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# Beyond Identification: HF RFID and NFC for Digital Twins

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# Presenters

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  - Norfolk State University & University of Nebraska Lincoln
  - Research: Metaverse, Digital Twin, Internet of Everything

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  - IIT Kanpur, Kanpur, India
  - Research: wireless sensor networks, reconfigurable optical networks, smart health-care, cyber-physical systems

# Related publications


- I. F. Akyildiz and H. Guo, “Wireless communication research challenges for Extended Reality (XR),” ITU Journal on Future and Evolving Technologies, vol. 3, no. 2, pp. 273–287, 2022.
- I. F. Akyildiz and H. Guo, “Holographic-type Communication: A New Challenge for The Next Decade,” ITU Journal on Future and Evolving Technologies, vol. 3, no. 2, pp. 421–442, 2022.
- H. Guo and A. A. Ofori, “The internet of things in extreme environments using low-power long-range near field communication,” IEEE Internet of Things Magazine, vol. 4, no. 1, pp. 34–38, 2021.
- A. Pal, F. Campagnaro, K. Ashraf, M. R. Rahman, A. Ashok, and H. Guo, “Communication for Underwater Sensor Networks: A Comprehensive Summary,” ACM Transactions on Sensor Networks, Aug, 2022.
- A. Pal, H. Guo, S. Yang, M. Akkas, and X. Zhang, “Taking Wireless Underground: A Comprehensive Summary,” ACM Transactions on Sensor Networks (under minor revision), 2022.
- A. Pal, and K. Krishna. "NFMI: Near field magnetic induction based communication." Computer Networks 181 (2020): 107548.
- A. Pal, and K. Krishna. "MagLoc: A magnetic induction based localization scheme for fresh food logistics." Internet of Things 19 (2022): 100552.

# Related publications


- Wang, Fei-Yue, et al. "Digital twin and parallel intelligence based on location and transportation: a vision for new synergy between the ieee cRFID and ITSS in cyberphysical social systems [society news]." IEEE Intelligent Transportation Systems Magazine 13.1 (2021): 249-252.
- Zhao, Renjie, et al. "NFC+ breaking NFC networking limits through resonance engineering." Proceedings of the Annual conference of the ACM Special Interest Group on Data Communication on the applications, technologies, architectures, and protocols for computer communication. 2020.
- Wang, Jingxian, et al. "Locating everyday objects using NFC textiles." Proceedings of the 20th International Conference on Information Processing in Sensor Networks (co-located with CPS-IoT Week 2021). 2021.
- Xu, Lin, et al. "HF RFID-based book localization via mobile scanning." 2020 17th Annual IEEE International Conference on Sensing, Communication, and Networking (SECON). IEEE, 2020.
- Minerva, Roberto, Gyu Myoung Lee, and Noel Crespi. "Digital twin in the IoT context: a survey on technical features, scenarios, and architectural models." Proceedings of the IEEE108.10 (2020): 1785-1824.

# Outline

- **Background**: digital world

- **Digital Twins**
  - Enabling technologies
  - System architecture
  - Applications

- **Wireless sensing using HF RFID and NFC**
  - Motivation and requirements for digital twins
  - Communication and networking protocols
  - Research challenges and solutions

- **Future research directions**

# The generations of wireless technologies

- **1G (1980):** Voice calling
- **2G (1990):** SMS (Short Message Service)
- **3G (2000):** Internet
- **4G (2010):** Internet of mobile applications
- **5G (2020):** Massive broadband and Internet of Things
- **6G (2030):** Towards a fully **digital** and **connected** world

# Digital contents

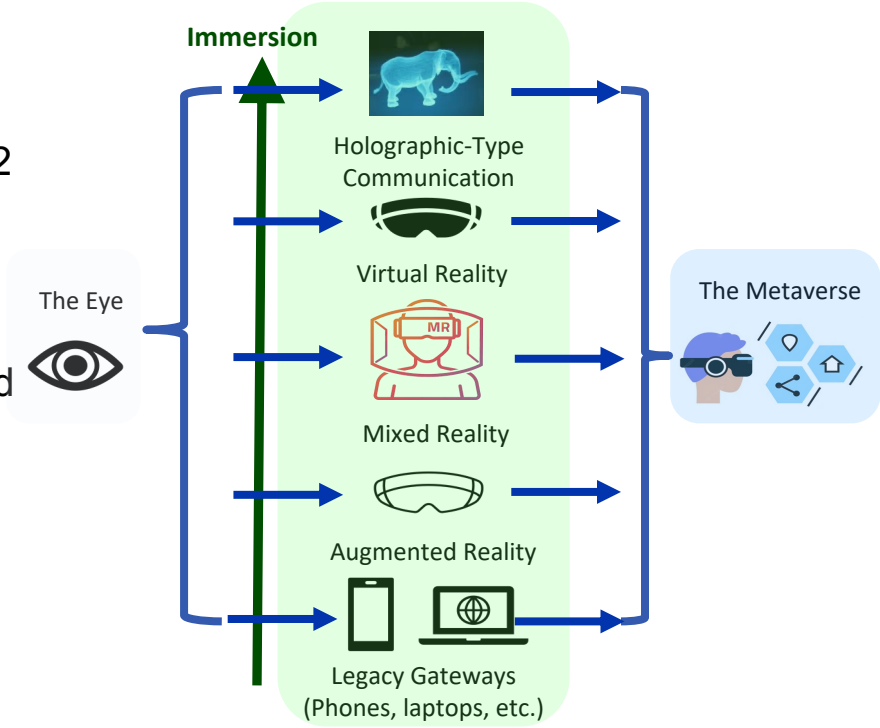
- Digital contents
  - Also called virtual contents
  - Digital twins: model, simulate, and guide
  - A network of digital twins?


Image: mouser electronics

Image: 12d Synergy

# Metaverse

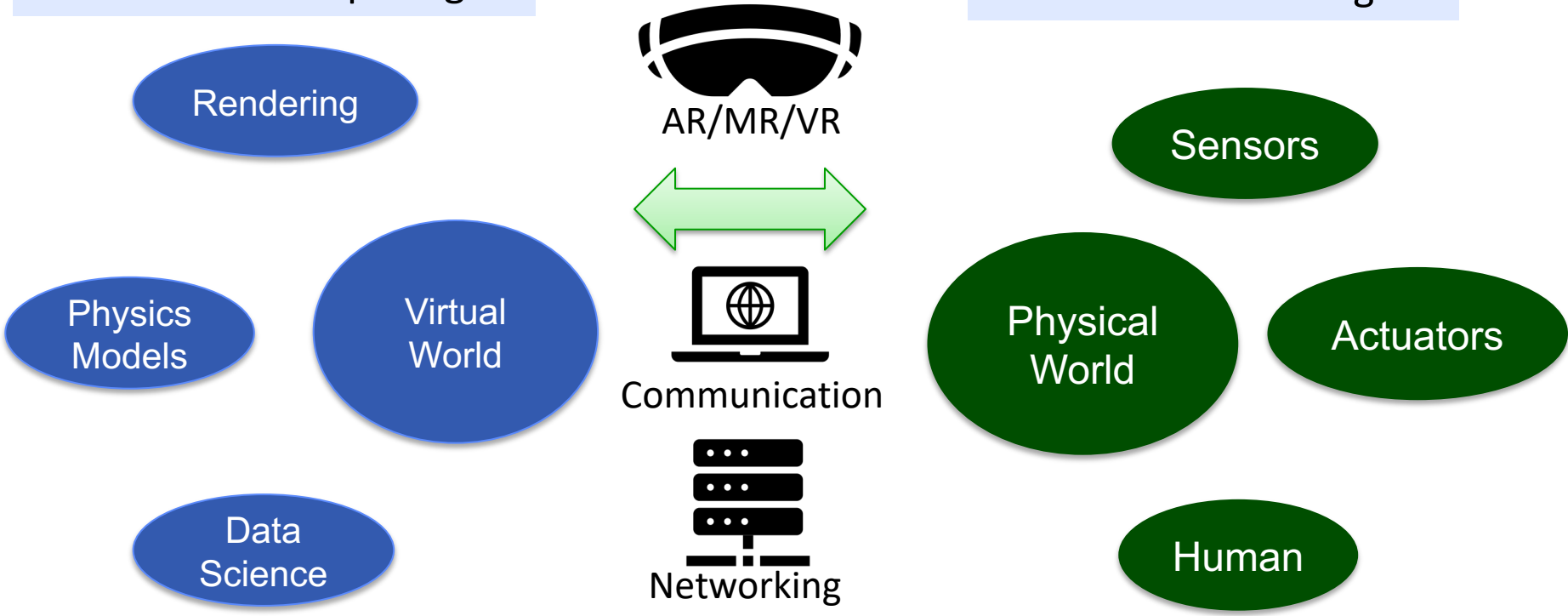
- "Metaverse" (meta= beyond, and verse=universe) originated in the science fiction novel “Snow Crash” by Neal Stephenson in 1992
- Metaverse is a network connecting physical and virtual worlds seamlessly
- No separation between digital and physical world
- Realized thanks to the convergence of key emerging technologies such as
  - eXtended Reality (XR)  (VR, AR, MR)
  - Holographic-Type Communication (HTC)
  - Digital Twin



# Virtual & physical worlds

Pervasive computing

Pervasive sensing



# Metaverse and wireless systems

## Metaverse


Education


Manufacturing

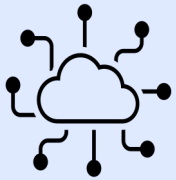

Healthcare


Shopping


Farming


Sports

## Network



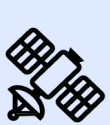
- New services and capabilities
- New architecture and frameworks

Sensory Data

Feedback & Control

## 5G & Beyond Wireless Systems

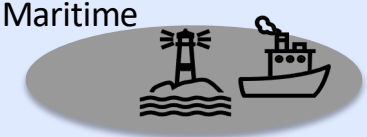
Space




Air


Terrestrial


Maritime



Indoor

- High-volume tiny-instant communication
- Space-air-ground integrated wireless systems

# Outline

- Background: Digital world
- **Digital Twins**
  - **Enabling technologies**
  - **System architecture**
  - **Applications**
- Wireless sensing using HF RFID and NFC
  - Motivation and requirements for digital twins
  - Communication and networking protocols
  - Research challenges and solutions
- Future research directions

# Definition of digital twin

- "A Digital Twin is a set of **virtual information constructs** that mimics the **structure, context, and behavior** of an individual/unique **physical asset**, is **dynamically updated** with data from its physical twin throughout **its lifecycle**, and **informs decisions** that realize value"

  - AIAA Institute Position Paper, 2020

# History of Digital Twins

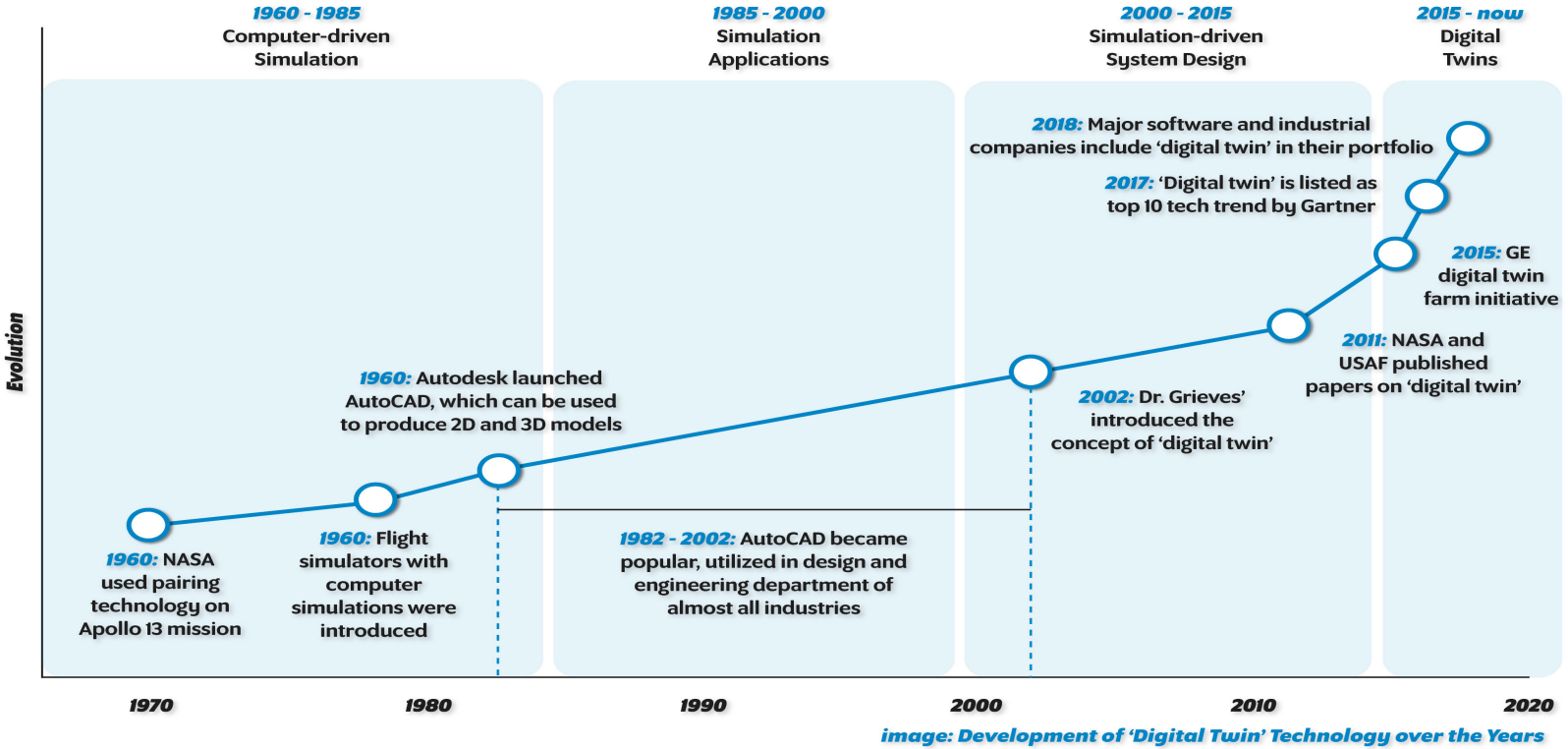



image: Development of 'Digital Twin' Technology over the Years

Simulations & Virtual Reality, Digital Twins and Augmented Reality Supporting Automation and Production Solutions
https://www.aaebv.com/news/simulations-virtual-reality-digital-twins-and-augmented-reality-supporting-automation-and-production-solutions-pt-2/

# Difference between Digital Twins and Simulation Models

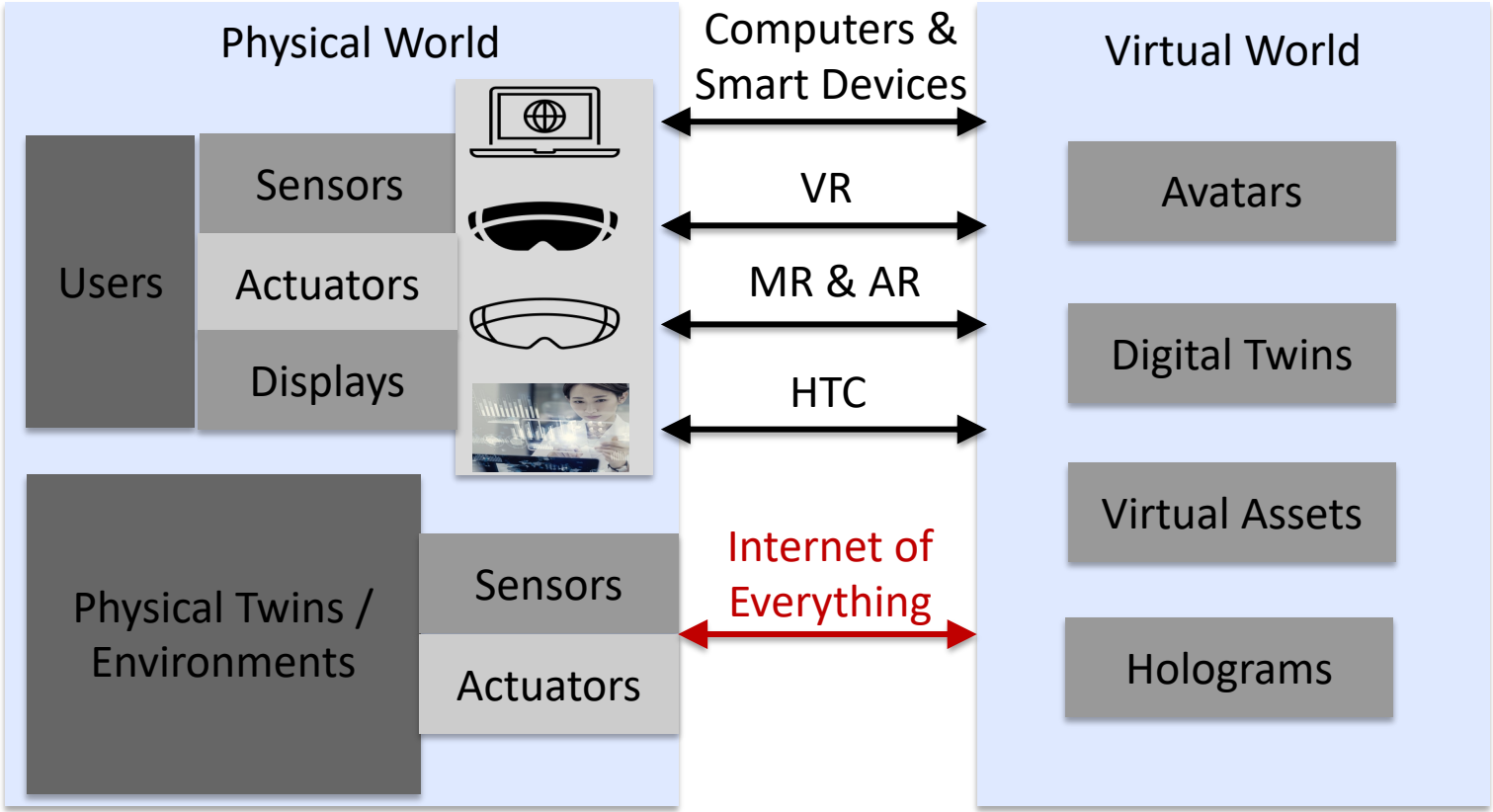
- Digital twin (It is alive!)
  - Real time update
  - Lifelong monitoring and computing
  - Strong interactions with the physical environment in real time
  - Can be displayed in 3D

- Computer simulation models
  - Data-driven/model-based; without using real time collected data
  - Simulate a certain time period
  - Not always display 3D models

# Enablers

- Extended Reality & Holographic-Type Communication
  - The technology that is used to **observe** digital twins
- Edge/Cloud computing
  - The technology that is used to **develop** digital twin models
- Internet of Everything
  - The technology that is used to **connect** digital twins and physical objects

# Metaverse and Internet of Things

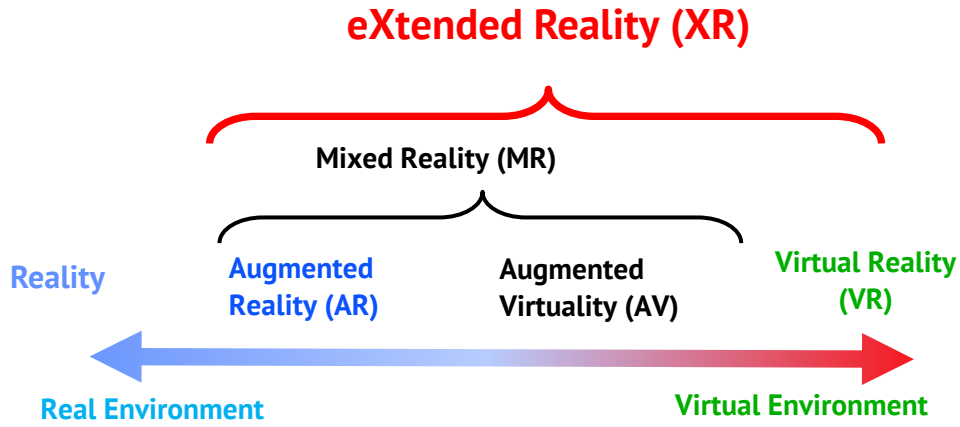


# eXtended Reality (XR) & Holographic-Type Communication (HTC)

# XR: eXtended Reality (AR, MR and VR)

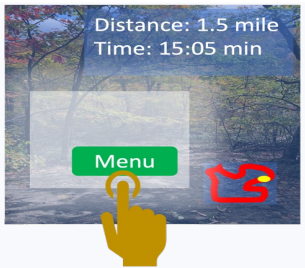
- **Reality:**
  - Human perception of real objects is based on five basic senses: Sight, Hearing, Touch, Smell, and Taste
- **Virtual Reality (VR):**
  - Creating digital virtual objects to represent the same real senses and environments (Fully virtual)
- **Augmented Reality (AR)**
  - Real environment is augmented with virtual objects and information
- **Mixed Reality (MR)**
  - A mixture of real and virtual environments
  - Low % of virtual contents → AR

P. Milgram and F. Kishino, "A Taxonomy of Mixed Reality Visual Displays" IEICE TRANSACTIONS on Information and Systems, 1994.



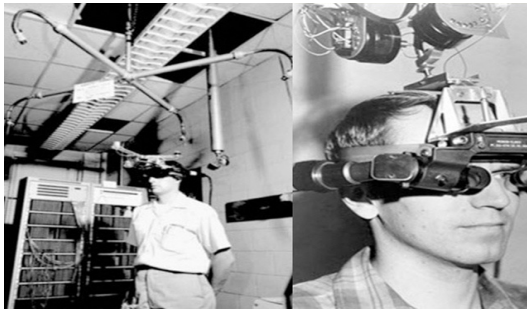

Reality-Virtuality Continuum

# Devices & use cases

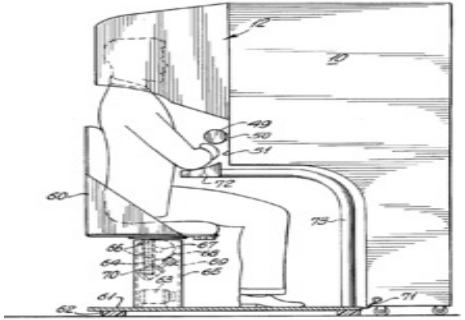
| | | Extended Reality (XR) | | |
|---|---|---|---|---|
| | Reality | Augmented Reality (AR) | Mixed Reality (MR) | Virtual Reality (VR) |
| Display | Naked Eye/Optical Glasses | Translucent Display | Translucent Display | Occlusion Display |
| Display Example |  |  |  |  |
| Example |  Real View of a Trail |  Augmented Virtual Map and Direction |  Interactive Virtual Contents |  Virtual Gaming |

# Then & Now

## Sword of Damocles AR (1968)



## Sensorama VR (1962)



# Existing devices

| | Vendor | Model | Weight (g) | Display (per eye) | Refresh rate (Hz) | Human understanding | Storage (GB) | Memory (GB) | Connectivity | Power (Hour) |
|---|---|---|---|---|---|---|---|---|---|---|
| AR | Epson | Moverio BT300 | 69 | 1280×720 | 30 | controller | 16 | 2 | Wi-Fi, Bluetooth, cable | ~6 |
| | VUZIX | M4000 | ~246 | 854×480 | – | touchpad, voice,buttons | 64 | 6 | Wi-Fi, Bluetooth, cable | 2 to 12 |
| MR | Microsoft | HoloLens2 | 566 | 2K | 120 | head/eye/hand tracking | 64 | 4 | Wi-Fi , Bluetooth | 2 to 3 |
| VR | Oculus | Quest 2 | 503 | 1832×1920 | 72 | controller | 256 | 6 | Air Link (wireless) | 2 to 3 |
| | HTC | Vive Cosmos Elite | – | 1440×1700 | 90 | controller | – | – | cable, wireless adapter (60GHz) | 2.5 (wire-less) |
| | Huawei | VR Glass | 166 | 1600×1600 | 90 | controller | – | – | cable | – |
| | HP | Reverb G2 | 550 | 2160×2160 | 90 | controller | – | – | Bluetooth, cable | – |







oculus

Microsoft

EPSON
EXCEED YOUR VISION

HUAWEI

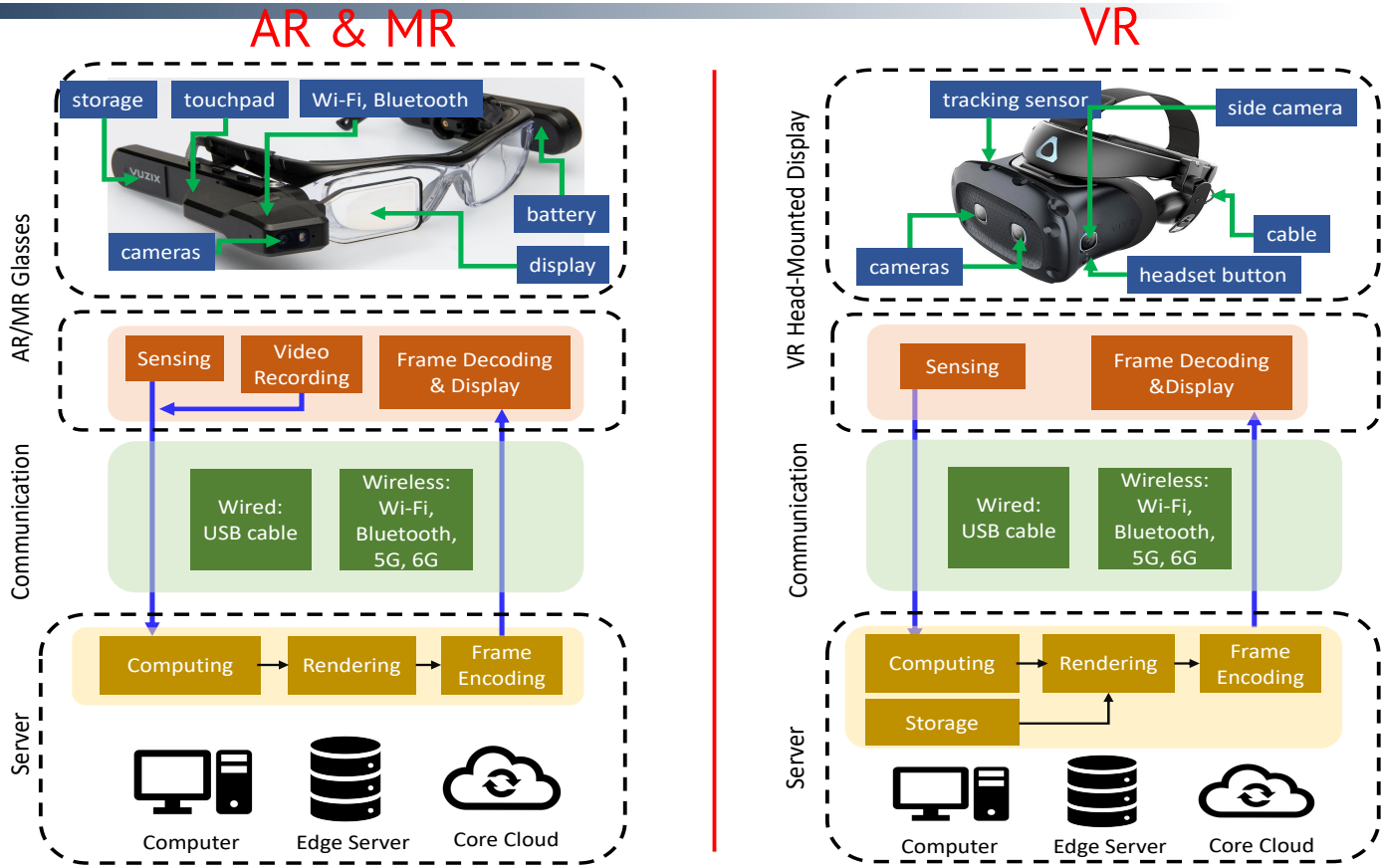
htc

# XR devices: Now and Future

- Tethered heavy headsets
- Low-quality content
- Inconvenient mobility support
- XR sickness for prolonged use

- Untethered wireless headsets
- Lightweight headsets
- High-quality contents
- Mobility support

# Communication architecture



# Use cases

- Manufacturing
- Remote Assistance
- Education
- Healthcare

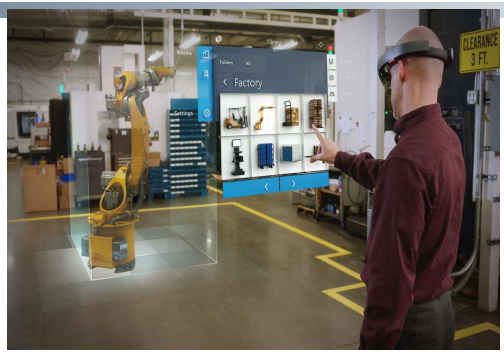
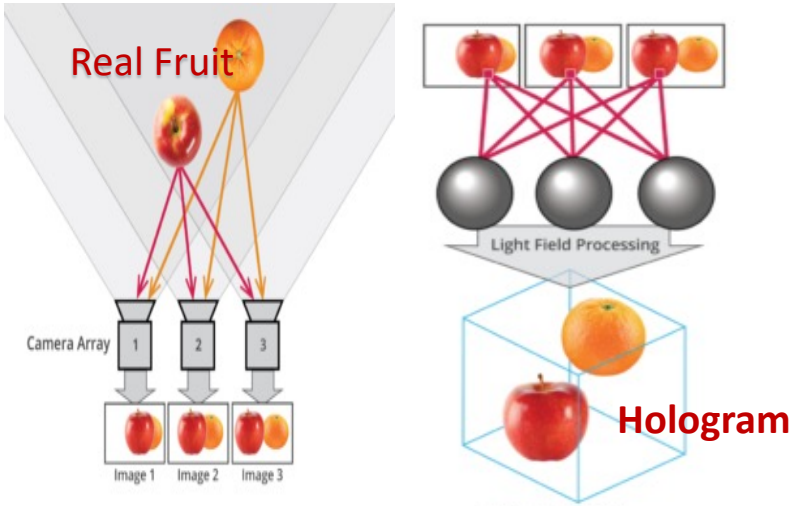




Image: microsoft

# Hologram

- Can we observe **3D virtual digital twins** without using Head-Mounted Displays?
  - **Holographic displays**
- A **hologram** is a photographic recording of light field
  - Consists of a set of virtual 3D images that reflect real physical objects, preserving the depth, parallax, and other properties of the original item
- Holography is a photographic technique that **records the light** scattered from an object, and then presents it in a way that appears 3D




**Source:** lightfield-forum.com/what-is-the-lightfield/

# Hologram creation

A. Clemm, M. T. Vega, H. K. Ravuri, T. Wauters, and F. D. Turck "Toward truly immersive holographic-type communication: Challenges and solutions," IEEE Commun. Mag., vol. 58, no. 1, pp. 93–99, Jan. 2020
X. Zhang, et. al. "Surface Light Field Compression using a Point Cloud Codec," IEEE Journal on Emerging and Selected Topics in Circuits and Systems 9.1, 163-176, 2018.

- Design-based
  - Computer Aided Design for products
- Image-based computer generated
  - Use an array of images from different view angles
  - Large-volume of data (>Tbps)

Light Field Cameras
Source: Road to VR

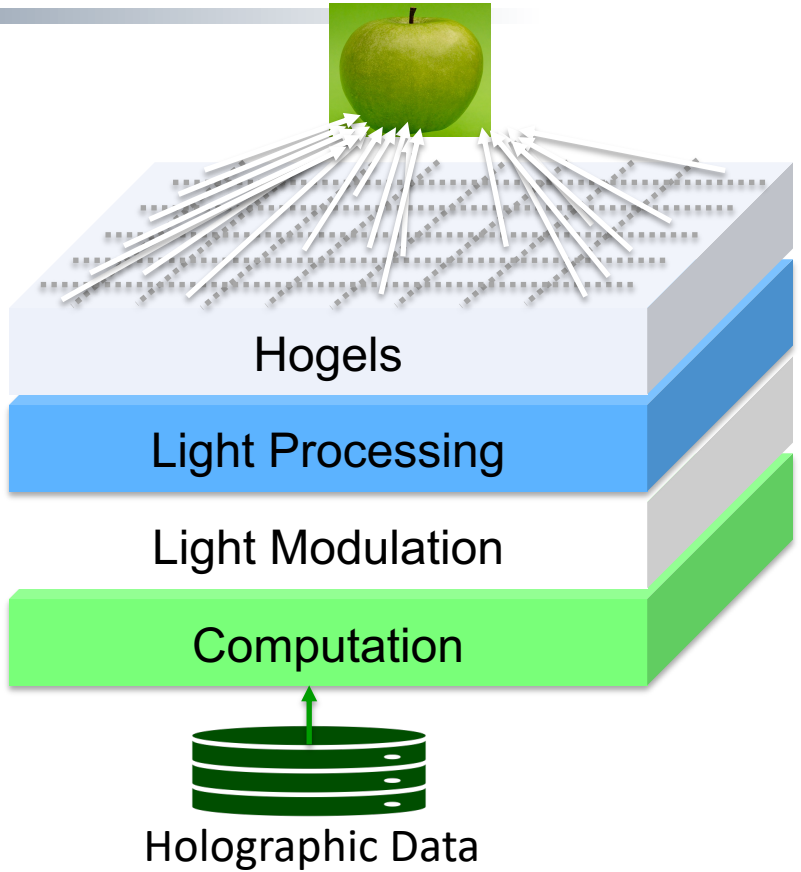
Multiview Images

Point Cloud Compression: Bandwidth Requirement > 500 Mbps

Direct Transmit: Bandwidth Requirement > 1Tbps

# Light field display

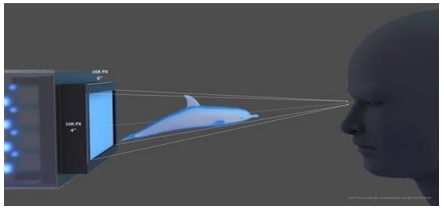
- Human perception of physical objects is based on light field
- **Light field display** regenerate the recorded light field to create 3D objects
- **Hogels** are light emitters that can generate light with different direction and intensity



# Holographic display

Naked Eyes

Light Field Display
> 1000 Views



Source:
fxguide.com

Volumetric Display
> 20 Views

Source: TechEBlog

Extended Reality
Head-Mounted Displays
> 2 Views

2D Display (Cannot
display hologram)
1 View

# Holographic display example

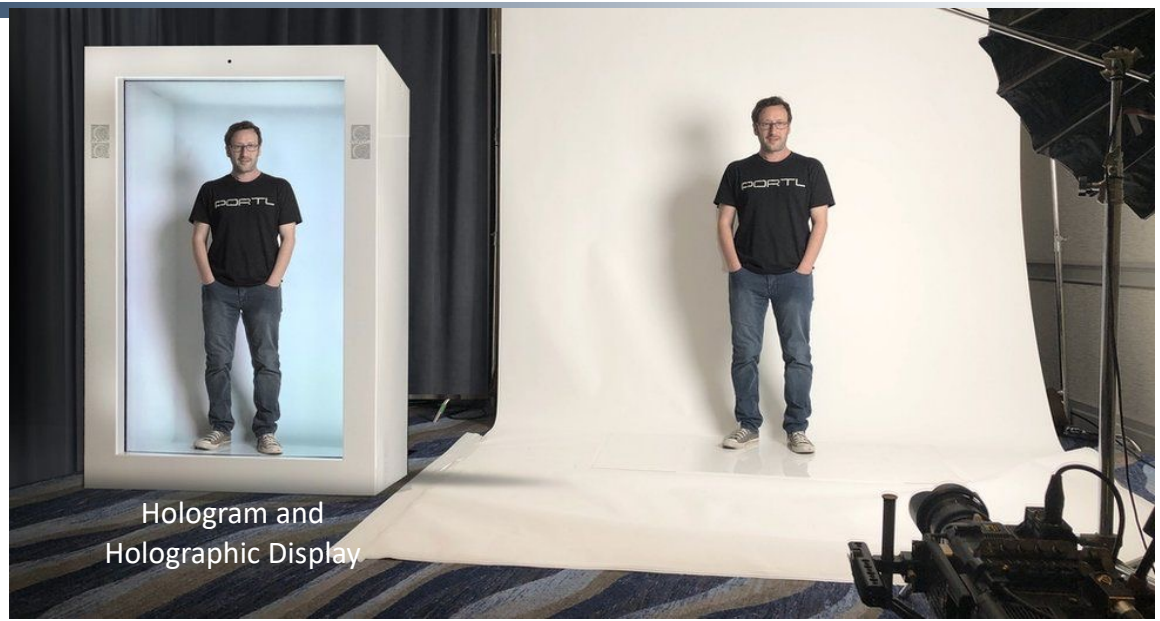
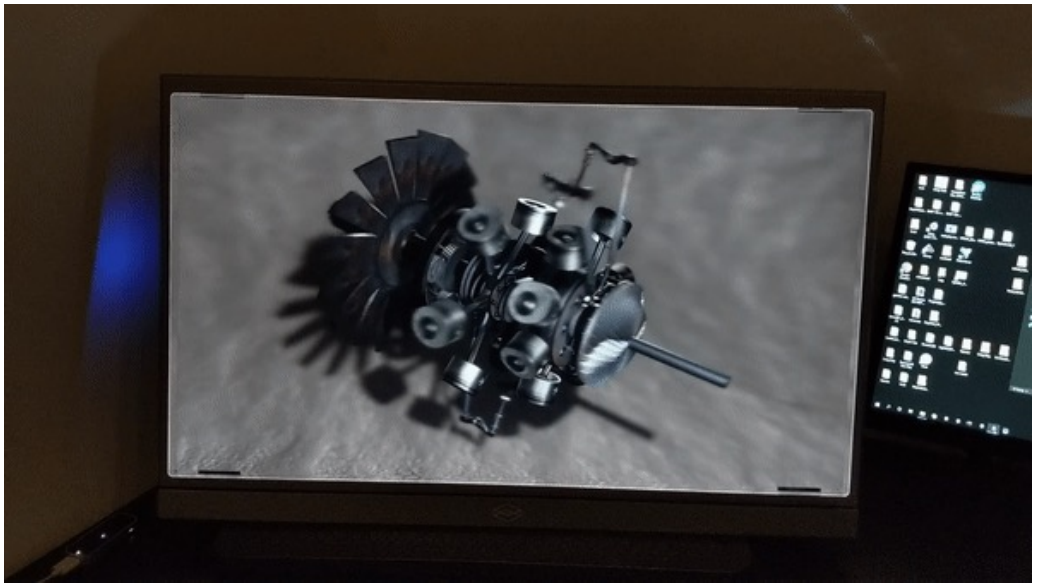



Image: BBC

- David Nussbaum (the founder of US holograms firm Proto) on the right-hand side and the hologram on the left-hand side.
- The holographic system is Proto.

# Holographic Digital Twins

- Observe digital twins without any headsets
- Displayed by holographic displays, e.g., light field displays



Holographic Digital Twins, Stephen Holts
https://blog.lookingglassfactory.com/learn/digital-twins-in-the-age-of-the-hologram/

# Relation between XR and HTC

Extended Reality (XR)

Holographic-Type Communication (HTC)

## XR: Head-Mounted Displays

- Use XR HMDs to see virtual contents
- 360-degree videos (not holograms)
- Augmented virtual information/pictures

## Holographic-type Communication: Head-Mounted Displays

- Use XR HMDs to see holograms
- Limited number of views → low quality holograms
- The weight of HMD is much larger than that of optical glasses

## Holographic-type Communication: Light Field Display

- Can be observed with naked eyes → do not require any external wearable devices
- Thousands of views → high-quality holograms

# Enablers

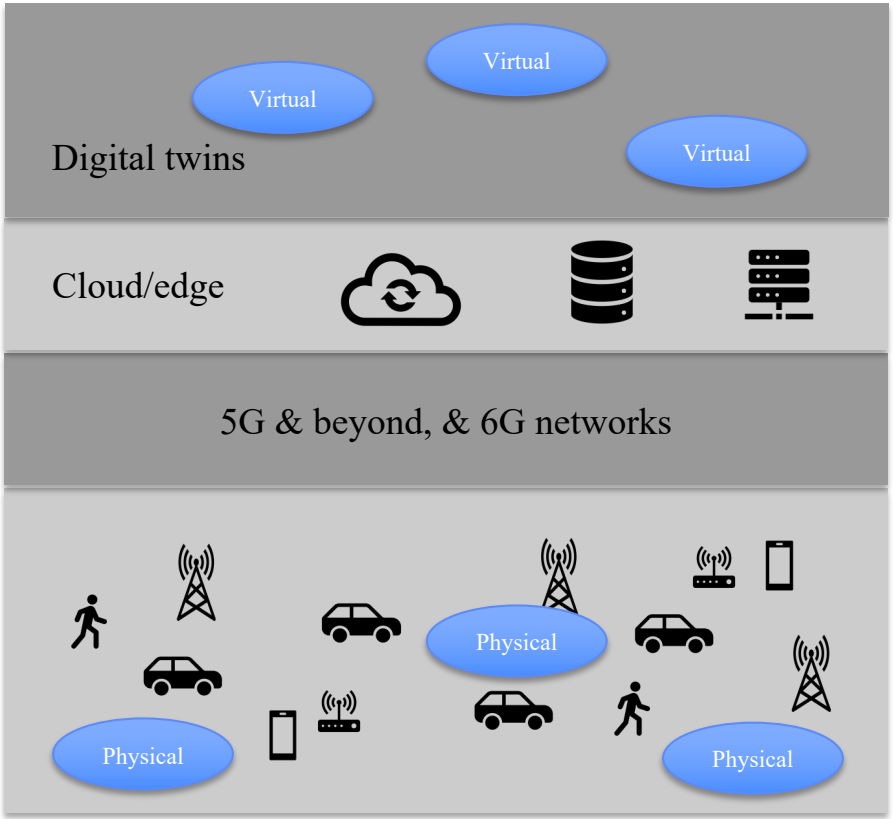
- Extended Reality & Holographic-Type Communication
  - The technology that is used to observe digital twins
- Edge/Cloud computing
  - The technology that is used to develop digital twin models
- Internet of Everything
  - The technology that is used to connect digital twins and physical objects

# Edge/Cloud Computing

# Digital Twin Computing

Wu, Yiwen, Ke Zhang, and Yan Zhang. "Digital twin networks: A survey." IEEE Internet of Things Journal 8.18 (2021): 13789-13804.

- **Data fusion**
  - Dimension reduction
  - Object identification and matching
  - Information expansion
- **Digital twin modeling**
  - General model
  - Specific model
  - Multidimensional model
- **Digital twin rendering**



# Digital twin modeling

- **Standardization** of digital twin modeling
  - Reuse
  - Facilitate design
- **High precision** modeling
  - Gather all available information using sensors
  - Fully replicate the physical dimension, materials, and function of the physical object
- **Continuous updating**
  - Continuously update the digital twin based on status of the physical object
  - Location, usage, etc.

# Cloud and edge computing

- Who and where perform the computation?
  - Computation resources
  - Latency requirements
    - Cloud: long latency
    - Edge: low latency
- Where is the digital twin?
  - Who owns it?
  - Depending on applications

Wu, Yiwen, Ke Zhang, and Yan Zhang. "Digital twin networks: A survey." IEEE Internet of Things Journal 8.18 (2021): 13789-13804.

# Internet of Everything

# Internet of Everything

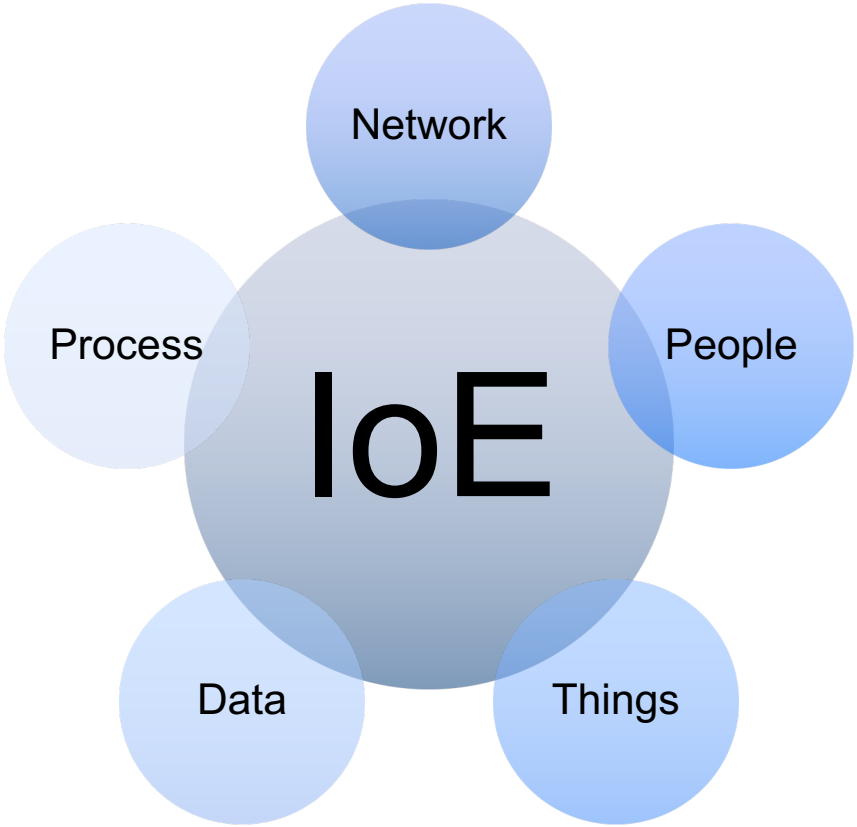
- **Internet of Everything (IoE)** refers to a network of connections between **people, things, data, and processes** that provide general intelligence and improved cognition across the networked environment

- Cisco estimates that 99.4 percent of physical objects that may one day be part of the Internet of Everything are still unconnected

- With IoE, any ordinary object can be equipped with digital features

- IoE is an **interconnected system of objects, devices, appliances, and machines** where all contributing units are **fitted with sensors** that expand networking capabilities

# IoE and IoT


Network
Process
People
IoE
Data
Things


Network
IoT
Physical
Devices

# IoE requirements

- Pervasive sensing
- Convergence of URLLC,  eMBB, and mMTC
  – High reliability, low latency, high data rates, and ubiquitous connectivity
- Distributed architecture
  – Large-scale networks
- Edge and cloud computing

# Outline

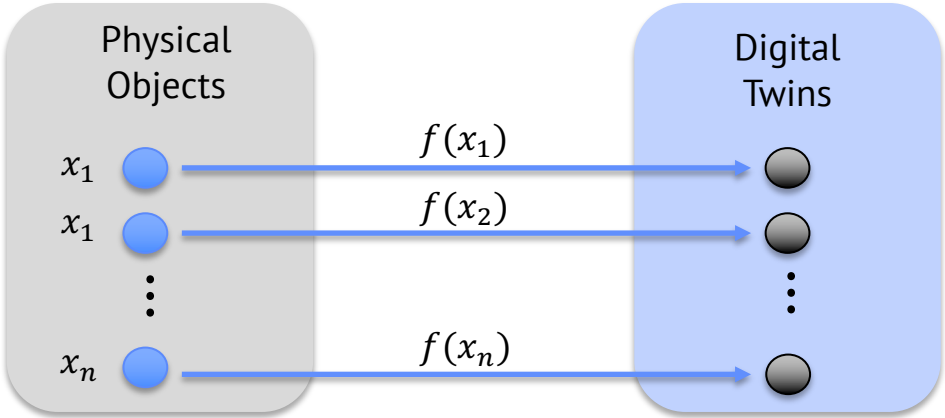
- Background: Digital world
- Digital Twins
  - Enabling technologies
  - Properties and system architecture
  - Applications
- Wireless sensing using HF RFID and NFC
  - Motivation and requirements for digital twin
  - Communication and networking protocols
  - Research challenges and solutions
- Future research directions

# Basic properties of Digital Twin: reflection

- 12 basic properties listed in

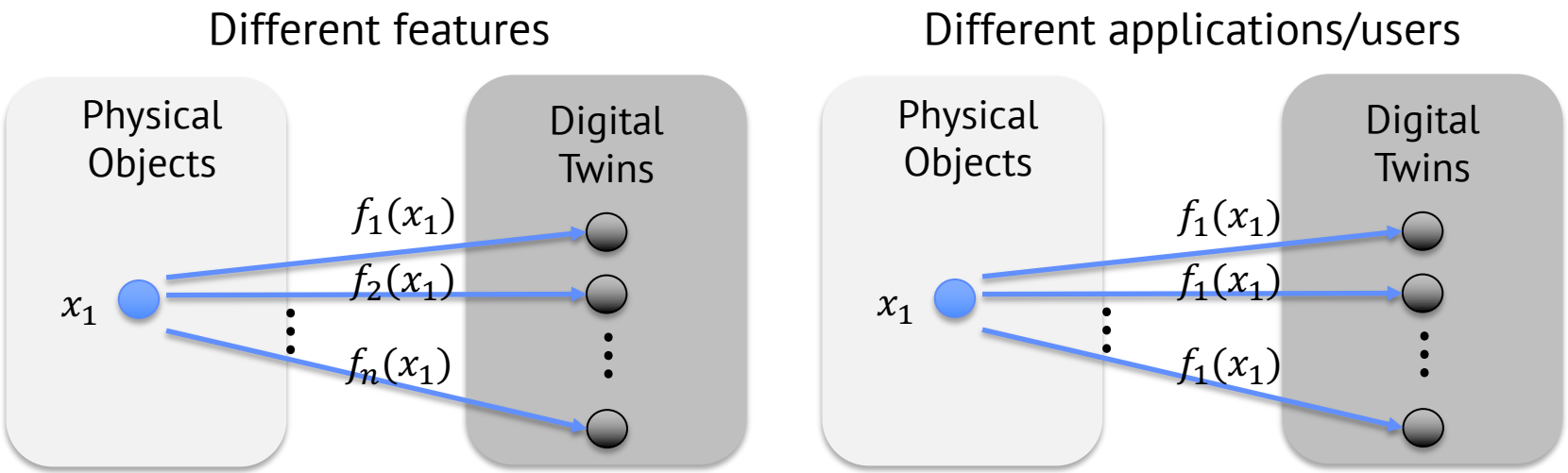
Minerva, Roberto, Gyu Myoung Lee, and Noel Crespi. "Digital twin in the IoT context: a survey on technical features, scenarios, and architectural models." Proceedings of the IEEE108.10 (2020): 1785-1824.

- The virtual **digital twin** can fully reflect the physical attributes, features, status, and other information that can characterize the physical object
- A function $f(x)$ can be used to describe such a mapping/reflection



# Basic properties of Digital Twin: replication

- The virtual digital twin can **replicate** physical objects in different ways depending on applications and requirements
- A physical device can be **shared** by multiple users/applications



# Basic properties of Digital Twin: entanglement

- **Connectivity**
  - A link to communicate the changes of status and related data between the physical objects and digital twins
- **Promptness**
  - The status update should have low latency to timely reflect the change of the physical objects
  - Medical, robots, machines, etc.
- **Association**
  - The association between the physical object and the digital twin can be unidirectional or bidirectional

# Other properties of Digital Twin (1)

- **Persistency**
  - Digital twin should be persistent over time
  - Constant availability
- **Memorization**
  - Store and represent the current and the past status of the digital twin
  - What is the relevant data? How to store?
- **Composability**
  - Group several objects into a composed one
  - Observe and control the behavior of the composed object as well as the individual component
- **Accountability/manageability**
  - Physical objects may fail or break
  - Digital twins should enter a recovery state where they can respond to queries and restore a previous functional state

# Other properties of Digital Twin (2)

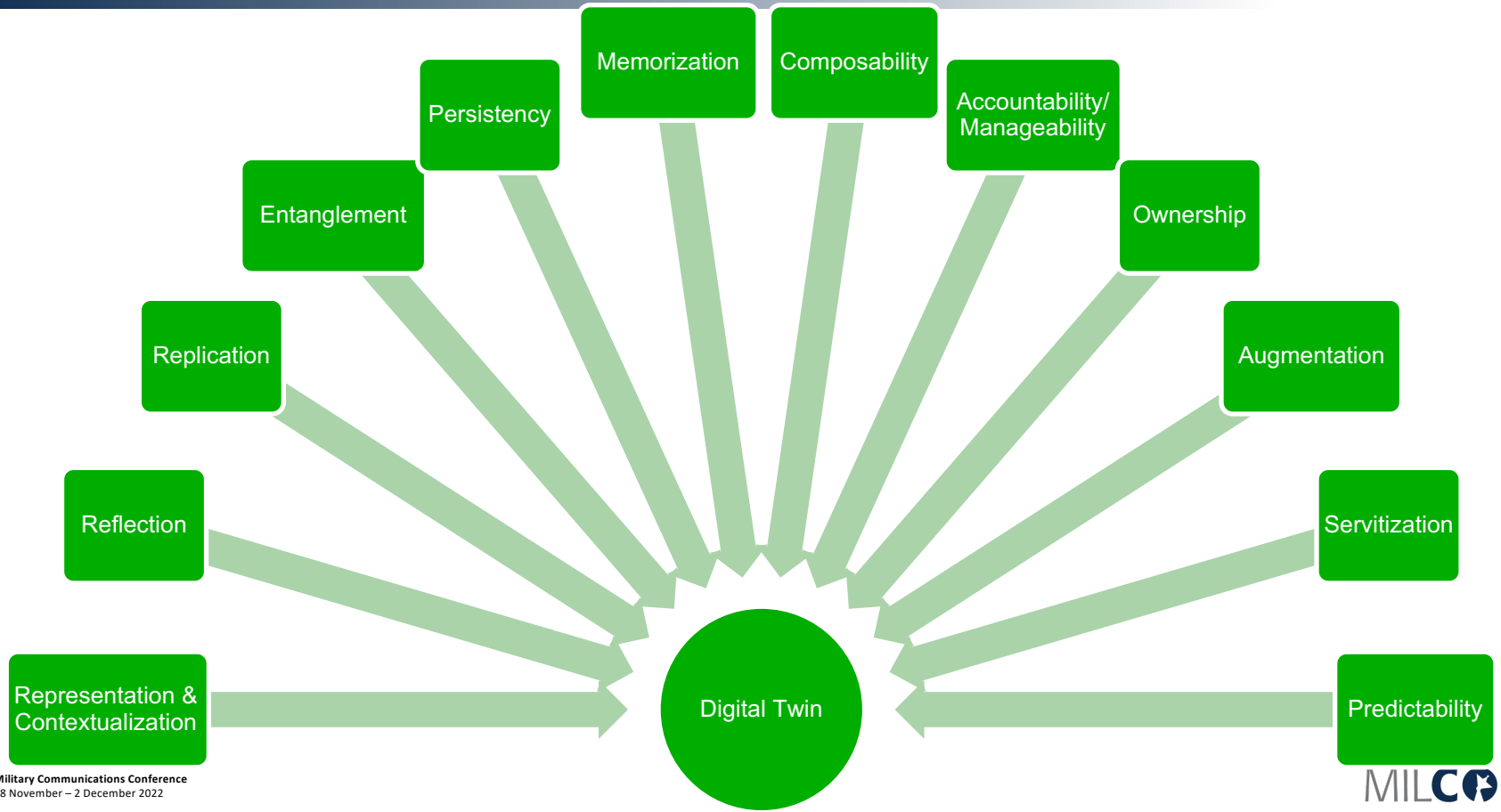
- **Representativeness and contextualization**
  - How much and how well the digital twin can/need to represent the physical object?
  - Features and data are needed to represent the physical object in a specific virtual space
- **Augmentation**
  - Physical objects cannot evolve or upgrade
  - Digital twins can use software dematerialization to modify, update, and improve its functions over time
- **Ownership**
  - Data ownership
  - Digital twin ownership
  - The physical object and digital twin may not share the same ownership
  - E.g., manufacturing, change ownership from manufacture to customer

# Other properties of Digital Twin (3)

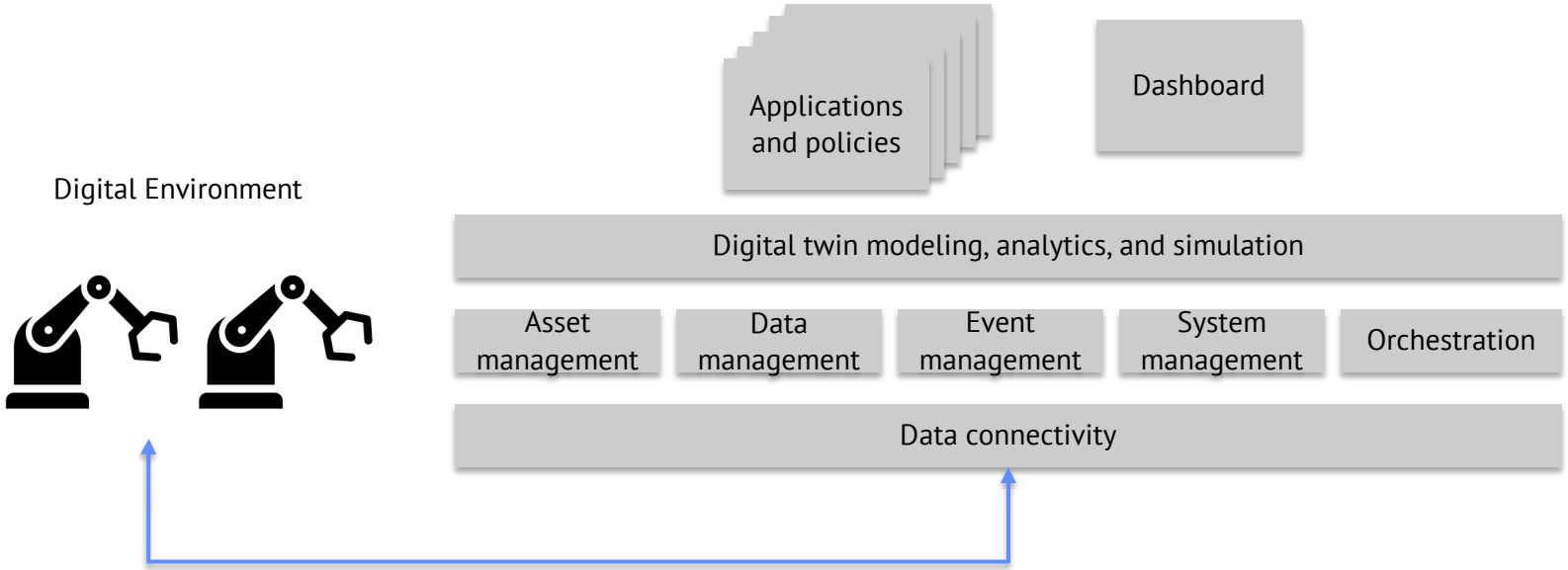
- **Servitization**
  - A large number of new services provided by digital twin
  - More ways to use digital twins than using the physical object
  - Digital twin software provides different interfaces for different applications

- **Predictability**
  - The possibility of embedding a digital twin in a specific environment and simulate its behavior and interactions with other objects in the future or during a specific time period
  - Artificial intelligence can be used for such prediction

# Summary: properties of Digital Twin



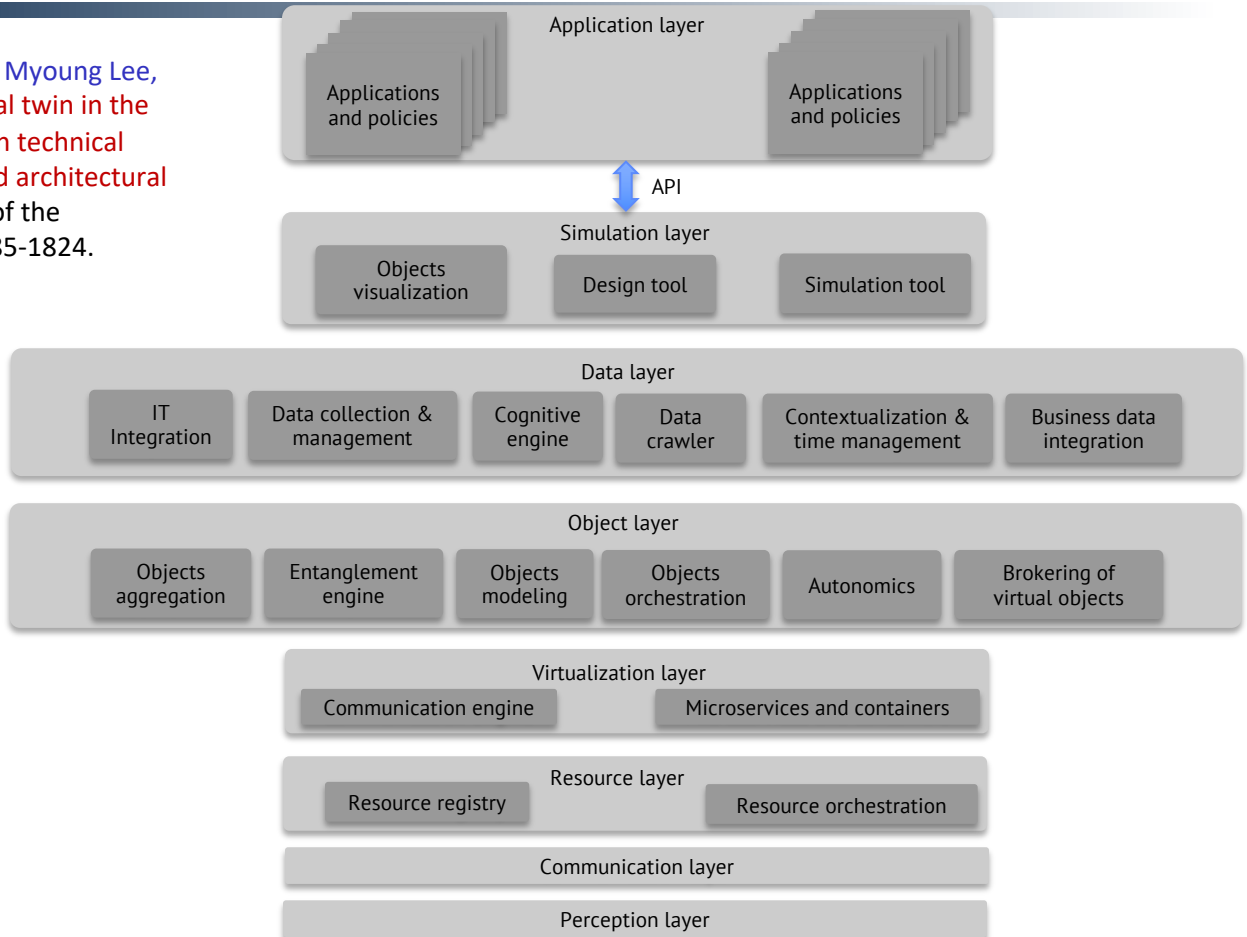
# Generic architecture




Minerva, Roberto, Gyu Myoung Lee, and Noel Crespi. "Digital twin in the IoT context: a survey on technical features, scenarios, and architectural models." Proceedings of the IEEE108.10 (2020): 1785-1824.

# Generic framework

Minerva, Roberto, Gyu Myoung Lee, and Noel Crespi. "Digital twin in the IoT context: a survey on technical features, scenarios, and architectural models." Proceedings of the IEEE108.10 (2020): 1785-1824.



# Outline

- Background: Digital world
- Digital Twins
  - Enabling technologies
  - System architecture
  - Applications
- Wireless sensing using HF RFID and NFC
  - Motivation and requirements for digital twin
  - Communication and networking protocols
  - Research challenges and solutions
- Future research directions

# Application 1: Agriculture

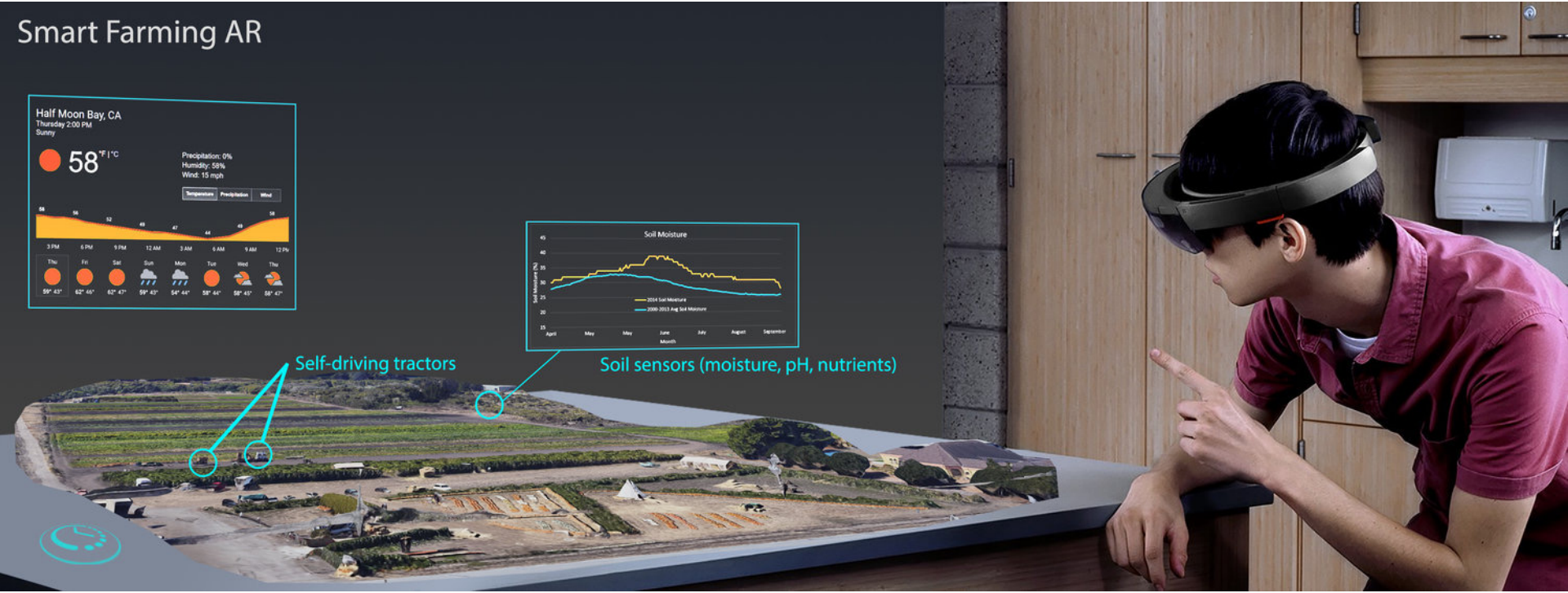



Image: microsoft

# Application 2: Underground pipeline safety


Image: enbridge

# Digital Twin manufacturing process

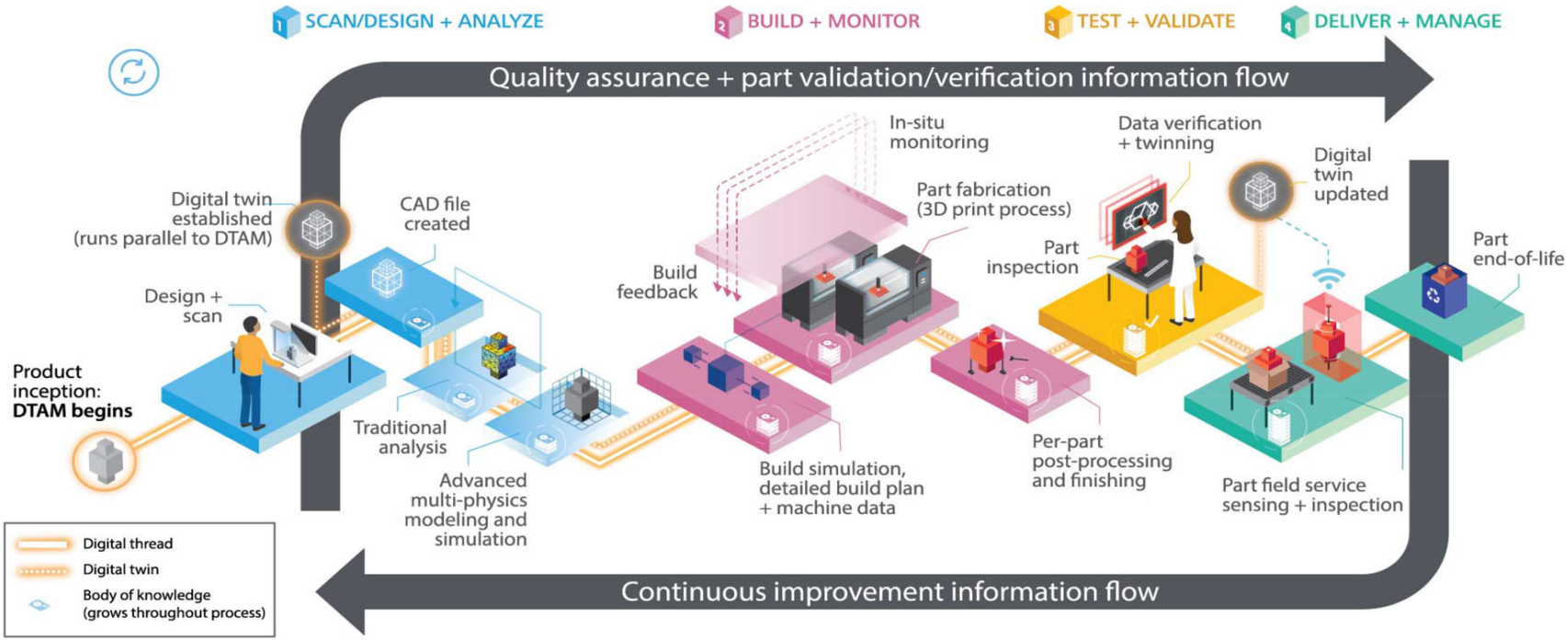





Image: Deloitte Development LLC

# Military application: manufacturing

- Digital twins extend lifecycle of products
  - Design
  - Simulation
  - Manufacture
  - Operation monitoring and optimization
  - Maintenance
  - Recycle

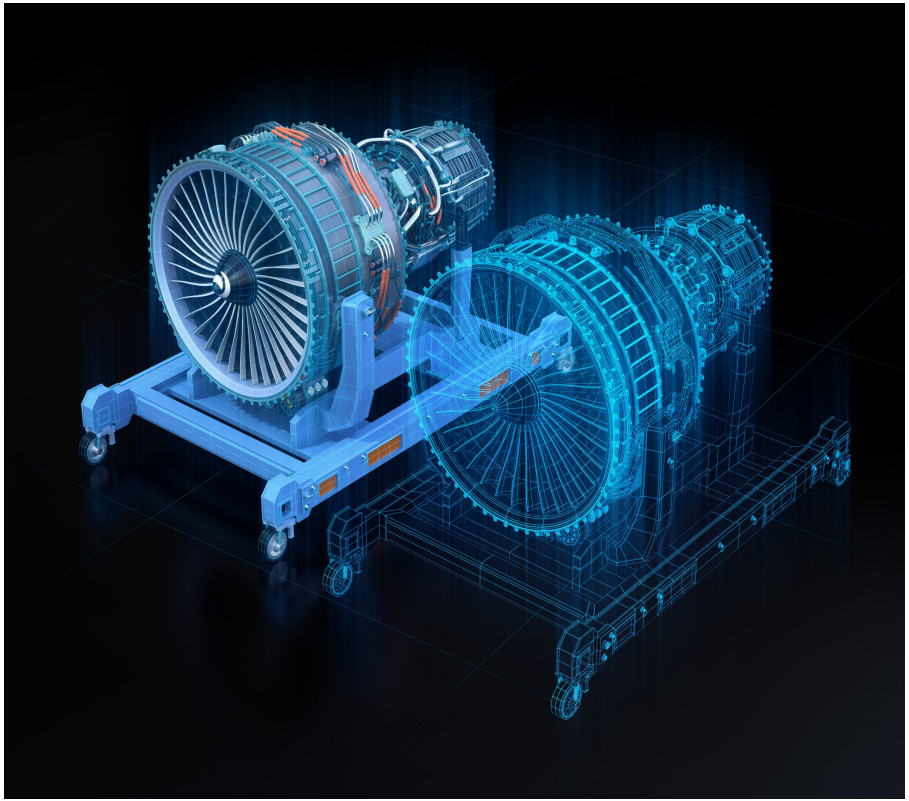


Image: govdesignhub.com

# Military application: warehouse

- Data from the warehouse IoT networks can be used to develop a dynamic, real-time model of the physical warehouse
- As pallets or robots moves in the warehouse, their digital twins' locations are updated
- Sensors send various information, such as temperature, inventory, etc., to the digital twin model
  - The model can be updated and simulated
- The more extensive the network of sensors and software in the warehouse, the more accurate the twin will be
- The more accurate of the physics model, the more accurate the simulation will be

# Military application: warehouse

- Companies can design, simulate, and test new warehouse operations and product flows electronically by building a digital twin of a specific warehouse, rather than making significant changes to already complicated locations

- Besides simulation, digital twins can provide model analytics and adjust things like layout and floor plan

- Digital twins can restore the warehouse to a previous setting (travel to the past)
  - Simulation is traveling to the future

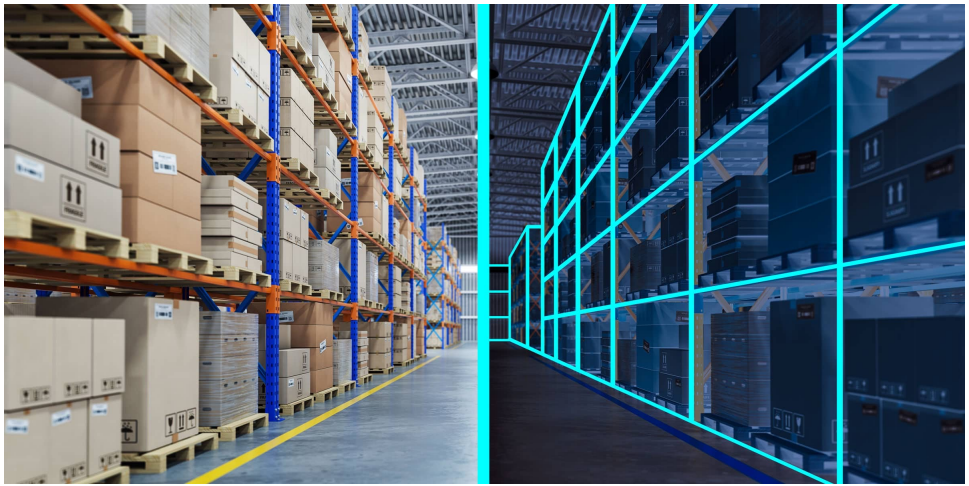


Image: servicenow

# Military food supply chain

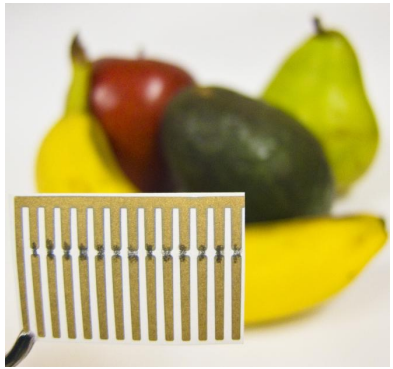
- Fresh Food Physical Internet
  - An extension of Physical Internet (PI)
- Motivation
  - 40% of fresh food wasted
  - Transportation efficiency ~15% → huge and avoidable carbon footprint
  - Long driving time of truckers → higher turnover rate

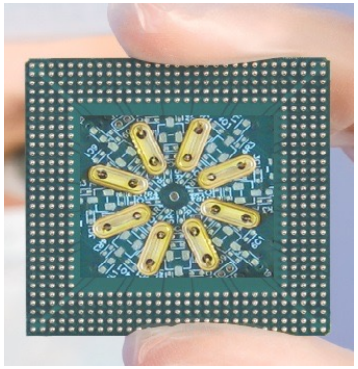

99% invisible.org

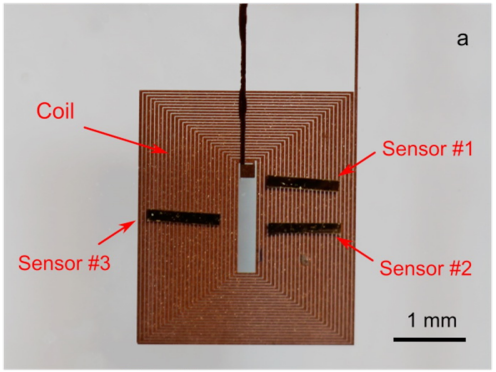
Presidio of Monterey Public Affa

# Food Sensing and Communication for Digital Twin

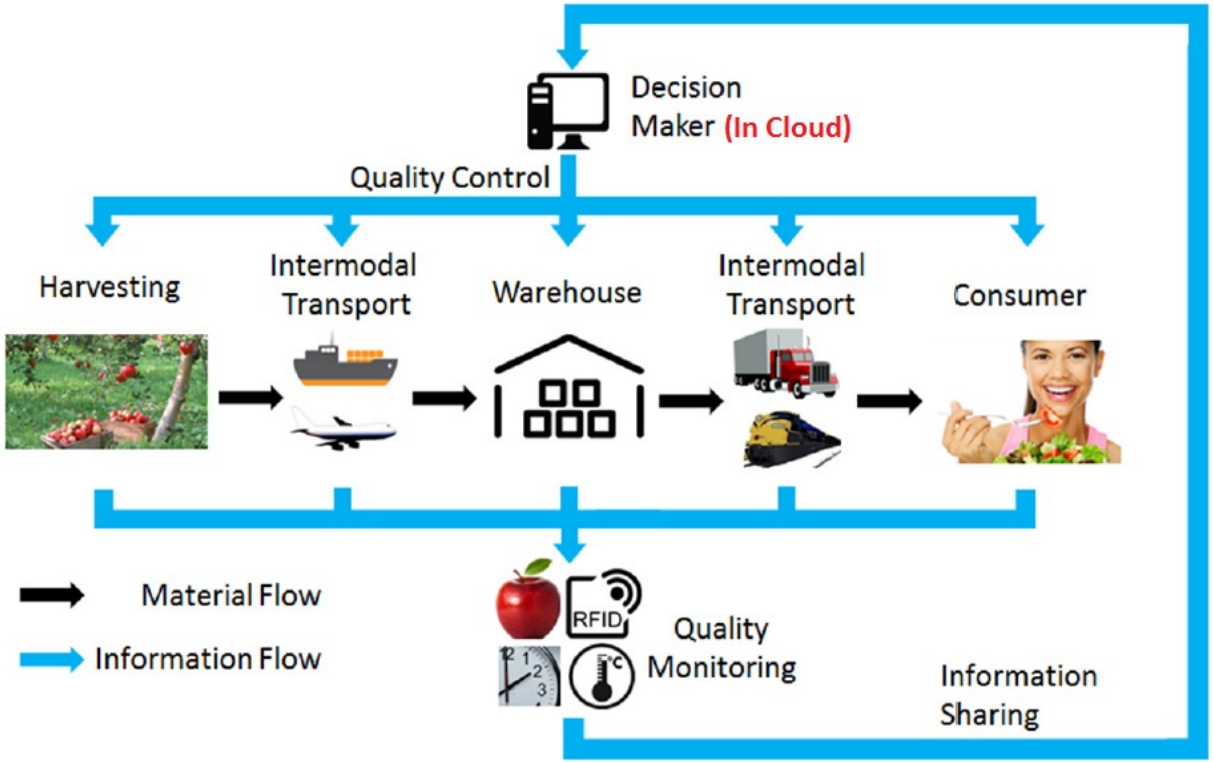
- A lot of food sensors are under development
  - C2Sense, FoodScan, Salmonella Sensing System etc.
- Developing food and supply chain digital twin leverages these sensors







# A Vision Towards Continuous Food Quality Monitoring & Reporting



# Military application: battlefield

- Digital Twin of physical battlefield environment
- Single synthetic environment in-support of military activities
- Deliver enhanced and improved global situational awareness
- Build a replication of an operating environment to help joint and combined forces to perform better
- Provide more realistic and efficient training

Image: CAE.com

https://www.cae.com/defense-security/what-we-do/training-systems/single-synthetic-environment-in-support-of-military-activities

# Military application: current status

- Example: digital twin of Black Hawk helicopter
- Designed using 2D drawings
- Manually scan each part to build 3D digital twins
- Approximately 5,000 individual parts over the course of 30 months

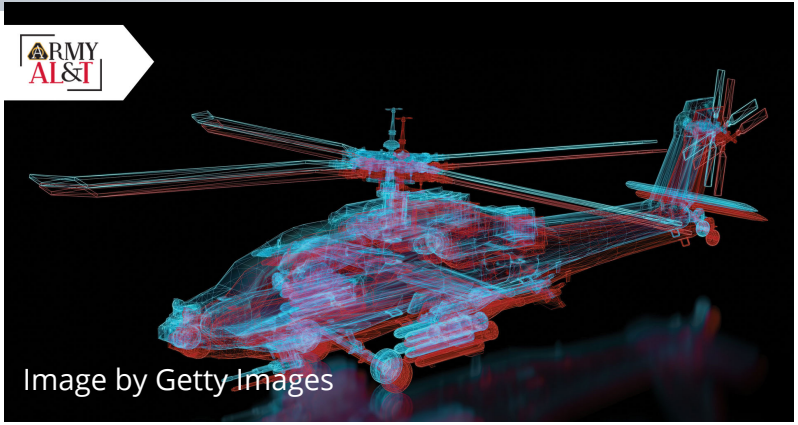
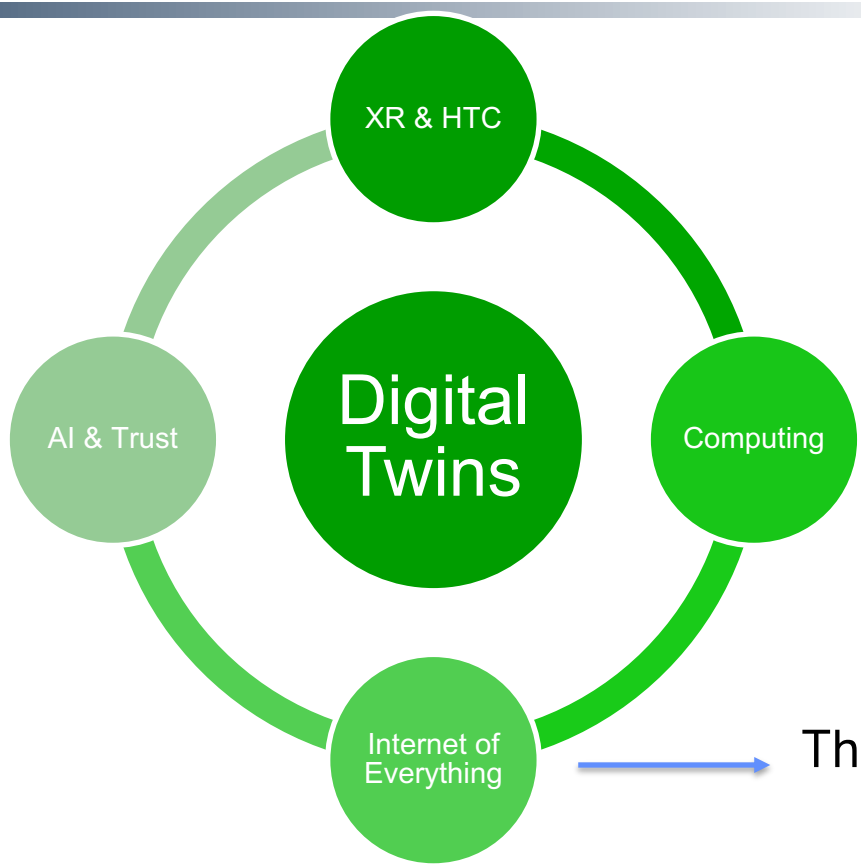


Image by Getty Images


Photo by Spc. Thoman Johnson, U.S. Army Pacific Public Affairs Office

https://asc.army.mil/web/news-on-the-double/

# Summary




The focus of the second half of this tutorial

- **2 PhD openings (Computer Engineering/Computer Science)**
- **School of Computing, University of Nebraska Lincoln**
  - Start from as early as Spring 2023
  - Digital twins, wireless sensing
  - Contact: hguo10@unl.edu
- **Call for papers https://www.itu.int/en/journal/j-fet/2023/002/Pages/default.aspx**
  - ITU Journal on Future and Evolving Technologies


**Deadlines**

Paper submission: 3 March 2023

Paper acceptance notification: 3 May 2023

Camera-ready paper submission: 3 June 2023