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# IoT Technology and Applications

## Transformation across Industry Value Chain

Dr. Ovidiu Vermesan, SINTEF, Oslo

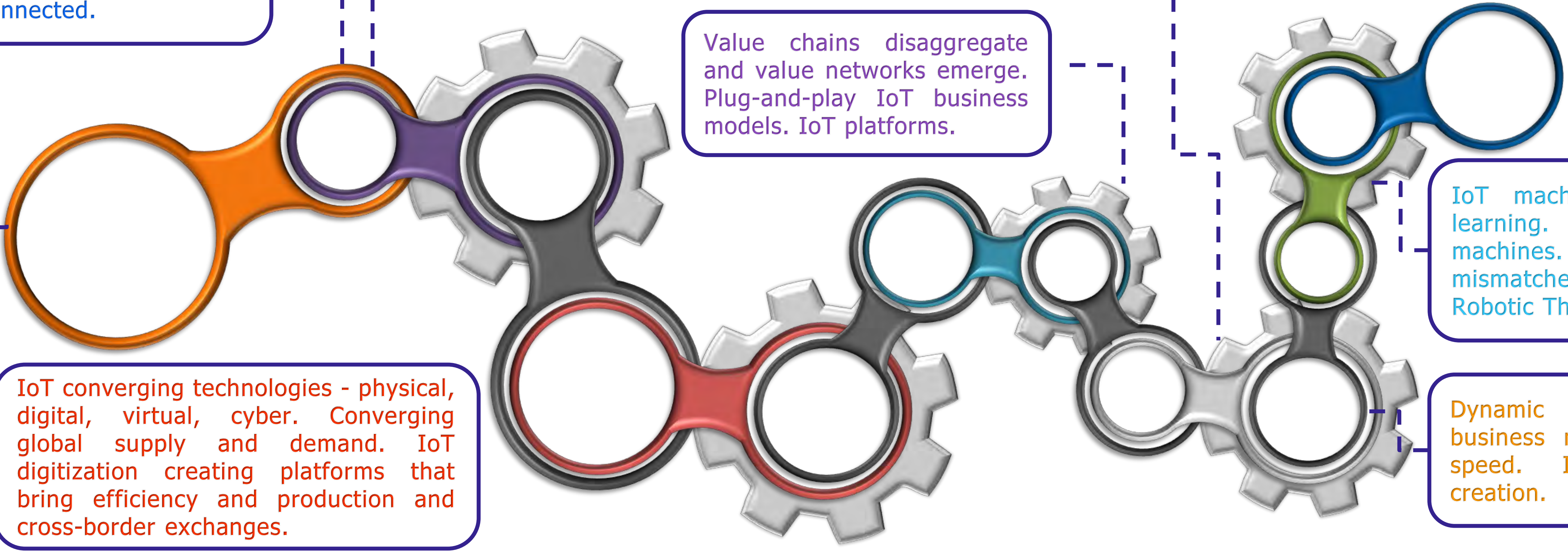
# The dynamics of IoT digital age

Pressure on prices and margins. Zero-marginal cost hyper connected society. Everything connected.

Digital dynamics change the barriers to entry and sources of product differentiation. Competitors emerge unexpected.

Winner-takes-all. Reduced transaction and labour costs, increased returns to scale from aggregated smart IoT data, and network ecosystem effects.

Value chains disaggregate and value networks emerge. Plug-and-play IoT business models. IoT platforms.



IoT machine to machine learning. Challenged by machines. Growing talent mismatches. Internet of Robotic Things. IoT Co-bots

IoT converging technologies - physical, digital, virtual, cyber. Converging global supply and demand. IoT digitization creating platforms that bring efficiency and production and cross-border exchanges.

Dynamic evolving IoT business models at higher speed. IoT value co-creation.

# The pathway of IoT digital transformation

**Systems of Systems**

- System optimisation.
- System of systems integration
- Virtualisation

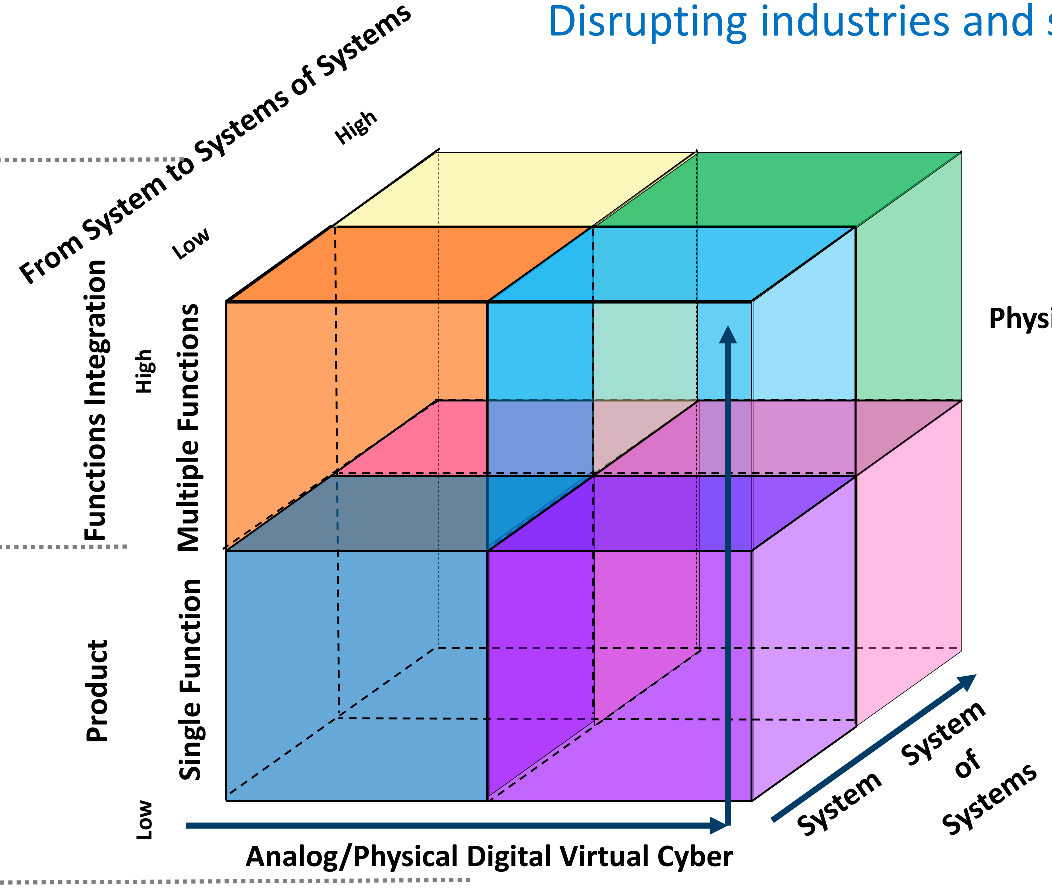
**Integration**

- Product, services, experiences.
- Multiple functions integration

**Connecting the Worlds**

- Physical
- Digital
- Virtual
- Cyber

Disrupting industries and society




**Integrated solutions**
**Ecosystem of digital propositions**
**Physical/Digital/Virtual/Cyber**
**Market Place**



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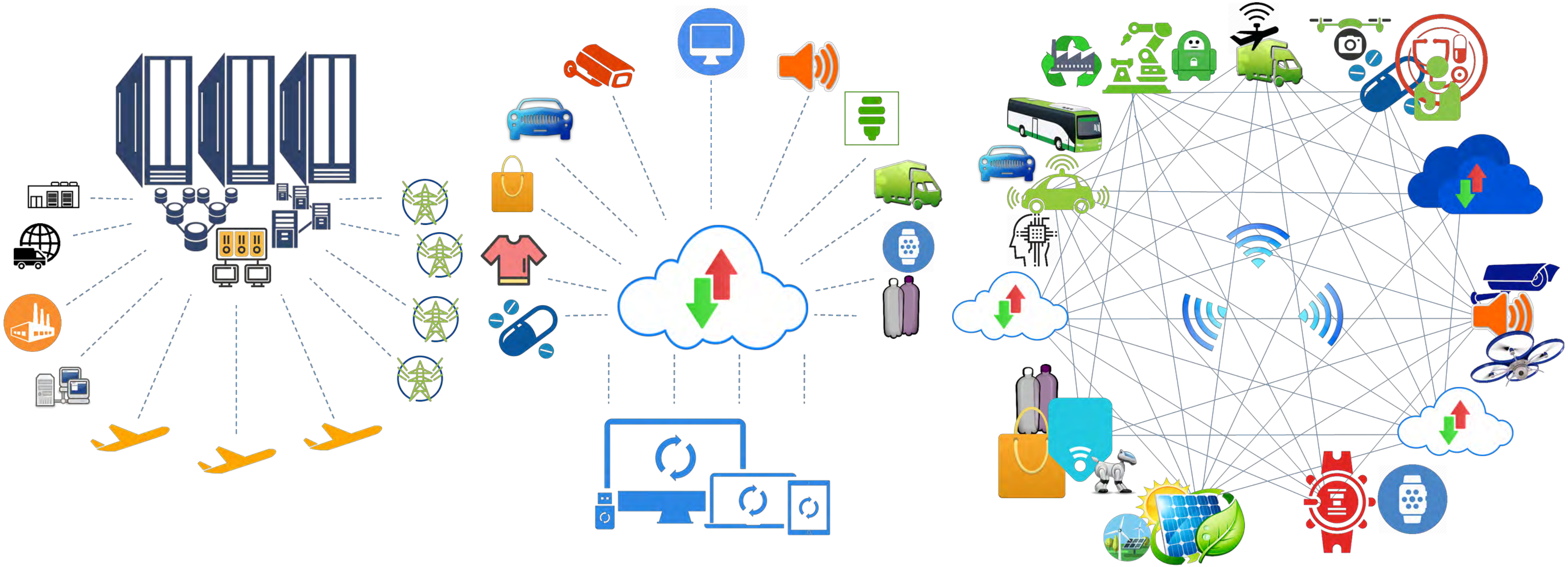
# IoT development

Before IoT | IoT Today | IoT in the Future



Closed and centralised IT networks

Open access IoT networks, centralised cloud, IoT platforms

Open access IoT networks, distributed cloud, open IoT distributed platforms



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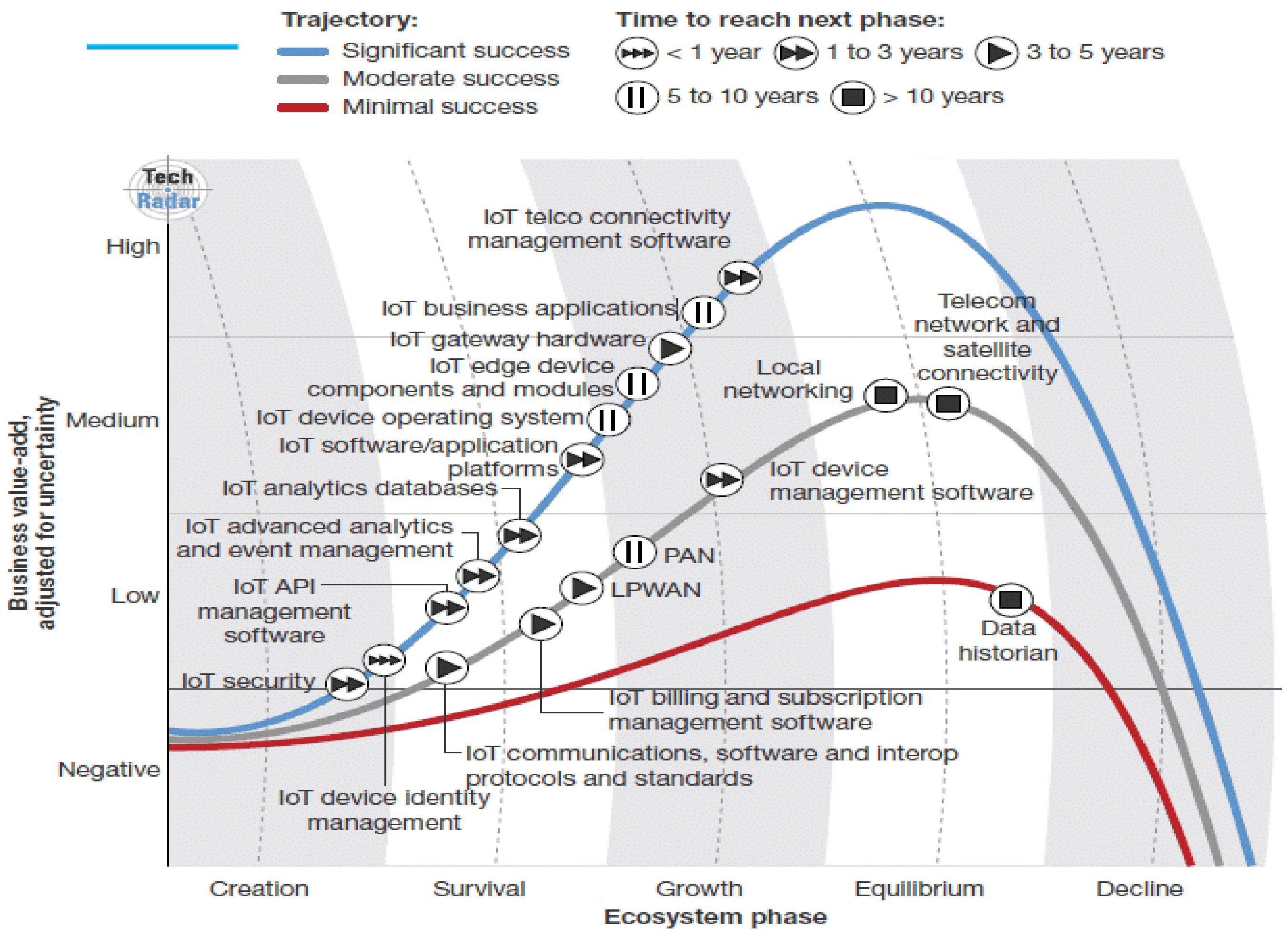
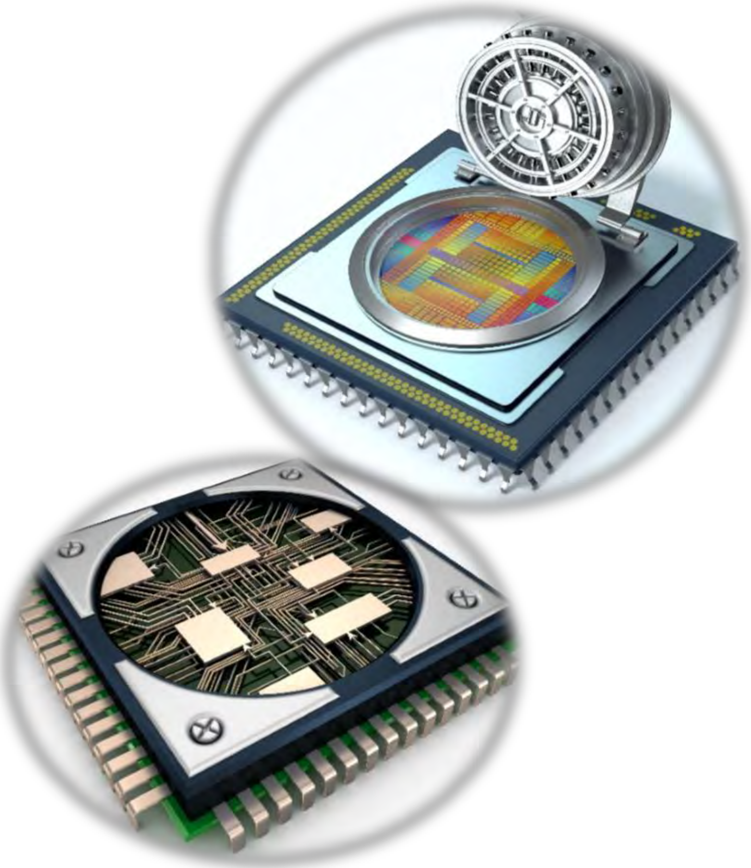
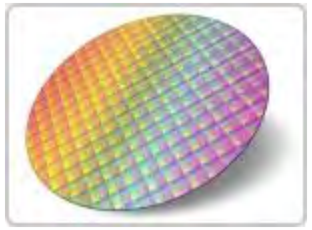
# IoT Development







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# IoT – Systems of Systems Integration

- Pervasive Sensing
- Cloud Computing
- Mobile Edge Computing

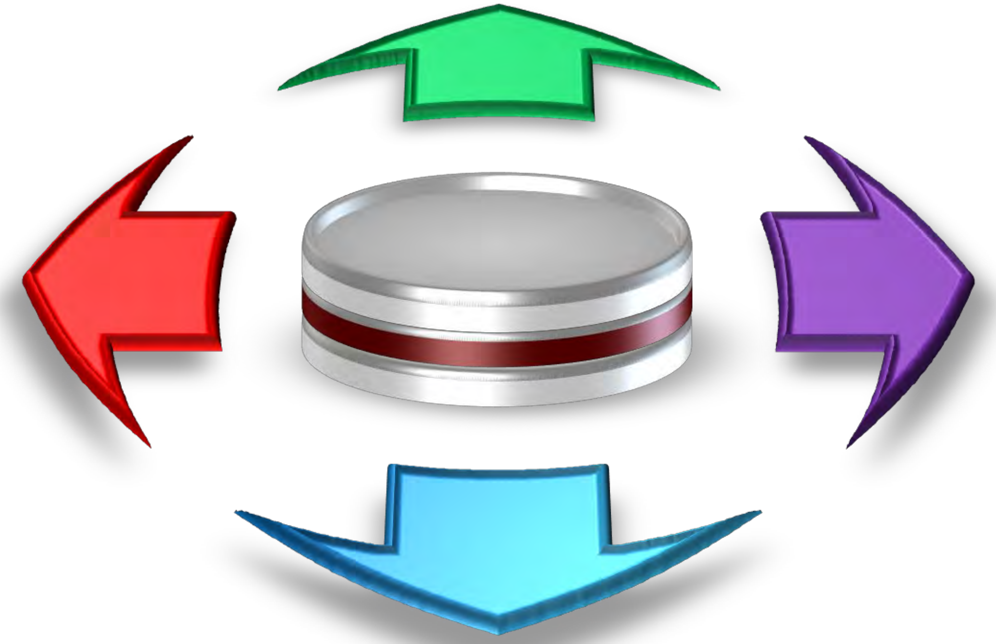
## IoT Smart Digital Information

Capturing, processing and analysing IoT information allows predictions and decisions to be made

- Autonomous Systems
- Electricity Everywhere
- Digital Shadow

## IoT Seamless Digital Access

IoT Internet access to customers, applications, platforms



## Autonomous

Combining IoT technologies with artificial intelligence – generate systems that work autonomously and organize themselves.

- Physical, Digital, Virtual, Cyber
- Cognition
- Sustainability Energy Efficiency

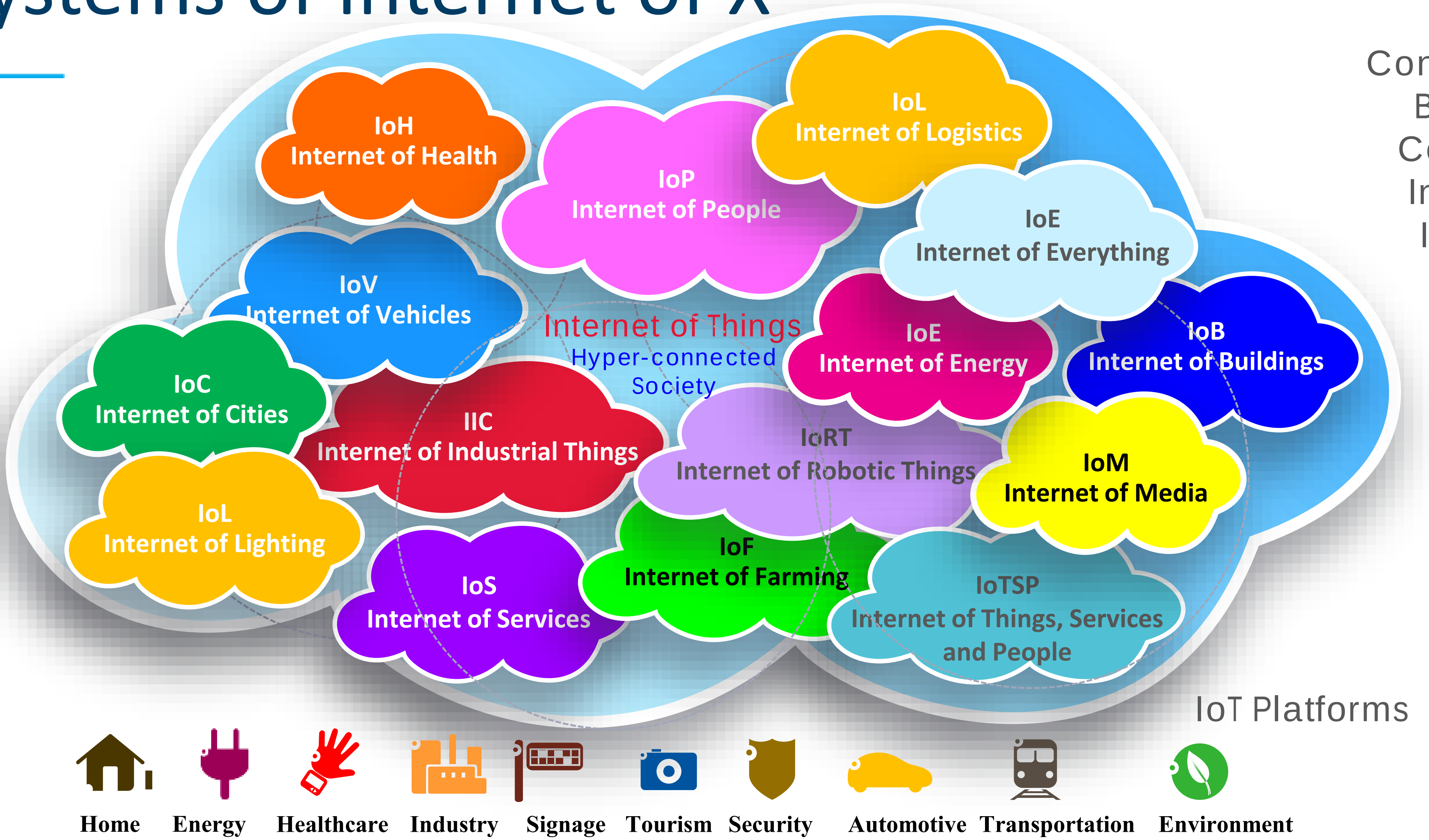
- Smart Data
- Ubiquitous Mobile Computing
- Computer-aided Collaboration

## IoT Connectivity

Interconnecting the entire value chain

Everything connected, everything analysed

# Systems of Internet of X




Convergence
Business
Consumer
Industrial
Internet

# IoT Architectural View

8 **Collaboration and Processes Layer**
(People and Business Processes)

7 **Application Layer**
Dynamic Applications
(Reporting, Analytics, Control)

6 **Service Layer**
(Services)

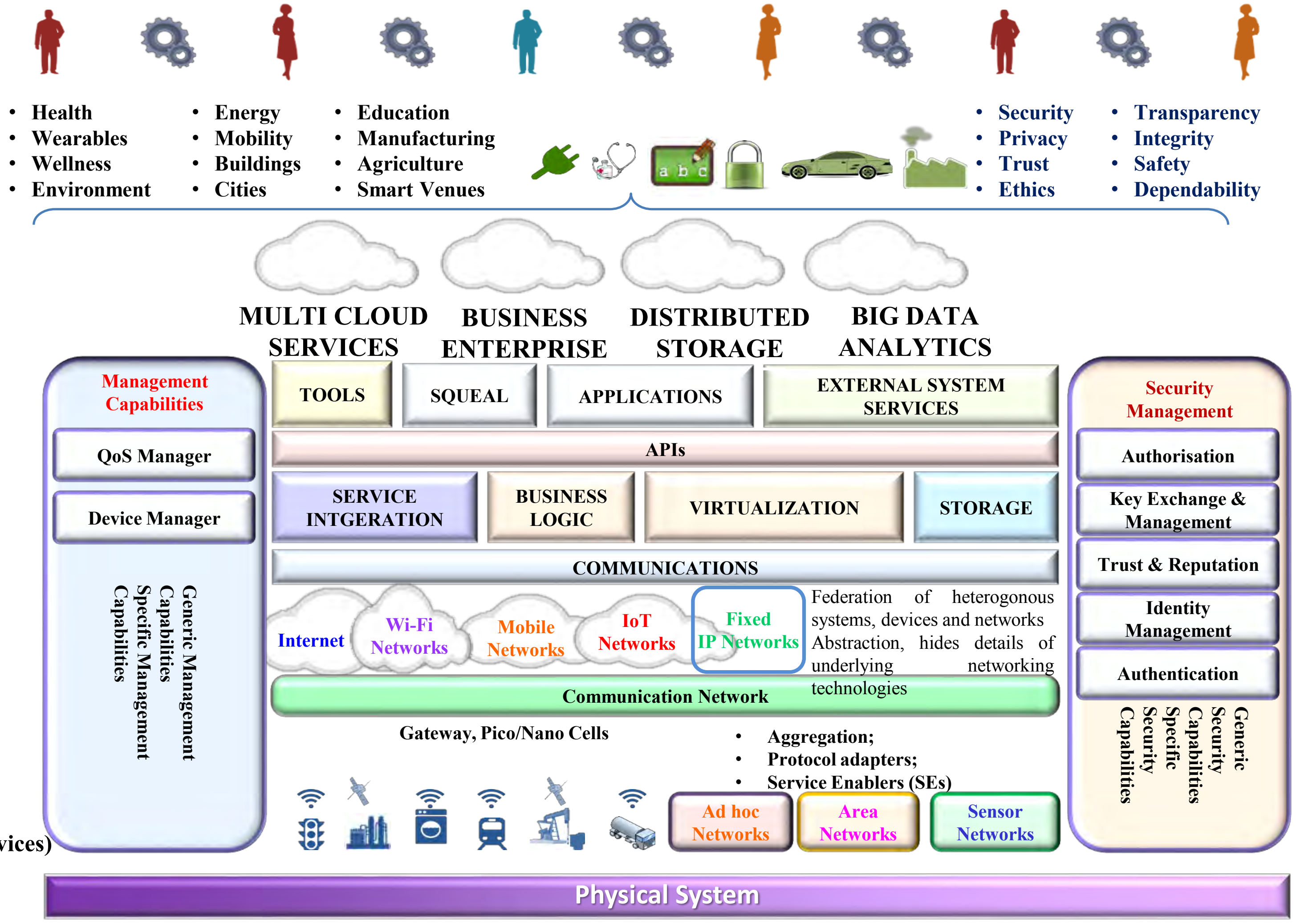
5 **Abstraction Layer**
Data Abstraction
(Aggregation and Access)

4 **Storage Layer**
Data Accumulation
(Storage)

3 **Processing Layer**
Edge Computing
(Data Element Analysis and Transformation)

2 **Network Communication Layer**
Connectivity Elements Gateways
(Communication and processing units)

1 **Physical Layer**
Devices and Controllers
("Things" - Sensors/Actuators Wired/Wireless Edge Devices)




## IoT Platform

- Reusable capabilities / enablers for applications
- Managed access to information based on secure, distributed and referable data
- Brokering for capability interaction plus export and import of enablers
- Support of different communication patterns
- Integration of different heterogeneous systems, devices and networks
- Abstraction, hides details of underlying (networking) technologies



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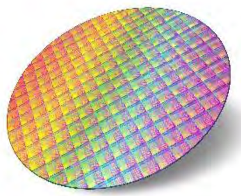
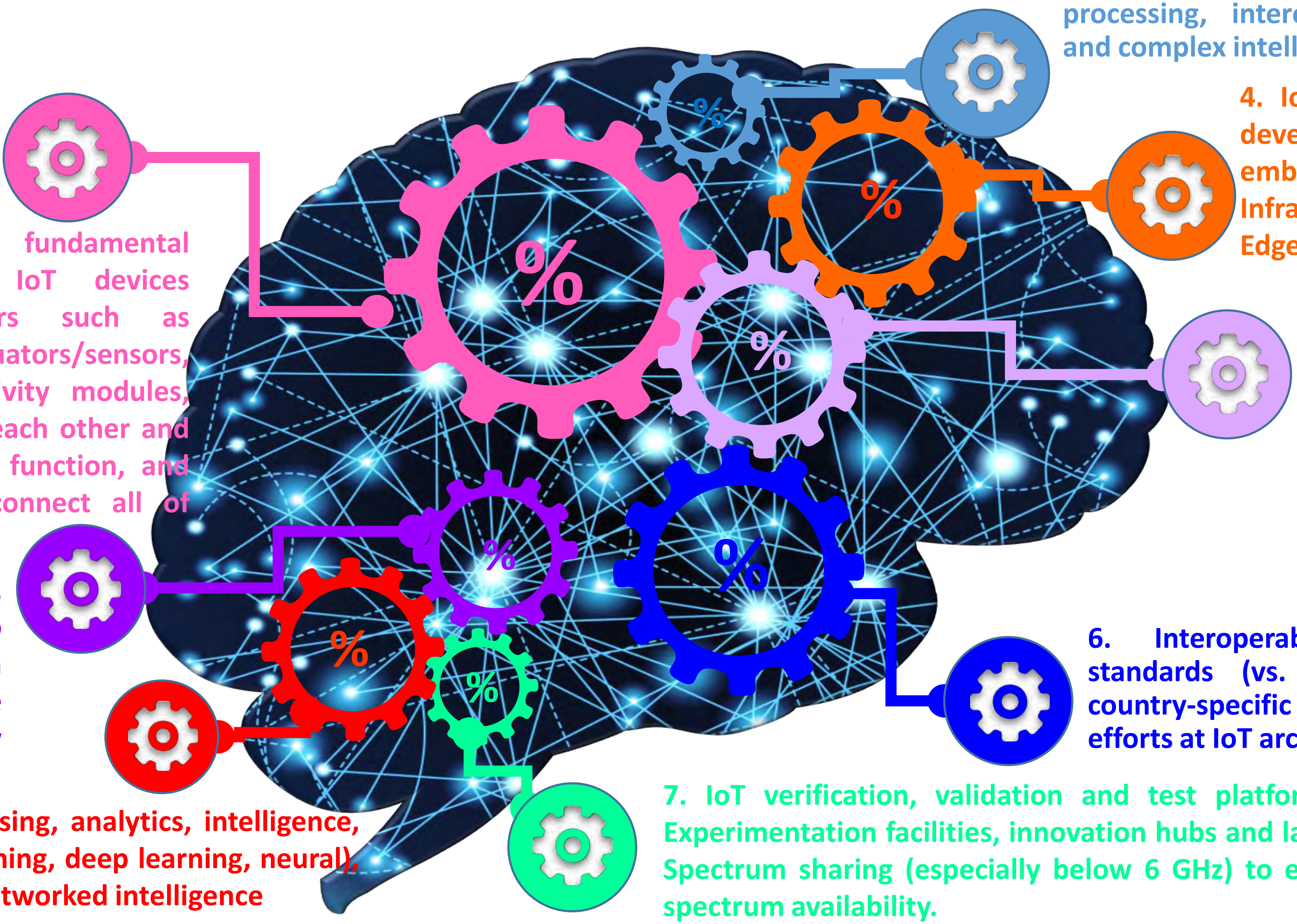
# IoT Neuromorphic Structure





1. Semiconductors fundamental enabling technology. IoT devices require semiconductors such as microcontrollers, actuators/sensors, communication/connectivity modules, memory to connect to each other and perform their intended function, and the infrastructure to connect all of these devices .

2. Robust and dynamic IoT ecosystems that promotes key capabilities, connectivity, real time processing, interoperability, scalability, security, and complex intelligent analytics

3. Design, modelling, simulation, testing tools to accelerate IoT adoption and enable cost-effective introduction of new technologies.

4. IoT Platforms, open architectures, development tools, SDK, software (OS, embedded, application, etc.). Infrastructure PaaS, IaaS, SaaS, IoTaaS. Edge computing, fog, cloud.

5. Policy framework supporting trustworthy solutions based on horizontal building blocks, open architectures frameworks, that are scalable, interoperable, and reusable across deployments, providers, and sectors. Multi-level end-to-end, by design, by default security solutions.

6. Interoperability, industry-driven global standards (vs. proprietary solutions and/or country-specific standards), open standards efforts at IoT architectural and platforms levels.

7. IoT verification, validation and test platforms framework. Experimentation facilities, innovation hubs and large-scale pilots. Spectrum sharing (especially below 6 GHz) to enable increased spectrum availability.

8. Real time processing, analytics, intelligence, learning (M2M learning, deep learning, neural), collaborative and networked intelligence

# IoT Architectural View

**Holistic approach to secure, interoperable and scalable IoT platforms**

***Secure, safe, trustworthy, assured, resilient IoT components, systems and platforms.***

- Health
- Wearables
- Wellness
- Environment

- Energy
- Mobility
- Buildings
- Cities

- Education
- Manufacturing
- Agriculture
- Smart Venues

- Security
- Privacy
- Trust
- Ethics

- Transparency
- Integrity
- Safety
- Dependability

| | |
|---|---|
| 8 **Collaboration and Processes Layer** (People and Business Processes) | |
| 7 **Application Layer** Dynamic Applications (Reporting, Analytics, Control) | Analytics, intelligence, learning (M2M learning, deep learning, neural), collaborative and networked intelligence. |
| 6 **Service Layer** (Services) | Advanced high computing server processors for processing, micro servers, virtualisation. New architectures for high performance computing. |
| 5 **Abstraction Layer** Data Abstraction (Aggregation and Access) | Distributed computing architectures. |
| 4 **Storage Layer** Data Accumulation (Storage) | Intelligent storage and new memory technologies and improved management systems to store and archive the data in order to maximize its use and action-ability. |
| 3 **Processing Layer** Edge Computing (Data Element Analysis and Transformation) | High performance microcontrollers for processing, micro servers, virtualisation. Storage. Memory at the edge level and multi-functional gateway level. Distributed computing paradigms/architectures for integrating clients, central nodes (cloud), gateways (fog) and edge nodes containing sensor/actuator interfaces. |
| 2 **Network Communication Layer** Connectivity Elements Gateways (Communication and processing units) | Enable universal connectivity. Ubiquitous broadband, high-speed broadband connections for advanced cellular technologies like 5G and advanced wireless technologies like next-generation Wi-Fi and NB-IoT, LoRa, SigFox, etc.. Networks virtualization. Multi-frequency, multi-protocol devices. |
| 1 **Physical Layer** Devices and Controllers ("Things" - Sensors/Actuators Wired/Wireless Devices) | Energy-efficient sensing/actuating and computing. Sensor/actuator nodes that operate using battery power or harvesting energy from the environment. Ultra small, new processors developed with novel materials, devices, and computational and physical architectures that reduce the energy used to collect, move, analyse, and store data. Low, energy efficient integrated connectivity solutions. Storage. Memory at the node level. |
| | **Physical System** |

## Security

Redundant multi-level, end-to-end, by design, by default hardware and software security solutions

Dedicated security components and security features embedded into hardware and software components. Scalable, dynamic security solutions built into hardware at the transistor level as well as software, from the edge of the network, gateways, processing, to the servers in the cloud. Hardware- and software- level security capabilities to create redundancies to prevent intrusions and enable robust, secure, trusted IoT end-to-end solutions.

Energy efficiency at all levels, from the smallest sensor/actuator to ultra-high performance processors and algorithms.

# IoT and Connectivity Scalability

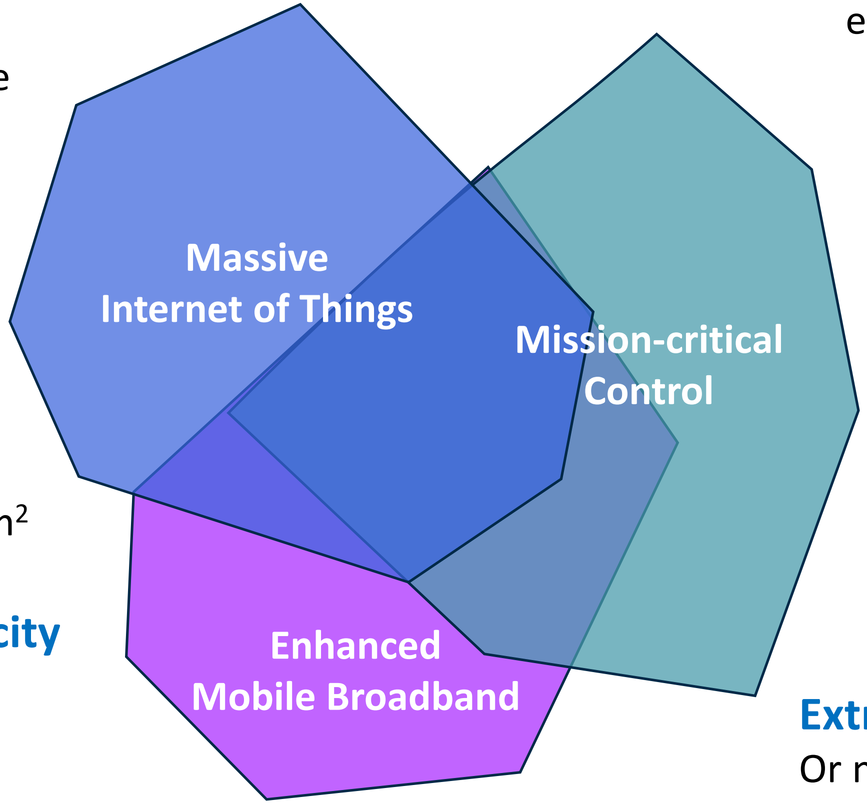
**Deep coverage**
To reach challenging locations

**Strong security**
e.g. Health, government, financial trusted

**Ultra-low energy**
10+ years battery life

**Ultra-high reliability**
< out of 100 million packets lost

**Ultra-low complexity**
10s of bits per second




**Ultra-low latency**
As low as 1 millisecond

**Ultra-high density**
1 million nodes per km$^2$

**Extreme capacity**
10 Tbps per km$^2$

**Extreme user mobility**
Or no mobility of all

**Deep awareness**
Discovery and optimization

**Extreme data rates**
Multi-Gigabits per second

Source: Qualcomm (adapted).



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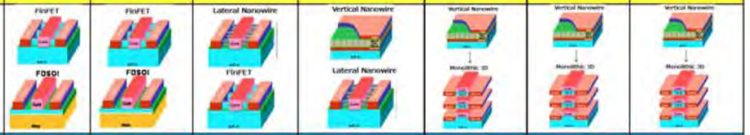
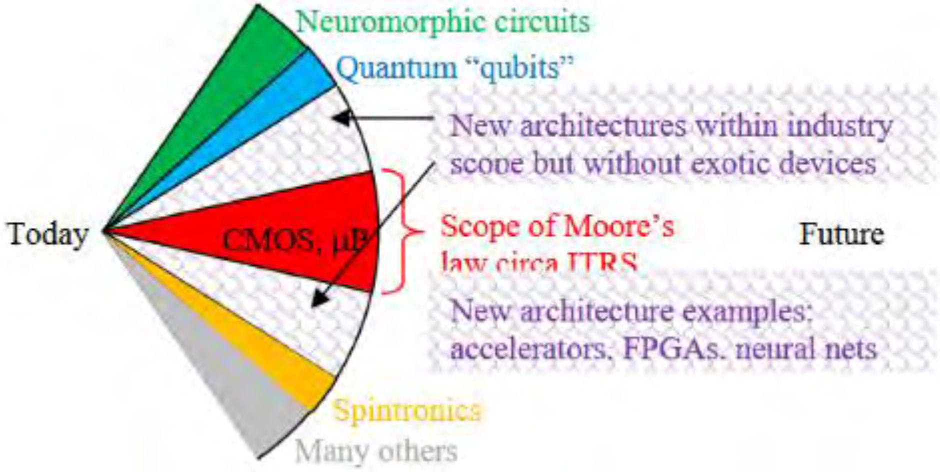
# Semiconductor technology challenges

*Table 1: Device architecture and ground rules roadmap for logic device technologies. PxxMxx notation refers to Pxx: contacted poly pitch and Mxx: metalx pitch in nm. This shows the technology capability. On top of pitch scaling there are other elements such as cell height, vertical integration, fin depopulation, DTCO contructs, etc define the target area scaling (gates/mm2).*

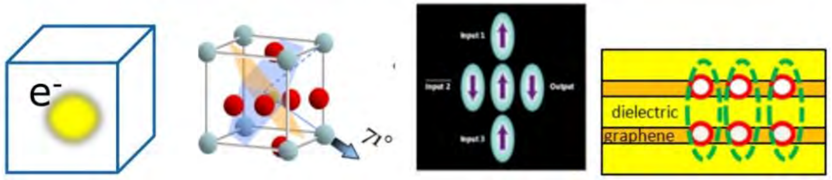
| YEAR OF PRODUCTION | 2015 | 2017 | 2019 | 2021 | 2024 | 2027 | 2030 |
|---|---|---|---|---|---|---|---|
| Logic device technology naming | P70M56 | P54M36 | P42M24 | P32M20 | P24M12G1 | P24M12G2 | P24M12G3 |
| Logic industry "Node Range" Labeling (nm) | "16/14" | "11/10" | "8/7" | "6/5" | "4/3" | "3/2.5" | "2/1.5" |
| Logic device structure options | finFET FDSOI | finFET FDSOI | finFET LGAA | finFET LGAA VGAA | VGAA, M3D | VGAA, M3D | VGAA, M3D |
| | | | | | | | |
|  | | | | | | | |
| LOGIC DEVICE GROUND RULES | | | | | | | |
| MPU/SoC Metalx ½ Pitch (nm)[1,2] | 28.0 | 18.0 | 12.0 | 10.0 | 6.0 | 6.0 | 6.0 |
| MPU/SoC Metal0/1 ½ Pitch (nm) | 28.0 | 18.0 | 12.0 | 10.0 | 6.0 | 6.0 | 6.0 |
| Contacted poly half pitch (nm) | 35.0 | 24.0 | 21.0 | 16.0 | 12.0 | 12.0 | 12.0 |
| $L_g$: Physical Gate Length for HP Logic (nm) [3] | 24 | 18 | 14 | 10 | 10 | 10 | 10 |
| $L_g$: Physical Gate Length for LP Logic (nm) | 26 | 20 | 16 | 12 | 12 | 12 | 12 |
| Channel overlap ratio - two-sided | 0.80 | 0.80 | 0.80 | 0.80 | 0.80 | 0.80 | 0.80 |
| Spacer width (nm) | 12 | 8 | 6 | 5 | 4 | 4 | 4 |
| Contact CD (nm) - finFET, LGAA | 22 | 14 | 16 | 12 | 11 | 11 | 11 |
| Device architecture key ground rules | | | | | | | |
| FinFET Fin Half-pitch (new) =0.75 or 1.0 M0/MI (nm) | 21.0 | 18.0 | 12.0 | | | | |
| FinFET Fin Width (nm) | 8.0 | 6.0 | 6.0 | | | | |
| FinFET Fin Height (nm) | 42.0 | 42.0 | 42.0 | | | | |
| Footprint drive efficiency - finFET | 2.19 | 2.50 | 3.75 | | | | |
| Lateral GAA Lateral Half-pitch (nm) | | | 12.0 | 10.0 | | | |
| Lateral GAA Vertical Half-pitch (nm) | | | 12.0 | 9.0 | | | |
| Lateral GAA Diameter (nm) | | | 6.0 | 6.0 | | | |
| Footprint drive efficiency - lateral GAA, 3x NWs stacked | | | 2.4 | 2.8 | | | |
| Vertical GAA Lateral Half-pitch (nm) | | | | 10.0 | 6.0 | 6.0 | 6.0 |
| Vertical GAA Diameter (nm) | | | | 6.0 | 5.0 | 5.0 | 5.0 |
| Footprint drive efficiency - vertical GAA, 3x NWs stacked | | | | 2.8 | 3.9 | 3.9 | 3.9 |
| Defice effective width - [nm] | 92.0 | 90.0 | 56.5 | 56.5 | 56.5 | 56.5 | 56.5 |
| Device lateral half pitch (nm) | 21.0 | 18.0 | 12.0 | 10.0 | 6.0 | 6.0 | 6.0 |
| Device width or diameter (nm) | 8.0 | 6.0 | 6.0 | 6.0 | 5.0 | 5.0 | 5.0 |

*Acronyms used in the table (in order of appearance): FDSOI: Fully-Depleted Silicon-On-Insulator (FDSOI), LGAA: Lateral Gate-All-Around-Device (GAA), VGAA: Vertical GAA, M3D: Monolithic-3D.*




## Computational Variables

| Class | Variables | Example |
|---|---|---|
| Charge | Q, I, V | CMOS, TFET |
| Electric Dipole | P | (FeFET) |
| Magnetic Dipole | $M, I_{spin}$ | All-Spin Logic (ASL), SpinWave Device (SWD), NanoMagnetic Logic (NML) |
| Orbital State | Bose condensate | BisFET |



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# Semiconductor device makers function

## IoT Stack

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***IoT Ecosystem***
***Services and Technologies***

**Connected Devices and Services**

Commercialising IoT enabled products and services via B2C, B2B, B2B2C, and M2M markets

***Traditional Semiconductor Industry Focus***

- Security
- Value-Added Services
- Connected Services
- IoT Stack Services
- IoT Platforms and Applications
- Networking and Edge Computing
- Intelligent Systems
- Computing/Processing
- Connectivity
- Sensing/Actuating

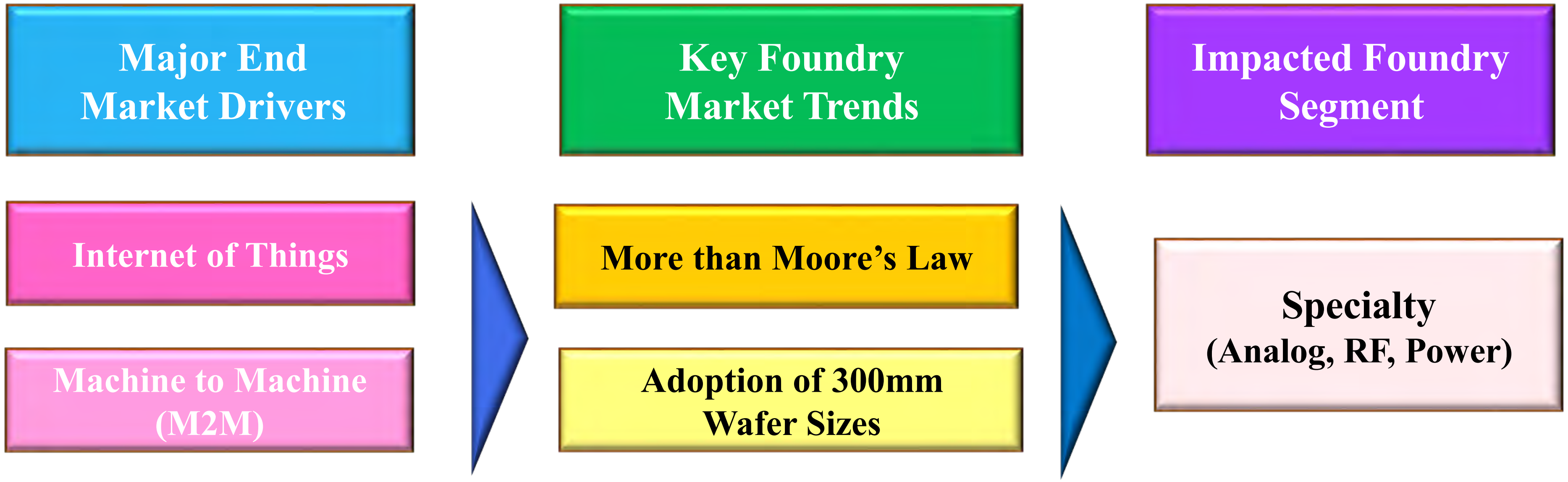
**3rd Party Services**

Offering business services that deliver IoT enabled devices with value-add information, interconnectivity, and/or digitally enabled capabilities.

**Enabling Services and Technologies**

Providing technologies, applications and/or services, which when are combined provide an integrated IoT platform.

# Specialty foundry market size




Market size for specialty devices especially in automotive and industrial segments will increase

The increase in number of fabless customers and specialty foundry applications could lead to adoption of 300mm wafer sizes

Source: PwC

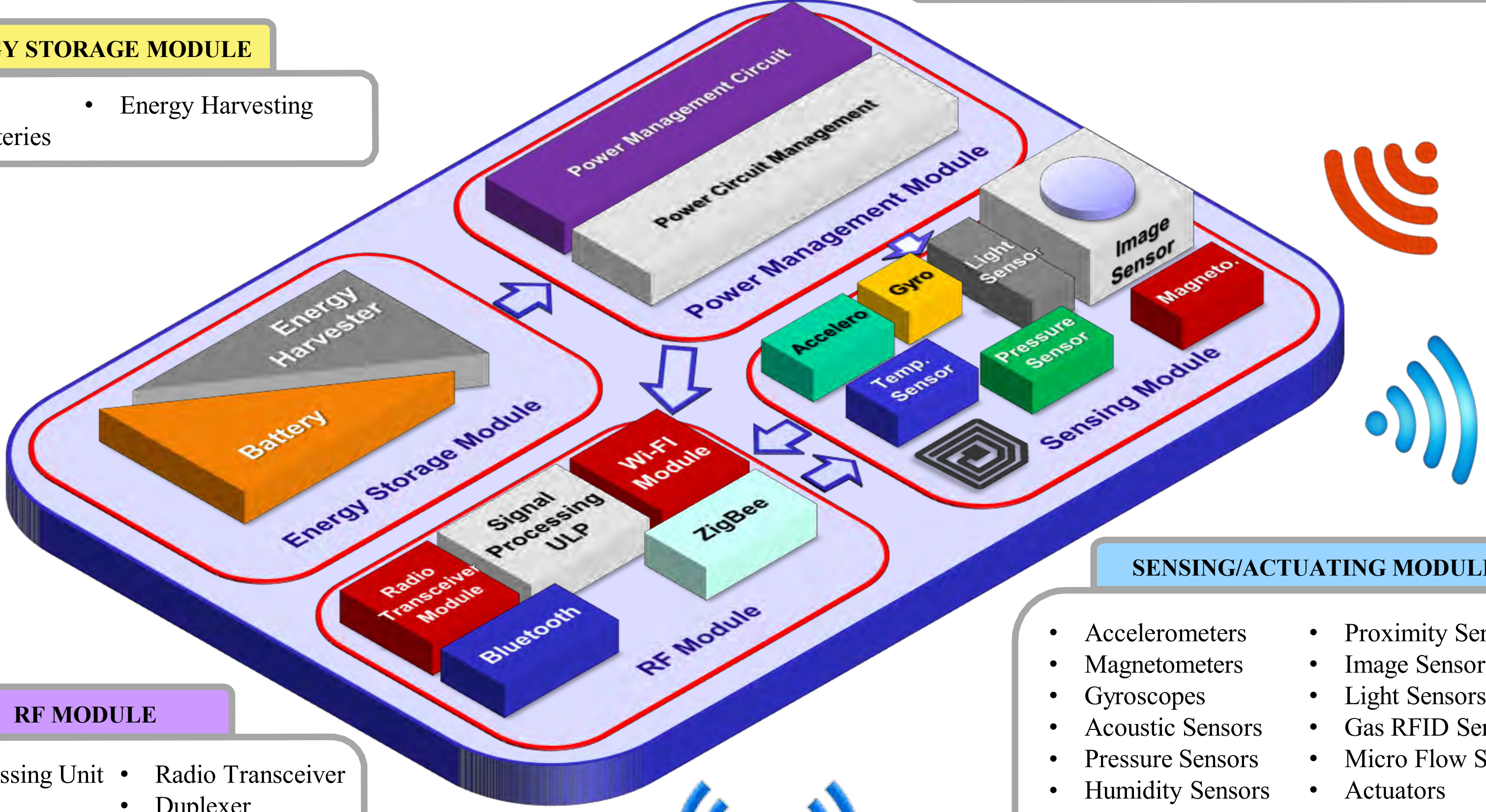
# IoT sensor/actuator map

**POWER MANAGEMENT MODULE**

- Ultra-capacitors
- Micro batteries
- PMU

**ENERGY STORAGE MODULE**

- Li-Ion battery
- AAA/AA Batteries
- Energy Harvesting




**RF MODULE**

- Signal Processing Unit
- Wi-Fi
- ZigBee
- Bluetooth LE
- Radio Transceiver
- Duplexer
- BAW

**SENSING/ACTUATING MODULE**

- Accelerometers
- Magnetometers
- Gyroscopes
- Acoustic Sensors
- Pressure Sensors
- Humidity Sensors
- Temperature Sensors
- Proximity Sensors
- Image Sensors
- Light Sensors
- Gas RFID Sensors
- Micro Flow Sensors
- Actuators

Source: Yole



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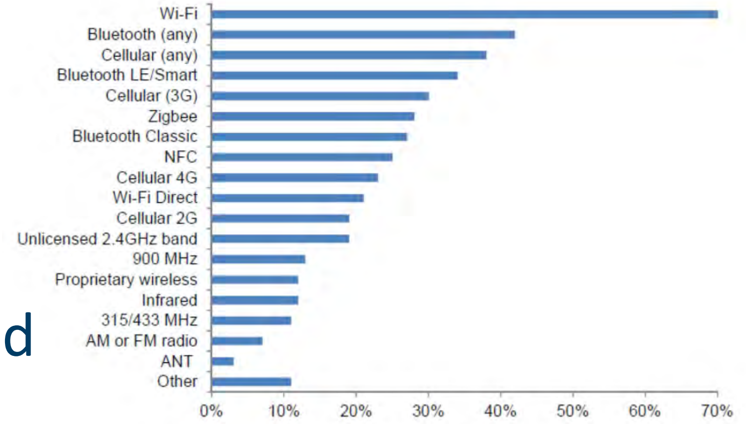
# IoT Technology - Communication

- Ethernet
- Power Line Communications
- Bluetooth/BLE
- 802.15.4/Zigbee/WirelessHART/ISA100.11a/Thread
- Z-Wave
- Wi-Fi
- LPWA (SIGFOX, LoRa, RPMA, Weightless, Telensa, Qowisio)
- GSM (GPRS, EDGE, EC-GSM)
- LTE (Cat-4, Cat-1, Cat-0, Cat-M1)
- NB-IoT (3GPP Cat-NB1)
- 5G IoT
- Satellite



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# IoT Technology - Communication

- WIRED IoT
  - Ethernet+Fieldbus
  - Power Line Communications
    - PRIME and G3-PLC
- SHORT-RANGE WIRELESS IoT
  - Bluetooth and BLE
  - RFID
  - 802.15.4
    - Zigbee
    - WirelessHART
    - ISA100.11a
    - Thread
  - 802.11
    - Wi-Fi a-n
    - Wi-Fi Direct

- LPWA
  - LPWA
    - *LoRa*
    - *SigFox*
    - *RPMA*
    - *UNB*
    - *Weightless*
    - *Qowisio*
- GSM AND EC-GSM
  - GSM, EDGE, and EC-GSM
- LTE AND NB-IoT
  - LTE *Cat-4, Cat-1, Cat-0, and Cat-M1*
  - NB-IoT
- 5G IoT
  - 5G IoT
- SATELLITE IoT
  - Satellite IoT
  - Globalstar, Inmarsat, Iridium

**36 Different Connection Technologies**

**IoT Connected Device Shipments**
**IoT Device Revenue**
**Enterprise vs. Govt. vs. Consumer**



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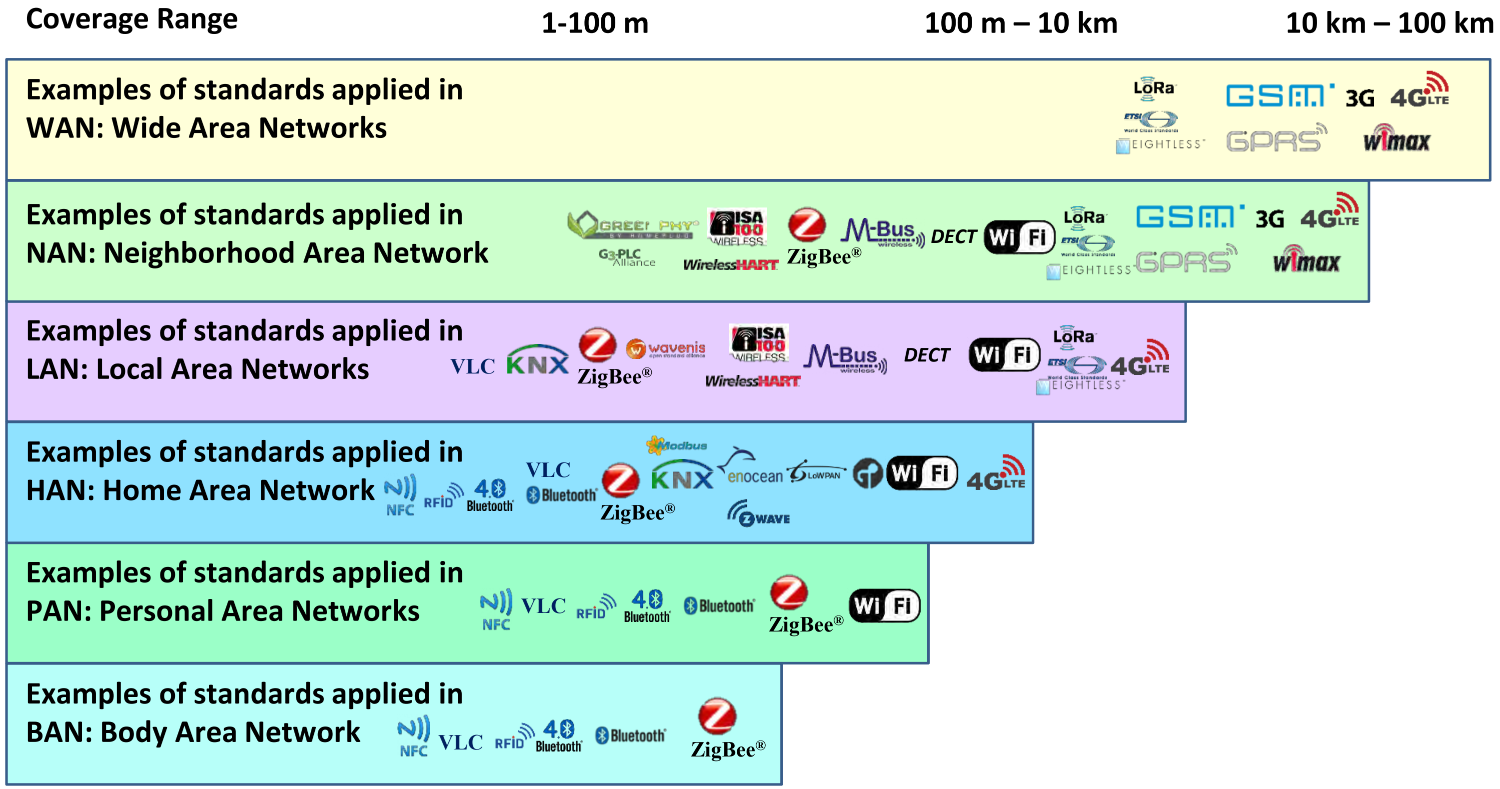
# Connectivity




WAN: Wide Area Networks cover a broad area, communication links that cross metropolitan, regional, or national boundaries. Internet is an example of a WAN.

NAN: Neighborhood Area Network is defined as a utility access network that connects meters and distribution automation devices to WAN gateways such as RF collectors or data concentrators and field devices.

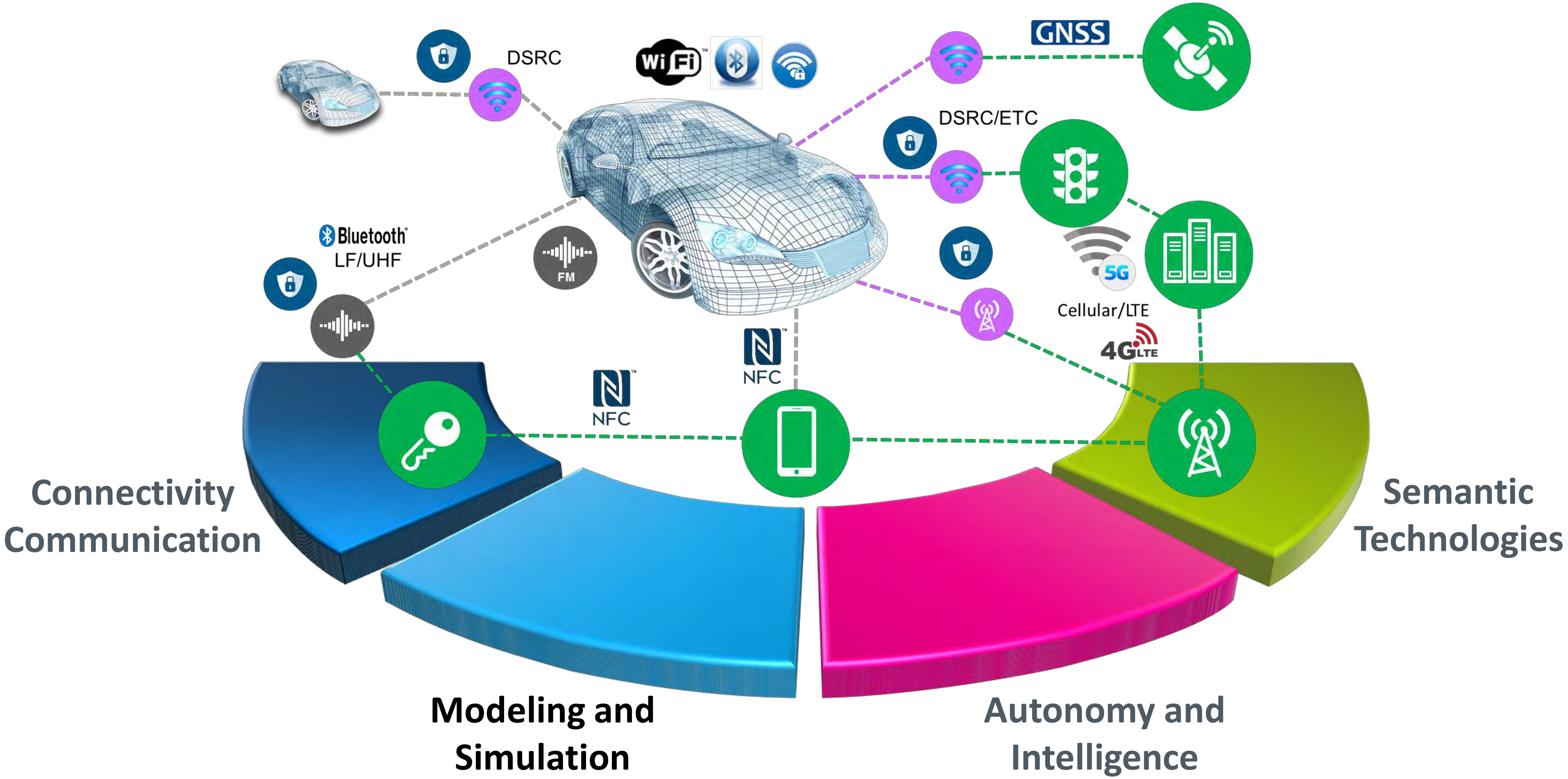
LAN: Local Area Networks cover a small physical area, like a home, office, or a small group of buildings or facilities. WLAN: Wireless Local Area Networks cover wirelessly a larger area that is connected to the network.

HAN: Home Area Network is the connection of network enabled devices in a domestic home.

PAN: Personal Area Networks are used for communication among various devices, such as phones, personal devices, fax, and printers, that are located close to a single user.

BAN: Body Area Network comprises communication between sensors placed on the human body.

# IoT pervasion of technologies

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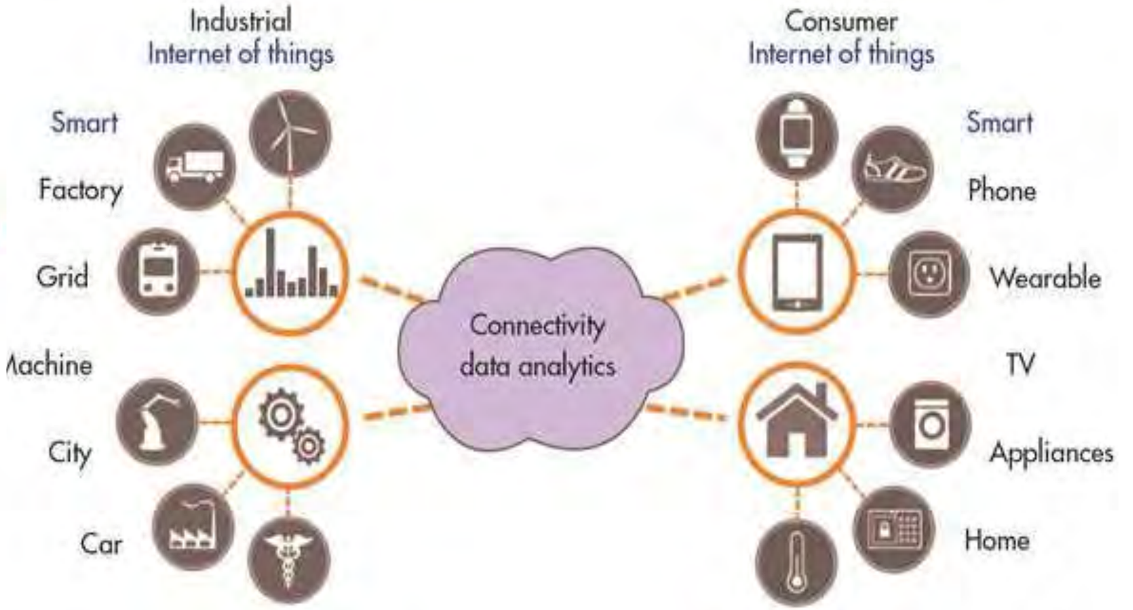
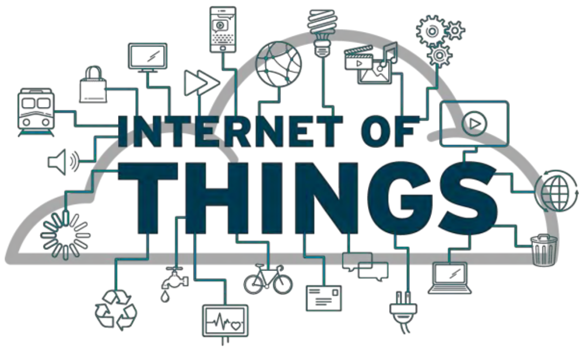
# IoT Consumer-Industrial-Business Convergence


Source: Designing the Industrial Internet of Things, electronicdesign.com.



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# Internet of Robotic Things IoRT

- IoT and robotics technologies combine to provide for Ambient Sensing, Ambient Intelligence and Ambient Localization, which can be utilized by new classes of applications to deliver value.




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# Security - convergence

**IoT Security**

**OT Security** ⟷ **IT Security**

**Dependent Devices**
- Authentication
- Authorisation
- Communication Encryption
- Monitoring
- Snooping – Data Leakage
- Spoofing

**Quasi Intelligent Devices**
- Access Control
- Data Encryption
- Firmware security
- Patch Management
- Intrusion Detection

**Intelligent Devices and Controllers**
- Device Provisioning
- OS Security

**SIEM and Analytics**
Security Information and Event Management

**Data Security**

**Application Security**

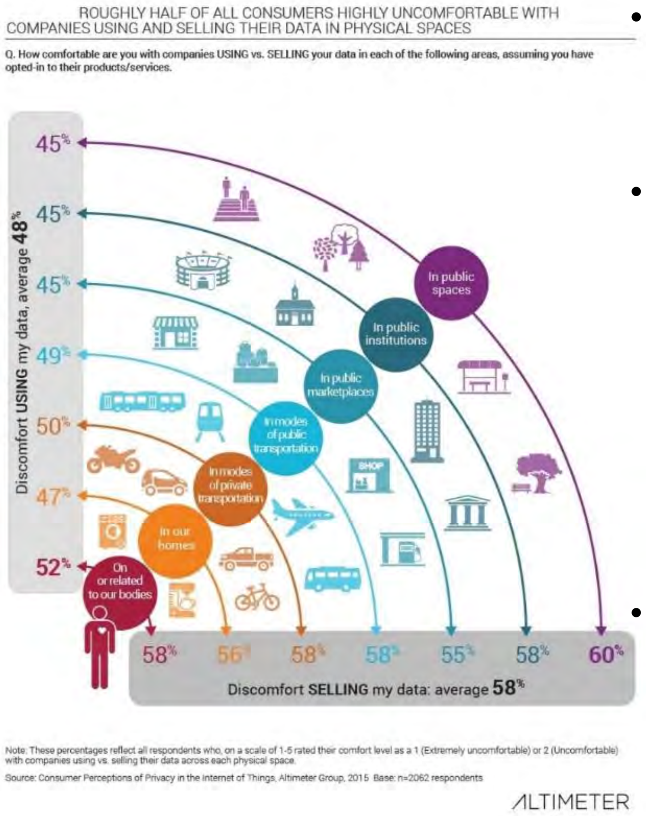
**Network and Communications**

**Device Authentication**
Access Provisioning and Monitoring

OT+IT threat models, control points and response processes

Information technologies: conventional computers, operating systems, networking components and software platforms.

Operational technologies: industrial control system and networks.

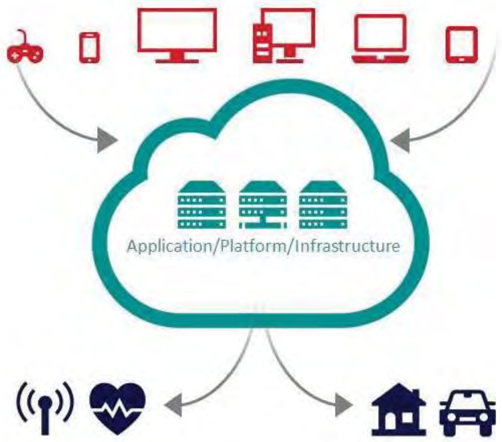



- Privacy is not something we can standardize or account for in a scripted template.
- Privacy is a function of shifting contexts, motives, and frameworks: culture, religion, location, age, gender, income, family, sexual orientation, life events, experiences, exposure, and more.
- Privacy is subject to each of our unique, yet deeply human sensitivities.

# Breaking down walls
# Convergence of devices

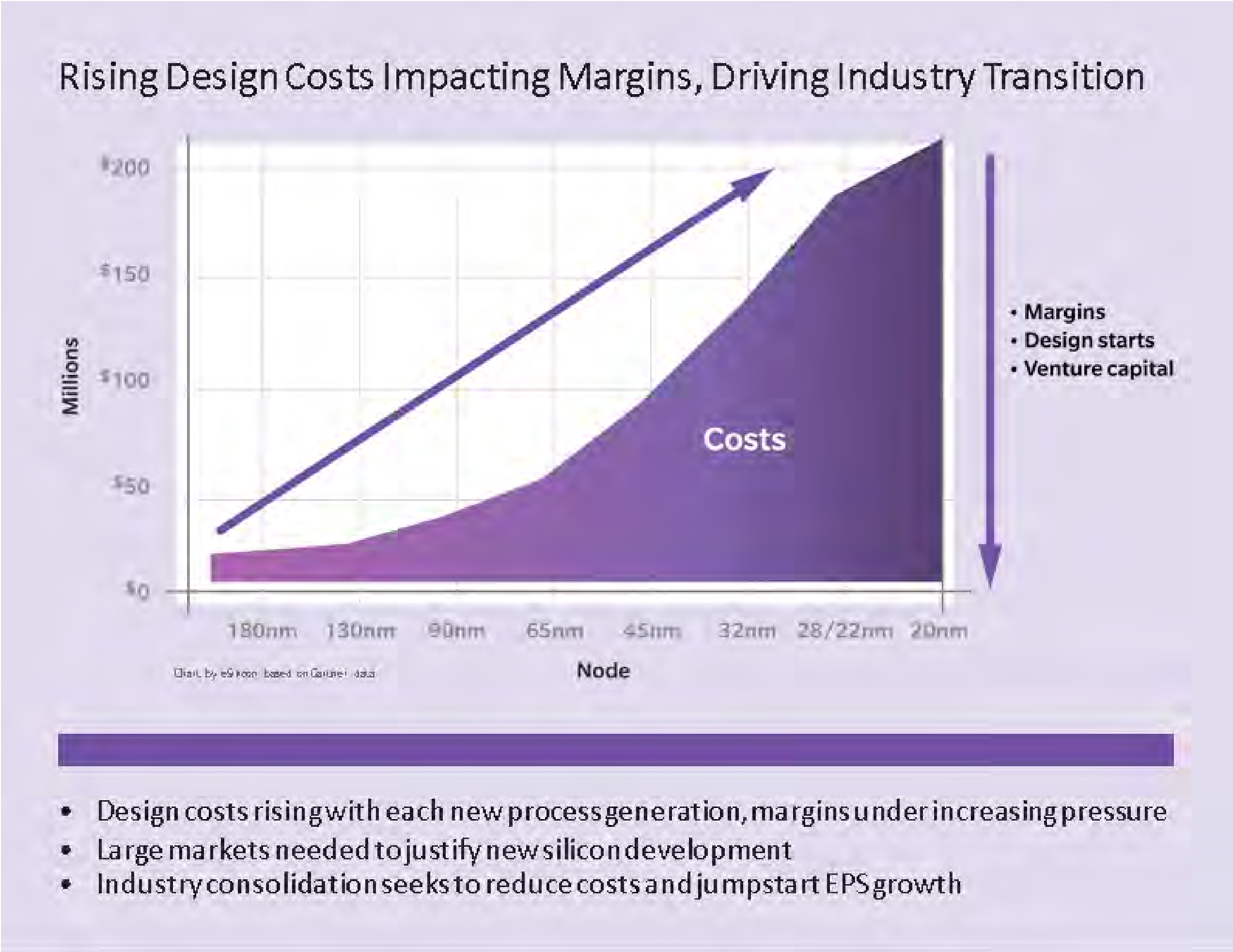
- The convergence of technology from formerly differentiated domains (e.g., consumer, computer, industrial, and automotive) requires a look at new challenges and new use models.
  - The connection of electronic products to the Internet, producing and consuming large amounts of information.
  - The need to design more devices to produce and consume information autonomously, independent of humans.
  - The need for companies, engineers, and technologies to constantly change and adjust the way in which products are being developed.


*Execution through Strategic Initiatives*




Source: 2016 BY Mentor Graphics

# Rising Chip Design/Manufacturing Costs



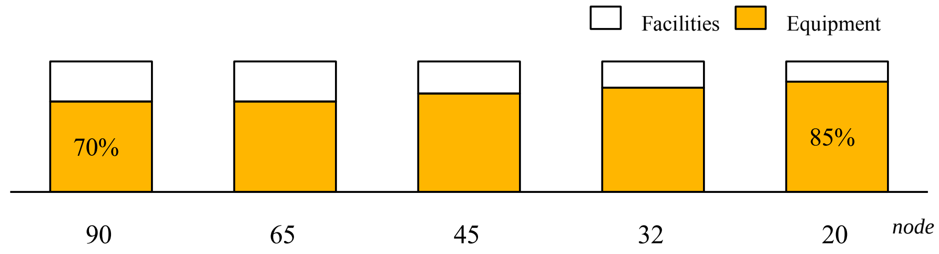

Source: 2015 Global Semiconductor Alliance.

# Cost increasing cost pressures

**Fab Costs**

+168%*

*Equipment cost rising to 85% of total fab costs*




**Process Development Cost**

+225%*

***Device***

- 2D transistor -> 3D FinFET
- Advanced Materials for 14nm and beyond

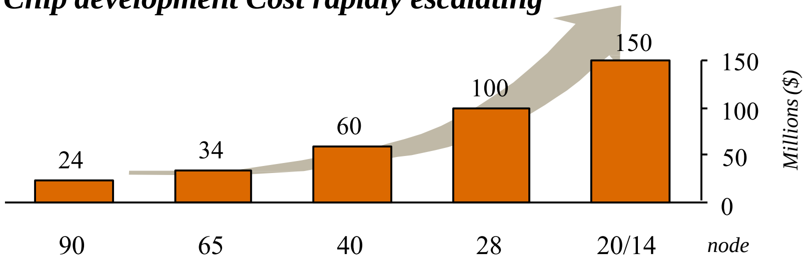
***Packaging***

- 2D->2.5D -> 3D
- 3D is 1.4x more expensive than 2D packaging

**Chip Design Cost**

+341%*

*Chip development Cost rapidly escalating*




* Morgan Stanley estimate of the cost increase in shift from 65nm to 20 nm

Source: PwC



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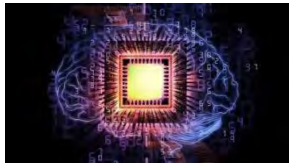
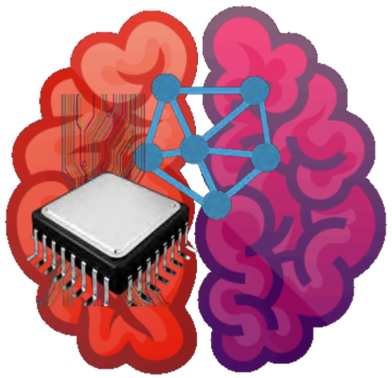
# Computing paradigm change

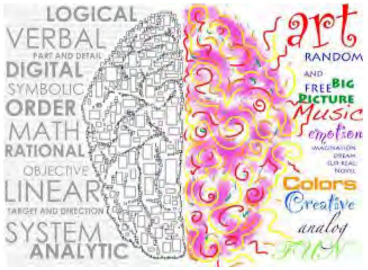


## Computers

**Serial architecture**

- High power (100MW), Large footprint (40M litter)
- Synchronous (master clock)
- Digital computing
- Digital communication
- Memory and computation are separated
- Intelligence via operating systems, programed algorithms, rules.
- Built with precise components operating at high speeds (GHz)
- Active when instructed

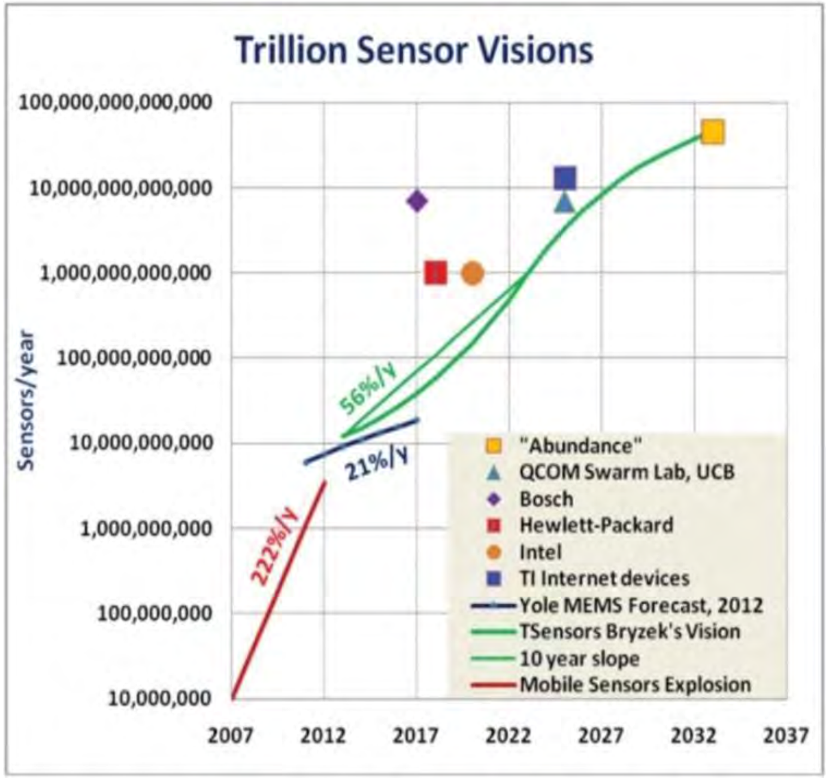




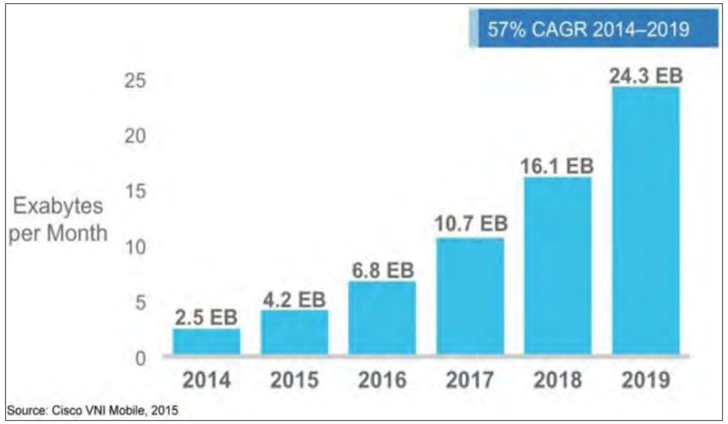

## Mammalian Brains

**Parallel distributed architecture**

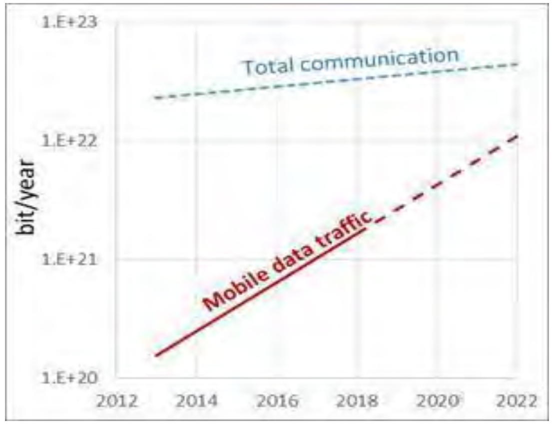
- Low power (25W), small footprint (1 litter)
- Asynchronous (no master clock)
- Analog computing
- Digital communication
- Integrated memory and computation
- Intelligence via learning trough brain body environment (BBE) interactions.
- Built with noisy components operating at low speeds (<10Hz)
- Unpredictable active




Source: 2015 Semiconductor Industry Association.




**Annual growth of mobile data traffic**




**Mobile data traffic vs. total communication**



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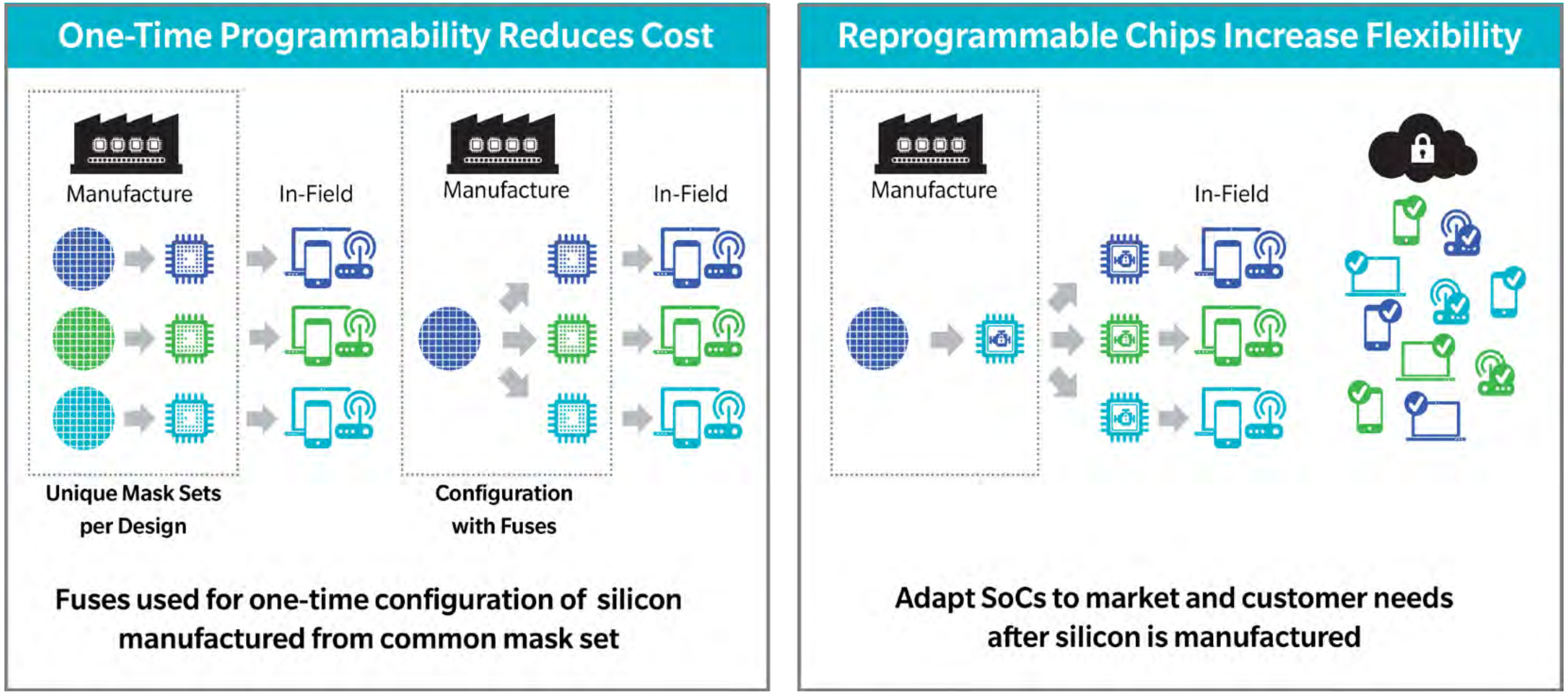
# Reprogrammable chips




- Reprogrammable silicon improves security and flexibility, enables downstream configuration
- Features as a Service (FaaS): Features and Services can be enabled and disabled in-field, opening up a wide range of new usage model



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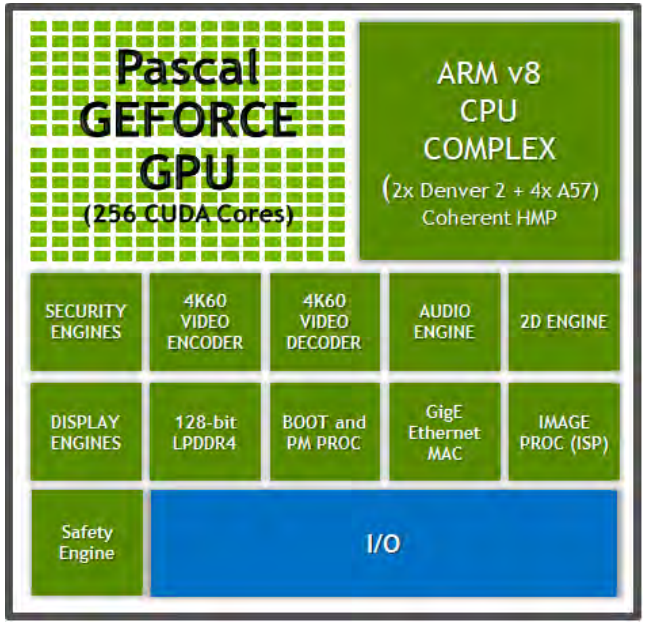
Source: 2015 Global Semiconductor Alliance

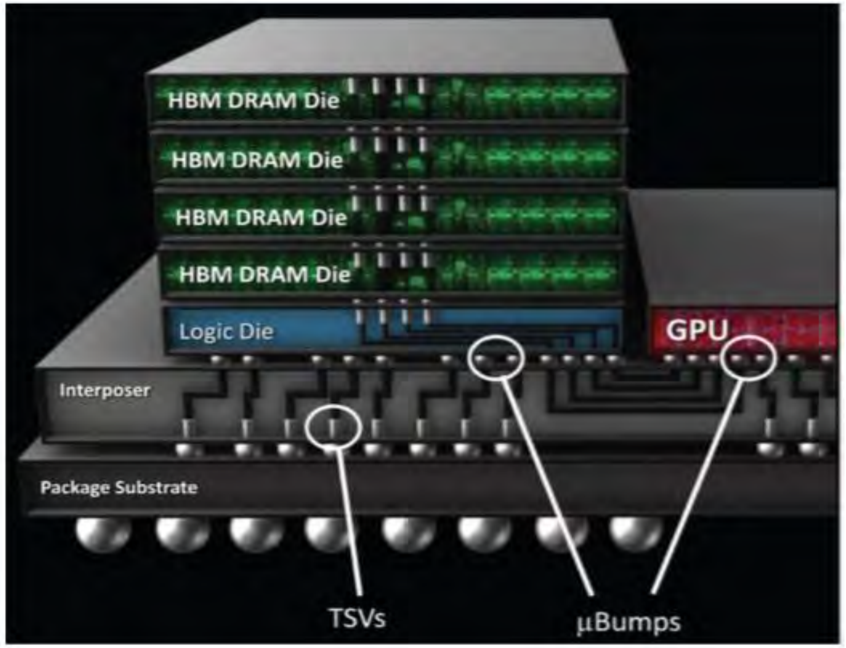
# Alternative to x86, ARM Architectures

- Shifting to Photonics

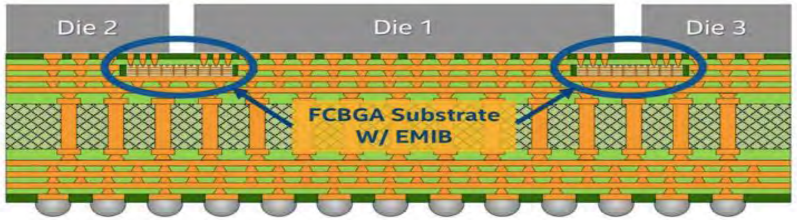
Device is built for throughput and speed. So while it includes a 16nm finFET-based CPU, with two 64-bit “Denver” ARM cores and four A57s, it also includes a number of other chips, including a 256-core GPU, display and audio engines, a safety engine, a secure boot processor, and DDR4 memory



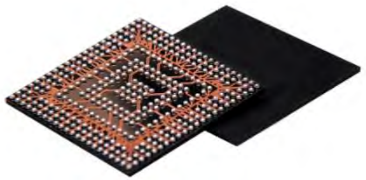

Nvidia’s Parker chip architecture. Source: Nvidia.




AMD’s Fiji solution. Source: TechSearch International/AMD




Intel’s Embedded Multi-die Bridge. Source: Intel



SPIL’s fan-out package on package (FO-PoP). Source: SPIL



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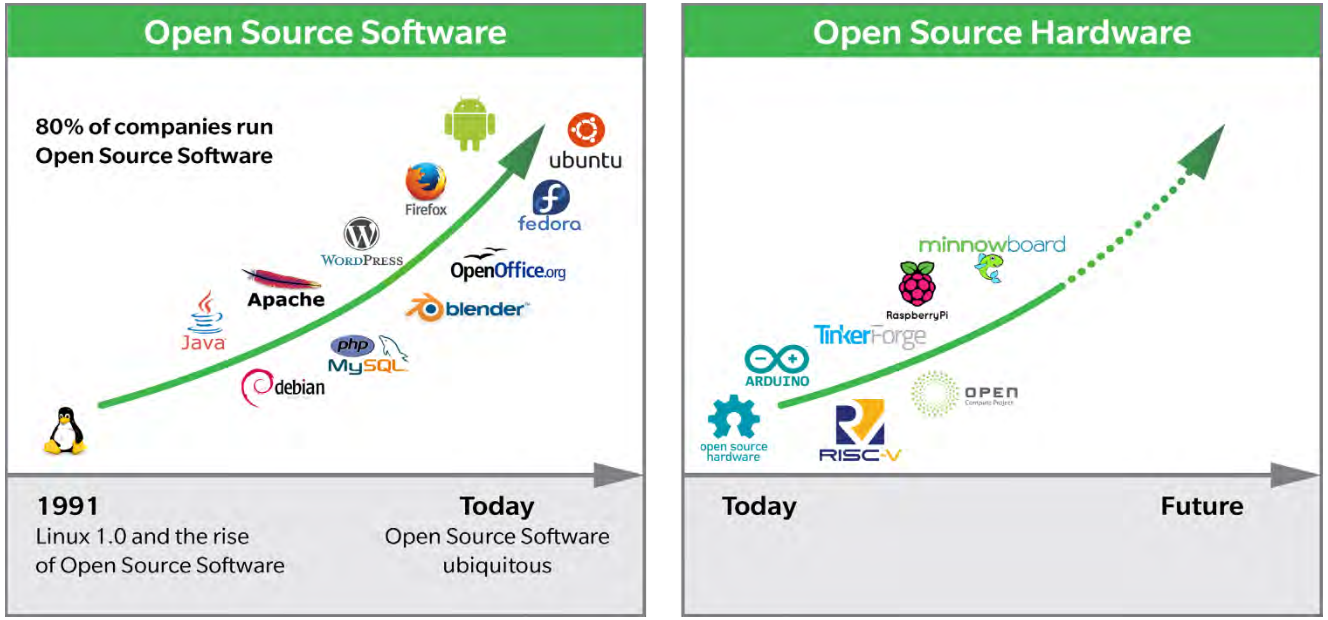
# Open-Source Semiconductors

- Open Source Software - Hardware




Google, Hewlett Packard Enterprise, Lattice Semiconductor, Microsemi and Oracle signed up as initial members of RISC-V trade group.

A R&D division of the Indian government is slated to receive approximately $45 million to fund the development of its first 64-bit microprocessor based on the RISC-V instruction set.

Designers at IIT Madras has been working for more than two years on a family of 32- and bit open source processors based on RISC-V, called Shakti. According to EE Times, the Shakti project now includes plans for at least six microprocessor designs along with fabrics and an accelerator chip.

- **Rapid growth in the adoption and number of open source software projects**
- More than 95% of web servers run Linux variants, approximately 85% of smartphones run Android variants
- Will open source hardware ignite the semiconductor industry? Is RISC-V the hardware industry's Linux?



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Source: 2015 Global Semiconductor Alliance.

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Technology for a better society