambiguously differentiate between sensor degradation events and degradation in the systems/processes under surveillance. The novel approach that is presented here does not replace the role of the human in operation of complex engineering systems and processes, but rather augments that role in a manner that minimizes cognitive overload by very rapidly processing, interpreting, and displaying final diagnostic and prognostic information to the human operator in a prioritized format that is readily perceived and comprehended.
Dynamically Scalable Distributed Virtual Framework Based on Agents and Pub/Sub Pattern for IoT Media Data	2019	The Internet of Things (IoT) continues to expand; as daily new smart-devices are connected to Internet and adding to a deluge of data created by our society. Compounding the challenges is that this data is very heterogeneous, including device or human activity trace data, structured data, sensor information, and media data. The computing needs for the IoT continue to rise in terms of scalable compute power, storage, and complex data processing pipelines to accommodate these diverse sources of data. For this reason, it becomes essential to develop a flexible framework that is able to efficiently manage the IoT data in a real-time and scalable approach. In this paper, we propose a novel framework to handle IoT data. Our framework is dynamically extensible, lightweight, resources efficient, and has the ability to handle stream data as well as batch data. We leverage autonomous agents along with the publish-subscribe pattern to achieve a run-time extensible, event-driven, and high-performance computational architecture. Additionally, we have incorporated localized and centralized databases into the framework to support structured and unstructured data for compute processing and analytical tasks. We have implemented the proposed framework and evaluated its performance using a visual object-detection case study on both a local cluster and within cloud-computing infrastructure. Our analysis shows that this framework utilizes the CPU, memory, and network resources efficiently. Additionally, the framework can scale horizontally as adding more processing nodes reduces the time and increases the goodput.
Archer: An Event-Driven Architecture for Cyber-Physical Systems	2018	A global Internet of Things demands new cloud architectures that can scale to support all kind of loosely coupled data and events producers and consumers. Moreover, these architectures need to be capable of offering low-latency delivery, which must not only feed real-time analytics applications, but also produce real-time actionable data that could enable operational business logic and automation triggers activation and transform microservices into cyber-physical microapplications. The design principles to build distributed event-driven applications are known to be complex and hard to handle at the application code level. As a result, there are several already well-known patterns that aim to provide a convenient solution and abstract the business logic development from the underlying architecture complexities. This paper proposes a common framework that addresses all the needs of an in-production application, that are hard to solve under the event-driven paradigm. It gathers existing patterns and combines them and extends them. These patterns are implemented and comprised in a middleware library which has been tested on a proof-of-concept architecture implementation, based on Apache Kafka.
Event model to facilitate data sharing among services: Closing the gap between research and implementation	2016	Development of smart city services is presently hindered because the data is too heterogeneous, despite the increasing availability of data in open data initiatives. We determined metadata fields and semantics for our proposed model after a survey of other event models, and after its trial implementation in actual applications. Our event metadata model is unique among event models in being extensible as needed. We illustrate our model by showing it with different data types, and we validate it using real-world data in a prototype smart cities service for pedestrian safety. Wide adoption of our event metadata model has the potential to broaden the number and scope of smart city services.
ThingStore — An Internet of Things Management System	2017	The emerging technologies in IoT unveils various devices for the convenience of users, but comes with the price of streaming and processing a large amount of data for delivering useful and presentable results. Especially the multimedia content can be estimated as the most expensive to compute and distribute in IoT environments due to the data size and complexity of algorithms. This may cause bottlenecks in current Internet and data-center infrastructures, thus affecting the service price and quality. ThingStore is an advanced app-store concept to bring device providers, application software developers, and end-users together in an Internet-scale IoT ecosystem. The concept of smart services in ThingStore allows the distribution of the massive computation on IoT to the edges, thus avoiding data transfers and making services with large computational volume possible. The Event Query Language (EQL) allows software developers without domain knowledge to develop applications over large scales of sensor devices. This study introduces the new event query processing approach in ThingStore, provides a new and more detailed definition of EQL and proposes an Internet architecture based on service-oriented computing.
An Approach for Real-Time Stream Reasoning for the Internet of Things	2017	As distributed IoT applications become larger and more complex, the simple processing of raw sensor and actuation data streams becomes impractical. Instead, data streams must be fused into tangible facts and these pieces of information must be combined with a background knowledge to infer new bits of knowledge. And since many IoT applications require almost real-time reactivity to stimuli from the environment this information inference process has to be performed in a continuous, on-line manner. This paper proposes a new semantic model for data stream processing and real-time symbolic reasoning based on the concepts of Semantic Stream and Fact Stream, as a natural extensions of Complex Event Processing (CEP) and RDF (graph-based knowledge model). The main advantages of our approach are that: (a) it considers time as a key relation between pieces of information, (b) the processing of streams can be implemented using CEP and that (c) it is general enough to be applied to any Data Stream Management System (DSMS).

Document Title	Added	Issue
LTCEP: Efficient Long-Term Event Processing for Internet of Things Data Streams	2015	Complex event processing has been widely adopted in different domains, from large-scale sensor networks, smart home, transportation, to industrial monitoring, providing the ability of intelligent procession and decision making supporting. In many application scenarios, a lot of complex events are long-term, which takes a long time to happen. Processing long-term complex event with traditional approaches usually leads to the increase of runtime states and therefore impact the processing performance. Hence, it requires an efficient long-term event processing approach and intermediate results storage/query policy to solve this type of problems. In this paper, we propose an event processing system, LTCEP, for long-term event. In LTCEP, we leverage the semantic constraints calculus to split a long-term event into two parts, online detection and event buffering respectively. A long-term query mechanism and event buffering structure are established to optimize the fast response ability and processing performance. Experiments prove that, for long-term event processing, LTCEP model can effectively reduce the redundant runtime state, which provides a higher response performance and system throughput comparing to other selected benchmarks.
Predictive Analytics for Complex IoT Data Streams	2017	The requirements of analyzing heterogeneous data streams and detecting complex patterns in near real-time have raised the prospect of complex event processing (CEP) for many Internet of Things (IoT) applications. Although CEP provides a scalable and distributed solution for analyzing complex data streams on the fly, it is designed for reactive applications as CEP acts on near real-time data and does not exploit historical data. In this regard, we propose a proactive architecture which exploits historical data using machine learning for prediction in conjunction with CEP. We propose an adaptive prediction algorithm called adaptive moving window regression for dynamic IoT data and evaluated it using a real-world use case with an accuracy of over 96%. It can perform accurate predictions in near real-time due to reduced complexity and can work along CEP in our architecture. We implemented our proposed architecture using open source components which are optimized for big data applications and validated it on a use-case from intelligent transportation systems. Our proposed architecture is reliable and can be used across different fields in order to predict complex events.
Predicting complex events for pro-active IoT applications	2015	The widespread use of IoT devices has opened the possibilities for many innovative applications. Almost all of these applications involve analyzing complex data streams with low latency requirements. In this regard, pattern recognition methods based on CEP have the potential to provide solutions for analyzing and correlating these complex data streams in order to detect complex events. Most of these solutions are reactive in nature as CEP acts on real-time data and does not exploit historical data. In our work, we have explored a proactive approach by exploiting historical data using machine learning methods for prediction with CEP. We propose an adaptive prediction algorithm called Adaptive Moving Window Regression (AMWR) for dynamic IoT data and evaluated it using a real-world use case. Our proposed architecture is generic and can be used across different fields for predicting complex events.
A Mobile Complex Event Processing System for Remote Patient Monitoring	2018	Complex Event Processing (CEP) is widely used for Remote Patient Monitoring (RPM). However, the state-of-the-art techniques use a centralized server to receive health sensor streams and detect complex events. This paper introduces an Internet of Things (IoT) based CEP approach that uses a mobile device on the edge and a remote IoT Hospital Server (IHS) deployed on the cloud. The prototype implementation of the system uses an open-source Siddhi CEP engine on the mobile device and an open-source Web Services Oxygen (WSO2) IoT Server on the IHS. In this architecture, complete complex event detection is performed on the edge and the complex event streams are sent to the hospital server using the Message Queuing Telemetry Transport (MQTT) protocol. The MQTT broker forwards complex event streams to an event listener service running on the hospital server that notifies the hospital staff. Advantages of performing CEP on the edge include circumventing out-of-order delivery of various health sensor streams, avoiding queuing delays at the hospital server and reducing the user cost for data transfer between the mobile device and the hospital server. Also, this technique provides the ability to generate local alarms for the patient even when the mobile network connecting the device to the hospital server is unavailable.
Complex Event Recognition Notification Methodology for Uncertain IoT Systems Based on Micro-Service Architecture	2018	One of the main purposes of the Internet of Things (IoT) systems is to provide information on the observed physical system and to notify when a certain observed complex event occurs in the system. The biggest challenge of the IoT systems is that the systems collect a massive amount of uncertain data from diverse IoT devices, where the devices are connected through the internet. In addition to that, some events are inferred from other events and uncertainty is propagated from parent events to the inferred events, which additionally contributes to overall system uncertainty. The observed complex events are a complex relationship of primitive events that are produced by IoT devices and collected in IoT system. There were a couple of attempts to quantify the system uncertainty by estimating the likelihood of the occurrence of events of interest while taking into account the uncertain data and uncertain parameters of the model of the physical system with rule-based complex event processing and/or Bayesian network. These methods were implemented as stand-alone software solutions that are unable to scale under heavy loads of incoming events. This paper proposes a micro-service based notification methodology that uses complex event recognition to handle the IoT system uncertainty.
Modeling business entities and physical workflow in the context of Internet of Things: The GSM-IoT framework	2015	Guard Stage Milestone (GSM) approach proved its ability to specify business entities lifecycle and the associated data. Although this framework is a promising approach for business process operations modeling, the concept of physical flows is missing. In workflow modeling, we usually have three main views, the strategic, the tactical, and the operational views. These views show different aspect of the business workflow from coarse grained level to finest grained level of granularity. The purpose of this article is to extend GSM framework by adding physical workflow concepts and take into account particularities of Internet of Things (IoT) smart entities and their mutual interactions. This extended framework called GSM-IoT framework eases physical workflow modeling, particularly the strategic and operational views we are interesting in this article. GSM-IoT framework also aims to enable services orchestration, data and event sharing among stakeholders in the context of Internet of Things. This will therefore ease business collaboration and interoperability enhancement in the Supply Chain (SC) ecosystem.
Support Dementia: Using Wearable Assistive Technology and Analysing Real-Time Data	2016	Support provided to sufferers of Dementia by the National Health Service (NHS) is mainly in the form of personal attendants such as nurses and social workers. The main focus of this paper is to present how the use of assistive technologies can help early sufferers of Dementia patients to overcome barriers in achieving their daily activities and to illustrate how data analytics, such as Complex Event Processing (CEP) in real-time can allow better monitoring of these patients. This activity will contribute to research work which is to provide a suitable framework to accurately analyse real-time data from assistive technology and wearable devices for remote healthcare, particularly monitoring early sufferers of dementia in order to promote good quality independent living.
CEP Rule Extraction From Unlabeled Data in IoT	2018	With the recent development of the Internet of Things, produced data are increasing day by day. These data have to be analyzed in real time. To provide real time analysis, Complex Event Processing is proposed to analyze the continuous and timely annotated data. Complex event processing detects complex events from atomic events via predefined rules which are mostly determined by domain experts. Determining complex event processing rules requires thorough knowledge of the data and data relations among data sources. It will be difficult to define a rule when it is considered that the scope and quantity of data is increased. Therefore, there is a need for extracting rules automatically. In this paper, we propose a novel model that extracts rules from unlabeled data by using clustering and rule mining algorithms. The model is evaluated in terms of classification performance and the results show that the proposed model is a promising solution for extracting complex event processing rules.

Document Title	Added	Issue
A Complex Event Processing based smart aid system for fire and danger management	2017	When hazardous events occurs in buildings or in large environments with different access points and with a large number of users, rescue workers (firefighters, first aid workers, civil protection teams, etc.) need to intervene in a timely manner, where there is a certainty that there are users to help. Topically such events require avoiding waste of resources in environments where there are no people at the time of the disaster or where the damage is of low magnitude. To guide rescuers at the points of the building where there are users to help, we modeled and built an Internet of Things-based framework that monitors data and environmental parameters of interest and, if certain thresholds are exceeded, alerts the rescuers through a telephone call to emergency numbers. The hardware infrastructure is driven by a complex, flexible and adaptive software layer that behaves depending on a Complex Event Processing engine and a reflective middleware according to the rule based engine that manages data from the sensors and reasoning mechanisms of a knowledge base that models the given domain.
Complex Event Processing for City Officers: A Filter and Pipe Visual Approach	2018	Administrators and operators of next generation cities will likely be required to exhibit a good understanding of technical features, data issues, and complex information that, up to few years ago, were quite far from day-to-day administration tasks. In the smart city era, the increased attention to data harvested from the city fosters a more informed approach to city administration, requiring involved operators to drive, direct, and orient technological processes in the city more effectively. Such an increasing need requires tools and platforms that can easily and effectively be controlled by nontechnical people. In this paper, an approach for enabling “easier” composition of real-time data processing pipelines in smart cities is presented, exploiting a visual and block-based design approach, similar to the one adopted in the Scratch programming language for elementary school students. The proposed approach encompasses both a graphical editor and a sound methodology and workflow, to allow city operators to effectively design, develop, test, and deploy their own data processing pipelines. The editor and the workflow are described in the context of a pilot of the ALMANAC European project.
Proactive personalized services through fog-cloud computing in large-scale IoT-based healthcare application	2017	With the development of medical sensors and IoT, personalized service assisted elder and patient living is a critical service in IoT-based healthcare application. However, the scale and complexity of personalized service is increasing because of ubiquitous deployment of various kinds of medical sensors, which cause response time increase and resource waste. Therefore, leveraging the advantage of complex event processing (CEP) in data stream processing, we propose a hierarchical fog-cloud computing CEP architecture for personalized service to accelerate response time and reduce resource waste. Firstly, we introduce the proposed architecture, which includes sensor layer, fog layer and cloud layer. Secondly, we propose a series of optimizations for the architecture, there are a partitioning and clustering approach and a communication and parallel processing policy to optimize the fog and cloud computing. Finally, we implement a prototype system based on the architecture named FogCepCare. Experimental result shows that FogCepCare is superior to the traditional IoT-based healthcare application.
Event management for simultaneous actions in the Internet of Things	2016	Complex event processing (CEP) is attracting much attention as a method for analyzing streaming data in the IoT environment. Since a CEP system selects and executes a rule from rules that match identified events, i.e., multiple rules are sequentially executed. This, however, causes a problem in the Internet of Things (IoT) environment since rule execution is slow and the remaining rules must wait to be executed. Simply executing rules in parallel may trigger interference between rules, and thus unexpected and undesirable results. This paper extends the traditional CEP system by developing an execution model for parallel rule firing in the IoT environment so as to be able to execute multiple rules in parallel without any interference. We start with an extended parallel firing condition by adding the definition of dependency between sensors and actuators to the condition. Next, we extend synchronization control of parallel firing so as to avoid the interference among rules that can occur when actions take a lot of time to execute. This paper reveals that the extended CEP system (i) realizes triple parallelism (i.e., data parallelism, task parallelism, and pipeline parallelism) in the IoT environment and (ii) avoids the case where rule execution triggers unexpected results.
An Ingestion and Analytics Architecture for IoT Applied to Smart City Use Cases	2018	As sensors are adopted in almost all fields of life, the Internet of Things (IoT) is triggering a massive influx of data. We need efficient and scalable methods to process this data to gain valuable insight and take timely action. Existing approaches which support both batch processing (suitable for analysis of large historical data sets) and event processing (suitable for realtime analysis) are complex. We propose the hut architecture, a simple but scalable architecture for ingesting and analyzing IoT data, which uses historical data analysis to provide context for real-time analysis. We implement our architecture using open source components optimized for Big Data applications and extend them, where needed. We demonstrate our solution on two real-world smart city use cases in transportation and energy management.
Management of IoT Devices in a Physical Network	2017	The internet of things is an evolving trend, connecting "things" to the internet, exchanging and collecting information about the surrounding environment. This is possible, by using different devices such as sensors and actuators feeding information that when connected together, enable to monitor and interact with the surrounding environment. Nowadays, there are many devices with different functionalities from multiple manufacturers, which create an interoperability issue of how to interconnect and manage this heterogeneous world of devices. In order to promote interoperability and effectively manage devices it's required to store their data and at the same time handle the registration of each device in a network. The development of a reference architecture can provide a solution for this problem, however a consensus on a reference architecture that can effectively manage this heterogeneous world of devices, is still not yet achieved. Device management is a key feature for any real world solution for a scalable reliable interoperable cloud platform. This gives the capability to add a device, and in that moment enable communication with the rest of the network, sharing information and providing knowledge in an interoperable balanced environment. Adding new devices to a network and assign the necessary services, interfaces and rules will provide a fast track not only in terms of a business-oriented solution but also in back-end management and interoperability. This paper proposes a device management solution based on an architecture and model, to support the registration of devices and propose the necessary services and events, which can be used by a specific device, during its life span inside the physical network.
An Approach for CEP Query Shipping to Support Distributed IoT Environments	2018	In recent years, the amount of data has significantly increased. Deriving information and, consequently, knowledge from this data leads to huge benefits. To realize this, oftentimes Complex Event Processing is employed. Usually, current solutions process data on monolithic IT infrastructures. However, for the emerging Internet of Things paradigm, this is not adequate, because high efficiency is of vital importance. To achieve this, distributed data processing with short communication paths and reduced network traffic need to be enabled. In this paper, we introduce an approach for CEP query shipping to support distributed Internet of Things environments.
Real-Time Probabilistic Data Fusion for Large-Scale IoT Applications	2018	Internet of Things (IoT) data analytics is underpinning numerous applications, however, the task is still challenging predominantly due to heterogeneous IoT data streams, unreliable networks, and ever increasing size of the data. In this context, we propose a two-layer architecture for analyzing IoT data. The first layer provides a generic interface using a service oriented gateway to ingest data from multiple interfaces and IoT systems, store it in a scalable manner and analyze it in real-time to extract high-level events; whereas second layer is responsible for probabilistic fusion of these high-level events. In the second layer, we extend state-of-the-art event processing using Bayesian networks in order to take uncertainty into account while detecting complex events. We implement our proposed solution using open source components optimized for large-scale applications. We demonstrate our solution on real-world use-case in the domain of intelligent transportation system where we analyzed traffic, weather, and social media data streams from Madrid city in order to predict probability of congestion in real-time. The performance of the system is evaluated qualitatively using a web-interface where traffic administrators can provide the feedback about the quality of predictions and quantitatively using F-measure with an accuracy of over 80%.

Document Title	Added	Issue
Exploring IoT Industry Applications: The Evolution of Internet of Things for Healthcare	2017	In this course, we will explore the main concepts that will provide you with the foundations and concepts related to Healthcare and Internet of Things. First, we will have a brief look into the evolution of healthcare from classic healthcare into diverse forms of electronic healthcare. Next, we will review the concept of Internet of Things and how it relates with healthcare in a variety of ways. Once these foundations are set, we will discuss the main challenges and opportunities that the use of the IoT paradigm implies for the healthcare sector. And we will finish with some conclusions and open questions.
Cyber-physical systems security through multi-factor authentication and data analytics	2018	We are living in a society where technology is present everywhere we go. We are striving towards smart homes, smart cities, Internet of Things, Internet of Everything. Not so long ago, a password was all you needed for secure authentication. Nowadays, even the most complicated passwords are not considered enough. Multi-factor authentication is gaining more and more terrain. Complex system may also require more than one solution for real, strong security. The present paper proposes a framework based with MFA as a basis for access control and data analytics. Events within a cyber-physical system are processed and analyzed in an attempt to detect, prevent and mitigate possible attacks.
EdgeCEP: Fully-Distributed Complex Event Processing on IoT Edges	2017	In this paper, we propose a general complex event processing (CEP) engine aiming for accomplishing at smart IoT edge devices in a fully distributed manner. We introduce a pseudo-source mechanism to cover a wide range of processing and obsolete prerequisite of source-specification at the same time, along with a brand-new event specification language defined to support relation-based processing. Against cloud-based approaches, our behind-edge approach can prevent data overflow and privacy issues, and fully distributed processing can draw the power of the edge devices. To achieve that in a resource-limited edge environment, we formulate an optimization problem of processing task assignment and stream delivery, and propose a fully-autonomous workload distribution mechanism. A large-scale simulation with a realistic smart-building scenario shows that our proposed method achieves about 6.6 times smaller flow volume and 2 times lower loss rate compared to centralization and is relatively superior to a hop-based distribution approach. Notably, a prototype engine is successfully deployed over an ad-hoc wireless sensor and actuator network through Intel Edison modules in the real environment.
Architecture of standard-based, interoperable and extensible IoT platform	2016	IoT Platform marketplace is gaining a lot of attention in many areas. The paper presents an interoperable and extensible IoT framework that follows oneM2M standard. The framework is validated by a reference implementation that includes automatic sensor recognition and pairing, NoSQL support, complex event processing and alarming and extensions for IoT devices communication over HTTP, WebSocket, CoAP, MQTT, Z-Wave, ZigBee and Bluetooth. The novelty includes the theoretical and practical solution to the proposed platform. Furthermore, we show the feasibility to build generally useful IoT platforms that are based on standards.
Information flow and complex event processing of the sensor network communication	2015	Research institutes and companies are focusing intensively on Complex Event Processing, Event Stream Processing, Information Flow Processing and Surprise Event Detection methods and algorithms. This phenomenon is intensified by the rapid evolution and spreading in practice of the Internet of Things services. A huge amount of data is created continuously by the physical and logical sensors embedded into various equipment and aimed to monitor the state of physical processes. Time critical query-response mechanisms of the QoS based systems are more and more penetrating in the low bandwidth wireless sensor environment, as well. The behavior of the wireless sensor network requires special evaluation of the state information sent to and processed by the sink node. The items of the status information flow are affected by the low energy and low bandwidth characteristics of sensor networks. Despite of uncertainty of the data transmission in wireless sensor networks the energy constraint permits rarely retransmission of data affected by error. To mitigate the aforementioned issues, cognitive infocommunication algorithms may prove to be an effective solutions. Consequently, this paper presents a method to detect special events and surprises in time processes of the sensor network communication. The proposed method is applied to ZigBee sensor network (based on IEEE 802.15.4 standard) in different congestion scenarios.
A complex event processing based approach of multi-sensor data fusion in IoT sensing systems	2015	The Internet of Things (IoT) has been widely applied in sensing systems, which connect various sensors and gather their information. Data fusion, which is to integrate multiple data representing the same real-world object into a consistent and accurate representation, is an important issue. Most of existing approaches of data fusion involve various analytical procedures whose high computational complexity usually requires massive computing resources. In this paper, an efficient data fusion approach is proposed. Stochastic models are presented to describe the measurements, and quantitative analyses are given to evaluate the efficacy of data fusion. Complex event processing engine is applied to improve the efficiency of data transmission and processing to meet the real-time demands. Finally, simulation experiments are conducted to validate the efficacy of the approach.
The Emerging Paradigm of the Social Internet of Things	2016	All market and technology studies forecast an explosive growth in the number of things which will be connected to the Internet. The resulting network is what is commonly known as the 'Internet of Things' (IoT). The IoT poses completely new challenges when compared to the traditional Internet which cannot be faced if the involved objects are just traditional smart objects. In fact, the extremely high complexity (huge number of nodes, extreme heterogeneity of their resources and capabilities, uncertainty on their trustworthiness, etc.) of the IoT environment cannot be faced by even very smart objects singularly. Social behavior is the answer to face the complexity of the surrounding environment. Accordingly, the concept of Social Internet of Things (SIoT) has been recently introduced and is the subject of a rapidly increasing research effort. The main objective is giving social-like capabilities to the objects in the Internet of Things and design conceptual (and software) platforms, which can be exploited to easily develop and implement complex applications that require direct interactions among objects. In this course we will provide an introduction to this paradigm, discuss related basic concepts, survey the existing literature and projects, and describe a specific solution in details by providing some example applications.
Technology foresight through the collaboration with human expert and machine intelligence	2016	We always make efforts to predict our future from the past and the present, since the prediction can make great changes in our life, especially in the fields of science and technology. Many organizations in the globe have surveys and announces emerging or disruptive technologies every year. Of course, they have developed their own processes to achieve the goal, but the insights of experts from related domains are usually absolute. In the era of Bigdata, due to the enormous amount of information, domain experts are struggling with timeliness and completeness in developing insights for the future. In KISTI, we introduced a methodology in which human experts are collaborating with machine intelligence to overcome the information flood. Data-intensive analysis methodology is applied to implement the machine intelligence to predict emerging technologies. The intelligent service platform, named InSciTe, includes data gathering, text mining, identity resolution, reasoning, complex event processing, and prescriptive analytics modules. InSciTe generates candidates of emerging technologies with the evidences why they are selected as candidates, and then domain experts make the final decision. In this talk, I will introduce our intelligent service platform based on the data-intensive analysis. Besides, I will show several case studies in the domains of ICT, internet security, and healthcare as joint works with NIPA, KISA, and KRIBB respectively. For the cases with KRIBB, human experts collaborated with machine intelligence interactively to derive the results. We named this approach as Chi(Computer Human Interacting)-Delphi method for technology foresight. As Web goes to connect machine intelligences in the era of Internet of Things, the collaboration between human intelligence and machine intelligence will be eventually the next great wave for predicting the future.

Document Title	Added	Issue
Hybrid controller for a software-defined architecture of industrial internet lab-scale process	2017	Internet of Things (IoT) is a thriving trend that has invaded many aspects of real life. The merging of IoT with industrial information is forming a new emerging direction of Industrial Internet of Things (I²oT). I²oT requires reliable methods for co-design of control and automation systems that can align their performance within deep and complex cyber layers of communication and computation. This paper investigates the utilization of hybrid control approach for modeling and analyzing distributed control of a quadruple-tank as a lab-scale benchmark process. The system is implemented via a software-defined architecture for I²oT using low-cost commercial IoT-enabled Intel Galileo Boards. The proposed I²oT software architecture utilizes Node.js and JavaScript for all different layers of the system with web sockets for handling real-time control packets. Node.js is considered reliable for event-driven scheme applications such as I²oT due to its optimal performance and resource utilization.
Proactive Complex Event Processing for transportation Internet of Things	2015	Complex Event Processing (CEP) has become the key part of Internet of Things (IoT). Proactive CEP can predict future system states and execute some actions to avoid unwanted states which brings new hope to transportation IoT. In this paper, we propose a proactive CEP architecture and method for transportation IoT. Based on basic CEP technology, this method uses structure varying Bayesian network to predict future events and system states. Different Bayesian network structures are learned and used according to different event context. A networked distributed Markov decision processes model with predicting states is proposed as sequential decision model. Q-learning method is investigated for this model to find optimal joint policy. The experimental evaluations show that this method works well when used to control congestion in transportation IoT.
A Soft Real-Time Stream Reasoning Service for the Internet of Things	2019	Most Internet of Things applications have their algorithms driven by elementary events or basic sensor data. While this may be sufficient for some applications, it precludes the possibility of describing and detecting semantic relationships among these events/data and to infer new application-relevant facts out of these relations, which could give an IoT application means of reasoning about the ambient and its context. But since many IoT applications also require timely response times, such semantic reasoning has to happen nearly in real-time, and hence reasoning has to be done over data/event streams, a.k.a Stream Reasoning. This work presents a semantic model and an IoT middleware service for data stream reasoning using a combination of Complex Event Processing (CEP) and continuous queries over streams of RDF semantic data. In our approach we use CEP in the IoT Edge devices to derive time-annotated RDF data from the basic events, and C-SPARQL for processing online queries over a domain ontology, aiming to check if some indirect fact or property about the system or the environment can be deduced. In order to showcase and test the capacity of nearly real-time inference over data streams of our middleware service, we designed and implemented a scenario of fire warning in a hypothetical multi-store building with temperature and humidity sensors.
TrustCEP: Adopting a Trust-Based Approach for Distributed Complex Event Processing	2017	The advent of the Internet of Things (IoT), with modern sensors and sensor-based devices, will significantly stimulate the development of context-aware applications. An effective means to extract higher-level contextual information from sensor data is distributed complex event processing (CEP), which facilitates the analysis of real-time data streams coming from heterogeneous and distributed sources. Considering that user context is inherently sensitive information, the preservation of privacy is critical once the processing of user context takes place over several (possibly malicious) devices, especially in collaborative scenarios. In this paper, we tackle this issue by introducing a trust-based approach for the placement and execution of CEP operators in a distributed environment. We propose a trust management model based on communication interactions among the users. Furthermore, we incorporate trust recommendations using a cosine-based similarity check in order to overcome collusion and on-off attacks. We developed a smartphone-based distributed CEP system called TrustCEP to evaluate our approach for trust management. Based on the evaluation of TrustCEP, we observe that our approach induces a minimal increase in average battery consumption compared to privacy-negligent approaches.
Automata-Based Generic Model for Interoperating Context-Aware Ad-Hoc Devices in Internet of Things	2018	Internet of Things (IoT) applications can be seen as network-controlled systems with a distributed architecture connecting many smart objects through the Internet. A typical IoT application aims to connect a set of nodes, capable of processing data and making decisions regarding the goal of the IoT application, with other nodes containing smart objects with robotic components to collect data from their environment. In this paper, a generic model for novel context-aware and adaptive IoT architecture is presented. A group of nodes contains a controller interface (CI) that is used to control other nodes containing a controller unit (CU) which communicates randomly. CU nodes have complex control systems comprising both actuators and sensors, however CI nodes typically do not have detailed knowledge of such individual functionalities. Instead, at run time, control program logic (CPL) is downloaded by the CI to facilitate control and communication. The system also allows for different CPLs for any particular CU. In such an open and adaptive IoT environment, an architecture is required that can provide sufficient flexibility in designing nodes while maintaining uniformity in the IoT system to allow for interoperability and reliability. Using the notion of automata, a generalized mathematical description is presented that allows modeling of the CI and CU nodes and their operation. This model can then be used to formulate and solve problems regarding the interaction between CIs and CUs. The application of this model is demonstrated through a case study involving remote access laboratories where the CI–CU model is used.
Context-aware stream processing for distributed IoT applications	2015	Most of the IoT applications are distributed in nature generating large data streams which have to be analyzed in near real-time. Solutions based on Complex Event Processing (CEP) have the potential to extract high-level knowledge from these data streams but the use of CEP for distributed IoT applications is still in early phase and involves many drawbacks. The manual setting of rules for CEP is one of the major drawback. These rules are based on threshold values and currently there are no automatic methods to find the optimized threshold values. In real-time dynamic IoT environments, the context of the application is always changing and the performance of current CEP solutions are not reliable for such scenarios. In this regard, we propose an automatic and context aware method based on clustering for finding optimized threshold values for CEP rules. We have developed a lightweight CEP called μCEP to run on low processing hardware which can update the rules on the run. We have demonstrated our approach using a real-world use case of Intelligent Transportation System (ITS) to detect congestion in near real-time.
A Data Generation Algorithm for Internet of Things Based on Complex Event Processing	2015	With the rapid development of the Internet of things(IOT), the applications are more and more extensive in smart grid, intelligent transportation, intelligent logistics, intelligent medical, smart home and so on. In this case, more and more big data analysis and processing engines are emerging. Because real data is difficult to obtain, how to provide fast test data with enough variety, large scale, and high complexity for these wide types of big data processing engines become a thorny issue. In order to meet the demand, this paper designs and implements a Data Generation Algorithm based on Complex event processing (CEP). The definition of selective event flow, sequential event flow, and causal event flow are proposed. The experimental results show that, the method is effective.
Study on distributed complex event processing in Internet of Things based on query plan	2015	Complex event processing is an efficient method in data stream processing of Internet of things, but more of these methods are referred to a single complex event or a small quantity of events. Aiming at this problem, a distributed complex event processing architecture for Internet of things is presented in this paper, in which a distributed query plan of complex event process structure based on directed acyclic graph (DAG) is given, moreover, a distributed query-plan complex-event-processing algorithm based on directed acyclic graph is proposed. The complex tasks are decomposed into several simple sub-tasks which are processed in parallel with the corresponding operator nodes, to realize distributed processing and to improve the efficiency of processing and execution. The simulation results indicate that our method is more efficient in lower RAM consumption, processing time, and others, and the efficiency of data stream processing for Internet of things is improved.

Document Title	Added	Issue
iDispenser — Big Data Enabled Intelligent Dispenser	2017	With healthcare-associated infections (HAIs) in the U.S. accounting for an estimated 1.7 million infections and 99,000 deaths annually, reducing and preventing these infections is a top goal for healthcare facilities throughout the country [1]. Not only healthcare facilities, in other captive environments, for instance, ships and cruises, provide environment that may increase risk of infection. According to Minooee and Rickman [2], “Ships provide an isolated environment that may increase the passenger's risk of infection if exposed to respiratory viruses. High attack rates of influenza, for example, are typically seen in closed settings such as cruises, military vessels, aircraft, and institutions”. The high rates of infection in captive areas are influenced by number of people entering and exiting the place. As per the research summarized by “Hospital infection control: reducing airborne pathogens”[3], the number of people entering and exiting provides a contaminant source. It's known that the concentration of airborne bacteria is proportional to the number of personnel in the room. The amount of surface contamination is also related to airborne contamination from occupation and activity since these microbes settle continuously.” Fencl [3] suggests that the use of disinfection, to control infectious agents in healthcare settings, is one of its oldest and most cost effective ways to control airborne infection. Nichols [1], importantly, suggest that touchless dispensing solutions as an effective way to help reduce the spread of germs. In our view, with advent of machine learning and Internet of Things, combining automated & intelligent dispensing with touchless systems provides more holistic approach to control infection in healthcare and, more importantly, captive places such as hospitals, cruises, casinos, airports and other places. In this research paper, we propose an innovative approach to prevent spread of airborne diseases through the application of Big Data Technologies and IoT Sensing. Our goal is to cutting down the millions of dollars spent on infectious diseases, intelligent dispenser promises to keep hospitals smelling fresh soothing and disinfecting. The paper presents prototyping solution design as well as its application and certain experimental results.
A Review on Complex Event Processing Systems for Big Data	2018	Over the years, huge volumes of data are continuously generated due to the increasing number of applications, efficient methods are therefore required to determine the event patterns of interest and manage highly dynamic events in real-time. There has been increasing demand for active systems within Internet of Things, which can automatically react to events that come from various sources. Complex Event Processing (CEP) is an impressive technology that can deal with large amount of data from various sources depending on the consistency of data to generate exact result to process dynamic data in real-time. Thus, understanding existing CEP methods and tools is essential to develop a robust and effective CEP system. In this paper, we had briefly described about event processing, CEP with different engines and CEP for uncertainty. This paper reviewed CEP tools available in the market from 2010 to 2017. It has been found that there are many commercialized and open-source CEP tools in current market, where commercialized tools are used for business intelligence purpose and open-source tools are mostly used for academic purposes. Most of the available processing tools are Query-based and very few are working with Machine learning. There is a huge potential for further research in the use of Machine Learning in Complex Event Processing.
A Hybrid Complex Event Service Based on IoT Resource Models	2015	Traditional Complex Event systems (CEP) did not consider the computation requirements of continuous dynamic behavior such as differential equations. In addition, the event composition rules were predefined before the CEP engine began working. The rule defining task is error-prone and cumbersome. In this paper, therefore, a hybrid complex event service is proposed, which deals with not only discrete events but also continuous behavior computation based on IoT (Internet of Things) resource models. In order to satisfy the real-time constraints of processing IoT events, a divide-and-conquer principle is adopted, where we give a combination theorem such that different events can be processed on different IoT resources and then these processed results can be combined to derive complex events. Based on the formal IoT resources and event knowledge, we define interest goals to direct event composition without enumerating event relation to define event composition rules. We finally present event composition algorithms and evaluation to show our idea.
Big Data Complex Event Processing for Internet of Things Provenance: Benefits for Audit, Forensics, and Safety	2017	Some Internet of Things (IoT) subsystems will be far less robust than others. Systems that rely on these sensors require considerable knowledge about the sensors, their calibration, test conditions, manufacturers' recommended maintenance procedures. Despite the drive toward increased dataset variety, and while Big Data has had a correspondingly large impact on containerization and DevOps, the impact on information assurance (IA) has been incremental. This chapter surveys approaches to leverage Big Data techniques to enhance IoT provenance, which is itself only one of multiple measures needed to improve information assurance. A number of thus far loosely connected approaches are identified and addressed. Systematic use of concept of complex event processing (CEP) can improve on current information assurance practices, especially if its paradigms and design practices are more widely incorporated into IoT architectures. Big Data is changing the nature of work for Chief Security Officers (CSO), auditors, and forensic investigators.
Parallel Processing of Big Heterogeneous Data for Security Monitoring of IoT Networks	2017	Networks of the Internet of Things (IoT) nowadays find greater widespread in many domains. Particularities of creation of IoT make the problem of their security monitoring rather actual, it is caused by necessity of processing of big amounts of heterogeneous data in real time. The problem may be solved by means of implementation of the parallel system for security data processing within IoT on the fly basing on complex event processing (CEP) technology. The paper considers basic solutions for creating such a system. The proposed system is oriented for usage of software environment Hadoop and includes data collection, data storage, data normalization and analysis, and data visualization components. The paper discusses the issues of architecture of this system, its implementation and experimental estimation. The experiments showed that the proposed approach to creation of the system on the basis of CEP technology provides suitable scalability and is capable to meet the requirements of processing data on security events in real time in IoT.
PACT-ART: Enrichment, Data Mining, and Complex Event Processing in the Internet of Cultural Things	2016	Artwork transportation processes are generally agreed-upon, and long running propositions between multiple partners that are specified over service level agreements, performance, and complex quality constraints to be maintained. The complexity of the constraints is defined by the sensitivity, value, and significance of artworks, where any recorded damage would probably leave undesired marks on the long-term, and diminish the lifetime of art pieces. Due to the uncontrollable, and unpredictable nature of the context during transportation, the specified constraints are often violated in real scenarios. In this paper, we introduce the PACT-ART architecture to integrate advanced computing techniques with transportation activities. This integration counts on external and Internet of Things (IoT) services to draw and understand the context of activities, thus it paves a way to predict a future state of the ongoing process and point out any possible violation in advance. Moreover, PACT-ART combines Complex Event Processing (CEP) techniques and makes this technology available even to non-experts in the domain. Finally, we showcase some initial experiments on real-life transportation scenarios that testify to the efficiency of our proposal.
Real time analysis of sensor data for the Internet of Things by means of clustering and event processing	2015	Sensor technology and sensor networks have evolved so rapidly that they are now considered a core driver of the Internet of Things (IoT), however data analytics on IoT streams is still in its infancy. This paper introduces an approach to sensor data analytics by using the OpenIoT¹middleware; real time event processing and clustering algorithms have been used for this purpose. The OpenIoT platform has been extended to support stream processing and thus we demonstrate its flexibility in enabling real time on-demand application domain analytics. We use mobile crowd-sensed data, provided in real time from wearable sensors, to analyse and infer air quality conditions. This experimental evaluation has been implemented using the design principles and methods for IoT data interoperability specified by the OpenIoT project. We describe an event and clustering analytics server that acts as an interface for novel analytical IoT services. The approach presented in this paper also demonstrates how sensor data acquired from mobile devices can be integrated within IoT platforms to enable analytics on data streams. It can be regarded as a valuable tool to understand complex phenomena, e.g., air pollution dynamics and its impact on human health.

Document Title	Added	Issue
Efficient Multipattern Event Processing Over High-Speed Train Data Streams	2015	Big data is becoming a key basis for productivity growth, innovation, and consumer surplus, but also bring us great challenges in its volume, velocity, variety, value, and veracity. The notion of event is an important cornerstone to manage big data. High-speed railway is one of the most typical application domains for event-based system, especially for the train onboard system. There are usually numerous complex event patterns subscribed in system sharing the same prefix, suffix, or subpattern; consequently, multipattern complex event detection often results in plenty of redundant detection operations and computations. In this paper, we propose a multipattern complex event detection model, multipattern event processing (MPEP), constructed by three parts: 1) multipattern state transition; 2) failure transition; and 3) state output. Based on MPEP, an intelligent onboard system for high-speed train is preliminarily implemented. The system logic is described using our proposed complex event description model and compiled into a multipattern event detection model. Experimental results show that MPEP can effectively optimize the complex event detection process and improve its throughput by eliminating duplicate automata states and redundant computations. This intelligent onboard system also provides better detection ability than other models when processing real-time events stored in high-speed train Juridical Recording Unit (JRU).
An Efficient Secure Data Aggregation Technique for Internet of Things Network: An Integrated Approach Using DB-MAC and Multi-path Topology	2016	Internet of Things is a network of interconnected objects embedded with computational power and digital communications. The objects have an addressable and locatable counterpart on the Internet and can open a communication channel with any other entity at any time and in any place and generate data which is considered private by many users. Hence, one of the requirements of ubiquitous applications would be privacy preservation. After collecting the data, we need to do event filtering and complex event processing which enable us to process simple events in the data. This is achieved through data aggregation. In this paper we first discuss the challenges in security and privacy of Internet of Things. It provides a comprehensive review on the existing data aggregation techniques as applied to wireless sensor networks. Further we propose an integrated approach for data aggregation in the Internet of Things environment. Our approach takes into account the computational limitations and communication constraints associated with the Internet of Things network while also incorporating security features with the aim of designing a full-fledged secure data aggregation technique.
Research on Data Process Method of Engineering Training Based on Cloud Service	2017	In order to adapt to the complex and varying data process logic for the engineering training in the new manufacturing background, and achieve the management of RFID (Radio Frequency Identification) data in the shop floor. This paper proposes a complex event engine mechanism for the training data process based on cloud service. In the cloud, the training resource object is mapped into training cloud object with its atomic data operations. Then, the engine combines these atomic operations into the event execution to support the engineering training according to the service rules.
A Self-Organized Task Distribution Framework for Module-Based Event Stream Processing	2019	Tackling bottleneck and privacy issues of cloud computing, we attempt to push event stream processing down to devices which are currently empowered to compute and communicate at the edge of the networks. To accomplish that, we propose a self-organized task distribution framework that is composed of multiple brokers collaborating through our module-based event stream processing engine called <italic>EdgeCEP</italic>. Our system request is event-dependent specified in a brand-new event specification language; still, the event is stored and processed by the relational database. We newly formulate the problem of self-organized task distribution subjective to preferable constraints of computation and communication. The solution for each broker to find individual optimal decision is to apply tabu search with flow-based greedy move regarding pre-ranking flow table. Many experiments are conducted to study and evaluate the performance of the proposed system. The simulation shows that the proposed flow optimization outperforms the naïve algorithm, concretely, 2-times more tasks getting processed and successfully delivered within the same fixed period. The proposed edge-centric method achieves data traffic 7-times less than the cloud-centric approach. The prototype engines have been deployed and evaluated in the real environment.
A Novel Runtime Verification Solution for IoT Systems	2018	Internet of Things (IoT) systems promise a seamless connected world with machines integrating their services without human intervention. It's highly probable that the entities participating in such autonomous machine to machine interactions are to be provided by different manufactures. Thus, integrating such heterogeneous devices from many providers complicates design and verification of IoT systems at an unprecedented scale. In this paper, we propose a novel runtime verification approach for IoT systems. The contributions of our proposed solution include: exploiting the interactions in message sequence charts (MSC) to specify message exchanges of constrained application protocol-based IoT systems in terms of events, a novel event calculus for formally describing IoT system constraints specified by means of MSCs, and an event processing algebra that uses complex-event processing techniques for detecting failures in the system by monitoring the runtime event occurrences with respect to the system constraints defined by event calculus. We further demonstrate the viability of proposed solution with case studies.
Cognitive Acoustic Analytics Service for Internet of Things	2017	The rapid development of the Internet of Things (IoT) has brought great changes for non-contact and non-destructive sensing and diagnosis. For every inanimate object can tell us something by the sound it makes, acoustic sensor demonstrates great advantages comparing to conventional electronic and mechanic sensors in such cases: overcoming environmental obstacles, mapping to existing use cases of detecting problems with human ears, low cost for deployment, etc. It could be widely applied to various domains, such as predictive maintenance of machinery, robot sensory, elderly and baby care in smart home, etc. Whether we can use the acoustic sensor data to understand what is happening and to predict what will happen relies heavily on the analytics capabilities we apply to the acoustic data, which has to overcome the obstacles of noise, disturbance and errors, and has to meet the requirement of real-time processing of high volume signals with large number of sensors. In this paper, we propose a scalable cognitive acoustics analytics service for IoT that provides the user an incremental learning approach to evolve their analytics capability on non-intuitive and unstructured acoustic data through the combination of acoustic signal processing and machine learning technology. It first performs acoustic signal processing and denoising, enables acoustic signal based abnormal detection based on sound intensity, spectral centroid, etc. Then based on the accumulated abnormal data, a supervised learning method is performed as baseline and a neural network based classifier is used to recognize acoustic events in different scenarios with various volume of sample data and requirement of accuracy. In addition, acoustic sensor arrays processing is supported for localization of moving acoustic source in more complex scenario. In this paper, we designed a hybrid computing structure. Finally, we conduct experiments on acoustic event recognition for machinery diagnosis, and show that the proposed system can achieve high accuracy.
Runtime verification of IoT systems using Complex Event Processing	2017	Internet of Things (IoT) is a new computing paradigm that is proliferated by wide adoption of application level protocols such as MQTT and CoAP, each of which defines different styles of sequential interaction of events. Even though there is a considerable effort in the literature for verification of such complex and distributed systems, a practical solution for IoT systems that supports runtime system verification is still missing. In this paper, we present a runtime monitoring approach for IoT systems that exploits event relations expressed in terms of sequential interaction messaging model of Constrained Application Protocol (CoAP). We propose the use of Complex-Event Processing (CEP) to detect failures at runtime by exploiting complex event patterns defined via predetermined event algebra. We further present a simple case scenario to demonstrate the applicability of the approach on Wireless Token Ring Protocol execution.

Document Title	Added	Issue
Investigating Metrics to Build a Benchmark Tool for Complex Event Processing Systems	2016	Despite companies' demand for data streams processing systems to handle large volumes of flowing data, we did not find many software to assess these sort of systems. In fact, up to date, there are few papers proposing metrics to evaluate these systems or describing software for benchmarks. Most of the papers focus on metrics such as throughput, latency and memory consumption. However, there are other metrics, which system administrators and users should consider, such as information latency, the correctness of results, adaptability on different workloads and others. Therefore, in this paper, we summarized some key metrics used to assess systems for processing online data streams. In addition, we discuss three benchmark tools found in the literature to assess this type of system. At the end of this paper, we propose a new benchmark tool for complex event processing distributed systems called B2-4CEP, which incorporate the metrics described in this paper.
A Feature-based Learning System for Internet of Things Applications	2019	In many applications of Internet of Things (IoT), the huge amount of data are generated by sensor nodes and processing them are complex. Offloading data classification and anomaly event detection tasks to sink nodes in sensor networks can reduce the computing complexity, lower remote communication loads and improve the response time for the delay-sensitive IoT applications. Many existing classification and anomaly detection methods cannot be directly applied to these IoT applications, because the computing and energy resources of sensors are limited. In this paper, a new feature-based learning system for IoT applications is proposed to effectively classify data and detect anomaly event. Especially, based on the theory of distributed compression, the sparsity and relativity of the data are exploited to obtain the classification features, which can reduce the computation overhead and energy consumption. Further,a RBF-BP hybrid neural network is employed to detect the anomaly event based on the classification results, by which the training time of neural network can be significantly reduced and the accuracy can be improved for users' decisions.
Towards stream-based reasoning and machine learning for IoT applications	2017	As distributed IoT applications become larger and more complex, the pure processing of raw sensor and actuation data streams becomes impractical. Instead, data streams must be fused into tangible facts and these pieces of information must be combined with a background knowledge to infer new pieces of knowledge. And since many IoT applications require almost realtime reactivity to stimulus of the environment, such information inference process has to be performed in a continuous, on-line manner. This paper proposes a new semantic model for data stream processing and real-time reasoning based on the concepts of Semantic Stream and Fact Stream, as a natural extension of Complex Event Processing (CEP) and RDF (graph-based knowledge model). The main advantages of our approach are that 1) it considers time as a key relation between pieces of information; 2) the processing of streams can be implemented using CEP; 3) it is general enough to be applied to any Data Stream Management System (DSMS). Lastly, we will present challenges and prospects on using machine learning and induction algorithms to learn abstractions and reasoning rules from a continuous data stream.
An Approach to Aggregation of Security Events in Internet-of-Things Networks Based on Genetic Optimization	2016	Nowadays, the Internet-of-Things (IoT) networks find more, more wide distribution in many areas. IoT peculiarities do rather actual the problem of parallel processing of big arrays of the collected data, including data on security events. It is possible to solve this problem by realization of security event data preprocessing "on the fly" on the basis of the complex event processing (CEP) technology. However, issue of parallel processing of CEP queries is poorly addressed in the current literature. This paper presents an approach to solving this problem based on the principles of parallelization of CEP operators in IoT, using genetic algorithms. The genetic algorithm is used for finding the optimum scheme of the distribution of CEP operators on IoT network hosts. Experimental results showed that the usage of the offered approach allows to receive a gain in throughput to 50 percent. At the same time, the operation of the genetic algorithm does not violate the real-time scale.
Data-centric publish-subscribe approach for Distributed Complex Event Processing deployment in smart grid Internet of Things	2016	Smart grid is an important application of Internet Of Things (IOT). Monitoring data in large-scale smart grid are massive, real-time and dynamic that collected by a lot of sensors, services components etc. There are many challenges in deploying and managing distributed real time monitoring systems. This paper adopted data-centric approach in deploying Distributed Complex Event Processing (DCEP) monitoring system based on OMG Data Distribution Service (DDS) middleware, to bring about a more robust and scalable distributed monitoring system, and that easier to maintain and enhance over time. The DDS data-centric publish-subscribe programming model with support for a number of QoS properties gives many advantages for supporting DCEP components communications, that reliably transports events from data producers to Event Processing Agents (EPAs), between internal DCEP Processing Node (PN), and from the EPAs to the event consumers. This paper analyzed DCEP requirements in IoT, and its PN configuration and deployment flow, designed a DDS/DCEP integration architecture for smart grid IoT monitoring system, and gave a detail design about DCEP development and configuration method based on DDS data-centric programming model, that can simplify the DCEP complex deployment work. This work has beneficial for DECP large scale development & deployment research.
Learn by Examples How to Link the Internet of Things and the Cloud Computing Paradigms: A Fully Working Proof of Concept	2015	This paper describes a fully-working proof of concept centered around a smart enterprise scenario and able to shed led on the power offered by linking the Internet of Things (IoT) and the Cloud Computing (CC) paradigms together. More specifically, in this showcase all the sensing and actuation capabilities are implemented in the tiny micro-controllers on-board the "things" and exposed, through a short-range radio module, as interfaces and commands, while all the smart capabilities (from identity management, to complex event processing, from data contextualization to persistent storage) are implemented as cloud services. In this way one can keep the computational and memory requirements of the devices extremely low, by off-loading the smartness of the application to the cloud services, where computational and memory resources are not an issue. Finally, to connect the two worlds together, a small linux embedded micro-pc is used as a controller, hence playing the role of a smart IoT gateway.
CARED-SOA: A Context-Aware Event-Driven Service-Oriented Architecture	2017	Currently, context awareness has become essential in software applications and services owing to the high demand by users, especially for mobile computing applications. This need to provide context awareness requires a software infrastructure not only to receive context information but also to make use of it so that it provides advantageous services that may be customized according to user needs. In this paper, we provide an event-driven service-oriented architecture supported by an enterprise service bus, which will facilitate the incorporation of Internet of Things data and provide real-time context-aware services. The result, which has been validated through a real-world case study, is a scalable context-aware architecture which can be applied in a wide spectrum of domains.
An IoT-Enabled Framework for Dynamic Supply Chain Performance Management	2018	This paper presents a framework of smart real-time performance monitoring and controlling of next-generation supply chains. It is based on enabling a set of Internet-of- Things (IoT) functions across the supply chain for dynamic and intelligent information processing and performance management. This is realized through the utilization of IoT technology in conjunction with workflow modeling to address the dynamic aspects of supply chain in a real-time environment. The proposed mechanism is referred to as Dynamic Supply Chain Performance Management (DSCPM) which is a computerized event-driven system that runs in real-time, monitors a set of selected supply chain performance measures, and effectively enables real-time decision-making. DSCPM functionality is based on the concepts of Complex Event Processing (CEP) to manage the massive event-instances across the supply chain and to convert them into beneficial information. Adopting DSCPM is expected to facilitate realtime corrective actions that reduce wastes and costs and maximize value across the supply chain.

Document Title	Added	Issue
Real-time processing of IoT events using a Software as a Service (SaaS) architecture with graph database	2016	IoT is a computational notion where each of the tangible objects around are termed as things, which will be connected to other things through the web and will communicate or transfer data between each other. But if the focus is just on the things or devices, than there may be a key ingredient missing, that is all these internet of things are connected to each other. What this entitled is that all of the devices, from appliances to smart phones will be able to share information with one another. When gone into details about Internet of things (IoT), it has lots of different types of things it has devices, it has locations, it has people and they all are connected. That mean a big and a complex connection data is generated. When to model this connected data a relational database or other type of No SQL database is used, they under perform. As those relational and No SQL type abstractions are not optimized for connection data, they are optimized for different kinds of connections. To overcome this, a highly robust, scalable, pluggable and faster architecture is proposed which tries to solve the issues of connected data in IoT domain with the unification of three open source technologies such as Ejabberd, Apache spark and Neo4j database. And to a get more secure and efficient performance this three open source technologies are implemented on a Microsoft azure public cloud. This proposed architecture stack is equally suitable for projects with high ambitions.
SEDA-SOA: A Scalable Event-Driven Context-Aware Service Oriented Architecture	2018	The increase in the number of Internet of Things (IoT) devices and their vast streaming data, results in data explosion. Context awareness has also become essential in software applications for better service delivery to users. It poses the urgent need for scalable integrated software systems which can analyze, store, extract meaningful events and to deliver information to the customers in real-time considering their context. A highly scalable architecture is proposed which uses distributed queues for decomposability and comprises of three functional components. 1. Distributed complex event integrated system where each of the complex event processing engines are taking care of event detection, 2. The context detection module which extracts contextual information and match them with detected events and, 3. A notification module and an application programming Interface is provided for the bulk alert information delivery. The presented model evaluation shows that our system well suits the current trend and requirements of IoT applications.
Energy-Efficient ECG Event Signal Processing Using Primitive-Based QRS Complex Detection	2018	The low-power QRS complex detection in the Internet-of-Things (IoT) edge node is helpful in decreasing the number of wireless communications required for serverside DSP computation in wearable applications. This paper proposes an energy-efficient ECG signal processing technique using primitive-based QRS complex detection and demonstrates successful realization in commercial microcontrollers with lowpower consumption, small code size and low profile of required data memory space. The on-chip digital signal processing (DSP) algorithm efficiently extracts the complex's onset and offset based on the QRS complex's morphological characteristics as important information for medical treatment. The events of these timed features are only transferred to the server computing platform. The proposed method is validated on an Arduino mega microcontroller (MCU) for physical human body signals and shows a 2.75% reduction in power consumption, compared to the server-centric DSP for the sampled raw data.
Healthcare informatics and analytics framework	2015	Healthcare industry is constantly undergoing changes owing to the advancements made in its medical and technological dimensions. Healthcare Informatics has evolved over decades by leveraging upon best of the computer technologies available. It has come a long way from being just a database to a comprehensive source of useful information for analytics and research. Emergence of technology paradigms like Big Data, Internet of Things (IoT), Complex Even Processing (CEP), Cloud Computing etc are changing the way things were. Healthcare informatics is now at juncture to find a complete solution to all its woes by adopting an integrated solution framework based on Big Data, IoT and CEP. This paper proposes one such framework which can act as reference for implementing a holistic healthcare informatics and analytics ecosystem.