VLSI in the era of internet of things … and sensors

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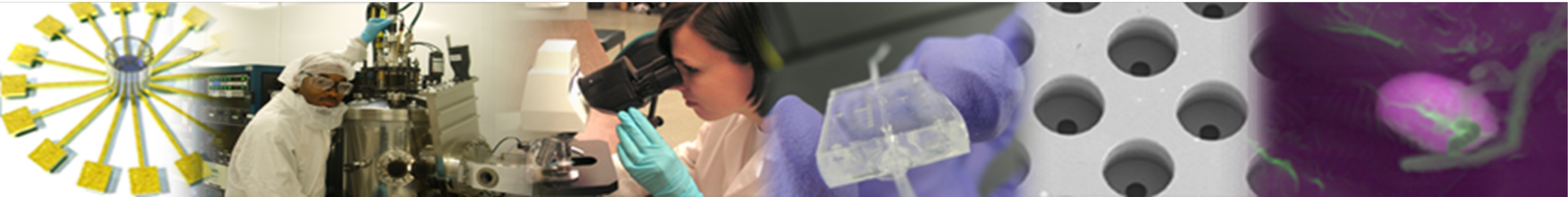
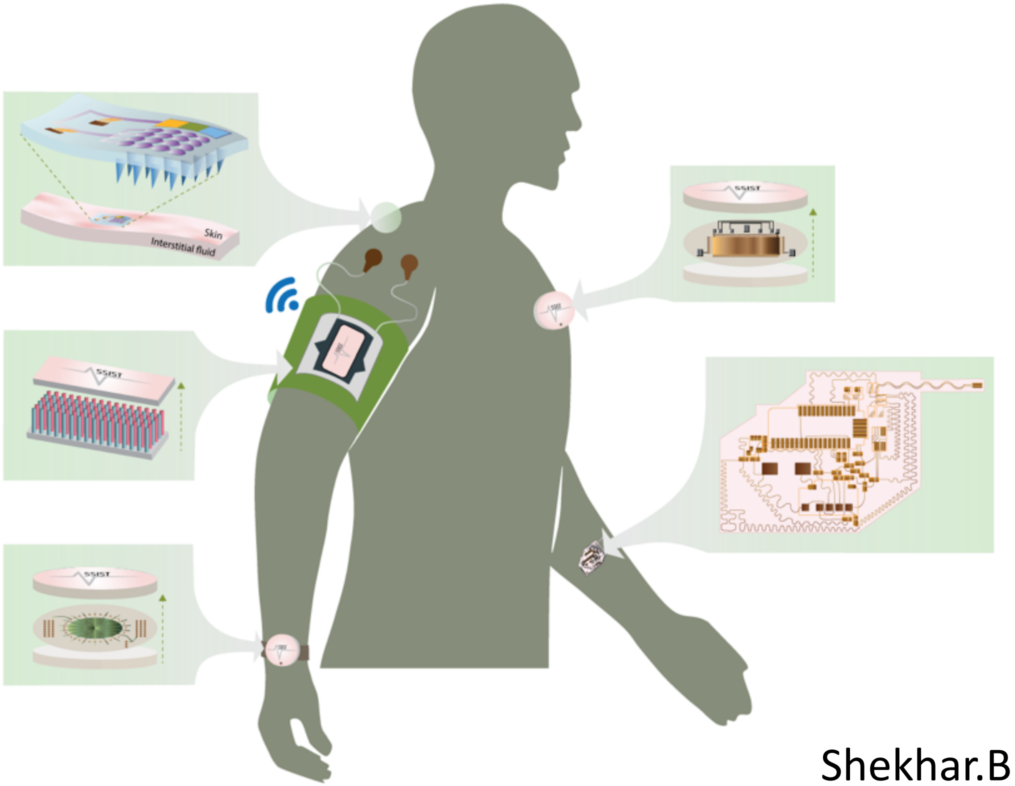


Advanced Self-Powered Systems of Integrated Sensors and Technologies (ASSIST)

NSF funded Engineering Research Center (class of 2012)

Wearable Sensors

ASSIST's vision is to create self-powered sensing, computing, and communication systems to enable data-driven insights for a smart and healthy world



- *Self-powered*
- ***Physiological, biochemical** and **environmental** sensors*
- *Wearable, wireless and comfortable*
- *Informative and continuous data*

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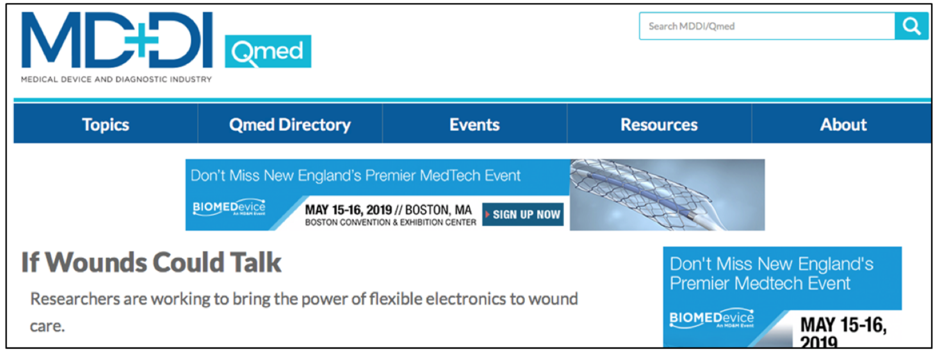
- ASSIST's mission is to develop **leading-edge** systems for high-value applications such as **healthcare** and **IoT** through:
    - fundamental advances in **energy harvesting**, **low-power electronics**, and **sensors** with a focus on **usability** and actionable **data**
    - multidisciplinary researchers, practitioners, and industry partners in a diverse and **inclusive ecosystem** that encourages **innovation** with a focus on **education** and **outreach**

ASSIST enables continuous health monitoring

- Multiple Health Signals: Physiological, biochemical & environmental sensing
- New digital biomarkers from multiple data sources through machine learning/artificial intelligence
- Self-powered, continuous, cost-effective, individualized
- Explain/ Influence/ Predict health outcomes
- Gain fundamental insight into disease origins

"Digital biomarkers are an opportunity to translate new data sources into informative, actionable insights" * *RockHealth



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https://www.theage.com.au/national/how-a-clever-little-cube-can-help-you-pick-the-best-spot-in-the-office-20190507-p51kwa.html

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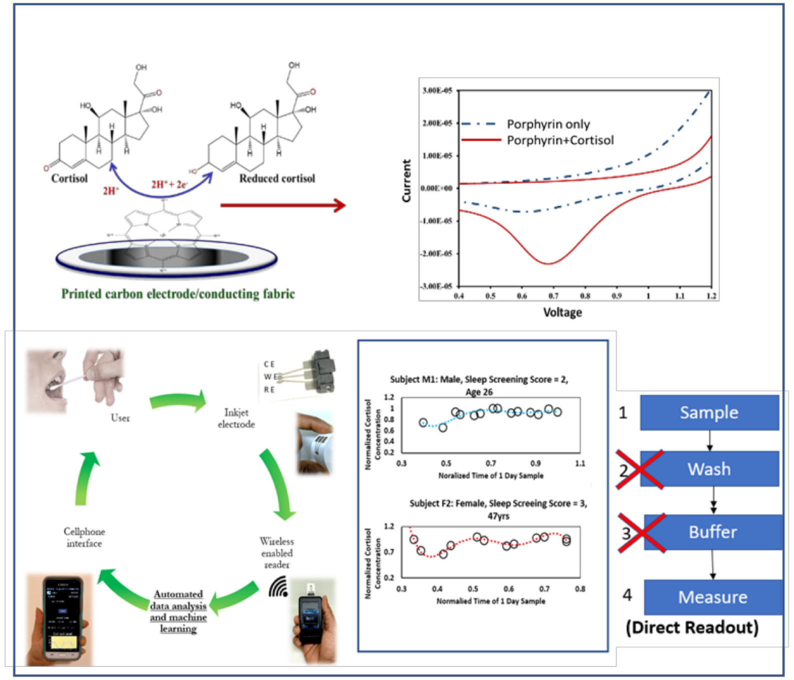
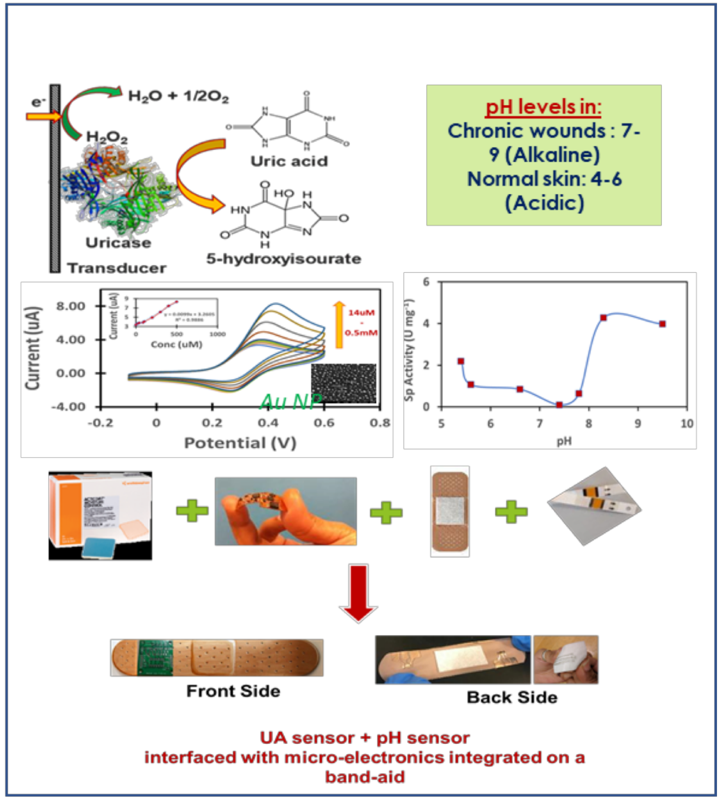
Sampling of Active Biosensor Research

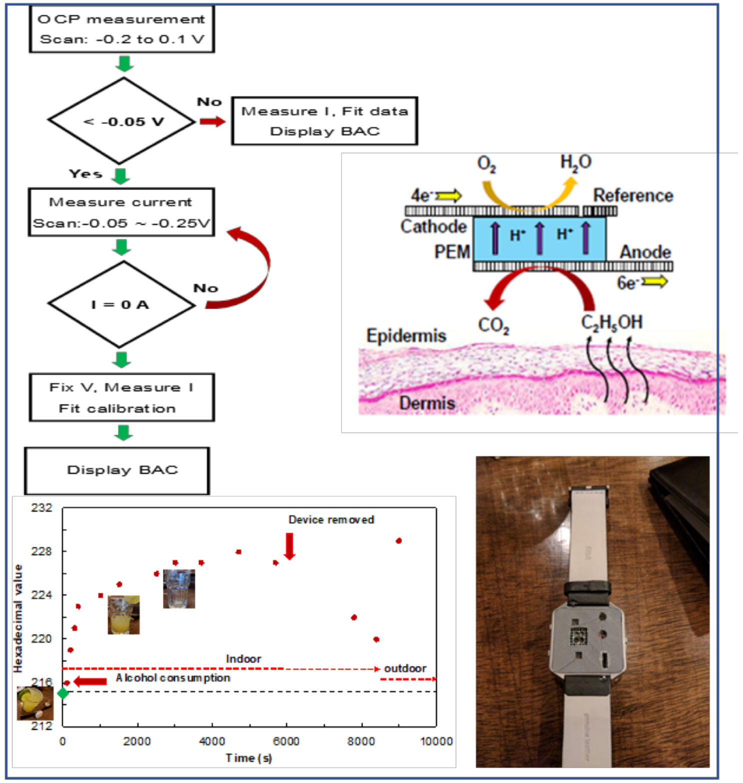
Cortisol Monitoring



Uric Acid Sensing



Acetone and Alcohol Monitoring



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Agriculture Sensors

Agriculture sensors have shown considerable promise, but have yet to be widely explored in miniature, low-powered, continuous monitoring wireless agriculture sensor

We are using microfluidic platforms for their high throughput, which gives the device the ability to control various parameters simultaneously and study plant system accurately..

- ***Monitor Nutrient uptake of plants in soil***
- ***Real time monitoring of soil moisture, temperature and environmental*** *parameters.*
- *Informative and* ***continuous data***

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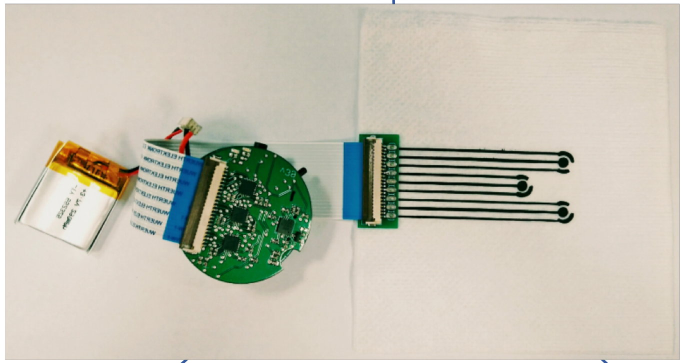
Exciting Issues in developing sensors

1) Portability of the device

2) Real time analysis

3) Format of sensor (solid/flex printed)



Wearable wound monitoring sensor – how to make them comfortable

1) Sensor correlation with clinical data

2) Security of Data transfer across cloud

1) Cost of the sensor

2) Accuracy of the sensor

3) Accurate validation

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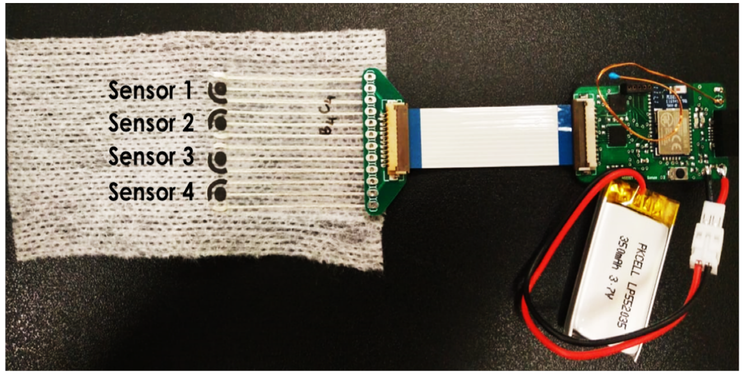
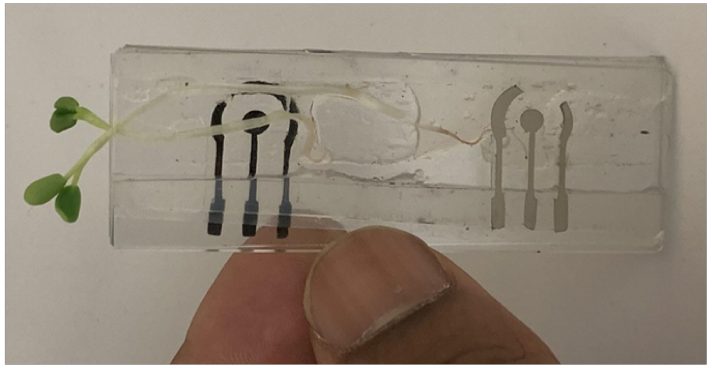
Affordable VLSI in the IOT Era

- Sensors
  - Wearable Sensor
  - Agriculture Sensors



Smart Dressing a wound monitoring sensor



Plant nutrient monitoring sensor

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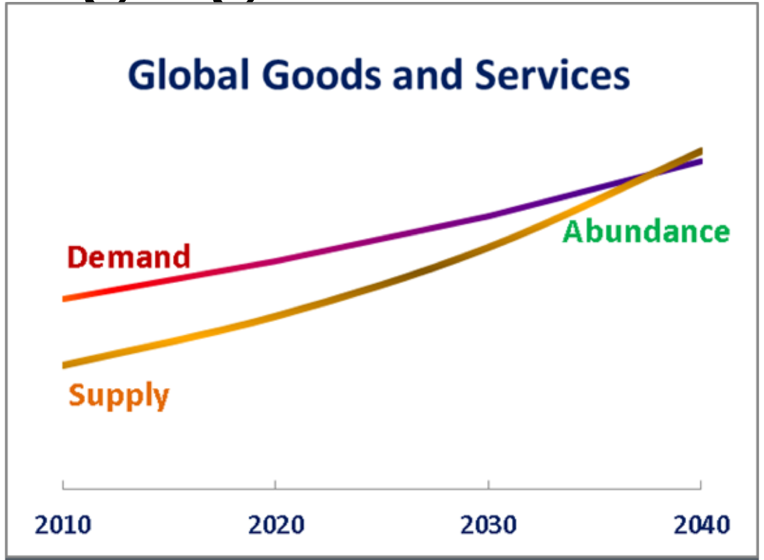
Sensing and connectivity and the key to ensuring Abundance/managing crisis

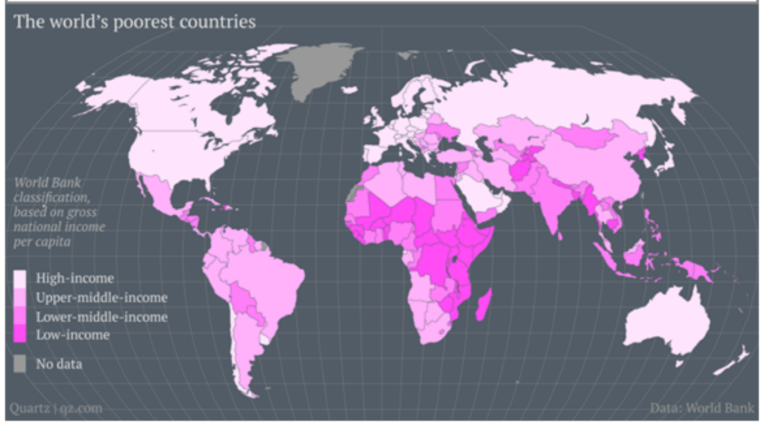
- There are two schools of thought

(a) Abundance is expected to be reached between 2035 and 2040 –driven by technological advances

(b) By 2035 - 2040 the world will be at crisis-rising sea levels, lack of clean air, clean water pervasive hunger

- Abundance* (Peter Diamandis) / world in crisis
  - World without hunger/ hunger everywhere
  - With medical care for all/ medical care for few
  - With clean water and air for all/ does not exist
  - With clean energy for all/ unclean energy
- "Abundance will need 45 trillion connected devices, most with sensor arrays"_–Janus Bryzek
- Managing crises may still need 45 trillion sensors!





Bill Gates (annual foundation letter 2014) :
No Poor Countries by 2035

* http://www.abundancethebook.com/

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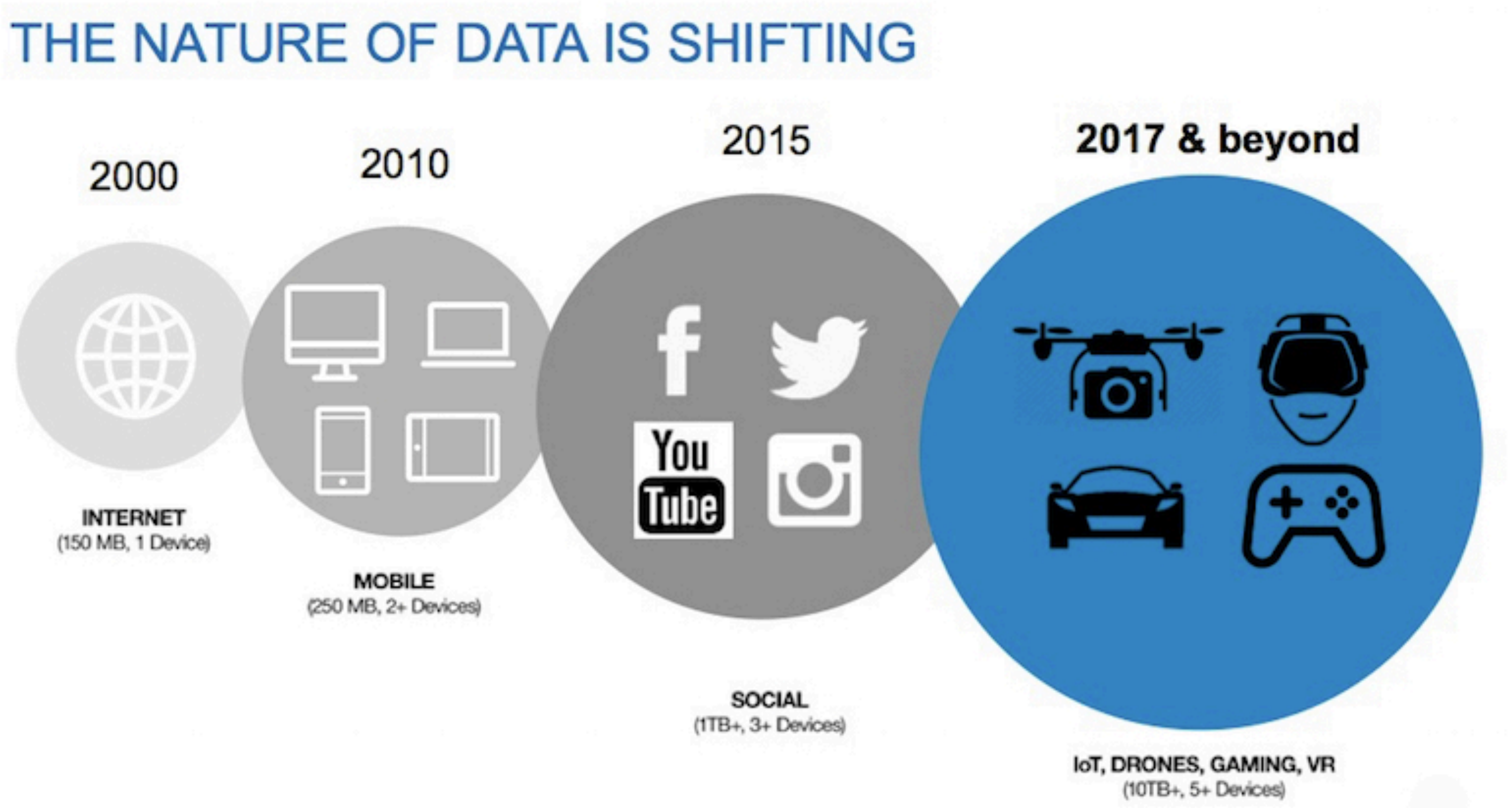
- Evolution of IOT has drastically changed the modern living
- With sensors being omnipresent there has been an exponential growth in VLSI and hardware needs.



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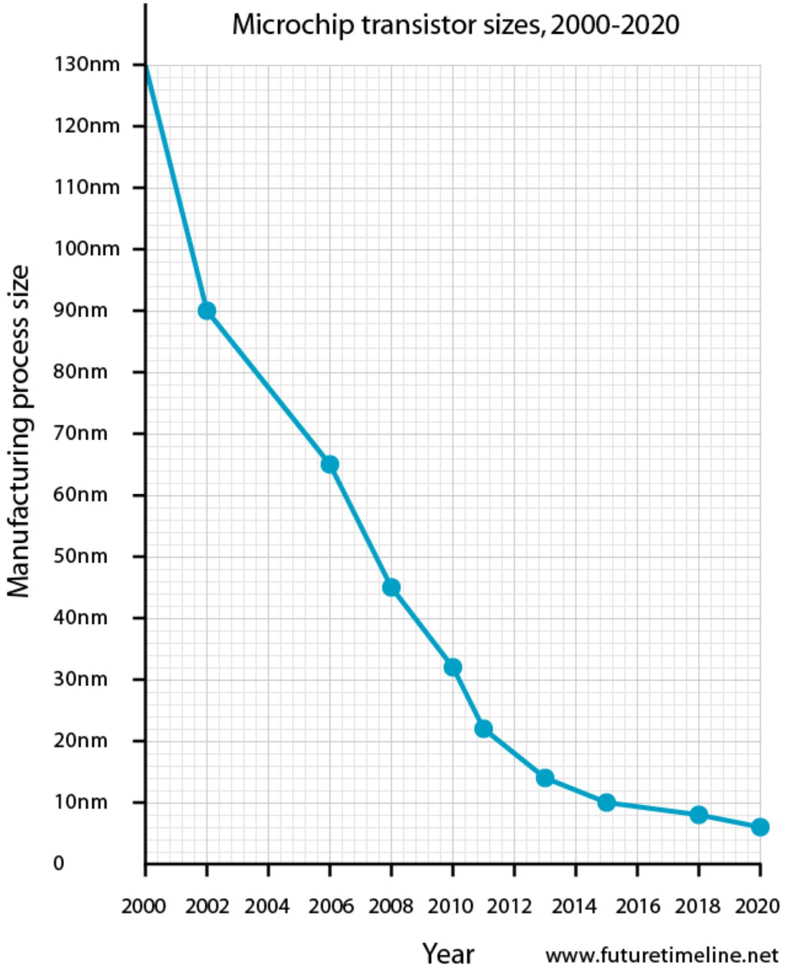
VLSI Current Scenario

- 2x transistors & clock speeds every 2 years over 50 years (Moore's law)
- 1 Mb/s DSL to 10 Mb/s Cable to 2.4 Gb/s Fiber to Homes
- 3G to 4G to 5G wireless communications
- 480 x 270 (0.13 million pixels) NTSC to 1920x1080 (2 million pixels) HDTV resolution
- This data is only till 2016. The current (2018) lowest technology node in production is 7nm and one under development is 5nm. There is also a test chip produced in 3nm



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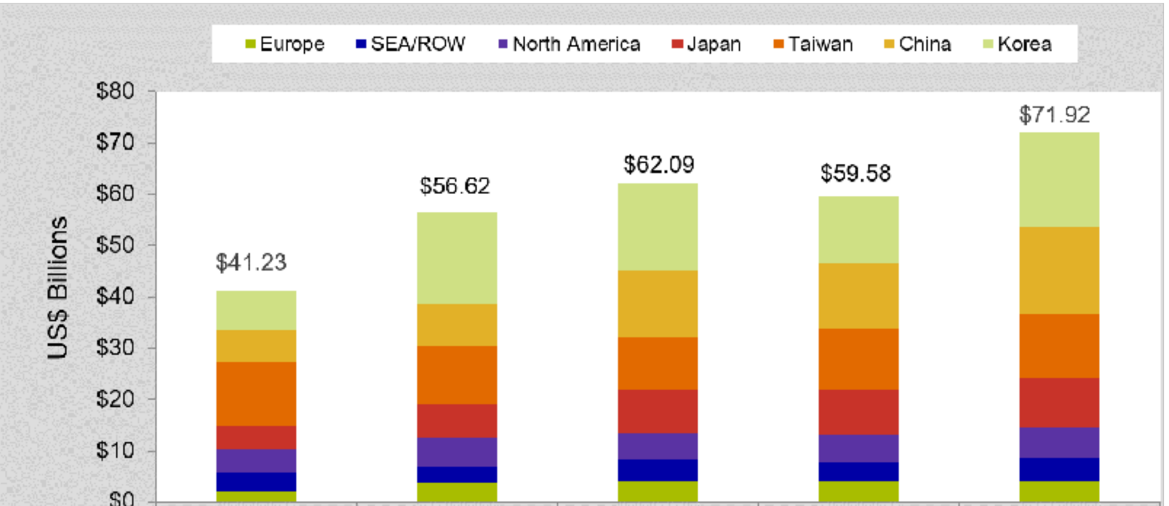
VLSI challenges and worldwide investments

Challenges

- Ultra high speeds
- Noise, crosstalk
- Reliability
- Power dissipation and clock distribution
- Cost of fabrication
- Time to Market
- Design challenges of scaling reduce gate delay and reduce energy per transition



	2016	2017	2018E	2019F	2020F
Korea	7.69	17.95	17.11	13.20	18.31
China	6.46	8.23	12.82	12.54	17.06
Taiwan	12.23	11.49	10.11	11.81	12.49
Japan	4.63	6.49	8.60	8.89	9.47
North America	4.49	5.59	5.29	5.36	6.02
SEA/ROW	3.55	3.20	3.96	3.82	4.35
Europe	2.18	3.67	4.19	3.96	4.22

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VLSI in the IOT era

45 trillion sensors with current cost structure is not feasible

Challenges

- Cost per sq cm
- Cost per device
- Cost per application
- Reliability
- Recyclability
- Degradability (Landfill)
- Toxicity

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Technologies that will be needed to drive the changing world

- Nanomaterials and nanotechnology
- Sensors and Networks
- Non-traditional substrates
- Computational systems
- Biotechnology and bioinformatics
- Digital manufacturing
- Medicine
- Artificial intelligence
- Robotics
- Energy

Technologies become dramatically affordable – the next 1000X reduction is the key

Technology	Cost Drop	Over Time Span of:	Cost	Change
Graphene (forecast)	1000x	5 years		-298%/y
DNA Sequencing	10,000x	7 years	$10 million (2007)- $1000 (2014)	-273%/y
DNA Sequencing (forecast)	100x	5 years		-152%/y
Sensors, Lidar	250x	5 years	$20,000 (2009) – $79 (2014)	-202%/y
Sensors, Gyroscope	1000x	7 years		-168%/y
3D Printing	400x	7 years	$40,000 (2007) -$100 (2014)	-135%/y
Drones	142x	6 years	$100,000 (2007)- $700 (2013)	-128%/y
Neurotechnology	44x	5 years		-113%/y
Accelerometer	100x	7 years		-93%/y
Magnetometer (forecast)	100x	7 years		-93%/y
Industrial Robots	23x	5 years	$500,000 (2008)-$22,000 (2013)	-87%/y
Solar Energy	200x	30 years	$30/Kwh (1984) - $0.16/Kwh (2014)	-19%/y
NOKIA	20X	7 years	140Billion (2007) -7.2Billion (2014)	-35%/y

https://www.slideshare.net/vangeest/exponential-organizations-h

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Trillions of sensors means

100s of healthcare sensors/person.

1000s of sensors is robots skins.

100s of chemical/biological/pollutant sensors in billions of pollution nodes.

100s of sensors/person in smart fabrics.

Trillions of sensors in billions m^2 of Wallpaper

Trillions of degradable agricultural sensors in billions m^2 of farmland/weedblock

Trillions of sensors in disposables.

Electronics needs be reimagined – cost metrics needs to be redefined

e.g. VLSI how to shrink cost of devices and package 6 orders of magnitude.

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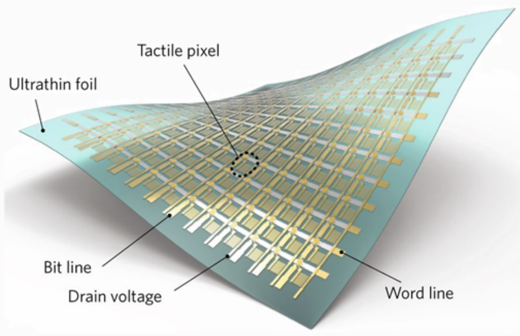
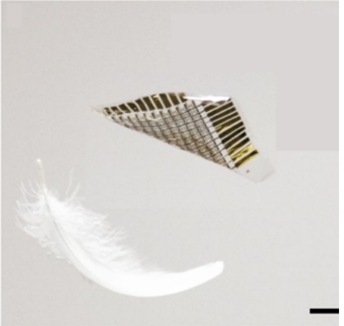
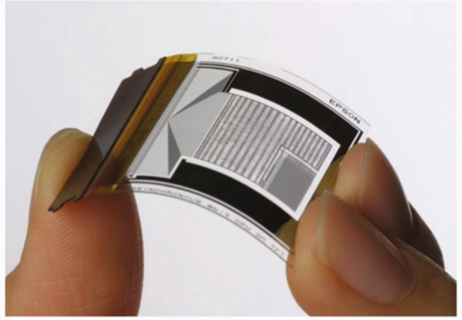
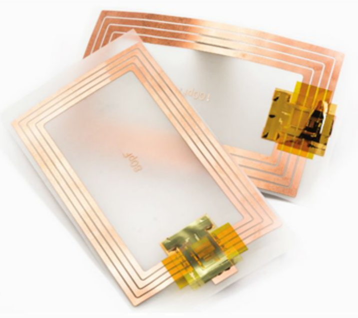
VLSI reimagined

- low cost per unit area VLSI
- VLSI on biodegradable, biocompatible flexible substrates.

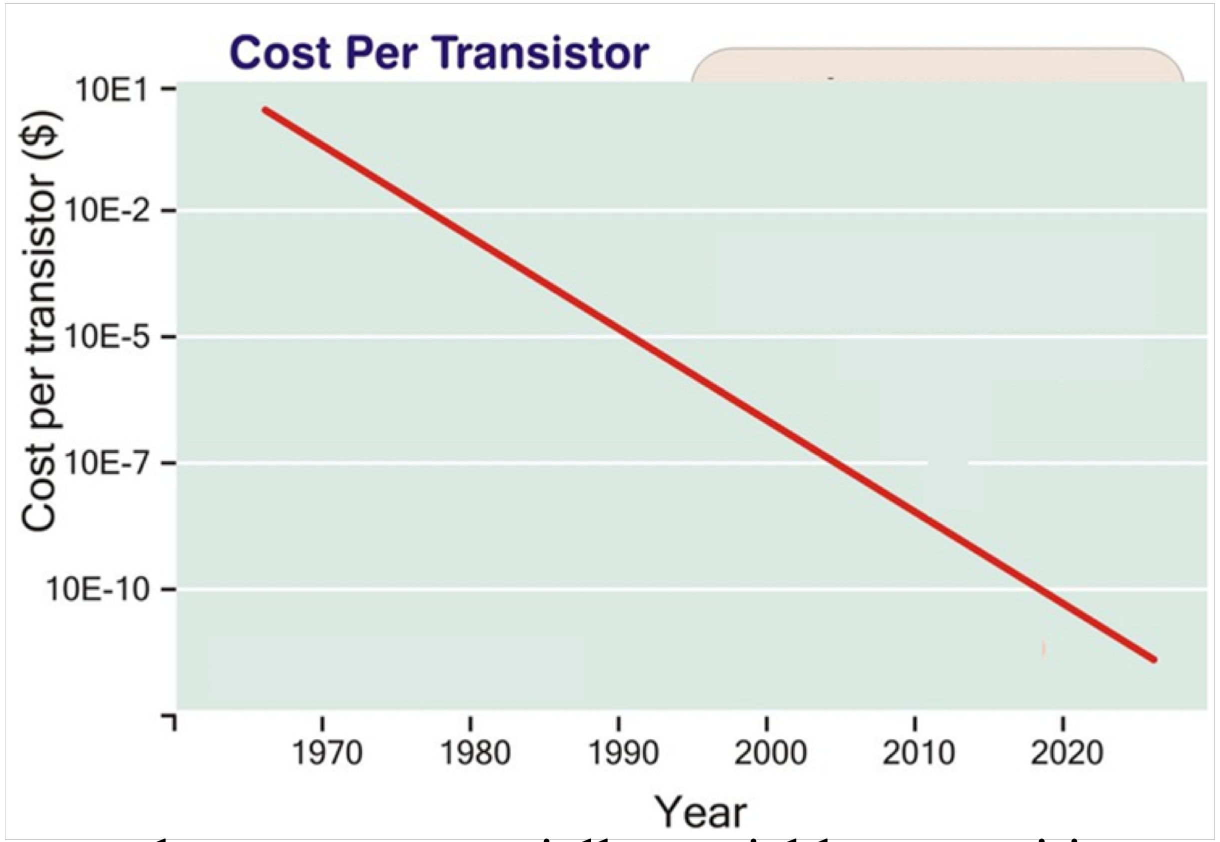








Economics and Cost



- It is becoming more and more commercially unviable proposition to fund advancement in VLSI designing and development.
- Eg: It costs $271 million to design a 7nm system-on-a-chip, which is about nine times the cost to design a 28nm device.

- The first half of 2019 projected a significant long-term growth for semiconductors showing a shift away from consumer to industrial, automotive and storage applications.

Wafers are 50% of the materials value input for ICs.

Industry would like silicon wafer prices to go up, to encourage more investment in wafer fab capacity and capability.

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Hardware/Sensor Challenges

- How is the device powered in order to function sustainably over the intended life of the sensor platform?

- Will the power source support high frequency of data sampling (especially when it is a health monitoring sensor running on low power)?

- How much of the sensor system is reconfigurable – the calibration of the sensor can be reconfigured to increase or decrease the precision or sensitivity. The machine learning model can be updated if the sensor platform can communicate. But the sensing technology remains the same and it can degrade over time…

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Data Processing Challenges

- How are variables sampled at different frequencies fused together? (such as heart rate, cortisol level)
- How to handle missing data. If one of the sensors goes offline or becomes unreliable it can cause missing data
- How to handle the variation in data formats if the sensors are sourced from different vendors
- How to ensure data reliability. If the transmitters and receivers in the network degrade over time, then it can lead to unreliable data

Data Processing Challenges Cont.

- If data is processed on the edge:
  - How is the ML / AI model deployed on the sensor hardware
  - How is the model updated from time to time
  - Does the power source support this
  - Assumption is that the model training will not be done on the sensor platform since it is severely resource constrained.

- How to ensure the sensor data security.
  - Need to protect the data from being corrupted by hackers
  - Need to protect the data from falling into the wrong hands

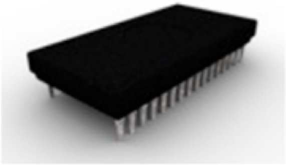
System Level Challenges

- The machine learning models built on the data will only be as good as the data.
  - How to test that we have not corrupted the sensor when we updated it.
  - How to continuously test sensors and systems once deployed

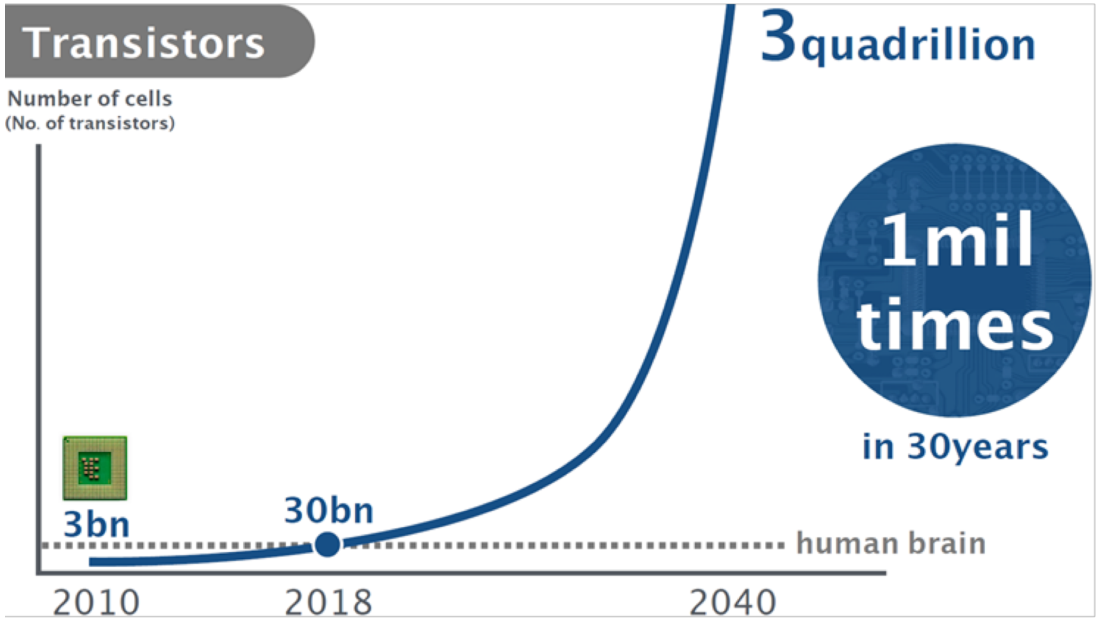
- Not all the sensors are sampled at the same frequency.
  - Challenges and opportunities abound in correlating and fusing the data from various sources

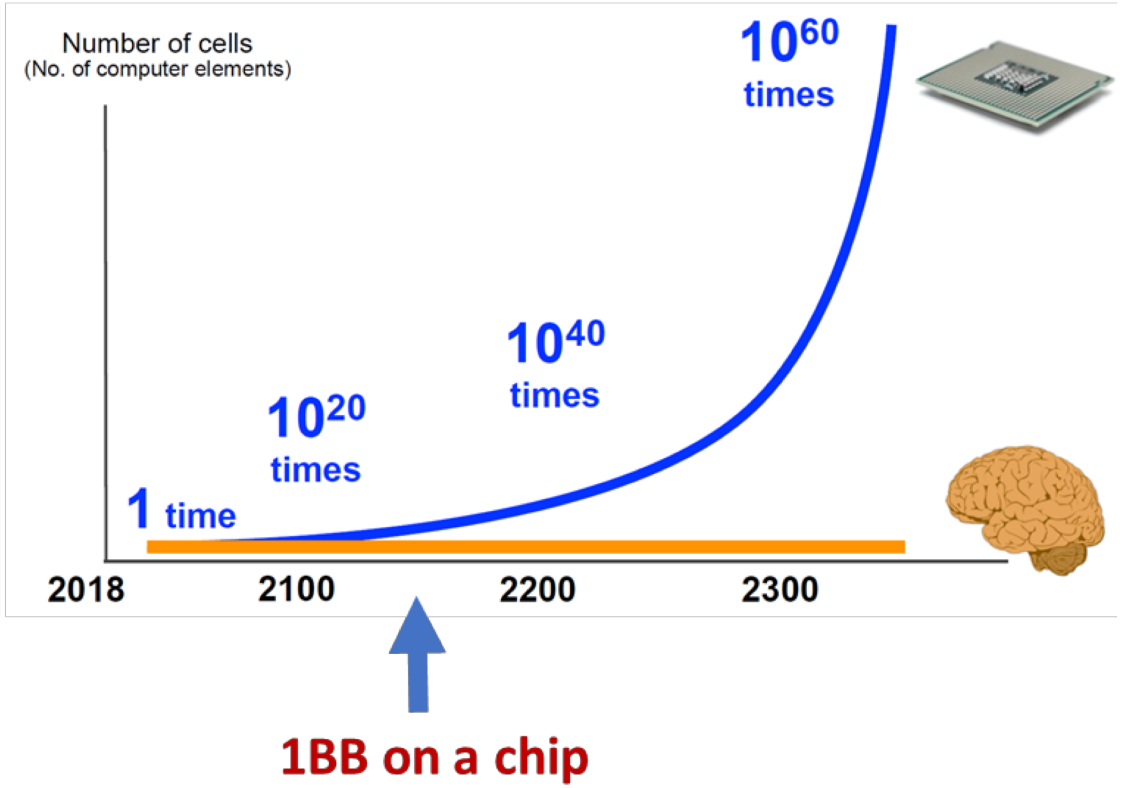
- Application of deep learning requires a large amount of data.
  - Fast changing signals can be sampled at a high frequency-anomaly detection.
  - Many signals may be very slow frequency – how to work with sparse data.

Exponential Computing

		2010		2040
CPU Number of transistors		**3bn**	**1mil times** →	**3quadrillion** (100k times of human brain)
Memory		**32GB**	**1mil times** →	**32PB**
Network speed		**1Gbps**	**3mil times** →	**3Pbps**

Exponential Artificial Intelligence





SoftBank/Singularity

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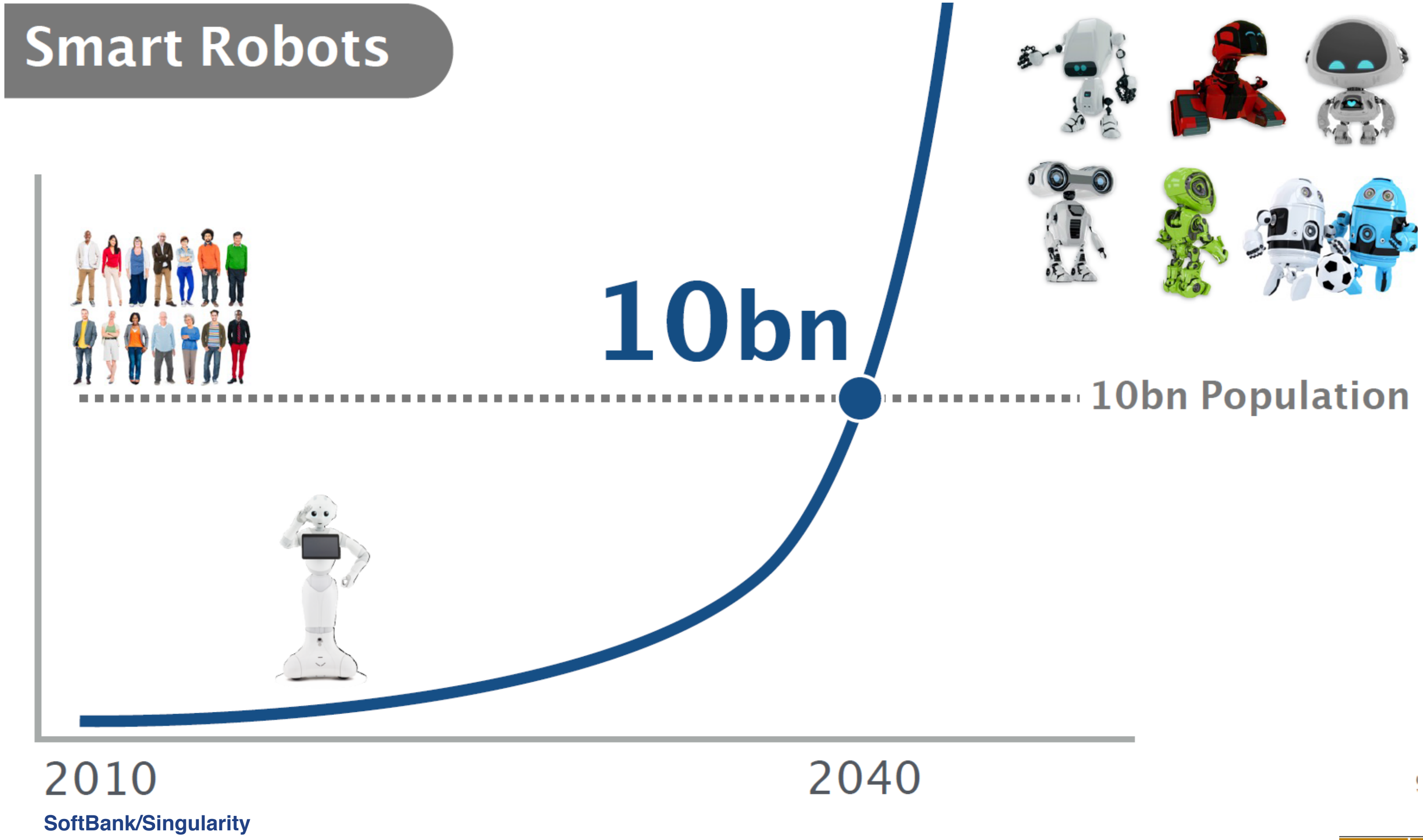
Exponential Robotics



Concluding Thoughts

- Technologies that leverage VLSI continue to Ripen
- Low cost VLSI is need of the hour
- Can VLSI reimagine itself and change the cost paradigm ?
- Can S in VLSI be a physical scale?
- Can VLSI translate using flexible biodegradable substrates ?

Cost per transistor to cents per sq.cm. → Sq.cm. to few magnitude down

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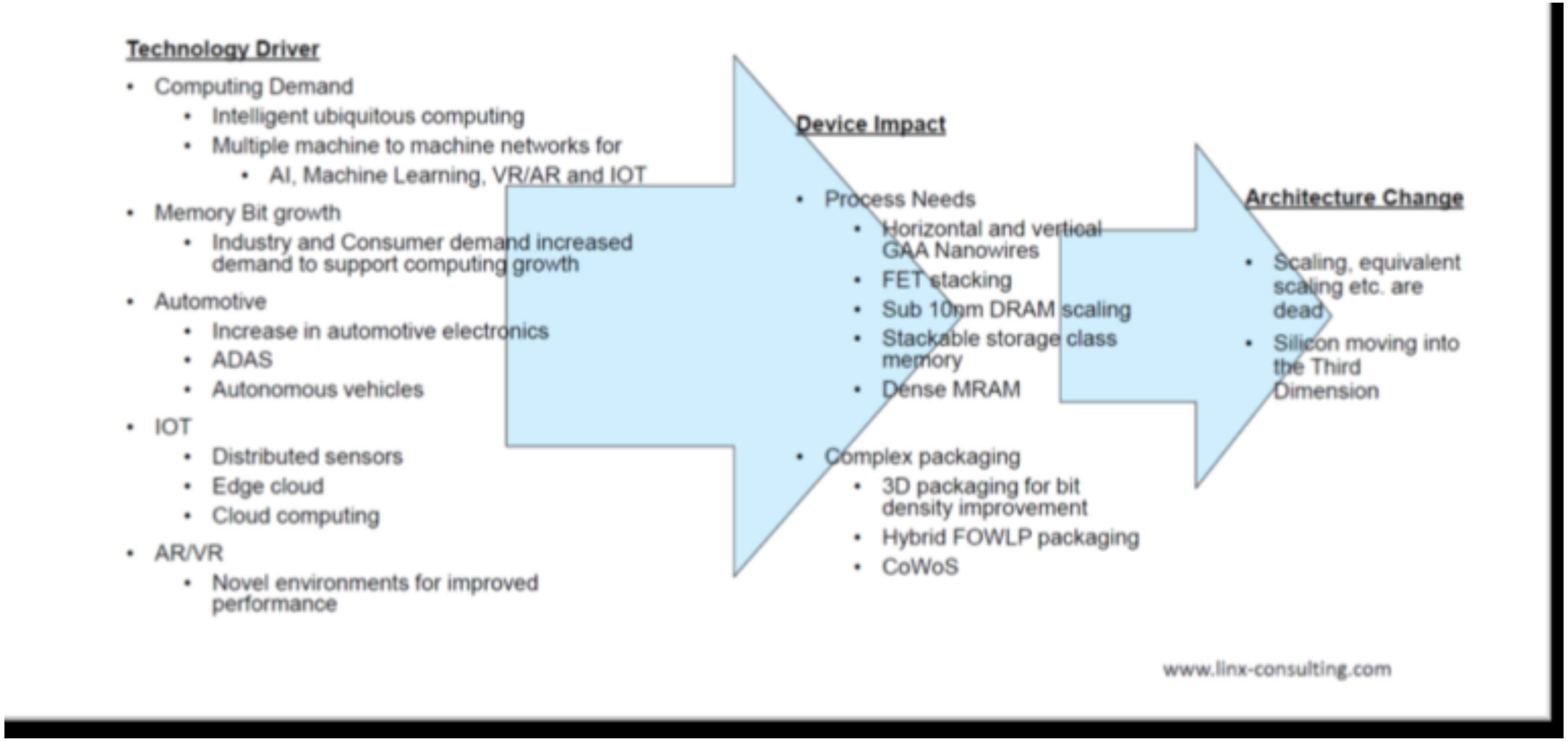

In 2019, silicon wafer shipments will reach 13,090 million square inches, up 5.2% over 2018, according to SEMI. In 2018, silicon wafer shipments grew 7.1%. Then, the photomask market is forecast to exceed $4 billion in 2019, up 4% over 2018, according to SEMI.

Future

- **Artificial Intelligence**
  - Enhanced image analysis will be needed, e.g. to improve factory productivity.
  - Many IoT applications will need much shorter latency and higher bandwidth of 5G to provide practical value – needs new semiconductor materials and metrology/test techniques to ensure high performance per Watt as well as reliable products and systems.
  - Can the cost be shrunk 6 orders of magnitude.

- **Data processing**
  - Data processing at the IoT edge nodes is increasing significantly to reduce network load and minimize response times. Currently Image sensors are being deployed in factories, public buildings, even in the agriculture industry to monitor assets, animals, and persons for which better processing power is in high demand

- **Personalized Medicine**
  - Increased computing power – enabled by semiconductors – has lowered the cost of genome sequencing from $ 2.7B in 2003 to $ 100 today. This enables the development of personalized, highly effective drugs.