

# Trillion Sensors: Foundation for Abundance, Exponential Organizations, Internet of Everything and mHealth

Introduction of Wii game in 2006 and iPhone in 2007 triggered a Tornado for sensors in consumer products. In 2007, 10 million sensors were absorbed by mobile devices. In 2014, the usage grew to 10 billion units, with the largest volume MEMS sensors being microphones, acceleration sensors, magnetic sensors and gyroscopes. Leading cellphones embedded pressure, IR, humidity, temperature, light and proximity sensors, as well as multiple RF filters, antenna tuning and camera autofocus.

Large number of new sensors are expected to enter mobile devices in coming years, with most visible ones being health sensors.

## Utopian Vision: Abundance

In 2013, a vision of Abundance has emerged ([www.abundancethebook.com](http://www.abundancethebook.com)). This vision forecasts that all major global problems, such as hunger, lack of medical care, lack of clean environment and energy will be solved in one generation (20 to 30 years) through:

- Exponential technologies, producing goods and services faster than demand growth.
- DIY (Do-it-Yourself) revolution, which deployed global scale project (e. g., flying to space) by billionaires.
- Unrivaled in history billionaires

tech-nophilanthropy, providing significant funding for addressing global problems, such as malaria.

- The rising billion of poorest people on earth being plugged into economy, enabling growth of global GDP. Eight technologies are classified as exponential and include:
  - Biotechnology and bioinformatics
  - Computational systems
  - Networks and sensors
  - Artificial intelligence
  - Robotics
  - Digital manufacturing and infinite computing
  - Medicine

■ Nanomaterials and nanotechnology. Sensors are not only one of the eight exponential technologies, but are also embedded in other exponential technologies. Abundance projects the need for perhaps 45 trillion networked sensors helping to solve global problems for all people on earth.

## Global Tides Supporting Abundance

While Abundance had been seen by many as a utopian dream, several emerging global economic tides support Abundance goals, bringing the real possibility of the Abundance coming true. These tides include:

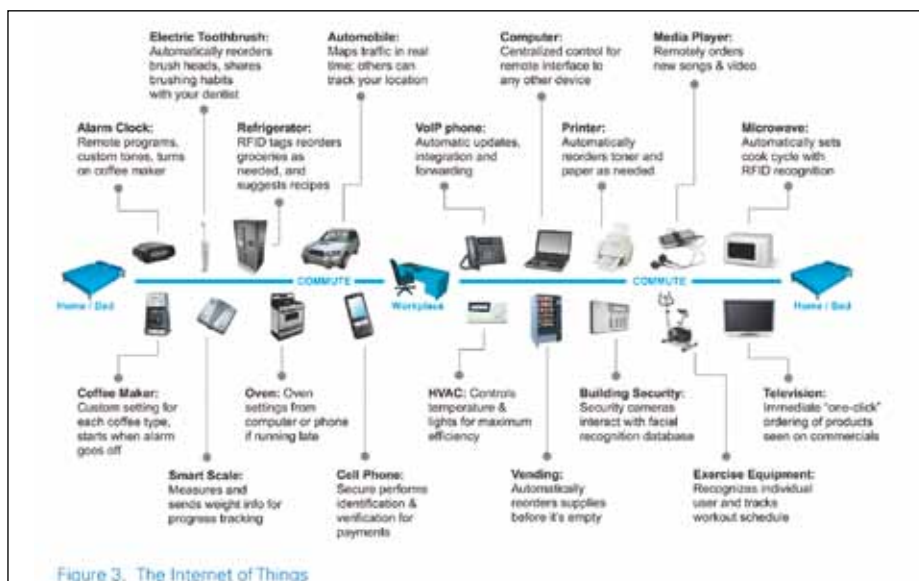
- 3rd Technical Revolution impacting global GDP shift
- Exponential Organizations
- Internet of Things and Everything
- mHealth

## Technical Revolutions Shifting Global GDP<sup>1</sup>

In the 18th century, GDP depended on the size of population. China and India dominated global DGP, having the largest populations.

The first Technical Revolution brought steam, electricity, internal combustion, radio, aeronautics. Europe, where most innovation was created, started to dominate the global GDP. The Second Technical Revolution brought transistor, computer, Internet. US and Japan started to dominate the global GDP.

The emerging third Technical Revolution fuses computing, communication and sensing. It is expected to free people from manual labor, leaving for them creative work, and crating the foundation for Abundance. Global GDP leadership will be captured by



### ▲ Not your Father's Internet

nations with the largest number of creative people.

In the follow-up forth Technical Revolution: machines take over the world, leaving for humans the enjoyment in a virtual world through a direct computer-brain communication. The global GDP leadership may be irrelevant...

### Exponential Organizations (ExO)

A new breed of Exponential Organizations has emerged demonstrating exponential sales growth. ExO's create new business models disrupting and accelerating growth of global economy, in line with Abundance objectives. Selected examples of ExO's:

- Grand Theft Auto game: \$ 800M sales in 72 hours.
- Instagram: 2 years to \$1B sales
- Uber: 3 years to \$1B sales
- AirBnB: 3 years to \$1B sales
- Square: 2 years to \$1B sales
- DropBox: 4 years to \$1B sales.

ExO's follow a 6D process that affects every product, service, company and industry, defined as follows:

- Products or services are *Digitized*
  - E. g., ICs are converted to downloadable designs to be printed on local printers.
- which leads to *Deceptive* phase
  - New technologies seem not good enough for key players, such as current generation of 3D printed transistors.
- which leads to *Disruptive* phase
  - Technologies improve and disrupt existing players; e. g., 10 nm printed transistors to be demonstrated in late 2014 by IBM<sup>2</sup>.
- which leads to *Dematerialization*
  - Physical products or service becomes digitized and distributed as bits on the pre-existing ubiquitous platforms; e. g., transistors printed on IBM developed printers, with customers buying inks instead of silicon.
- which leads to *Demonetization*
  - Dematerialized products (bits) can be freely distributed globally.
- which leads to *Democratization*
  - Enabling global access.

ExO's are expected to affect every business and service, thus affect global economy. ExO's are transforming business landscape from linear to exponential and bring a death sentence to companies not joining the revolution. 40 % of Fortune 500 companies is expected to disappear within 10 years, similarly to Kodak in 2012, while Instagram was acquired for \$1 billion by Facebook. Similar traumatic changes are expected across the World. For example, one of the next industries expected to disappear is a \$5B medical EKG equipment industry, to be replaced by mobile EKG diagnostics.

### Internet of Things (IoT) and Everything (IoE)

IoT/IoE are defined as world of connected all things around us, enabled by:

- IPv6 addressing providing 3x10<sup>38</sup> IP addresses, one for every »thing« on Earth.
- Fog and Swarm connectivity/computing (below the Cloud).
- Sensors.

Boldest forecasts for IoT come from Cisco, \$19 trillion by 2020 (over 20 % of the global 2020 GDP !!!) and GE, \$15.5T by 2020, with networked sensors expected to represent 5 % of the IoT. Such accelerated growth will directly benefit Abundance objectives.

First major IoE startup acquisition was NEST developing networked home automation components, acquired in 2013 for \$3.2B by Google.

IoT and IoE gained major momentum in 2013, when four major network providers, Cisco, IBM, GE and Amazon, decided to roll out Internet infrastructure modifications supporting IoT and IoE. These changes include a support for new below-Cloud layers, Fog and Swarm, targeting connectivity of edge devices.

Major IoT sensor applications are expected to be focused on information and analysis (such as tracking behavior of persons, things and data through space and time, enhanced

real time situational awareness of physical environment and sensor driven decision analytics through deep analysis and data visualization), and automation and control. While most of companies dream of catching this largest economic tide in history of humans, most don't yet envision the revolutionary new applications which will be driving such growth.

**Digital Health**

Digital Health (mHealth, eHealth) represents the emerging market for mobile fitness, wellness and health-care devices and services. It is enabled by emergence of low cost sensors and has more advanced market development than the IoT (see Gartner's Hype Curve).

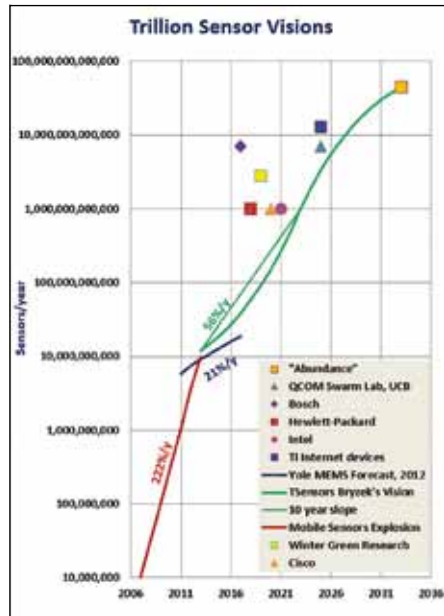
US Healthcare spending is about 19 % of GDP. mHealth is expected to save 35 % of cost of treatment of chronic medical conditions in coming years, which represents vast majority of health care spending.

It is also expected to bring healthcare to everybody on Earth, thus creating healthcare abundance.

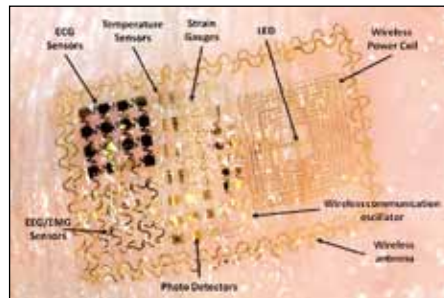
mHealth will dramatically redefine medical industry and the function and responsibility of doctors. Large number of traditional medical equipment medical companies will cease to exist, to be replaced by personal handheld monitors. Diagnostics will shift to AI computers (such as Dr. Watson<sup>3</sup>). Doctors will need to learn how to use Big Data generated by sensors and processed by supercomputers in patients' hands.

One of the biggest programs in this space is Medicine's Manhattan project<sup>4</sup>. Patrick Soon-Shiong, the world's richest doctor, launched the program to advance medical care. Patient's real time data generated by sensors (from DNA to the proteins in blood) will get instantly analyzed via a superfast network. In real time computers will recommend the treatment and follow up patients in real time.

Currently, about 100 sensor types migrated to consumer health and fitness



▲ Mobile sensor market grew exponentially over 200 %/y between 2007 and 2014. Several organizations presented their visions for a continued growth to trillion(s). Market research companies don't yet see this growth (see Yole's forecast). TSensors Roadmap development is being launched to improve visibility of emerging sensors to enable their accelerated development. Copyright: Janusz Bryzek



▲ Tattooed sensor from UC San Diego powered by external RF pulse.

devices. It may be expected that in 10 years we may see hundreds more. To keep the cost of sensor based eHealth solutions affordable to all, 3D printed electronics and sensors will need to be deployed.

One of such technologies are tattooed sensors developed at several organizations (shown UC San Diego development).

**Emergence of Trillion Sensors (TSensors) Vision**

Abundance implied the need for 45

trillion sensors between 2023 and 2033.

Several other Market research organizations focused on sensor market had been releasing their forecasts based on way below trillion sensors, extrapolating the growth of known applications at a very respectable rate over 20 %/year. Several visionary organizations, including Bosch, IBM, Hewlett Packard, Intel, Texas Instruments, Winter Green Research and Swarm Lab at US Berkeley, presented their visions for the emerging sensor market exceeding trillion sensors between 2017 and 2024 (see chart).

Sensor market acceleration was triggered in 2007 by introduction of iPhone, including two MEMS based devices: microphone and acceleration sensor. In 2007, about 10 million MEMS sensors were absorbed by mobile market. In 2014, MEMS sensor consumption in mobile space reached 10 billion units, representing the unprecedented growth in excess of 250 %/year. Such dramatic growth had a very disruptive impact on sensor technologies (Table), paving a foundation for ultrahigh volume low cost other sensors for the IoT and eHealth, thus helping to reach Abundance.

To support the forecasted demand for 45 trillion sensors to make Abundance a reality, likely a majority of this volume will be represented by new types of sensors.

Historically, each new sensor type took about 30 years to move from concept prototypes to volume production due to complexity resulting from deployed »multi-physics« and »multi-bio-chemistry«, as well as from lack of standardization (one product-one process-one ASIC-one package-one test system). To accelerate this cycle and thus accelerate solutions to global problems, a Trillion Sensor (TSensors) Initiative was launched in 2013.

TSensors strategy is based on a three activities:

- **TSensors Summits™** aiming at collecting visions from sensor visionaries for new ultrahigh volume sensor

Item	Impact	Comments
Market size	Growth by \$11B	From \$2 B to \$13 B
Shipments	<b>1000x increase</b>	From 10 M to 10 B
ASP	<b>1000x decrease</b>	E. g., from \$ 250/axis for gyros to \$ 0.75 for three axis
Power	<b>1000x decrease</b>	From W to mW and mW to $\mu$ W, depending on sensor
Physical Volume	<b>1000x decrease</b>	E. g., gyro from 2000 mm <sup>3</sup> to 2 mm <sup>3</sup> /axis
Transistors	<b>1000x increase</b>	From 1000s/sensor to 1,000,000s/sensor

▲ **Disruptive Impact of Mobile Market growth on Sensors between 2007 and 2014.**

applications (TApps™) to create development targets reducing development cycle.

- 2013 Summits: UC Berkeley and Stanford University.
- 2014 Summits: Tokyo (February), Munich (September), San Diego (November 12-13), Tokyo (December 8-9).
- 2015 Summits: discussion started with Abu Dhabi, Korea, China and US.

■ **TSensors Roadmap and TSensors System Roadmap** aiming at collecting information about emerging

sensor technologies helping to eliminate hunger, provide medical care, clean environment and generate energy (TSensors Roadmap) and sensor infrastructure such as networks, ultralow power wireless communication, energy harvesting, analytics, security (TSensors Systems Roadmap) capable of supporting TApps™.

■ **TSensors Supply Chain** supporting TSensors through:

- Restructuring of academic and R&D programs.
- Providing directions to startups

from leading research organization.

- Promoting cooperation (Cooptition) between sensor suppliers, customers, infrastructure companies, academia and research organizations.
- Encouraging Governments and billionaires funding.
- TSensors Challenge incentive competition.

Trillion sensors translates to about 130 sensors/person/year. We already are using up to about 200 sensors/car, 100 sensors/smart home, 15 sensors/cell phone, 10 sensors/wearables, etc.

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Massive adoption, however, will depend on sensor cost. For example:

- At \$1/networked sensor, sensors should enable the first wave of IoT applications fighting global hunger, pollution, healthcare and energy.
  - At \$0.10/sensor, ultrahigh volume applications for personal health, fitness and lifestyle using arrays of sensors could be enabled for most of people on Earth. 7 billion people collectively own about trillion things (clothing, shoes, jewelry, toothbrushes, pets, etc.).
  - At \$0.01/sensor, monitoring of trillion shipped packages (UPS alone ships about 160 million/year) could be enabled, monitoring temperature, shock, location, etc.
  - At \$0.001/sensor monitoring freshness and quantity of food in trillions of food packages sold every year could be enabled. To complement sensors, IoT infrastructure will need to be deployed, for example:
    - Your refrigerator will have a Swarm Server collecting food packaging information, and e. g., alerting you while detecting your visit to a grocery store to buy needed food matching your (hopefully healthy) diet stored in your profile, or
    - Scheduling food delivery by Google or Amazon based on AI algorithm predicting your needs, or
    - Searching for incentives (coupons) to buy food early.
  - At \$0.0001/sensor planting sensor arrays with plant seeds to monitor health and nutrient needs of every plant to optimize the crop yield, minimize usage of water and fertilizers, and best adopt to expected weather forecasts could be deployed.
- When trillion sensors ship even at \$0.0001/sensor, it would enable a \$100 million revenue, attractive for many



▲ **Sensor based luxury wearables: Smart Tshirt from Ralph Lauren.**



▲ **World's first portable Xray imager 25lbs, MODIS™ 810 from Tribogenics is the world's smallest self-contained imaging system. Battery powered and solar rechargeable. Unfolds in seconds to provide rapid imaging anywhere in the world for both diagnostic and industrial needs.**

entities. The ultralow pricing level for sensors is expected to be enabled by one of the exponential technologies, 3D printing. 3D printed transistors and sensors are under development and have been entering the market. The manufacturing infrastructure is dramatically less expensive than for classical semiconductors. For example, a 3D transistor printer capable of 10 nm lines is priced at only \$500k<sup>5</sup>, as opposed to a multibillion dollar fab. Once printed sensors and ICs are available in ultrahigh volumes, sensor based applications will be limited by the imagination of developers.

One of the biggest challenges for TSensors will be size of data generated by sensors, expected to reach 1 BB (Bronto Byte, or 10<sup>27</sup>) in 10 years.

### Summary

Growth of sensor market to trillions will be supported by multiple global tides using sensors to provide a link to physical and biological worlds. Funding of deployment seems to be strongly incentivized by the expected benefits and opening of new large market segments.

The net effect of this explosive growth will be Abundance in two decades, a dream which slowly becomes a reality. In parallel, these global transformations will bring us longer and healthier life, enable all of us to live in less polluted and more energy efficient world, and have more fun than ever.

Due to a sheer size of forthcoming changes driven by global tides (growth by \$19 trillion in 6 years!), multiple business opportunities will be created. The byproduct of these opportunities will be emergence of MEMS Billionaires, with first ones created by a \$3.2B acquisition of sensor-based Nest by Google.

<sup>1</sup>Concept of the first three Revolutions was introduced by Vijay Ullal, President of Fairchild Semiconductor. Extrapolation to the 4th revolution was envisioned by J. Bryzek.

<sup>2</sup>[http://www.eetimes.com/document.asp?doc\\_id=1322091](http://www.eetimes.com/document.asp?doc_id=1322091)

<sup>3</sup><http://www.businessinsider.com/ibms-watson-may-soon-be-the-best-doctor-in-the-world-2014-4>.

<sup>4</sup><http://www.forbes.com/sites/matthewherper/2014/09/10/medicines-manhattan-project-can-the-worlds-richest-doctor-fix-health-care/>.

<sup>5</sup>[http://www.eetimes.com/document.asp?doc\\_id=1322091](http://www.eetimes.com/document.asp?doc_id=1322091)

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