COMP3516: Data Analytics for IoT

Lecture 1: Introduction

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2025 Spring

ACK: Part of the course materials are adapted with permission from below course/companies. Many thanks!
ECE439@UIUC, CMSC715@UMD, CSE-891@MSU, CS462@SMU, Origin Wireless Inc., TI, etc.

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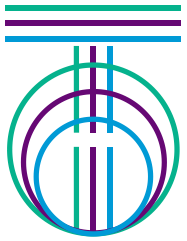


HKU AIoT LAB
香港大學人工智能物联网實驗室

What’s a computer?

Dictionary

Search for a word

com·put·er

/kəmˈpyo͞odər/

noun

an electronic device for storing and processing data, typically in binary form, according to instructions given to it in a variable program.

- a person who makes calculations, especially with a calculating machine.

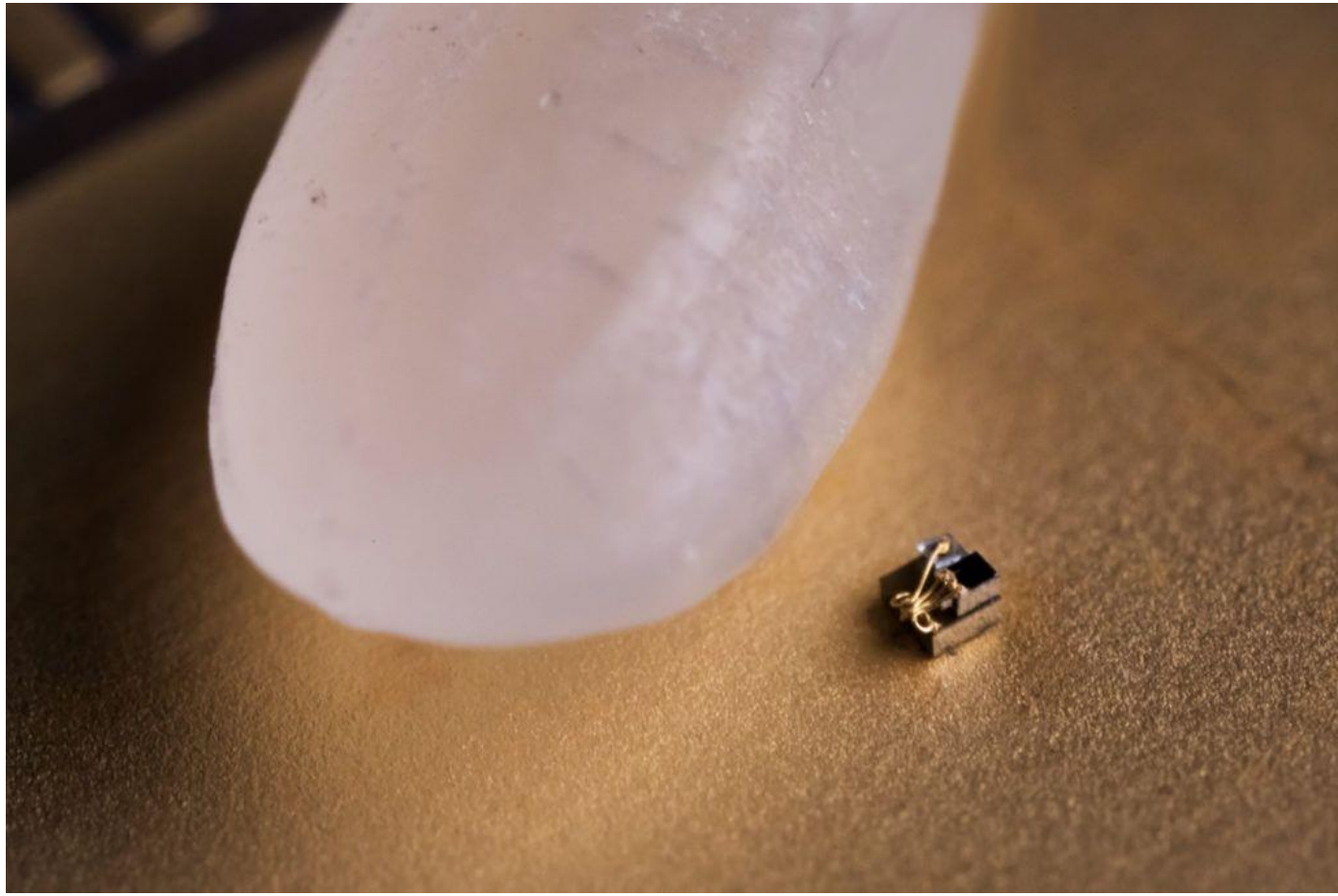
A computer is a machine that can be instructed to carry out sequences of arithmetic or logical operations automatically via computer programming. Modern computers have the ability to follow generalized sets of operations, called programs. These programs enable computers to perform an extremely wide range of tasks. Wikipedia

What's a computer?

What's a computer?

- M3: Michigan Micro Mote

- The device was designed to be a precision temperature sensor that can report temperatures in clusters of cells with an error of about 0.1 degrees Celsius.



What's a computer?

- By the middle of the 20th century, this term referred to a human computer, a person who carried out calculations or computations.

Computers have replaced "computers" (humans)!

So, will AI replace humans?

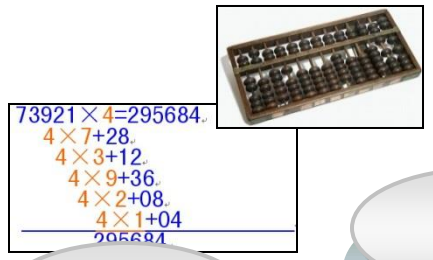
- Today?
  - Will probably replace those who truly believe today's AI will replace humans :-P
- Eventually?
  - Maybe yes, maybe not…

How the desk changed over time

How the desk changed over time

Computing as Science

Computing infrastructure



1946

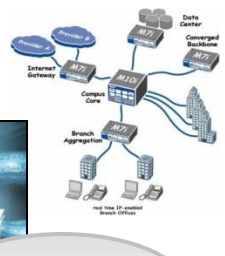
First Computer

1965

High Performance Computing

1980

Personal Computer



1995

Internet

2010

Smart Planet/ CPS/Intern et of Things

2020

AIoT

Omnipresent connectivity & sensing

Science → **Internet** → **AI Service**

Human-Machine

Machine-Machine

Things-Things

Things-Things, Smartly

Internet of Everything

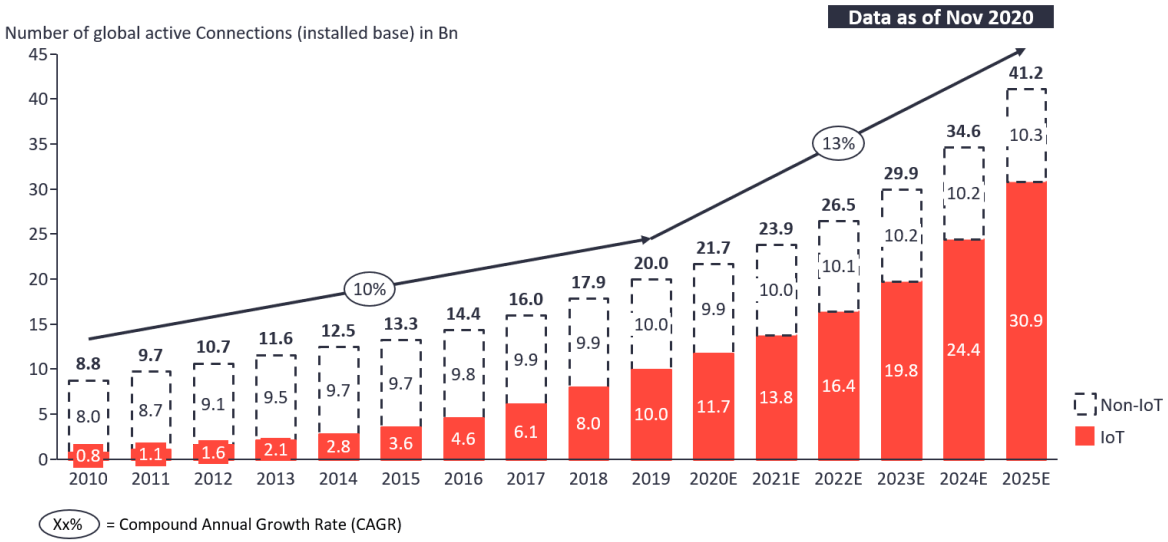
- Billions or even trillions of connected things.

IOT ANALYTICS

Insights that empower you to under

Total number of device connections (incl. Non-IoT)

20.0Bn in 2019– expected to grow 13% to 41.2Bn in 2025



Note: Non-IoT includes all mobile phones, tablets, PCs, laptops, and fixed line phones. IoT includes all consumer and B2B devices connected – see IoT break-down for further details

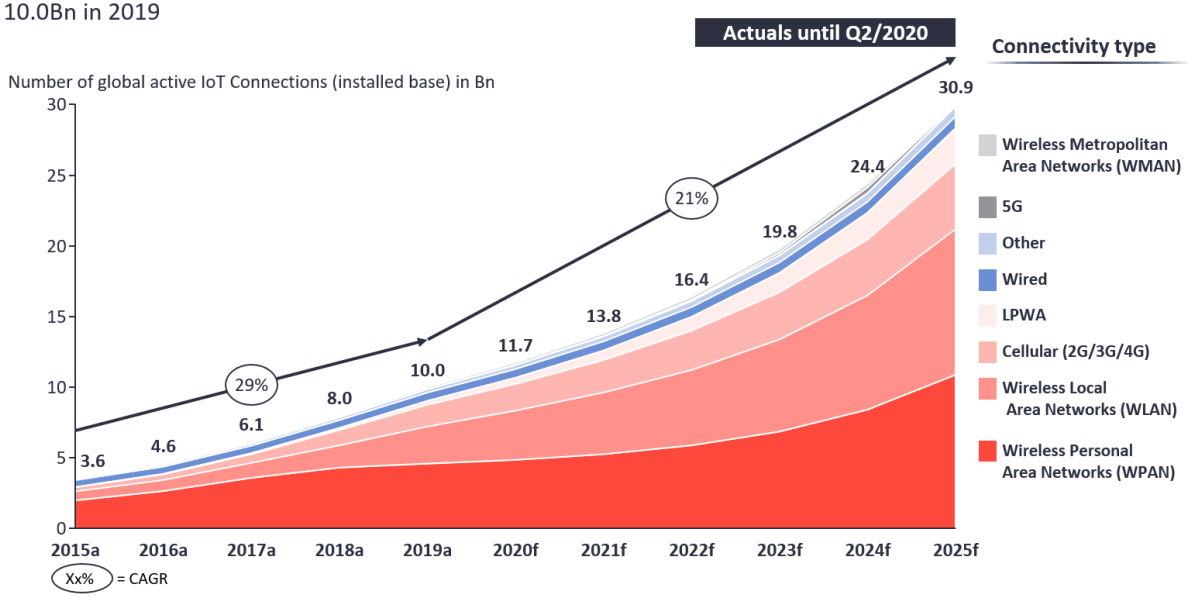
Source(s): IoT Analytics - Cellular IoT & LPWA Connectivity Market Tracker 2010-25

IOT ANALYTICS

Insights that empow

Global Number of Connected IoT Devices

10.0Bn in 2019

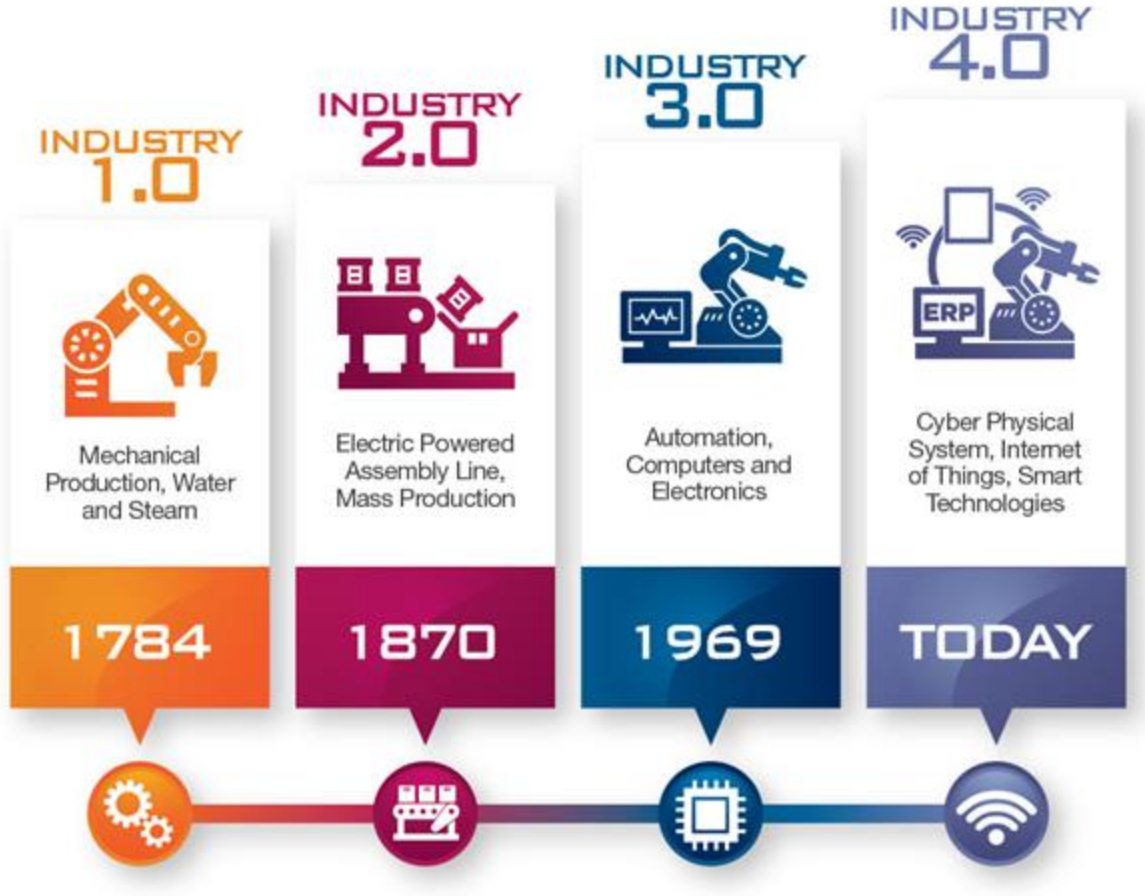


Note: IoT Connections do not include any computers, laptops, fixed phones, cellphones or tablets. Counted are active nodes/devices or gateways that concentrate the end-sensors, not every sensor/actuator. Simple one-directi considered (e.g., RFID, NFC). Wired includes Ethernet and Fieldbuses (e.g., connected industrial PLCs or I/O modules); Cellular includes 2G, 3G, 4G; LPWAN includes unlicensed and licensed low-power networks; WPAN includes includes Wi-fi and related protocols; WMAN includes non-short range mesh, such as Wi-SUN; Other includes satellite and unclassified proprietary networks with any range.

Source(s): IoT Analytics - Cellular IoT & LPWA Connectivity Market Tracker 2010-25

Industry 4.0: Industrial Internet of Things

- The Fourth Industry Revolution, Another 100 Years?



What is AI?

Alan Turing in 1950:
“Can Machines Think?”

A. M. Turing (1950) Computing Machinery and Intelligence. *Mind 49:* 433-460.

COMPUTING MACHINERY AND INTELLIGENCE

By A. M. Turing

1. The Imitation Game

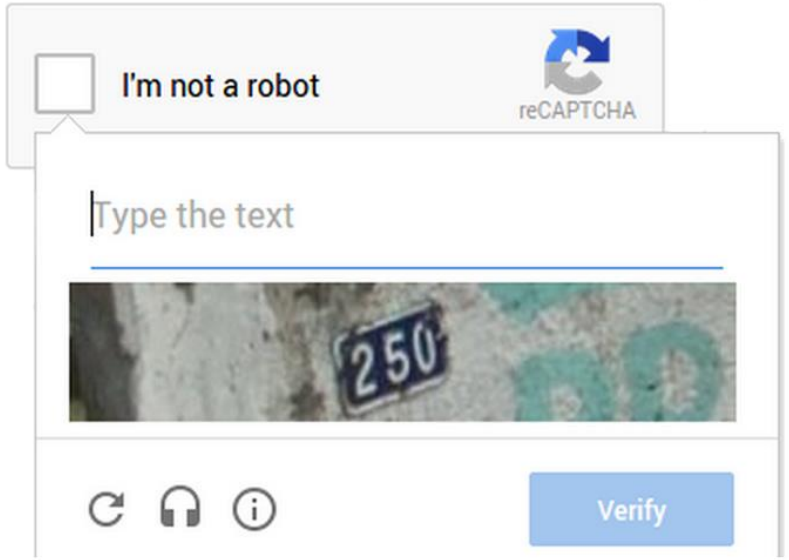
I propose to consider the question, "Can machines think?" This should begin with definitions of the meaning of the terms "machine" and "think." The definitions might be framed so as to reflect so far as possible the normal use of the words, but this attitude is dangerous, If the meaning of the words "machine" and "think" are to be found by examining how they are commonly used it is difficult to escape the conclusion that the meaning and the answer to the question, "Can machines think?" is to be sought in a statistical survey such as a Gallup poll. But this is absurd. Instead of attempting such a definition I shall replace the question by another, which is closely related to it and is expressed in relatively unambiguous words.

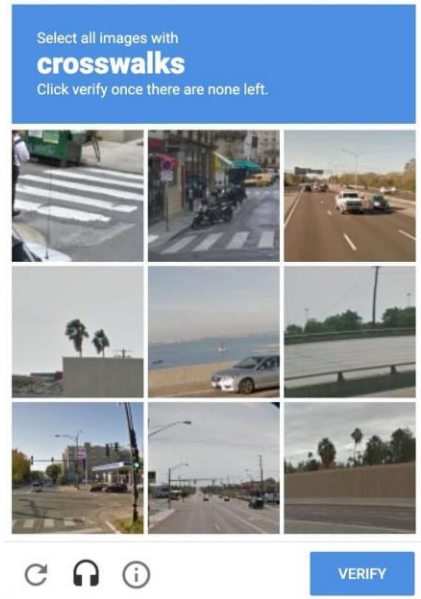
What is AI?

Alan Turing in 1950:
"Can Machines Think?"

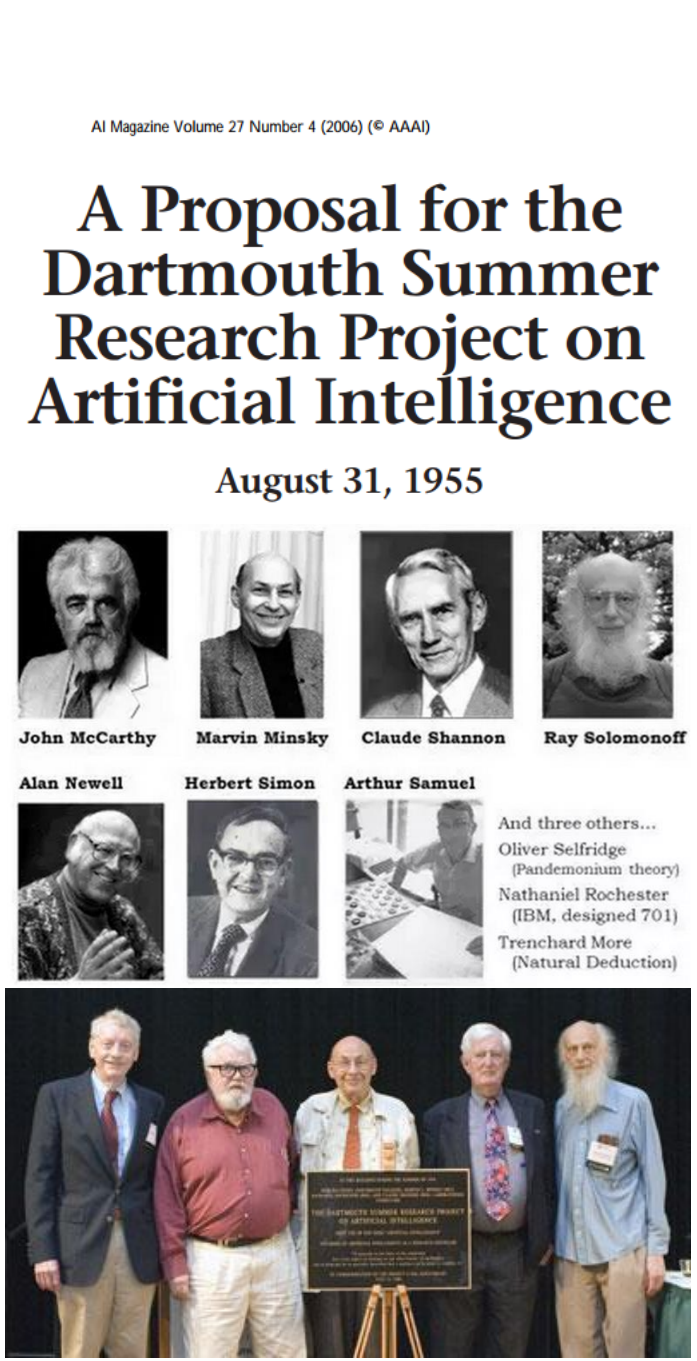
"Completely Automated Public Turing test to tell Computers and Humans Apart"

Google reCAPTCHA





ARTIFICIAL INTELLIGENCE



AI Magazine Volume 27 Number 4 (2006) (© AAAI)

A Proposal for the Dartmouth Summer Research Project on Artificial Intelligence

August 31, 1955

John McCarthy | Marvin Minsky | Claude Shannon | Ray Solomonoff

Alan Newell | Herbert Simon | Arthur Samuel

And three others...
Oliver Selfridge (Pandemonium theory)
Nathaniel Rochester (IBM, designed 701)
Trenchard More (Natural Deduction)

Computational Intelligence

Machines can do calculating as human beings and process huge amounts of data.

Perceptual Intelligence

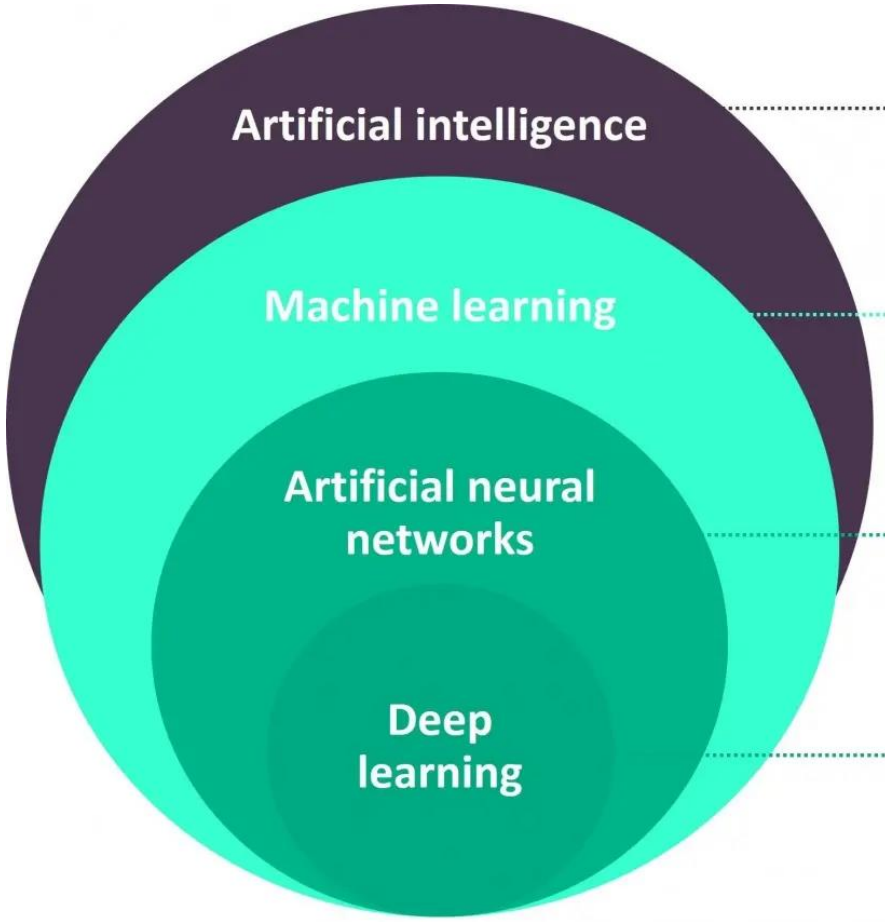
Machines can read and understand, typically like speech and vision recognition.

Cognitive intelligence

Machines can turn information into knowledge while trying to think of, assist or even substitute human beings for most of the work.

5 Dartmouth Workshop participants on AI 50th anniversary, 2006

What is AI?



Artificial intelligence (AI)
Any techniques that enable machines to solve a task in a way like humans do

Machine learning (ML)
Algorithms that allow computers to learn from examples without being explicitly programmed

Artificial neural networks (ANN)
Brain-inspired machine learning models

Deep learning (DL)
A subset of ML which uses deep artificial neural networks as models and automatically builds a hierarchy of data representations

Three Laws

01 Moore’s Law

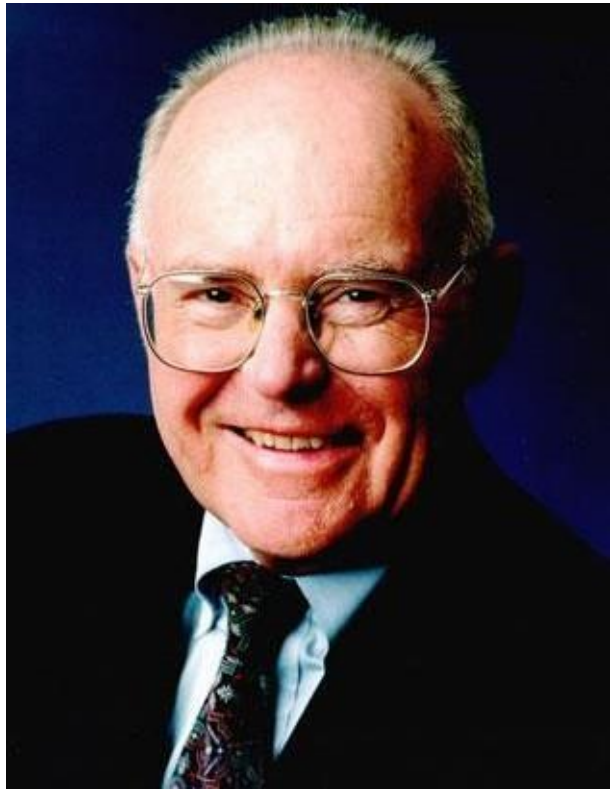
02 Gilder’s Law

03 Metcalfe’s law

1 Moore's Law

- The number of transistors that can be packed into a given unit of space will double every two years.

- Processor speeds, or overall processing power for computers will double about every 18 month's.



Gordon E. Moore

Co-Founder of Intel

2 Gilder's Law

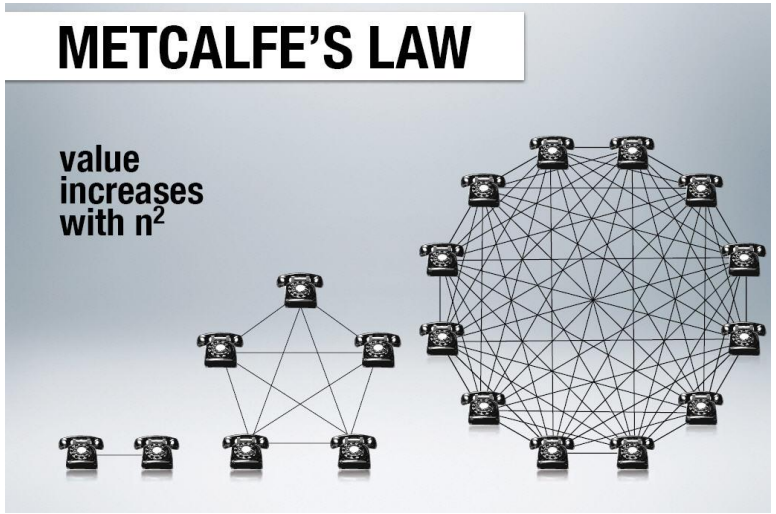
- The bandwidth of communications systems doubles every 6 months.

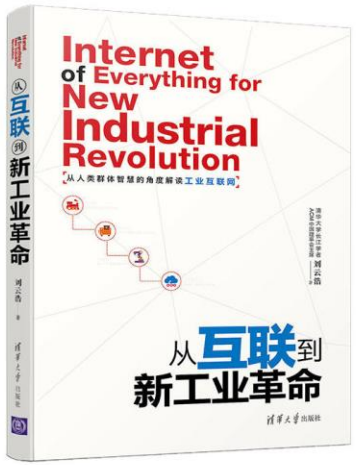
George Gilder

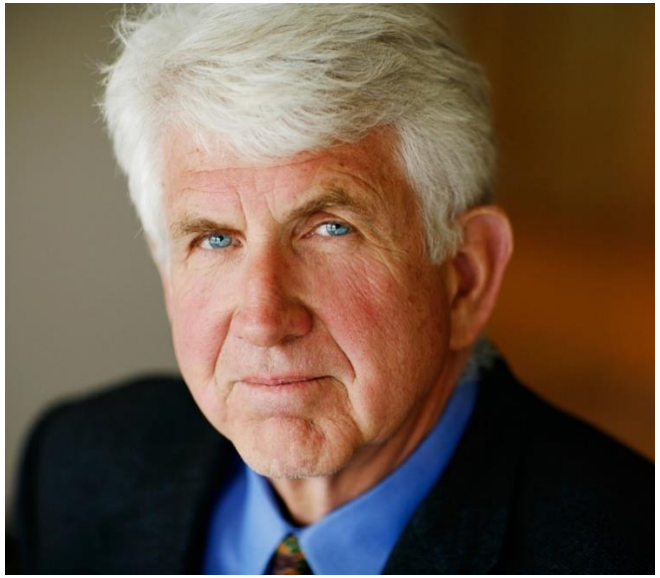
Investor, Writer, and Economist

3 Metcalfe's Law

- The value of a telecommunications network is proportional to the square of the number of connected users (compatible communicating devices) of the system







Robert Melancton Metcalfe

Turing Award (2022)

Co-Inventor of Ethernet

Co-Founder of 3Com

The Fourth Industry Revolution

Is Coming.

🔑: Take an IoT course at HKU.

What Is IoT?

Dates back to the 1980s…

- The first connected object: Coca-Cola cans!
- A vending machine in the Carnegie Mellon University School of Computer Science.
- To go or not to go: because the machine was four minutes from his office and would occasionally be out of stock…
- “Great, now I can find out whether I have a coke.”

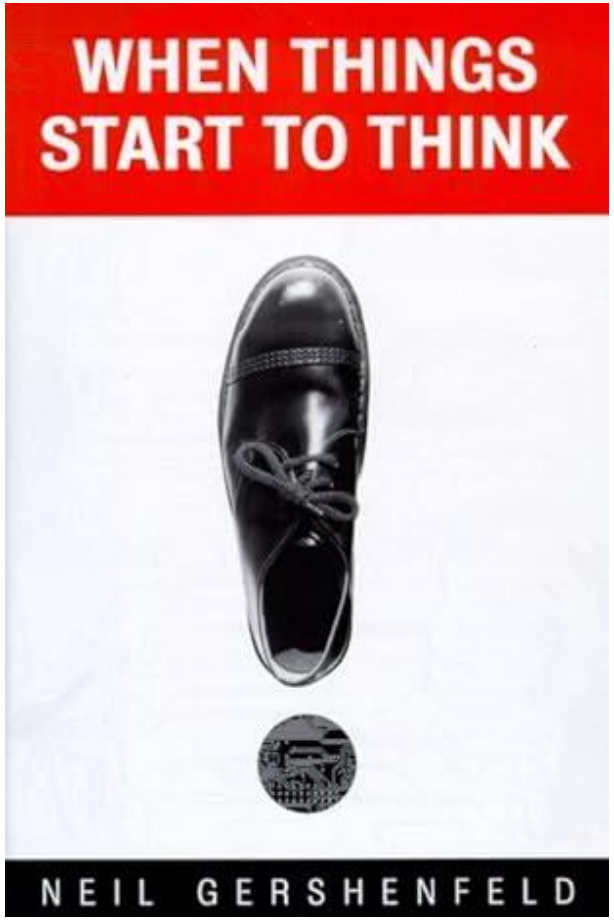
Source: https://csd.cmu.edu/news/decoding-the-internet-of-things

“When Things Start to Think”

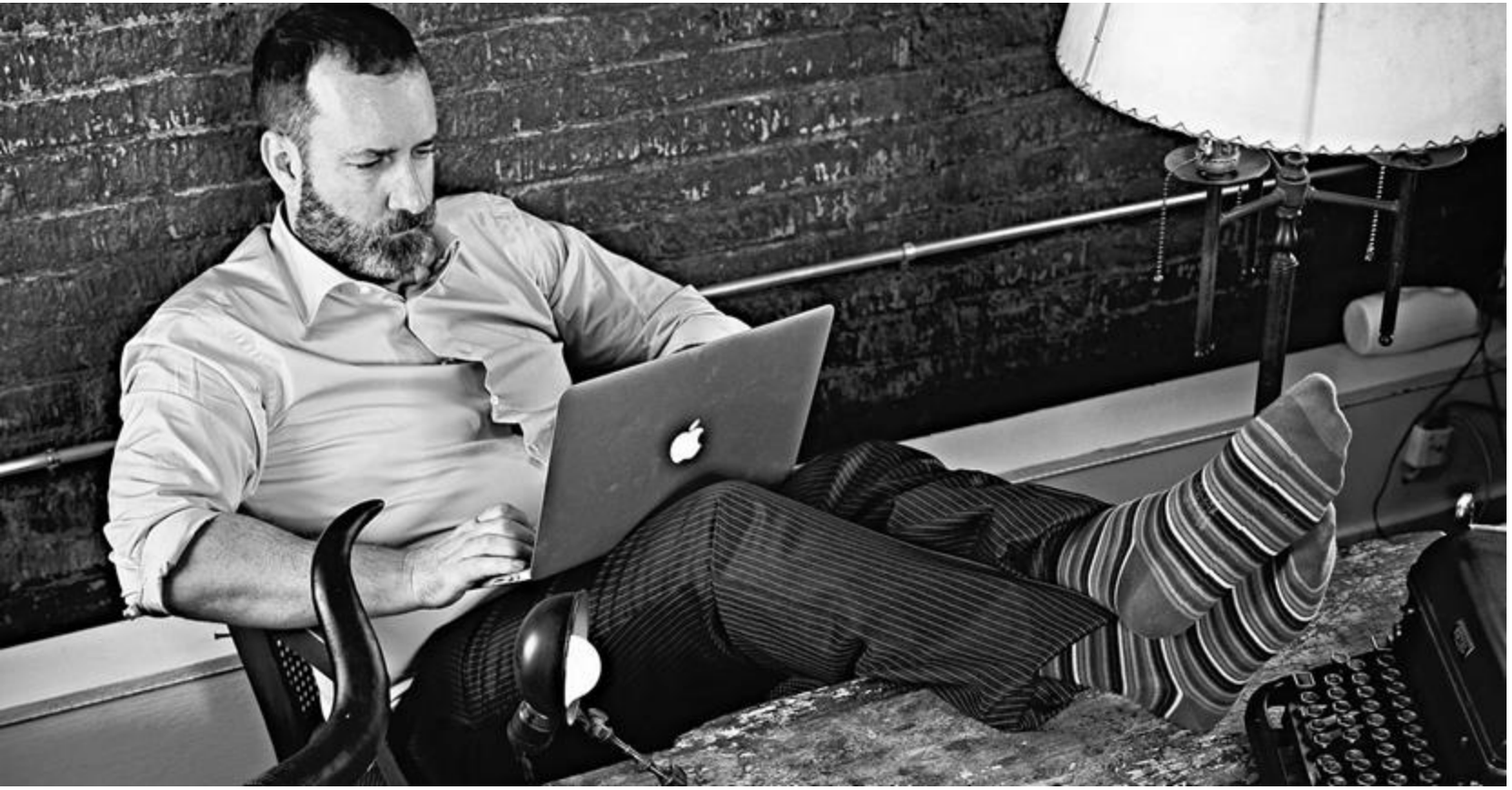
- January 12, 1999
- MIT professor Neil Gershenfeld, Director of The Center for Bits and Atoms

- "the real electronic revolution will come when computers have all but disappeared into the walls around us.”

- Explained the concept but not using the term.



“Father of IoT”



“I was talking about the supply chain being a ‘Network of Things,’ and the Internet being a ‘Network of Bits,’ and how sensor technology would merge the two together. Then I thought of an ‘Internet of Things,’ and I thought, ‘That’ll do – or maybe even better.’ It had a ring to it. It became the title of the presentation.” (1999)

- Kevin ASHTON

How Kevin Ashton named The Internet of Things, Avast, 2019

Kevin Ashton, Father of the Internet of Things & Network Trailblazer, Cisco, 2014

Definition of IoT

- No Universally Agreed IoT Definition

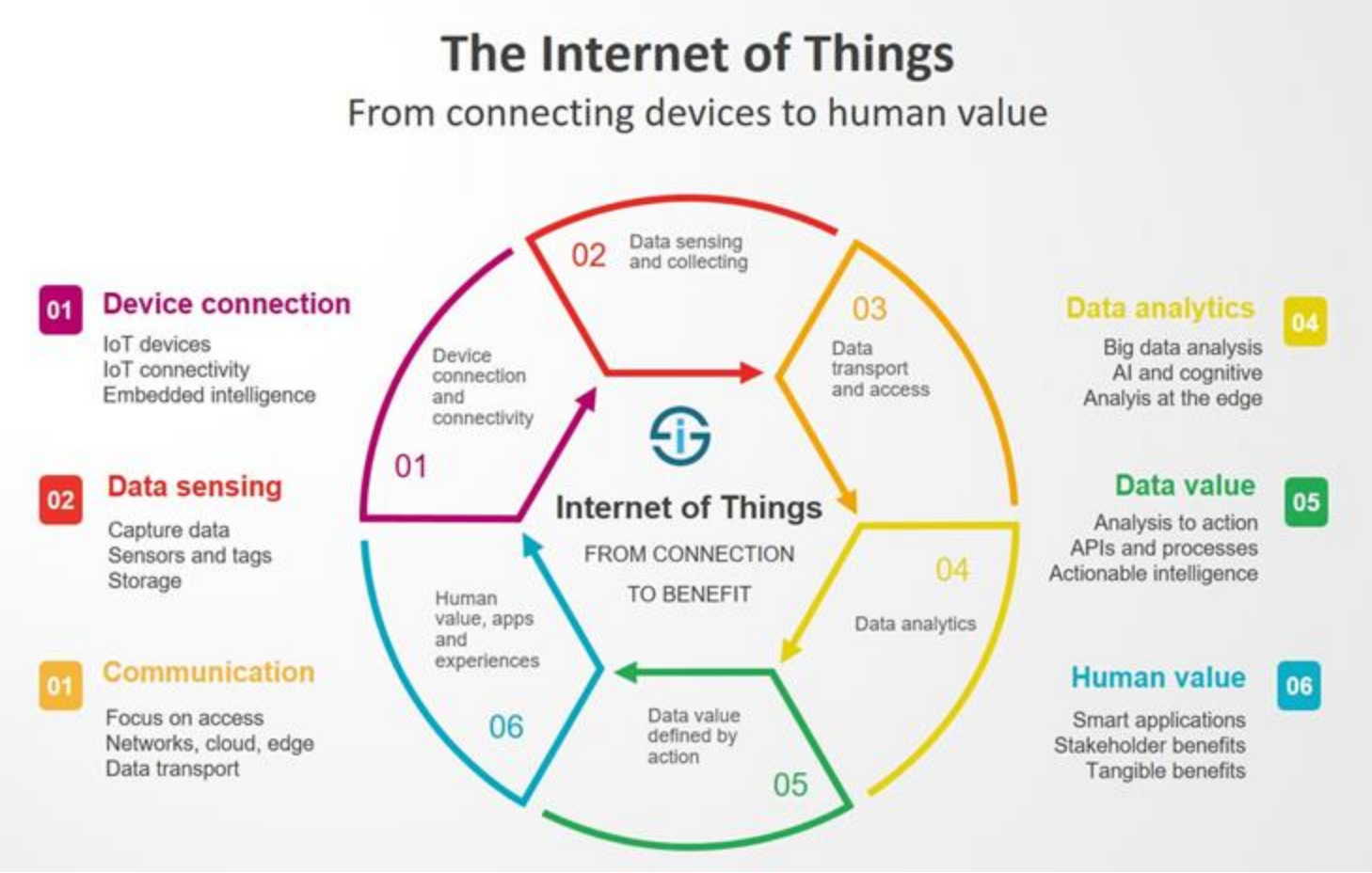
> *giant network of connected things and people – all of which collect and share data about the way they are used and about the environment around them*
>
> - IBM

Definition of IoT

- No Universally Agreed IoT Definition

> *IoT is an umbrella term which describes a multi-faceted foundation for a range of applications and goals which are enabled through the connection of items (devices, sensors, tagged beings), equipped with data capture and communication capacities, uniquely identifiable and connected, in order to transmit and/or received data for a clear human, business or societal purpose.*
>
> - i-scoop.eu

What is IoT?



What is IoT? The Internet of Things – definitions and facts, i-scoop.eu

7 Characteristics of IoT

CONNECTIVITY
M2M / Network / Internet

THINGS
Sensors / Devices

ECOSYSTEM
Community / Context / Internet of Everything

DATA
Information

ACTION
Decision / Automation

COMMUNICATION
Data Flows

INTELLIGENCE
Smart / Analytics

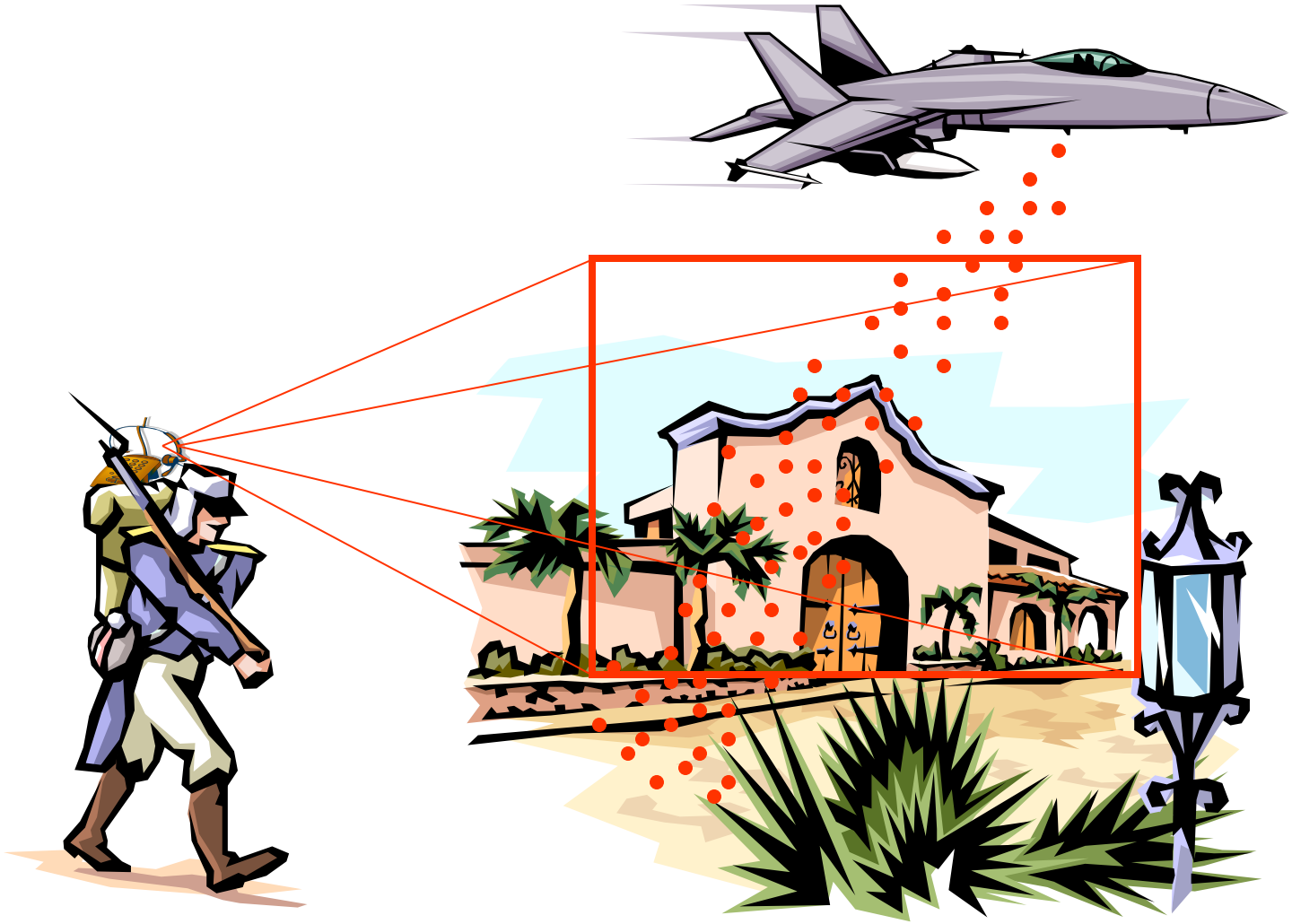
What is IoT? The Internet of Things – definitions and facts, i-scoop.eu

Early Efforts in IoT: WSN

- In early days (2000-2010), great efforts in WSNs

- Wireless Sensor Networks (WSN)
  - Smart Dust
  - Great Duck Island
  - VigilNet
  - ZebraNet
  - GreenOrbs
  - ……
- The FOCUS: Connectivity
  - Wireless, Ad-hoc, large-scale connectivity

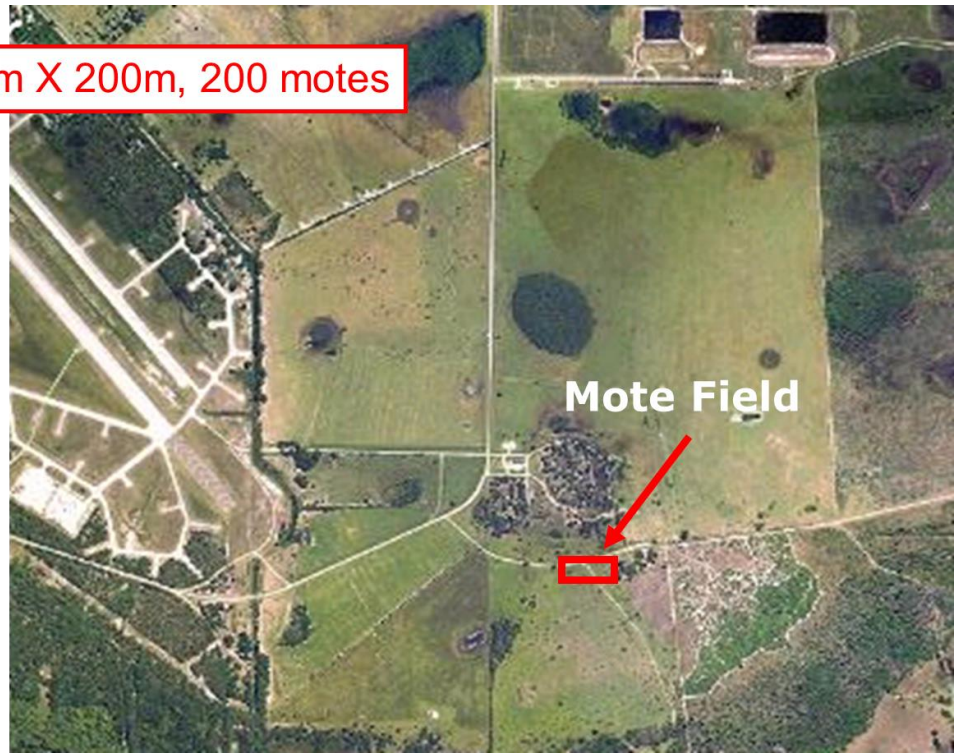
Military Applications – Smart Dust

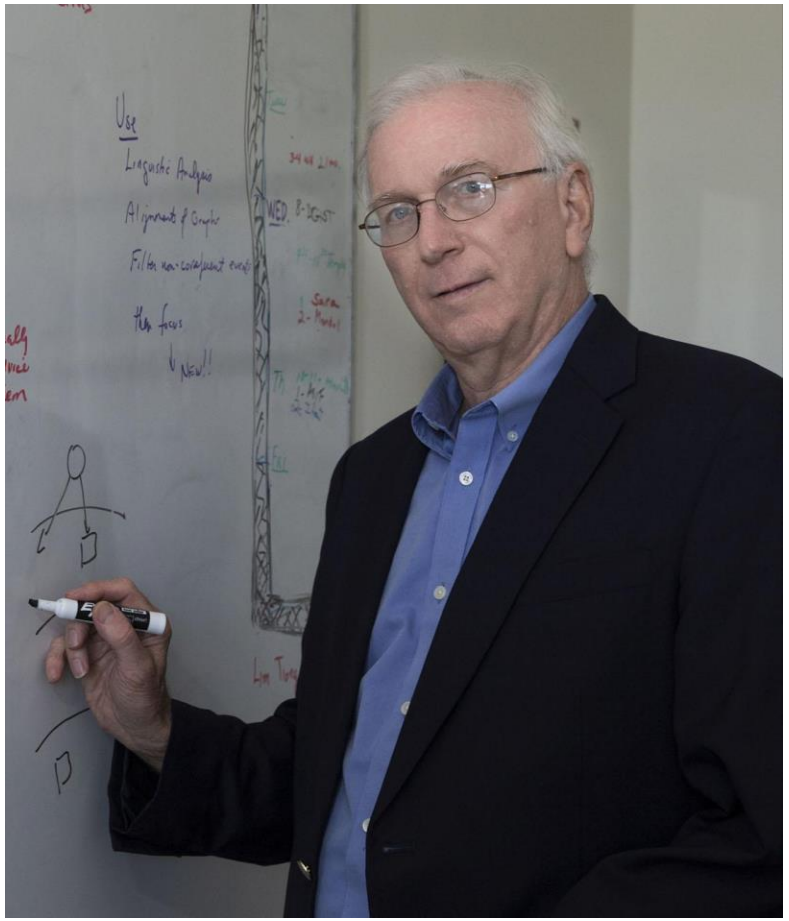


Great Duck Island

David Culler

VigilNet

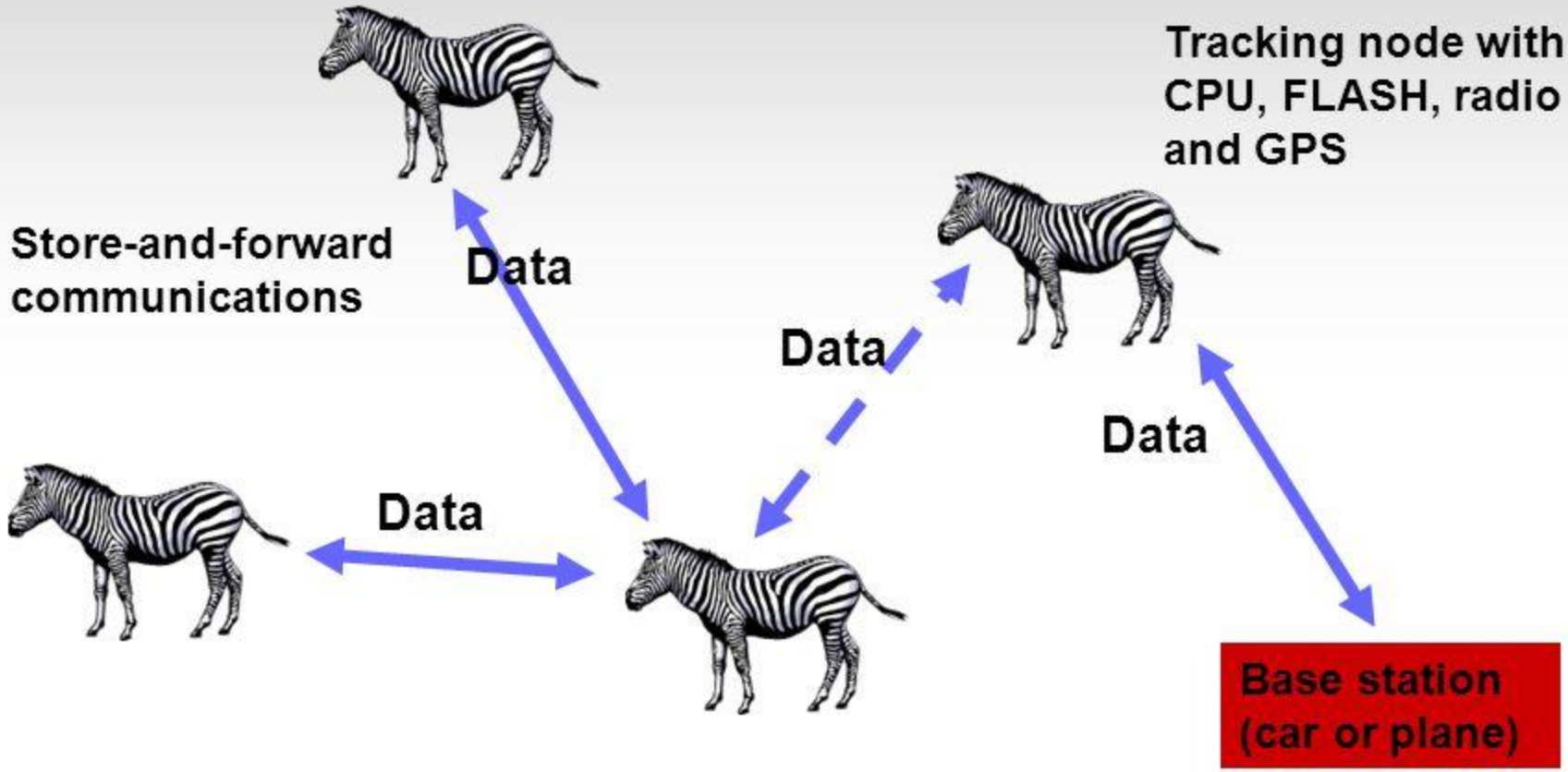




John Stankovic

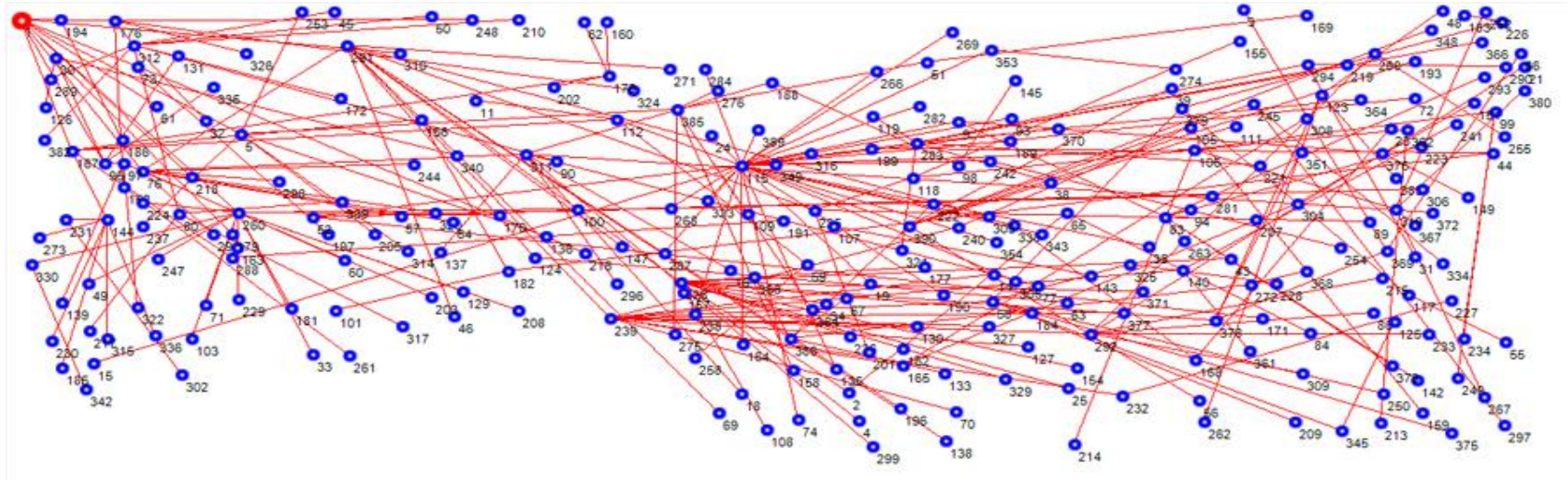
ZebraNet: An application of sensor networks

ZebraNet as Computing Research

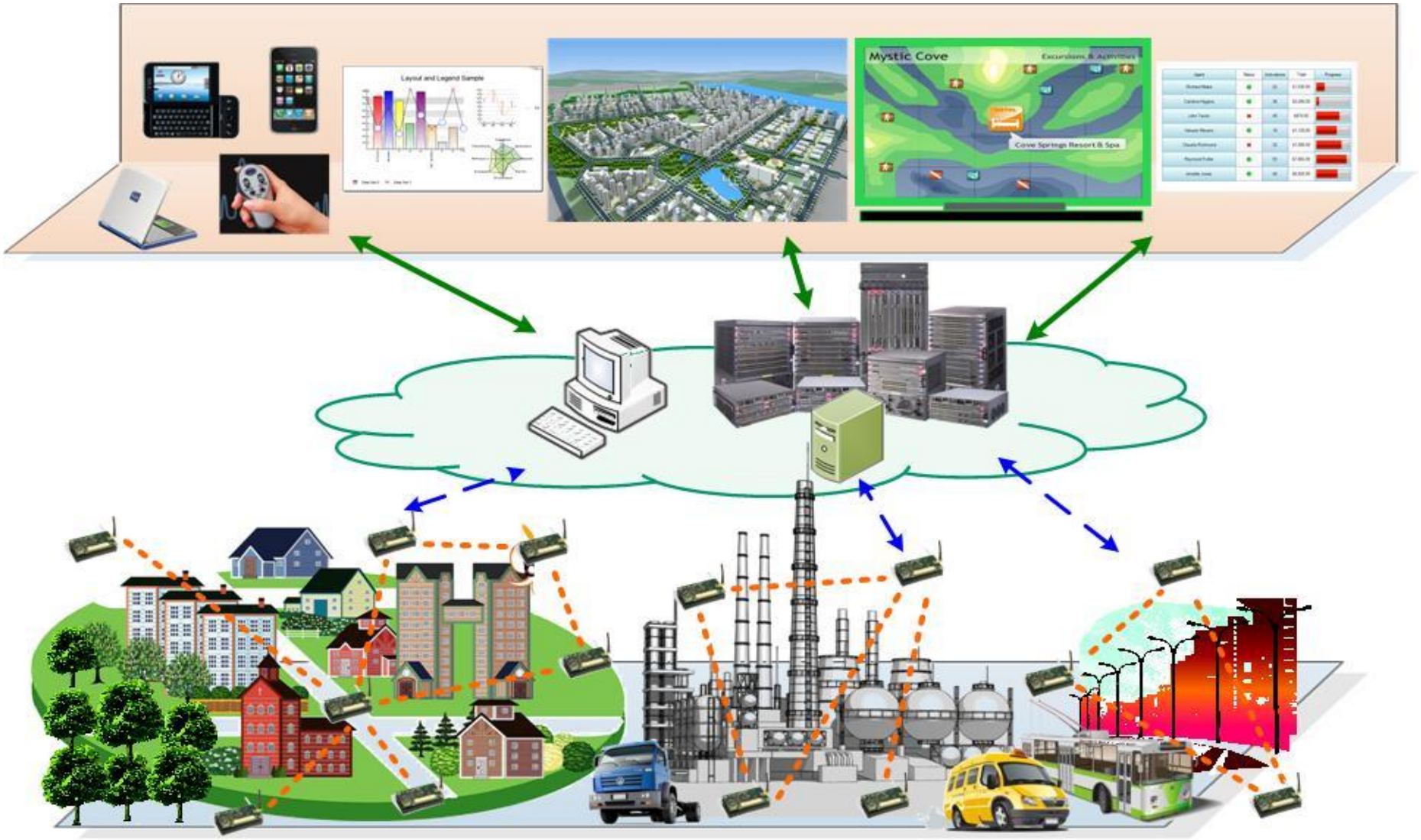


GreenOrbs System Deployment

System Deployment on Campus



CitySee: City-Wide Urban Sensing



FarmBeats: AI, Edge & IoT for Agriculture

How about Sensing?

- Sensing is mostly done by sensors, but not always.

- Dedicated sensors
  - Usually basic sensors, e.g., temperature, light, humidity sensors
  - Embedded in “sensor node” in WSNs

- Sensorless sensing
  - Re-use Radio-Frequency/sound/infrared/etc for sensing

Sensing is usually done by Sensors

Which of these are binary / multi-level sensors?

door contact

light

loudness

gyroscope

motion

3-axis accelerometer

gas

ultrasonic (range)

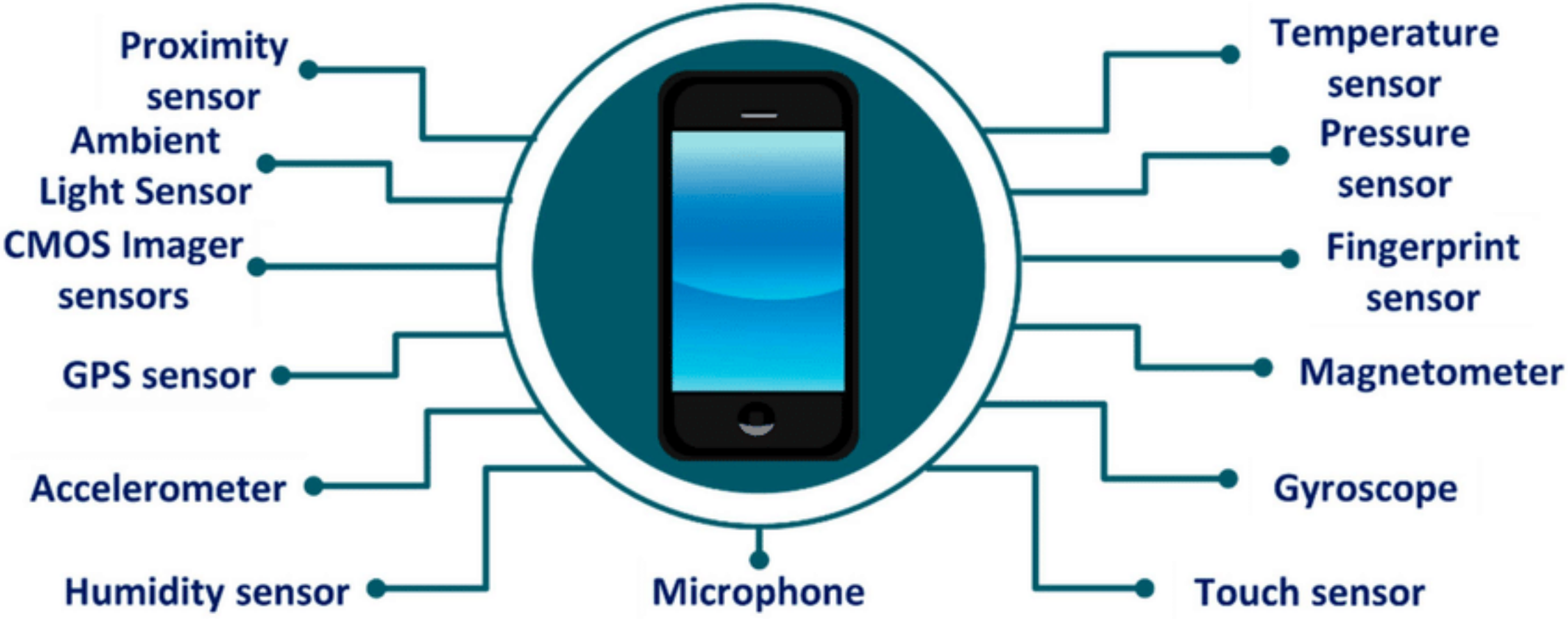
touch

moisture

temperature

camera

Sensors on smartphones?

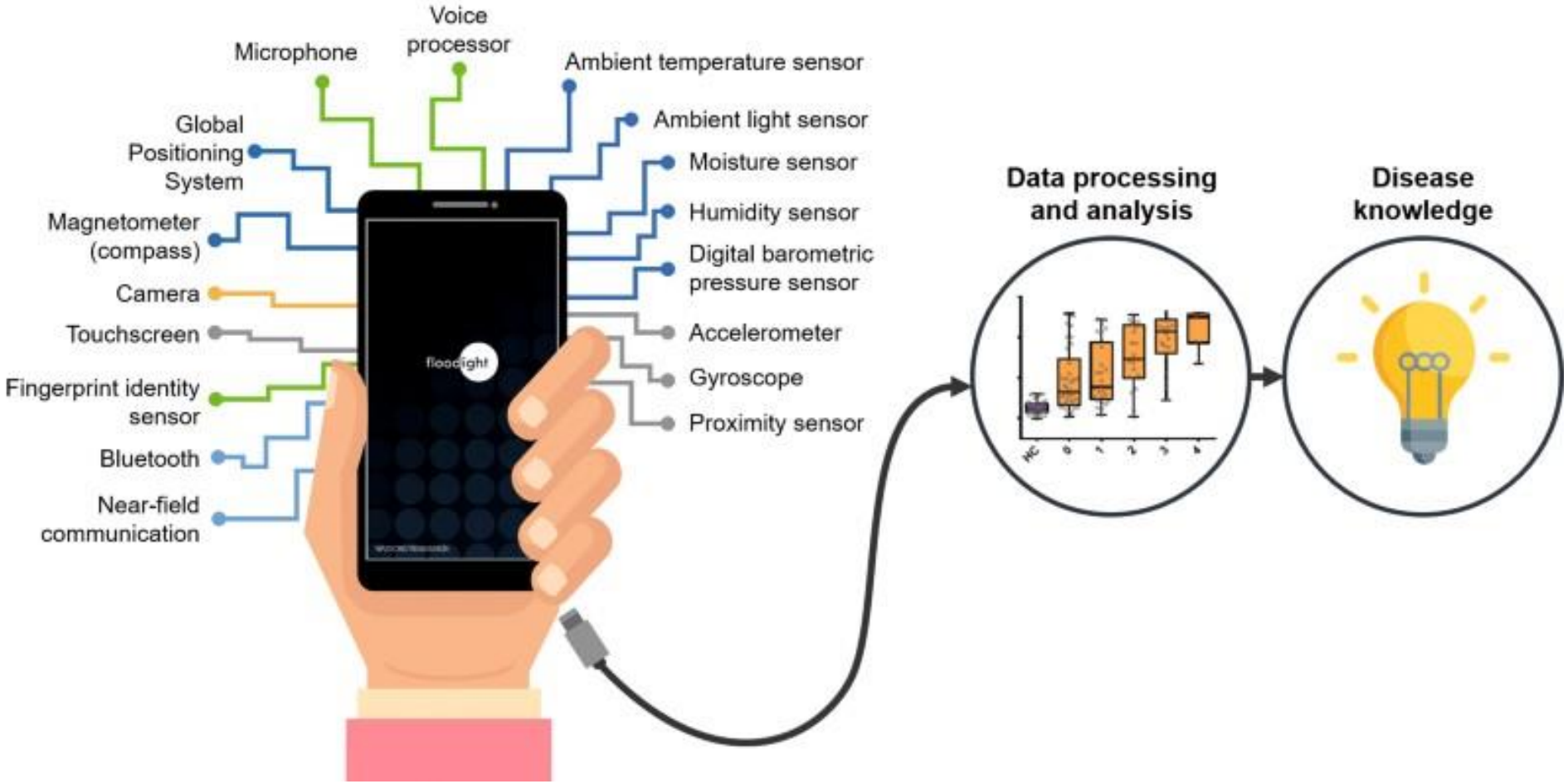


Role of "Things" in IoT

- mimic the role of 'people' connected over Internet

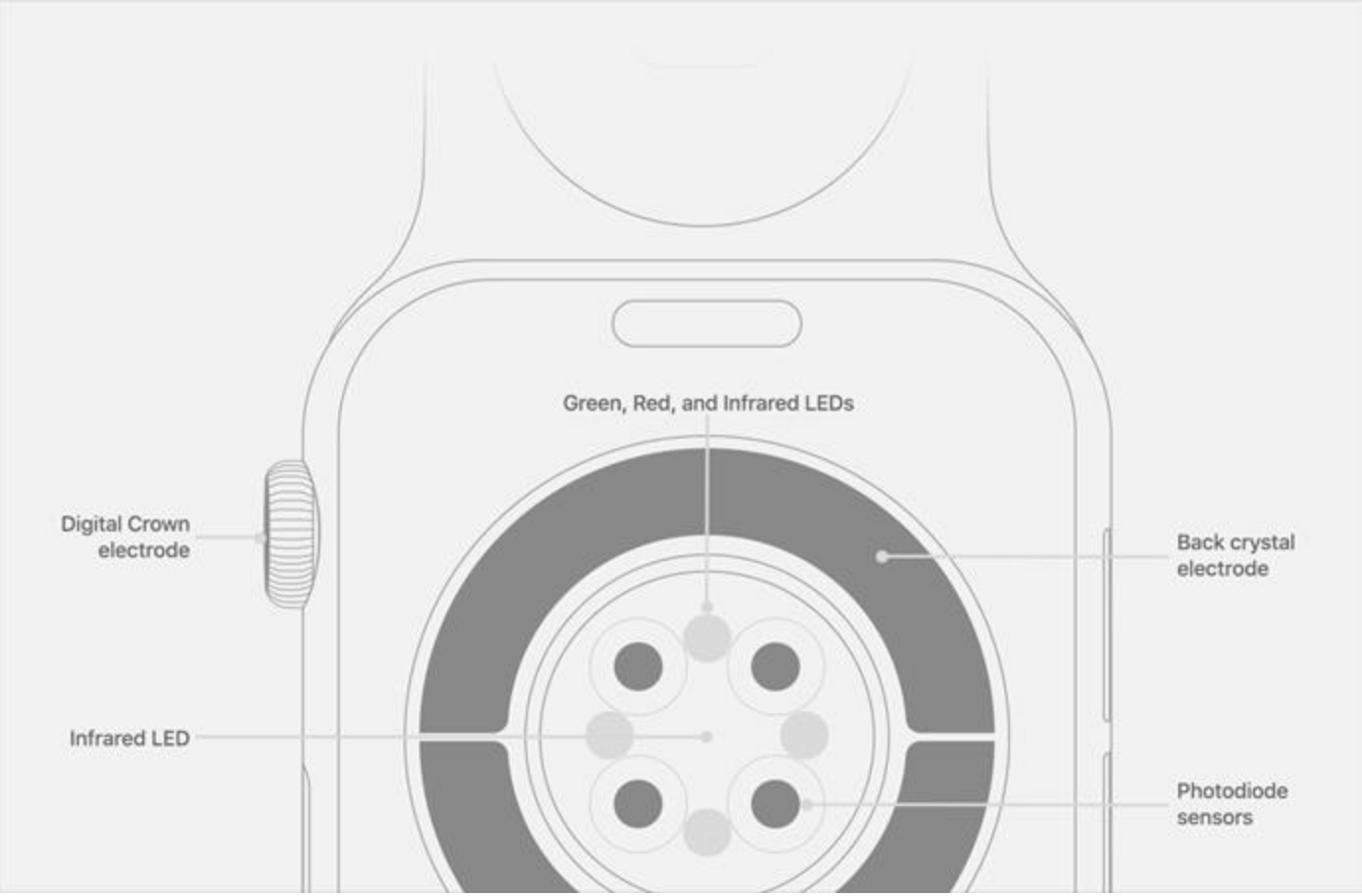
Ability to express context	sensors
Ability to respond	actuators
Intelligent	embedded processing/memory
Energized	battery/AC/energy-harvesting
Identifiable	unique addressing
Locatable	positioning
Reachable	wired/wireless connectivity

Things: Smartphones



Digital health: Smartphone-based monitoring of multiple sclerosis using Floodlight, Nature

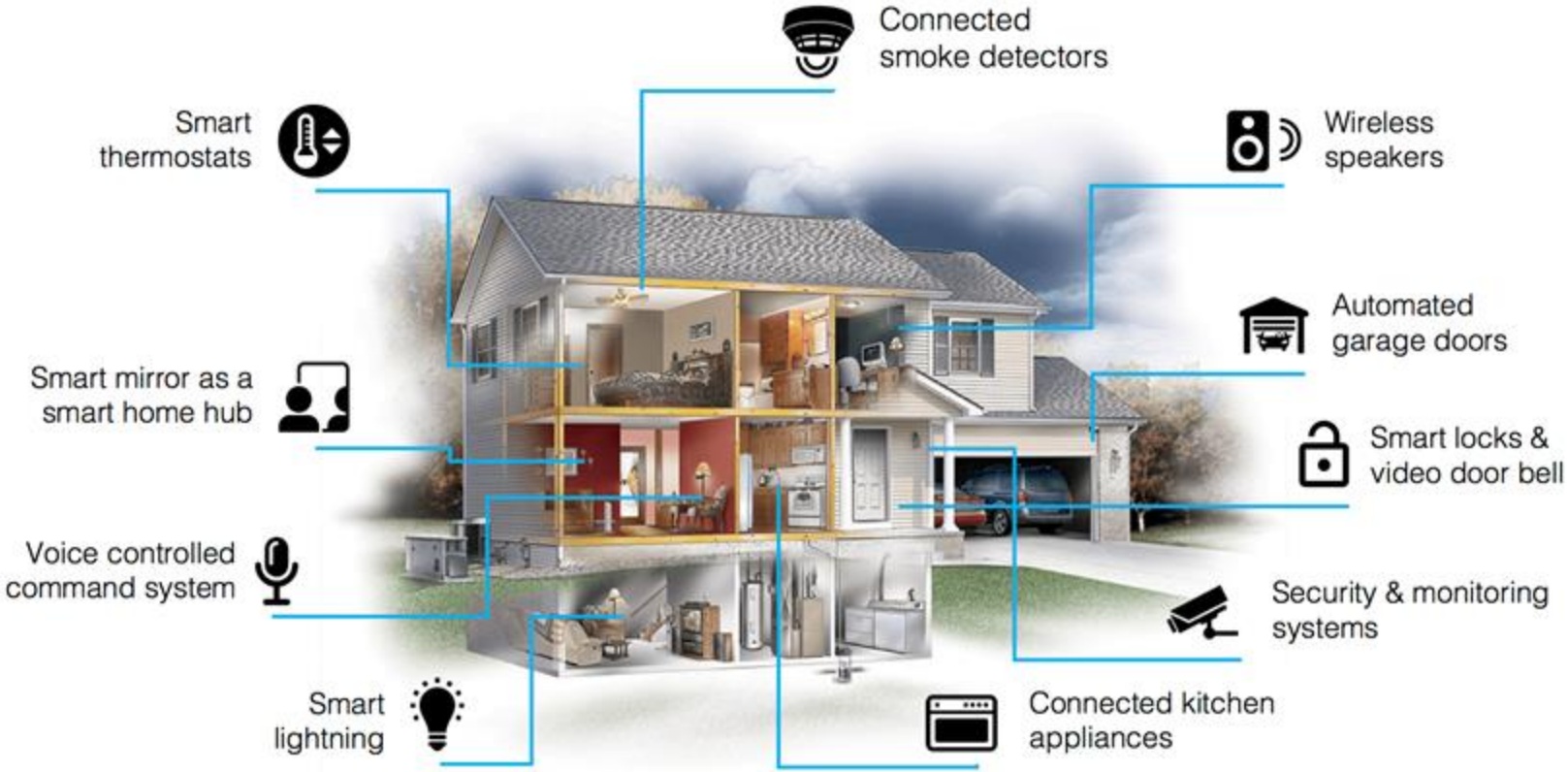
Things: Wearables



Monitor your heart rate with Apple Watch, apple.com

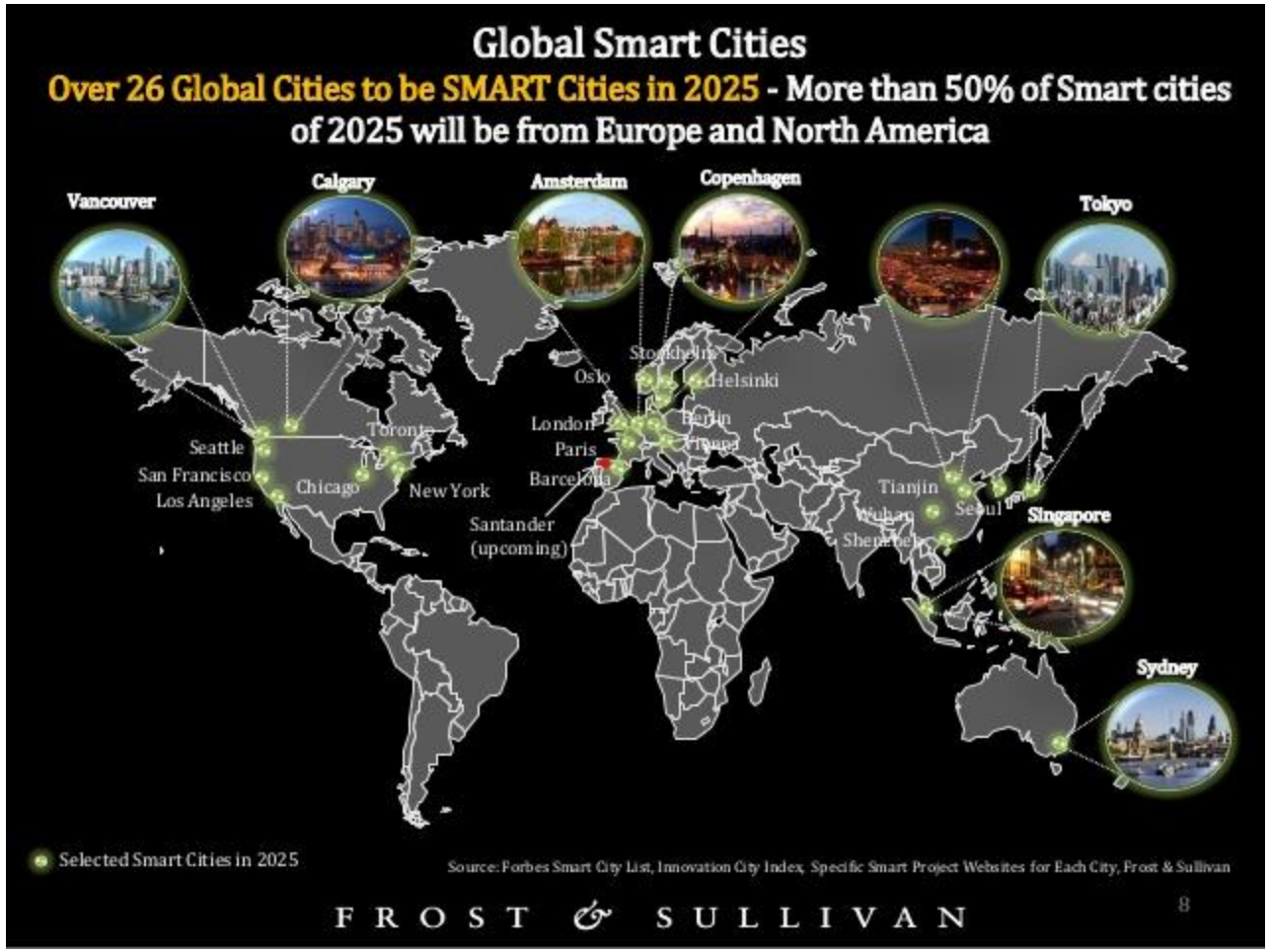
Things: Earables/Hearables

Things: Smart Home



Smart home infographic, dirror.com

Things: Over 26 Smart Cities in 2025



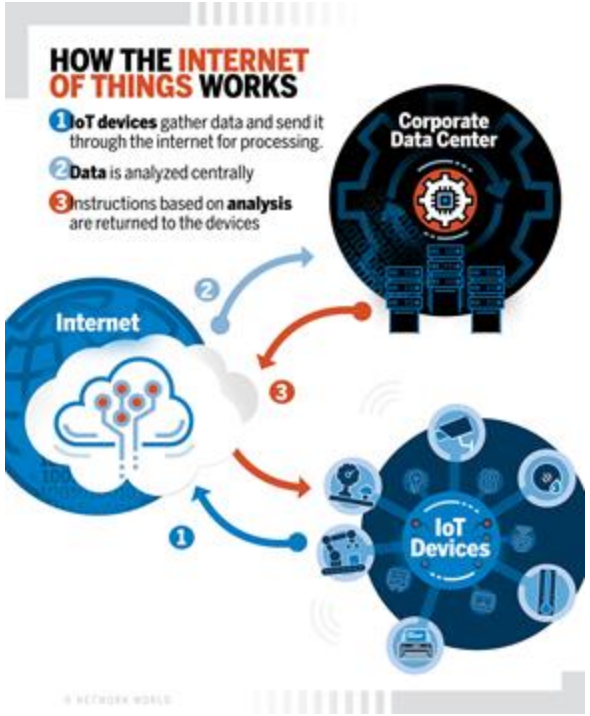
Smart cities' spending on technology in the next six years is expected to reach $327 billion by 2025 from $96 billion in 2019.

Smart Cities to Create Business Opportunities Worth $2.46 Trillion by 2025, Frost & Sullivan, 2020

What are we talking about when we talk about IoT?

- **Connectivity**
  - How to connect billions/trillions of things?
- **Sensing**
  - How to enable those connected things to sense the space?

How Does IoT Work?



IoT works by utilizing all its three main components:

1 SENSING: sensorized things to generate context (data)

2 CONNECTIVITY: interconnect data from things to the internet, and to sense-making infrastructure

3 SENSE-MAKING: converts data to actionable wisdom

IoT: Bridging Cyber and Physical Space

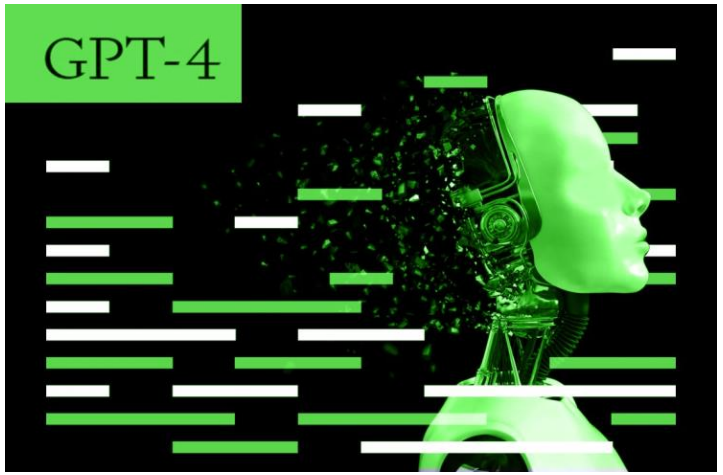
Connecting Billions of Things
Sensing the Environments

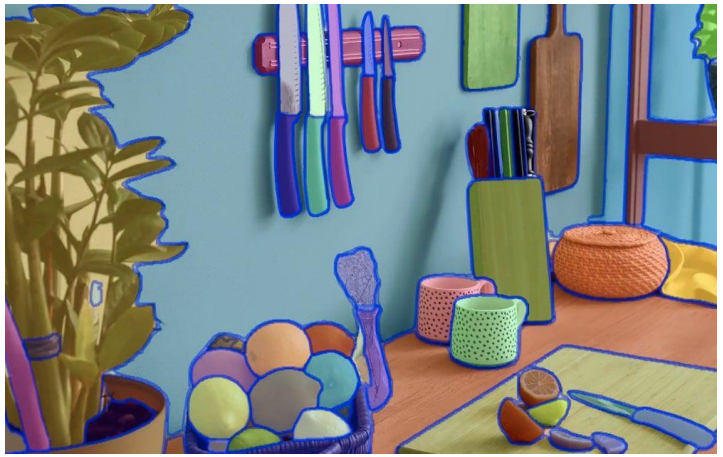
Applications

Networks

Sensing

Today's AI Has Achieved Big Success





Cannot see in the dark or through the wall;
Neither with privacy.

Why Wireless Sensing?

Any other concerns for Vision?

Tesla Vision Update: Replacing Ultrasonic Sensors with Tesla Vision

Safety is at the core of our design and engineering decisions. In 2021, we began our transition to Tesla Vision by removing radar from Model 3 and Model Y, followed by Model S and Model X in 2022. Today, in most regions around the globe, these vehicles now rely on Tesla Vision, our camera-based Autopilot system.

Now it appears radar is back. It's not yet clear which models will get the new radar. The type of radar Tesla intends to market next year is of a frequency that's allocated by the FCC for ADAS use cases, according to Ram Machness, chief business officer at Arbe Robotics, which produces ultra-high-resolution 4D imaging radar.

Tesla had originally filed with the FCC to use the new radar — which is described in filings as "76-77 GHz Automotive Radar" — in its vehicles back in June.

"From the frequency of operation (76-77GHz) as well as the mechanical design of the sensor from Tesla's FCC filing, it

teven Hong, VP and general manager of radar

ch.

Tesla Adding Radar Back

Google Pixel 4

Amazon + Vayyar

Constant protection.
Touchless fall detection.

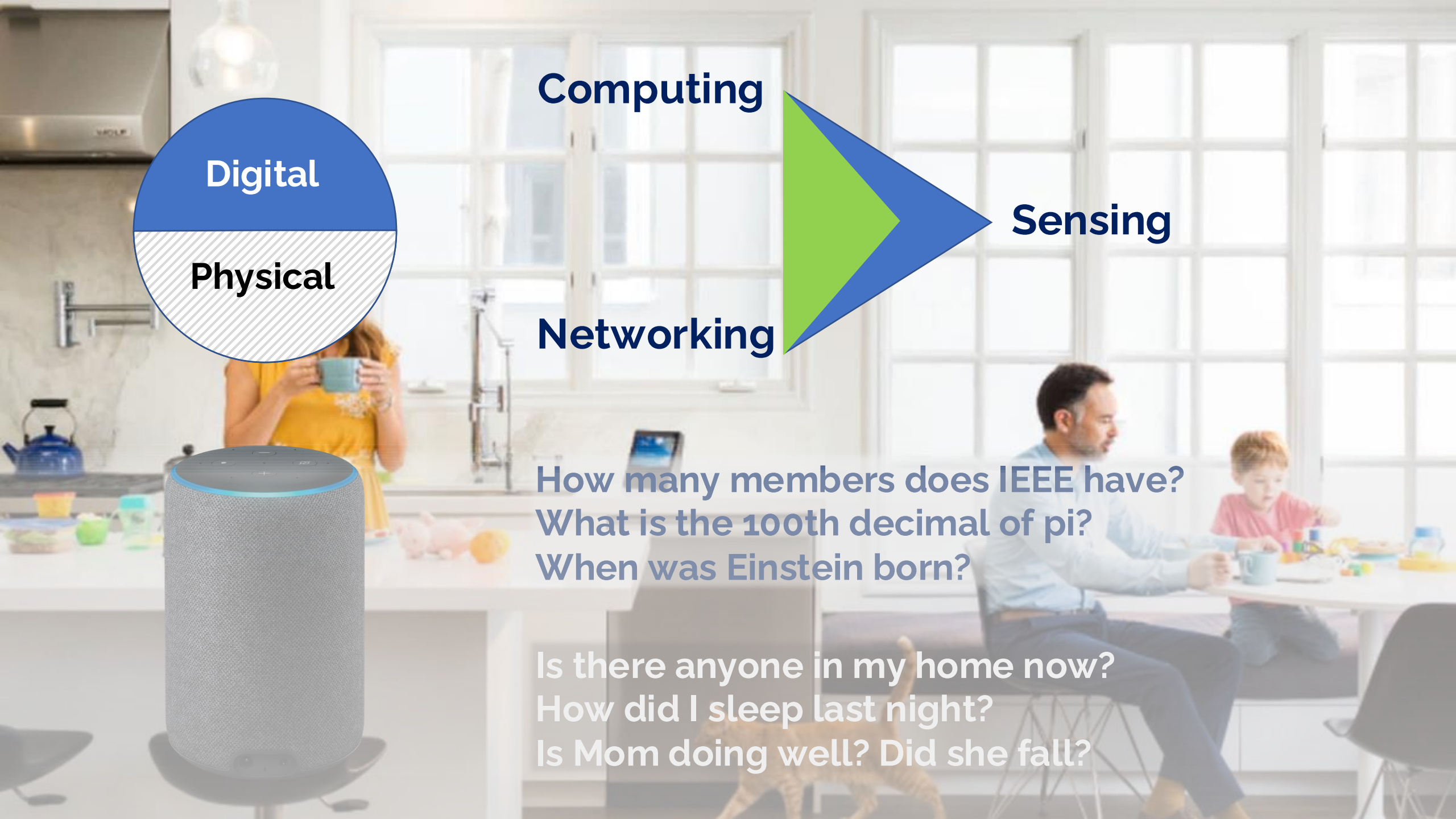
BUY NOW FROM AMAZON

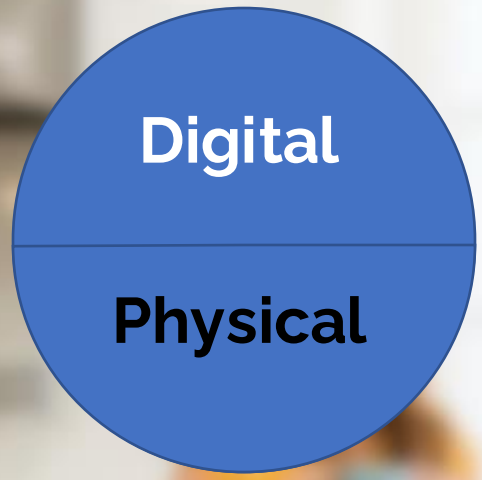
AI Also Has “Big” Problems…

GET SMALL, GET PHYSICAL

TOO BIG

VIRTUAL


Digital
Physical
Computing
Networking
Sensing
How many members does IEEE have?
What is the 100th decimal of pi?
When was Einstein born?
Is there anyone in my home now?
How did I sleep last night?
Is Mom doing well? Did she fall?



Computing

Networking

Sensing

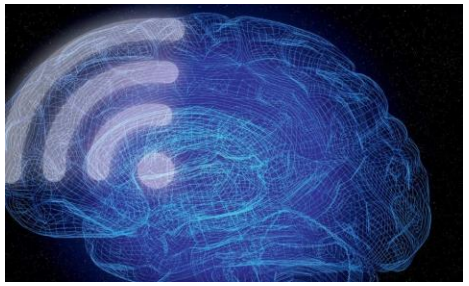
Sensing AI

Equip connected devices with sensing AI to bridge the cyber and physical spaces

What Is Sensing AI?

Computer Vision
deals with how computers understand visual signals

Speech Recognition
enables machines to recognize human speech signals

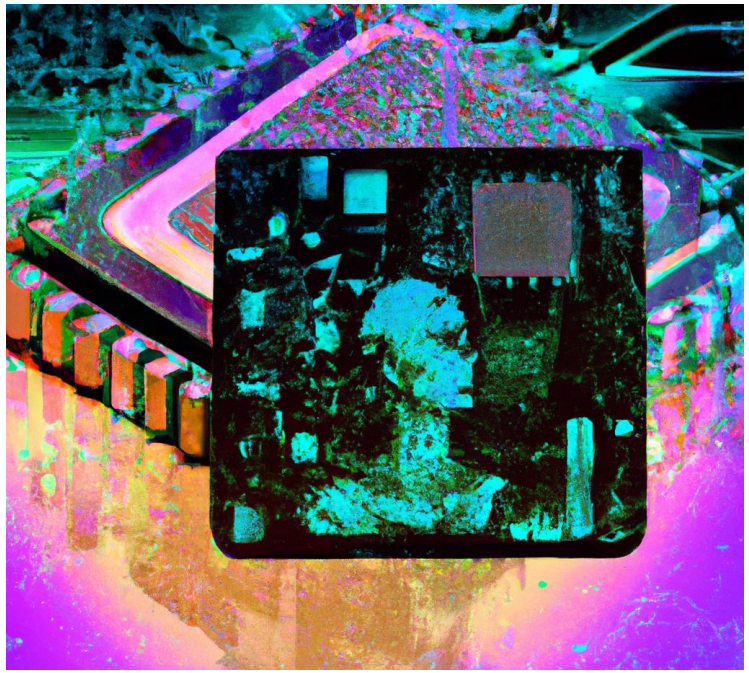


Sensing AI
enables IoT to sense the physical world with various signals

Photo courtesy: *

*: Liu, K., & Wang, B. (2019). Wireless AI: Wireless Sensing, Positioning, IoT, and Communications. Cambridge: Cambridge University Press.

The Era of AI



Computational AI

Perceptual AI

Cognitive AI

@Images generated by DALL·E 2

What are we talking about when we talk about AIoT?

Q: What word do you use to describe a smart person in Chinese?

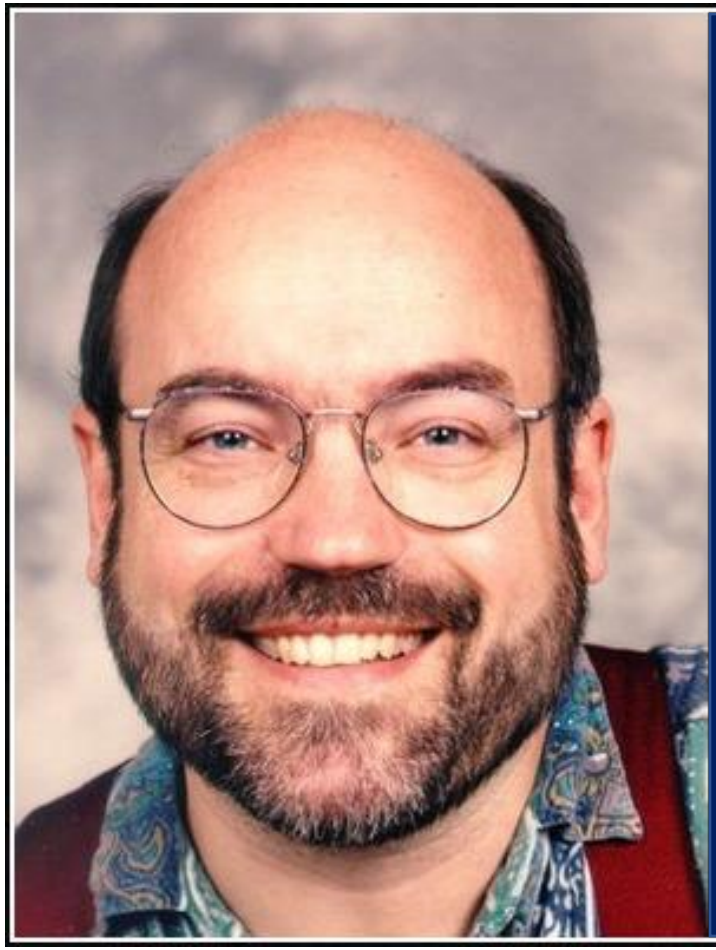
聪明

HUMAN SENSES

MACHINE SENSES

Sensors, CV, Speech Recognition…

Ubiquitous Computing



The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it.

-- Mark Weiser
(The Father of Ubiquitous Computing)

The Computer for the 21st Century

Specialized elements of hardware and software, connected by wires, radio waves and infrared, will be so ubiquitous that no one will notice their presence

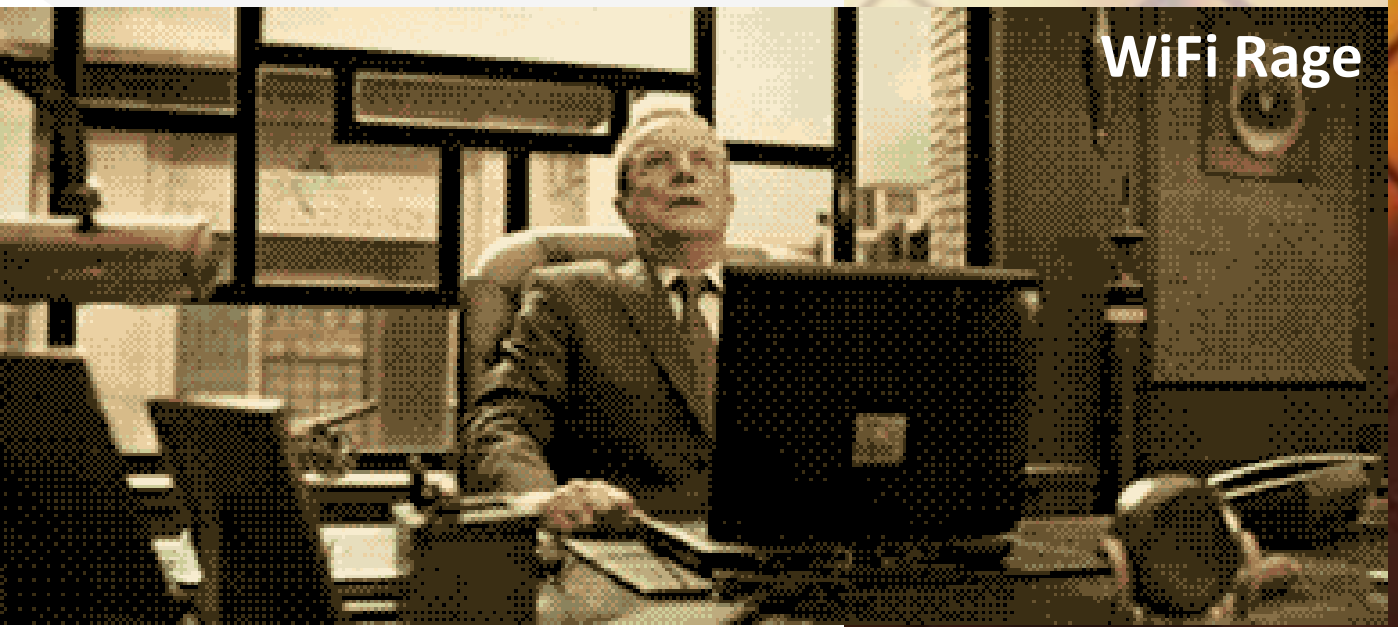
(Scientific American, 1991)

This course dives deeper into the ”most profound sensing technologies that disappear”.

“Is WiFi bad to our health?”

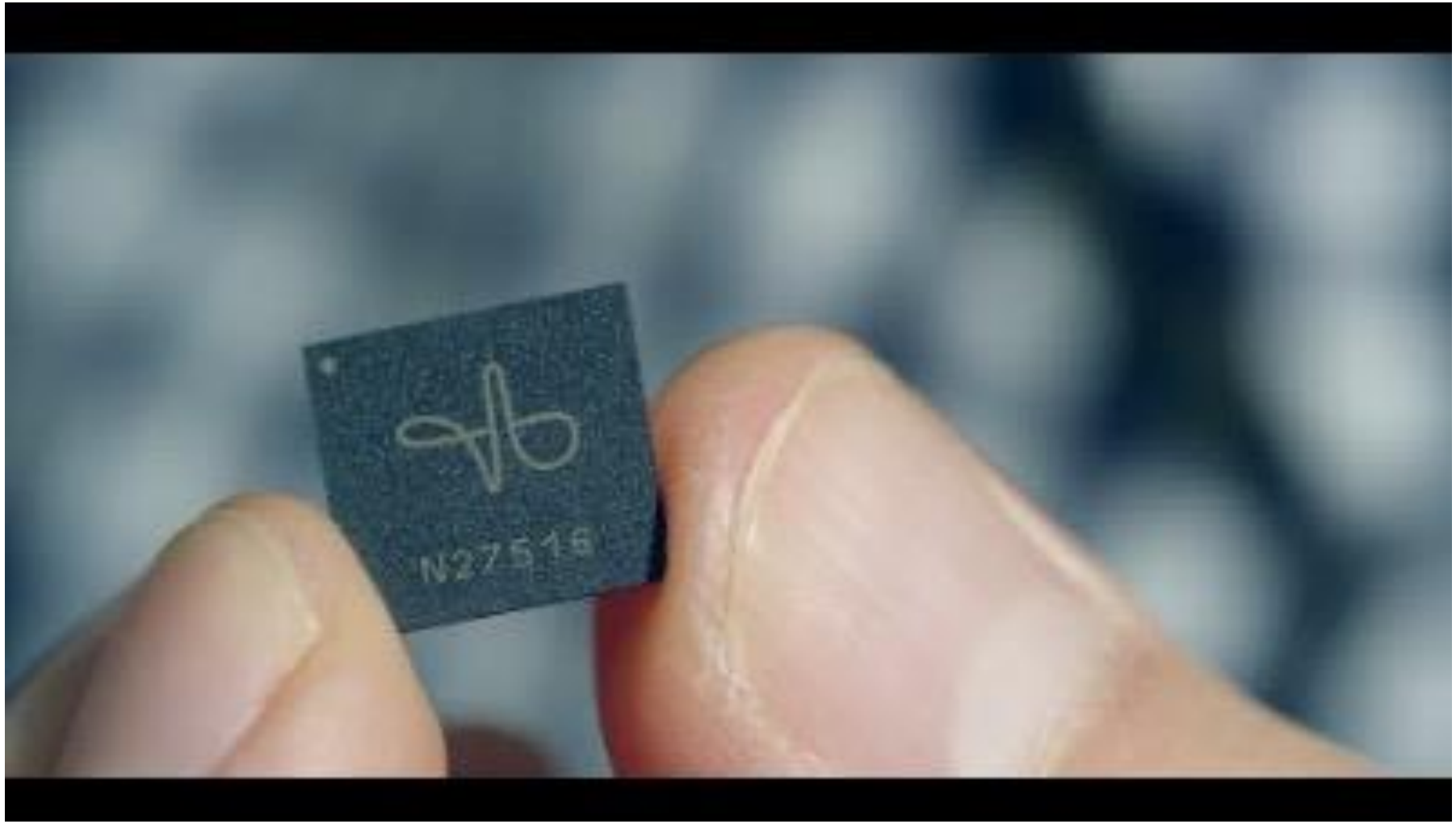
“Yes! Absolutely!

I feel anxiety once there’s NO WiFi!”



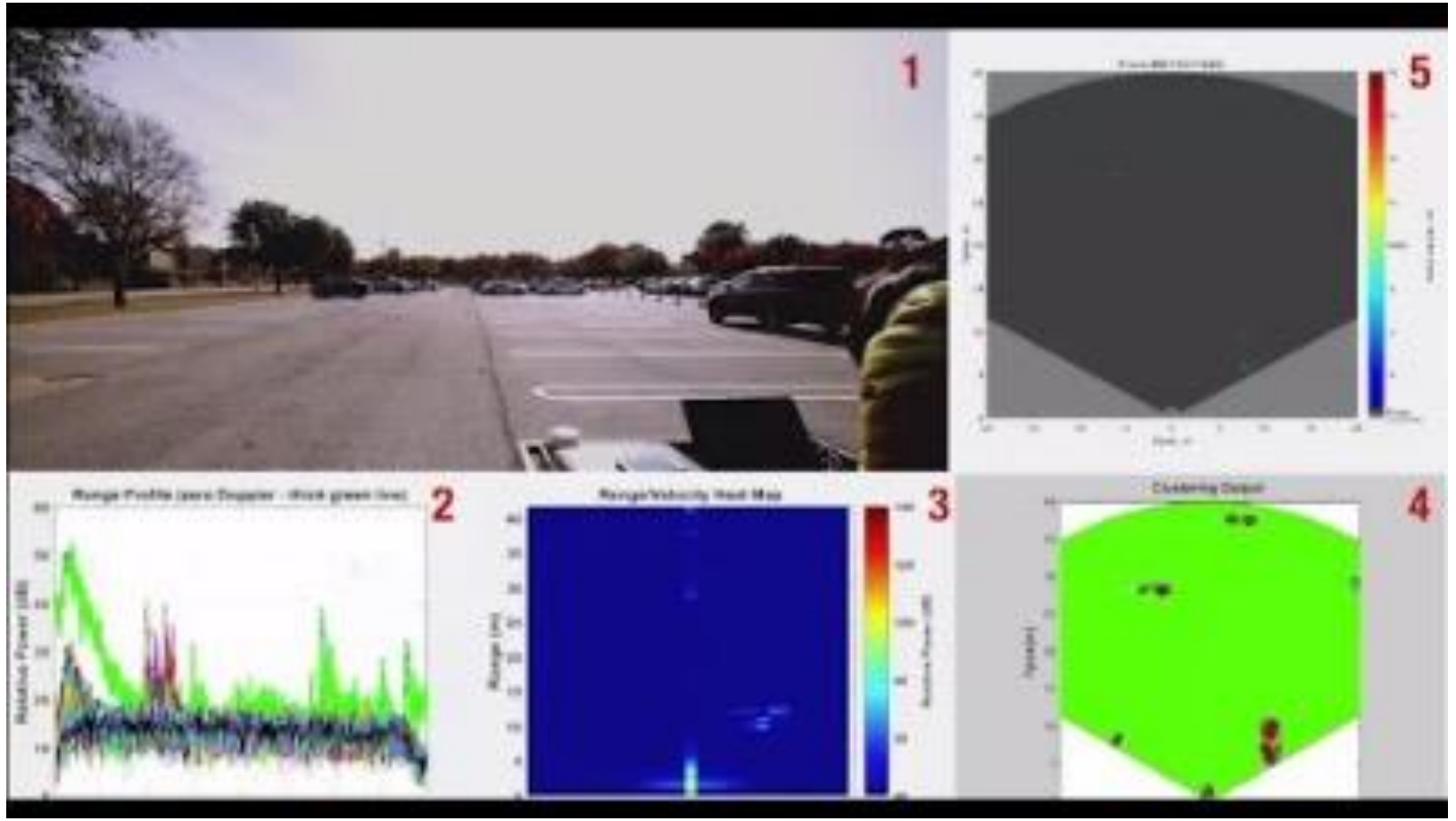

Motion
Bathroom
100
75
50
25
0
60s
30s
0s

Google Soli Project



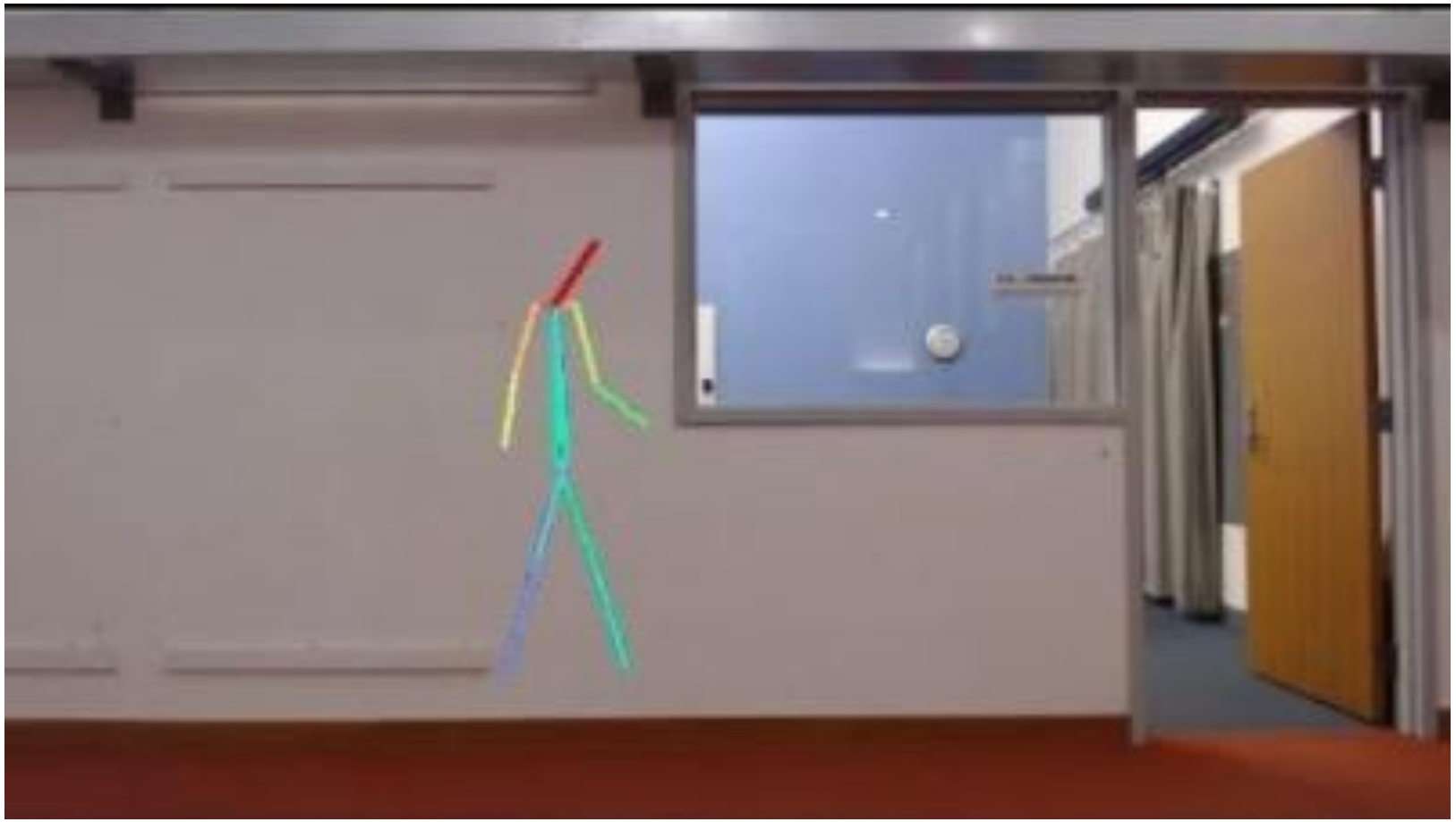
https://www.youtube.com/watch?v=0QNiZfSsPc0

TI mmWave Radar



https://www.youtube.com/watch?v=ziQjbVXcSts&t=140s

RF Pose



https://www.youtube.com/watch?v=HgDdaMy8KNE

[CVPR'18] Through-Wall Human Pose Estimation Using Radio Signals
Mingmin Zhao, et al

WiFi DensePose

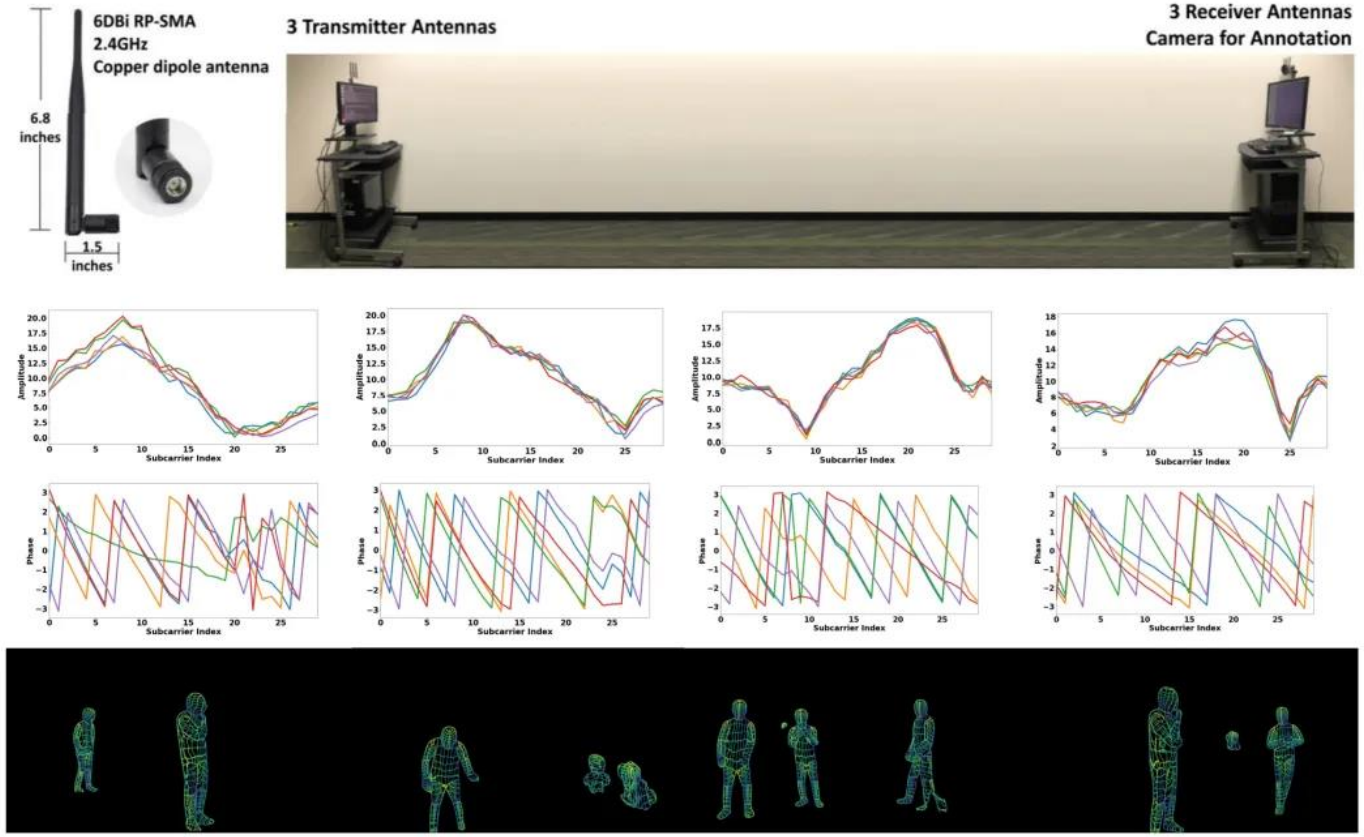
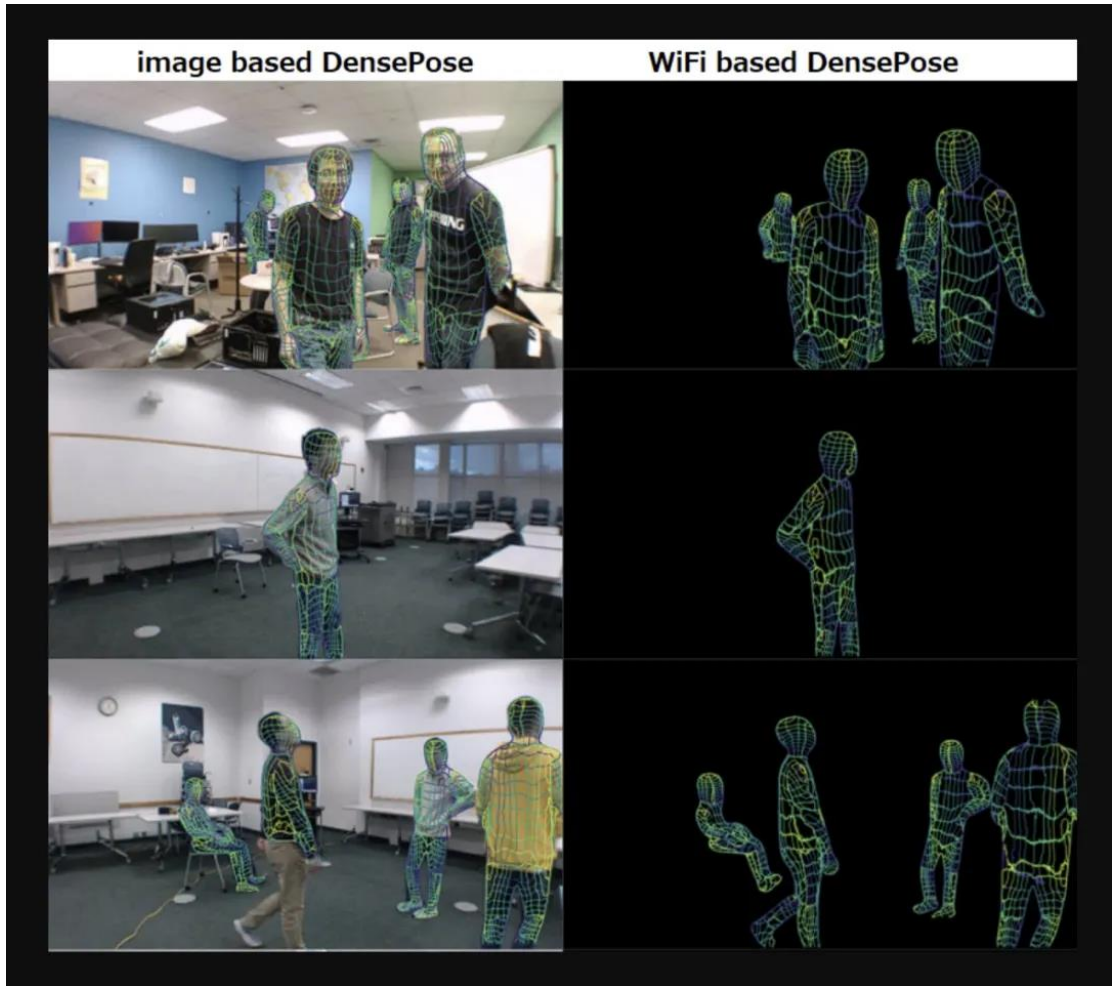


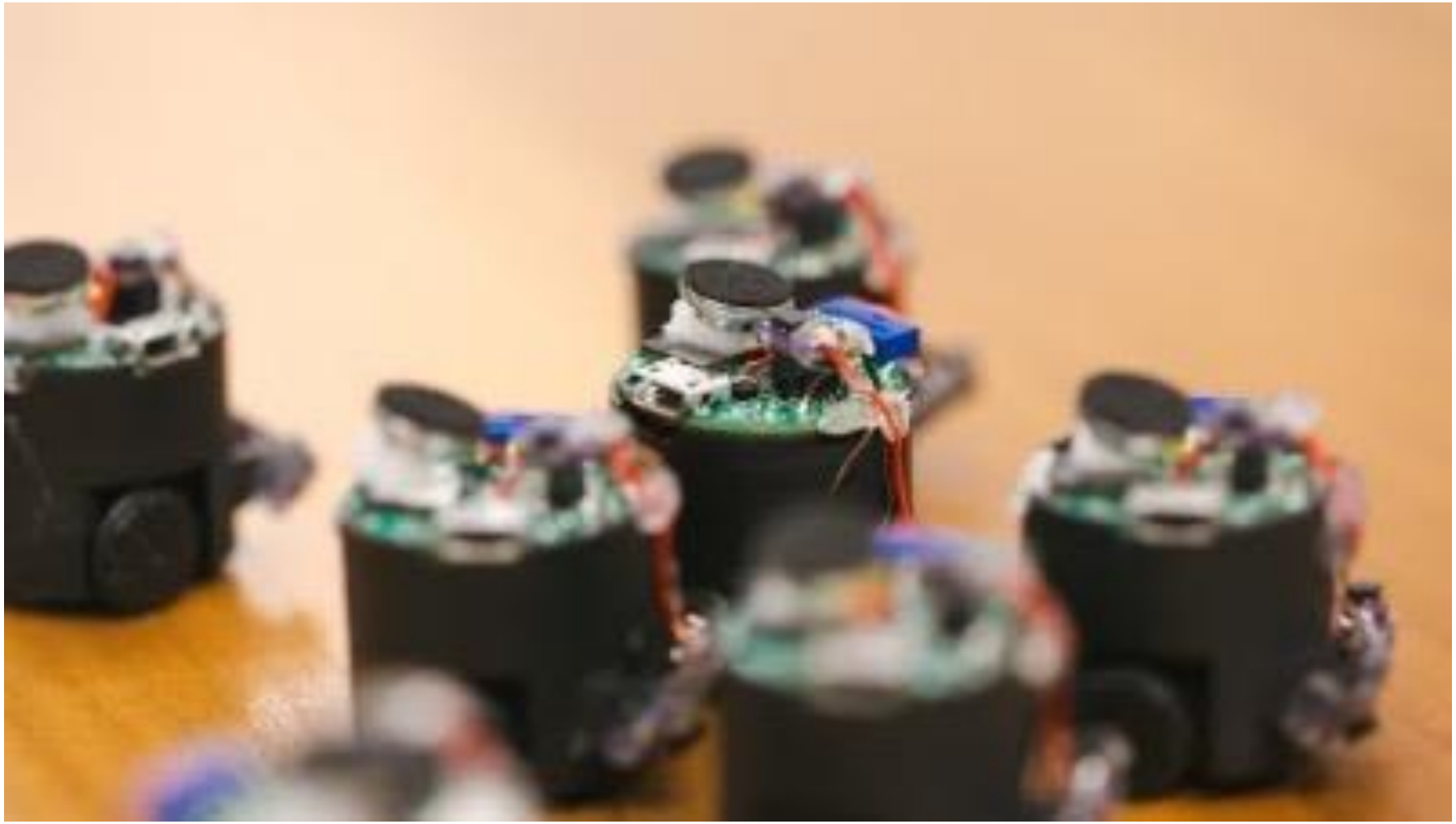
Figure 1: The first row illustrates the hardware setup. The second and third rows are the clips of amplitude and phase of the input WiFi signal. The fourth row contains the dense pose estimation of our algorithm from *only* the WiFi signal.



DensePose From WiFi: https://doi.org/10.48550/arXiv.2301.00250

Augmented Reality with X-Ray Vision

Sound Bubbles



This course dives deeper into the "most profound sensing technologies that disappear".

Specifically, we will learn sensing technologies beyond vision.

In absolute darkness

Through the walls/obstacles

Wireless, **C**ontactless, **S**ensorless

Data Analytics for IoT

- Introduction
- Connectivity
  - Wireless networks
  - Wireless protocols
  - Wireless communication
- IoT Signals & Data
  - Signal basics
  - Time-frequency
  - Periodicity/Correlation
  - Detection
  - Filtering
  - Similarity
- Radio Analytics: mmWave Sensing
  - Range Estimation
  - Doppler Estimation
  - Angle Estimation
- Radio Analytics: Wi-Fi Sensing
  - Channel State Information
  - Signal modeling
  - Motion detection
  - Breathing rate estimation
  - Speed estimation
- Mobile Analytics: Mobile sensing
  - Inertial sensors
  - Sensing applications
- Location Analytics: Localization
  - Fingerprinting
  - Triangulation/Trileteration
  - Inertial Tracking
- Edge AI
  - Deep Wireless Sensing
  - Edge Learning
- Selected advanced topics

Questions?

- Thank you!