EMBEDDED SYSTEMS PROGRAMMING 2017-18

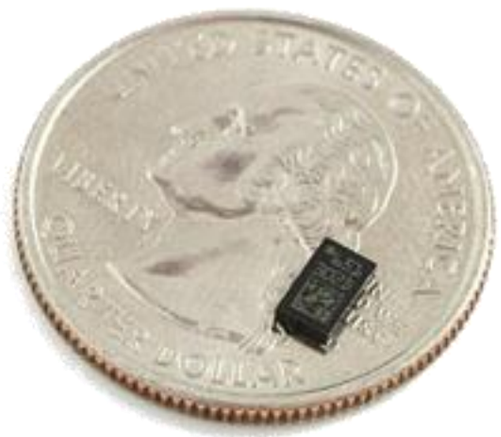
Accessing Hardware

HARDWARE LIST

- **Accelerometer**
- **Vector magnetometer** (compass)
- **Gyroscope**
- GPS and/or other **location** facilities
- (Front/rear) **camera**
- **Microphone**
- **Speaker**
- **Battery**

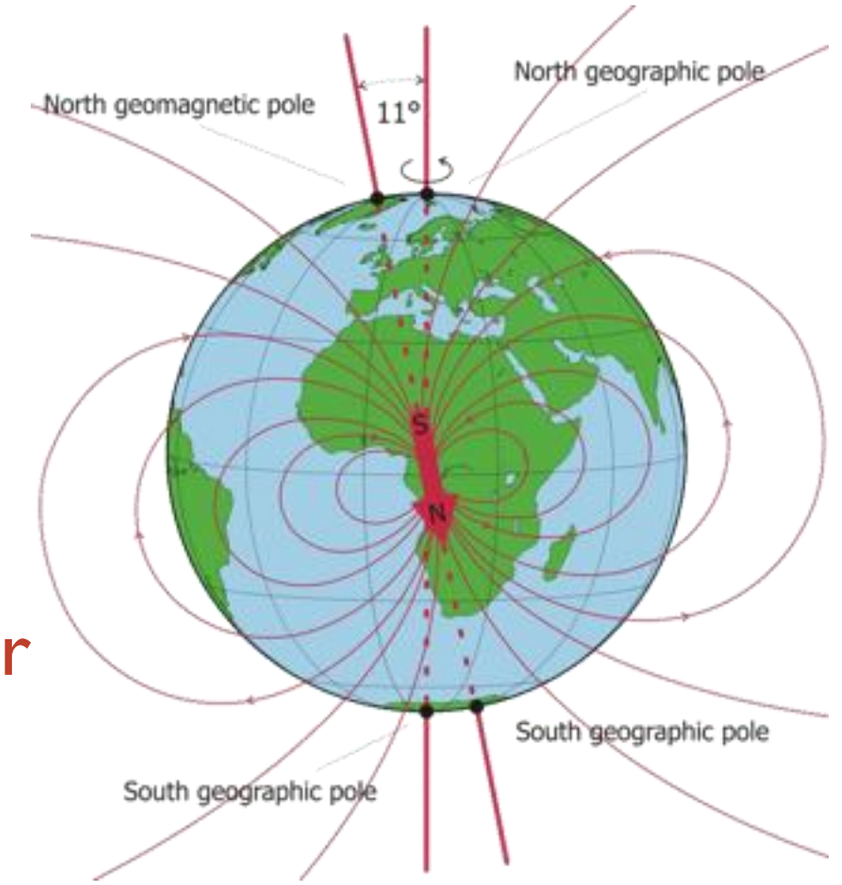
ACCELEROMETER

- Measures **proper acceleration** in m/s^2 along one or more axes
- Acceleration due to the force of gravity is detected
- In smartphones and similar devices
  - Solid-state, 3-axis MEMS accelerometer
  - Reads per seconds: some hundreds
  - Measurement range: from 0 to ~10 *g*'s
  - Can be used to detect the orientation of the device. However, a simpler tilt sensor can be used for this purpose



VECTOR MAGNETOMETER

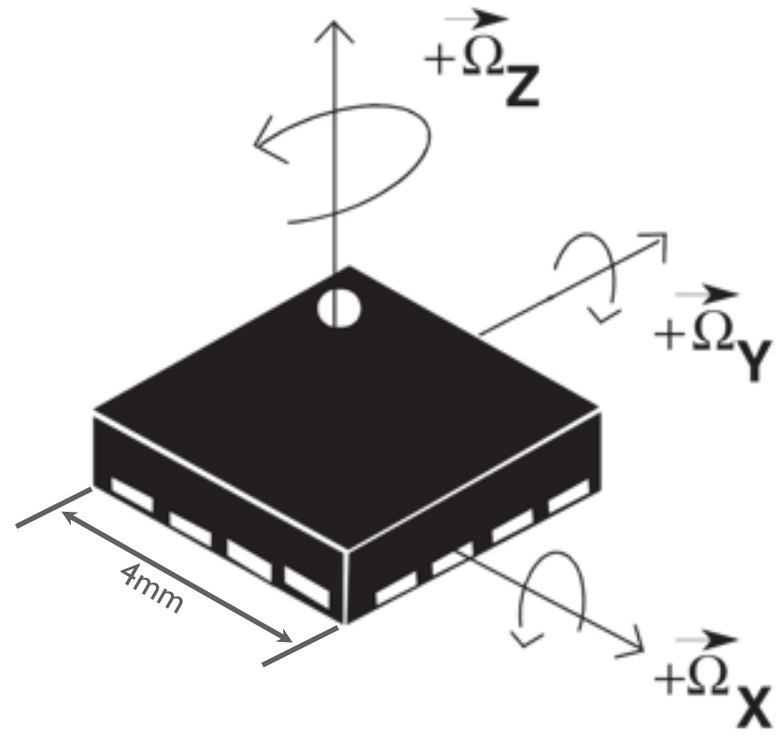
- Measures the **strength of the magnetic field** (in T) along one or more axes
- Can be used to determine orientation with respect to the magnetic or (if position is known) geographic North
- In smartphones and similar devices
  - Solid-state, Hall-effect 3-axis magnetometer
  - Reads per second: ~10
  - Measurement range: from 0 to ~2000 μT



Picture from INGV.it

GYROSCOPE (1/2)

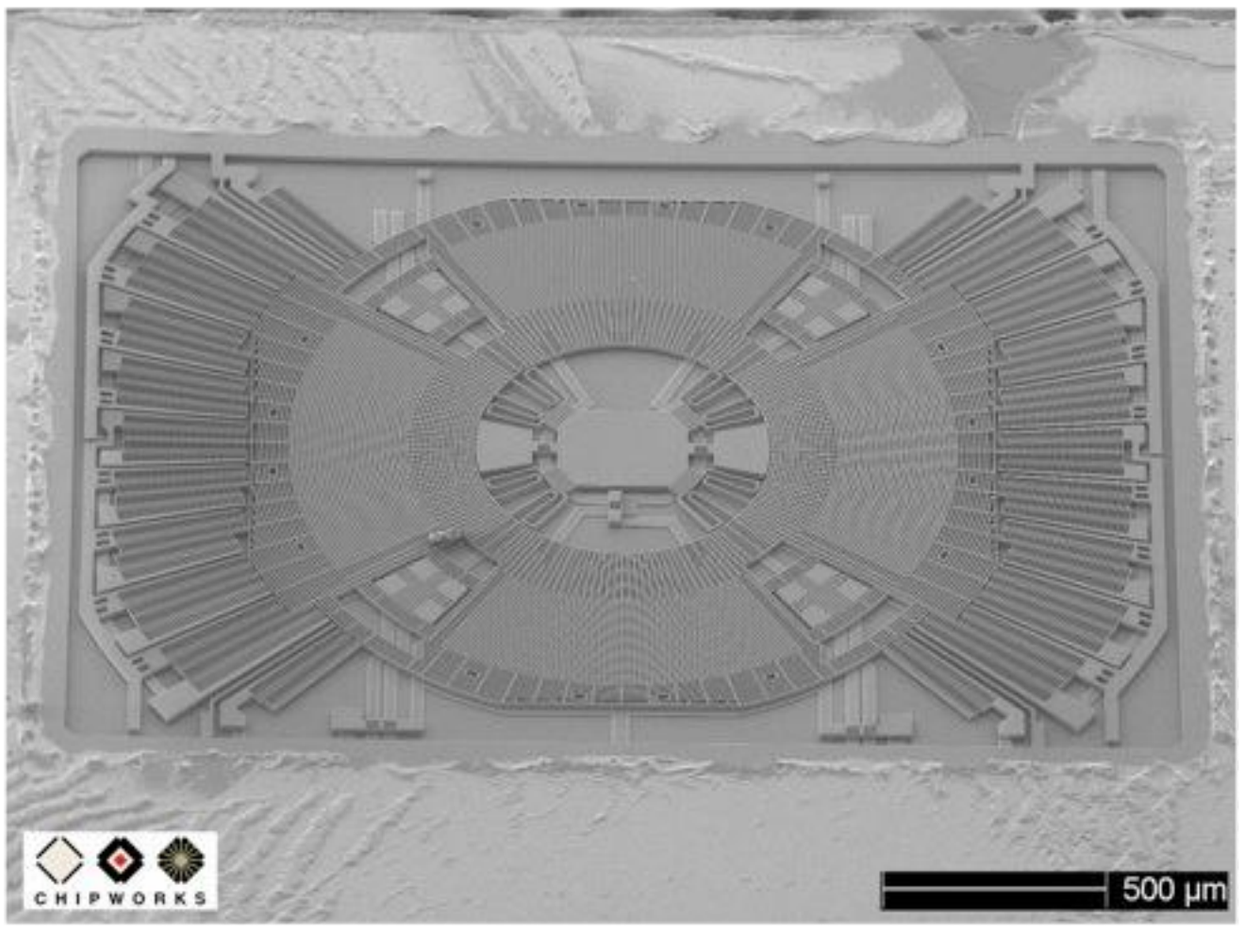
- Measures **angular velocity** (in rad/s) along one, two or three axes

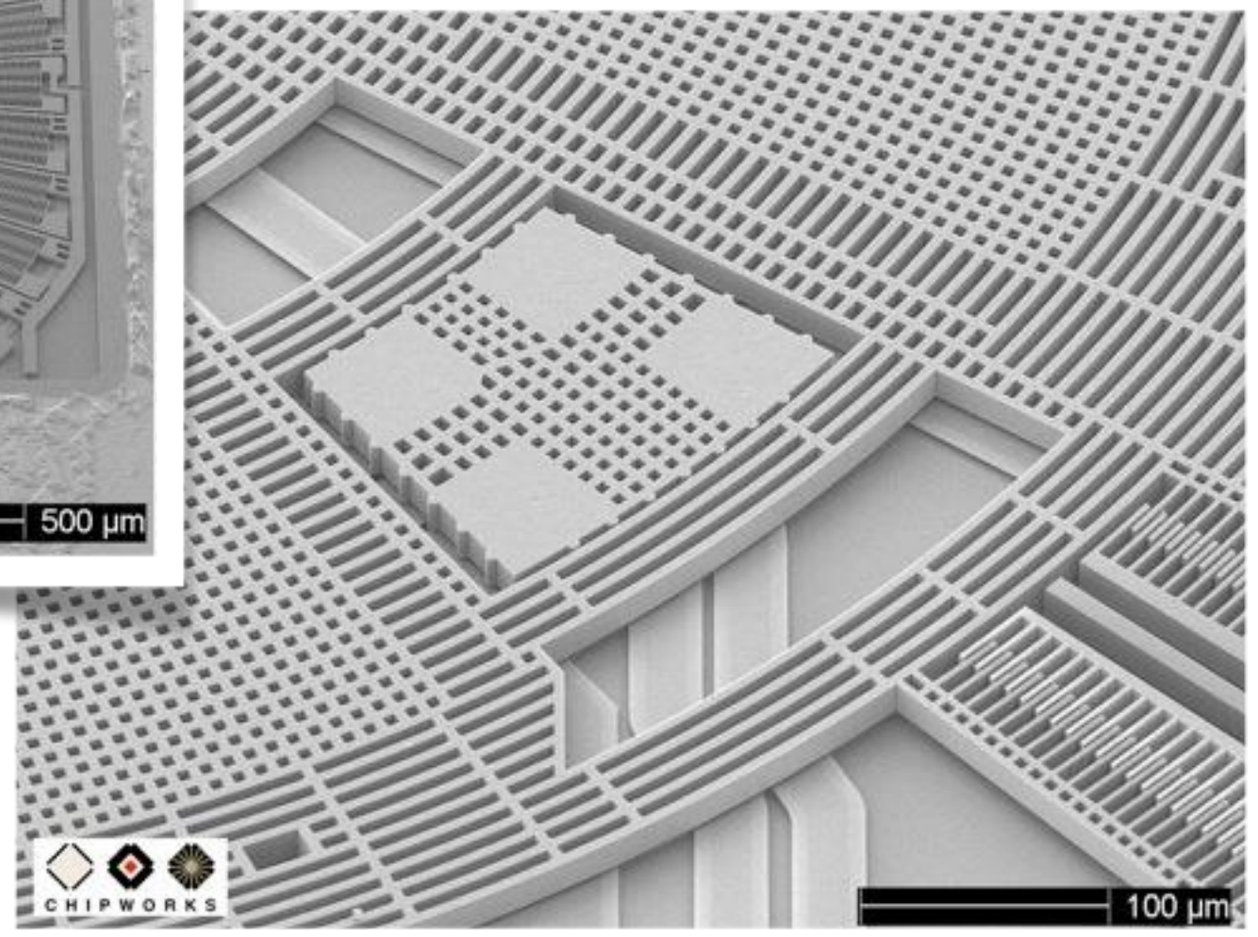


- Can be used to determine orientation without the need of a compass

- In smartphones and similar devices
  - Vibrating-structure, 3-axis MEMS gyroscope
  - Reads per second: ~100
  - Measurement range: from 0 to ~35 rad/s

GYROSCOPE (2/2)

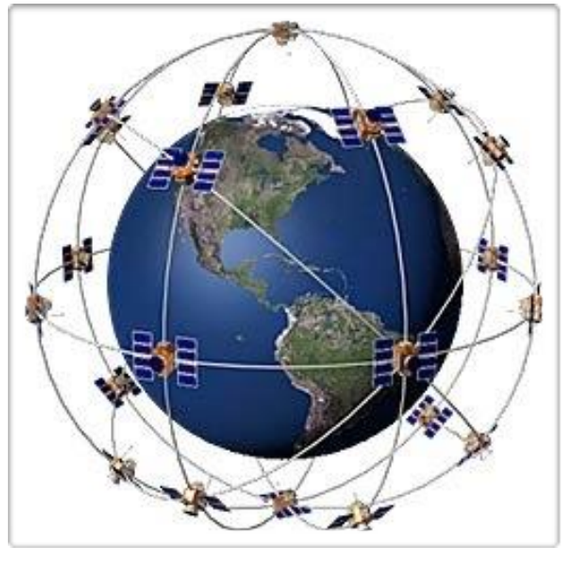




Pictures from iFixit.com

GPS

- Triangulates position by accurately timing the signals of **GPS satellites** precisely located into space
- A minimum of three satellites are necessary; receivers use four or more to increase accuracy
- Non-military devices (including smartphones) have access to degraded-precision signals (~10m accuracy, 1÷2 reads per second)
- Alternative GNSSs: Galileo, GLONASS



OTHER POSITIONING SYSTEMS

- **Based on the Cellular network**
  Requires a database of cell tower IDs

- **Based on Wi-Fi**
  Requires a database of Wi-Fi networks

- Less accurate (but less power-hungry) than GPS

CAVEAT

- Sensors in embedded devices have
  - **poor resolution**, sometimes 8 bits or less,
  - **limited linearity**
- Not suitable for “serious business”

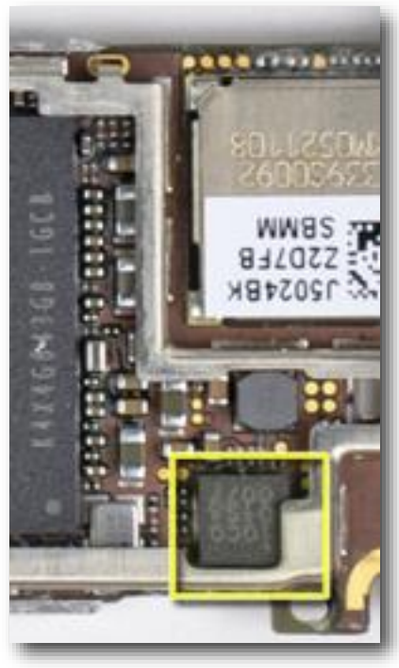
- **Power consumption** is high for the standards of battery-powered devices

CAMERA

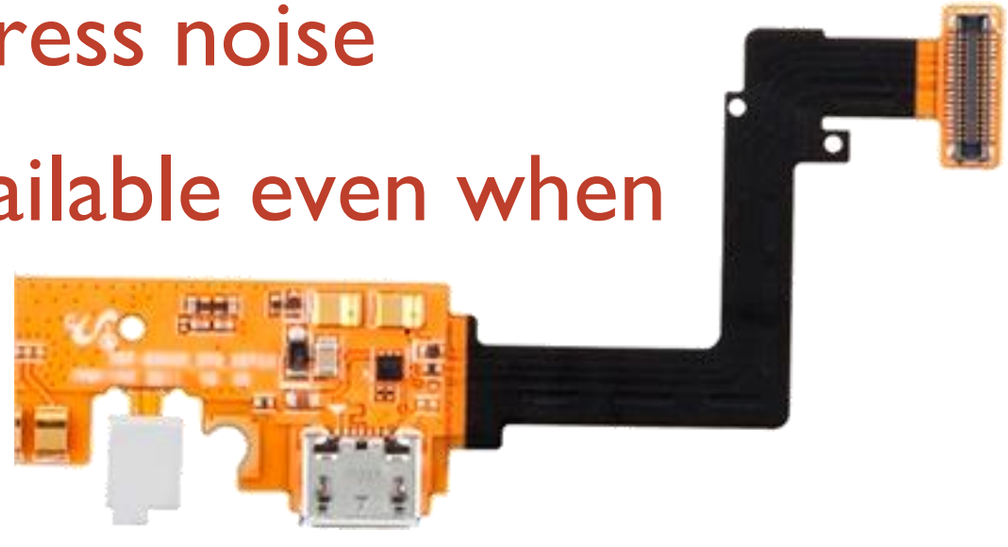
- Takes pictures and videos
- In smartphones and similar devices
  - CMOS sensors
  - Fixed-focus, EdOF and autofocus
  - Multiple cameras
  - Resolution for images: from 0.3 Mpix to 41 Mpix
  - Resolution for video: from 240p to 4K

MICROPHONE

- Captures sounds
- In smartphones and similar devices
  - Optimized to enhance voice (< 8 KHz) and suppress non-voice “noise”
  - Voice processors and multiple microphones may be present to better suppress noise
  - Stereo recording is often unavailable even when multiple mikes are available



Picture from iFixit.com

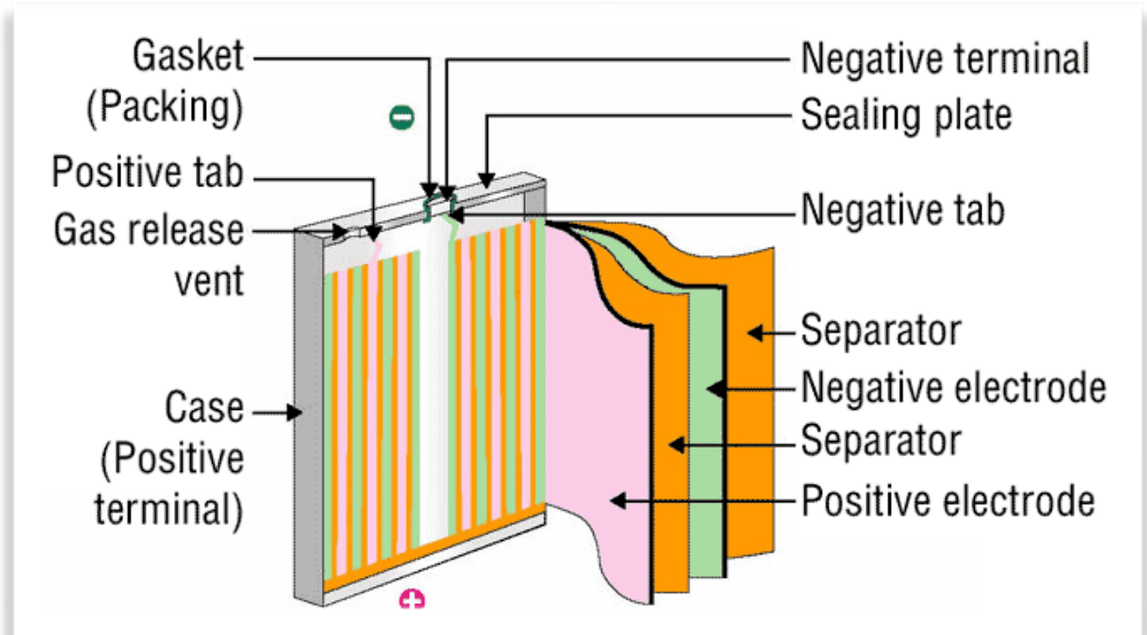


SPEAKER

- Reproduces sounds
- In smartphones and similar devices
  - Optimized to be as loud as possible regardless of the minute dimensions
  - Sometimes performance is enhanced by a tiny sound box
  - Sometimes the same speakers is used for both audio reproduction and telephony functions
  - Stereo speakers are seldom available
  - Nowadays, an audio jack for headsets is seldom present

BATTERY (1/2)

- Rechargeable
- Many chemistries.
  Lithium-ion and Lithium-ion polymer batteries are the most common for their power density and because thay can be easily made in any shape and size



Picture from Digimax.rs

- Typical voltage: 3.7 V (nominal)
- Typical capacity (smartphone): 1000÷3000 mA·h
- Occupy a sheer fraction of the volume inside the device

BATTERY (2/2)

- Deteriorates (loses capacity) if
  - it runs too hot,
  - it runs too cold,
  - it is overcharged,
  - it is not charged often enough...
- Self-discharges when not used
- Voltage varies nonlinearly during charge and discharge. The curve depends on the battery chemistry, temperature, age...

Picture from Switched.com

MORE SENSORS

- **Proximity sensor**
  Typically, a photoelectric, infrared sensor
  Usually, it does not return a measure and simply tells whether something is near the device or not

- **Barometer**
  Piezoresistive MEMS sensor
  Also used for a quicker fix of the altitude

- **Thermometer**
  Typically, a band-gap sensor

- **Hygrometer**
  Capacitive sensor

- **Fingerprint scanner**
  Electro-optical or capacitive sensor

MORE HARDWARE

- NFC

- Bluetooth (Smart)

NFC (1/2)

- Proximity wireless communication
- Evolution of RFID technologies of the 1980s
- 3 modes:
  NFC initiator, NFC target, NFC peer to peer
- Targets can be passive and powered by the initiator using electromagnetic induction

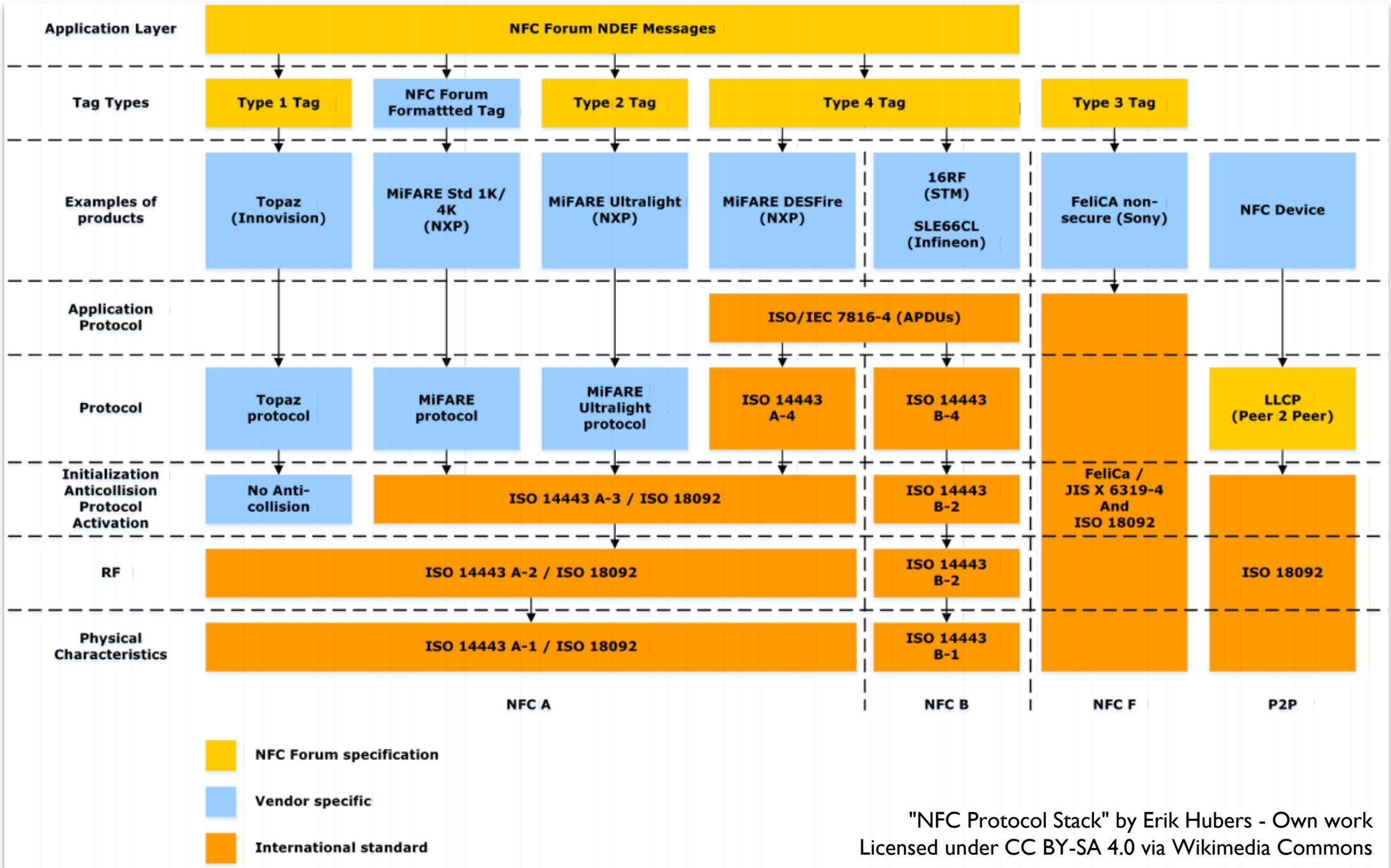
NFC (2/2)

- All devices can contain data, even targets (order 1K bytes)

- Protocol stack: lower levels are ISO standards, higher levels — including data encoding — are vendor specific and not interoperable

- Security is not part of the standards

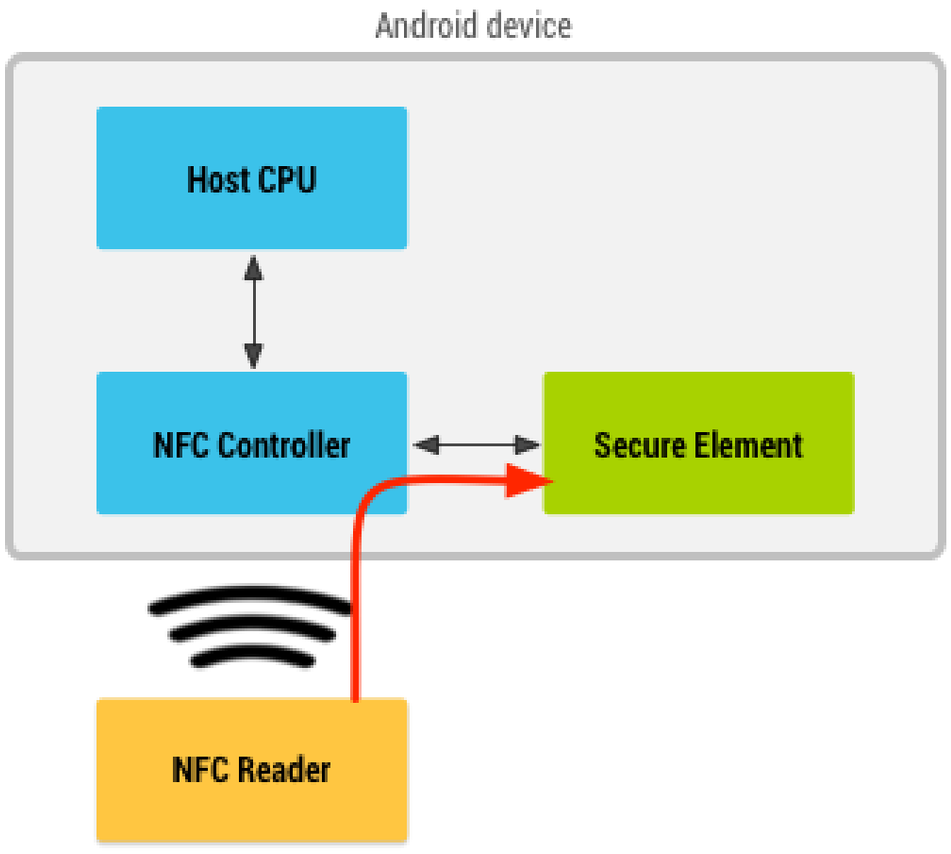
NFC PROTOCOL STACK



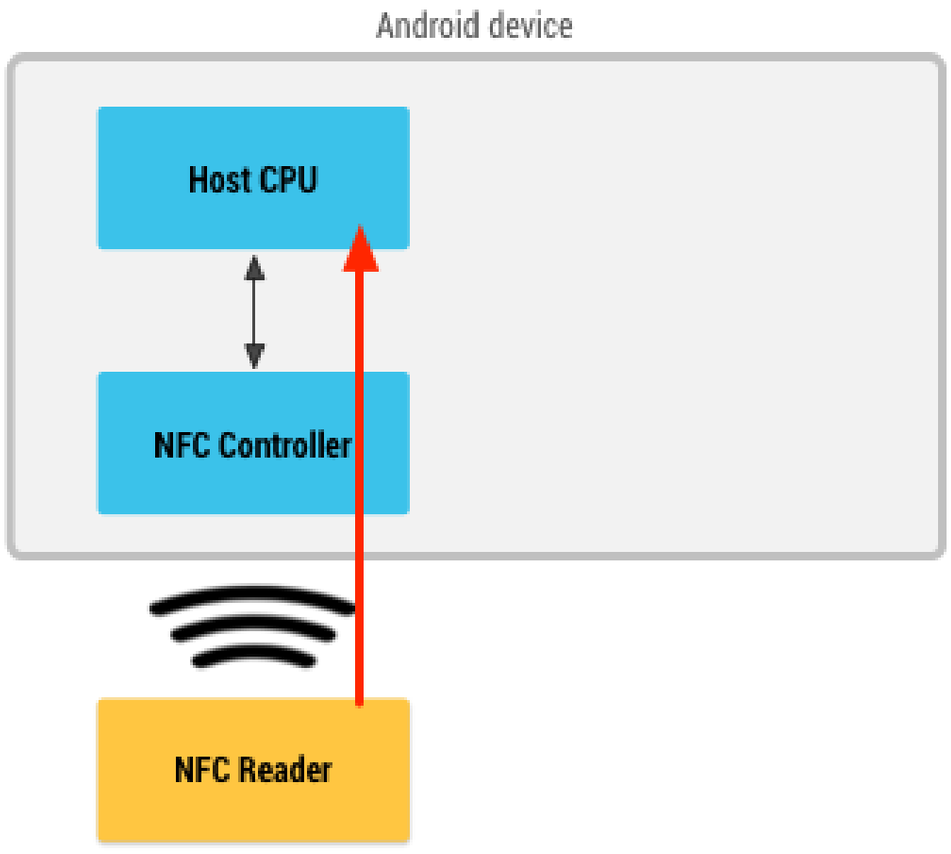
NFC: ANDROID

- NFC supported since Android 2.3 (2010), packages `android.nfc` and `android.nfc.tech` (2.3.3)
- Android 4.4 (2013): added NFC reader mode and host-based card emulation (`android.nfc.cardemulation` package)
- APIs based on the NDEF standard
- **Google Wallet** payment service

CARD EMULATION



With a Secure Element (<4.4)



Host-Based Card Emulation (4.4+)

Pictures: developer.android.com

NFC, ANDROID: SUMMARY

As of Android 5.0, three simultaneous modes of operations are supported:

- **Reader/writer mode,**
- **P2P mode,**
- **Card emulation mode**

Note: NFC controller is off when screen is locked

NFC: IOS

- Support introduced with iOS 8.1 and iPhone 6
- No APIs for the developer
- **Apple Pay** payment service, PassKit framework

BOOTSTRAPPING

NFC can be used to bootstrap more capable wireless connections

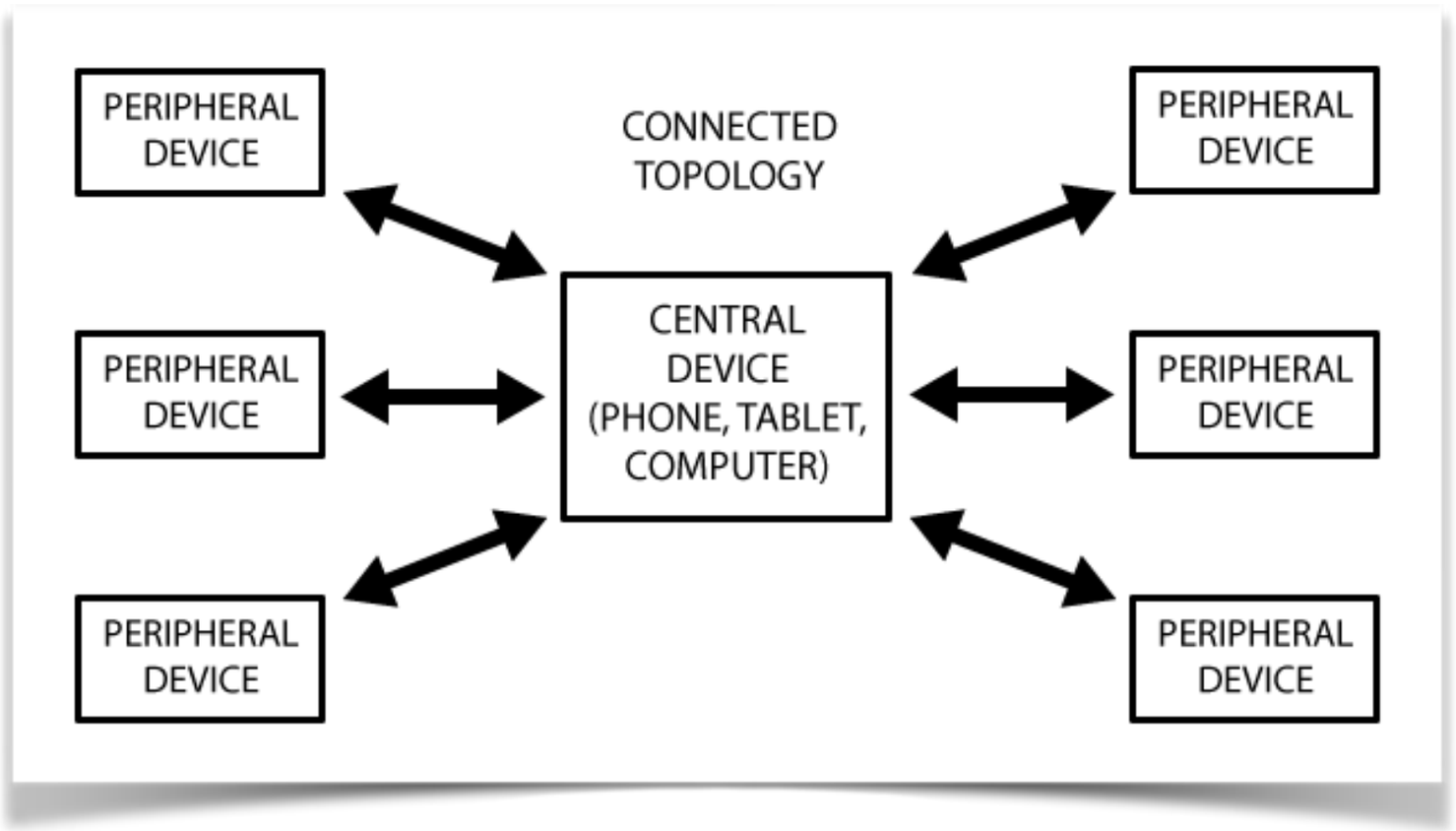
- Android Beam (>4.1): uses NFC to bootstrap a Bluetooth connection for file transfer
- Samsung S-Beam: uses NFC to bootstrap a Wi-Fi Direct connection for file transfer
- Nokia, Samsung, BlackBerry, Sony: use NFC technology to pair Bluetooth headsets, media players, and speakers with one tap

BLUETOOTH SMART (1/3)

- Also known as “Bluetooth Low Energy”, or BLE
- Introduced with Bluetooth Specification 4.0
- Physical layer is completely different from “Classic Bluetooth”, and not compatible/interoperable

BLUETOOTH SMART (2/3)

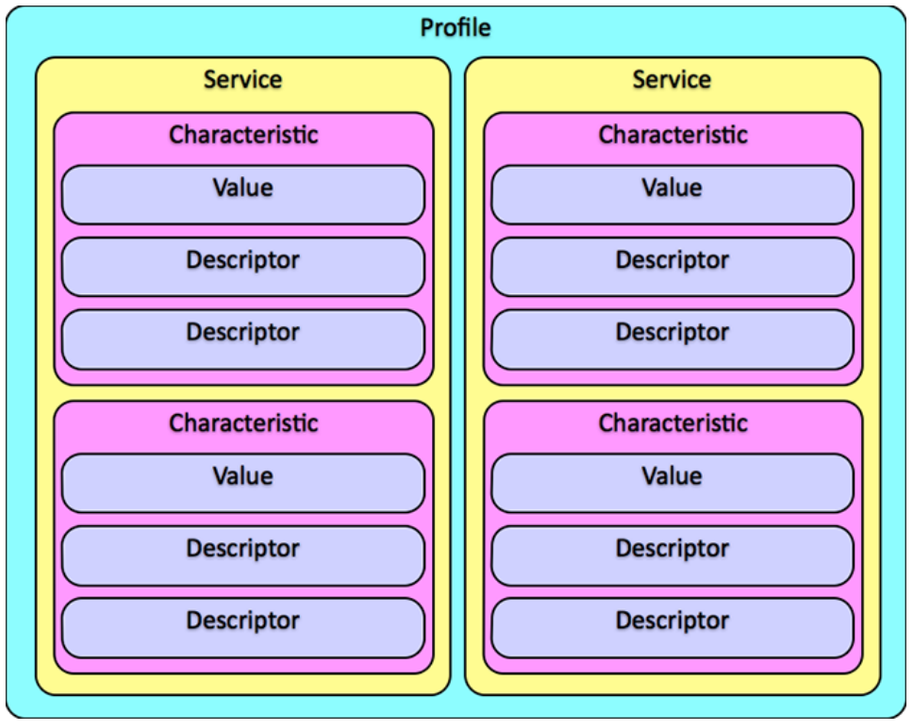
- 2 device roles: **Bluetooth central** and **Bluetooth peripheral**



Picture: Adafruit

BLUETOOTH SMART (3/3)

- All current BLE application profiles are based on the Generic Attribute Profile (**GATT**)
- The central device is the GATT client, and each peripheral is a server, providing a certain number of **characteristics** organized into **services**



- A peripheral can provide multiple services

Picture: thenewcircle.com

BLUETOOTH SMART: ANDROID

- BT Classic supported since Android 2.0 (2009),
  BT Smart supported since Android 4.3 (2013)
- Unified `android.bluetooth` package
- Android 4.3: central only
- Android 5.0: central and peripheral;
  new `android.bluetooth.le` package

BT SMART VS. NFC (1/3)

	BT SMART	NFC
Frequency	2.4 GHz	13.56 MHz
Range	50 m	0.1 m
Data rate	1 Mbit/s	From 0.1 Mbit/s to 0.4 Mbit/s
Security	128-bit AES	None

BT SMART VS. NFC (2/3)

	BT SMART	NFC
Power consumption	0.01 to 0.5 W	0 W for target, 0.5 W for initiator
Network topology	WPAN “Piconet” (up to 8 devices)	Point to point (2 devices)
Start-up time	High (discovery, pairing)	Low
Set-up time	< 0.006 s	< 0.1 s

BT SMART VS. NFC (3/3)

	BT SMART	NFC
Cost of device	order $5	order $0.1
Defined by	Bluetooth SIG	ISO/IEC and various SIGs
Applications	Watches, sports and fitness, healthcare, …	Tickets, access control, payments, …

LAST MODIFIED: APRIL 10, 2018