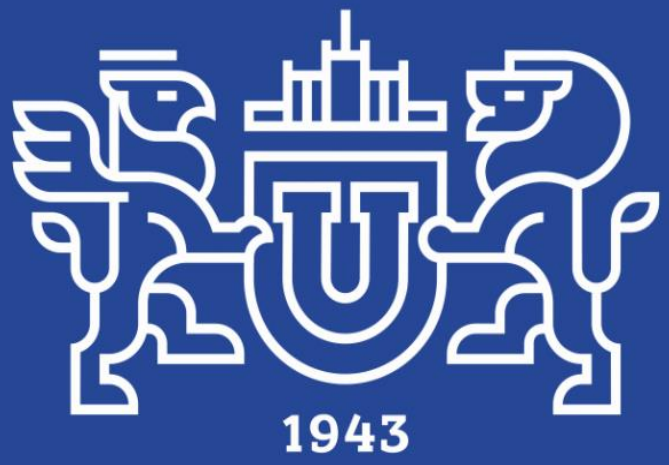

South Ural State University

National Research University

Digital Twin of City: Concept Overview

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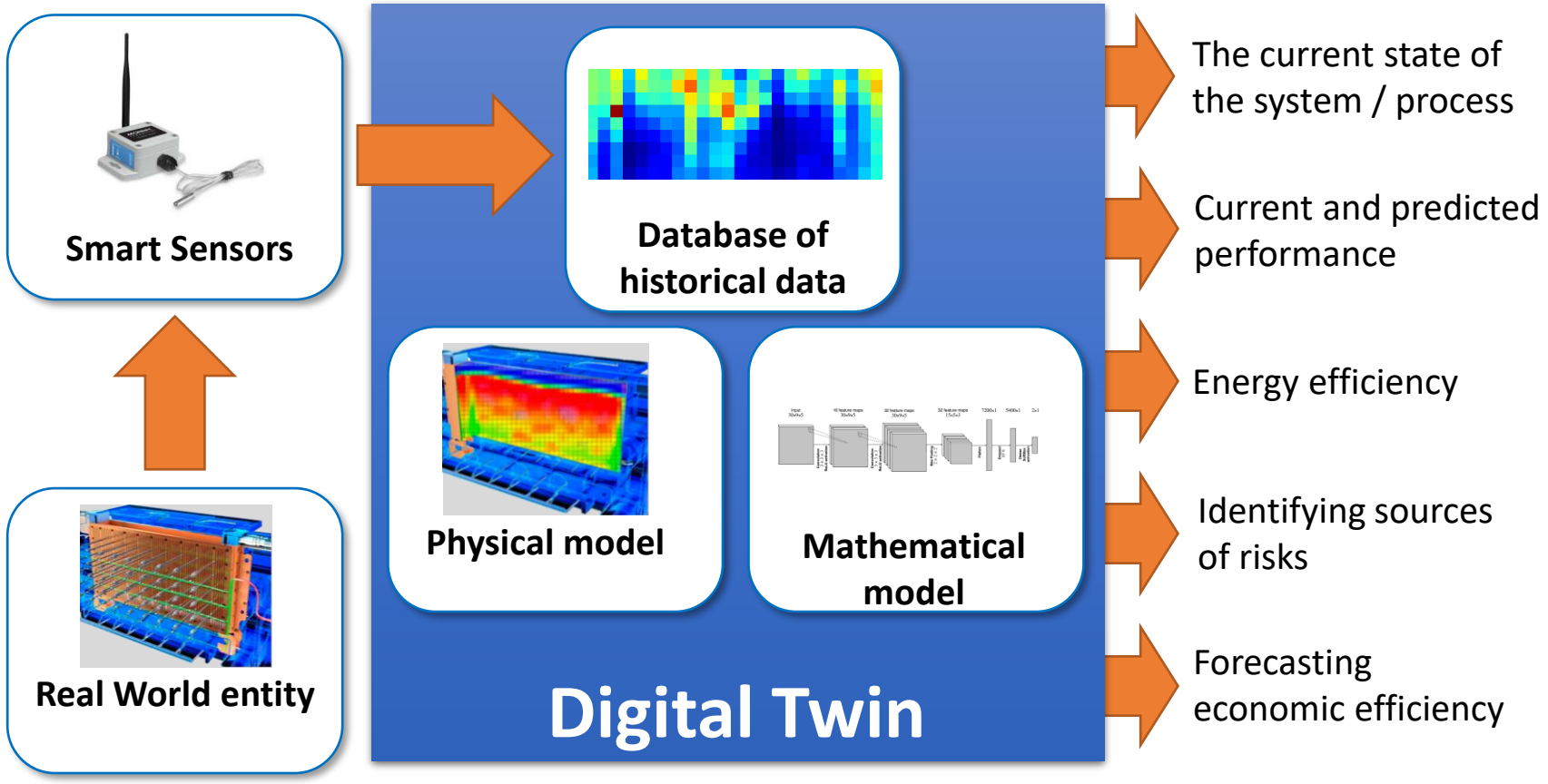
Smart City

- **Smart City** can be defined as a strategic approach to integrating data and digital technologies to ensure sustainability, citizen welfare and economic development of the urban environment
  - It defines a space in which the key components of the urban infrastructure (environment, emergency management, traffic management, and power) are integrated in such a way that their functions and capabilities can easily be combined with each other as well as with new systems
- **“IQ of cities”** (Russian Ministry of Construction Industry) index aimed to digitalization of urban economy, calculated in 10 areas (urban management, intelligent housing and utilities, smart urban transport, etc.).
- One of the important indicators of “IQ of cities” is the presence of a **Digital Twin** of the city

The Digital Twin

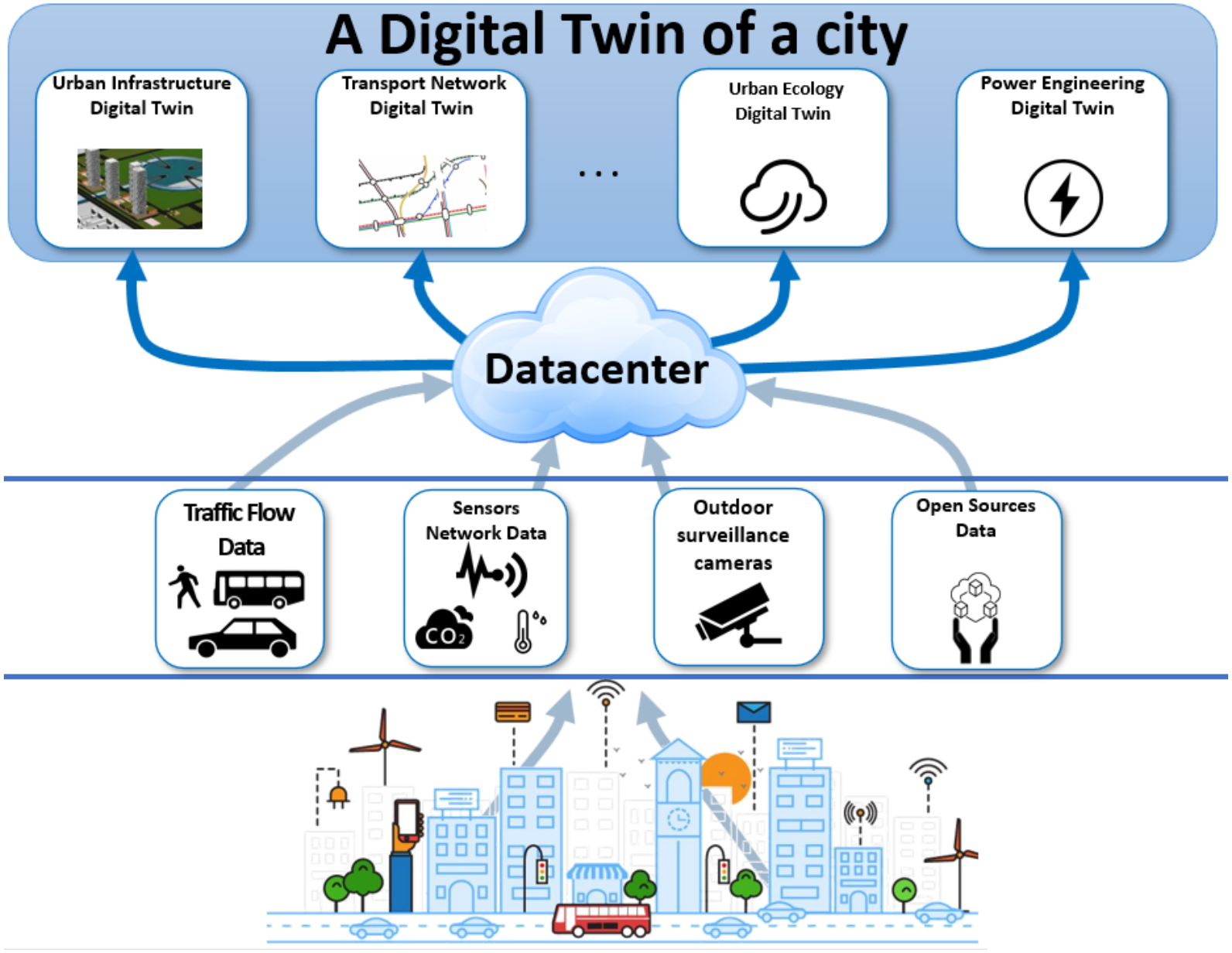
- **The Digital Twin** is a hierarchical system of integrated multiphysical, multiscale probabilistic simulations of a complex object that uses the most appropriate models, actual sensor data, etc. to obtain the most accurate representation of the corresponding real object
  - **Real-time reflection.** A DT reflects a physical object (equipment, process and system) that keeps ultra-high synchronization and fidelity with the real world.
  - **Hierarchy.** A DT of a process or an object can contain DTs of the process stages or components, which, in turn, contain DTs of the equipment enforcing these stages.
  - **Self-evolution.** Since a DT provides a reflection of the object or process, it should perform undergoing continuous model improvement by comparing the simulation process with a physical object and process
- For the DT to be able to provide synchronization between the state of the process in the real world and its virtual copy, we must ensure that it can receive, transmit and analyze the data stream from the intelligent end devices of the Internet of Things (IoT) **in accordance with the latency requirements of the analytical models that make up the DT**

The Digital Twin Concept



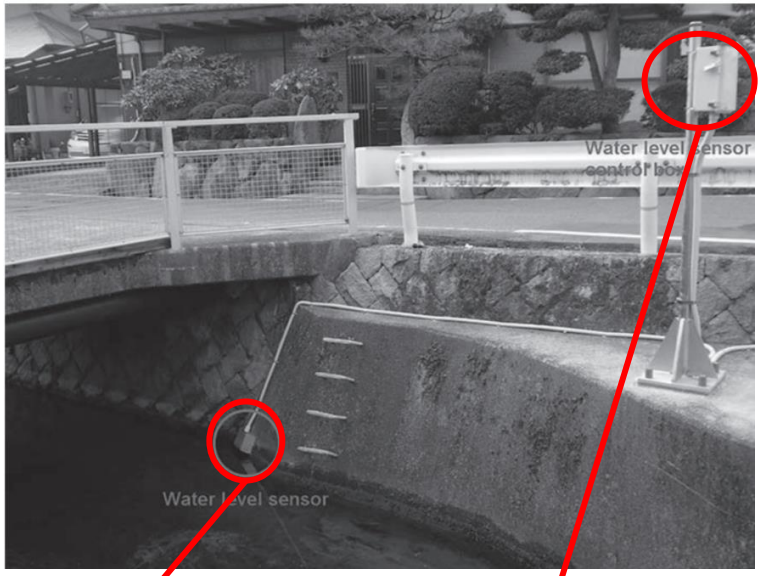
Digital Twin of a City

- The **digital twin of a city** is a system of interconnected digital twins, representing certain aspects of the functioning and development of the urban environment, including:
  - A digital twin of urban infrastructure
  - A digital twin of the transport network
  - A digital twin of urban ecology
  - A digital twin of power engineering
  - …
- These digital twins support fine-tuning and synchronization with the real state of urban infrastructure through data from various sources in real-time

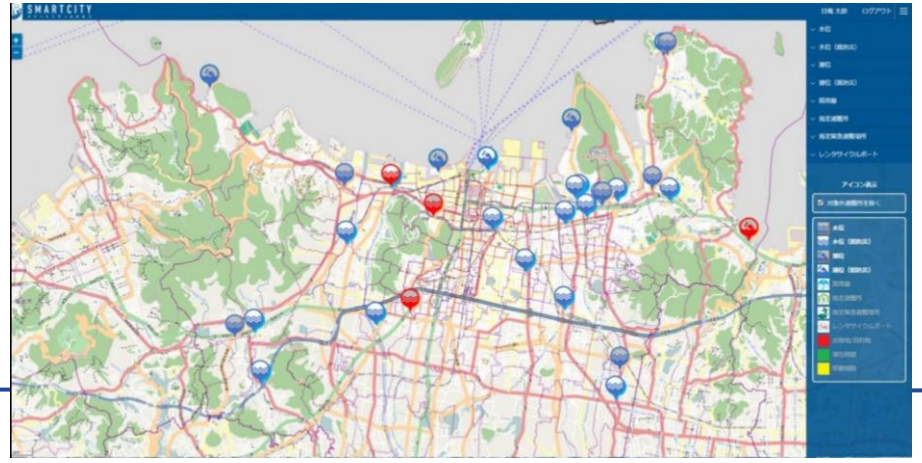

A Digital Twin of a city
Urban Infrastructure Digital Twin
Transport Network Digital Twin
...
Urban Ecology Digital Twin
Power Engineering Digital Twin
Datacenter
Traffic Flow Data
Sensors Network Data
Outdoor surveillance cameras
Open Sources Data

A case of a Digital Twin of a City

- Takamatsu City (Japan) has introduced a Digital Twin that consisted of two parts:
- Disaster management DT
  - Real-time collection of water level information (water level sensors)
  - Monitoring of the condition of shelters available for city residents (humidity sensors, power consumption)
  - Providing information to residents and notification of emergency situations in real time through a mobile application
- Tourism DT
  - Explore the development of new tourism resources
  - Make the city more attractive to foreign tourists by installing multilingual signage, increasing the number of bilingual or multilingual staff, and adopting Universal Design principles.



Water Level Sensor **Control Block**

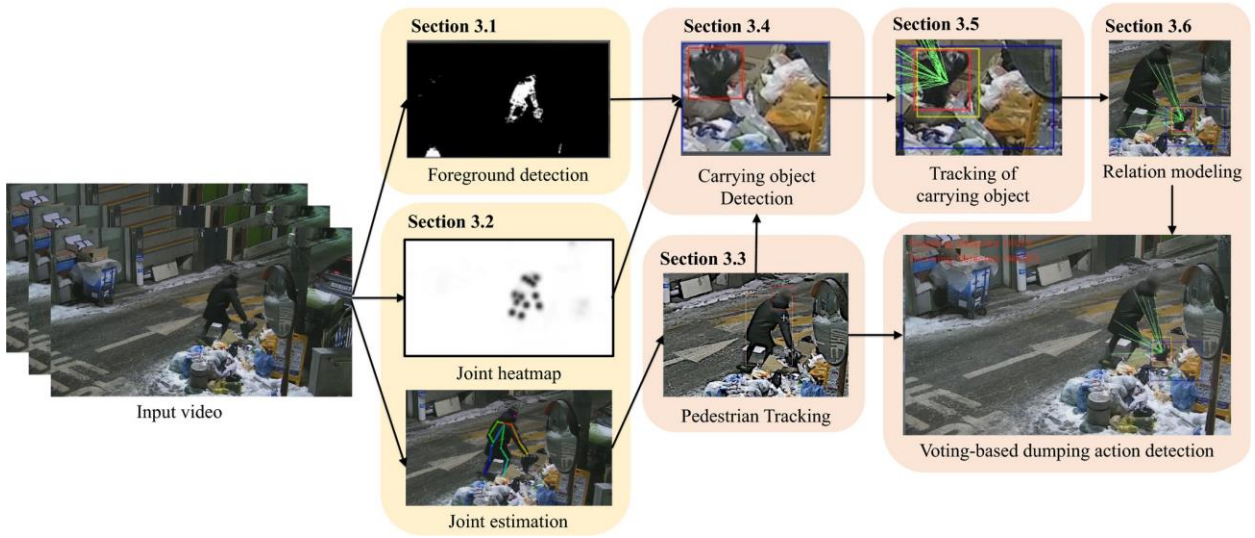


Key Cases of Models for Digital Twins

- **Physical models** - use fundamental knowledge of the physical and chemical features of the processes to simulate. Such models include models, based on the Navier-Stokes equation (simulation of hydro-gasodynamic processes) and models based on the finite element method (simulation of structures made of solid materials).
- **Optimization models** provide search of target function optimums in case of restrictions with the use of mathematical methods. The basic approaches to the optimization modeling are Linear programming; Mixed Integer Programming; Non-linear programming.
- **Data Mining Based Models** are used to discover previously unknown, non-trivial, practically useful, and feasible for interpretation knowledge from the data, which are necessary for making strategic important decisions in various spheres of human activity.
- **Neural Network Models** can detect complex relationships between input and output data, as well as to perform generalization and able to return the correct result based on data that was absent in the training sample, as well as incomplete and/or “noisy”, partially distorted data

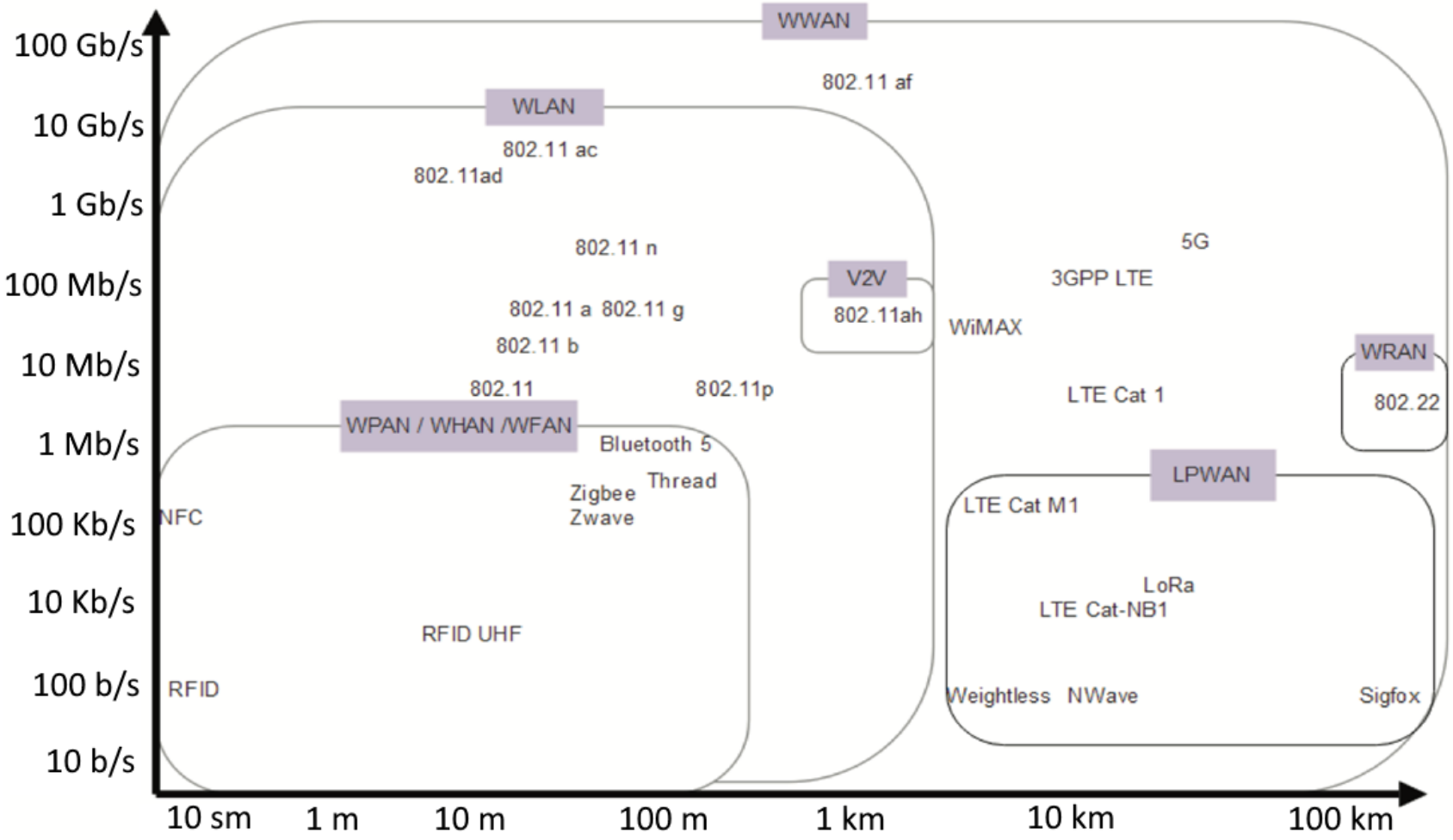
Neural Networks for Machine Vision

Example of neural network operation for car recognition



Example of a neural network operation to detect garbage in the image

Sensor networks to support Data Gathering



Fog Computing

- **Fog Computing** is a layered model for enabling ubiquitous access to a shared continuum of scalable computing resources. The model facilitates the deployment of distributed, **latency-aware applications and services**, and consists of fog nodes (physical or virtual), residing between smart end-devices and centralized (cloud) services.
- The **Fog nodes** are context-aware and support a common data management and communication system.
- **Fog computing** minimizes the request-response time from/to supported applications, and provides, for the end-devices, **local computing resources** and, when needed, network connectivity to centralized services

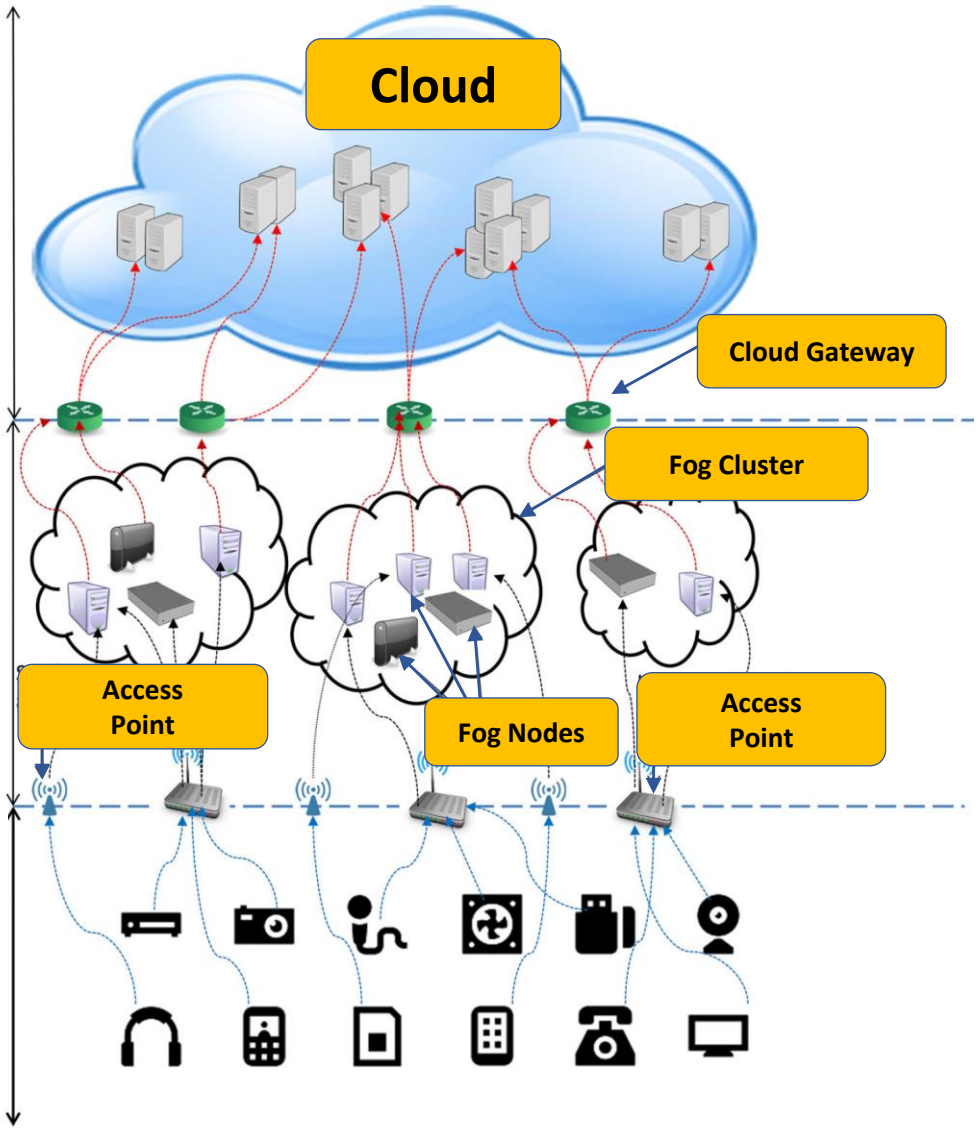
Fog Clusters

Fog Nodes typically organized in clusters.

Fog Cluster is a set of fog nodes interconnected by communication channels, representing a single hardware and software resource from the point of view of the user. Fog Nodes can be combined into clusters based on different principles:

- *vertically* (to support isolation and to provide computing capabilities to specific groups of end devices)
- *horizontally* (to support federation)
- *relative to fog nodes' latency-distance* to the smart end-devices.

Fog Computing



Cloud computing)

- Storage and processing of Big Data
- For analytical data processing and forecasting

Fog computing

- servers near the cameras for data pre-processing
- servers next to clusters of IoT devices and sensors - for data pre-processing

Internet of Things (IoT) and Sensors

- Provide generation of a constant data stream for analysis
- Can support remote control capability

Fog Computing Applications: Intelligent Video Processing

To " fit" the video stream into the communication channel:

- Harder compression
- Low resolution
- FPS Limit

Raw Video Stream

Cloud

As a result, the recognition quality is worse

Intelligent video stream analysis:

- Segmentation and selection of objects
- Background Removal
- Intelligent Compression

- Reducing the volume of data transmitted over trunk communication channels
- Higher quality recognition of tagged data

Stream of Raw Video-Data

Stream of Raw Video-Data

Fog

Pre-processed data

Pre-processed data

Cloud

Conclusion

- We analyzed the existing technologies for the construction of digital twins of cities.
- The definition and key components that make up the city digital twin have been considered.
- We have considered the key methods for simulation of real objects and processes, which find their application in the implementation of digital twins.
- Separately, based on practical examples, we considered models based on intelligent data analysis, and neural network models.
- We also described the key elements of the information infrastructure of the digital twin of a city and considered the key elements of that infrastructure, such as sensor networks.
- It was separately noted that for the successful construction of such a system it is necessary to form an information environment based on the concept of the Fog Computing Model, since the tasks of pre-processing data flows often require substantial computational resources for pre-processing data located close to the sources.

Thank you!

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