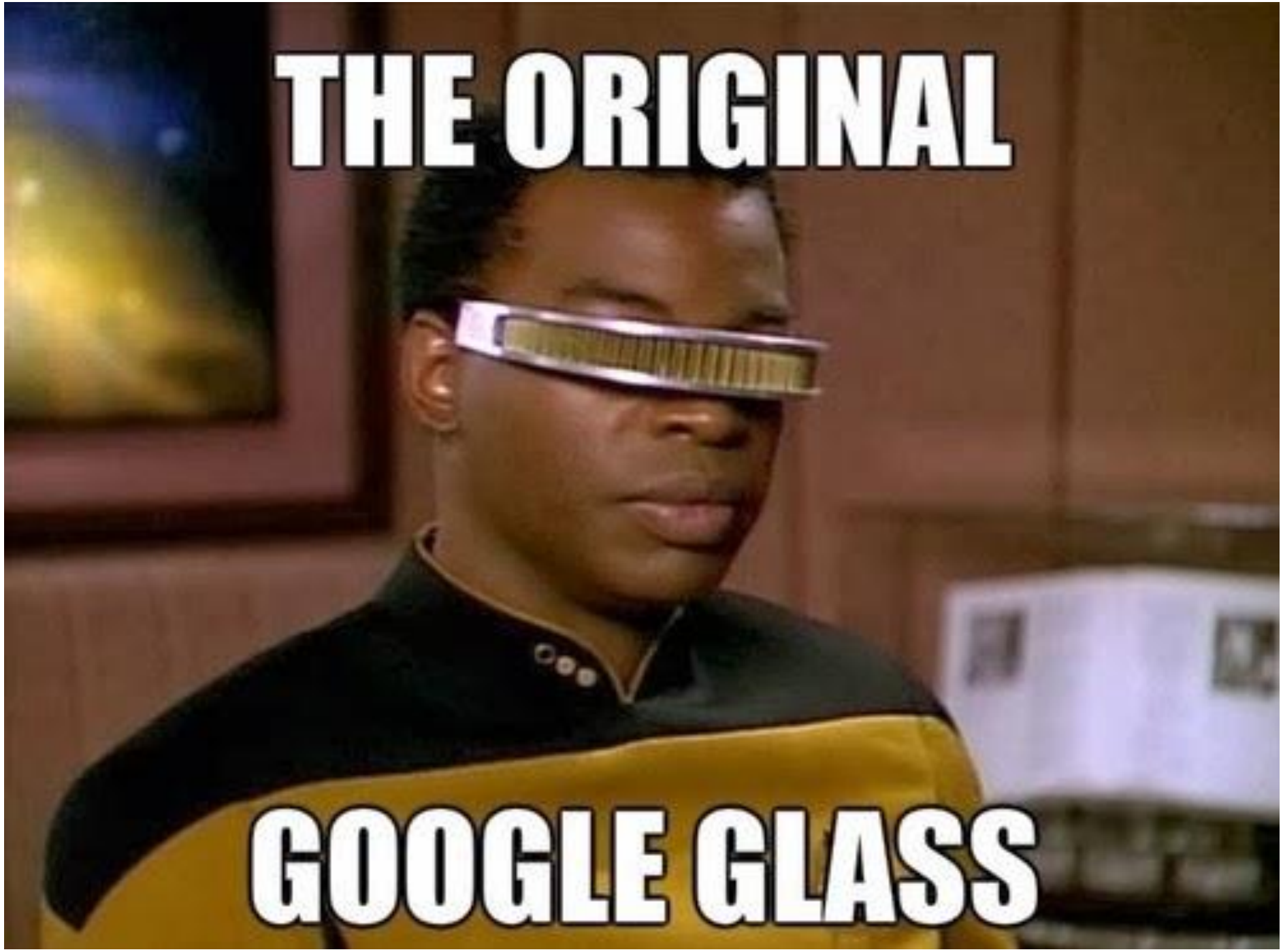
PROIECTAREA CU MICROPROCESOARE

Cursul 12
Wearable Computing

Facultatea de Automatică și Calculatoare
Politehnica București

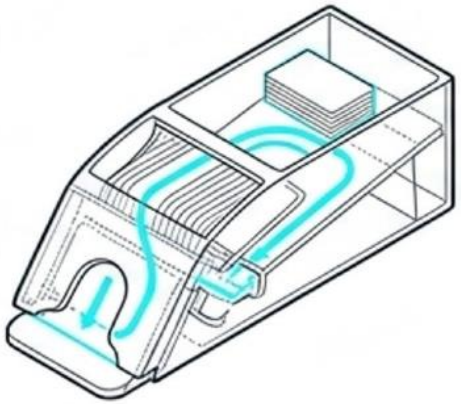

THE ORIGINAL
GOOGLE GLASS

A wearable device is a computer
that is subsumed into the personal space of a user,
controlled by the user,
and has both operational and interactional constancy,
i.e., is always on and always accessible.

The Evolutionary Curve of Human Augmentation

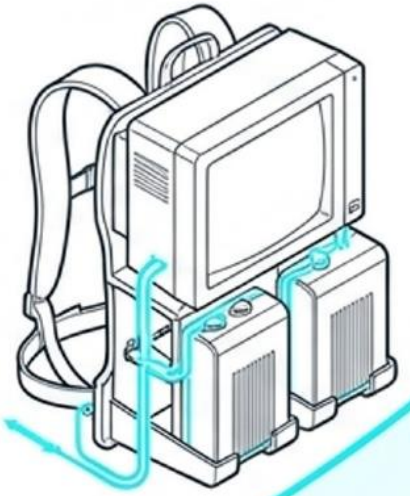
Analog Augmentation

- **1268:** Eyeglasses
- **1510:** Nürnberger Ei (Pocket Watch)



Application-Specific

- **1961:** Analog roulette shoe
- **1984:** Digital hearing aid



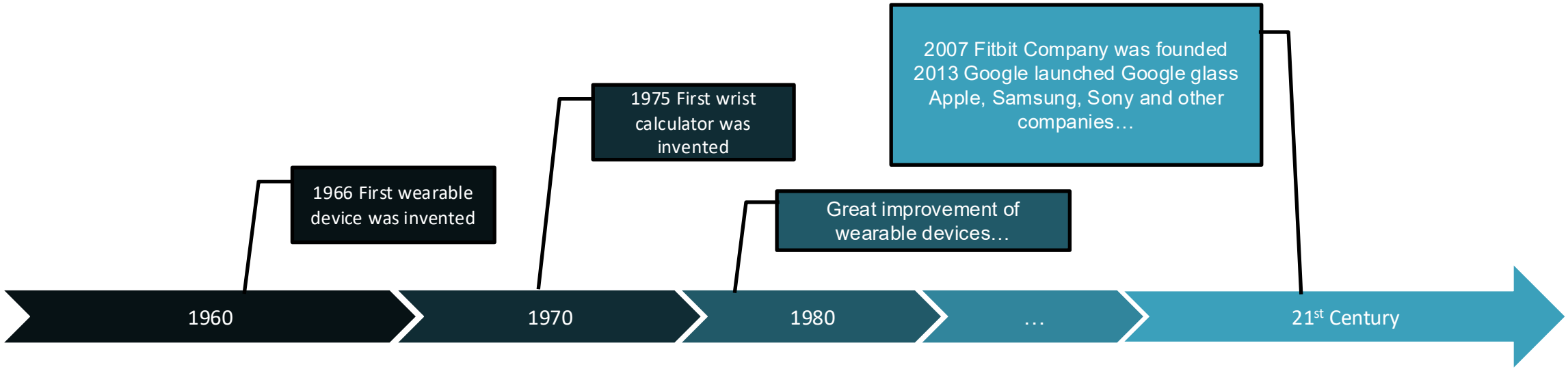
The Academic Pioneers

- **1981:** Apple II backpack
- **1991:** CMU VuMan 1

Ubiquitous Sensor Networks

- **2003:** Garmin Forerunner
- **2012:** Pebble
- **Modern:** Continuous physiological monitoring

Wearable History



Forms

- Head-mounted (glass, helmet..)
- Body-dressed (coat, underwear, trousers..)
- Hand-worn (watch, bracelet, gloves..)
- Foot-worn (shoes, socks..)

Functions

- Healthy living (sports wrist band, smart bracelet..)
- Information consulting (smart glass, smart watch..)
- Somatosensory Control (somatosensory controller..)

From Gadget to Platform

1970s–80s
Calculator & digital watches

Miniaturized electronics on the wrist

2012
Pebble Kickstarter

Low-power display + SDK + phone gateway

2014/15
Apple Watch

Ecosystem, sensors, payments, health

2020s
Rings, earbuds, patches

Passive sensing and longitudinal health

Now
AI glasses & textiles

Context-aware interfaces beyond the wrist

Pattern: each wave improves one constraint — battery, sensors, UX, connectivity, trust, or integration.

Business case

- In 2013, investors poured $458 million into 49 wearable company deals (*CB Insights*)
- $90 Billion Industry in 2025 – 600M devices shipped
- Expected to triple in size by 2030
- Major tech companies like Apple, Google, Samsung and Intel investing heavily in wearables, with non-tech giants like Nike, Under Armour, Adidas, Fossil, Timex etc.

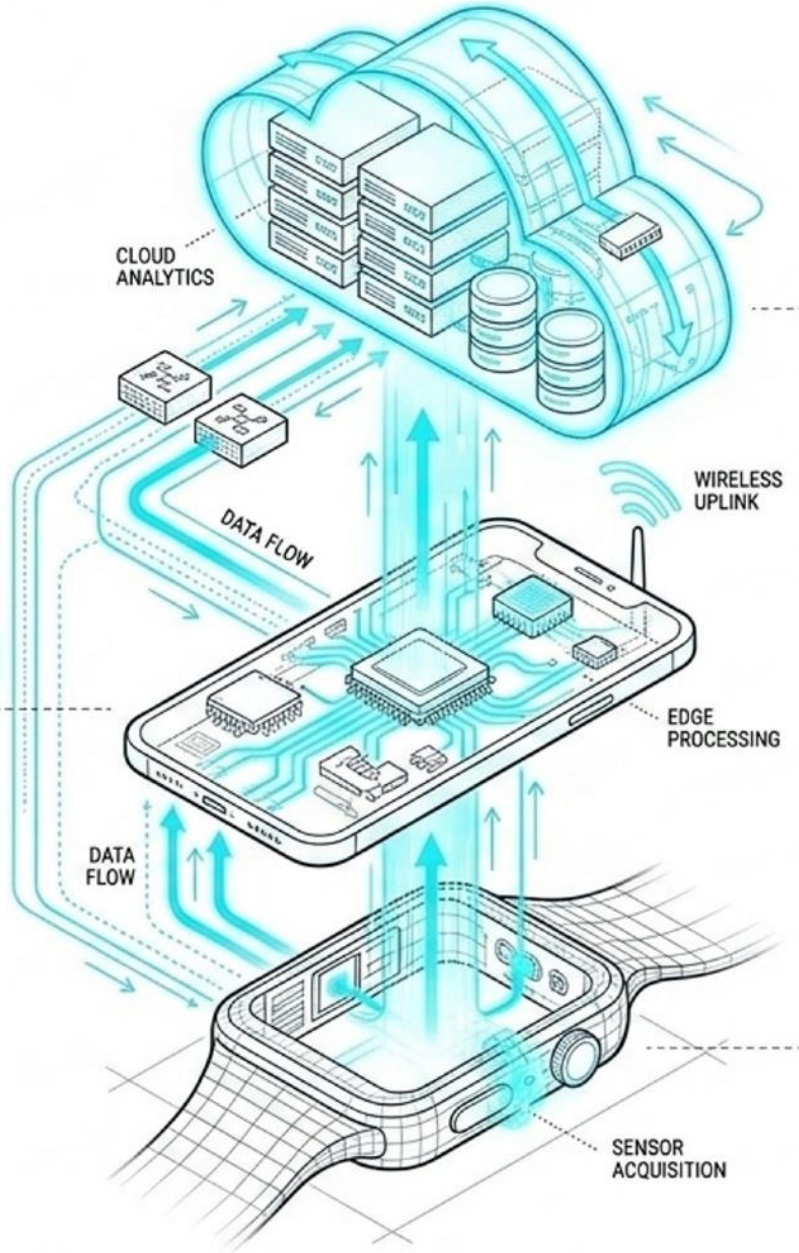
What makes wearables special?

- Used while the wearer is in motion
- Used while one or both hands are free or occupied with tasks
- Exist within the corporeal envelope of the user
  - Not merely attached to the body but becomes and integral part of the person's clothing
- Allows the user to maintain control
- (Should be) constantly available

Form Factor vs. Functionality

Wrist-Worn (e.g., Smartwatches)	Chest-Worn (e.g., Cardiac Straps)	Head-Worn (e.g., AR/VR, EEG)
		
• **Primary Sensors:** Accelerometer, Optical PPG	• **Primary Sensors:** 1-lead ECG, Seismocardiogram	• **Primary Sensors:** EEG, IMU, Microdisplays
• **Constraints:** Strict power limits, moderate latency tolerance	• **Constraints:** Requires skin contact, low latency tolerance	• **Constraints:** Heavy computational load, ultra-low latency required to prevent motion sickness
• **Reliability:** High convenience, limited clinical fidelity	• **Reliability:** High clinical accuracy, intrusive form factor	• **Reliability:** High immersion, significant heat dissipation challenges

A Three-Tier Ecosystem



Tier 3: Off-Body Cloud Services

Distributed cloud infrastructure for longitudinal analytics, machine learning, and secure data persistence.

Tier 2: Near-Body Gateways

Local processing hubs handling immediate computation, short-range aggregation, and user interface.

Tier 1: On-Body Sensors

Endpoints acquiring physical, chemical, and biological data through continuous sensing.

Some interesting issues

Operating Systems

Data Transmission

Energy Consumption

Security & Confidentiality

Data Management

Application Development Platform

Popularity Example

- Pebble – launched 2012
- Kickstarter Campaign
- Seeks : $100K
- Raises : $10+ Million

KICKSTARTER

Factors in Wearable Tech Today

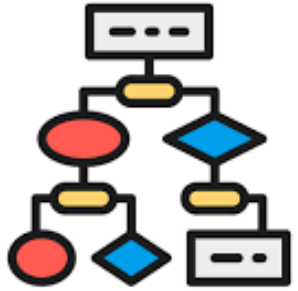
- Faster and Cheaper Hardware
- Cloud Storage
- Location Data
- Quantified Self Activity
- Gaming Industry
- Visual & Voice Technology
- User Experience
- AI/ML Everywhere

State-of-the-art

Devices

Inputs

Applications



Algorithms

Hardware

Anatomy of a Wearable System

Sensors
IMU, PPG, ECG, temp

Analog front-end
ADC, filtering, gain

MCU / SoC
Firmware, DSP, ML

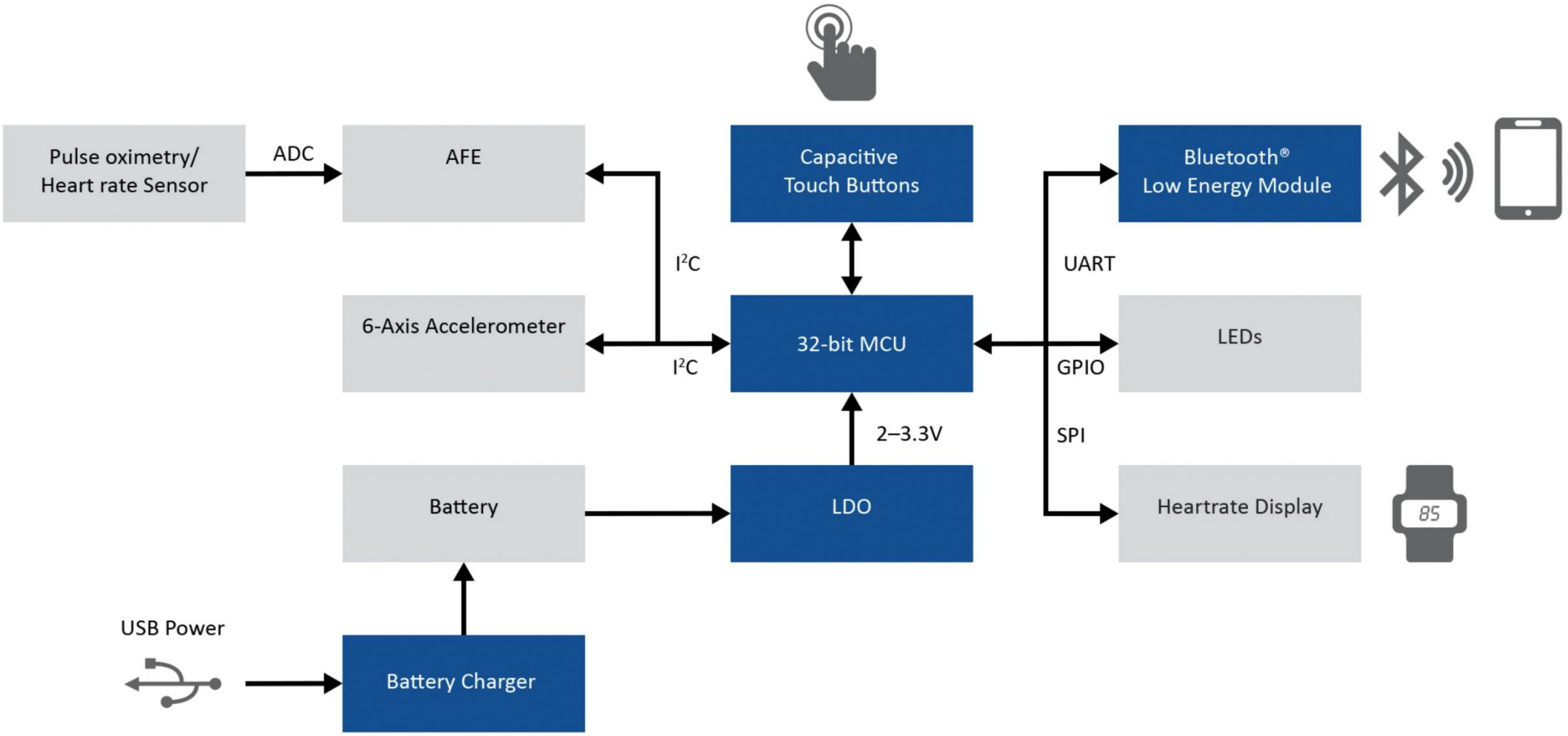
Radio
BLE, Wi-Fi, LTE, NFC

Phone / Gateway
app, UI, storage

Cloud / Clinician
analytics, alerts

Cross-cutting constraints: battery · memory · latency · thermal comfort · waterproofing · security · regulatory claims

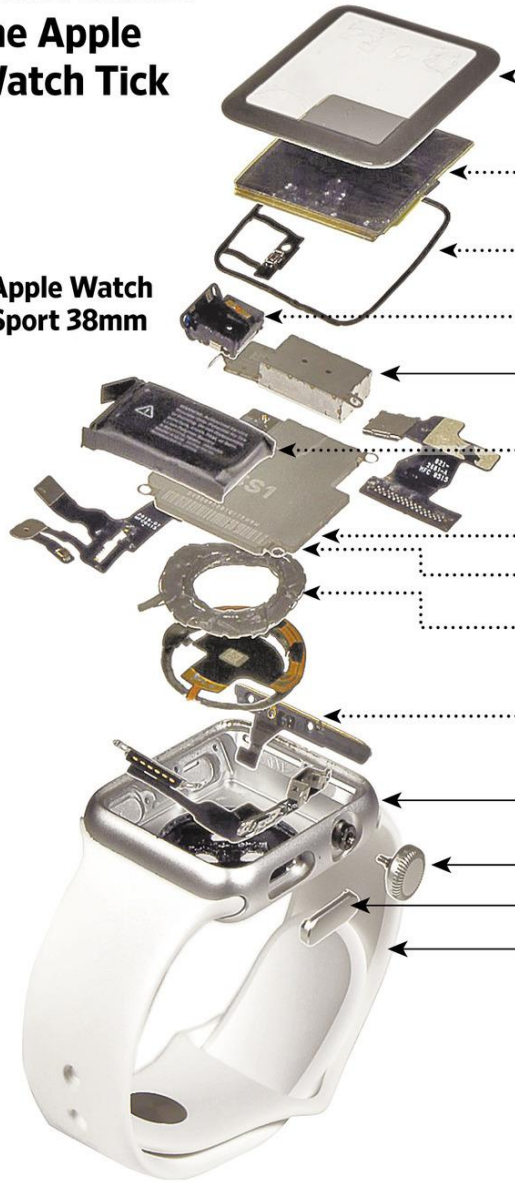
What is (typically) inside a wearable?



Apple Watch (Smartwatch)

What Makes the Apple Watch Tick

Apple Watch Sport 38mm



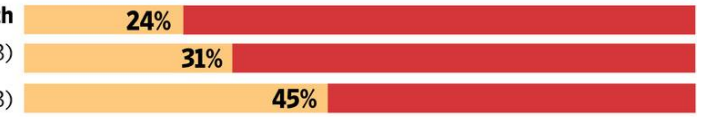
	Supplier	Estimated cost
Touchscreen	TPK	$20.50
Display module	Analog Devices	
Force touch sensor		
Loudspeaker		
Taptic engine		
Battery		$0.80
Processor	Apple	$10.20
Memory	Toshiba/Micron	$7.20
Wireless charging coil		
Bluetooth antenna		
Aluminum housing		$16.50
Digital crown		
Side button		
Watch strap		
Other materials		$26.00
Labor		$2.50
TOTAL		**$83.70**
RETAIL PRICE		**$349**

Note: Cost analysis excludes logistics, manufacturing, software and IP expenses.

Source and photo: IHS Technology

THE WALL STREET JOURNAL.

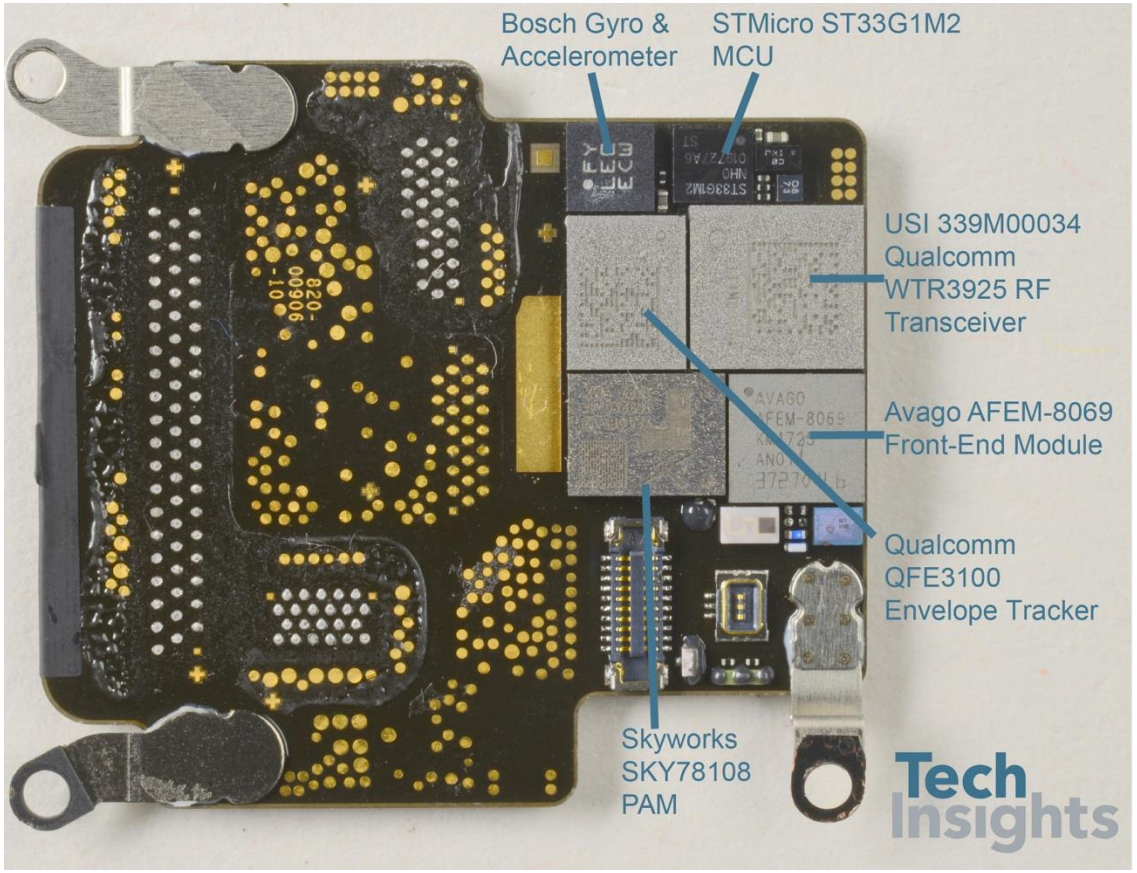
Materials and labor as a share of retail price

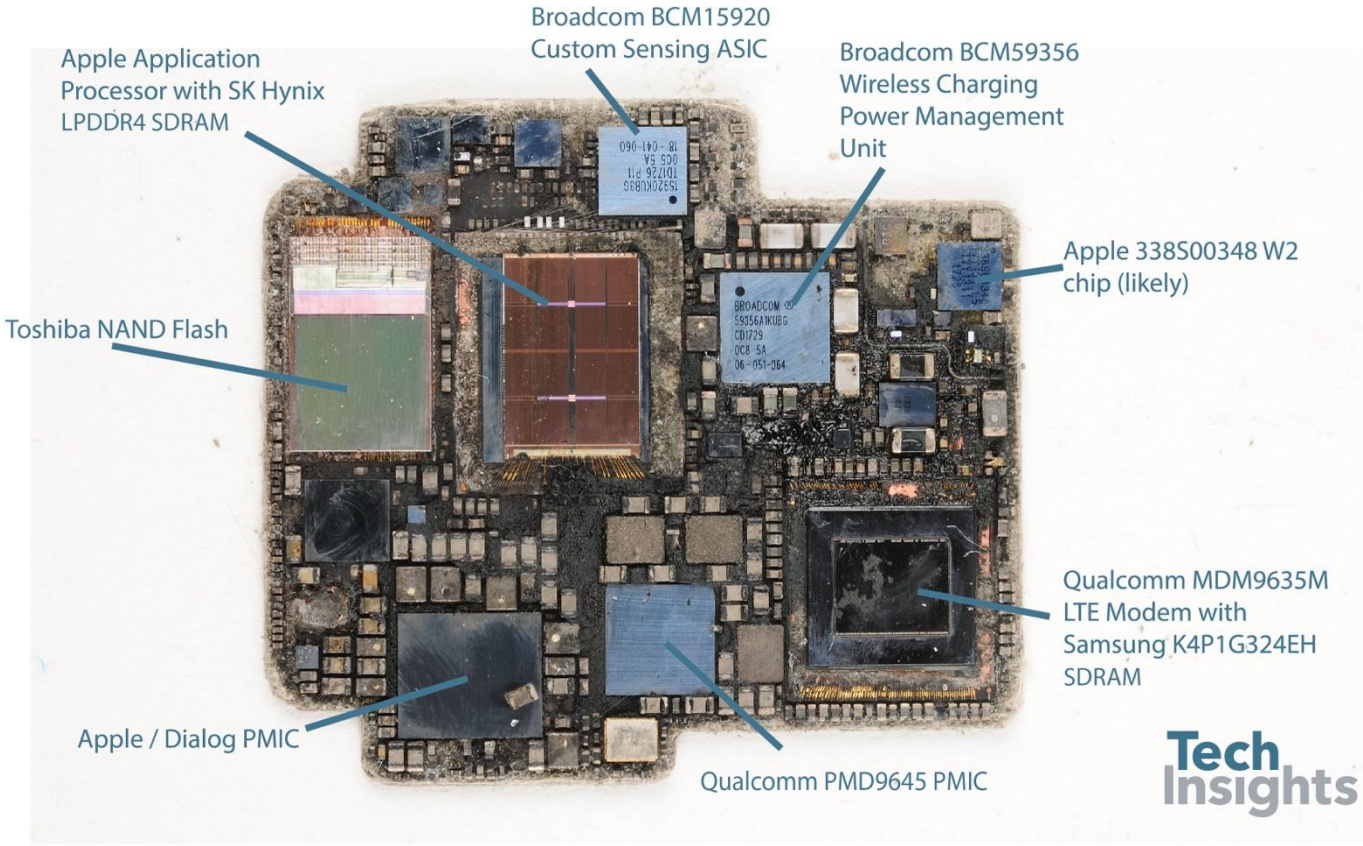


Apple Watch

https://www.ifixit.com/News/53688/three-former-apple-engineers-helped-us-tear-down-apple-watch-series-7

Apple Watch – main board





https://www.techinsights.com/blog/apple-watch-series-3-teardown

Apple Vision Pro

https://www.ifixit.com/News/90137/vision-pro-teardown-why-those-fake-eyes-look-so-weird

Jawbone (Activity Monitor)

MotionX® Powered

RECHARGEABLE BATTERY

Up to 10 days of use on a single charge.

VIBRATION MOTOR

Powers your silent alarm clock & reminds you to move.

PRECISION MOTION SENSOR

Accurately tracks your movement and sleep activity.

3.5MM PLUG

Syncs your band with the app on your phone.

SWEAT-PROOF & WATER-RESISTANT*

Wear the band while showering or working out.

* Water-resistant up to 1m.

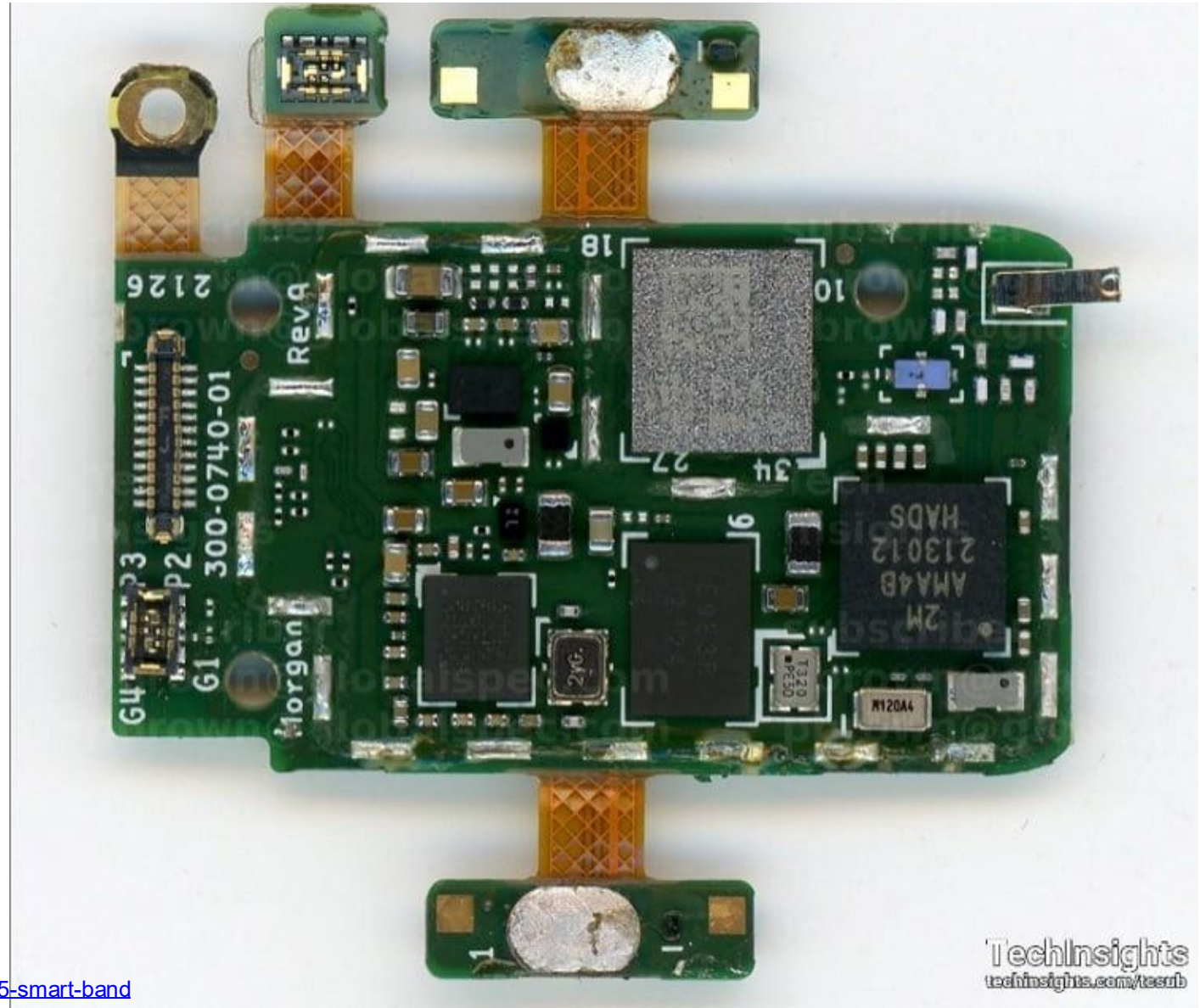
Fitbit Charge 5 (Fitness Tracker)

https://electronics360.globalspec.com/article/18433/techinsights-teardown-fitbit-charge-5-smart-band

Fitbit Charge 5 – main board

- 1.02 inch OLED touchscreen
- ARM M-4 microprocessor
- Heart rate monitor and sensor

- TI AFE for heart rate monitor and bio-sensor
- TI's load switch, LDO regulator, haptic driver & 600 mA step-down converter
- Zinitix's DC-DC controller
- ST Microelectronics' 300 mA LDO regulator, three-axis MEMS accelerometer



https://electronics360.globalspec.com/article/18433/techinsights-teardown-fitbit-charge-5-smart-band

Oura (Smart Ring)

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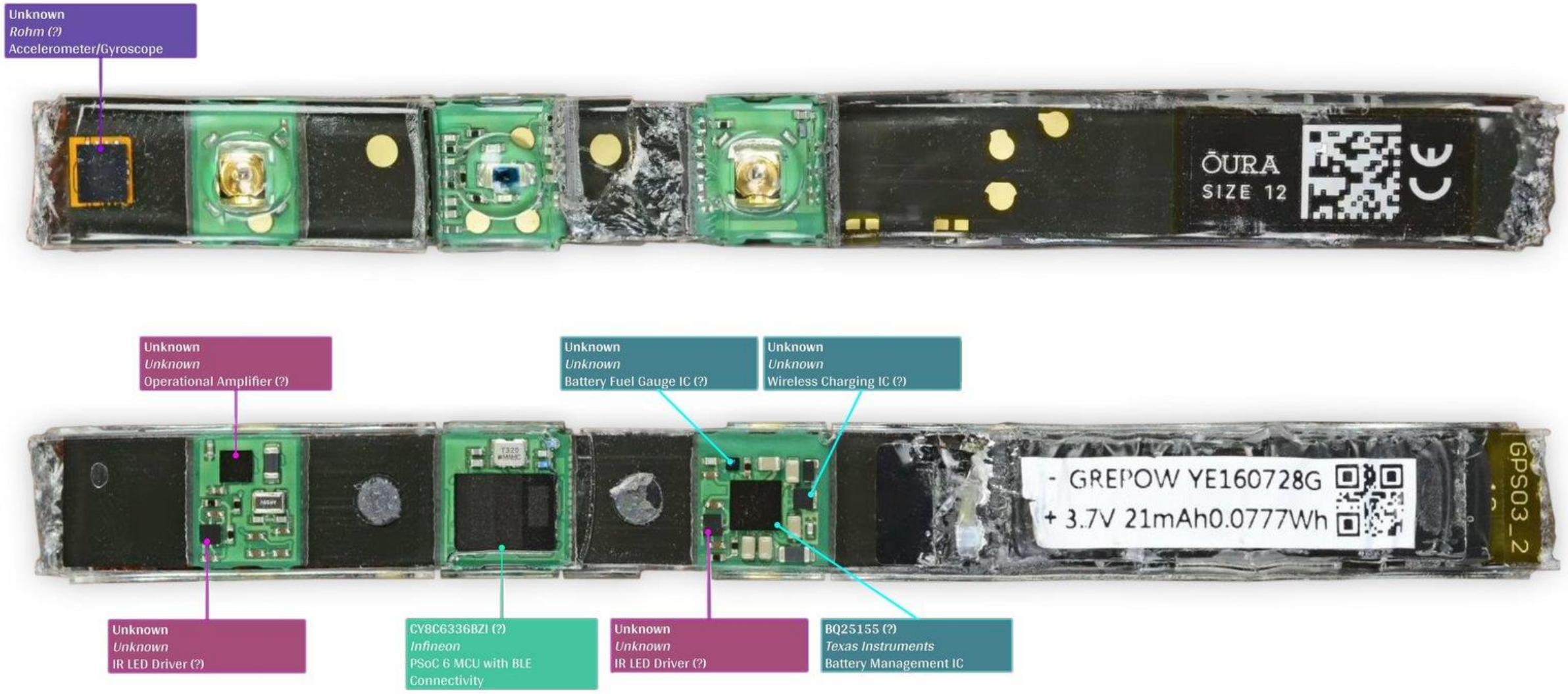


https://www.ifixit.com/Teardown/Oura+Ring+2+Teardown/135207

Apple AirPods (Smart Headphones)

Apple AirPods (Smart Headphones)

- Apple 343S00289 (likely Apple's new H1 chip)
- Dialog Semiconductor (Formerly Adesto) AT25SL128 128 Mb serial flash memory
- Apple 338S00420 (likely a low-power stereo audio codec)
- Bosch Sensortec BMA280 3-axis accelerometer (likely)

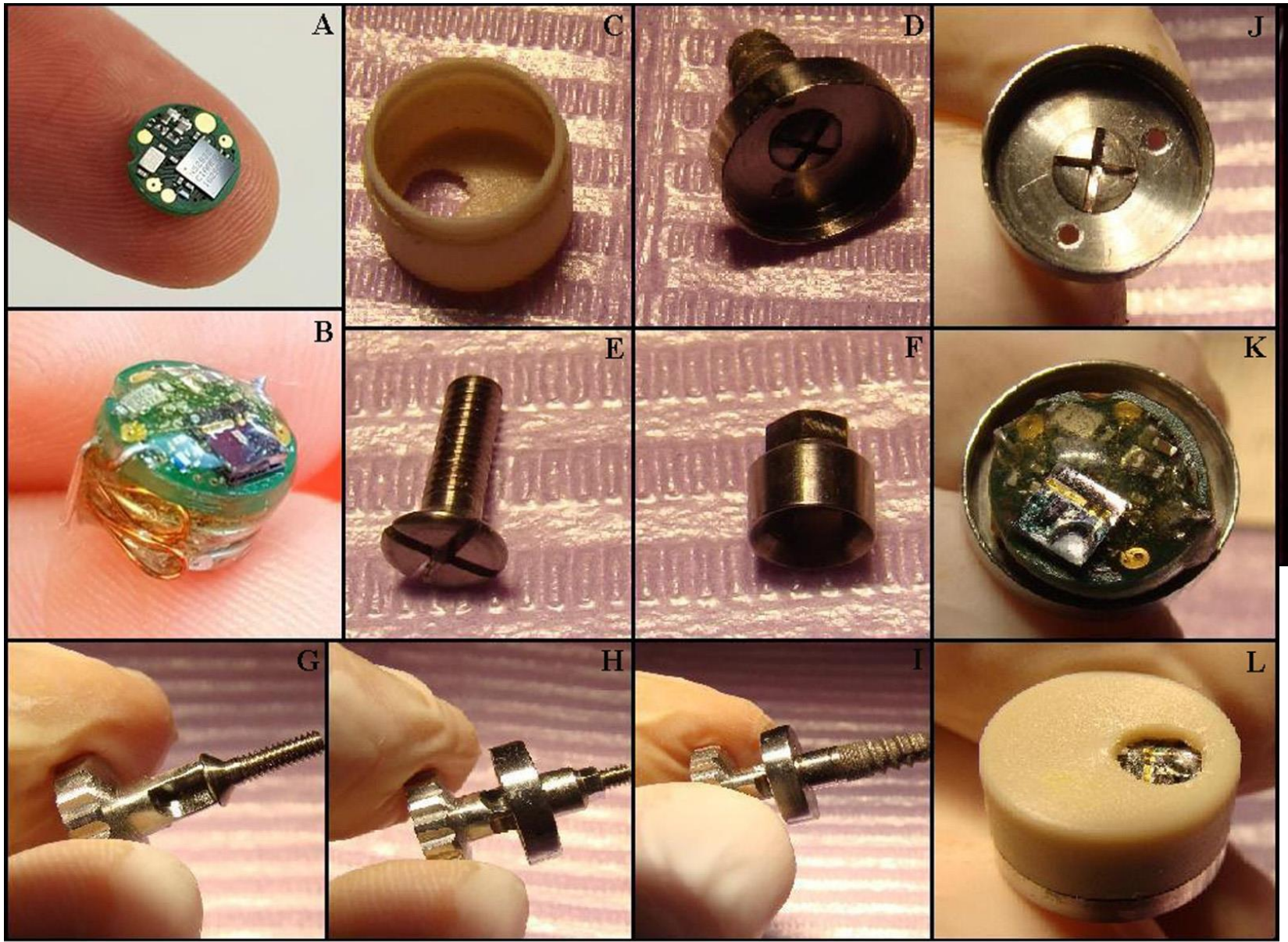
https://www.ifixit.com/Teardown/AirPods+2+Teardown/121471

Apple AirPods (Smart Headphones)

- 93mWh battery
- T 8 36 (likely STMicroelectronics inertial sensor)

https://www.ifixit.com/Teardown/AirPods+2+Teardown/121471

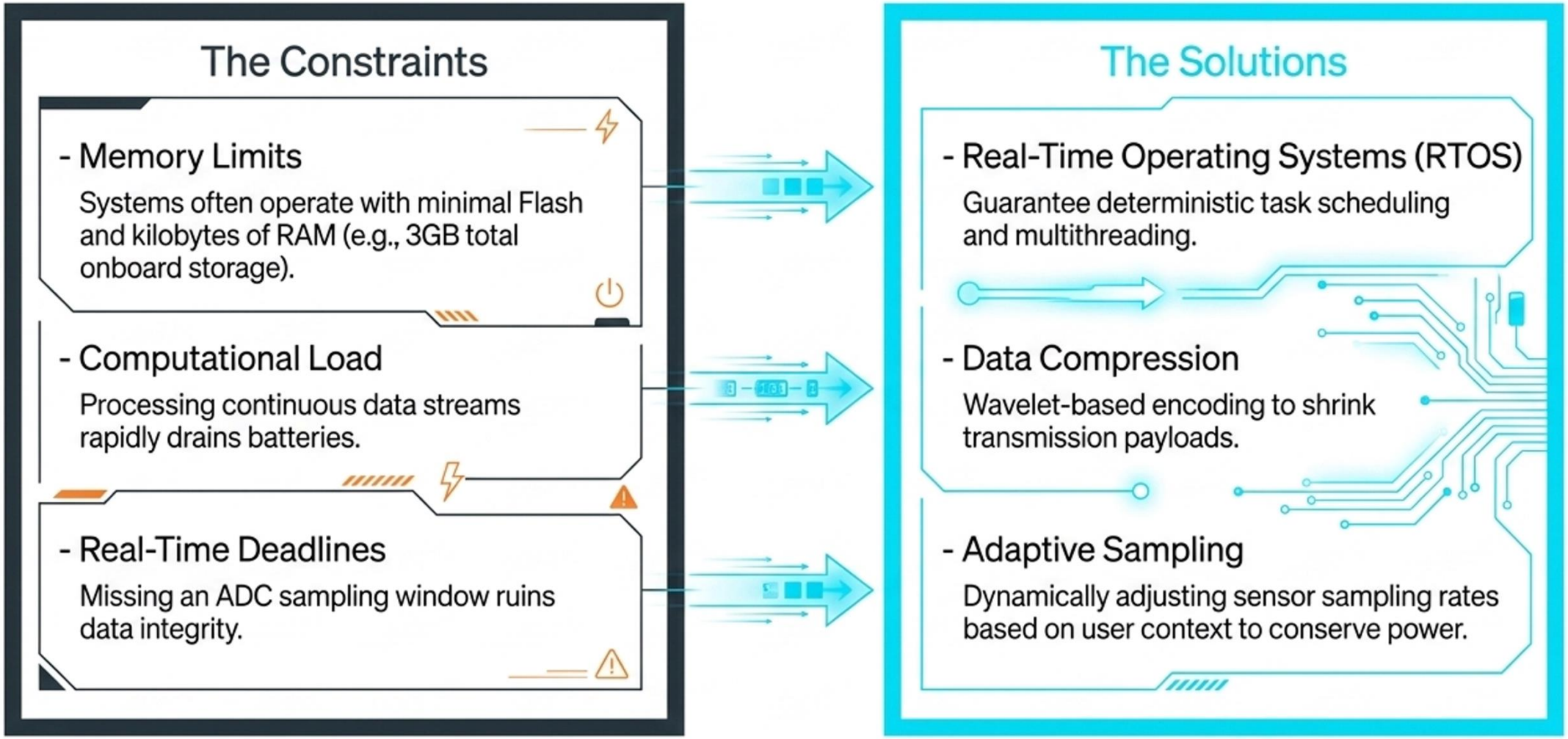
Microsal (Smart Dental Implant) - 2016



A New Model of Salivary Pacemaker—A Proof of Concept and First Clinical Use, Funieru, Cristian; Tudose, Dan Ștefan; Dobrică, Bogdan; Săndulescu, Mihai; Popovici, Ion Alexandru; Slușanschi, Emil Ioan; Croitoru, Sorin Mihai; Vrînceanu, Daniela; Bănică, Bogdan; Nicolescu, Mihnea Ioan, Medicina 2023, 59, 1647.

Software

Embedded Software for Wearables



watchOS

- Released 2015 exclusively for Apple Watch
- Limited open-source components
- WatchKIT API for developer use
- UNIX-like, slimmed down version of iOS
- Mostly closed ecosystem

apple.com/watchos/watchos-9

Tizen OS

- Open-source OS
- Developed by Intel, Vodafone, Orange, Samsung
- Not exclusively for wearables
- Native HTML5 app support
  - HTML, CSS and JS
- Tizen for wearable OS
  - Light version developed by Samsung
- Low footprint
- Optimized battery life

tizen.org

Wear OS

- Launched 2014, multiple HW platforms
  - 32-bit ARM, x86
- Open-source, closed source components
- Modified Linux kernel
- Multiple partners
  - LG, Asus, Samsung, Sony, Motorola

wearos.google.com

NuttX

- Open-source RTOS
- Runs on a variety of HW platforms
  - From 8-bit AVR to 32-bit ARM
- UNIX-like, POSIX compliant
- Modified versions for trackers & watches
  - Fitbit, Xiaomi
- Growing user base and following

nuttx.apache.org

Concerns

Privacy

- Wearables might lead to an improved, better life
- Putting your body online might not always benefit you
- Give whole level characteristics to the service provider not each user level specific information
- Ensure visibility for what the user is sharing
- Human agency and responsibility need to be in the loop

Security

- Wearable Device can be hacked and attacked wirelessly. Patients may die.
- Spoofing and altering are dangerous phenomena which can actually derail the whole purpose. May create panic.
- Side channel attack through power trace analysis is possible.

Energy

- Main reason applications on wearables are limited
- A lot of R&D effort spent at all levels (HW+SW) to solve this issue
- Main trends
  - Processors become more and more efficient – smaller nm technologies for ICs
  - Software becomes more and more optimized – double-edged sword
  - New energy sources become attractive – wearable might end up powered by you

Intrusion

- Too much personalization or assistance will repel users
- Users will be overwhelmed by the huge amount of data and can easily be panicked by misinterpreting any vital health data
- May curb creativity and reduce recall rate

What comes next?

Deeper Integration?

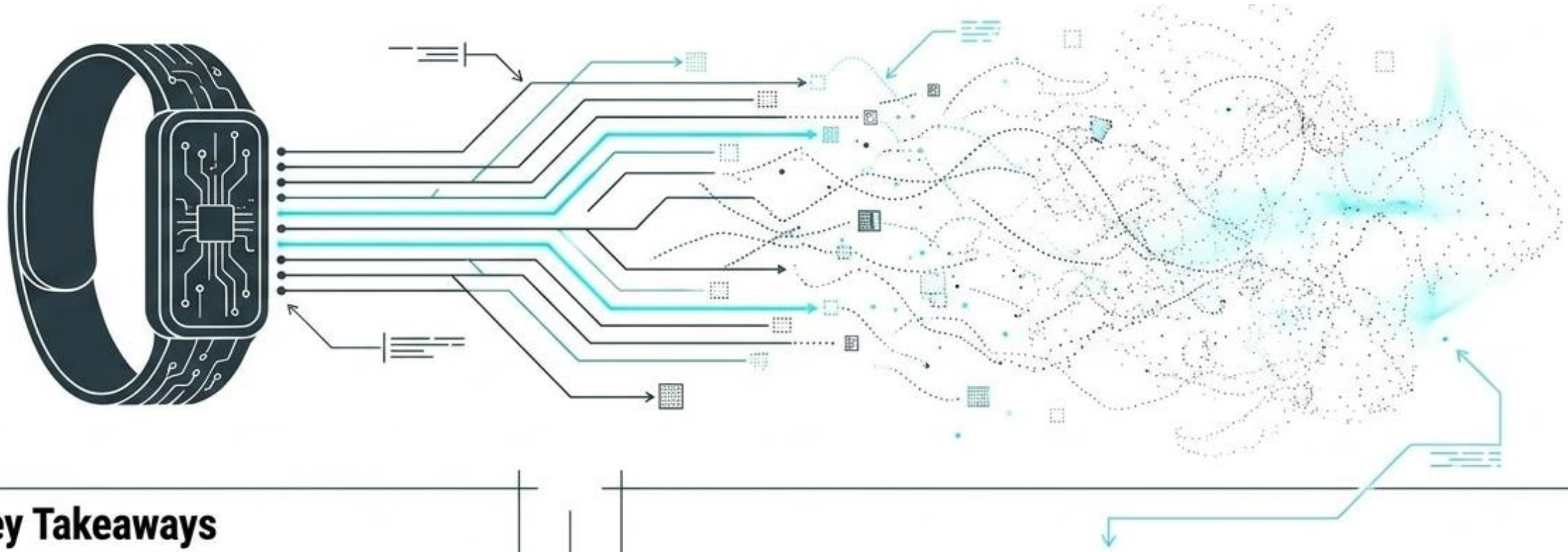
- Move towards seamless integration with other systems
- Market becomes more consolidated and standardized
- Advanced sensing – neural link, health assessment
- Metaverse?

Edible Computers?

- "I expect to see edible computers pills, which will act like little medical monitors, downloading information about your state of health to a computer you wear.“
  - Nicholas Negroponte, MIT Media Lab, 1999

- Technology already small enough to become implantable, only limitation is battery life

Future of Wearable Computing



Key Takeaways

- **Form Factor:** Transitioning from rigid electronics to soft materials, flexible substrates, and e-textiles.
- **Function**: Shifting from reactive tools to continuous, predictive, secondary intelligent assistants.

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 Computer for the 21st Century* (1991)