Lecture Notes Unit-03 Chapter-01 Lecture-01 Dimension and Computing

CO-1:- Identify the need for Spatial Dimensions of Big Data

Introduction

Geography can be considered an important binding principle in the Internet of Things, as all physical objects and the sensor data they produce have a position, dimension, and orientation in space and time, and spatial relationships exist between them. By applying spatial relationships, functions, and models to the spatial characteristics of smart objects and the sensor data, the flows and behaviour of objects and people in Smart Cities can be more efficiently monitored and orchestrated. In the near future, billions of devices with location— and other sensors and actuators become internet connected, and Spatial Big Data will be created. This will pose a challenge to real-time spatial data management and analysis, but technology is progressing fast, and integration of spatial concepts and technology in the Internet of Things will become a reality.

1.1 Smart Cities

The world is faced with challenges in all three dimensions of sustainable development—economic, social, and environmental. The United Nations predicts that the world population will grow to 8.92 billion by 2050 and peak at 9.22 billion in 2075 [42]. At the same time, the population living in urban areas is projected to rise by 2.6 billion, increasing from 3.6 billion in 2011 to 6.3 billion in 2050 [43]. Furthermore, population growth becomes largely an urban phenomenon concentrated in the developing world [36].

Population growth and rapid urbanization, especially in developing countries, creates many economic, environmental and social problems, and calls for major changes in the way urban development is designed and managed. The concept of a Smart City (or Smart Environment) can support these changes by using Information Technology and (Spatial) Big Data to monitor, steer and optimize processes in our environment in real-time.

A Smart City is defined by GSMA [16] as: “A city that makes extensive use of information and communications technologies, including mobile networks, to improve the quality of life of its citizens in a sustainable way. A Smart City combines and shares disparate data sets captured by intelligently-connected infrastructure, people and things, to generate new insights and provide ubiquitous services that enable citizens to access information about city services,move around easily, improve the efficiency of city operations and enhance security, fuel economic activity and increase resilience to natural disasters”.

1.2 The Internet of Things and Big Data

New technological developments continue to penetrate countries in all regions of the world, as more and more people and objects are getting connected to the internet. More countries are reaching a critical mass in terms of ICT access and use, driven by the spread of mobile

Internet [21]. This accelerates ICT diffusion and enables the development of Smart Environments. As network availability and speed are improving at a steady rate and computers become smaller, more energy efficient and lower priced, Internet connected devices with sensors and actuators are deployed on ever larger scales in our environment, creating an *Internet of Things (IoT)*.

Currently, the number of internet connected devices is rising exponentially. Cisco's Internet Business Solutions Group (IBSG) predicts some 25 billion devices will be connected by 2015, and 50 billion by 2020 [13]. The total amount of information in the world is estimated to have grown from 2.6 optimally compressed exabytes in 1986 to 15.8 in 1993, over 54.5 in 2000, and to 295 optimally compressed exabytes in 2007 [17]. An increasing part of this *Big Data* is created by internet connected devices, and consists of device states (properties), data collected by its embedded sensors and by humans using applications running on these devices (e.g. smart phones).

1.3 The Role of Geography in the Internet of Things

Geography is a holistic and broad interdisciplinary research field. Scholten et al. [38] describe the use of geospatial concepts and technology in a variety of study areas. The research field of Geographic Information Science and Technology (GIS&T) is well described by Dibiase et al. [9] in the GIS&T Body of Knowledge. Geography can be considered an important binding principle in the Internet of Things, as all physical objects and the sensor data they produce have a position, dimension, and orientation in *space and time*, and spatial relationships exist between them. By applying spatial relationships, functions, and models to the spatial characteristics of smart objects and the sensor data, the flows and behaviour of objects and people in Smart Cities can be more efficiently monitored and orchestrated. To be able to spatially analyze Big Data from internet connected devices for realtime spatial decision making, the Big Data has to be geo-referenced or "spatialized" (i.e. spatial coordinates have to be assigned to the data elements), to create *Spatial Big Data*.

2 Spatial Modelling of Things

2.1 Introduction

The Internet of Things is about connected things. But what do we actually consider a Thing? In a philosophical context, a Thing is an object, being, or entity [47]. The term 'object' is often used in contrast to the term 'subject'. The pragmatist Charles S. Peirce defines the broad notion of an object as anything that we can think or talk about [48]. Smart objects (or smart things) are defined by Serbanati et al. and Magerkurth [25] as objects which are directly or indirectly connected to the Internet, that can interact with their environment and can describe their own possible interactions. Smart objects have a physical and digital representation and have a unique identity on the web. The conceptual models of a smart thing and a proposed IoT reference are shown in Fig. 1.

2.2 Spatial Modelling

Our environment consists of physical objects (or things), the Earth's natural objects (trees, rocks, etc.) and man-made artificial objects, some of which are smart objects. All these objects have spatial properties. According to Huisman and De By [18], spatial properties of objects are: (1) location ("where"); (2) shape ("what form"); (3) size ("how big"); and (4) orientation ("facing which direction"). The sphere of influence or effective range of an object (e.g. surveillance camera or siren) can be considered a fifth spatial property of an object. The spatial properties of an object can change in time.

Digital spatial representations (models) of real-world objects and beings have to be developed in order for computer systems to apply spatial algorithms. Use cases determine which of these spatial parameters are required to represent the object, and how the object will have to be spatially modelled. In most cases, only the location is needed, but in specific cases also shape, size and orientation matter.

Objects can be modelled using a vector or raster method. In the vector method, points, lines, regions, or solids can be used to represent an object. The raster method uses pixel or voxels. The vector method is often used for discrete data (i.e. with clearly defined borders) while raster representations are used for continuous data (e.g. distributions of height, pollution, temperature, etc.). However, it is possible to use and mix both models.

CityGML [15] is an information model that can be used for the spatial representation of (sets of) urban objects. CityGML provides common definitions of the basic entities, attributes, and relationships. The model contains 13 modules, i.e. Core; Appearance; Bridge; Building; CityFurniture; CityObjectGroup; Generics; LandUse; Relief; Transportation; Tunnel; Vegetation; and WaterBody. Figure 2 shows the top level class hierarchy of the CityGML information model.

CityGML supports different Levels of Detail (LoD) for various application requirements, e.g. for spatial analysis and modelling, less detail is required or needed than in the case of data visualization. Therefore, the same object can be represented in different LoDs simultaneously, enabling the analysis and visualization of the same object at different degrees of resolution.

As CityGML is a generic model, in most cases this model has to be tailored for specific situations. The GenericCityObject and GenericAttribute classes (defined within the Generics module) can be used for modelling objects that are not covered by the thematic classes or which require attributes not represented in CityGML.

Objects are often derived from, or have relationships to, objects in other databases or data sets. CityGML allows for making external references links to corresponding objects in external information systems (Fig. 3) using unique identifiers (URIs). In thisway, external references can be made between the spatial representations of smart things in the CityGML model and their descriptions in external asset management systems.

Most objects in CityGML are spatially modelled in real-world coordinates (e.g. buildings, bridges). In other cases (e.g. city furniture), objects are modelled as prototypes (see Fig. 4) of which the shape, size and orientation can be adapted using a transformation matrix that facilitates scaling, rotation, and translation of the prototype. The prototypes are spatially modelled using an internal coordinate system and positioned in real-world coordinates using a 2D or 3D base-point.

The CityObjectGroup class in CityGML can be used to group spatial objects. This is valuable, as objects often consist of a collection of smaller objects, some of which are smart objects. As the definition of a thing is quite broad, grouping gives the flexibility to spatially constitute things from other things.

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Notes_Lecture_3.2_Dimension and Computing

CO 2:- Understand the different challenges and techniques for Spatial Dimensions of Big Data.

3 Determination of Spatial Properties

3.1 Introduction

Many problems and use cases have a spatial dimension. To solve them, we need to know *where* (smart) objects are, how they are oriented, and what are their spatial dimensions. This section discusses the determination of the position, orientation and dimension of internet connected devices. Spatial properties of smart objects can be determined directly through sensors (e.g. GPS+Gyroscope chips), or indirectly (e.g. through the known position of the RFID scanner).

3.2 Positioning Methods

To be able to perform spatial analysis on objects in a Smart City, the position of these objects needs to be known. Many methods are available to determine the position of an object. Zeimpekis et al. [49] provide a nice description of the various methods (Fig. 5).

The type of positioning method that can be applied depends on, for example, the size of the object (available physical space for placement of a positioning sensor in the object); the location of the object (indoor versus outdoor, above/on/in the earth’s surface); the available power sources at the location of use and the type of use; and the accuracy necessary for that use.

3.3 Positioning Accuracy

The accuracy of a measurement system is the degree of closeness of the measurements of a quantity to that quantity’s actual (true) value. The precision of a measurement system is the degree to which repeated measurements under unchanged conditions show the same results. Dias [7] presents an overview of common positioning technologies related to accuracy and operation scales (Fig. 6).

For each IoT use case, the positional accuracy has to be evaluated. For this, metadata related to spatial properties is needed (e.g. which positioning technology or specific chip was used to determine coordinates).

3.4 Spatial Orientation

In some use cases, the orientation (pitch, roll, yaw) of an object becomes important. For example, in the case of a surveillance camera, it is useful to know in which direction a camera is pointing and which area the camera is covering. Or, in the case of pictures taken with smartphones, when the orientations and positions of photos are stored, the positions of objects or people in that photo can be determined through, for example, Photosynth technology.

The spatial orientation of smart objects can be determined directly through sensors (e.g. Gyroscope and compass chip), or indirectly (e.g. determining the orientation of an object through 3D object recognition technologies). The orientation information can be stored in the header of photos or video frames.

3.5 Spatial Dimension

Considering the dimension of objects, it depends what we consider to be the object. Large objects like cars, trains, planes, and ships consist of many smaller objects, some of which are smart objects, able to detect their own position or orientation. This goes down to the microscopic levels (nano robots).

Spatial dimension plays an important role in spatial context, e.g. in “Does it fit?” cases, like “Does this container fit in that ship?”, or “Can this truck pass under that bridge?”. If containers could broadcast their dimension, misfitting could be prevented. If bridges could warn approaching trucks that they are too high to pass, trucks would not get stuck under bridges.

Spatial dimension is related to spatial modelling. The way an object is modelled (0D, 1D, 2D or 3D model) determines whether this spatial property can be used or provided by smart objects.

4 Georeferencing Big Data

4.1 Introduction

This section shows several techniques how data from internet connected devices can be georeferenced. When the position, dimension and the orientation of an object are available, the sensor measurements from that object can be spatially enabled (e.g. georeferenced photos, videos, and tweets). The spatial information related to the sensor measurements can either be stored as metadata in the header of the data file or as an attribute of the data itself. The georeferenced sensor data can be used as input for Spatial Big Data analysis.

4.2 Big Data Sources

Big Data can be produced by intelligent agents or by humans. Intelligent agents autonomously observe the environment through sensors (e.g. camera, microphone, chemical). People can also observe the environment using their natural sensors (eyes, ears, nose, tongue, tactile nerves) and brains. They can publish their observations through applications (e.g. social media applications like Twitter, YouTube, Flickr, Blogs) that run on fixed or mobile devices, e.g. smartphones [35]. Information on the status of smart objects (e.g. battery status) also adds to the data stream.

Sensors in smart objects can measure in-situ (i.e. in direct contact with an object or medium, e.g. a water temperature sensor in water) or remotely (i.e. in indirect contact with an object or medium, observing or interacting with an object or medium indirectly, e.g. a surveillance camera detecting cars' number plates from a distance). The same is true for in-situ and remote acting. Figure 7a, b show both situations.

During sensing, the position of objects can be static or dynamic. Figure 8 shows examples of sensors mounted on static or dynamic objects, (a) a moving smartphone measuring the air quality at a certain location in-situ (b) a moving satellite observing the earth remotely from space (c) fixed sensors in the asphalt measuring traffic speed and number of cars in-situ (d) fixed cameras remotely detecting number plates.

4.3 Geo-enabling Observations

To be able to perform spatial analysis on observations (events), the observations have to be geo-enabled. Figure 9 depicts five methods for geo-enabling events, depending on the capabilities of the object. In cases (a) and (b), the object has a positioning chip on board, the events can be spatialized by the object itself. In cases (c), (d), (e), and (f), the object does not have a positioning chip on board. In such cases, spatializing events can take place client- or server-side (depending on the capabilities of the object), using external geocoding or geotagging services. In the examples of Fig. 9, only server-side geo-enabling is elaborated. The spatial information can be stored either in the metadata (e.g. header) of a file (e.g. GeoTIFF), or in the event message itself (e.g. GeoJSON, GeoRSS, GeoSMS, KML, GML).

In case (a), the internal positioning chip (e.g. GPS) can be used to spatialize the events from sensors or apps installed on the object. The resulting georeferenced events can be sent to an event stream for further real-time spatial analysis. Also the position(s) of the object itself (with ID0) can be sent to the event stream. An example is a smartphone with a health app connected to external sensors (e.g. blood pressure, heart rate).

In Case (b), RFID tags on object ID1 are read by a mobile (GPS-enabled) mobile RFID reader ID2. The resulting RFID reading events can be spatialized using the location chip, thus creating georeferenced events that can be sent to an event stream for subsequent real-time spatial analysis. Also the position(s) of the object itself can be sent to the event stream.

In case (c), the object does not have an internal positioning chip, but the spatial position of the object and ID (ID3) are known (stored in a spatial object database). Using a geocoding service (which returns an XY position based on an ID), events can be spatialized based on ID. Examples of this are smart assets with a fixed position e.g. surveillance cameras, environmental sensor devices, and mobile network antennas.

In case (d), an RFID chip (ID4) is read by an RFID reader (ID5) without a positioning chip. An event containing the IDs (ID4 and ID5) is created (e.g. a bankcard with ID4 was scanned by ATM with ID5, time=yyyy:mm:dd hh:mm:ss). When the position of the RFID reader with ID5 is known (stored in a spatial object database), the position of the RFID reader can be assigned to ID4. In this way, two georeferenced events can be created. With a different technology (e.g. Bluetooth) the distance between objects ID4 and ID5 can become greater creating a positioning error. Examples illustrating this case are RFID readers with a fixed position and without a positioning chip, such as ATM machines, public transport gates, and readers in logistic centers.

In case (e), the object does not have a GPS chip, nor a known position related to an ID. In this case, if the event message contains one or more toponyms, the event can be geotagged using the known positions of the toponyms. Examples are RSS feeds that contain toponyms such as the name of an address or a Point Of Interest (POI), or other references that are stored with a location in the spatial database. For example, the toponym “O’Leary’s Irish Pub” + “Utrecht” returns lat 52.099124 long 5.115681. Other examples include a RSS feed from a blog page or a QR tag message containing toponyms. As the data is unstructured, it can contain spelling errors, so in some cases no match will be found. In other cases, more than one location will be assigned to the event, if the unstructured text contains multiple toponyms.

In case (f), location information (spatial coordinates) is encrypted in a Bar code or QR code, or is stored on board in an RFID or NFC chip. When scanned, the position of the object is revealed, and can be attached to the event. In cases where it is certain that an object will stay in the same location (e.g. a chip in a concrete wall or buried into the soil of a dike), the location may be stored on the chip itself.

A special way of positioning is by using object and subject (face, gesture) recognition algorithms. Footage of surveillance cameras (with known positions) or geotagged crowdsourced photos and videos are the basis for this type of analysis. Using the algorithms, number plates, faces and voices can be detected. Since the video or photo material is geotagged and timestamped, the location and time where and when the object or subject was seen can be deduced. For example, when a new geotagged photo is posted on the web (e.g. Picasa, Flickr), a photo recognition scan action can be triggered. When a person is recognized, an alert can be initiated subsequently. In the case the video or photomaterial is not geotagged, sometimes the location can still be deduced, e.g. when a photo contains a face and a well-known object (landmark). When the landmark is recognized by object recognition and the position is stored in a spatial database (e.g. Eiffel tower), then the position of the face (person) can be deduced.

Last but not least, through direct Machine-to-Machine (M2M) communication, smart objects without positioning capabilities can also retrieve a position from another nearby smart object that has a positioning chip, inferring thus its own position from the other object.

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CO 4:- Applying spatial relationships, functions, and models for IoT in the real world.

5 Spatial Context

5.1 Introduction

This section discusses the spatial relationships between a smart object with other (smart) objects. Once its spatial context is known, a smart object can efficiently interact with other smart objects in its vicinity. Spatial algorithms (relations, functions, models) can be used to determine the spatial context of smart objects.

5.2 Spatial Context of Things

Spatial context is an important aspect in the Internet of Things, as all physical and virtual objects have spatial relationships with other objects. This characteristic can be used for the effective deployment of smart objects. Spatial algorithms (relationships, functions and models) can be applied to geo-enabled objects, events, and their effect areas, in order to determine and analyse the spatial context. The definitions of spatial relationships and functions are standardized by ISO [20].

The spatial context of smart objects and events relates to: (1) the effective area and range of sensors and actuators of these objects or events; and (2) the spatial relationships between smart objects and events and other (smart) objects or events. Spatial context is applicable to both physical and virtual objects. Physical objects are objects tangible and visible in reality. Virtual spatial objects with real-world positions are objects that do not exist in reality, but which do have an influence in the environment, e.g. virtual zones (permit areas, administrative areas, danger zones). Alternatively, they can be virtual 3D objects (virtual sculptures), which can be made visible through, for example, augmented reality techniques. Smart virtual objects (with virtual sensors and actuators) can even create virtual events.

5.3 Effective Area

The first aspect of spatial context is the effective area. The sensors and actuators of smart objects have an effective area or sphere of influence. This can be a sensing range (e.g. the view area of a surveillance camera, the measuring range of a smoke detector), or an actuating range (e.g. the audible range of an air alarm,wifi transmitter range, light beam of a lighthouse). These ranges can be modelled as 2D or 3D spatial objects and can then be used in spatial context algorithms.

As spatial properties (location, shape, size, orientation) and non-spatial properties of smart objects and events can change over time, the spatial properties of effect areas can be static or dynamic in time as well. For example, when the focal length or tilt angle of a surveillance camera lens changes, the shape and size of the view area of the camera changes, and when the bearing of the camera is changed, the orientation of the view area changes as well.

5.4 Spatial Relationships

The second aspect of spatial context is the spatial relationship. A spatial relationship can be used to geographically select (smart) objects that match a certain spatial relationship condition. Figure 10 presents an overviewof four commonly-used spatial relationships between (smart) objects that are spatially modelled as points, lines, or regions (polygons).

Acommonly used spatial relationship inLocationBased Services is the "contains" relationship. For example, when an tourist with a smartphone is entering a virtual zone (e.g. a municipality area), the "contains" spatial relation is true, and based on this, some action can be taken, e.g. sending a message with touristic information to that phone. Or, when a criminal with an electronic bracelet is entering a no-go zone, an alarm can be sent. Or when a smartphone or car is within 500m from home, the carport opens and the coffee machine switches itself on. The possibilities of using spatial relationships in real-world use cases are virtually endless.

5.5 Spatial Functions

A spatial function creates one or more new spatial features based on the spatial properties of the input objects. The newly created spatial features can be associated or assigned to objects.

A commonly used spatial function is the "buffer" function (Fig. 11a). For example, based on the range property of an air alarm (e.g. 900m) and the position of that object (x, y), a geographic buffer function can be applied, creating a new spatial object (region) that spatially represents the effective range of that air alarm. It can be associated with the air alarm object and subsequently be used in other spatial algorithms and spatial analysis. Another common function is the spatial cluster function (Fig. 11b) which groups closely related positions of objects or events.

Other spatial functions include intersect, union, difference, convex and concave hull, spatial joins, routing, and geocoding. A geocoder/reversed geocoder returns x, y coordinates based on address information, and vice versa. A routing function calculates a route based on 'from', 'to', and 'via' locations. A spatial join makes it possible to transfer attributes from one object to another based on spatial relationships. Further, spatial interpolation functions can be used to predict sensor values at locations where no physical sensors are present. For this, input from nearby sensors is used. There are many spatial interpolation methods, e.g. splines, IDW, and Kriging.

5.6 Spatial Models

On the basis of historical and current data, a spatial model can predict future situations. Model output (predictions) can be used to initiate precautionary actions on things. For example, when a weather model predicts severe rainfall for a certain area, a flood model can calculate the expected excess rainwater. Subsequently, water drainage can be preventively intensified by stepping up the pumping activity (actuators) at certain locations in the effect area. An example of a flood forcasting model based on real-time sensor data is described by Berger [3].

Using weather sensors and spatial prediction models, weather patterns can be predicted and weather alerts can be sent to people's smartphones or to things, e.g. sun screens or other weather-dependent things. This can be combined with route planning, predicting routes that keep you dry.

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CO 2:- Understand the different challenges and techniques of Spatial Dimensions of Big Data.

6 Spatial Big Data Analysis

6.1 Introduction

In the previous section it was shown how Big Data from smart objects can be georeferenced. This section discusses real-time spatial analysis of this Spatial Big Data. Spatial characteristics can be used in real-time Spatial Big Data analysis, providing the necessary information, knowledge and wisdom to optimize processes and to solve problems in Smart Cities efficiently.

Once the positions and other spatial properties of objects and events are clear, real-time spatial analysis can be performed, and based on this analysis, decisions can be made. This process is described by the OODA loop. Real-time spatial analysis can be performed by integrating spatial concepts and technology in an Event Driven Architecture (EDA). The event stream engine in an EDA filters raw data events and outputs meaningful events. These can in their turn be used as input for (semi)automated processes, that steer actuators in smart objects. A *catalog of things* is an important component in such architecture, as this provides information on status and capabilities of smart objects.With current “smartness” of objects, the IoT has to be choreographed centrally. Once smart objects become more intelligent, decentral autonomous acting will become possible.

6.2 The Ooda Loop

In a smart city, large numbers of smart objects are connected to the Internet. These smart objects can be used either to monitor their environment (i.e. other objects, events or subjects) through their sensors or to act on the environment by using their actuators. To use the capabilities of smart objects efficiently, a continuous process of orchestration and choreography of smart objects is needed. This process is described by Boyd [5], see Fig. 12.

The Observe-Orient-Decide-Act (OODA) model captures what happens between the onset of a stimulus and the onset of a reaction to that stimulus. In all the phases of the OODA loop, spatial concepts and technology can be integrated and used to improve the efficiency of processes in a Smart City (Fig. 13). Based on location, appropriate sensors and sensing ranges can be selected or activated. Spatial decisions can be made in real-time based on spatial characteristics of observations, and by applying spatial algorithms (relationships, functions,models) to positions of object and events. Furthermore, based on detected spatial patterns or exceeded spatial thresholds, appropriate actuators and actuating ranges can be selected or activated spatially.

6.3 Real-Time Spatial Analysis

Real-time spatial analysis of event streams can be realized by integrating spatial algorithms in a SOA-EDA(Service Oriented Architecture-Event DriveArchitecture) configuration, as shown in Fig. 14.

In such architecture, raw events from smart objects are collected through feed adapters of an Enterprise Service Bus (ESB). From there, these events are sent to the EDA module. The first step in the EDA module is *event pre-processing*, which can be (geo)filtering, (geo)transformation, (geo)routing, or (geo)enrichment of events. Geocoding and geotagging of events can take place in this step, turning Big Data into Spatial Big Data. The result of the pre-processing step is filtered and enriched (georeferenced) events. When a smart object contains positioning capabilities (e.g. GPS), then events can already be georeferenced client-side and spatial pre-processing on the server-side is not needed.

The next step is real-time spatial event stream analysis by a *Geo-enabled Complex Event Processing (CEP) Engine*. In this step, raw filtered geo-events are analyzed against predefined geo event rules (spatial patterns). After processing, events can be stored in a spatial event sink for further causal processing or for spatial modeling purposes that need time series. The output of the CEP Engine is meaningful events. An example of real-time spatial event stream analysis is credit card fraude detection. When multiple credit card transactions are made from spatially remote places within a short period of time, it means that the credit card has been compromised and will be automatically blocked. In the same way, the behavior of smart objects and their sensors and actuators can be monitored and controlled based on their spatial characteristics and their spatial relationships with other smart objects.

After the CEP step, *post processing* can be performed when needed. Finally, *event processor actions* can be initiated based on the meaningful events from the CEP Engine, e.g. publish (geo) event, start business process, notify client, invoke (geo) service, capture (geo) event, or generate (geo) event. These actions will be processed by the ESB.

In all steps of the EDA module, spatial services from the Enterprise GIS system (e.g. geocoding, geotagging, routing, geoprocessing, spatial modeling, geostatistics, catalogs) can be used, and combined with other non-spatial business services through the ESB.

6.4 Catalogue of Things

In the Internet of Things, with its billions of sensors and actuators, it is vital to know where they are, and what they can measure or do. To effectively orchestrate and choreograph things with sensors and actuators in the IoT, a standardized catalogue service is required. This catalogue can be queried on location by objects or by operators, e.g. “Give me all air quality sensors in a range of 1.5 km from location x, y”, or “Give me all cameras with Automatic Number Plate Recognition(ANPR) capabilities in an area of 500m around abc street”. A good “things” catalogue with spatial capabilities is vital and can be used to select the appropriate sensors or actuators in patterns or action scenarios. A catalogue service standard for geospatial data sets and webservices is available (OGC CS-W 2.0) Nebert et al. [28]. A candidate standard for a sensor catalogue service is proposed by Jirka and Nüst [22] as part of the OGC SWE standards. The application of semantic web concepts to sensor discovery has been described by Pschorr et al. [34].

6.5 Acting on Smart Objects

The last step in the OODA loop is acting. Based on sensor input and pattern analysis, notable events are generated by the Event Stream Processing (ESP) engine, and certain actions are initated. These actions or scenarios can be defined using business processmodels or business rules engines in an Enterprise Service Bus (ESB).This can include for example sending alerts, activating actuators in the right place, etc. Sensors and actuators can also react directly to each other through M2Mcommunication, e.g. an irrigation system with smart soil moisture sensors and smart valves. When certain sensors detect drought, they can ask the valves to orientate themselves such that the water flows towards that sensor.

Physical actuators can be speakers, lights, motors, and electronic switches. Figure 15 shows examples of in-situ and remote acting objects, (a) a moving grass mower mowing the grass in-situ (b) a moving laser gun hitting a target remotely (c) a fixed automatic bollard that acts in-situ (d) a fixed air alarm acting remotely on ears through sound waves.

In most cases, smart objects contain both sensors and actuators (e.g. a surveillance dome camera contains an image sensor, a microphone sensor, and actuators like electro-motors to change the direction and zoom of a camera).

6.6 Central Versus Decentral Spatial Processing

The process of spatial orchestration and choreography of smart objects has to be managed either centrally or decentrally depending on the “smartness” of the object. In this respect, the different levels of complexity of the use case and the actors, related to the five phases of evolution of the IoT described by Pschorr et al. [6] have to be considered.

When smart objects become autonomous intelligent agents, they can operate independently and make certain (spatial) decisions autonomously (client-side), based on their spatial capabilities (e.g. calculating the shortest route). Additionaly, agents can acquire (pull) additional contextual spatial information (e.g. “Which smart objects with certain capabilities are closeby?”) or receive (push) instructions (“Go to location x, y using route r and look there for a person with a red coat and blue pants.”) from central systems. Intelligent systems can also retrieve contextual spatial information directly from other smart objects nearby (e.g. asking information from nearby sensors using M2M communication).

Depending on the intelligence of a smart object, their events are either simple measurement values or the outcome of a complex internal analysis, performed client-side by the smart object, signalling a problem or an impending problem, an opportunity, a threshold, or a deviation. For example, when a surveillance camera has built-in face and number plate recognition capabilities, it could act as an intelligent agent, looking out for a wanted person or car by comparing a photo of that person or car number platewith its own direct observations. Itwill only send a georeferenced event (alert)when that person or car is detected, instead of sending unnecessary continuous streams of raw camera data to a central server for processing.

Especially formoving autonomous agents like drones and robots, real-time spatial situational awareness (Where am I? Where am I going? Where are other (smart) objects and subjects? And, where are they going?) will be vital for efficient operation in the Internet of Things.

6.7 A Sensing and Acting Scenario

Sensors at a large chemical complex detect smoke or high temperatures, sent as georeferenced events. ESP Engine pattern analysis reveals “fire”. As the position of the sensors is known, the fire can be pinpointed to a location. A smoke-plume model can calculate the direction of the smoke, using as input the location of the fire and using data from the closest weather sensors (using the “nearest” spatial algorithm). The model predicts a danger zone, people in the smoke-plume area are alerted by triggering the GSM towers in that area (using the “inside” spatial algorithm) to transmit a cell broadcast. The appropriate air alarms in the direction of the smoke are signalled (the properties of the air alarms are used to make the selection, range of air alarms = 900 m, inside algorithm with smoke area). The right actuators (sprinklers) in the fire area are activated, and the appropriate fire doors are closed. To select the right actuators and sensors, a sensor catalogue service is used. Then the closest fire department is warned (nearest algorithm), the position of the fire is sent to the fire truck and to the control rooms, the shortest route is calculated (routing algorithm, from position = fire station, to position = location of fire). The fire truck drives off, following the route. The firetruck’s position if determined by its GPS sensor, and based on this position and the predicted route, the traffic light gives green light to the fire truck, open bridges on the route are closed, and automatic bollards are lowered.

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