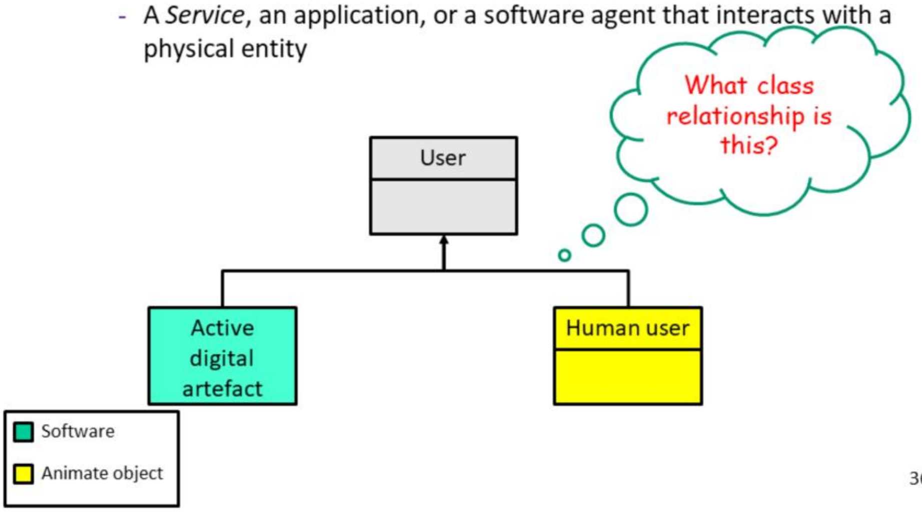
Basic Concepts of IoT Domain Model

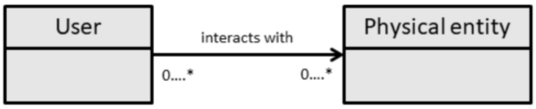
- *User:* can be any animate or inanimate object
  - A human user or an *(Active) Digital Artefact*
    - A *Service*, an application, or a software agent that interacts with a physical entity

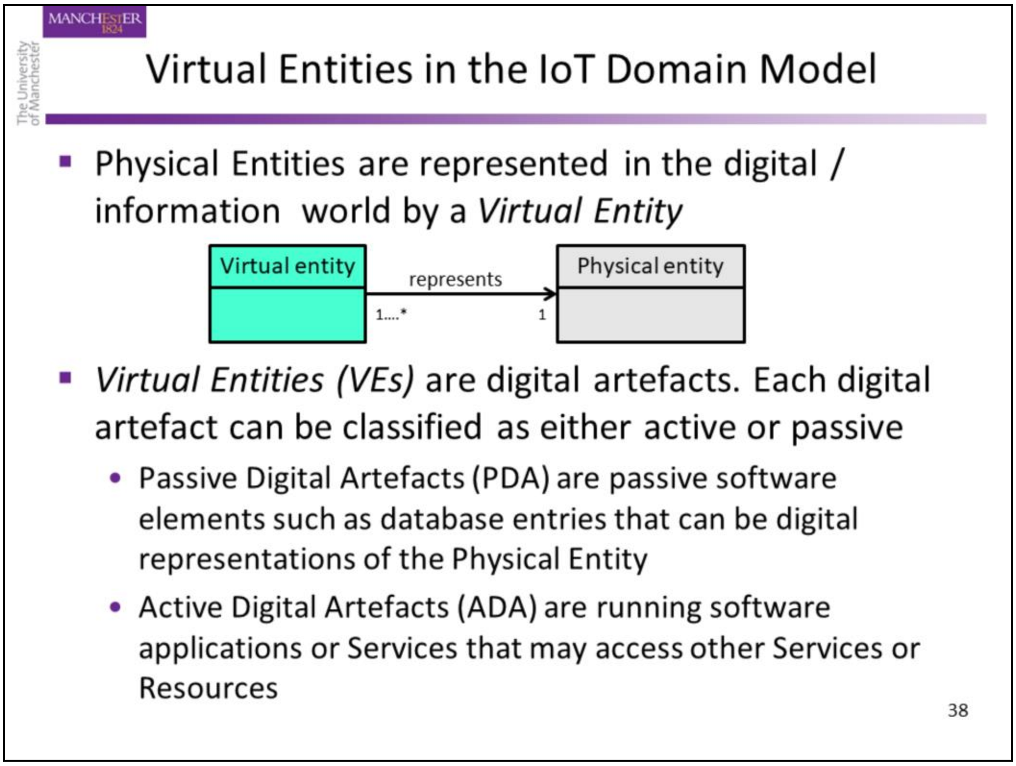


36

Physical Entities in the IoT Domain Model

- *Physical Entity (PE)* can be any physical object or part of the environment that can be identified
  - Examples: Humans or animals, rooms, stores, cars, trucks, logistics chain items, computers, electronic appliances, clothes

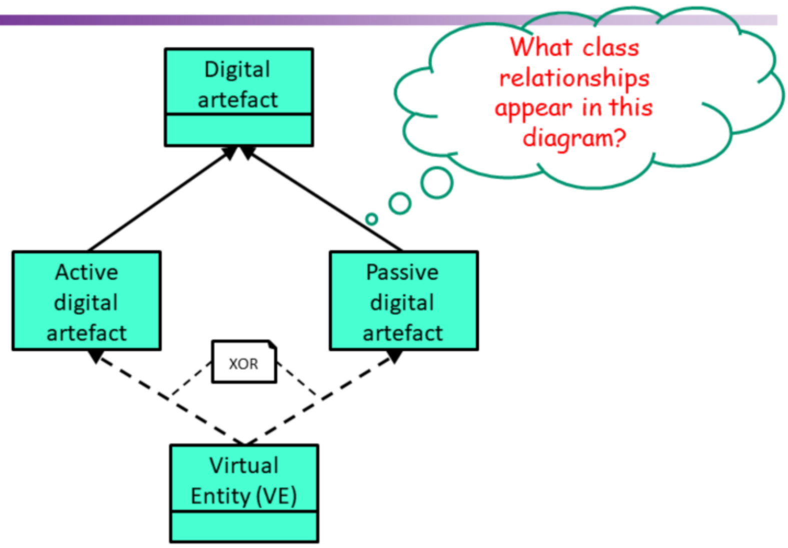




- Each Virtual Entity must have one and only one ID that identifies it univocally.
- A Virtual Entity is associated with and represents only one Physical Entity.
- Conversely, a physical entity can be associated with many virtual entities.

Another important property of virtual entities is that ideally, Virtual Entities are synchronised representations of a given set of properties of the Physical Entity. Synchronization means that relevant digital parameters representing the characteristics of the Physical Entity are updated upon any change of the physical entity.

Representing VEs in the IoT Domain Model



Software

39

Describing IoT Devices in the Domain Model

- A **Device** typically attached to a Physical entity relates an object of the physical world to a virtual entity in the digital world (of the Internet)
- **Devices** are typically categorised into
  - **Sensors** that provide information, knowledge, or data about the Physical Entity they monitor. In this context, this ranges from the identity of the Physical Entity to measurements of the physical state of the Physical Entity
  - **Tags** are used to identify Physical Entities, to which the Tags are usually physically attached
  - **Actuators** can modify the physical state of a Physical Entity

40

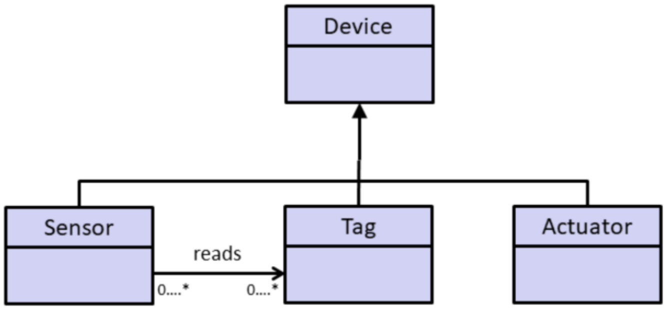
Identifying Physical Entities (PEs) is fundamental to IoT for any User (in the broader definition) to interact with the physical world via the virtual world. Two ways of identification can be distinguished.

- Primary identification where tangible features of a PE are utilized
- Secondary identification where tags (or labels) are attached to the PE

These ways of identification are captured by the IoT Domain Model developed herein.

- Extraction or derivation of natural characteristics can, for example, be performed from a camera and related software. In physical spaces, a GPS or indoor location device can capture the coordinates of the PE.
- For the case of secondary identification, tags or labels attached or affixed to the PE are utilized. These tags can be in the form of RFID or as simple as barcode technologies.

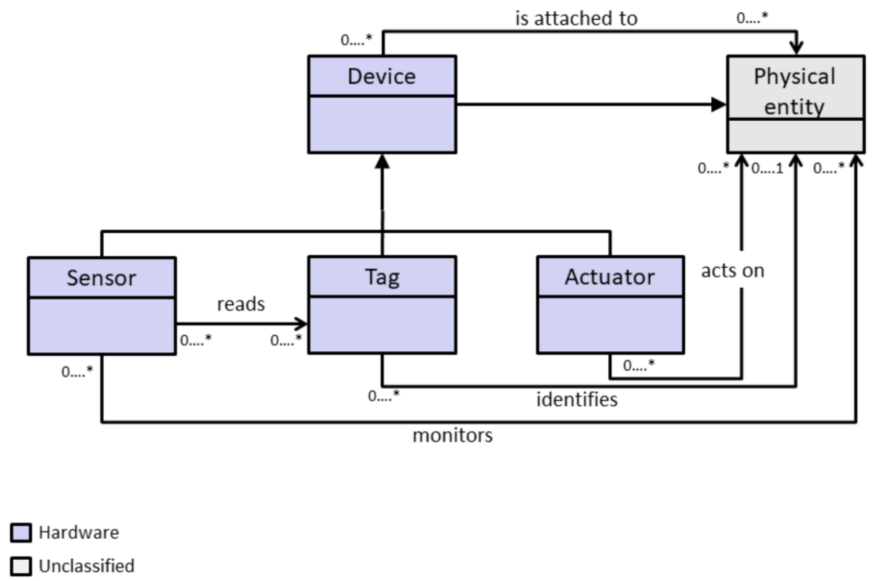
Representing Devices in the IoT Domain Model



Hardware

41

Relating a Physical Entity with a Device



42

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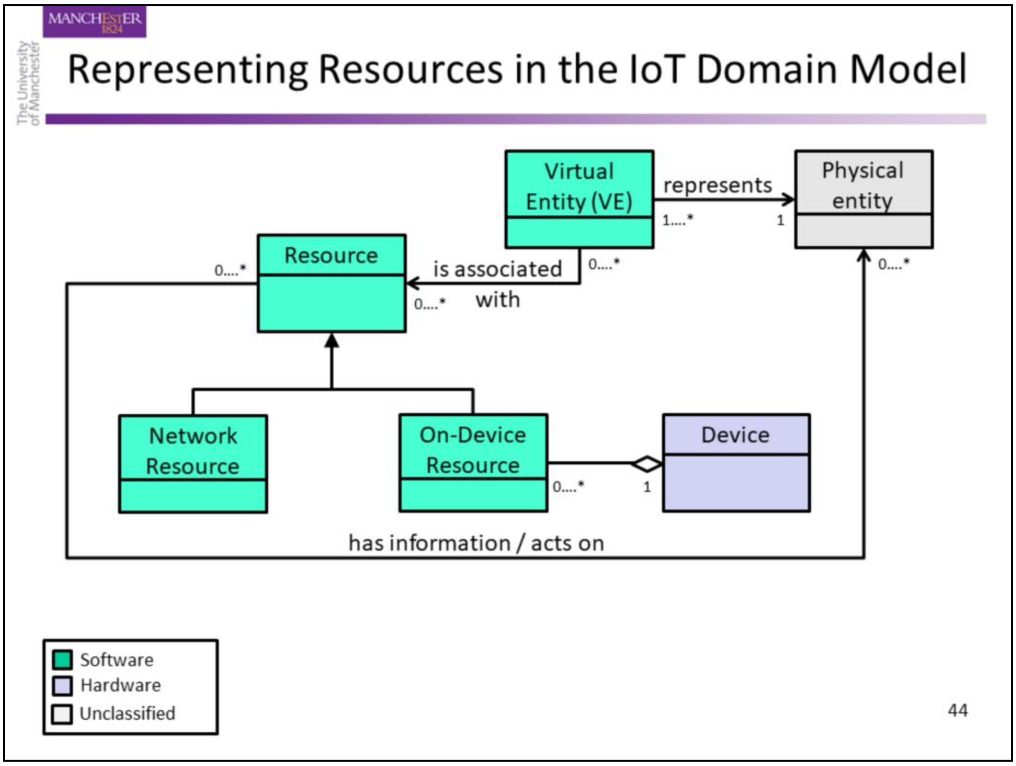
Resources in IoT

- **Resources** are software components that provide data from or are used in the actuation on Physical Entities
  - Resources are distinguished between **On-Device** and **Network** resources
- **On-Device resources** are hosted on Devices
  - Software locally deployed on the Device associated with the Physical Entity. Examples include executable code for accessing, processing, and storing Sensor information and controlling Actuators
- **Network resources** are Resources available somewhere in the network
  - Back-end or cloud-based databases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Representing Resources in the IoT Domain Model
Virtual
Entity (VE)
represents
Physical
entity
1....*
1
Resource
0....*
is associated
with
0....*
0....*
0....*
Network
Resource
On-Device
Resource
Device
0....*
1
has information / acts on
Software
Hardware
Unclassified
44

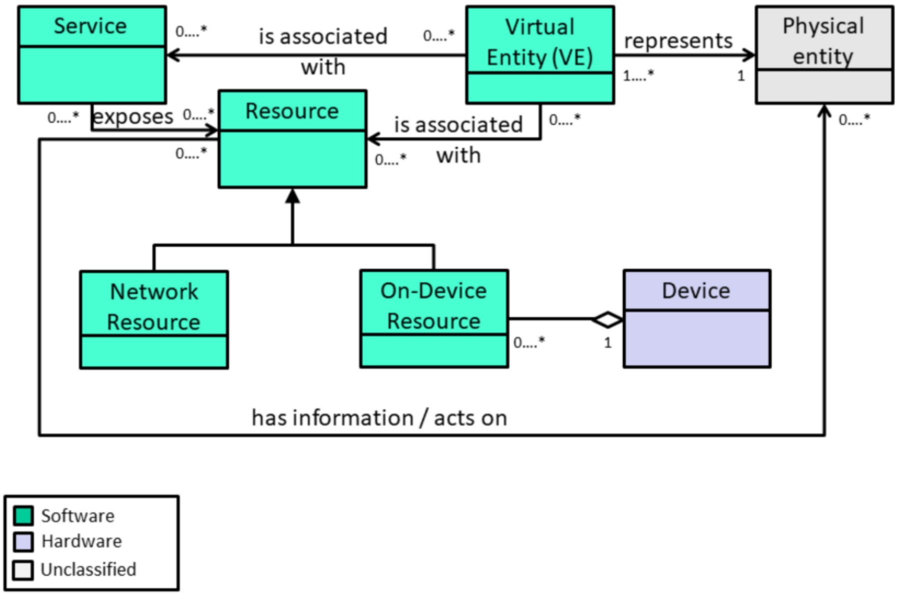
Services in the IoT Model

- Services expose Resources and offer the necessary functionalities for interacting with the Resources / Devices associated with Physical Entities
  - Services have the form of open and standardised interfaces
  - At the lowest level the Service exposes the on-device resources
- Relations between Resources and Virtual Entities are modelled as **associations** between Virtual Entities and Services
- Interaction with the Services is done via the network

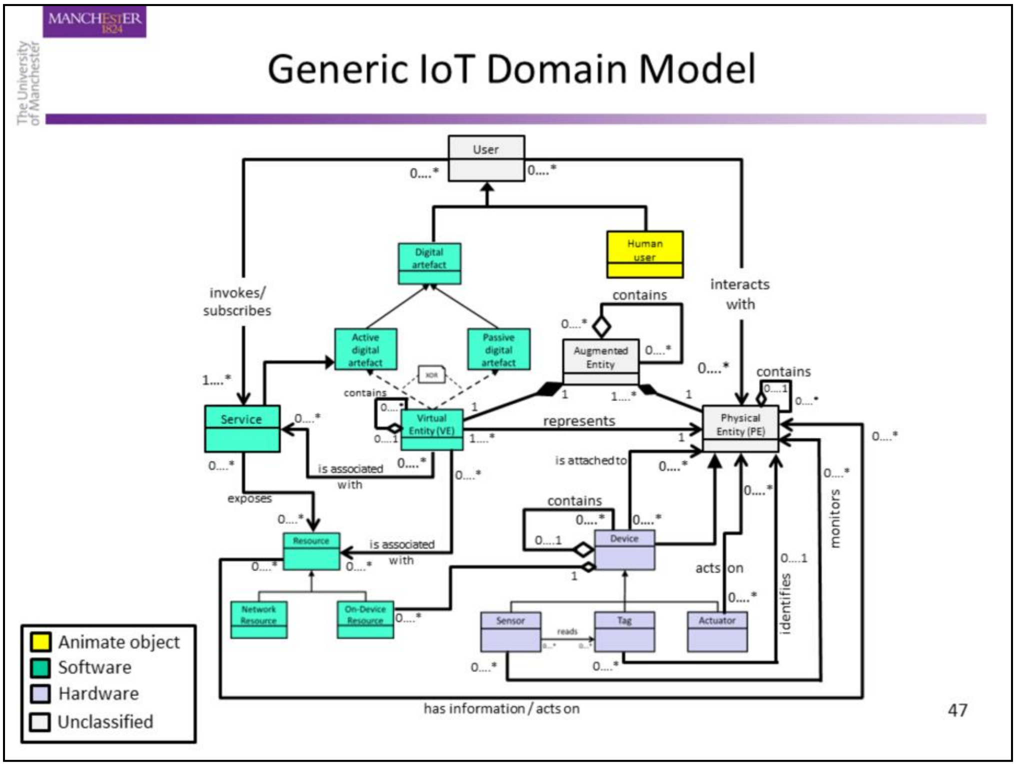
45

In other words, Services are therefore digital artefacts with which Users interact with Physical Entities through the Virtual Entities.

Representing Services and their Associations



46



- Augmented entities are effectively the “Things” of the Internet of Things, that is a Physical Entity in the physical world that includes several hardware Devices (typically, physically attached/integrated/embedded to it) and its representation with at least one Virtual Entity in the digital world.

Sensitive Flowers – Forgetful Driver

- **A truck driver** transports highly sensitive flowers. After loading the flowers on the truck, **an array of sensors is attached to the load carriers to measure temperature**. During the route, the driver stops for a lunch break. By turning the engine off, the driver unintentionally switches off the air condition for the transported goods highly sensitive flowers and since it is a very hot day, the temperature inside the truck starts rising. When the temperature reaches a predefined critical level inside one of the load carriers, **one of the sensors notices this and sends an emergency signal to the driver's IoT-Phone**, which due to **its delicate nature cannot be received by the phones of other drivers**.
- On the IoT-Phone's display, the driver can see that the flowers in load carrier number 6 are in danger due to the rising temperature so he rushes back to the vehicle and turns the air condition back on. **The IoT-Phone also keeps track of any alert messages received from the load carriers and this message history is saved for future inspection in a way that cannot be altered.** When the truck reaches the retail store for delivery**, the sensor history is transferred to the store's enterprise system and the sensors authenticate themselves as being un-tampered**."

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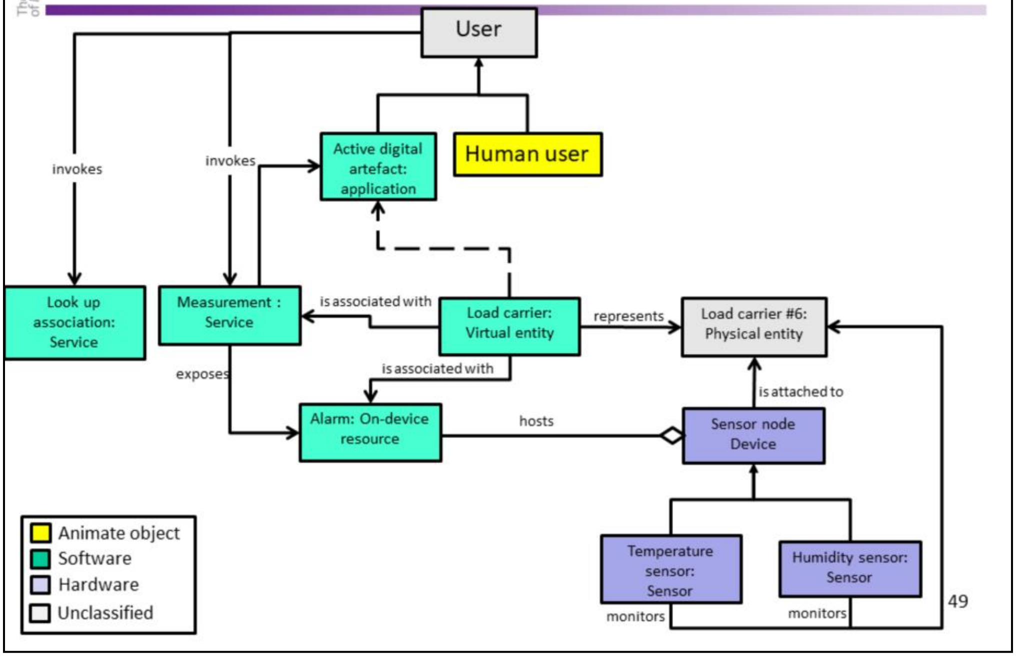
IoT Domain Model “Sensitive Flowers”



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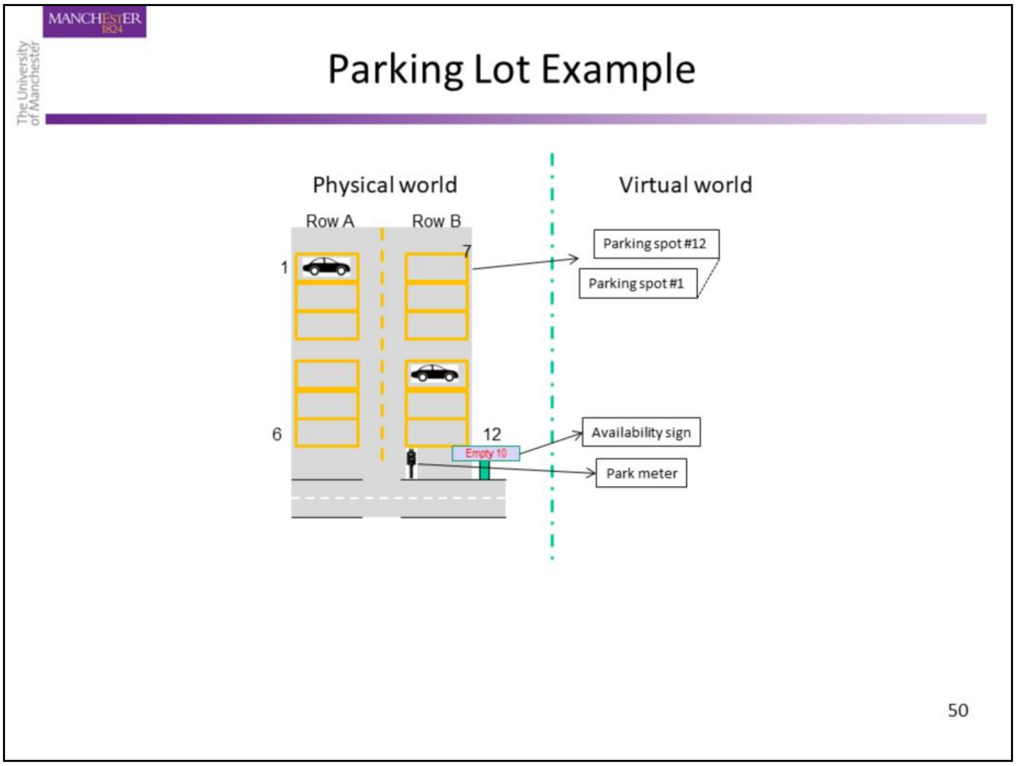
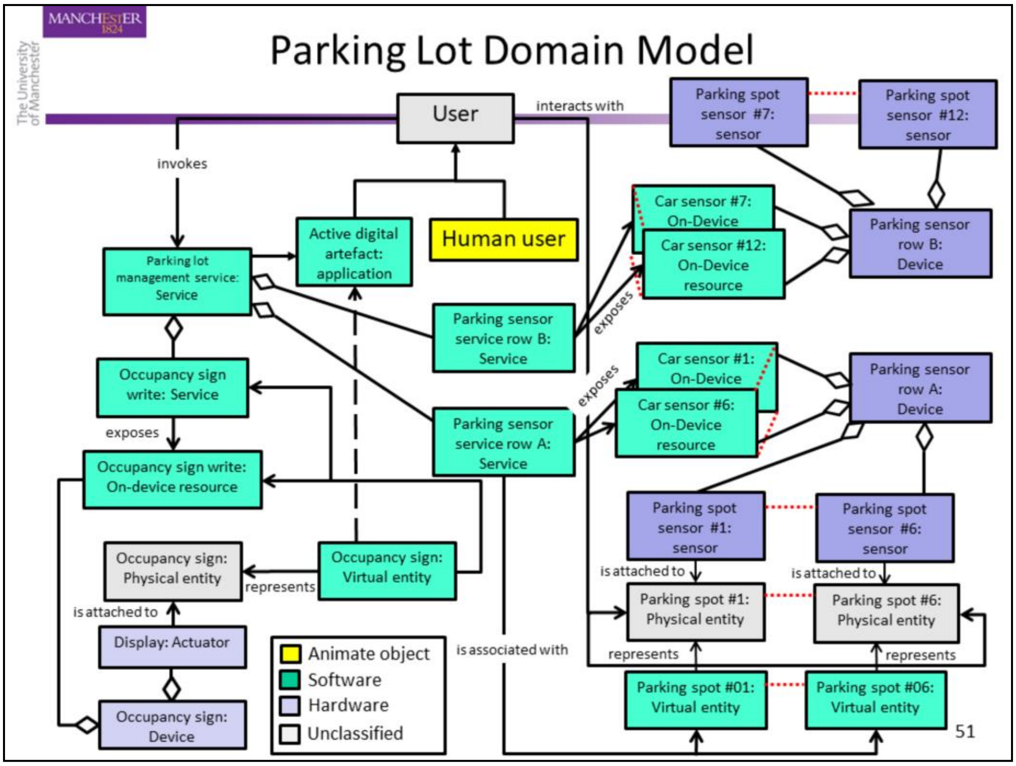


- The slide presents an example of a parking lot which includes a sign (and/or application) to inform the drivers on the availability of the parking space and a pay station (which can also be an application) for paying for the parking spot.
- To provide information and services to the drivers for this parking lot, information about this lot should be mapped in the digital world as shown on the slide.
- The PEs of this example include the parking spaces, the payment station, and the availability sign mapped into the virtual world by appropriate VEs.
- To derive information about the properties of the PEs, each parking space is instrumented with sensors (e.g., metal sensing sensor) and each is represented in the digital world as shown.
- The availability sign and payment station need to also be represented in the virtual world, such that the information about the space availability as well as the received payment for each parking space.



- Note that this example slightly deviates from the generic IoT domain model where Sensors are linked to Devices through a specialization relation. In this example, the sensors are physically attached to the PE rather than the device that controls all sensors (Parking sensor row A/B) and relates to the sensors through an aggregation relation. The same applies to the PE of the Occupancy sign. Yet, the structure, meaning, and importance of the Domain model in representing physical things in the digital world does not change.

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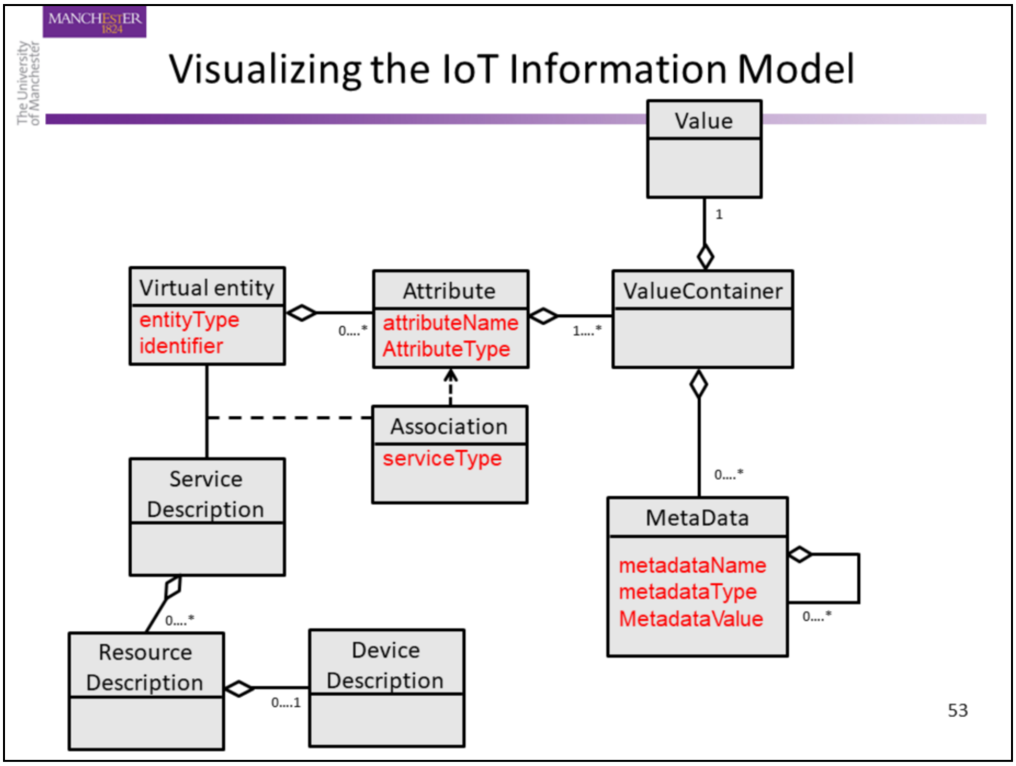
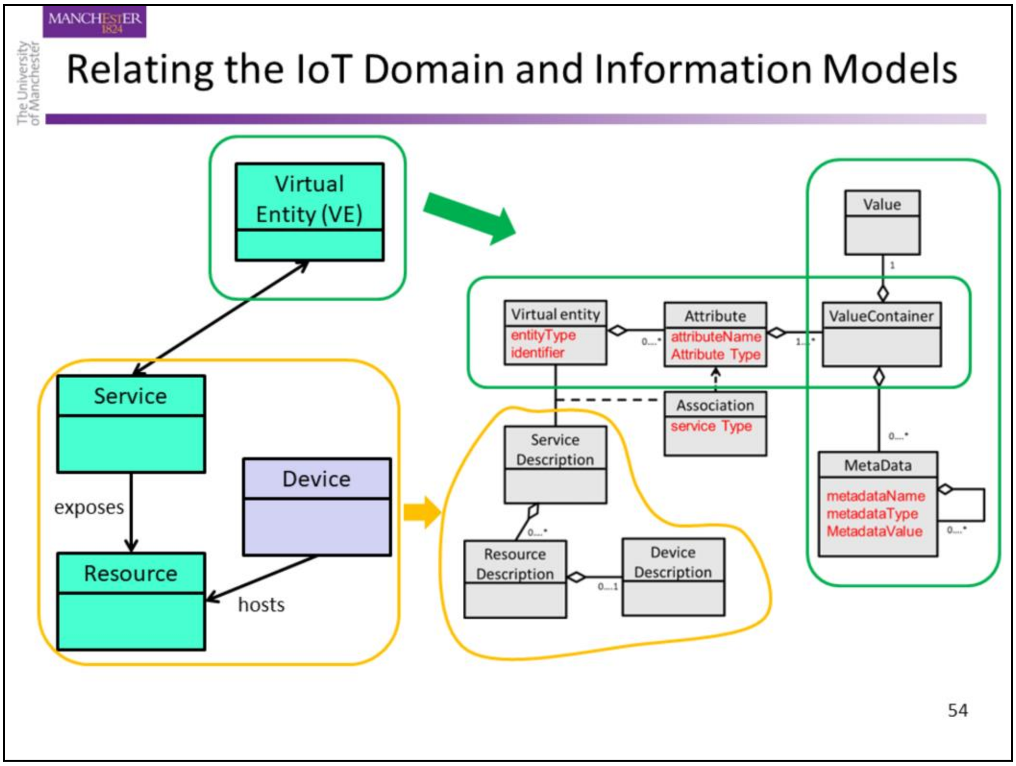
IoT Information Model

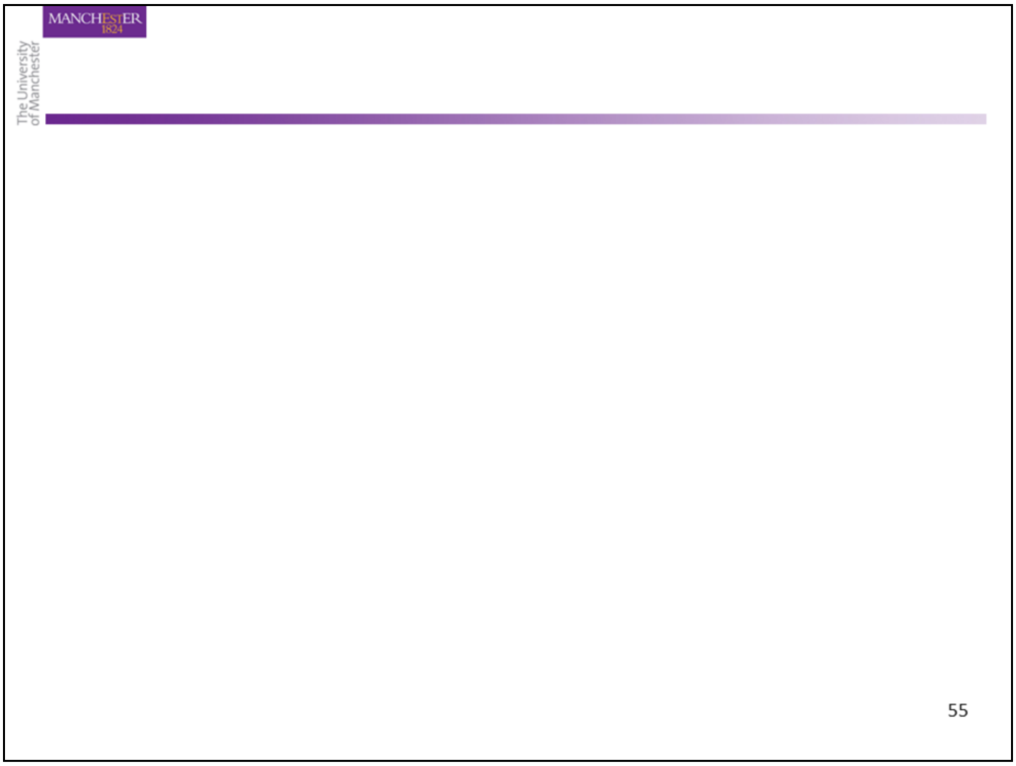
- The IoT Information Model is a meta-model that defines the structure of key aspects of the information being managed in an IoT system.
  - This includes all the information for Virtual Entities on a conceptual level
- A Virtual Entity has several attributes with a name, type, and value
  - Attribute
  - attribute_type
  - attribute_name
  - Value
  - Metadata



- The Virtual Entity represents a Physical Entity (PE)
- The Service Description describes a Service about the PE or the environment.
- An Attribute of a VE is linked to the Service Description through an Association (for example the Service acts as a "get" function for an Attribute value).
- The association (Association) between a Virtual Entity and a Service relates a specific Attribute of the Virtual Entity. The "serviceType", for instance, can be set either to INFORMATION, if the Service provides the attribute value to be read or to ACTUATION, if the Service allows the Attribute value to be set, as resulting of a corresponding change in the physical world.
- A unique identifier should exist for each VE.
- A VE can have zero to many different attributes (Attribute class on the slide).
- Each Attribute has a name (attributeName), a type (attributeType), and one to many values (ValueContainer). The attributeType specifies the semantic type of an attribute, for example, that the value represents humidity.
- Each ValueContainer groups one Value and zero to *many* metadata information units belonging to the given Value.
- Metadata includes meta-information; for example, when and where was the information taken and the quality of the information.
- Metadata can be further composed of metadata (see the reflexive aggregation relationship); for example, in what format is the recorded time information.



- The viewgraph above presents the relationship between the core concepts of the IoT Domain Model and the IoT Information Model. The Information Model captures the Virtual Entity in the Domain Model being the "Thing" in the Internet of Things as several associated classes (Virtual Entity, Attribute, Value, MetaData, Value Container) that basically capture the description of a Virtual Entity and its context.
- The Virtual entity description in the Information Model can include the following attributes and properties:
  - Location and temporal information because Physical Entities represented by Virtual Entities exist in space and time. These properties are extremely important when the interested Physical Entities are mobile (e.g. a moving object). Describing whether the Physical Entity is static or mobile is still useful information. A mobile Physical Entity affects the associations between Attributes and related Services, e.g. a person moving close to a camera (sensor) is associated with the Device, Resource, and Services offered by the camera for as long as she stays within the field of view of the camera. In such cases, the temporal availability of the associations between Attributes and Services need to be captured, as availability denotes also temporal observability of the Virtual Entity.
  - Even non-moving VEs contain properties that are dynamic with time, and therefore their temporal behaviour should be modelled and captured by the information model.
  - Information such as ownership is also important in commercial settings because it may determine access control rules or liability issues.



- In the same context, the Service description some of the included information can contain the following
  - The type of service (Service type), such as Big Web Service or RESTful Web Service. The interfaces of a service are described based on the description language for each service type, for example, Web Application Description Language (WADL) (Hadley 2009) for RESTful Web Services, Web Services Description Language (WSDL) (Christensen 2001) for Big Web Services, Universal Service Description Language (USDL) (Kadner & Oberle 2011), etc. The interface description includes, among other information, the invocation contact information, e.g. a Uniform Resource Locator (URL).
  - Service area and Service schedule are properties of Services used for specifying the geographical area of interest for a Service and the potential temporal availability of a Service, respectively. For sensing services, the area of interest is equivalent to the observation area, whereas for actuation services the area of interest is the area of operation or impact.
  - Associated resources that the Service exposes.
  - Metadata or semantic information used mainly for service composition. This is information such as the indicator of which resource property is exposed as input or output, whether the execution of the service needs any conditions satisfied before invocation, and whether there are any effects of the service after invocation.
- Similarly, a Resource description contains the following information:
  - Resource name and identifier for facilitating resource discovery.
  - Associated Service information.
  - Associated Device description information.

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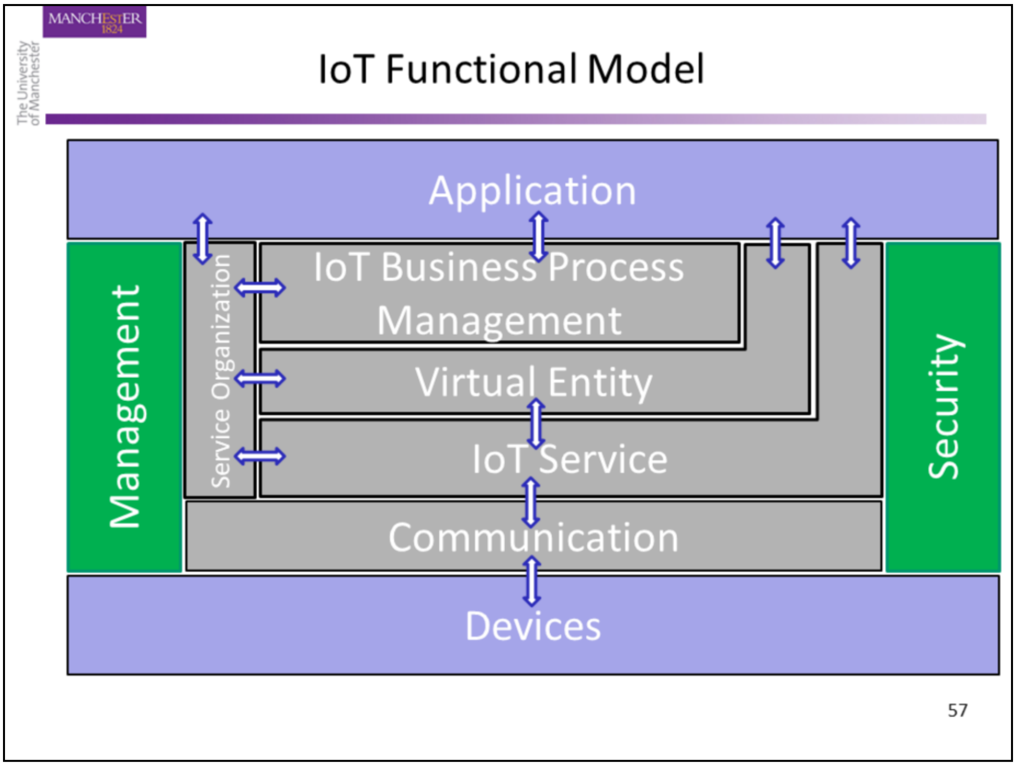
56

- Resource type, which specifies if the resource is (a) a sensor resource, which provides sensor readings; (b) an actuator resource, which provides actuation capabilities (to affect the physical world) and actuator state; (c) a processor resource, which provides processing of sensor data and output of processed data; (d) a storage resource, which provides storage of data about a Physical Entity; and (e) a tag resource, which provides identification data for Physical Entities.
- Free text attributes or tags used for capturing typical manual input such as “fire alarm, ceiling.”
- Indicator of whether the resource is an on-Device resource or network resource.
- Location information about the Device that hosts this resource in case of an on-Device resource.

• Finally, the Device description class can contain some or all of the following information relating to the Devices of the IoT system:
  - Dimensions of physical packaging
  - The physical placement of sensors, actuators, tags, processors, memories, batteries, cables, etc., on the printed circuit board of the Device.
  - A Device identifier or name
  - Location of deployment, either expressed in global coordinates or local human readable text (e.g. Auditorium).



- The Functional Model describes both the functional groups included in a general IoT system and the interaction among these components.
- From the main concepts (abstractions) of the IoT Domain Model (i.e., Users, Virtual Entities, Resources, and Devices), some functional groups for the Functional Model are produced. These groups include the Application, Virtual Entity, IoT Service, and Devices groups.
- Due to the large number and disparity of communication technologies that the IoT ARM should support, the requirement for a “Communication” FG is identified.
- Requirements expressed by stakeholders regarding the possibility to build services and applications on top of the IoT are covered by the “IoT Process Management” and “Service Organisation” Functional Groups.
- The two transverse Functional Groups, Security and Management cross several other Functional Groups, as these aspects are important for most of the horizontal Functional Groups.

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IoT Process Management Functional Group

- **Objective**: Provide the functional concepts to enable conceptual integration of the idiosyncrasies of the IoT world into traditional (business) processes
- This aim allows the use of common standards and best practices, thereby avoiding the overhead and costs of proprietary “Intranet-of-Things” island solutions
- The specificities of the underlying business domain including the different roles of the business objects and users should be considered
- The IoT Process Management FG relates to the conceptual integration of (business) process management systems with the IoT ARM

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Service Organization Functional Group

- The Service Organisation FG is used for composing and orchestrating Services of different levels of abstraction
- This group effectively links Service requests from high level FGs such as the IoT Process Management FG, or even external applications, to basic services that expose Resources
  - Example: a translation of high-level requests dealing with properties of entities (e.g., “give me please the pressure of the valve 345”) down to the concrete IoT services (e.g., “sensor service ABC”) can be realised

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Communication Functional Group

- The Communication group abstracts the variety of interaction schemes derived from the many technologies (Device FG) involved in IoT systems and provides a common interface to the IoT Service FG
- Starting from the top layers of the OSI model, the following are considered
  - End to end path information
  - Addressing issues (i.e. Locator/ID split)
  - Network management
  - Device specific features
- The Communication FG is derived from the Communication Model along with requirements for a specific IoT system

60

- Examples of the above requirements include integrity and security that can be enforced utilizing different signature and encryption schemes at various ISO/OSI layers
- Reliability which is supported either by means of link layer acknowledgements or end to end error correction schemes at the upper layers
- Quality of service provided through queue management techniques
- Other issues that provision for the different communication technologies, protocol translation, and context passing functionalities are also described.

Types of Communication in IoT Systems

- User <-> Service communication
- Service <-> Service communication
- Service / Device / Resource interactions

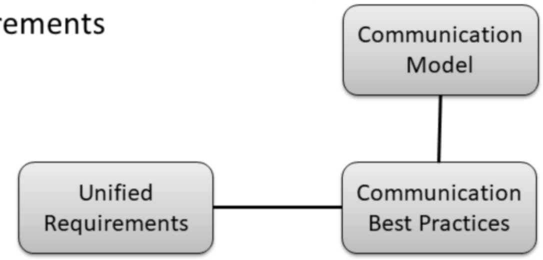
- User <-> Service interaction is most common
  - Also typical in most Internet-based communication
    - User interact with Services/software over the Internet
    - Standard internet-based and related protocols are used for this type of communication

Non-Typical Service <-> Service Interactions

- Special attention is required if two Services communicate to one another and one or both these Services belong to a constrained network
- Examples of the non-typical internet-based communication include
  - Services deployment on constrained Devices such as Sensor nodes and when
    - Use of constrained communication protocols is required
  - The two elements belong to different sub-networks, gateway(s)
    - Gateways and/or proxy(ies) should be deployed to ensure successful end-to-end communication
    - A general rule, if a Service is constrained, or if it needs to provide access to constrained Users, it must be accessible with constrained protocols (e.g., 6LoWPAN, UDP, CoAP, etc.)

IoT Communication Model

- **Key objective**: Build interoperable protocol stacks
  - How? Develop a Communication Model that leverages the ISO/OSI 7-layer model for computer networks
- Role of the Communication Model
  - Help the definition of the Functional Components in the Communication Functional Group of the Functional Model
  - Derive Communication best-practices based on system requirements



63

Functional Requirements

- Lifetime of devices
- Responsiveness
  - Frequency of data reporting, invocation of services, etc
- Robustness
  - How much data loss is permitted
- Sensor related
  - Sampling freq, processing capabilities -> level of reasoning
  - Characteristics of the monitored phenomenon/quantity
  - Accuracy, power, signal conditioning, sensitivity to environmental conditions
- Actuator related
  - Response time, power, processing capabilities

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Non-Functional Requirements

- Regulations
  - Device deployment, RF related regulations, e.g., TX power, frequency band
- Installation, maintenance, accessibility
- Physical constraints
  - Size and weight limits
  - Integration of electronics
  - Antenna size
  - Power supply availability
- Cost
  - Component choice, integrated devices