



# An Analysis of Reference Architectures for the Internet of Things

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# Outline



- Introduction:  
the Internet of Things (IoT)
- Relevance of reference architectures  
for IoT
- Analyzing the IoT ARM and WSO2  
reference architectures
- Discussion

# Internet of Things (IoT)



The **Internet of Things (IoT)** is a paradigm in which **smart objects** actively collaborate with other **physical and virtual resources** available in the Internet

# Internet of Things (IoT)



smart cities



environment



energy



logistics



industry



smart homes



retail



health care

The dissemination of the IoT has a wide potential to considerably impact the daily lives of human beings in several application domains

# Challenges in IoT

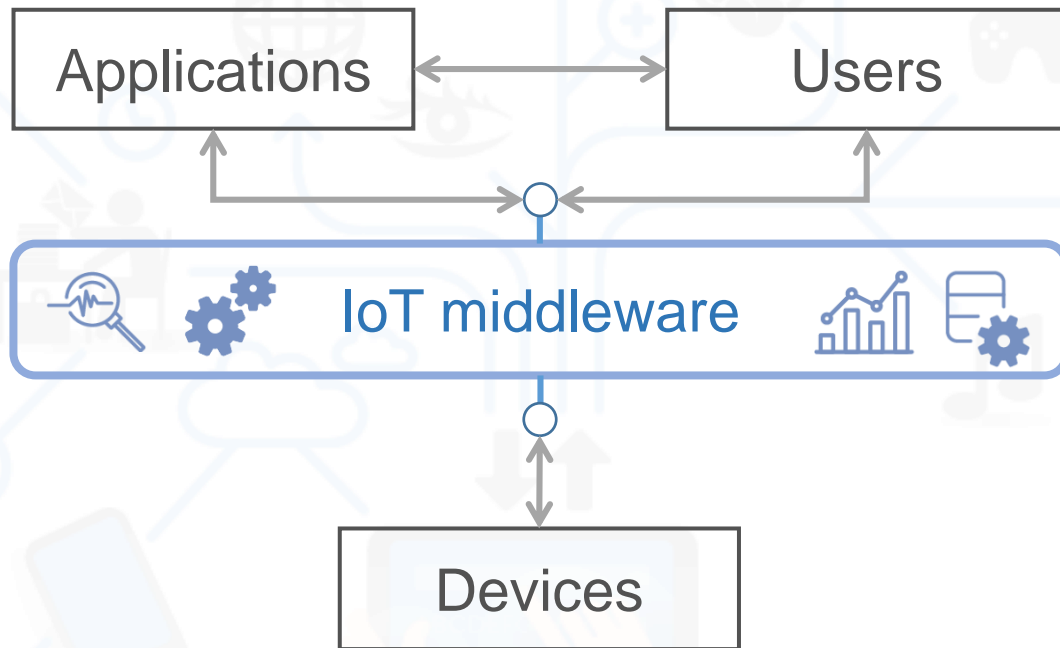
High heterogeneity  
due to the huge diversity  
of physical devices in  
terms of

- Hardware and software
- Protocols and proprietary solutions
- Data formats



# IoT middleware platforms

Promising solutions: IoT middleware platforms



Software layer inserted into applications/users and the underlying infrastructure (communication, processing, sensing)

# IoT middleware platforms

Promising solutions: IoT middleware platforms

- Abstract away the specificities of physical devices from applications and/or users
- Key elements to promote interoperability and seamless integration of physical devices
- Contribute to make the development of IoT applications easier
- Recent research field that has drawn attention from industry and academia

# Challenges in IoT

The **lack of standardization** leads IoT platforms to

- adopt **different programming models** typically not compatible with each other
- **not properly address** some functional and non-functional requirements
- **neglect** privacy and security issues



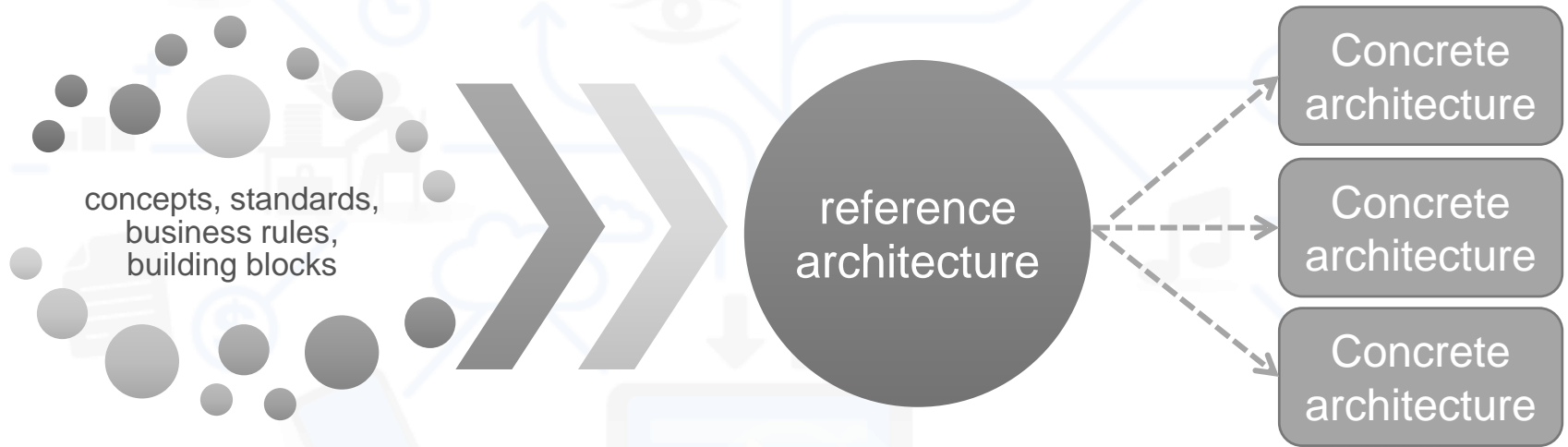
# Challenges in IoT



There is still **no complete consensus** on which functional elements and non-functional properties must be addressed by platforms targeting IoT

# Challenges in IoT

Possible solution to the lack of standardization:  
adoption of **reference architectures**



# Reference architectures for IoT

- Relevant means of defining an initial set of building blocks for IoT environments
- Very recent research topic
- Few proposals have been introduced so far
  - IoT Architectural Reference Model (IoT ARM)
  - Architecture developed by the WSO2 company

# Goal of this work

- To **introduce** two reference architectures proposed for IoT
- To **analyze** such proposals in terms of their support for addressing the main requirements of the IoT paradigm
- To **shed light** on important issues to be addressed in future research on reference architectures for IoT



# Relevance of reference architectures for IoT

Establishing reference architectures is an important issue in IoT as they can

- describe essential building blocks and design choices for dealing with both functional and non-functional requirements
- provide directions to guide and facilitate the development of IoT applications
- promote interoperability as system architectures would be founded upon them

# IoT Architectural Reference Model

- Developed within the **Internet of Things Architecture FP-7 European Project**
- Established upon a **reference model** aiming to be a **baseline** for IoT system architectures
- Provide high-level **views** and relevant **perspectives** for constructing IoT systems



**IoT-A**  
Internet of Things - Architecture



# IoT Architectural Reference Model

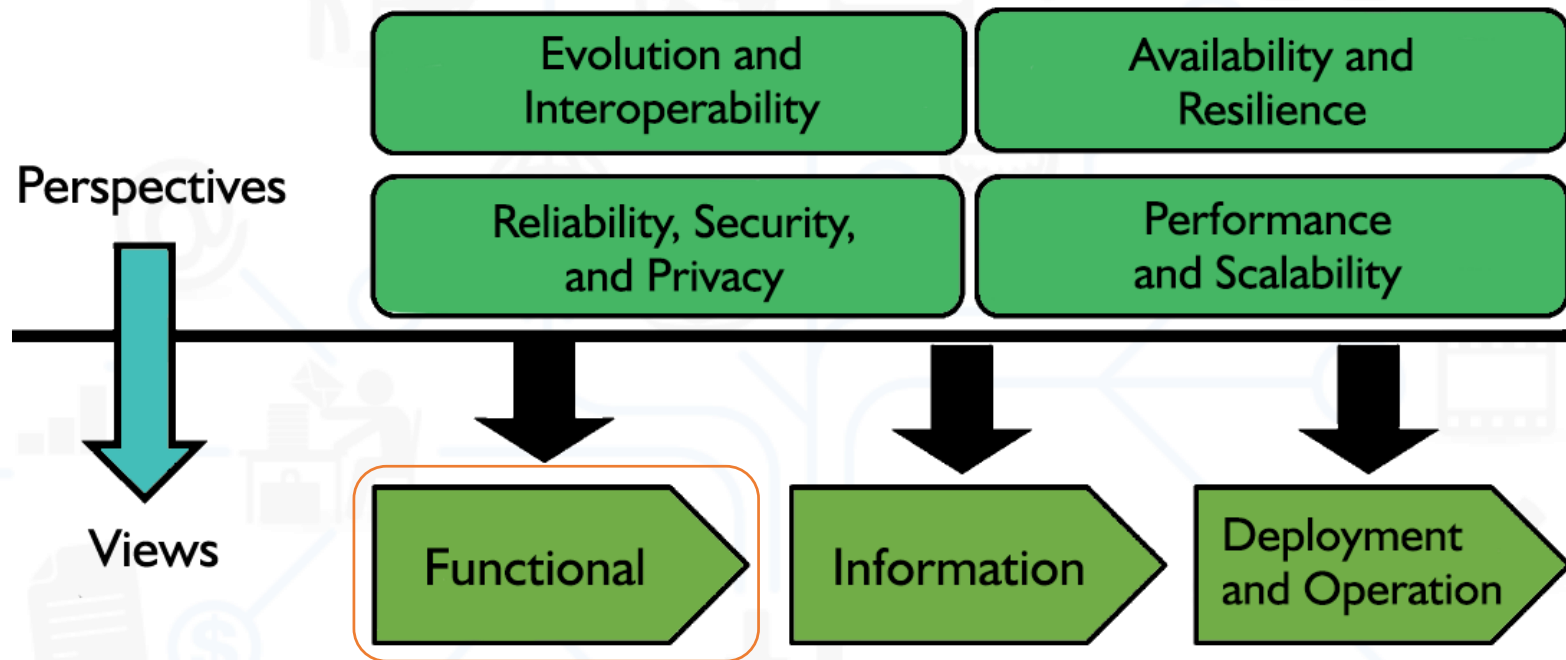
## Views

different **angles** for viewing an architecture that can be used when designing and implementing it

## Perspectives

set of **tasks, tactics, directives, and architectural decisions** for ensuring that a given concrete system accomplishes one or more quality attributes

# IoT Architectural Reference Model

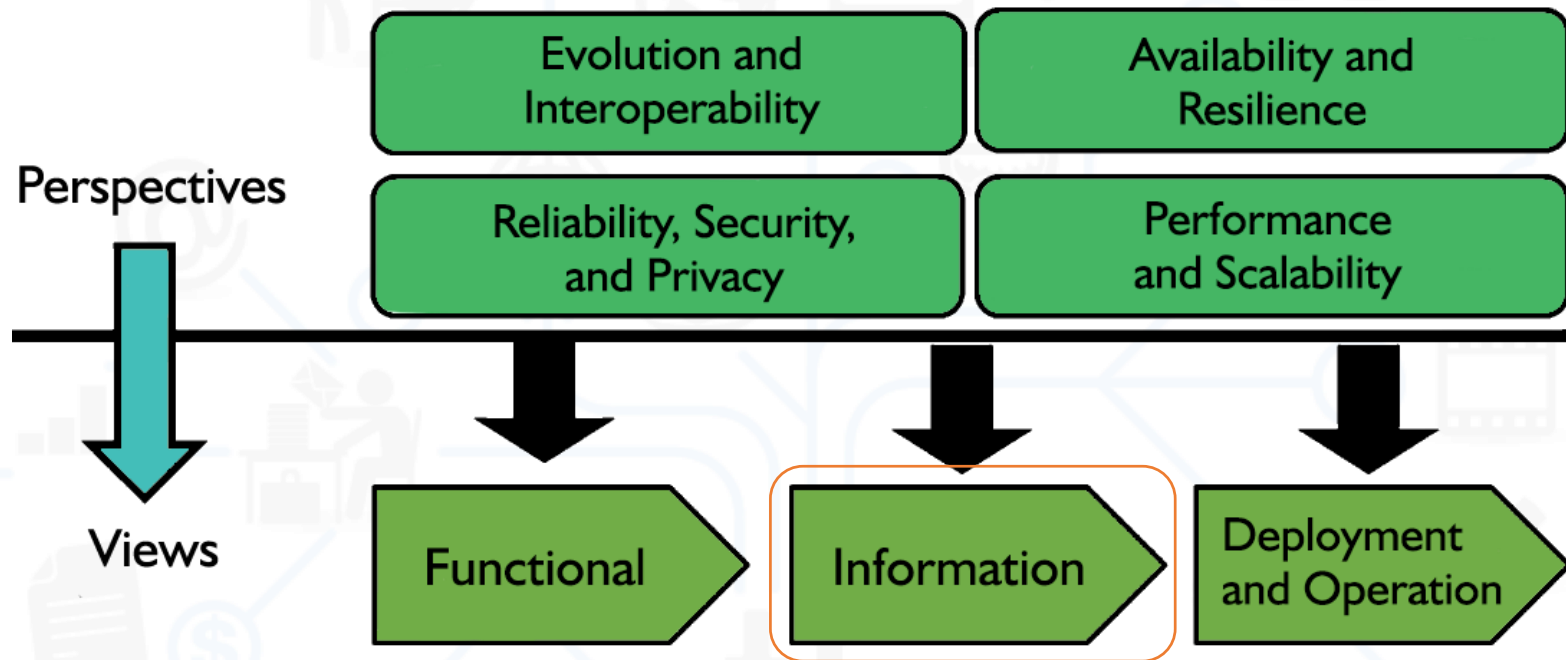


## Functional View

describes functionality groups, each one with one or more basic functional components (but not how they interact with each other)



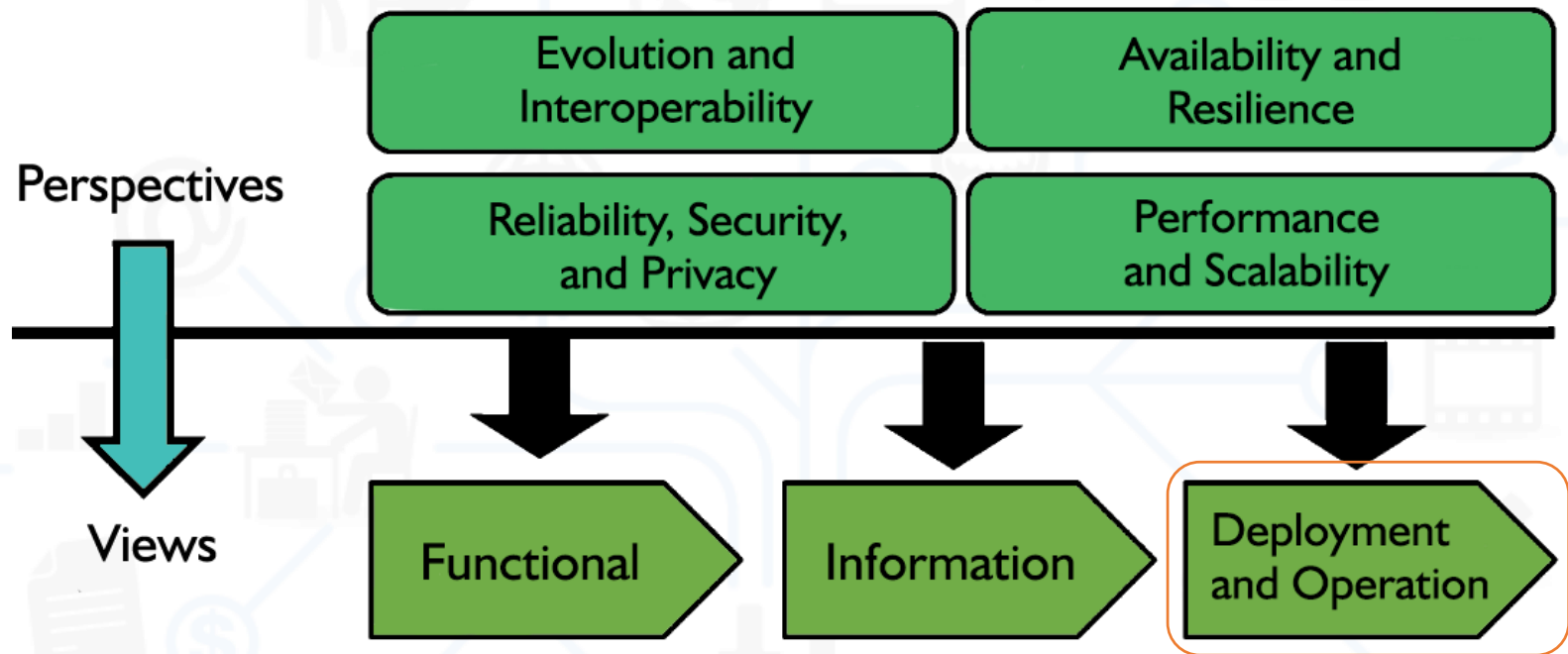
# IoT Architectural Reference Model



## Information View

concerns how representing relevant information in an IoT system as well as its exchange flow and life cycle

# IoT Architectural Reference Model



## Deployment and Operation View

addresses how an IoT system can be realized by selecting the proper technologies, devices, resources, and services, as well as guidelines for architects/developers through the different decisions to be made

# IoT Architectural Reference Model

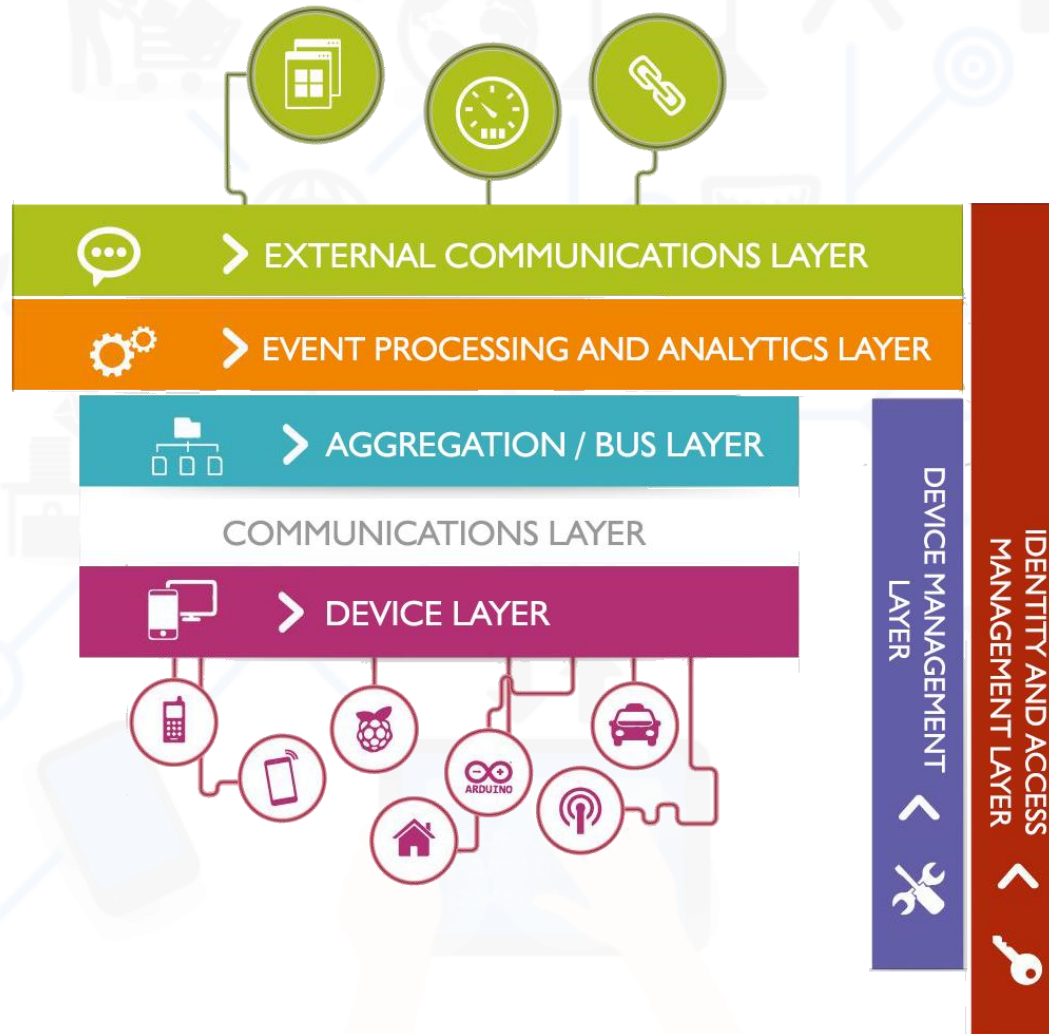
- Each perspective encompasses
  - a desired **quality** level
  - relevant IoT **requirements**
  - **applicability** to (types of) IoT systems
  - **activities** to achieve the desired qualities
  - architectural **tactics** to be used by architects
- Perspectives are relevant as **several quality attributes must be taken into account** in IoT
- Perspectives foster **knowledge reuse**

# WSO2's Reference Architecture

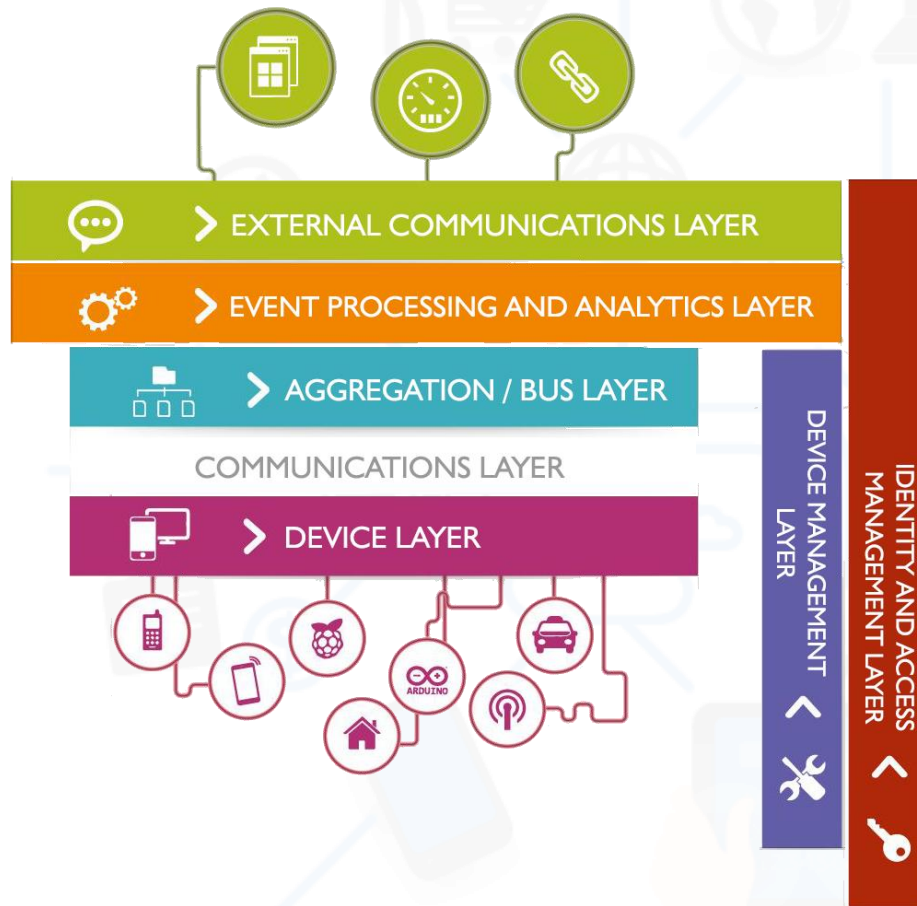
- Proposed by the **WSO2** American company based on its expertise in the development of IoT solutions
- Aims to provide architects and developers with an **effective starting point** covering most of the requirements of IoT systems and projects



# WSO2's Reference Architecture



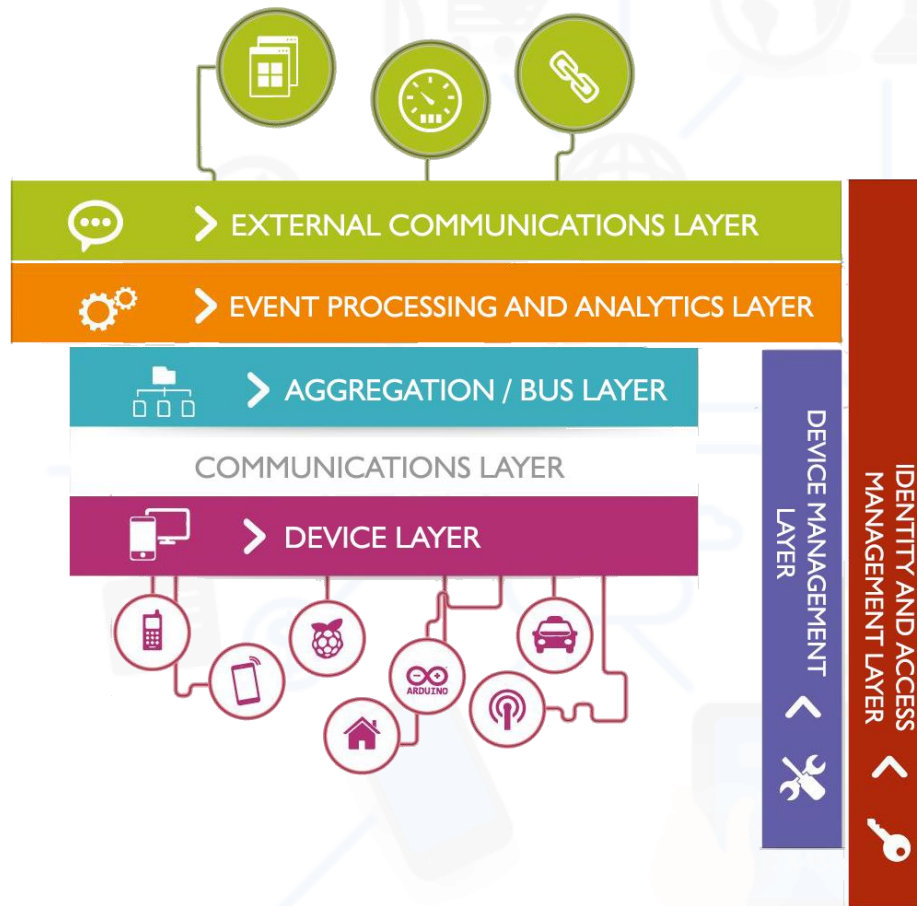
# WSO2's Reference Architecture



## Device Layer

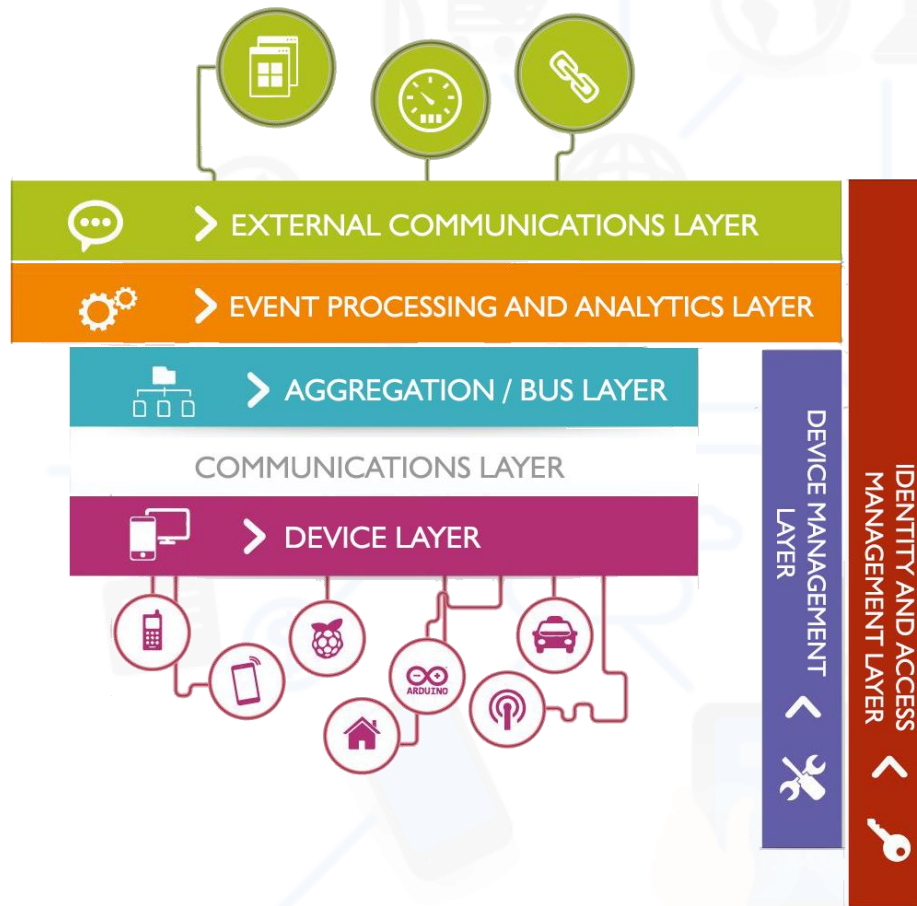
each device should have a unique identifier and direct or indirect communication with the Internet

# WSO2's Reference Architecture



Communications Layer supports device connectivity with multiple potential protocols

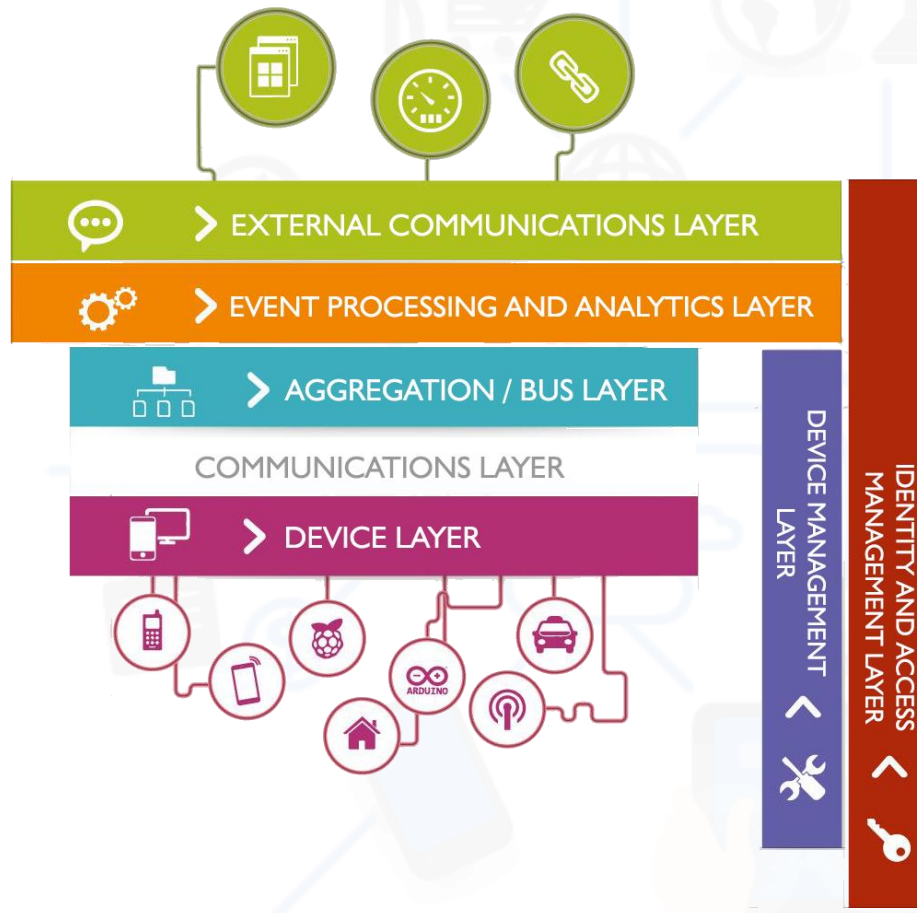
# WSO2's Reference Architecture



Aggregation/Bus Layer supports, aggregates, and combines communications from several devices, as well as bridges and transforms data among different protocols



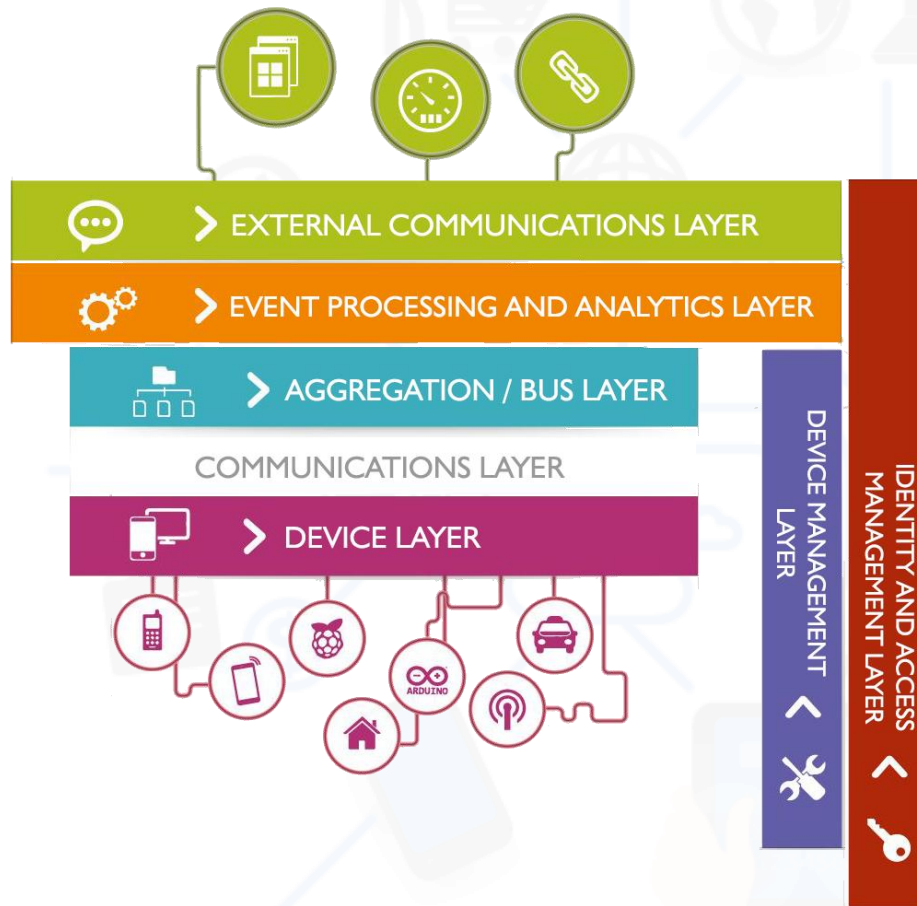
# WSO2's Reference Architecture



## Event Processing and Analytics Layer

processes and reacts upon events coming from the *Aggregation/Bus Layer*, as well as can perform data storage

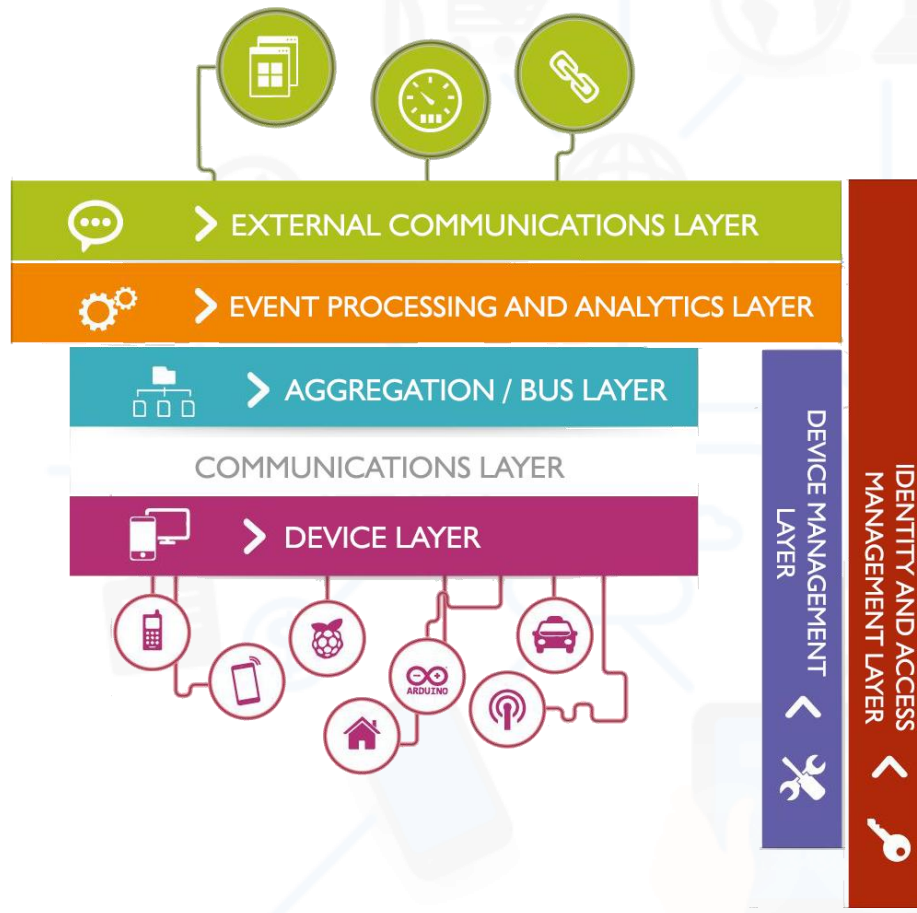
# WSO2's Reference Architecture



## External Communications Layer

through which users can interact with devices and access data available at the system

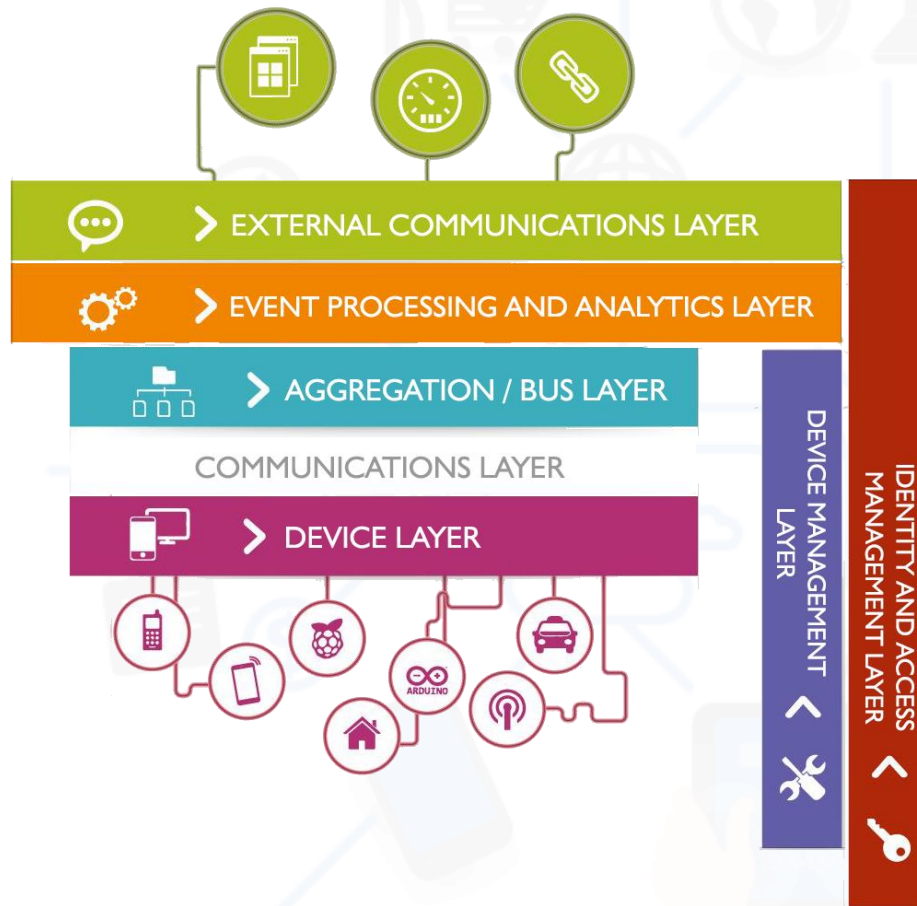
# WSO2's Reference Architecture



## Device Management Layer

communicates with devices through different protocols and allows remotely managing them

# WSO2's Reference Architecture



Identity and Access Management Layer responsible for access control and security directives

# Analyzing reference architectures for IoT

In the IoT context, there is a set of requirements that must be fulfilled by platforms and systems aiming at meeting needs of users and applications, as well as addressing the challenges that arise in this scenario

- Interoperability
- Device management and dynamic discovery
- Context-awareness
- Scalability
- Management of large volumes of data
- Security, integrity, privacy
- Dynamic adaptation

# Analyzing reference architectures for IoT

Requirement	IoT ARM	WSO2
Interoperability	✓	✓
Device discovery and management	✗	○
Context-awareness	✗	○
Scalability	✓	✓
Management of large volumes of data	✗	○
Security, privacy, and integrity	✓	✓
Dynamic adaptation	✗	✗

# Discussion

- Undeniable role played by reference architectures in the IoT context
  - Guidance to the construction of IoT platforms
  - Minimization of the existing lack of standardization when developing IoT systems
- Need of going a step further towards fulfilling the essential requirements for the IoT realm
  - Low maturity points out that more research efforts on reference architectures for IoT are needed

# Discussion

Need of proposing **reference models** for IoT

- **Comprehensive understanding** of the IoT paradigm and related application domains
- Support the **establishment of reference architectures** in the IoT context
  - IoT ARM includes an IoT Reference Model
- **High-level and generic reference models** can provide a better baseline for **generic and domain-specific reference architectures** for IoT





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