eHealth: Path to Healthcare for All

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Outline

- Introduction to eHealth
- Sampler of eHealth devices
- Digital Manufacturing
- TSensors Roadmap
- Conclusions

Introduction to eHealth

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What is eHealth

- My definitions: electronically enhanced medical care.
- Encompasses:
  - Digital Health: medical care enhanced by digital signal processing, and
  - Mobile Health: medical care ported to mobile devices
- Applications:
  - Diagnostics
  - Therapeutics
  - Diagnostic and therapeutic algorithms
- Implemented as:
  - Out-the-Body
    - Broad range of (not-yet-integrated) sensing and actuating devices.
      - E.g., ultrasound scanners, dialysis machines, X-ray scanners, tc.
  - On-the-Body
    - Diverse range of wearable devices monitoring and controlling health and wellness.
  - In-the-Body
    - Emerging family of sensors and actuators implanted in the body.
      - E.g., glucose sensors and infusion pumps.

Why eHealth

- Brings medical care to patients.
  - As opposed of bringing patients to medical care.
    - In extreme cases, shrinks room sized equipment to a portable devices.
      - Benefitting from extreme integration of computing/displaying/communication power of mobile devices.
  - Enables bringing medical care to all people on Earth (Abundance vision).
    - Once it is low cost and mobile.
- Creates personal medical care.
- Brings “instant” medical feedback.
- Significantly reduces cost of medical care.
  - In the US it exceeded 18% of GDT and is growing at unsustainable rate 8%/year.
- Is the next killer application riding on low cost mobile technology.

eHealth Enablers

- Unprecedented growth of mobile market.
  - Fusing computing, communication and sensing and making it affordable.
- Low-cost high-volume fabrication of eHealth sensor and actuators based on MEMS and NEMS.
  - Mobile sensor absorption grew from 10M units in 2007 to 3.5B units in 2012.
  - There is potential for sensor growth to trillions by 2023.

eHealth Has Emerged

- Wearable devices market (ABI Research):
  - 2010: 12M devices (almost all of them for sports and fitness)
  - 2014: 420 million wearable health monitors with 59 million used at home.
- Sales of remote monitoring devices grew from $3.9B in 2007 to $10B in 2012.
  - Initial focus: monitoring chronic conditions.
  - Emerging: automatic monitoring of an individual's weight, vital signs and sleeping patterns to detect early signs of trouble.
- Over 600,000 of 2.5 million implanted devices in use (such as pacemakers) are linked to home networks for remote monitoring.
- 500M people are forecasted to be using mobile health apps by 2015 (www.alivecor.com)
- Apple app store offers 12,000 health related apps.
- At 2013 CES Show in Las Vegas:
  - 19 Digital Health conference sessions
  - 350 exhibitors in Digital Health section.

Global eHealth Market Tides

Market	2018 Forecast $Billion	CAGR %/year
eHealth	**$10.2**	**42**
Point of Care Diagnostics	$52.4	32
BioMEMS	$6.6	23
Wireless Health	$46.0	20
BioPhotonics	$39.4	9

Sources: Yole, Solid State Technology, Markets and Markets, mHIMSS

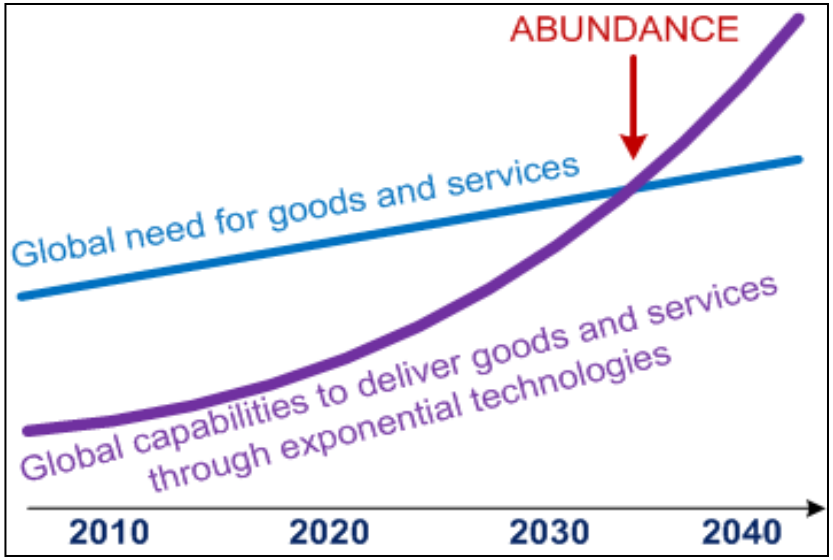
FDA on eHealth (March 21, 2013)

- FDA plans to regulate:
  - Small subset of mobile medical apps that present a potential risk to patients, if they do not work as intended.
  - Peripherals and apps that turn a mobile device into a medical device in some way (e.g., wireless glucometer).
  - Mobile apps that measure patients' vital signs or control devices such as CT scanners.
- FDA doesn’t plan to regulate:
  - Consumer devices such as the iPhone, tablets and app stores like iTunes and Google.
  - Mobile apps that provide access to electronic health records (EHRs).
  - Wellness, fitness and medical resource apps.
  - Medical apps with low-risk to consumers, such as an e-book of medical information.

http://www.eweek.com/print/mobile/fda-clarifies-plans-for-mobile-health-app-regulation/

eHealth and Abundance*

- Abundance Vision:
  - The biggest global problems, such as hunger and lack of medical care, will be solved in one generation through growth enabled by:
    - Exponential technologies.
    - DIY (Do-it-Yourself) Revolution.
      - Power of individual innovators capable of impossibles, such as flying into space (Burt Rattan) and sequencing human genome (Craig Venter).
    - Unrivaled in history Technophilanthropic force.
      - Funded by billionaires (Gates, Zuckenberg, Omidyars, etc.).
    - The rising billion,
      - Billion of the very poorest of the poor on earth being plugged into global economy through a global transportation network, Internet, microfinance and wireless communication.
- eHealth tide is well correlated to this vision.



* http://www.abundancethebook.com/

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Exponential technologies

- Biotechnology and bioinformatics
- Medicine
- Nanomaterials and nanotechnology
- Networks and sensors
  - 45 trillion networked sensors in 20 years.
- Digital manufacturing (3D printing) and infinite computing
- Computational systems
- Artificial intelligence
- Robotics

Most impact eHealth

QUALCOMM TRICORDER X PRIZE

Healthcare in the palm of your hand

Search the Site

XPRIZE FOUNDATION

Competition Details | Media | Blog | About

As envisioned for this competition, the device will be a tool capable of capturing key health metrics and diagnosing a set of 15 diseases. Metrics for health could include such elements as blood pressure, respiratory rate, and temperature. Ultimately, this tool will collect large volumes of data from ongoing measurement of health states through a combination of wireless sensors, imaging technologies, and portable, non-invasive laboratory replacements.

Introducing the Qualcomm Tricorder X PRIZE.

A $10 million competition to bring healthcare to the palm of your hand.

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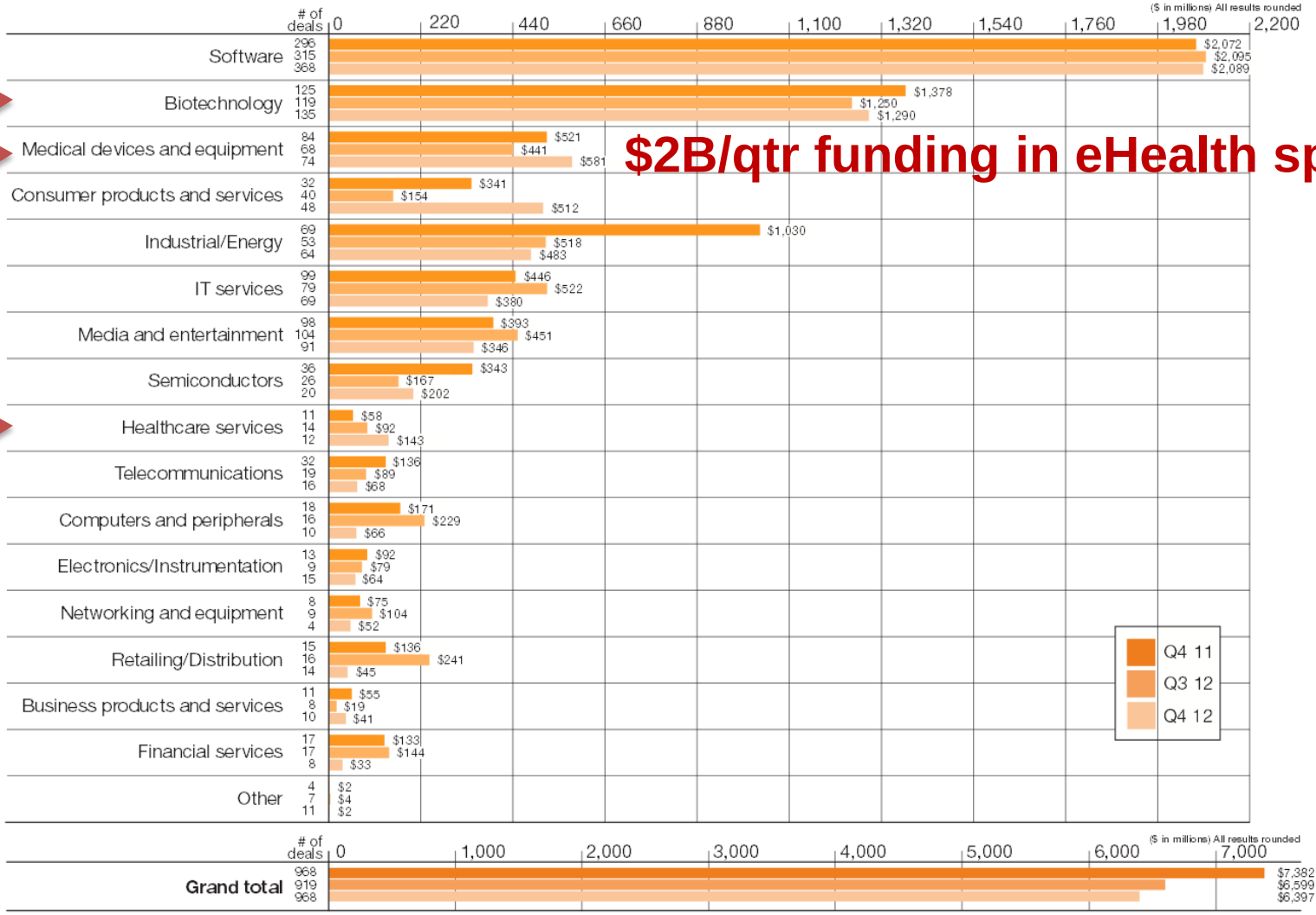
VC Funding of eHealth



$2B/qtr funding in eHealth space

/Tree

13

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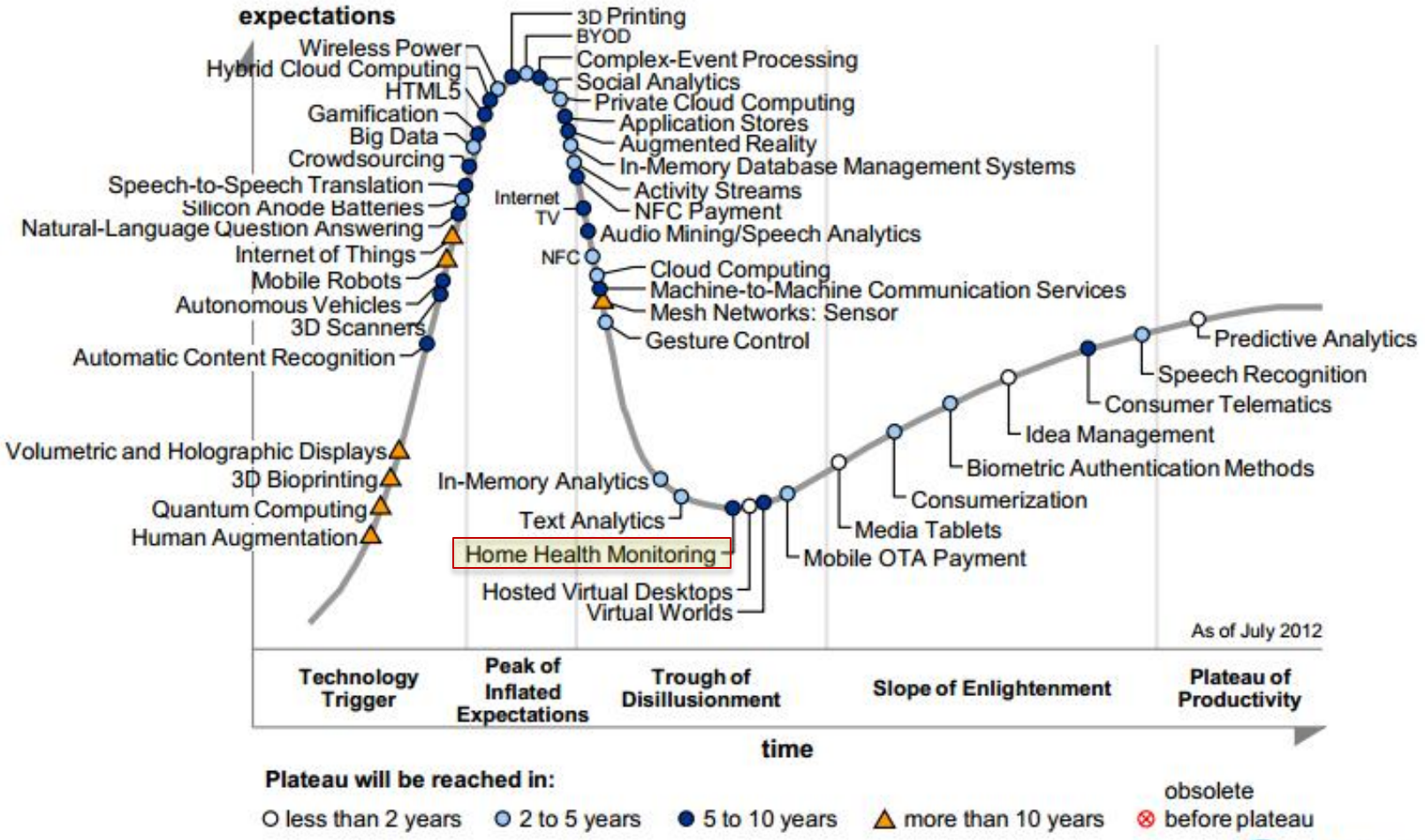
Fastest Growing BioMEMS

- 42%/y Microfluidic drug delivery
- 37%/y Microfluidic cell chips
- 26%/y Proteomic analysis
- 26%/y Human POC
- 23%/y Microfluidic environmental testing
- 21%/y Microfluidic clinical diagnostics
- 20%/y PCR chips

Source: Yole

Emerging Technologies Hype Cycle 2012



http://speck-informatik.ch/2/wp-content/themes/webmagazine/images/Gartner-Hype-Cycle-2012.png

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Sampler of eHealth devices

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eHealth Devices

- First generation of eHealth devices was/is based on sensors developed for the mobile tide: temperature, acceleration, pressure, moisture, etc.
  - Focus on activity monitoring, fittness, wellness and elderly care.
- Second generation added actuators (e.g., insulin pumps) and more advanced sensors (e.g., EKG), and addressed FDA approvals.
- Emerging products aim at gradual replacement of traditional medical lab equipment.
  - Reuse mobile computing, displaying and communication infrastructure, thus…
  - Development can focus only on sensing, actuation and data processing.

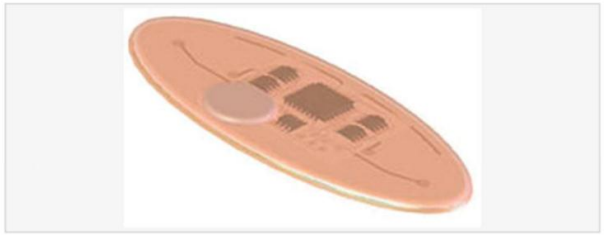
Sensor based Appcessories, Sampler 1

The market for wearable wireless sensors is predicted to grow to 400 million devices by 2014.

Graphic from Don Jon

THE WIRELESS HEALTH MARKET IS PROJECTED TO MORE THAN TRIPLE FROM $2.7B IN 2007 TO $9.8B IN 2012

Calorie-counting smart patch measures energy intake and expenditure



Heart Rate
Fluid Status
Activity Level
Posture
Respiratory Rate
Arrhythmia Detection
Temperature
ECG

Vital signs monitor

Sleep monitor

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Sensor based Appcessories, Sampler 2

Smart pedometers

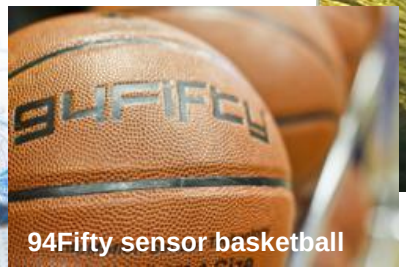
http://www.kickstarter.com/projects/597507018/pebble-e-paper-watch-for-iphone-and-android

Nike Fuel Band

Smart Shoe

Smart surfboard with GPS and IMU

Baolab tennis racket



94Fifty sensor basketball

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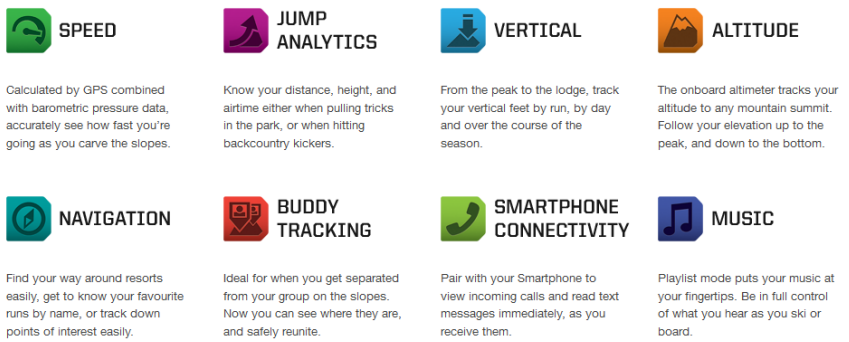
Sensor based Appcessories Sampler 3

Augmented Reality
(Google Glasses)

Headset with brain interface



Recon Goggles with heads-up display, GPS and IMU for skiers

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Sensor based Appcessories, Sampler 4

- Lapka: gathers:
  - Humidity
  - Temperature
  - Radiation
  - Electromagnetic frequencies (EMF)
  - Organicity (checks for nitrates, which are commonly used in chemical fertilizers).
- Node: includes
  - Motion sensors for wakeup
  - Temperature gauge
  - Barometer
  - Ambient light
  - Humidity
  - Point-and-shoot temperature sensor
  - Color sensor for matching colors
  - Forthcoming range of gas sensors.
-

http://www.fastcodesign.com/1670479/iphone-sensors-test-if-your-food-really-is-organic#1

http://www.tuaw.com/2012/12/11/node-gives-your-iphone-sensory-input/

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Sensor Based Appcessories, Sampler 5

Proteus digestible sensors send wireless signal through the body to a receiver.
Records type of drug, the dose, and the place of manufacture.
Measures an heart rate, activity, and respiratory rate.

Low cost DNA chips containing up to 64 reactions of less than 1 µl volume.
Assay time is 10-30 minutes, cost < $1,000, assay cost $5-$10 per chip.

Alcohol breathalyzer, $79 accessory.

Uchek (MIT) can detect up to 25 diseases, such as diabetes, urinary tract infections, and pre-clampsia based cell phone camera reading.
It can also measure the levels of glucose, proteins, ketones, and more.

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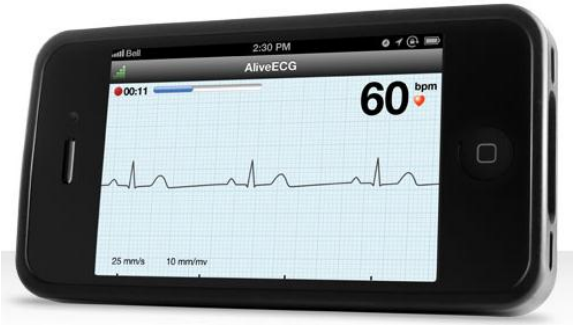
Sensor Based Appcessories, Sampler 6

LifeWatch V

Tests ECG, body temperature, blood glucose, heart rate, oxygen saturation, body fat percentage and stress levels (heart rate variability).

It contains health tests and apps, test result delivery, historical data analysis and even physician connectivity

http://www.lifewatchv.com/?page_id=480



EKG Monitor

http://www.alivecor.com/?gclid=CP-vwdDO4bUCFZOe4Aod4kcA8Q

Ultrasound machine from Mobisante went on sale in October 2011

http://www.mobisante.com/

Blood pressure monitoring cuff

http://www.deccanherald.com/content/230784/monitoring-your-health-mobile-devices.html

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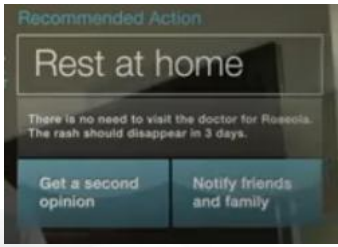
“Doctor in a pocket”

- Scanadu is a 2010 startup based at NASA-Ames Research Center.
- Introduces in 2013 three home diagnostic tools based on imaging, sound analysis, molecular diagnostics, data analytics and a suite of algorithms to create a comprehensive, real-time picture of your health.
  - Uploadable to Scanadu smartphone app via Bluetooth.
- SCOUT: collects vital signs In less than 10 seconds contact with the temple:
  - Pulse transit time
  - Heart rate (pulse rate)
  - Electrical heart activity
  - Temperature
  - Heart rate variability
  - Blood oxygenation (pulse oximetry)



- ScanaFlo: uses smartphone as a urine analysis reader.
  - Designed to be sold over-the-counter as a disposable cartridge, will test for pregnancy complications, preeclampisa, gestational diabetes, kidney failure and urinary tract infections.
  - For pregnant women, is the first to provide a healthfeed throughout the duration of a pregnancy.
- ScanaFlu
  - Assesses cold-like symptoms, removing guess work from early diagnosis of upper respiratory infections.
  - By testing saliva, the disposable cartridge will provide early detection for Strep A, Influenza A, Influenza B, Adenovirus and RSV.

http://www.scanadu.com/news/#sthash.oeuESQSK.dpuf

Asian Flu Detector

- Veredus Laboratories announced that the current version of VereFlu detects the current subtype of H7N9 (Avian Flu) (responsible for the flu outbreak in China), along other types of human subtypes of Influenza A.
- It is the market's first integration onto a Lab-on-Chip of two powerful molecular biological applications:
  - Polymerase Chain Reaction (PCR) and
  - Microarray
- VereFlu can detect infection with high accuracy and sensitivity, within two hours.
  - Provides genetic information on the infection that traditionally could take days to weeks to learn.

Veredus uses STMicroelectronics' lab-on-chip platform to detect avian flu.

DNA and RNA Sensing

- From a drop of blood, DNA and RNA signature of any patogen in your system can be detected, named and reported to a central computer
- **Nanobiosym®** (NBS) is an innovation engine integrating physics, biomedicine, and nanotechnology.
  - Focuses on incubating transformational technologies that have the potential for game-changing impact and commercializing and…
  - Scaling up these technologies for deployment in developed and developing world markets.
  - Addresses planet's greatest unmet needs in global health, energy and the environment.
- **Nanobiosym® Diagnostics** (NBSDx) focuses on the commercialization of the Gene-RADAR®
  - Portable nanotechnology platform that can rapidly and accurately detect genetic fingerprints from any biological organism,
  - Empowers people worldwide with rapid, affordable, and portable diagnostic information about their own health.

http://www.nanobiosym.com/

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X-Ray Diagnostics

- Tribogenics developed small, cheap and powerful X-ray sources based on a breakthrough new metal-polymer technology.
  - Triggered by discovered Scotch tape X-ray generation.
- Technology eliminates the need for high voltage and is mechanically robust.
- Enables mobile X-ray machines.

http://tribogenics.com/about/

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Information Based Medicine

- Medicine is growing exponentially: no chance even for best doctors to keep up.
  - 45% of time, our doctors are wrong.
  - Preventable medical errors result in 10s thousand of deaths/year.
- IBM developed medical decision support using Watson supercomputer.
  - Watson made its first public appearance in 2011 on 'Jeopardy' defeating the best humans.
    - Had 16TB memory, 80 Tflops processing power and access to 200M pages of content.
    - Could handle 500 GB of data per second (2.6B books/hour)
- Watson is now offered commercially to doctors and health insurance companies.
  - So far three applications: one for recommending of cancer treatment options and two for reviewing and authorizing treatments and related health insurance claims.
- Under development with Mayo Clinic, algorithms to quickly draw meaning from:
  - Wealth of medical data to support medical treatments
  - Genomic information from public and private databases
  - Retrospective studies of millions of archived records collected from informed, consenting patients.
- Watson was the size of a master bedroom, now is the size of a bathroom.
  - It will get to be a handheld device by 2020, based on a trajectory of Moore's Law.

http://www.nydailynews.com/life-style/health/watson-supercomputer-assist-medical-teams-article-1.1259506#ixzz2RiBYvu3A

http://www.medica-tradefair.com/cipp/md_medica/custom/pub/content,oid,4188/lang,2/ticket,g_u_e_s_t/mcat_id,7858/local_lang,2

Digital Manufacturing

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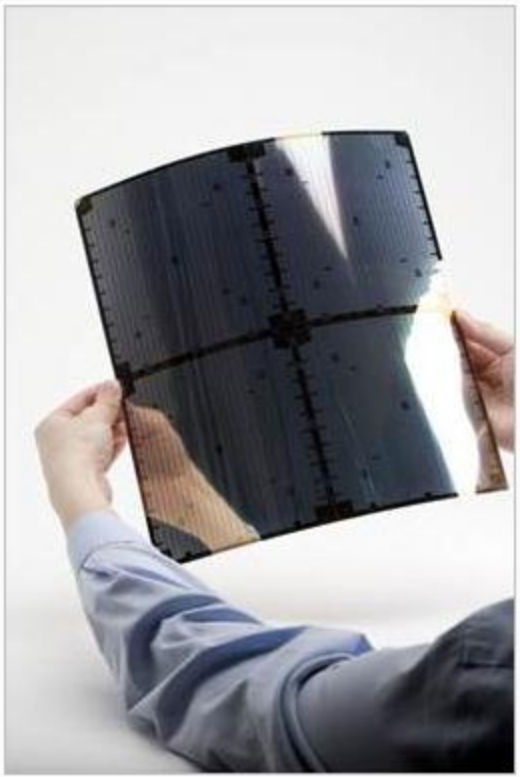
Emergence of Digital Manufacturing

- Digital manufacturing is one of the exponential technologies expected to change the world.
- Includes 3/4D printing.
- Comes in variety of flavors: from macro to nano.
  - First printed home in 2014 in Amsterdam).
  - Medical implants, etc.
  - Printing electronics.
- Kovio (San Jose) ships millions of RFID, NFC and EAS smart tags:
  - 1000 transistors in 5 µm printed (30 µm thick) technology.
  - Potential for 2018: 10s of billions smart tags with sensors.
- UC Berkeley is starting a program to print 0.2 µm transistors and sensors.
- UMASS got $35M funding to develop roll-to-roll fabrication of transistors and sensors.
  - Objective: reduction of equivalent wafer cost from $25,000 to $25 per square meter…
- Digital manufacturing could be one of the enablers for fabricating trillions sensors at acceptable price.
- Digital manufacturing starts re-writing eHealth.



300mm Metal Sheet (Kovio RF Barcode)

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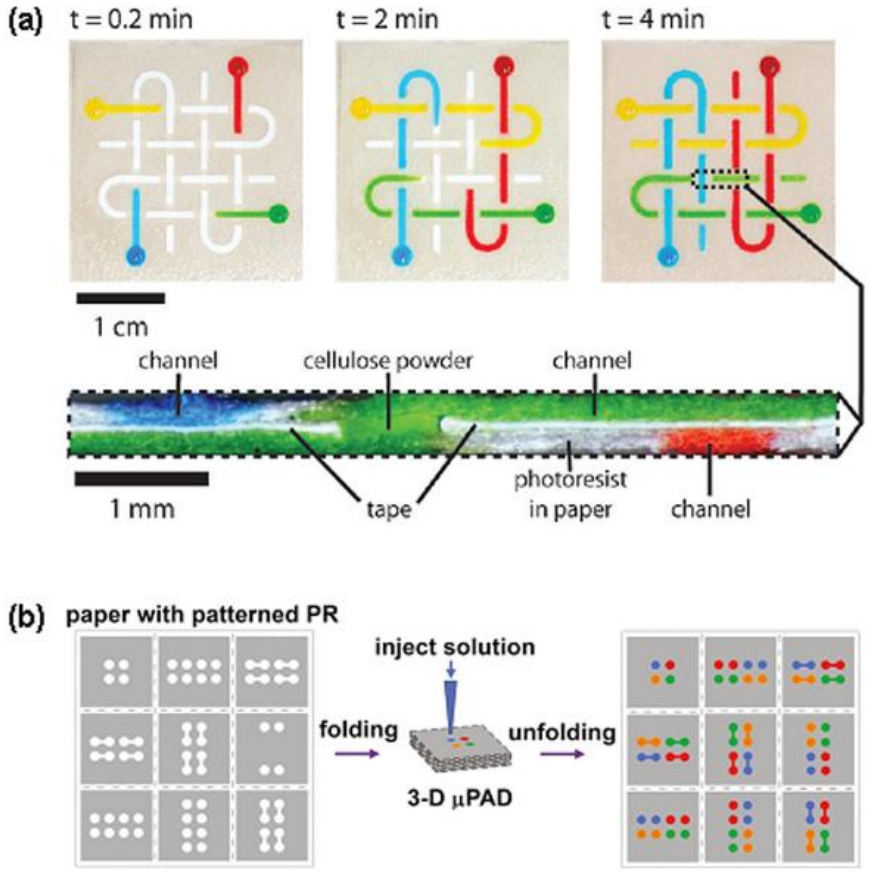
Paper Microfluidics

- Lab-on-Chip can be printed on paper.
- Why:
  - Paper is a ubiquitous and extremely cheap material.
  - It is compatible with many chemical/biochemical/medical applications.
  - It transports liquids using capillary forces without the assistance of external forces.
    - No need for MEMS pump.
  - Is low-cost, easy-to-use, disposable, and equipment-free, and therefore a promising technology particularly relevant to improving the healthcare and disease screening in the no- or low-infrastructure developing world.
- The research in paper-based microfluidics is experiencing a period of explosion; most published works have focused on:
  - Inventing low-cost and simple fabrication techniques for paper-based microfluidic devices.
  - Exploring new applications of paper-based microfluidics by incorporating efficient detection methods.

http://scitation.aip.org/getpdf/servlet/GetPDFServlet?filetype=pdf&id=BIOMGB000006000001011301000001&idtype=cvips&doi=10.1063/1.3687398&prog=normal&bypassSSO=1

Applications of Paper Microfluidics

Health diagnostics (e.g., urinalysis, saliva analysis, sputum analysis, pregnancy test, blood typing)
Biochemical analysis (e.g., enzyme activity)
Environment monitoring
Health diagnostics
Environment monitoring
Food quality control
Health diagnostics
Biomedical analysis
Biochemical analysis (e.g., ELISA)
Forensic (e.g., detection of blood)



http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3365319/#c19

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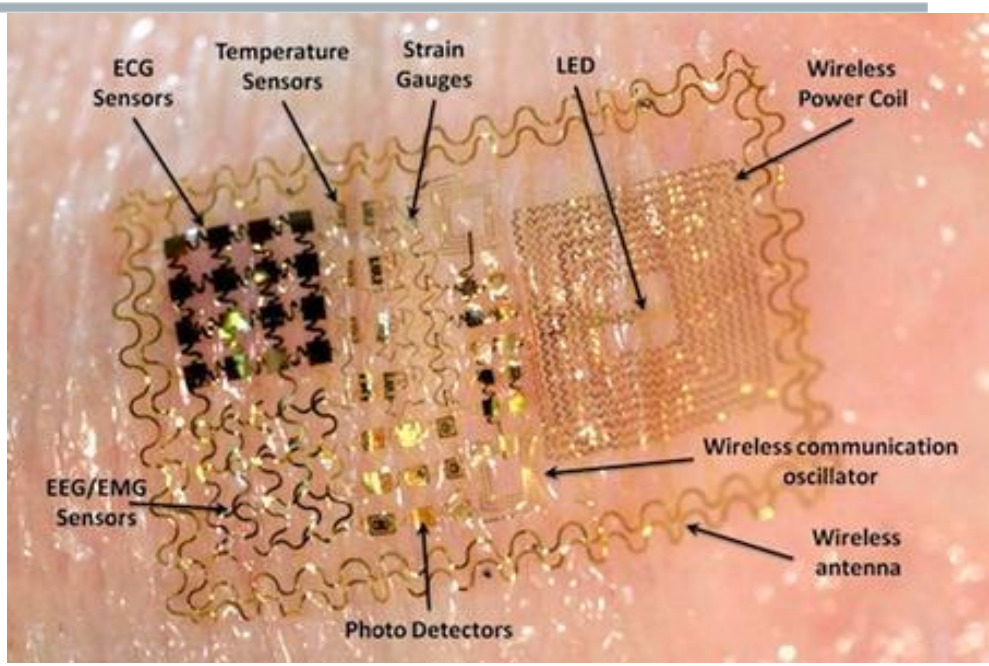
Tattoo Sensors Printed on Skin

Sensing temperature, strain, and the hydration state of the skin, all of which are useful in tracking general health and wellness, and monitoring wound healing (UoI).



Sensing multiple variables (UCSD)

http://www.technologyreview.com/news/512061/electronic-sensors-printed-directly-on-the-skin/

http://forum.eetasia.com/thread!printPreview.jspa?threadID=1200250860&start=0

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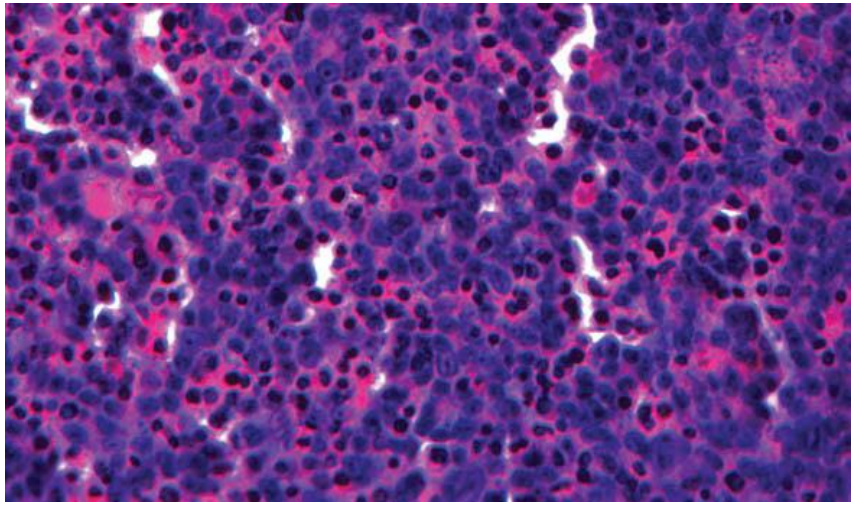
3D Human Tissue Printing

- Organovo designs 3D printable functional human tissues.
  - Develops a range of tissue and disease models for medical research and therapeutic applications.
  - Takes cultured cells and aims to create human tissue for organs such as livers and lungs.



Cross-section of multi-cellular bioprinted human liver tissue, stained with hematoxylin & eosin (H&E).

http://www.organovo.com/company

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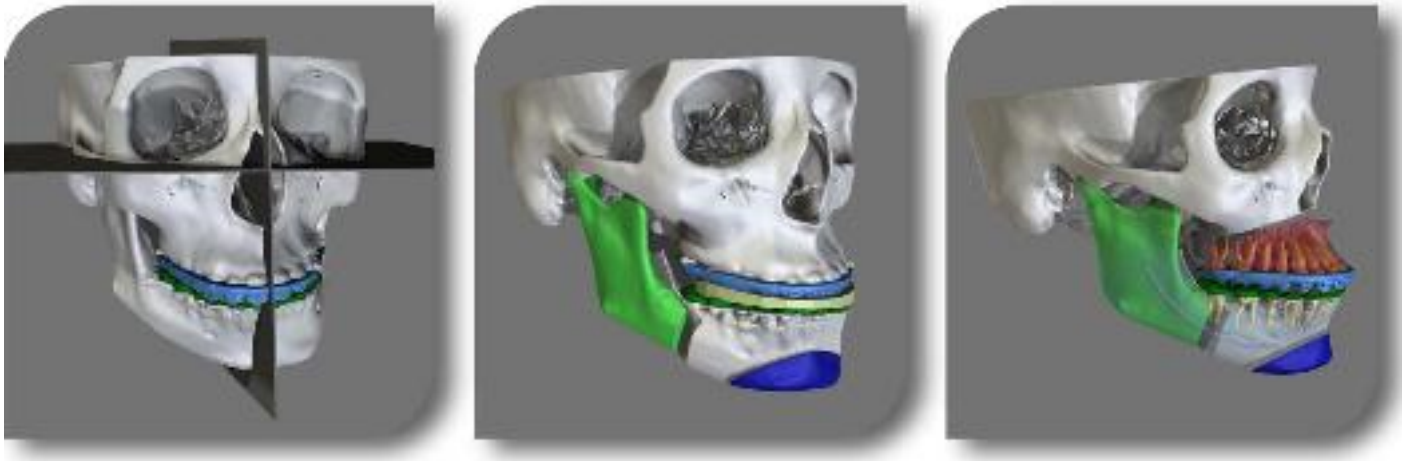
Generation of 3D Models of Body Parts

- Medical Modeling Inc. focuses on creating three-dimensional X-rays, which can then be used to make replacement body parts.
  - For example, a “physical replica of someone’s jaw.”



Quantification of deformities in 2D and 3D

Surgeon defined osteotomies and bony movements

Optimization of surgical plan before splint fabrication

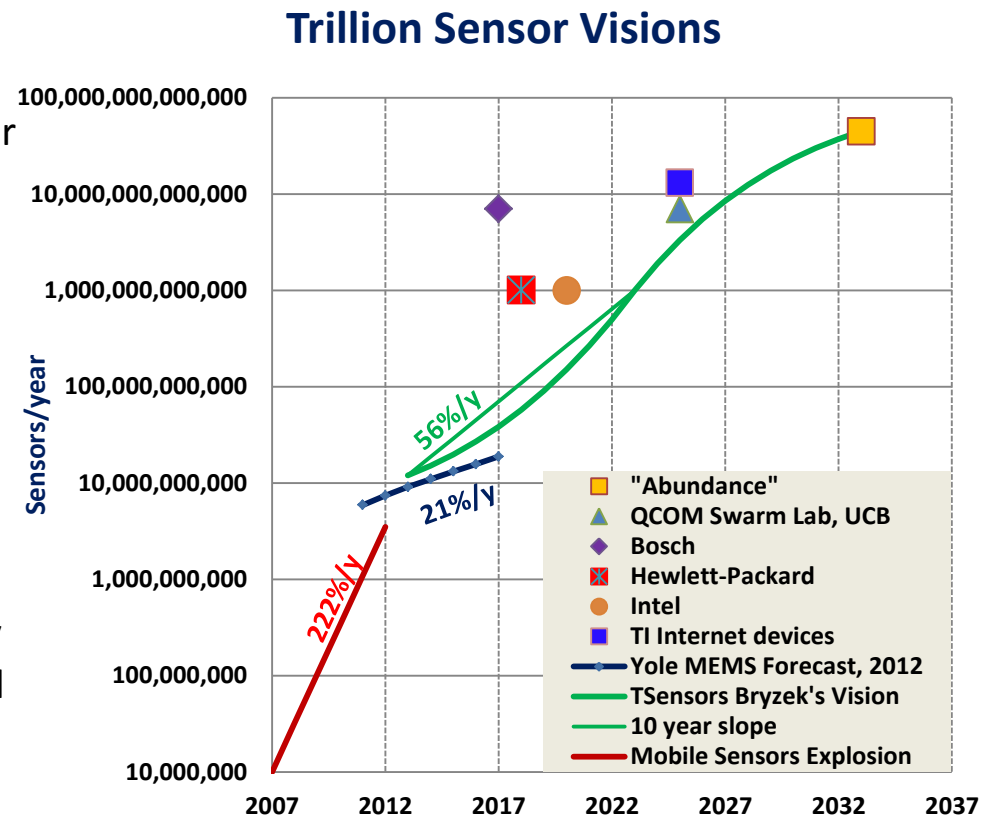
http://www.medicalmodeling.com/flashsite/splash.html

TSensors Roadmap

Trillion Sensors (TSensors) Vision

- Sensors are a foundation for eHealth.
- Mobile sensor market for volumes *not envisioned* by leading market research organizations in 2007, grew exponentially over 200%/y between 2007 and 2012.
- 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).
- So the explosion to trillion(s) is likely to be driven by applications *not yet envisioned* by leading market research organization.
- TSensors Roadmap* aims to improve visibility of needed sensors to enable their accelerated development.
  - 1st step: **The TRILLION Sensor Universe**, Conference at BSAC, March 6, 2013
  - 2nd Step: **TSensors Summit** at Stanford University

    www.TSensorsSummit.org



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Conclusions

- eHealth Revolution is underway.
- MEMS and NEMS technologies are the enablers.
- The next decade eHealth will:
  - Reduce global healthcare cost.
    - Bringing healthcare to most of us by 2023 and all of us by 2033?
  - Make medical diagnostic and therapeutics faster, cheaper, portable, wireless… personal.
  - Improve healthcare quality.
  - Improve quality of life and extend the life span …
  - Redefine the doctors' profession.
- In process eHealth will:
  - Create multiple opportunities for startups and existing companies.
  - Make mobile devices the hub for personal health.
- In longer term: eHealth will cure diseases rather than alleviate symptoms.

Thank you

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