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at Northeastern University

EECE5155: Wireless Sensor Networks and the Internet of Things

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Module T2: Data Acquisition

Module T2: Data Acquisition

Outline

- Introduction to Data Acquisition Systems
- Sensors and Sensor (Nano) Technology
- On-chip Sensor Interconnects

Internet of Things: Abstraction

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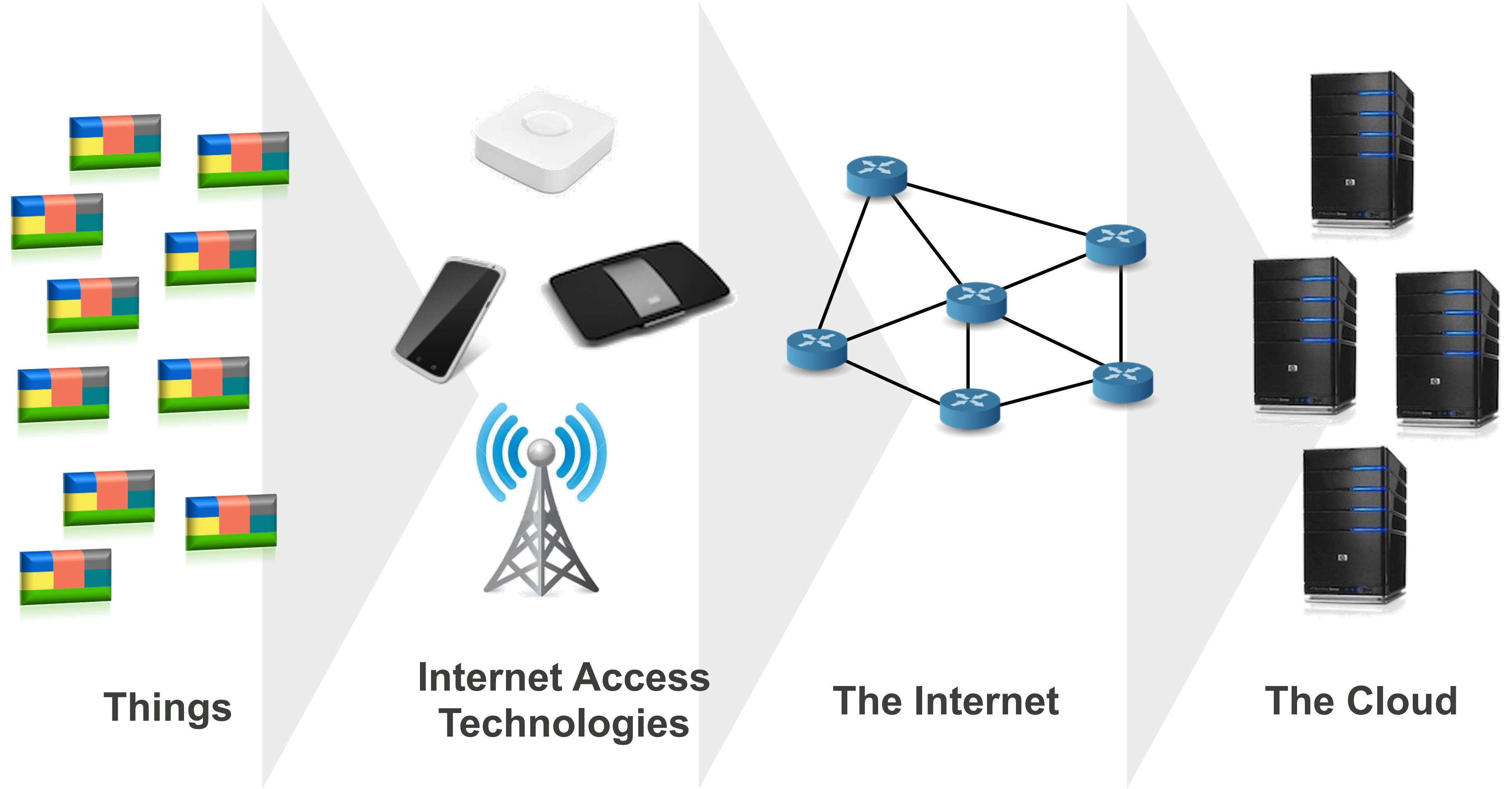

Things = Embedded Systems

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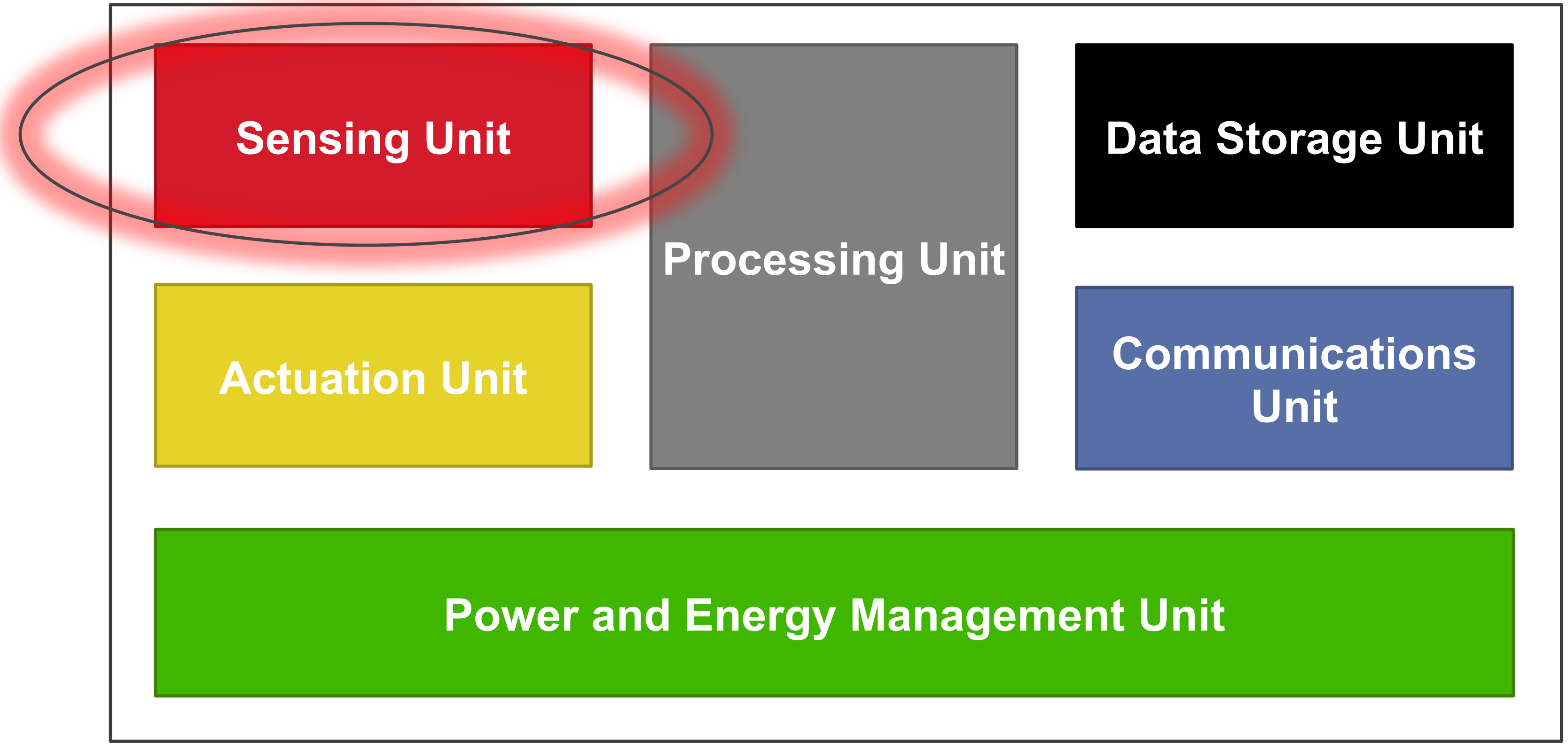

Introduction

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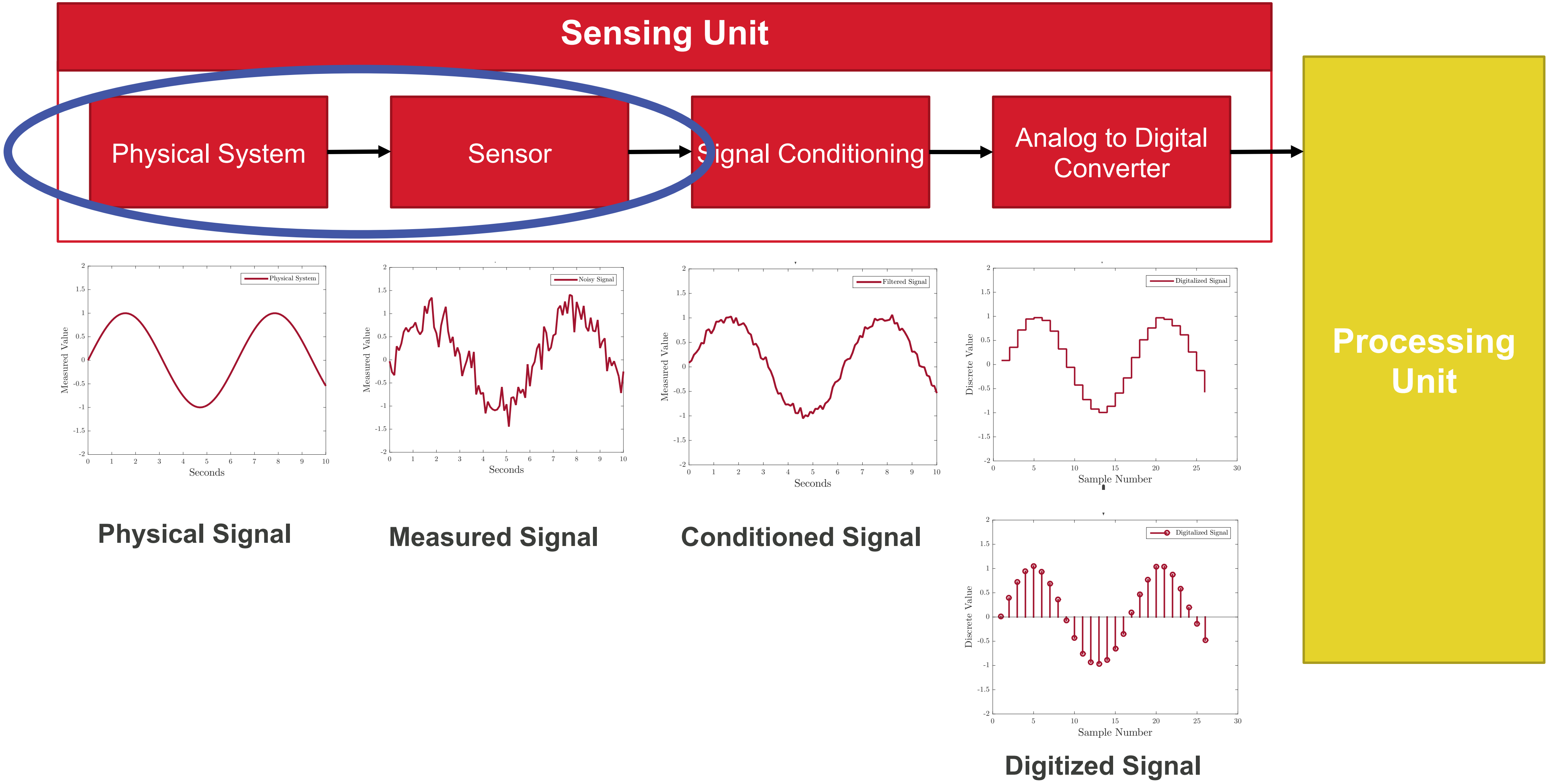
- **Data acquisition (DAQ)** is the process of
  1. Sampling signals that measure real world physical conditions
  2. Converting the resulting samples into digital numeric values that can be manipulated by a processor

- **DAQ systems** are integrated by
  1. Sensors, to convert physical parameters to electrical signals
  2. Signal conditioning circuitry, to convert sensor signals into a form that can be converted to digital values
  3. Analog-to-digital converters, to convert conditioned sensor signals to digital values

Data Acquisition System



Sensors

Sensors and Transducers

- **Sensor:**
  - A device that responds to a stimulus or input quality (referred to as measurand) by generating a processable output
    - A measurand is a quantity intended to be measured
  - From the Latin “sentire,” which means to perceive
- **Transducer:**
  - A device that converts energy from one form to another
    - Remember, energy cannot be created or destroyed, but only converted from one type to another
  - Sensors are one type of transducers

Energy Forms and Their Measurands

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Energy	Measurand
Mechanical	Length, area, volume, linear/angular velocity, linear/angular acceleration, mass flow, force, torque, pressure, acoustic wavelength, acoustic intensity
Thermal	Temperature, specific heat, entropy, heat flow, state of matter
Electrical	Voltage, current, charge, resistance, inductance, capacitance, dielectric constant, polarization, electric field, frequency, dipole moment
Magnetic	Magnetic field intensity, flux density, magnetic moment, permeability
Electromagnetic	Intensity, phase, wavelength, polarization, reflectance, transmittance, refractive index
Chemical	Composition, concentration, reaction rate, pH, oxidation/reduction potential

Sensor Technology

- Independently of the application, all sensors have the same objective:
  - *To achieve accurate and stable monitoring of target measurands*

- A good sensor obeys the following rules:
  - It is sensitive to the measured property
  - It is insensitive to any other property likely to be encountered in its application
  - It does not influence the measured property

- Sensor technology has flourished as the need for physical, chemical and biological recognition has grown

Example: Sensors in a Cellphone

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- **Motion sensors:**
  - Accelerometers
  - Gyroscopes
- **Position sensors:**
  - Orientation sensors
  - GPS → Much more sophisticated, but, still a sensor
- **Environmental sensors:**
  - Barometers
  - Thermometers
  - Photometers (ambient light, proximity sensors)
- **Imaging Sensors:**
  - Camera
- **Others:**
  - Touch sensors (e.g., resistive and capacitive sensors)
  - Fingerprint readers (used to be optical, now capacitive, can be ultrasonic)

How About Nanosensors?

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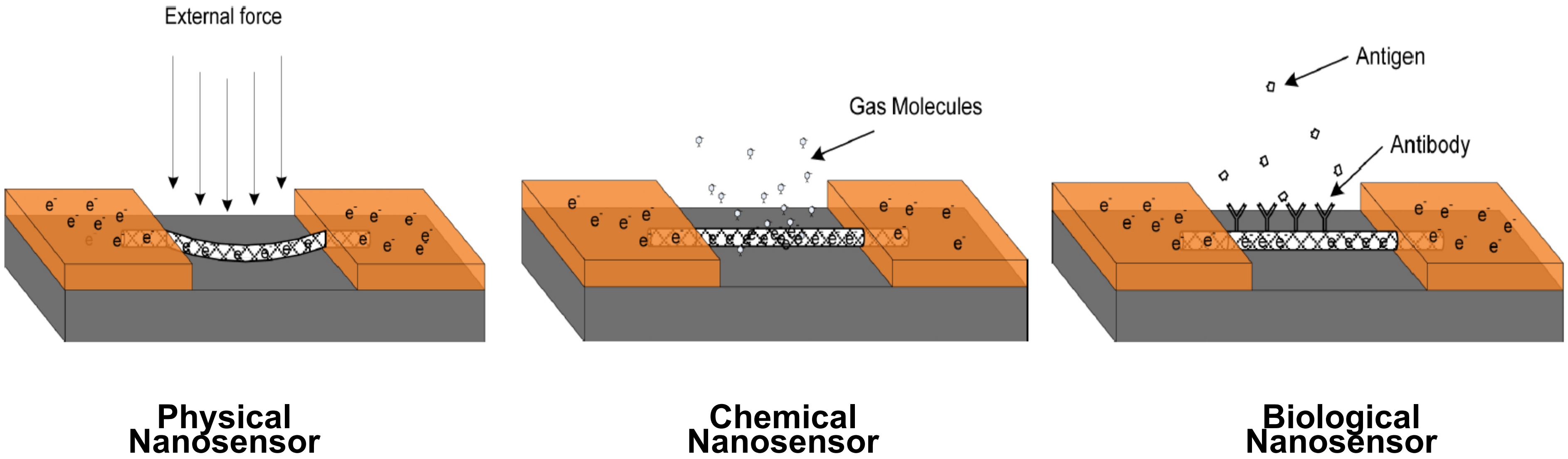
- Nanotechnology is enabling the development of miniature sensors which can measure events at the nanoscale
- Nanosensors are not only smaller, but also able to measure magnitudes with unprecedented accuracy and resolution, e.g.,
  - Single molecule detectors
  - Nanometric cracks in structures



Applications: Health Monitoring Systems

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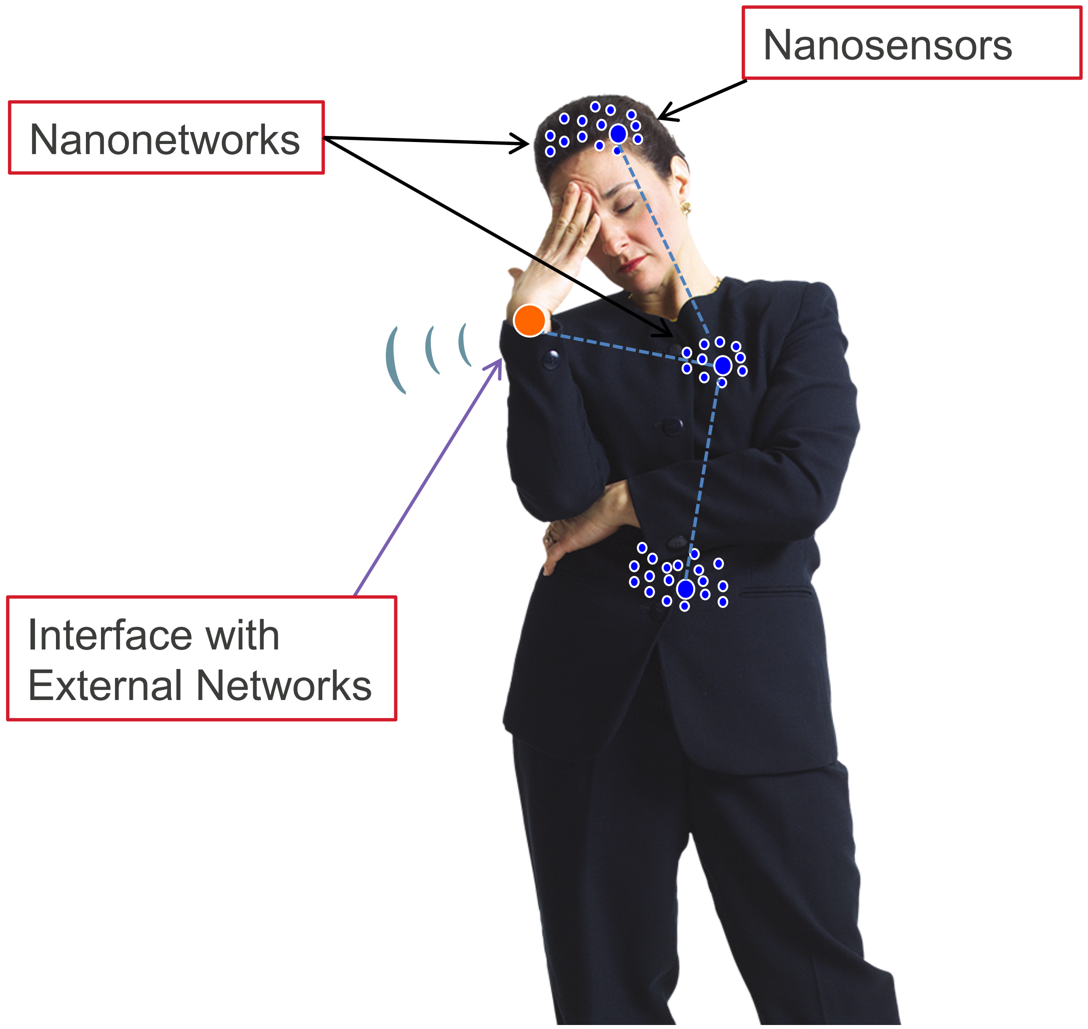
- **Chemical and biological nanosensors are being used for:**
  - Monitoring glucose, sodium, cholesterol
  - Detection of infectious agents
  - Localization of cancerous cells



Applications:
Chemical and Biological Attack Prevention

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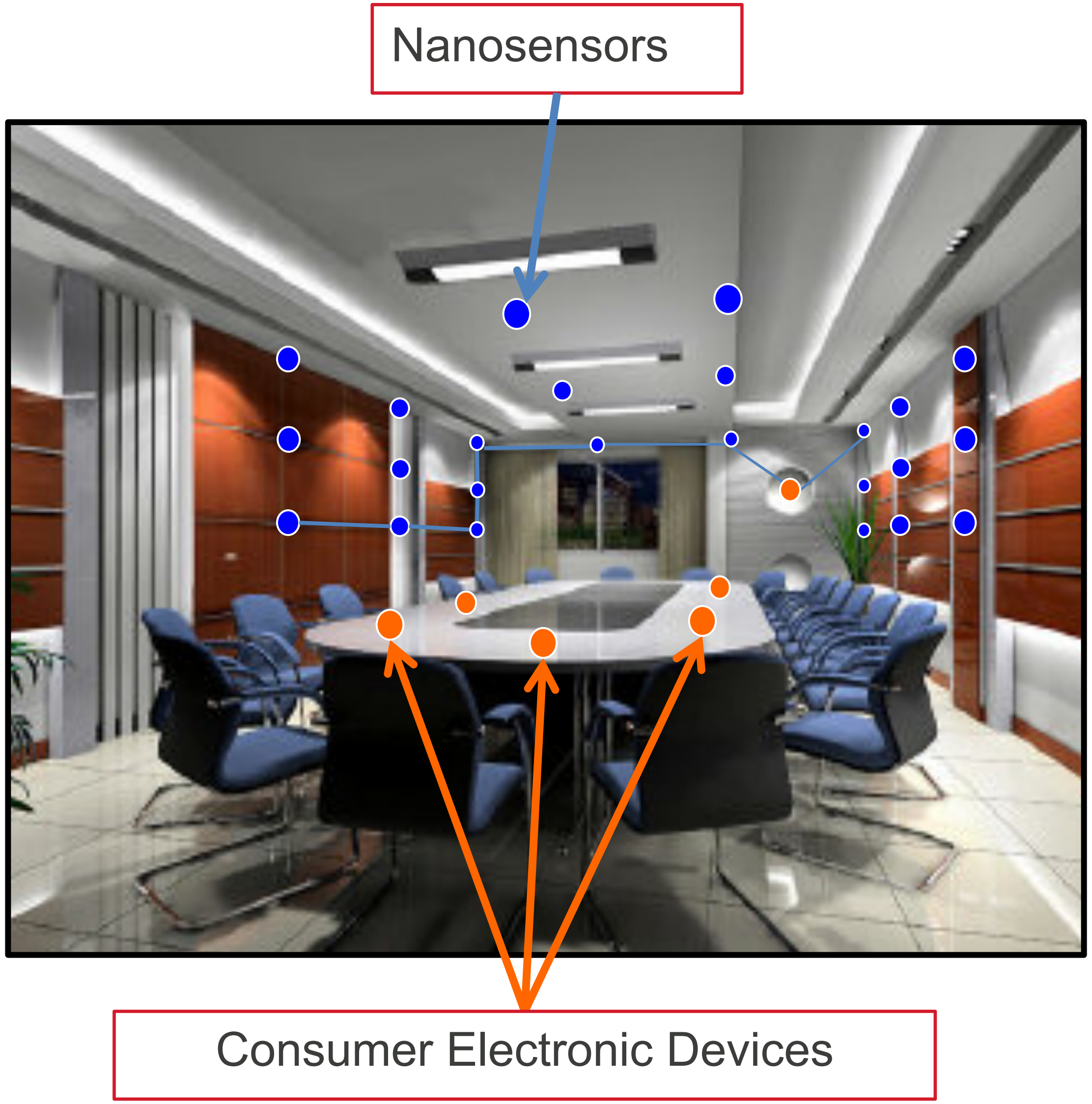

- Nanosensors can detect biological and chemical hazards
    - Faster
    - In lower concentrations

  than existing microsensors

Applications: The Internet of Nano-Things

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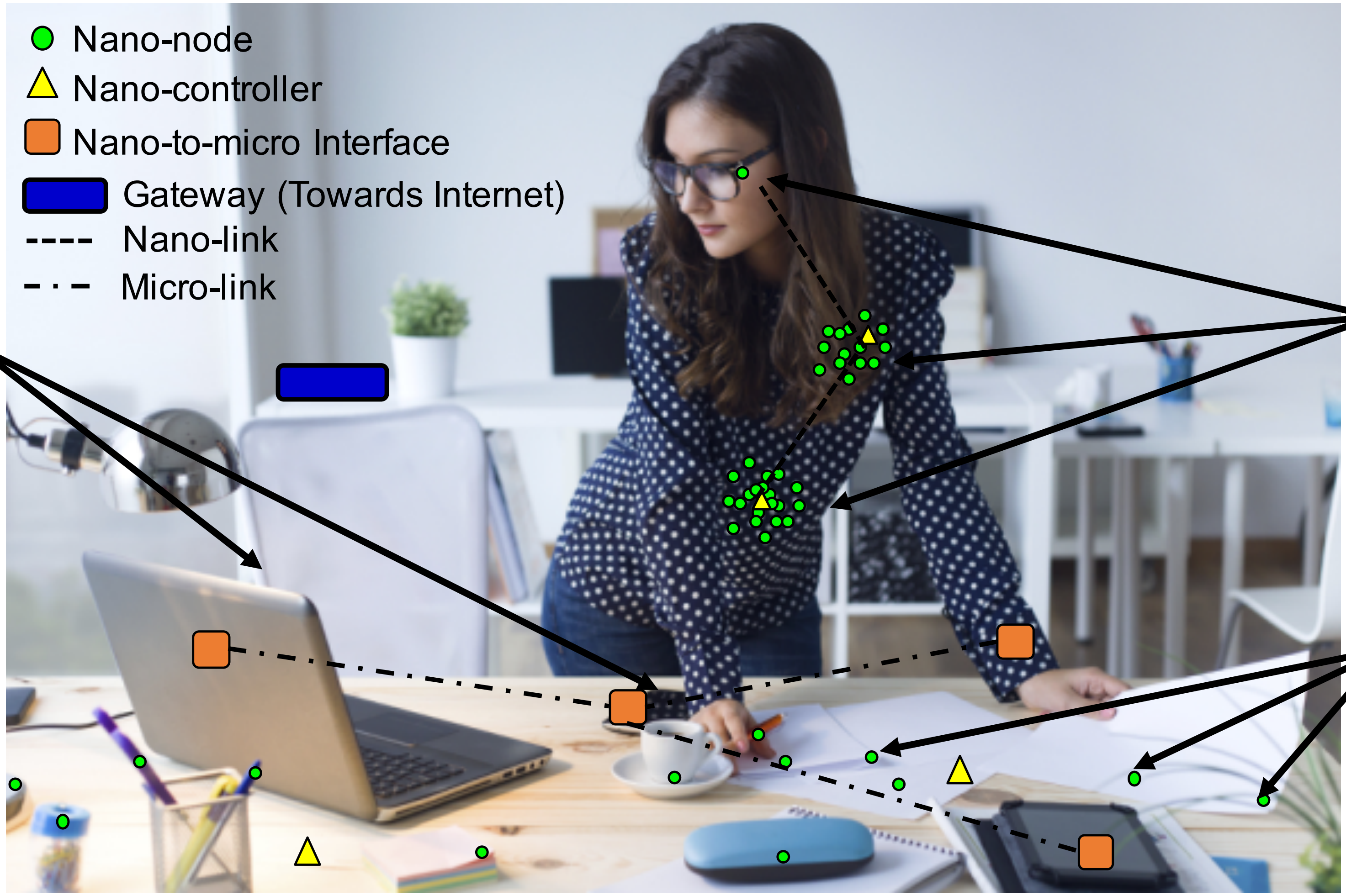

Personal Electronic Devices

Wearable / Over-the-body Nano-Things

Other Nano-Things

How far are we? (2017)

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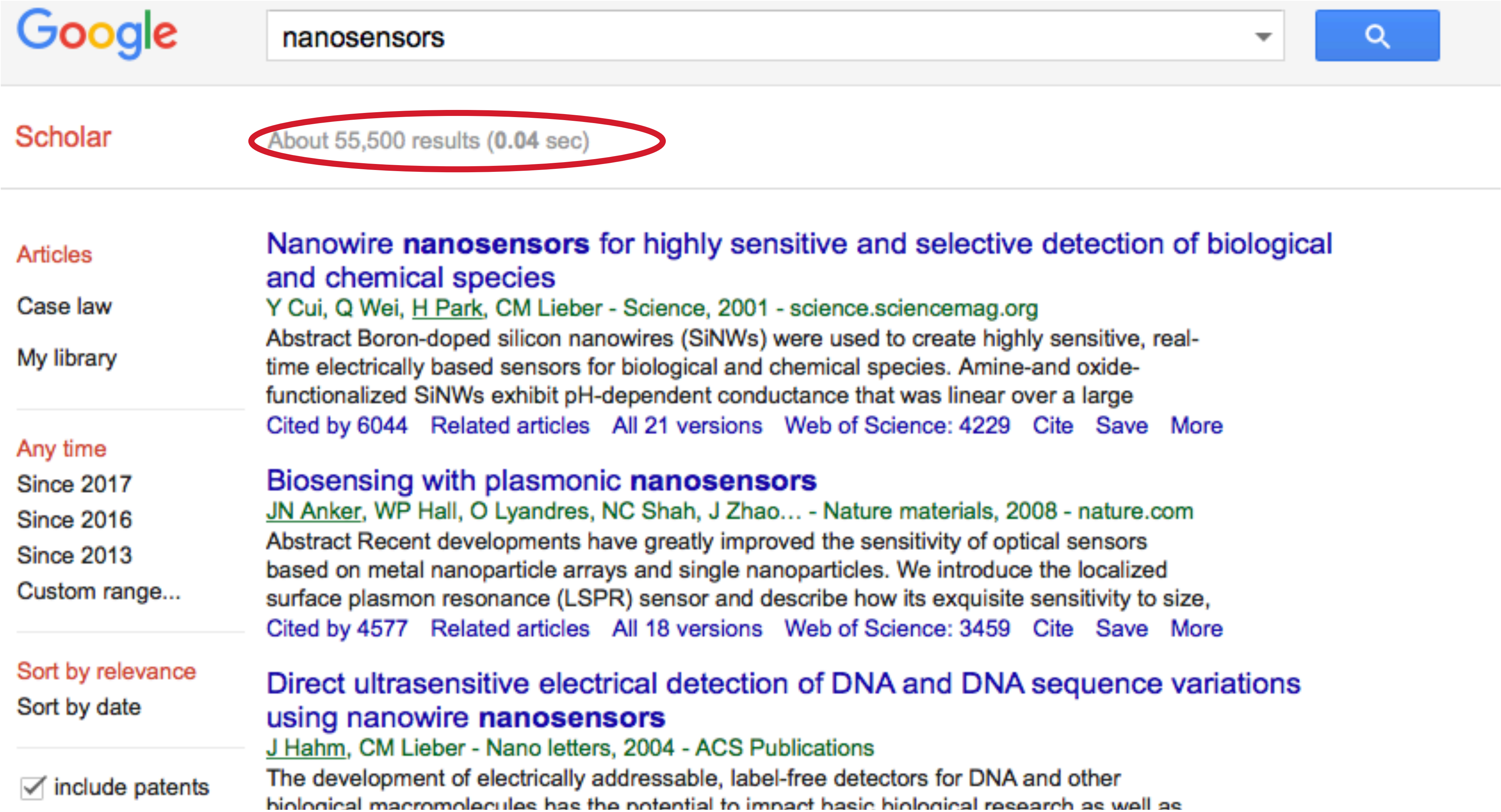

How far are we? (2018)

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Google Scholar

nanosensors

Articles

About 66,900 results (**0.09** sec)

Any time
Since 2018
Since 2017
Since 2014
Custom range...

Sort by relevance
Sort by date

include patents
include citations

Create alert

Nanowire nanosensors for highly sensitive and selective detection of biological and chemical species
Y Cui, Q Wei, H Park, CM Lieber - Science, 2001 - science.sciencemag.org
Boron-doped silicon nanowires (SiNWs) were used to create highly sensitive, real-time electrically based sensors for biological and chemical species. Amine-and oxide-functionalized SiNWs exhibit pH-dependent conductance that was linear over a large …
Cited by 6416 Related articles All 20 versions

Biosensing with plasmonic nanosensors
JN Anker, WP Hall, O Lyandres, NC Shah… - … And Technology: A …, 2010 - World Scientific
Recent developments have greatly improved the sensitivity of optical sensors based on metal nanoparticle arrays and single nanoparticles. We introduce the localized surface plasmon resonance (LSPR) sensor and describe how its exquisite sensitivity to size, shape …
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Photochemical Sensing of NO_2 with SnO_2 Nanoribbon Nanosensors at Room

How far are we? (2020)

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Articles — About 80,400 results (**0.05** sec)

Any time
Since 2020
Since 2019
Since 2016
Custom range...

Sort by relevance
Sort by date

include patents
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Create alert

Nanosensors — [PDF] googleapis.com
CM Lieber, H Park, Q Wei, Y Cui, W Liang - US Patent 7,129,554, 2006 - Google Patents
US PATENT DOCUMENTS 6,902,720 B1 6/2005 McGimpsey 6,946,197 B1 9/2005 Yadav et al. 5,607,876 A 3/1997 Biegelsen et al. 6.958. 216 B1 10/2005 Kekkey et al. 5,620,850 A 4/1997 Bamdad et al. 6,962,823 B1 11/2005 Empedocles et al. 5,640,343 A 6/1997 …
Cited by 617 Related articles All 4 versions

[HTML] Nanowire **nanosensors** — [HTML] sciencedirect.com
F Patolsky, CM Lieber - Materials today, 2005 - Elsevier
The detection of biological and chemical species is central to many areas of healthcare and the life sciences, ranging from uncovering and diagnosing disease to the discovery and screening of new drug molecules. Hence, the development of new devices that enable …
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Biosensing with plasmonic **nanosensors** — [PDF] researchgate.net
JN Anker, WP Hall, O Lyandres, NC Shah… - … and Technology: A …, 2010 - World Scientific
Recent developments have greatly improved the sensitivity of optical sensors based on metal nanoparticle arrays and single nanoparticles. We introduce the localized surface plasmon resonance (LSPR) sensor and describe how its exquisite sensitivity to size, shape …
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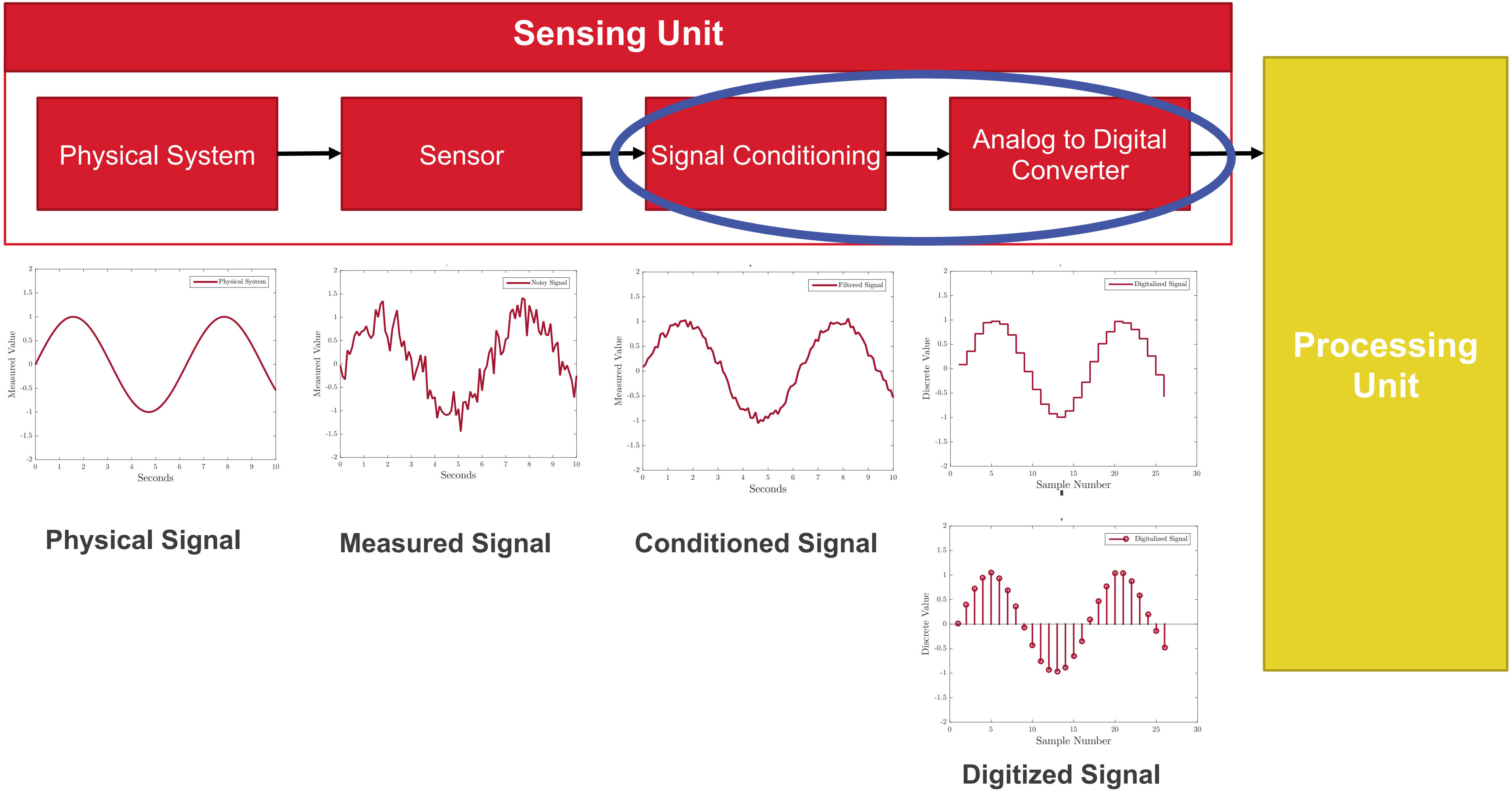
Data Acquisition System



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Signal Conditioning

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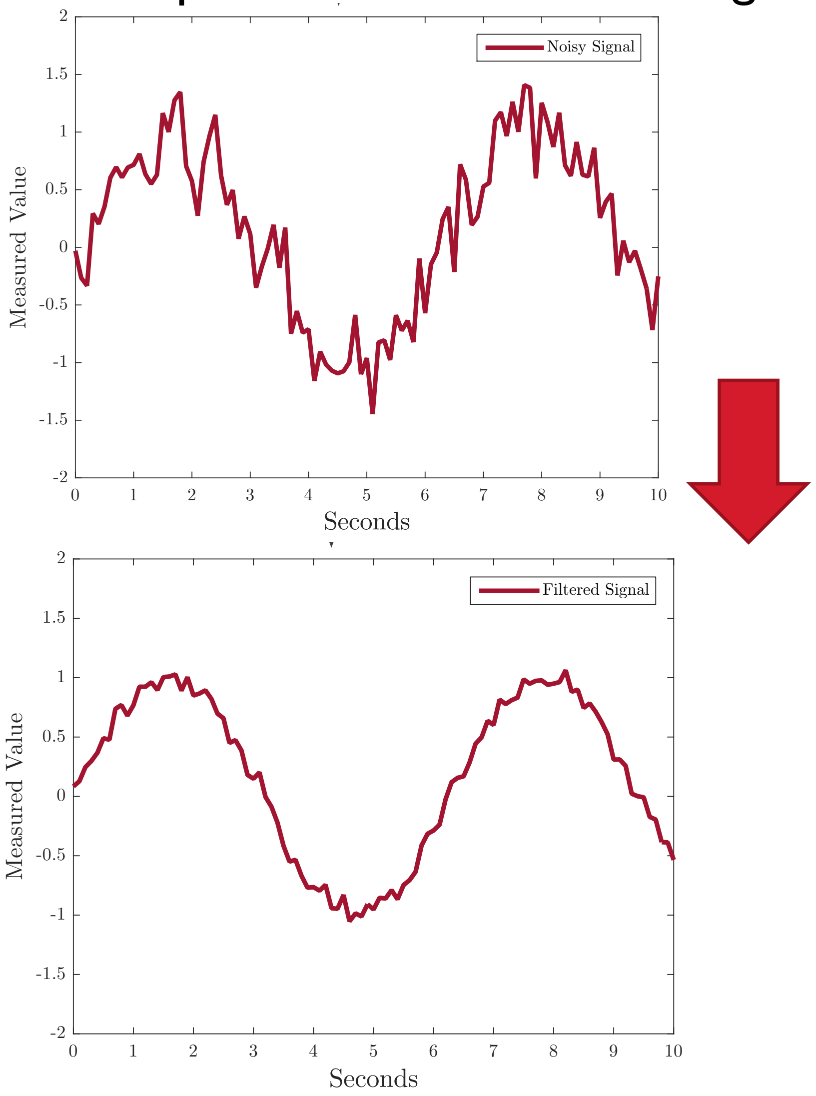
- Manipulation of the analog signal in such a way that it meets the requirements of the next stage:
  - Filtering
    - Noise reduction
    - Interference reduction
  - Amplification / Attenuation

- All in the analog domain…



Filtering

Analog VS Digital Signal Processing

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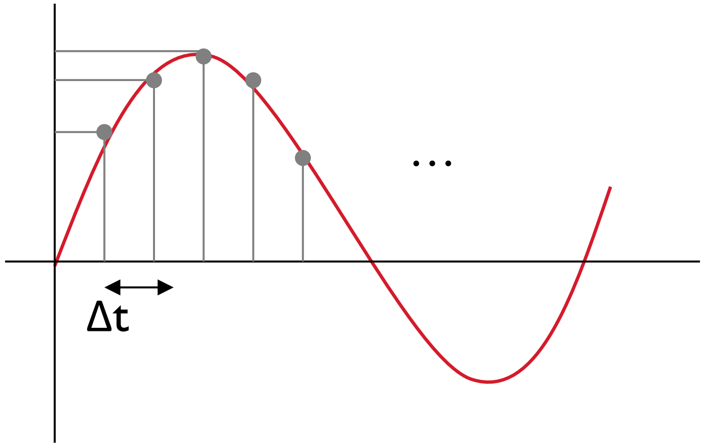
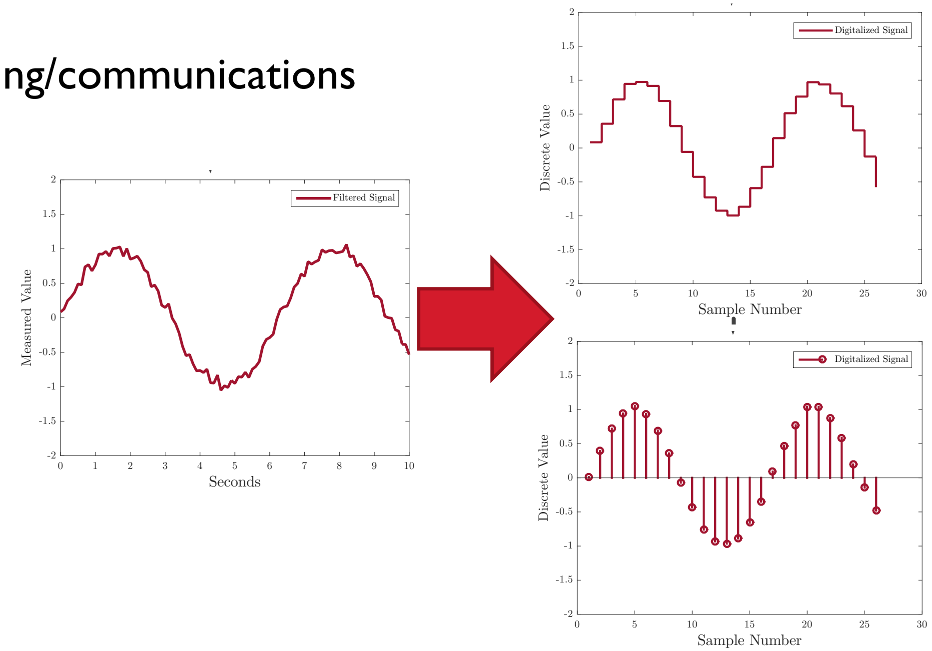
Analog Signal Processing	Digital Signal Processing
Based on the use of analog circuit elements, i.e., resistors, capacitors, transistors, diodes, etc.	Based on the use of digital signal processors (require prior analog to digital conversion)
Rely on the ability of the analog system to solve differential equations	Rely on numerical calculations applied to the digitized signal values
Real time operation	Might not be in real time
Single purpose system	Flexibility: A digital signal processor can be programmed to implement very different solutions
Results might change based on system status (e.g., fluctuations of temperature)	Repeatability: The same operation can be repeated multiple times, the result will always be the same
Cost?	Cost?

Analog to Digital Converter (ADC)

- Performs two operations:
  1. Samples the signal in time
     - Key metric: **sampling frequency**
       - Nyquist Theorem: $f_s > 2B$ – otherwise: aliasing
  2. Quantizes the sample amplitude
     - Key metric: **resolution**
       - Usually given in bits, e.g., N=8, 2^8 = 256 levels



- One of the major bottlenecks for high-speed digital signal processing/communications
  - Fastest ADCs in the market:
    - ~100 GSamples/second, 6 bits
    - ~92 GSamples/second, 8 bits
    - …
    - ~3 GSamples/second, 14 bits



Data Acquisition System

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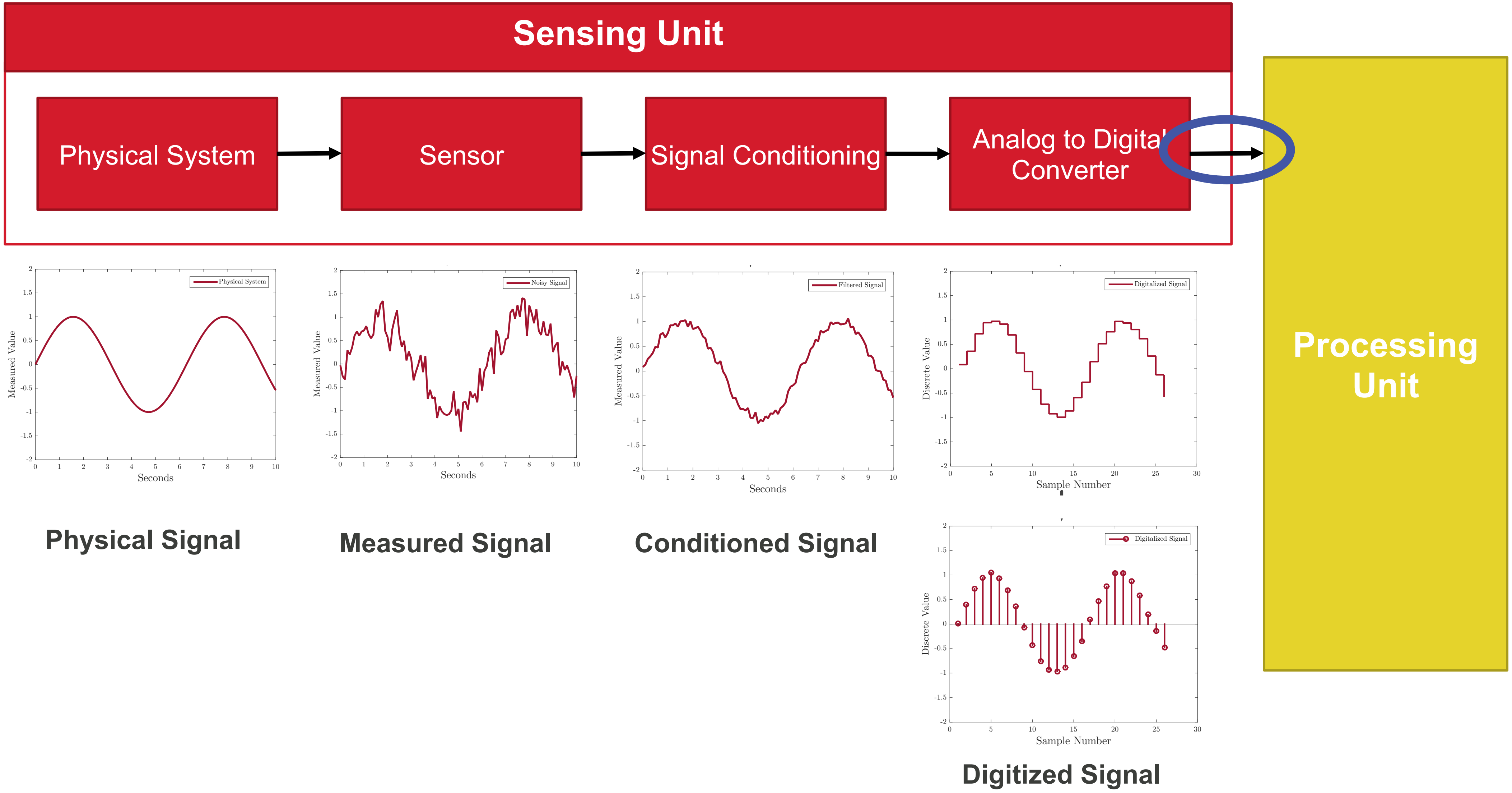

Sensor Interconnects

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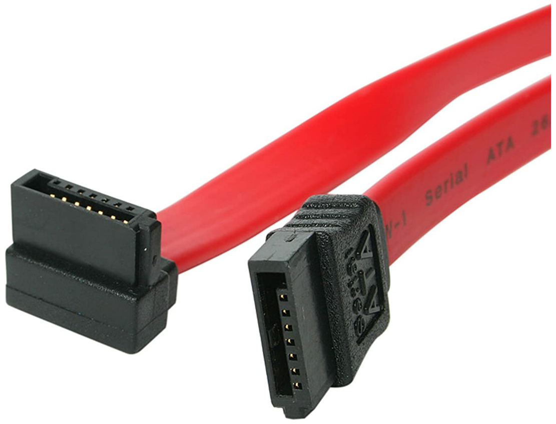
- Enable the communication between the sensing unit with the processing unit

- **Classification:**
  - Analog vs Digital
  - Serial vs Parallel
  - Wired vs Wireless
  - …

Serial Communications

- Data is sent "one bit at a time"
- **Examples:** (alphabetical order, E=external, I=internal)
  - CAN (E)
  - FireWire (IEEE 1394, E)
  - InfiniBand (I/E)
  - I^2C (I)
  - PCI Express (I)
  - RS-232 (E)
  - Serial ATA (I, SATA, but there is eSATA)
  - Universal Serial Bus (USB, E)



Parallel Communications

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- Multiple bits are transmitted simultaneously
- **Examples:** (alphabetical order)
  - CAMAC (I)
  - ISA (I)
  - ATA (I)
  - SCSI (I/E)
  - PC Card (E)
  - Conventional PCI (I)
  - And many more "older" standards…
    - Abandoned mainly because of the cost and size:
      - Multiple transceivers, cables, ...

Our Focus: On-chip Interconnects

- Some of the most popular on-chip communication standards include:
  - SPI
  - I^2C
  - UART

Serial Peripheral Interface Bus (SPI)

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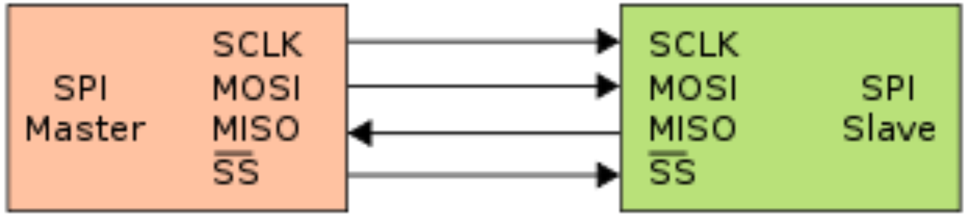
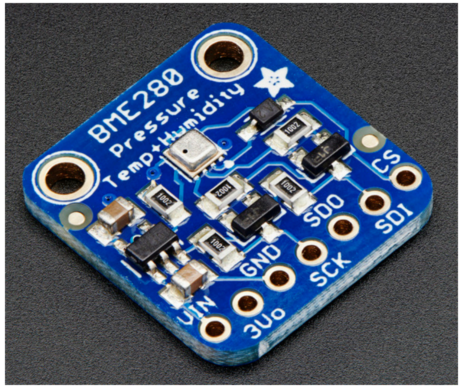
- Synchronous serial interface
- Full-duplex
- Master-slave architecture with single master
- Rate: set by the clock, often above 10 Mbps



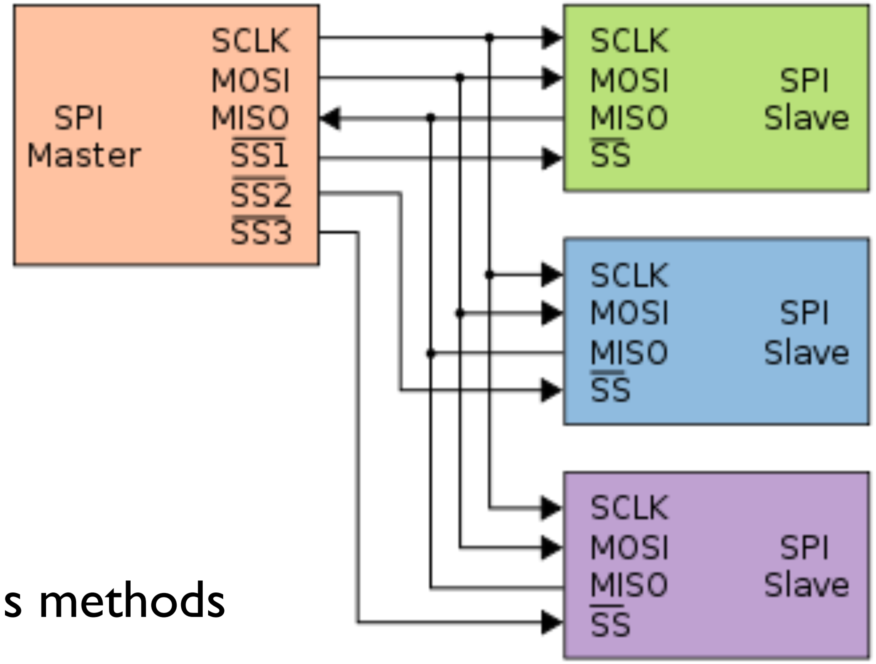


- **Four unidirectional lines:**
  1. SCLK: Serial Clock (output from master).
  2. MOSI: Master Output Slave Input, or Master Out Slave In (data output from master).
  3. MISO: Master Input Slave Output, or Master In Slave Out (data output from slave).
  4. SS: Slave Select

Serial Peripheral Interface Bus (SPI)

- The bus master:
  - Configures the clock, using a frequency supported by the slave device
  - Selects the slave device with a logic level 0 on the select line
- During each SPI clock cycle, a full duplex data transmission occurs:
  - The master sends a bit on the MOSI line and the slave reads it
  - At the same time, the slave sends a bit on the MISO line and the master reads it
- Transmission may continue for any number of clock cycles
  - When complete, the master stops toggling the clock signal, and typically deselects the slave

Serial Peripheral Interface Bus (SPI)



- **Pros:**
  - It is faster than asynchronous serial
  - It supports multiple slaves
    - Depends on the implementation
- **Cons:**
  - It requires more signal lines (wires) than other communications methods
  - The master must control all communications (slaves can't talk directly to each other)
  - It usually requires separate SS lines to each slave, which can be problematic if numerous slaves are needed

Inter-Integrated Circuit (I^2C)

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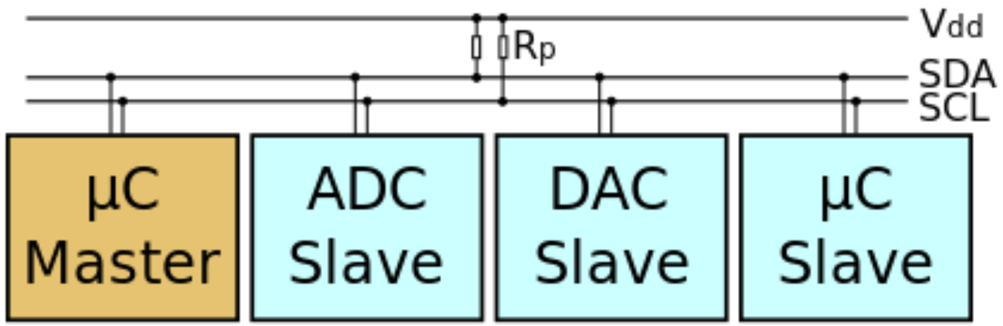
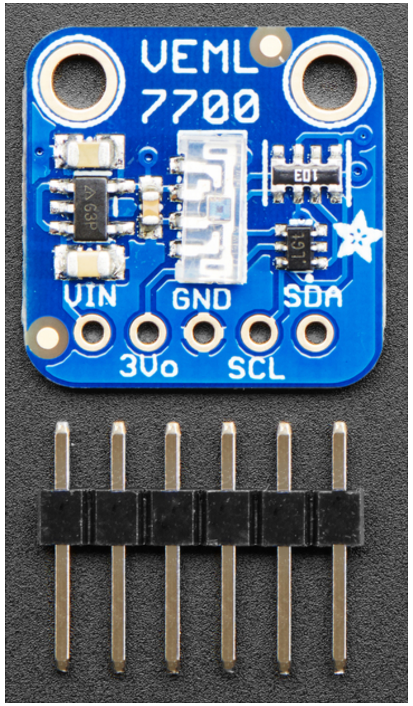
- Synchronous serial interface
- Packet switched
- Half-duplex
- Multi-master, multi-slave
- Rates: from 0.1 up to 3.4 Mbps

- **Only two bidirectional lines:**
  - Serial Data Line (SDA)
  - Serial Clock Line (SCL)





Inter-Integrated Circuit (I^2C)

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- The master is initially in master transmit mode by sending a **start bit** followed by the 7-bit address of the slave it wishes to communicate with
  - Followed by a single bit representing whether it wishes to write (0) to or read (1) from the slave
- If the slave exists on the bus then it will respond with an ACK bit (active low for acknowledged) for that address
- The master then continues in either transmit or receive mode (according to the read/write bit it sent), and the slave continues in its complementary mode
- The master then either ends transmission with a **stop bit**

Inter-Integrated Circuit (I^2C)

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- Start bit is indicated by a high-to-low transition of SDA with SCL high
- Stop bit is indicated by a low-to-high transition of SDA with SCL high
- All other transitions of SDA take place with SCL low

Inter-Integrated Circuit (I^2C)

- **Pros:**
  - It requires only two lines
  - It supports multiple masters and multiple slaves
- **Cons:**
  - It is slow compared to SPI
  - It is more complex

Universal Asynchronous Receiver-Transmitter (UART)

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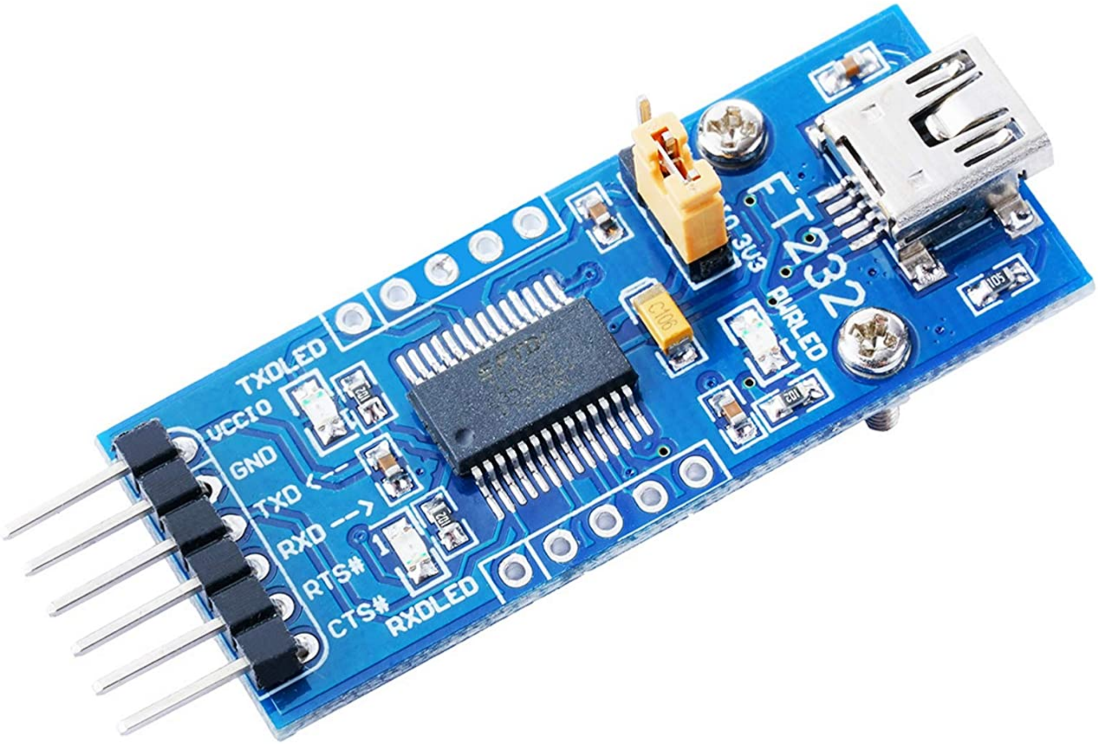
- Asynchronous serial interface
  - The transmitter and the receiver are not continuously synchronized by a shared clock
- Full-duplex
- Minimal implementation requires just 2 lines

- Rates:
  - Standard: 9600 bps
  - Up to 115200 bps



Universal Asynchronous Receiver-Transmitter (UART)

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- The UART takes bytes of data and transmits the individual bits in a sequential fashion
- At the destination, a second UART re-assembles the bits into complete bytes
- The idle, no data state is high-voltage, or powered
- The start bit (signal low) indicates the receiver that a new character is coming
- The next five to nine bits, depending on the codeset employed, represent the character
  - If a parity bit is used, it would be placed after all of the data bits.

Universal Asynchronous Receiver-Transmitter (UART)

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- **Pros**
  - Simple
  - Only two lines are needed (for full-duplex)
- **Cons**
  - Communication only between two nodes
  - Very slow

Course Contents

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- **Module T1:** Introduction to the Internet of Things ✓
- **Module T2:** Data Acquisition ✓
- **Module T3:** Local Data Processing
- **Module T4:** Data Communication
- **Module T5:** Data Streaming
- **Module T6:** Data Storage & Cloud
- **Module T7:** Data Analytics

Next Steps

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- Before Wednesday, make sure to indicate on the Student Hub whether you want to join the lectures in person or remotely
  - On Thursday, you can then know if you have been approved to come to class the following week
- Finalize the research project team creation and topic selection task:
  - Due end of next week
- Complete the first computer laboratory assignment (individually or in couples)
  - Due end of next week