Google, iPhone What Comes Next?

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Quiz 1: What is zettabyte?

Name	Value
Kilobyte (kB)	10^3
Megabyte (MB)	10^6
Gigabyte (GB)	10^9
Terabyte (TB)	10^{12}
Petabyte (PB)	10^{15}
Exabyte (EB)	10^{18}
Zettabyte (ZB)	10^{21}
Yottabyte (YB)	10^{24}

Apple
Market Value (2011)
$363 billion

Apple sues Samsung over Galaxy products

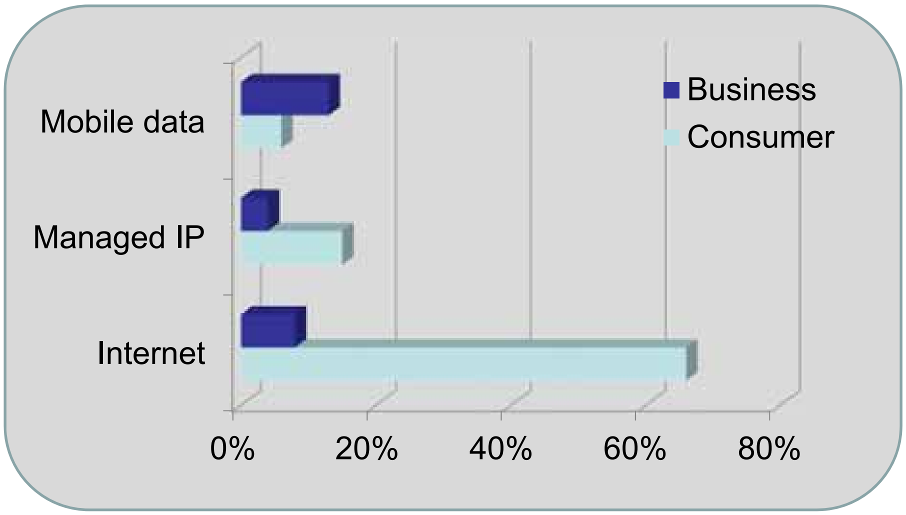
Google to acquire Motorola Mobility for $12.5B

Google
Market Value (2011)
$158 billion

Internet Traffic Trend

By the end of 2015, annual global IP traffic will reach the zettabyte threshold

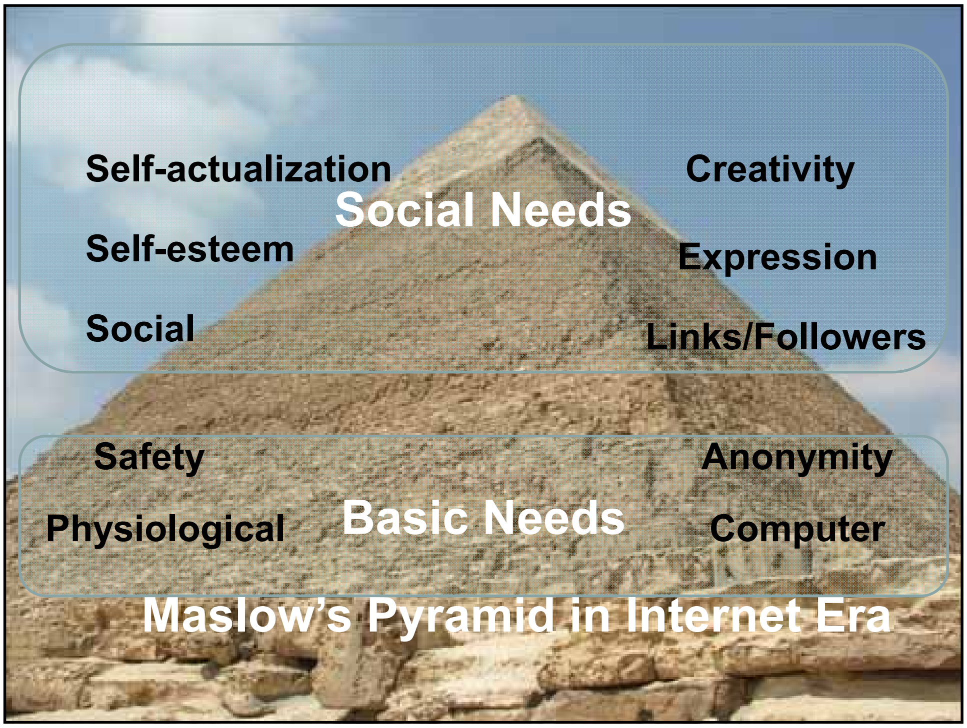
Network Traffic in 2015



Source: Cisco VNI, 2011

What Comes Next?

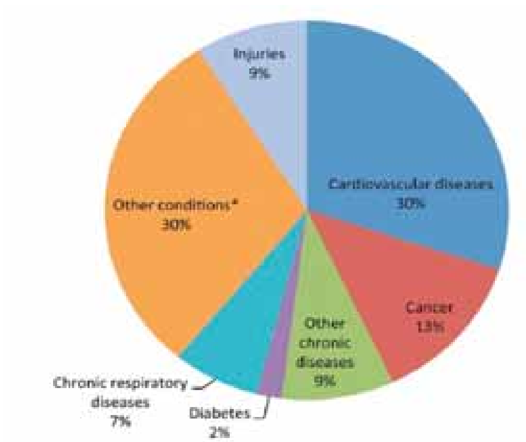
Source: http://www.youtube.com/watch?v=-2faggNVQtM


Self-actualization
Self-esteem
Social
Social Needs
Creativity
Expression
Links/Followers
Safety
Physiological
Basic Needs
Anonymity
Computer
Maslow's Pyramid in Internet Era


How about basic needs?
-Your body
-Your wellness
-Your health
Safety
Physiological
Basic Needs
Anonymity
Computer
Maslow's Pyramid in Internet Era

Are the Basic Needs Met?

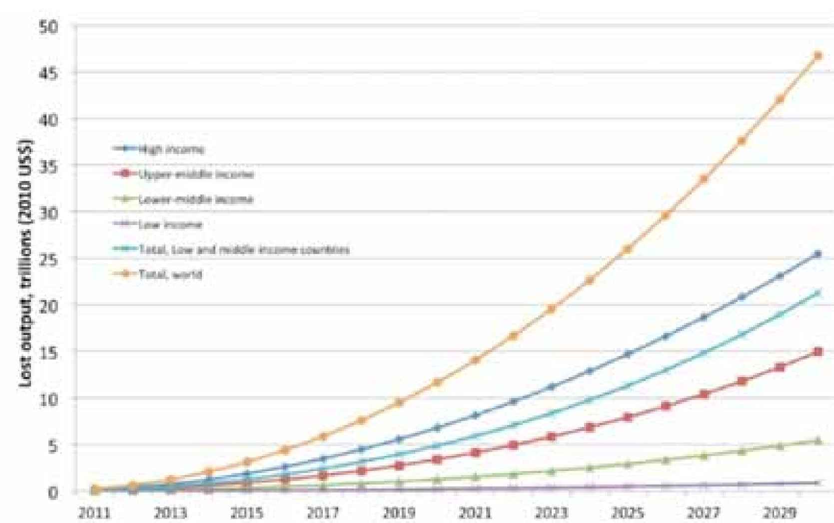
- Chronic diseases constitute more than 60% of deaths world



In Singapore, 2 in 5 adults aged > 20 are already suffering from at least one chronic ailment

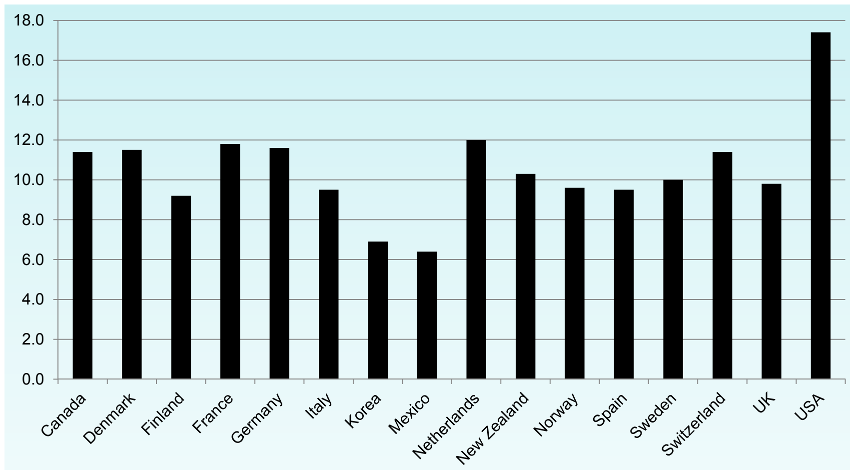
Source: World Economic Forum and the Harvard School of Public Health, 2011

Productivity Loss: 47 trillions by 2030



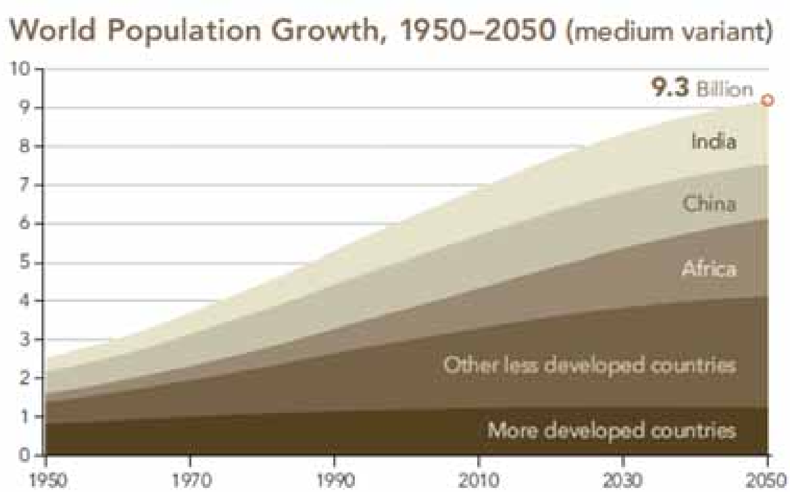
Source: World Economic Forum and the Harvard School of Public Health, 2011

Health Expenditure (% Gross Domestic Product)



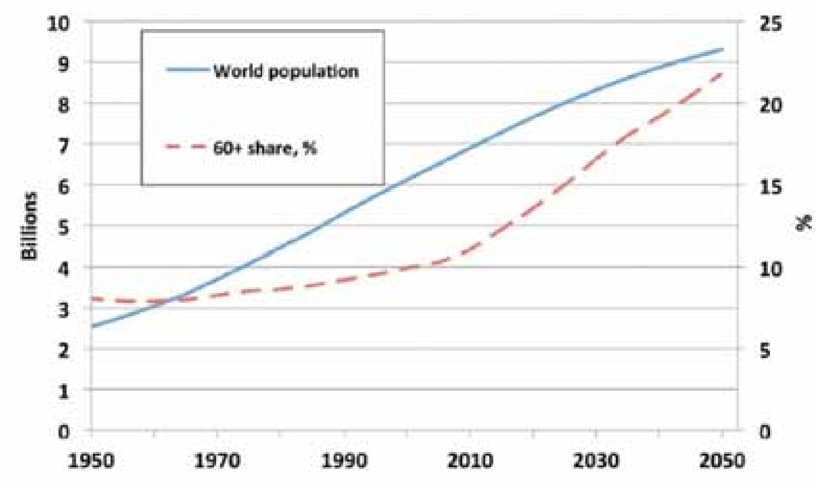
Source: OECD Health Data 2011

World Population



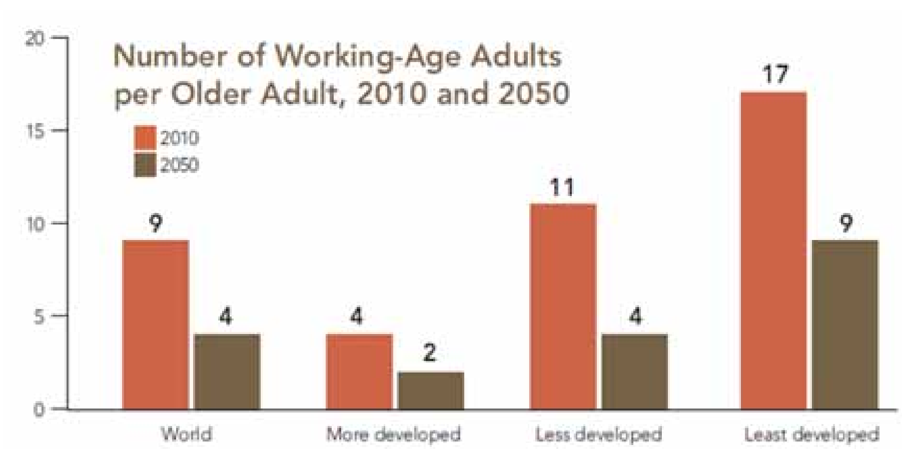
Source: Science, 333, 569 (2011)

The World Population Is Getting Older?



Source: UNFPA, State of World Population 2011

Working-Age Adults per Older Adults



Source: Science, 333, 569 (2011)

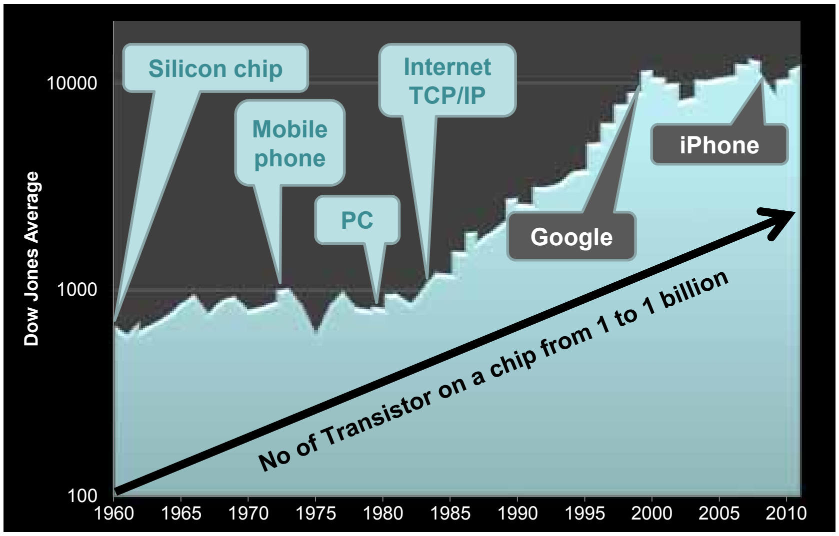
Challenges

- Largest issues faced in society today
  - Growing number of people with chronic conditions
  - Increasing healthcare costs
  - Ageing populations
- Healthcare systems are designed for "repair works", not for maintenance
- Hospital services are in the form of "point of care", no continuous effort

Unmet Needs

- Needs from healthcare provider
  - low cost, reduced workload, and efficient services
- Needs from individual
  - Personalized and prevention-oriented healthcare
  - Be well, keep well, get well
  - Continuous monitoring and instant feedback from healthcare provider

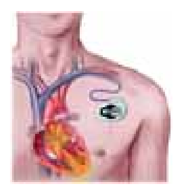
The Impacts of Electronics



Source: New York Stock & Commodity Exchanges

Developments in Biomedical Devices

- Pacemaker (1958)
- Cochlear implants (1984)
- Deep brain stimulation (1997)
- Retina implants (2007)
- e-nose
- Prosthetic arms
- Prosthetic knees

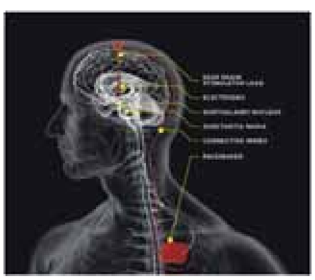


Bioelectronics

Pioneer of brain stimulation: Dr. Jose Delgado

Source: http://www.youtube.com/watch?v=6nGAr2OkVqE

Bioelectronics



Deep brain
stimulation for
Parkinson's Disease

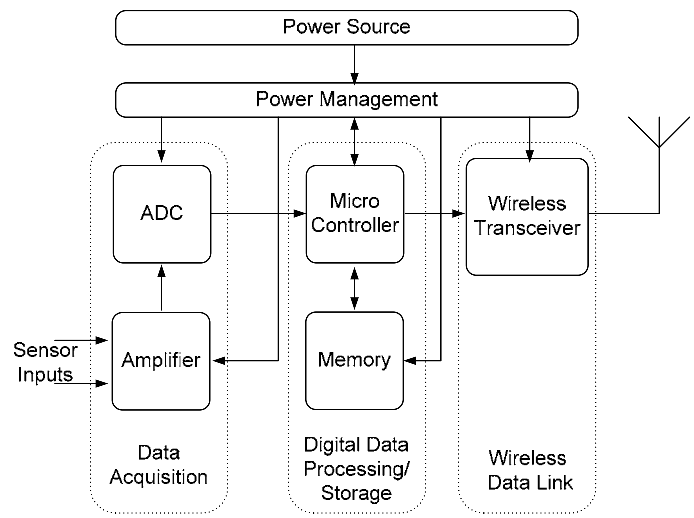
Source: http://www.youtube.com/watch?v=uMaCiuapAW0

The Next Wave: myHealth

- Seamless integration with home, working, and hospital environments.
- Continuous monitoring and instant feedback
- **Prevention-oriented healthcare**
  - **Prevention is better than cure**
- **Personalized service**
- **Key to the success**
  - **New healthcare business model**
  - **Innovations in engineering**
  - **Change of mindset**

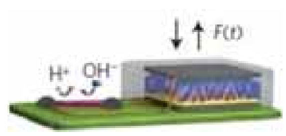
myHealth: A Melting Pot

Wireless Biomedical Sensor System

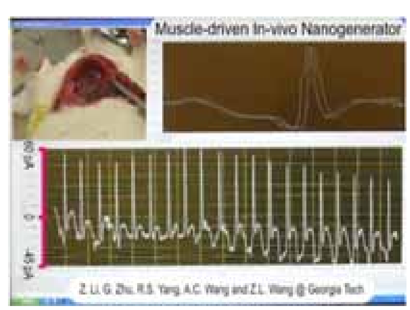


Human Energy Scavenging

- Wearable devices can generate 0.3mW – 8 W from breathing, finger motion, blood pressure, body heat, walking.
- Implantable nanowire devices:
  - Current density: ~8.9nA/ cm^2
  - Output voltage: ~96mV
  - Power density: 2.7mW/ cm^3



Z.L. Wang, *et al* "Self-powered nanowire devices", *Nature Nanotechnology,* Mar 2010.



Challenges in Designing of Self-Powered WBS

- Complicated system contains analog, mixed-signal, digital, RF, and power blocks.
- Energy scavenging from body and ambient are unstable.
- Limited power budget
  - Less than few mW for wearable devices.
  - Less than 1 mW for implants

Possible Solutions

- New system architecture
- Exploring new signal processing flow: continuous-in-time and discrete-in-amplitude.
  - Event driven ADC with continuous-time digital signal processing achieves up to 80% dynamic power saving in terms of number digital outputs for audio signals*.
- Cross-domain optimization and processing
- Wireless communication through human body
- Asynchronous architecture.
- Sub-threshold circuits.

*M. Kurchuk and Y Tsividis, "Signal-dependent variable-resolution clockless A/D conversion with application to continuous-time digital signal processing", IEEE Trans. on CAS I, May 2010 .

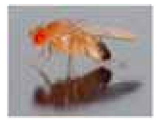
A Snapshot of Research in ECE

- 1-V 450nW programmable ECG sensor interface
- 1-V 2.3μW ECG-on-Chip
- 1-V 22μW 32-channel ECoG chip
- 0.5-V 18μW 16-channel neural recording chip
- Sub-mW UWB mostly digital wireless transceiver
- 0.5-V low power ADC (21 fJ/conversion-step)
- 300mV event driven ADC
- 250mV digital filter for bio-signal processing
- Computationally efficient DSP algorithm (QRS detection at 500 nW for ASIC implementation)

A Design Example: 0.5-V, 1.13-μW per Channel Multi-Channel Neural Recording Chip

How Many Neurons in the Brain?

~11,000



~100,000

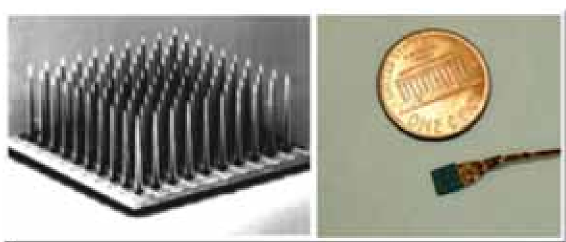
~16,000,000

~200,000,000,000

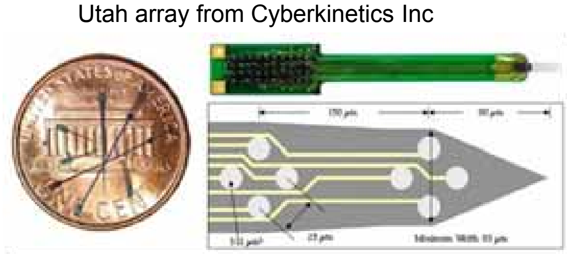
~100,000,000,000

Source: http://www.wikipedia.org

Neural Recording



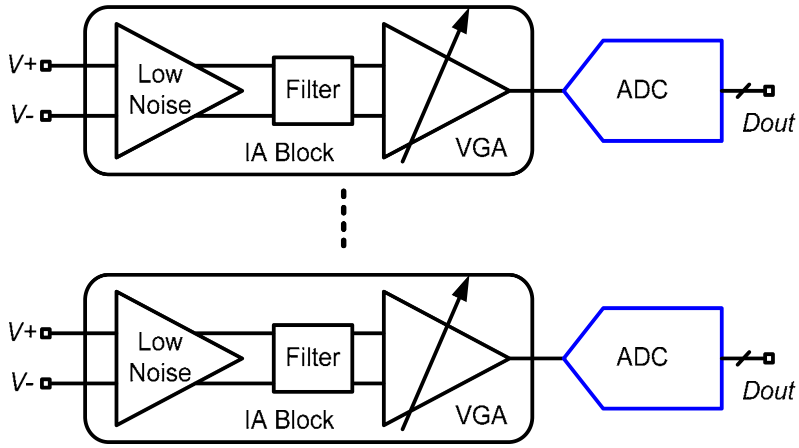
Utah array from Cyberkinetics Inc



Michigan array from NeuroNexus Inc

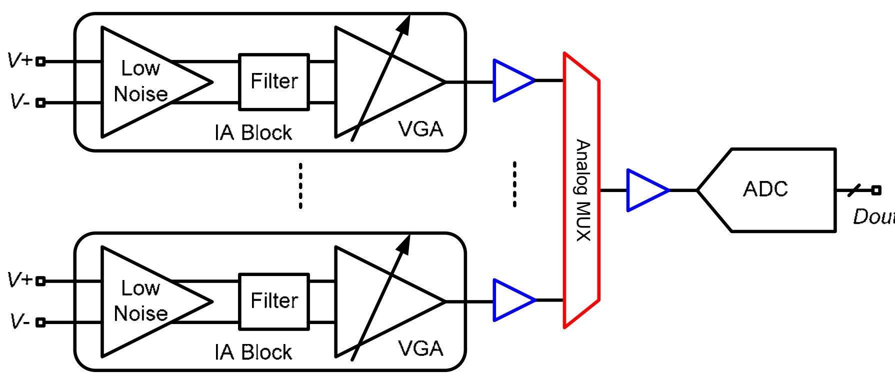
Multi-Channel Acquisition Systems

- One channel, one ADC



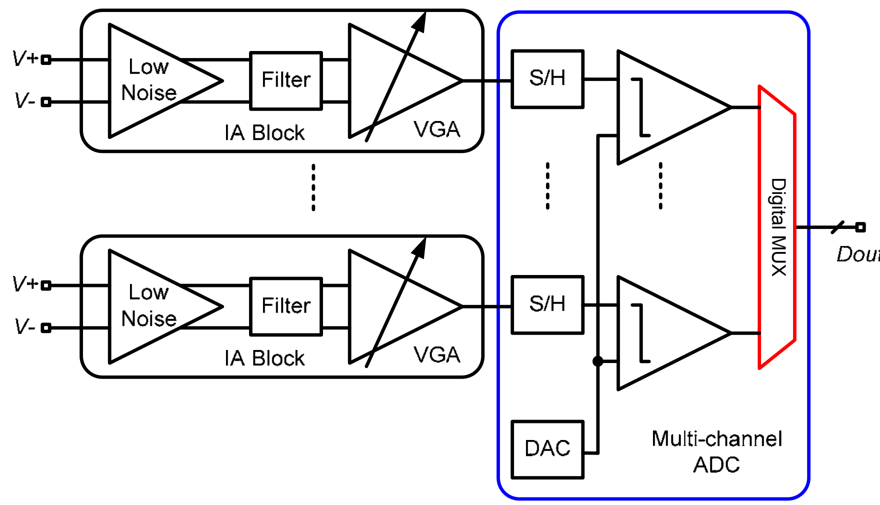
Analog Multiplexing

- Sharing one ADC among all channels – significant increase in power consumption due to additional buffers

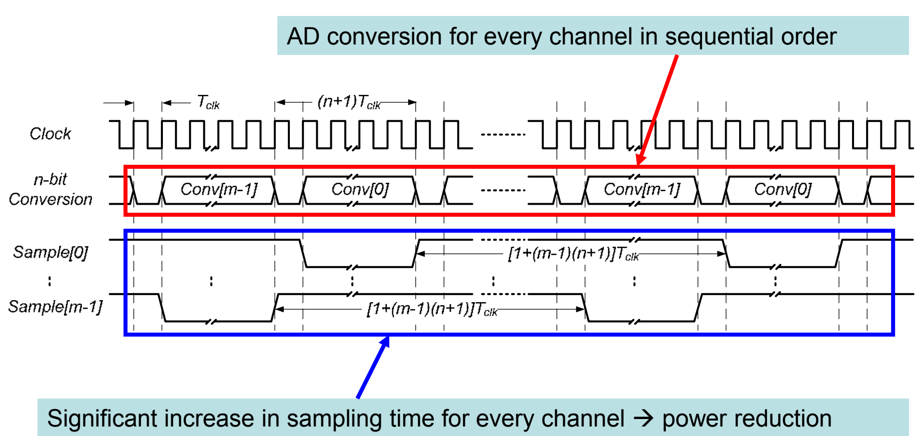


Proposed Digital Multiplexing

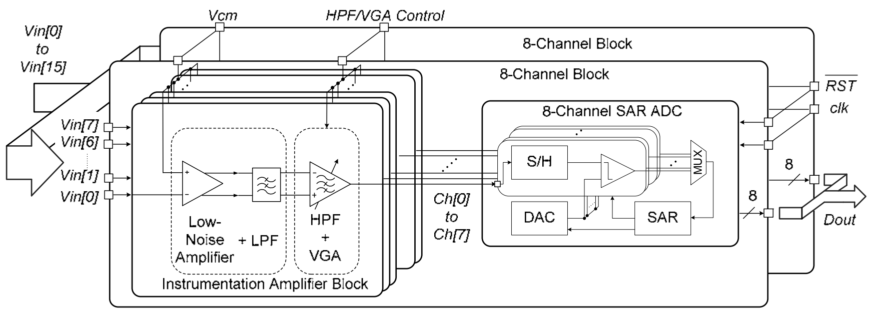
- Independent S/H stage for every channel, while sharing one large DAC in SAR ADC



Timing Diagram



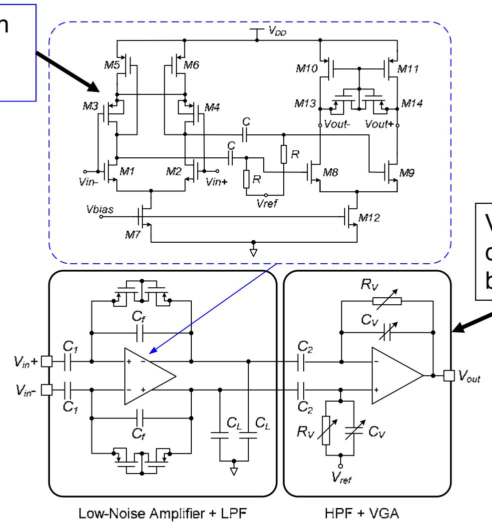
System Architecture



8-channel building block to form a larger array of recording interface

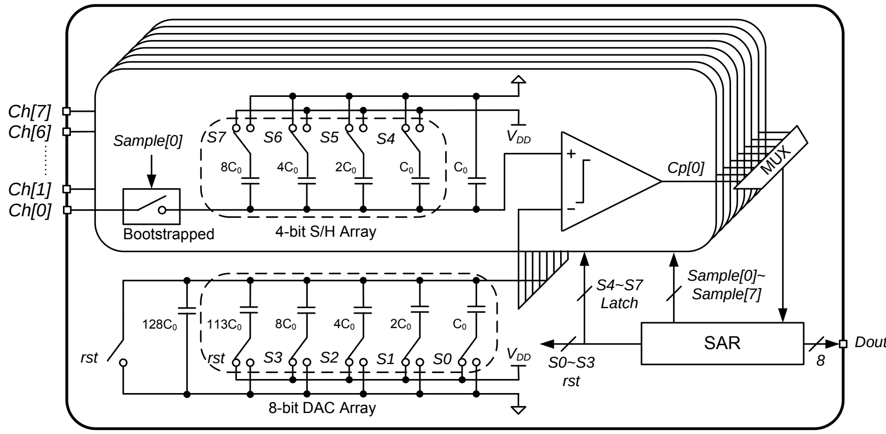
Instrumentation Amp. & VGA

Large gate area and high biasing current to lower noise floor

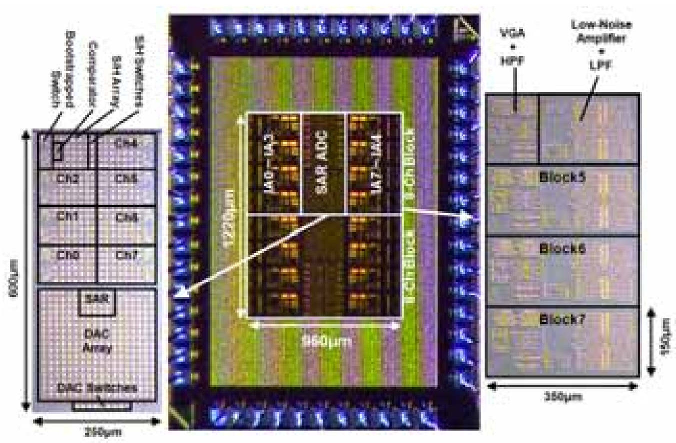


VGA as driving buffer

8-Channel 8-bit SAR ADC

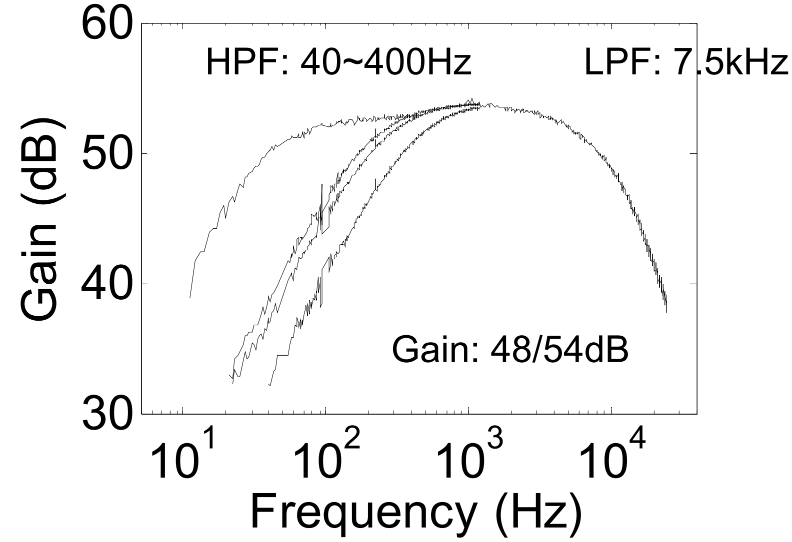


Chip Prototype

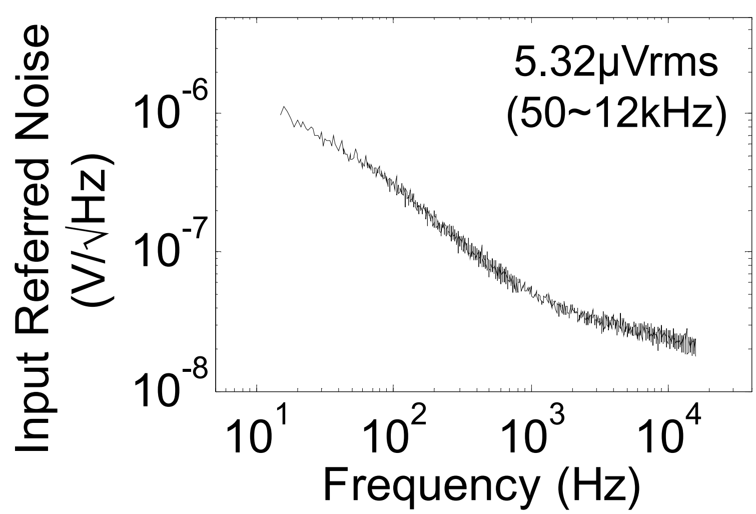


0.13µm CMOS → Core area: 1.17mm^2

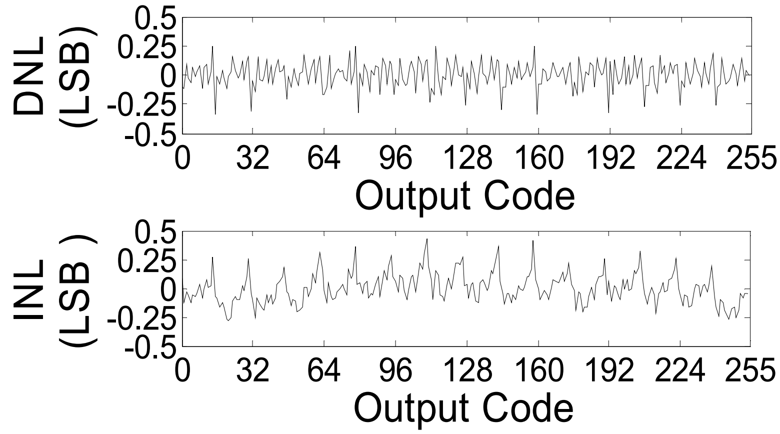
Frequency Responses



Input Referred Noise

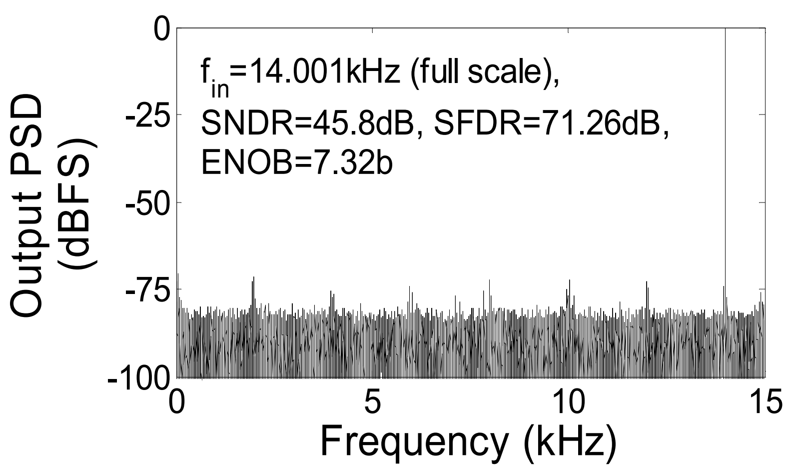


DNL & INL



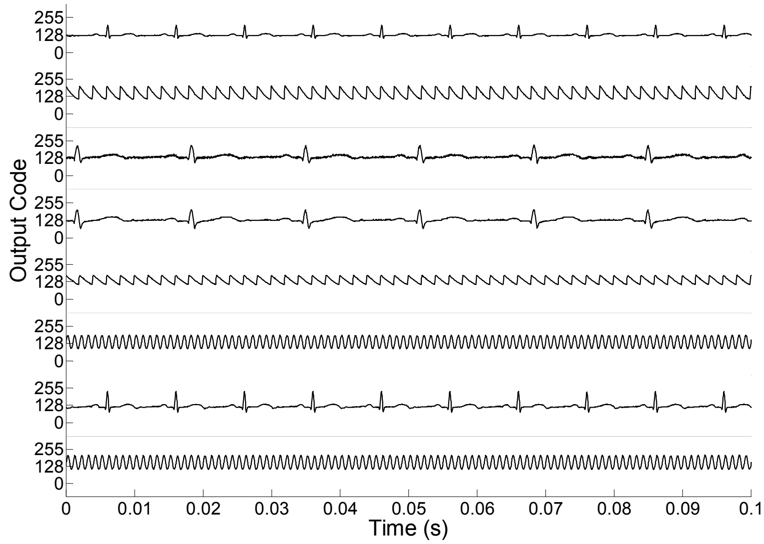
DNL/INL: 0.34/0.42 LSB

Output PSD

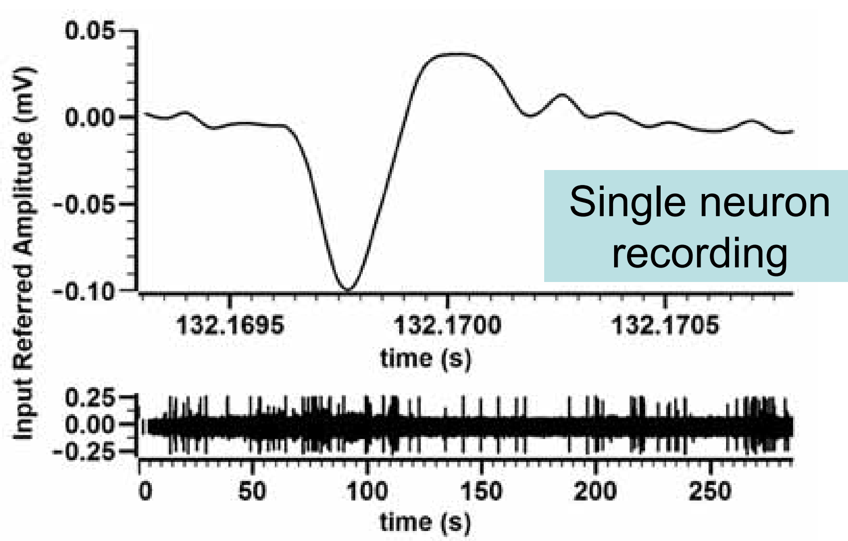


FOM: 21fJ/Conversion-step

Multi-Channel Performance



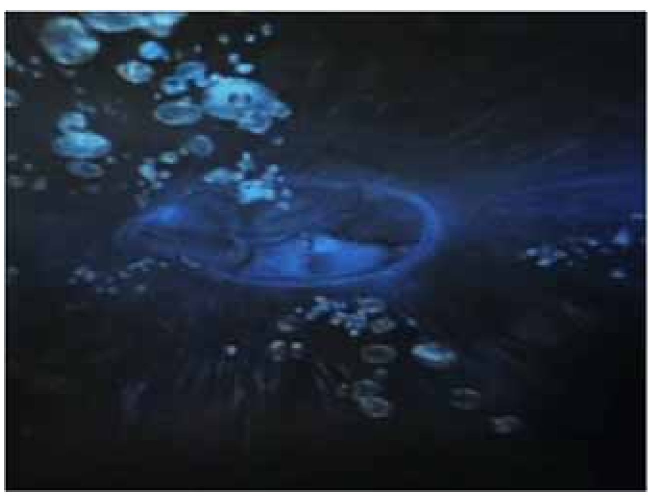
Extra-Cellular Recording



Performance Comparison

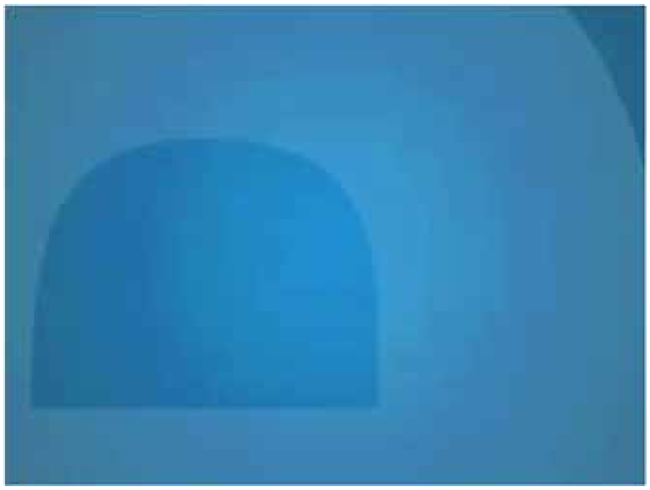
Parameter	Harrison'07	Chae'08	Lee'10	Muller'11	This work
Supply (V)	3.3	3.3	3	0.5	0.5
Process (μm)	0.5	0.35	0.5	0.065	0.13
FE Current (μA)	12.8	2	25	-	1.72
Input referred noise (μVrms)	5.1	4.9	4.39	4.9	5.32
NEF	-	-	-	5.99	3.09
ADC res. & Samp. rate per ch.	10b 15kS/s	6~9b 40kS/s	- -	8b 20kS/s	8b 30kS/s
No. of channel	100	128	32	1	16
Area per channel (mm^2)	0.15	0.36	0.26	0.013	0.073
Avg. power per channel (μW)	142.2	23.4	36.6	5.04	1.13

The Future of Bioelectronics



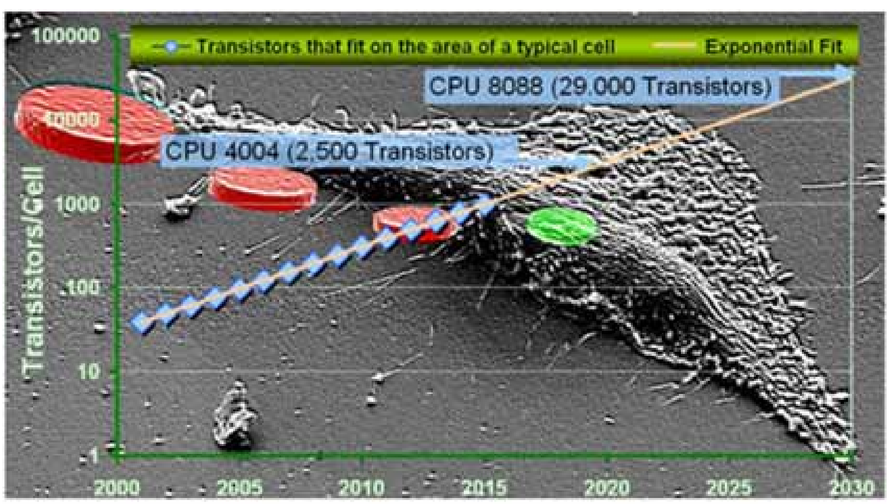
Fantastic Voyage (1966)
Source: http://www.youtube.com/watch?v=3o8vsU0Dw-4

Robot with Rat Neuron



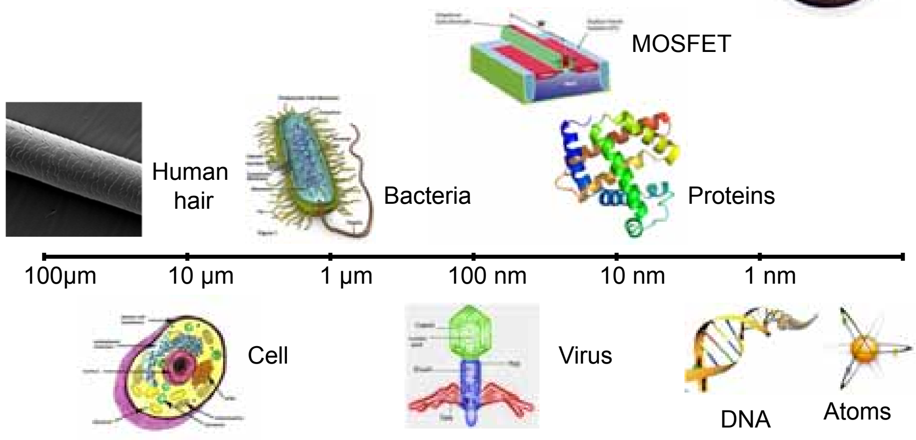
Source: http://www.youtube.com/watch?v=1-0eZytv6Qk

The Future of Bioelectronics



Source: http://www.nanowerk.com/spotlight/spotid=15292.php

The Future WBS



The Future of Biomedical Circuits & Systems

- Closed-loop diagnostic and therapeutic devices
- New circuit techniques for low voltage operation and 3D IC integration
- Wireless communication via human body
- System-in-package for miniaturized ingestible/injectable devices

Conclusions

- The next wave of technology may come from healthcare, especially on wireless health and biomedical circuits and systems.
- Expanding the frontiers of biomedical circuits and systems to ride on the new wave
  - Many challenges in system architecture, low voltage circuit techniques.
  - Call for revolutionary signal processing flow that improves energy efficiency.
  - Be aware of challenges beyond CMOS: system integration, packaging, etc.
  - Multidisciplinary is the key to the success.

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