

Multi-Cloud and Fog Computing for Internet of Things and Smart Cities



RAJ JAIN

Washington University in Saint Louis
Saint Louis, MO 63130

Jain@cse.wustl.edu

Talk at Installation as

Barbara J. and Jerome R. Cox Jr. Professor, May 24, 2016

These slides are available on-line at:

http://www.cse.wustl.edu/~jain/talks/iots_cox.htm



1. My story
2. My Research (A view from a 3000 ft)

Thanks to Those Who Changed My Life



Shri Shanti Lal Jain
Father



Smt. Sulochana Devi Jain
Mother



Aunt



Prof. N. L. Jain
GEC, Rewa



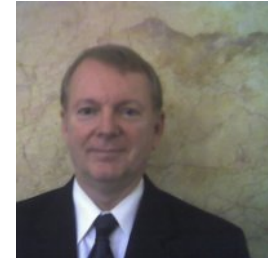
Prof. M. R. Chidambara,
I.I.Sc.



Prof. Raman Mehra,
Harvard



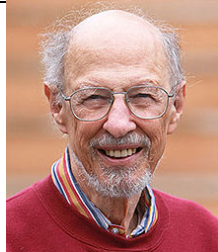
Prof. Ugo Gagliardi,
Harvard



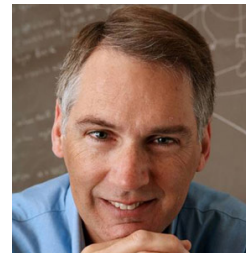
Dr. Terry Potter,
DEC



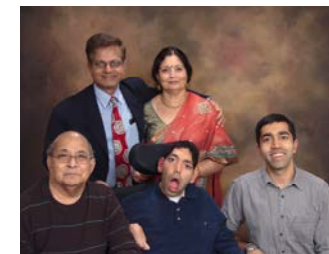
Prof. Jerome Saltzer
M.I.T.



Prof. Fernando Corbato
M.I.T.



Prof. Jon Turner
Wash U

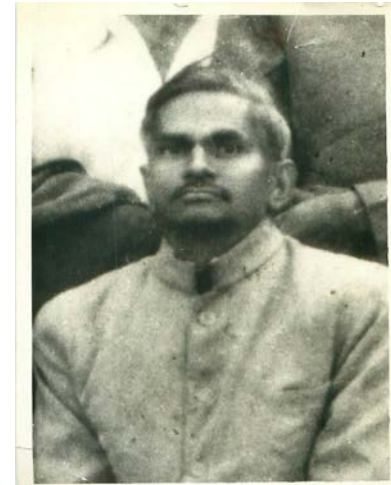
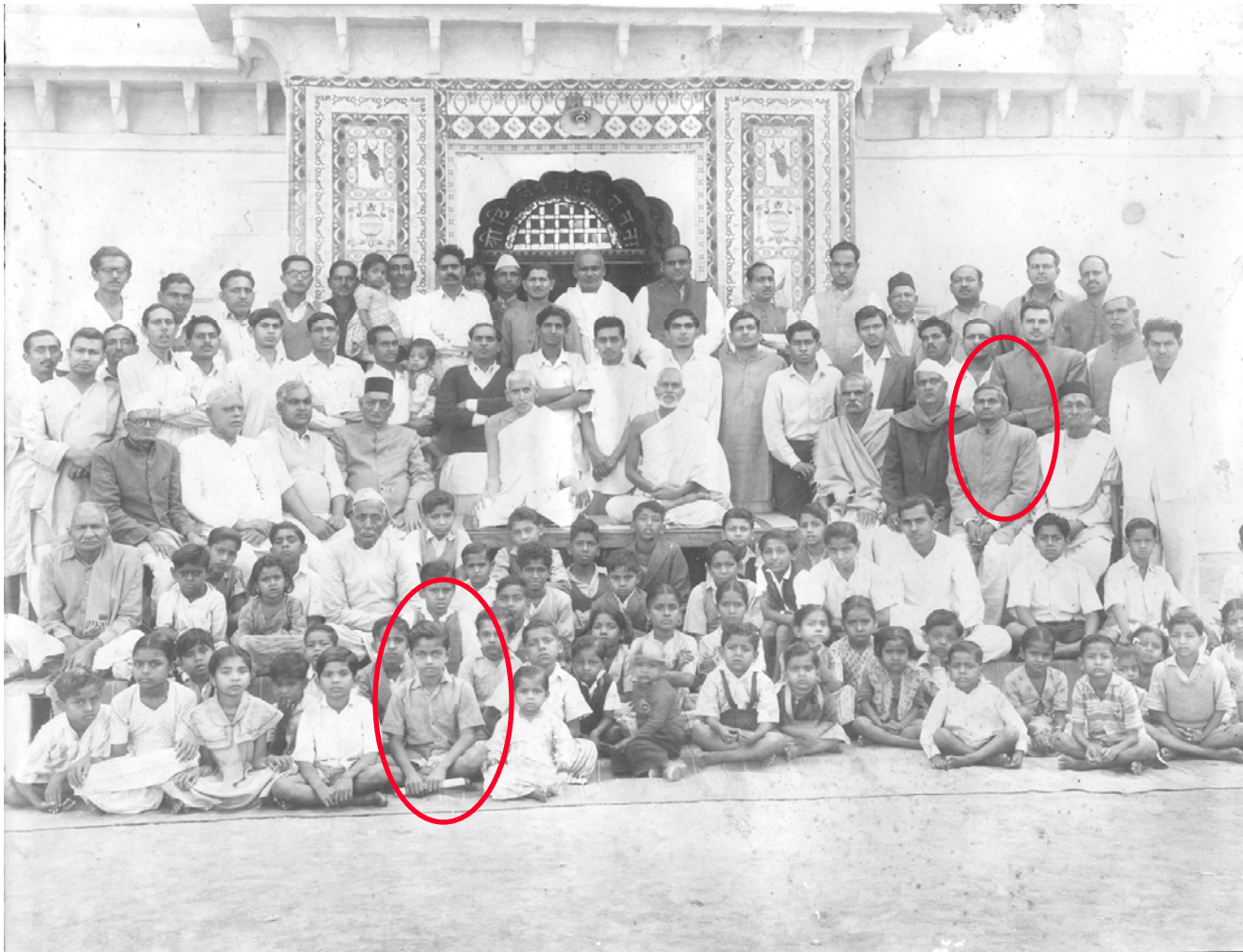


My
Family

Birthplace: Satna, India



Childhood



Father: Shri
Shanti Lal Jain

Family Businesses



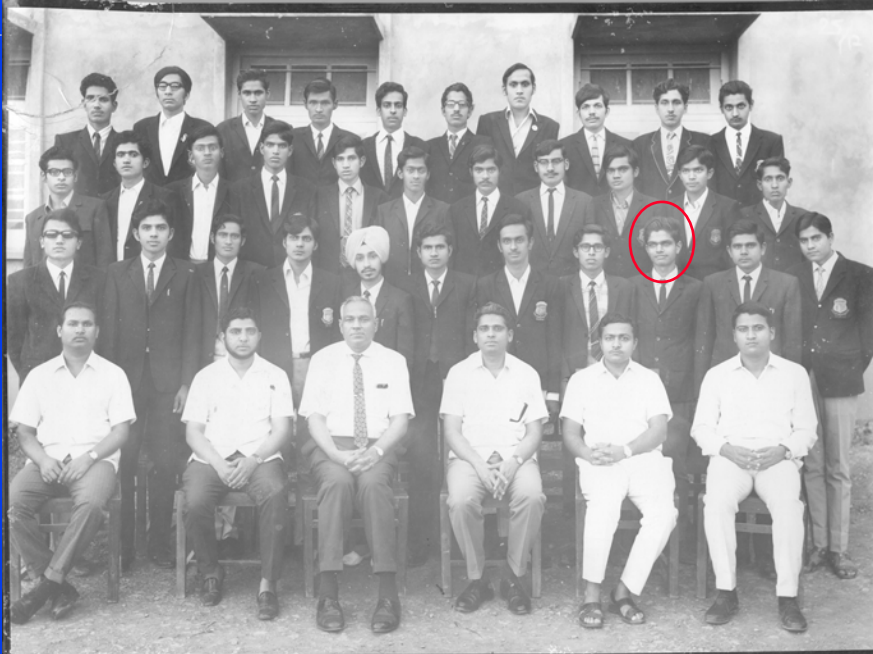
- ❑ Father: Jeweler
- ❑ My cloth store
(at the age of 11)

Family



Mother:
Smt. Sulochana
Devi Jain

B. E.: Govt. Engineering College, Rewa



Prof. N. L. Jain

Returned from Florida State University



Aunt

M.E.: Indian Institute of Science, Bangalore



Indian Institute of Science
Bangalore

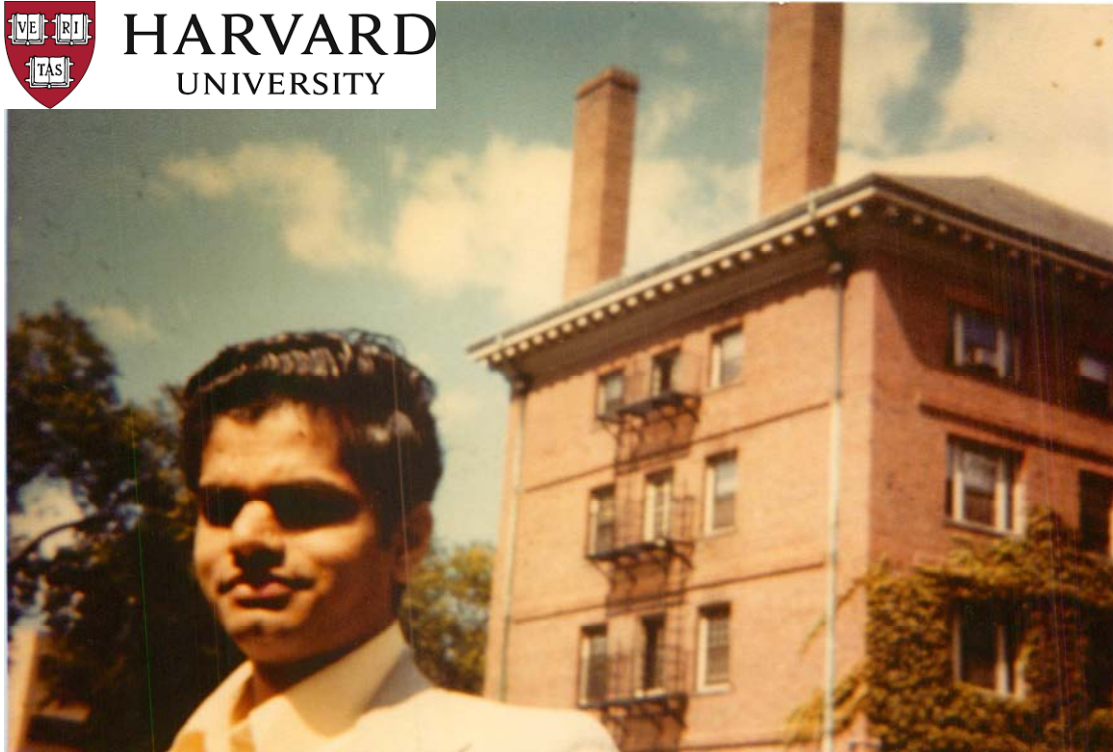


Prof. M. R.
Chidambara
IISc
Returned from
ESE/WUSTL

Ph. D.: Harvard University



HARVARD
UNIVERSITY



Prof. Raman Mehra



Prof. Ugo Gagliardi

- Thesis: “Control Theoretic Formulation of Operating Systems Resource Management Policies,” Outstanding Dissertations in the Computer Sciences Series, Garland Publishing Company, New York, N.Y., 1978

1978 - Digital Equipment Corporation



Dr. Terry Potter



Dr. Linda Wright

- High-speed (10 Mbps) Ethernet will congest the network
 - ⇒ DECbit Congestion Avoidance
 - ⇒ ECN bits in IP/TCP

1983 – Visiting Scholar at M.I.T.



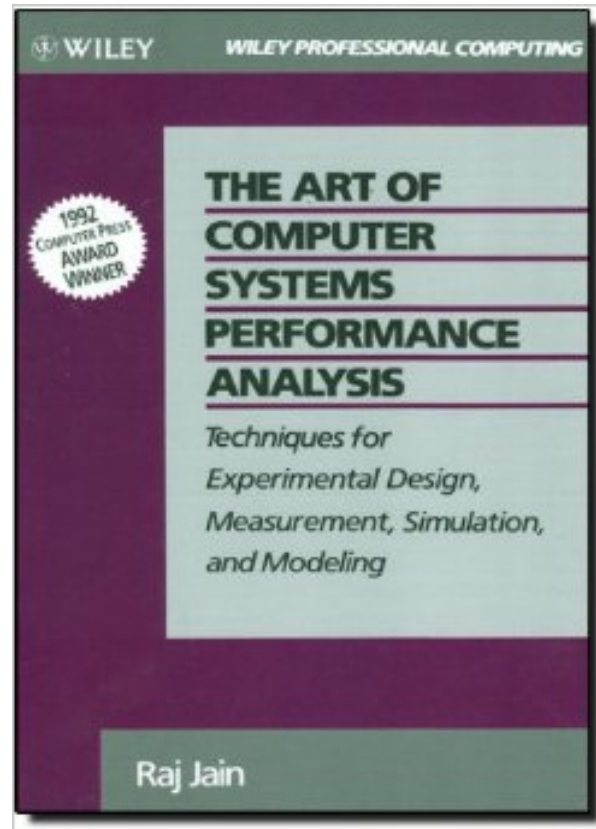
Prof. Jerome Saltzer



Prof. Fernando Corbato

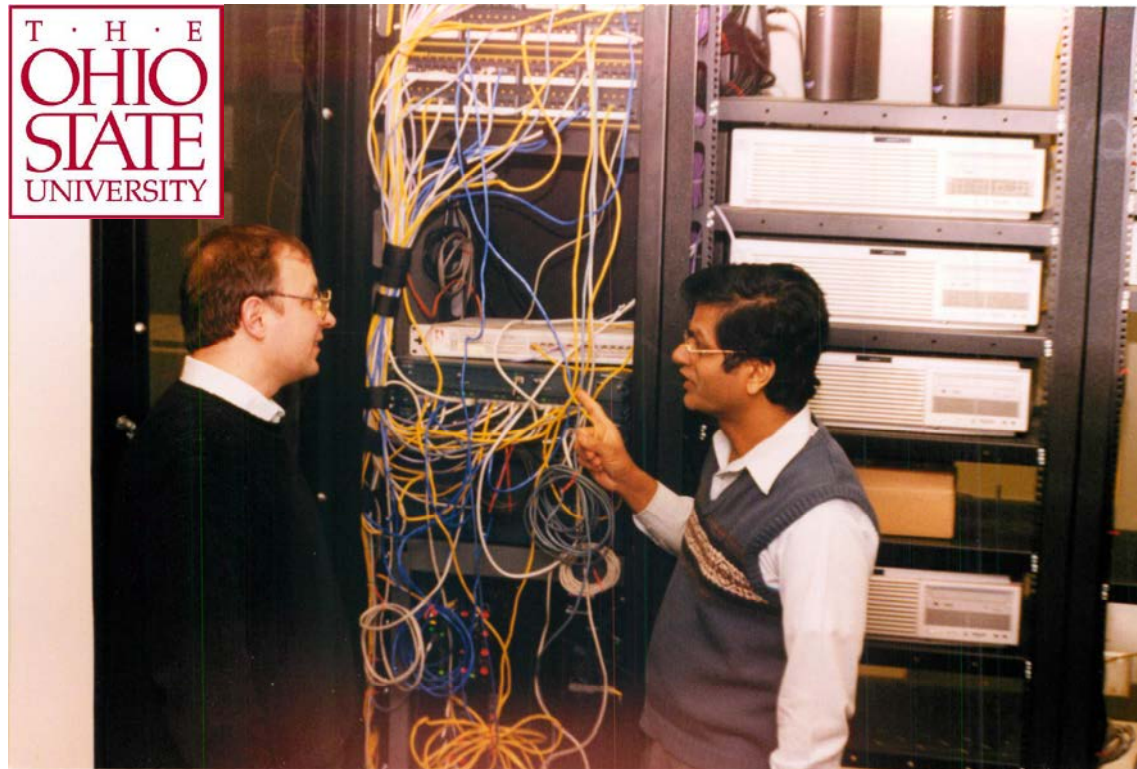
- Designed and taught a course on “The Art of Computer Systems Performance Analysis”

The Book



Winner of “Best-Advanced How-to Book, Systems ” Award
from Computer Press Association

1993 – Ohio State University



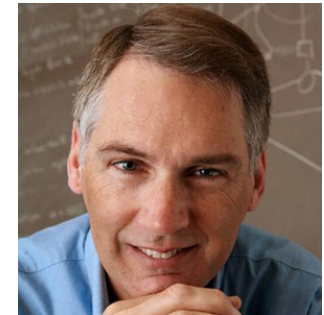
- ❑ Participation in “ATM Forum”
⇒ 1999 siliconindia Leadership Awards for Excellence and Promise in Business and Technology

2000-2005: Nayna Networks



1024-port All-Optical Switch

2005 - WUSTL



Prof. Jon Turner

□ Thanks also to:

- Dean Ralph Quatrano, Dean Aaron Bobick, Prof. Roch Guerin, Prof. Jerry Cox
- My colleagues, friends, and students

Family



□ Neelu, Papa (Father-in-Law), Sameer, and Amit

Trend: Smart Everything



Smart Watch



Smart TV



Smart Car



Smart Health



Smart Home



Smart Kegs



Smart Space



Smart Industries



Smart Cities

What's Smart?

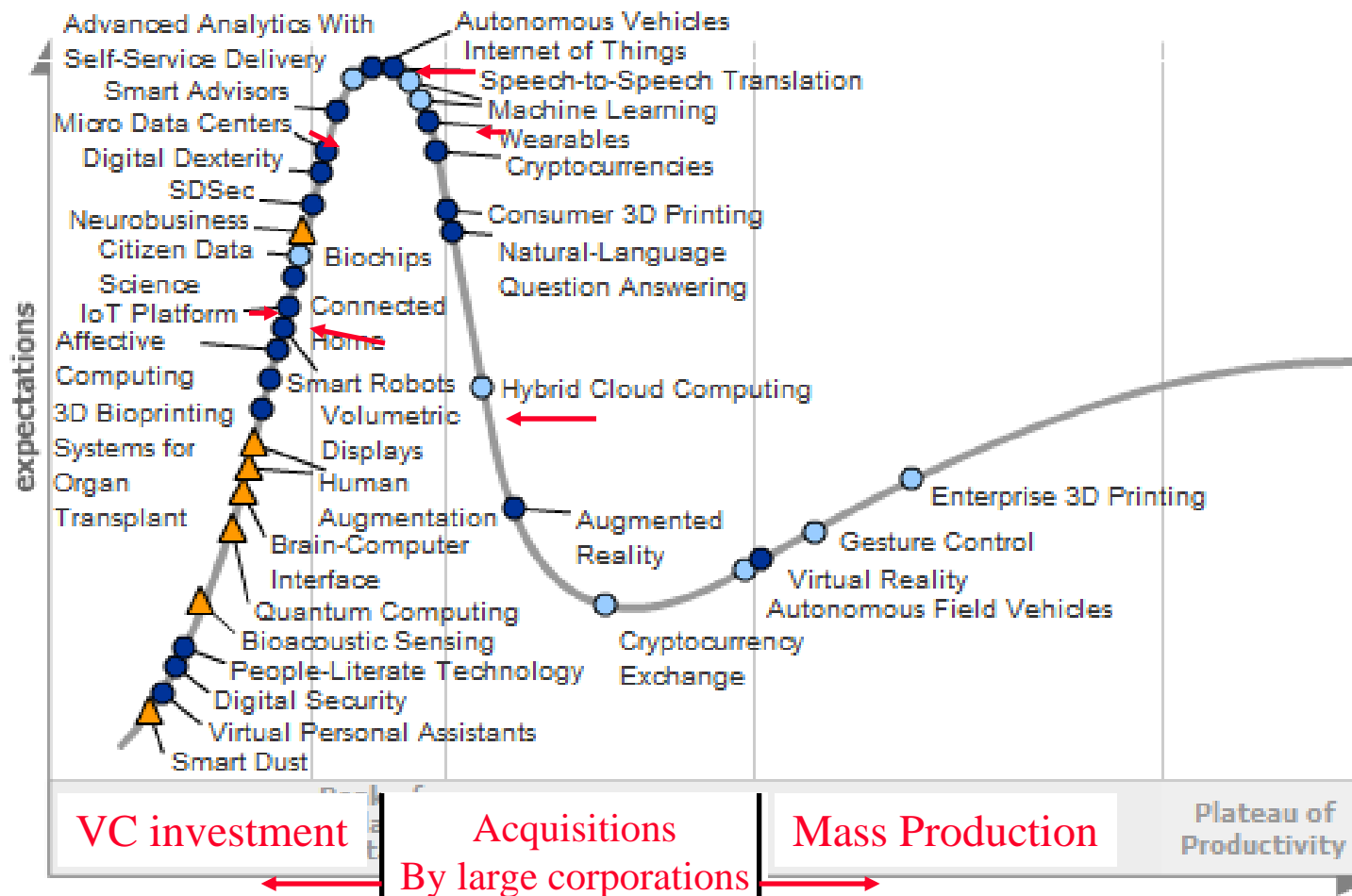
- ❑ Old: Smart = Can think \Rightarrow Computation
= Can Recall \Rightarrow Storage
- ❑ Now: Smart = Can find quickly, Can Delegate
 \Rightarrow Communicate = **Networking**
- ❑ Smart Grid, Smart Meters, Smart Cars, Smart homes, Smart Cities, Smart Factories, Smart Smoke Detectors, ...



Not-Smart

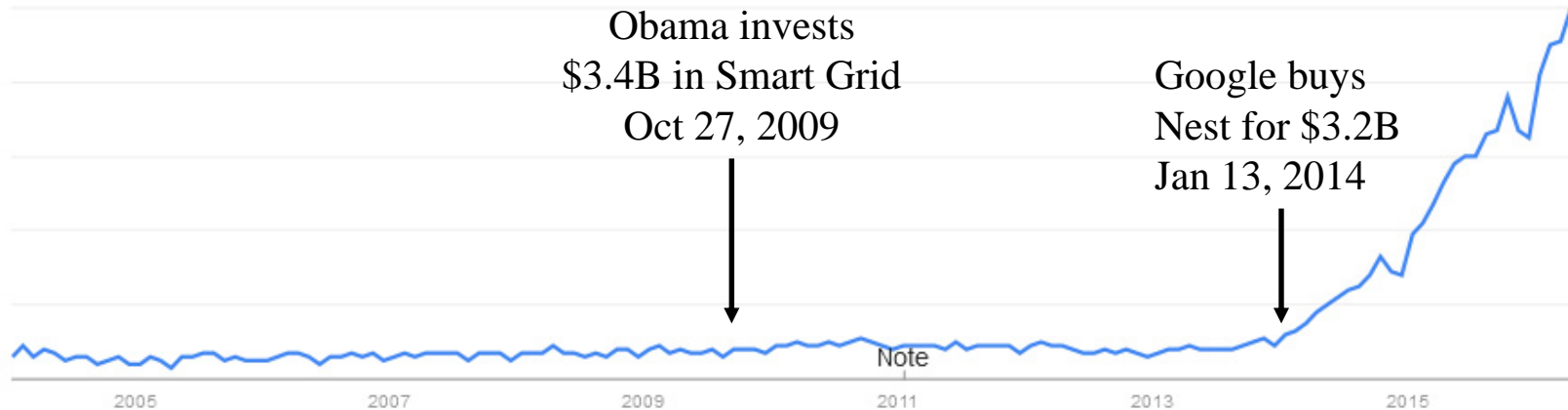
Smart

Gartner Hype Cycle 2015



Ref: Gartner, "Hype Cycle for Emerging Technologies, 2015," July 2015, [Available to subscribers only], <http://www.gartner.com/document/3100227?ref=QuickSearch&sthkw=hype%20cycle%202015&refval=156919648&qid=fe61993355944ace1c8c01ec2df676d9>

Google Trends



- ❑ Around for 10 years
- ❑ IERC-European Research Cluster on the Internet of Things funded under 7th Framework in 2009
⇒ “Internet of European Things”
- ❑ US interest started in 2009 w \$3.4B funding for **smart grid** in American Recovery and Reinvestment Act of 2009

IoT is a Data (\$) Mine



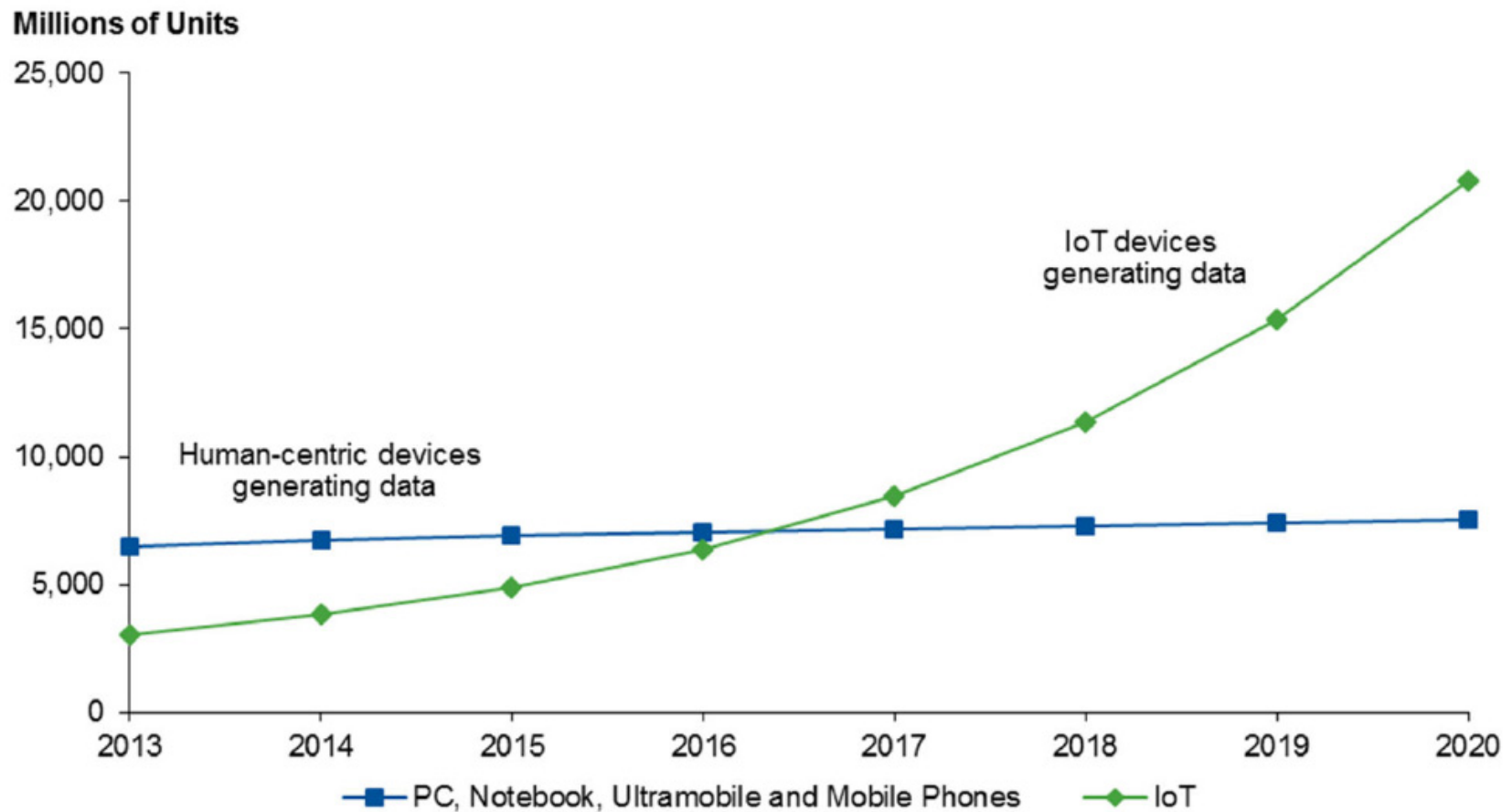
© marketoonist.com

Ref: <https://www.pinterest.com/iofficecorp/humor/>

Washington University in St. Louis

http://www.cse.wustl.edu/~jain/talks/iots_cox.htm

Computing vs. IoT



□ 21 Billion devices by 2020

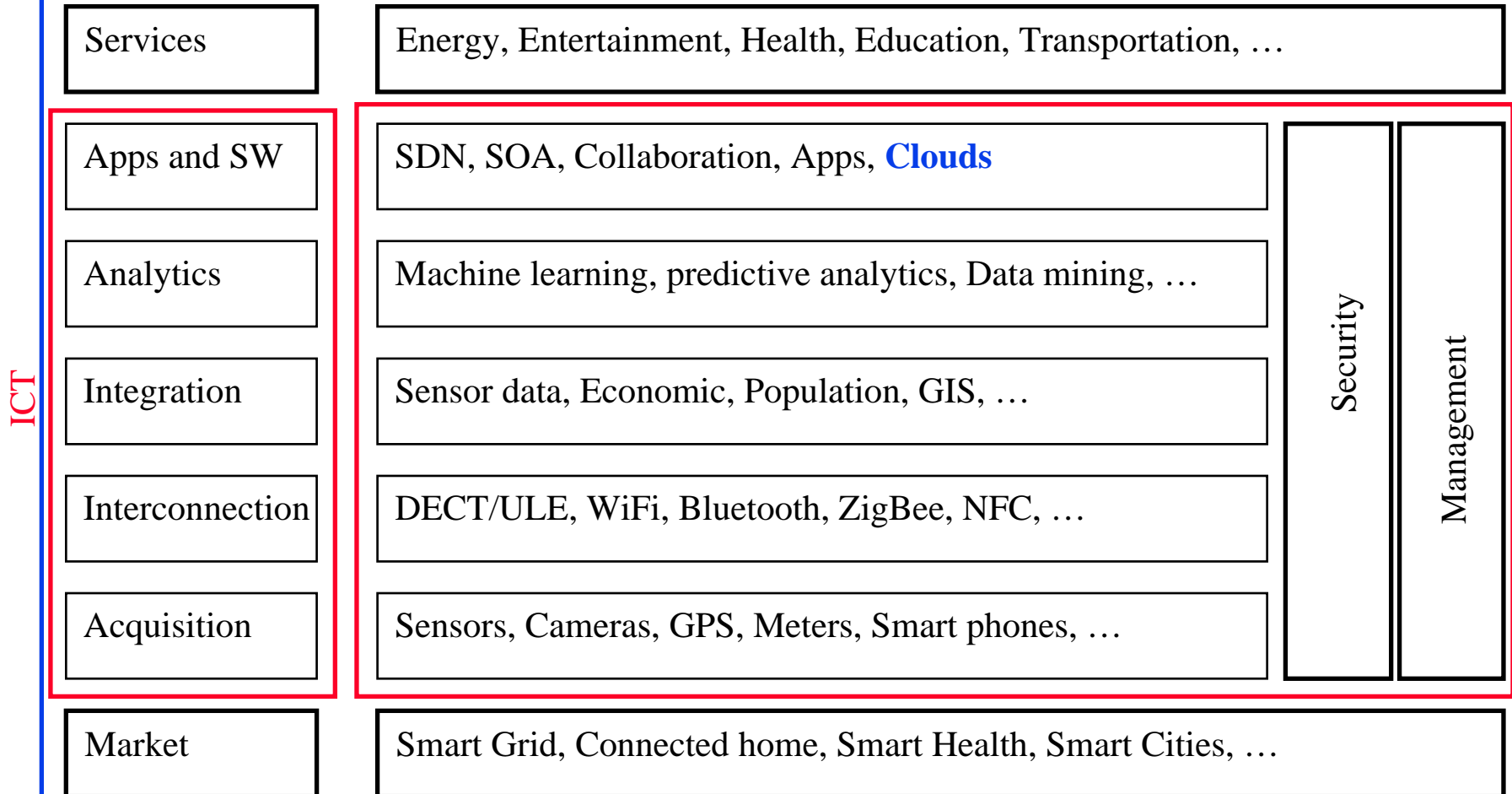
Ref: M. Moran, "Why the Internet of Things Will Dwarf Social (Big Data)," Gartner Report #G00289622, February 2016

Washington University in St. Louis

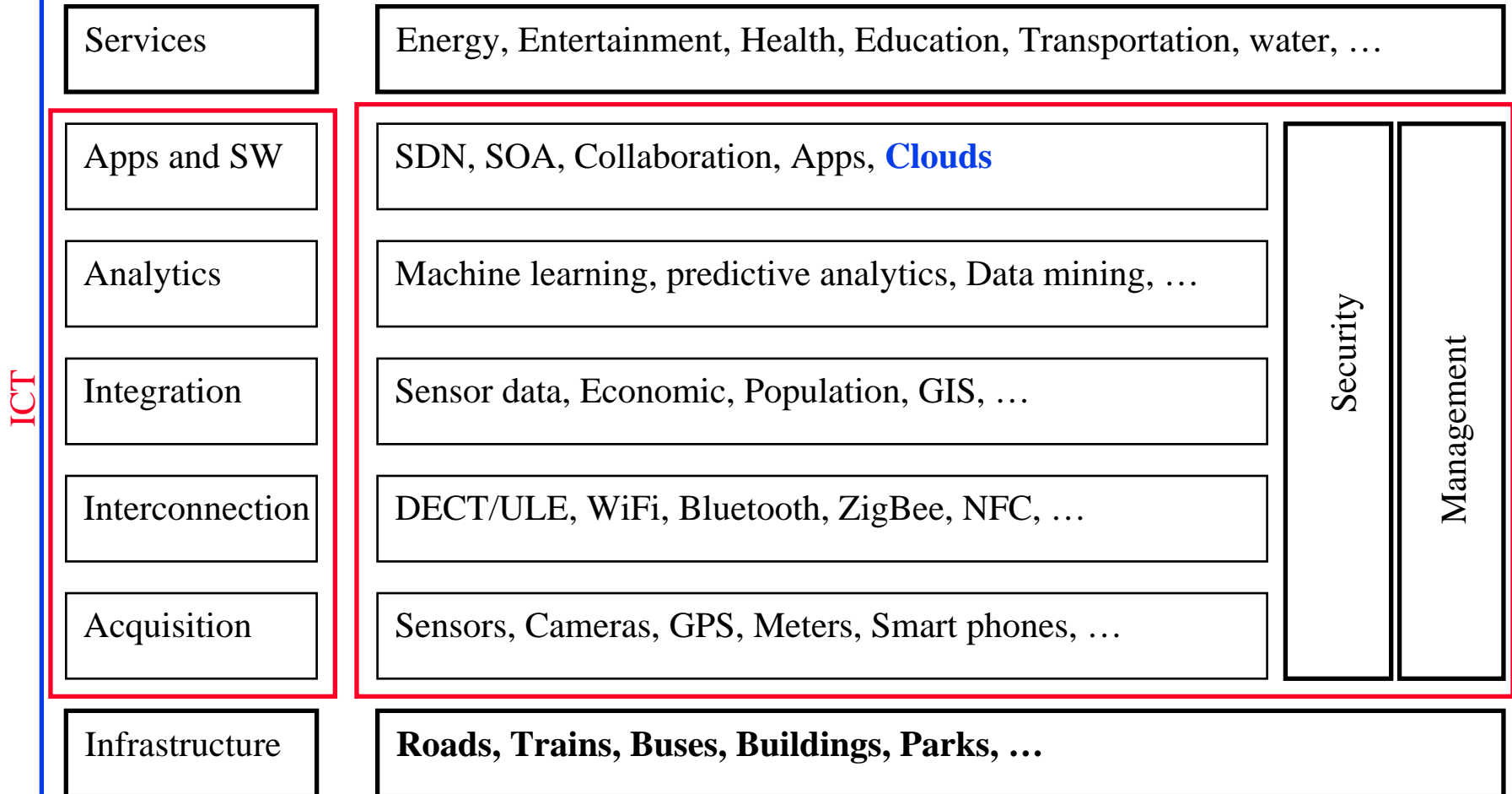
http://www.cse.wustl.edu/~jain/talks/iots_cox.htm

©2016 Raj Jain

A 7-Layer Model of IoT



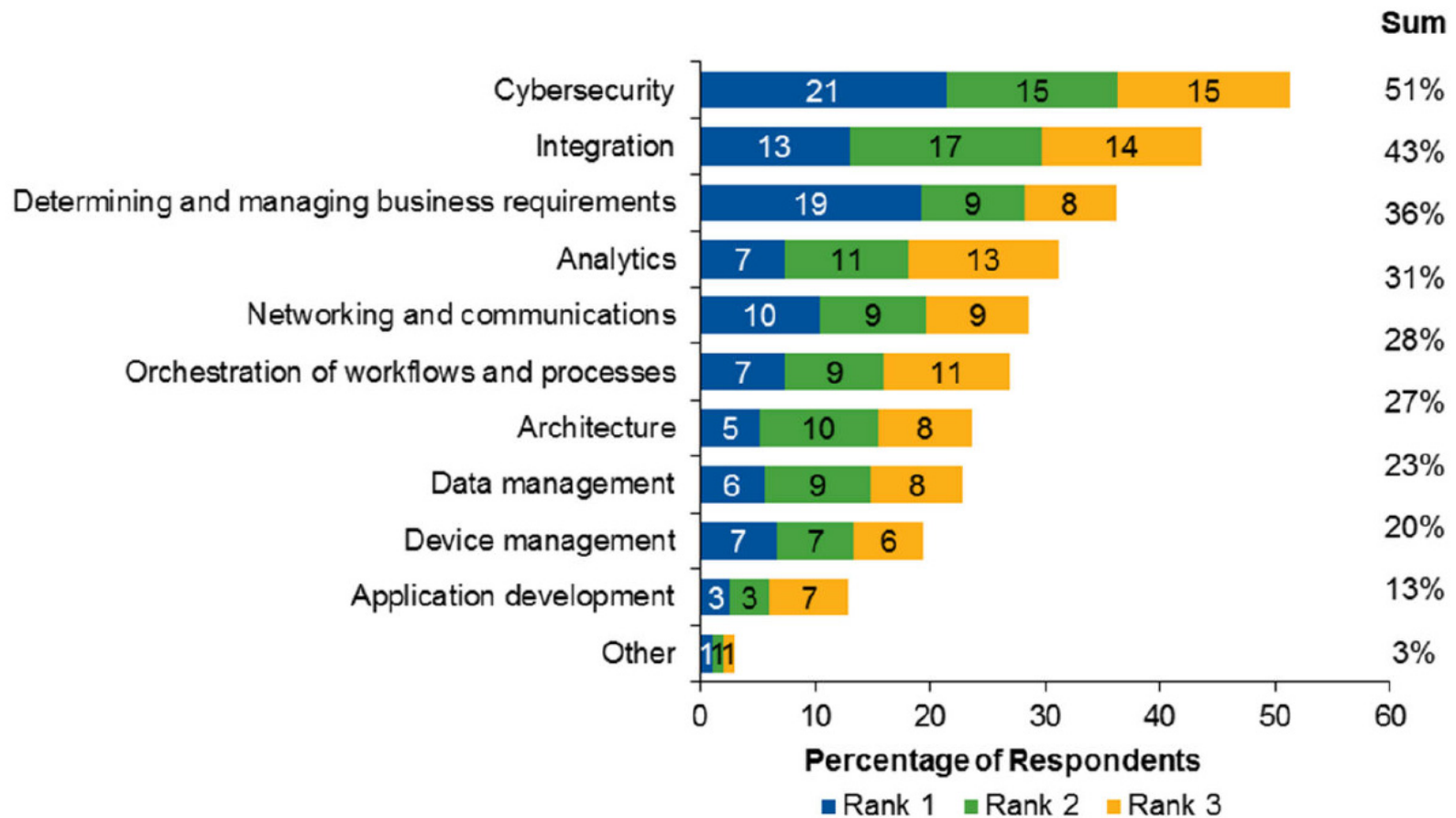
A 7-Layer Model of Smart Cities



Areas of Research for IoT

1. **PHY**: Smart devices, sensors giving real-time information, *Energy Harvesting*
2. **Datalink**: WiFi, Bluetooth, ZigBee, 802.11ah, ...
Broadband: DSL, FTTH, Wi-Fi, 5G, ...
3. **Routing**: *Multiple interfaces*, Mesh networking, ...
4. **Analytics**: Big-data, data mining, Machine learning, Predictive analytics, ...
5. **Apps & SW**: SDN, SOA, Cloud computing, Web-based collaboration, Social networking, HCI, Event stream processing, ...
6. **Applications**: Remote health, On-line education, on-line laboratories, ...
7. **Security**: Privacy, Trust, Identity, Anonymity, ...

Top Inhibitors to the Adoption of the IoT



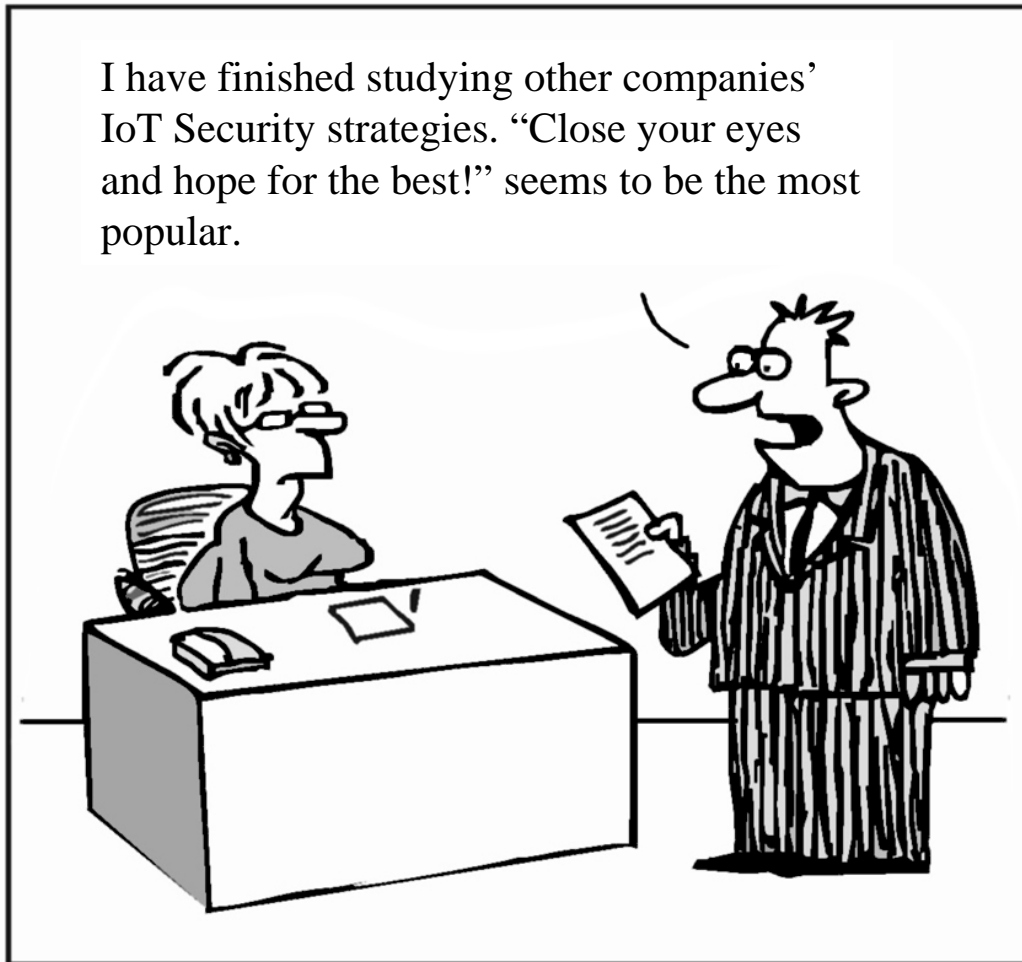
Ref: B. Lheurex, et al, "Survey Analysis: Users Cite Ambitious Growth and formidable Technical Challenges in IoT Adoption," Gartner Report #G00300127, March 2016,

Washington University in St. Louis

http://www.cse.wustl.edu/~jain/talks/iots_cox.htm

IoT Security: Popular Approach

I have finished studying other companies' IoT Security strategies. "Close your eyes and hope for the best!" seems to be the most popular.



Ref: <http://cloudtweaks.com/2011/08/the-lighter-side-of-the-cloud-the-migration-strategy/>

Washington University in St. Louis

http://www.cse.wustl.edu/~jain/talks/iots_cox.htm

Internet of Harmful Things

Imagine, as researchers did recently at Black Hat, someone hacking your connected toilet, making it flush incessantly and closing the lid repeatedly and unexpectedly.

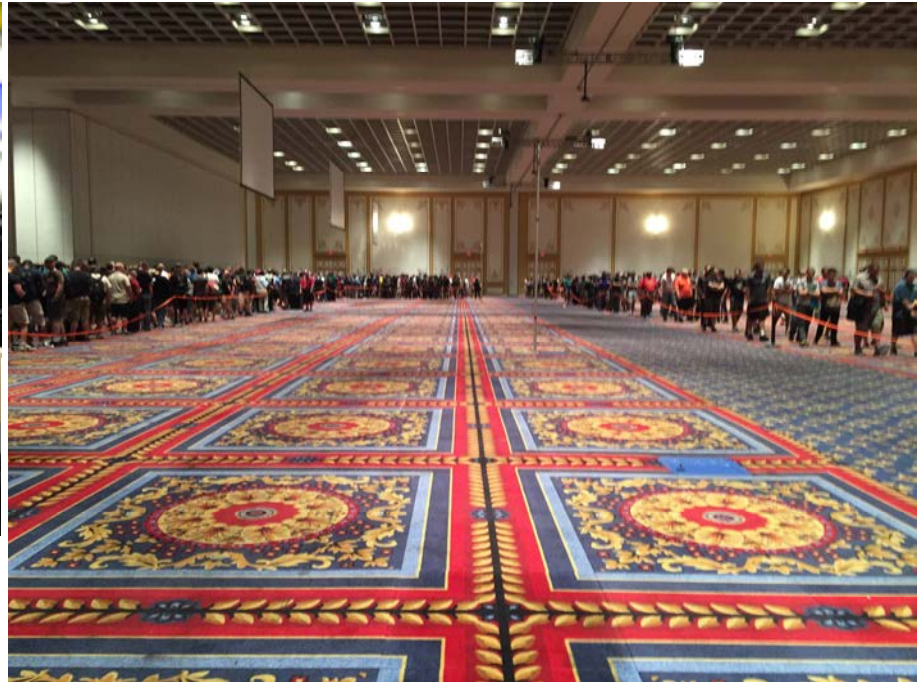


Ref: <http://www.computerworld.com/article/2486502/security0/worm-may-create-an-internet-of-harmful-things--says-symantec--take-note--amazon-.html>

Washington University in St. Louis

http://www.cse.wustl.edu/~jain/talks/iots_cox.htm

DEFCON 2015



DEFCON 2015 (Cont)

- ❑ Hacking a Linux rifle
- ❑ Hacking smart safes
- ❑ Wirelessly steal cars
- ❑ Hack a Tesla
- ❑ Hack ZigBee
- ❑ Hacking IoT baby monitors
- ❑ Hacking FitBit Aria
- ❑ Cracking crypto currency
- ❑ Hack out of home detention
- ❑ Insteon's false security
- ❑ Hacking RFID, NFC
- ❑ DARPA Cyber Grand Challenge \$2M



Ref: <https://www.ethicalhacker.net/features/opinions/first-timers-experience-black-hat-defcon>

Washington University in St. Louis

http://www.cse.wustl.edu/~jain/talks/iots_cox.htm

©2016 Raj Jain

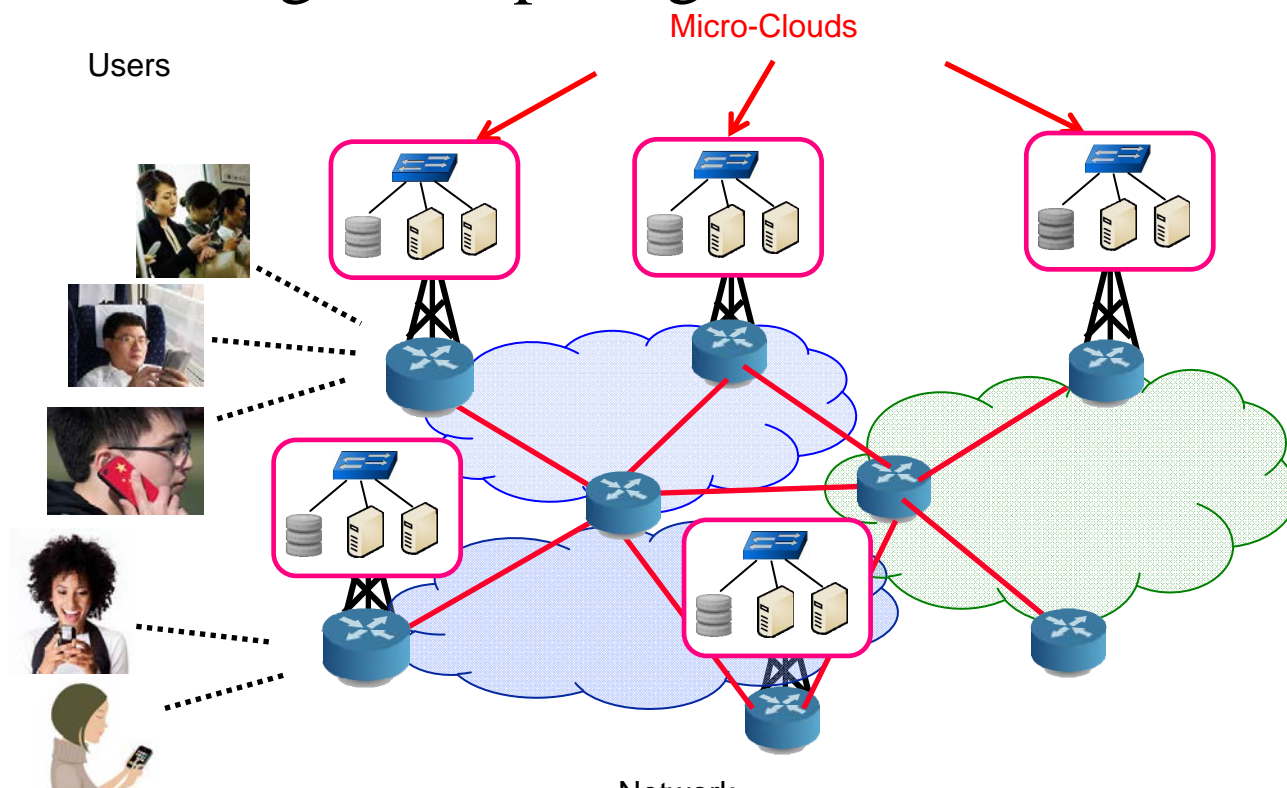
Attack Surface

1. **IoT Devices**
2. **IoT wireless access technology**: DECT, WiFi, Z-wave, ...
3. **IoT Gateway**: Smart Phone
4. **Home LAN**: WiFi, Ethernet, Powerline, ...
5. **IP Network**: DNS, Routers, ...
6. **Higher-layer Protocols**
7. **Cloud**
8. **Management Platform**: Web interface
9. **Life Cycle Management**: Booting, Pairing, Updating, ...



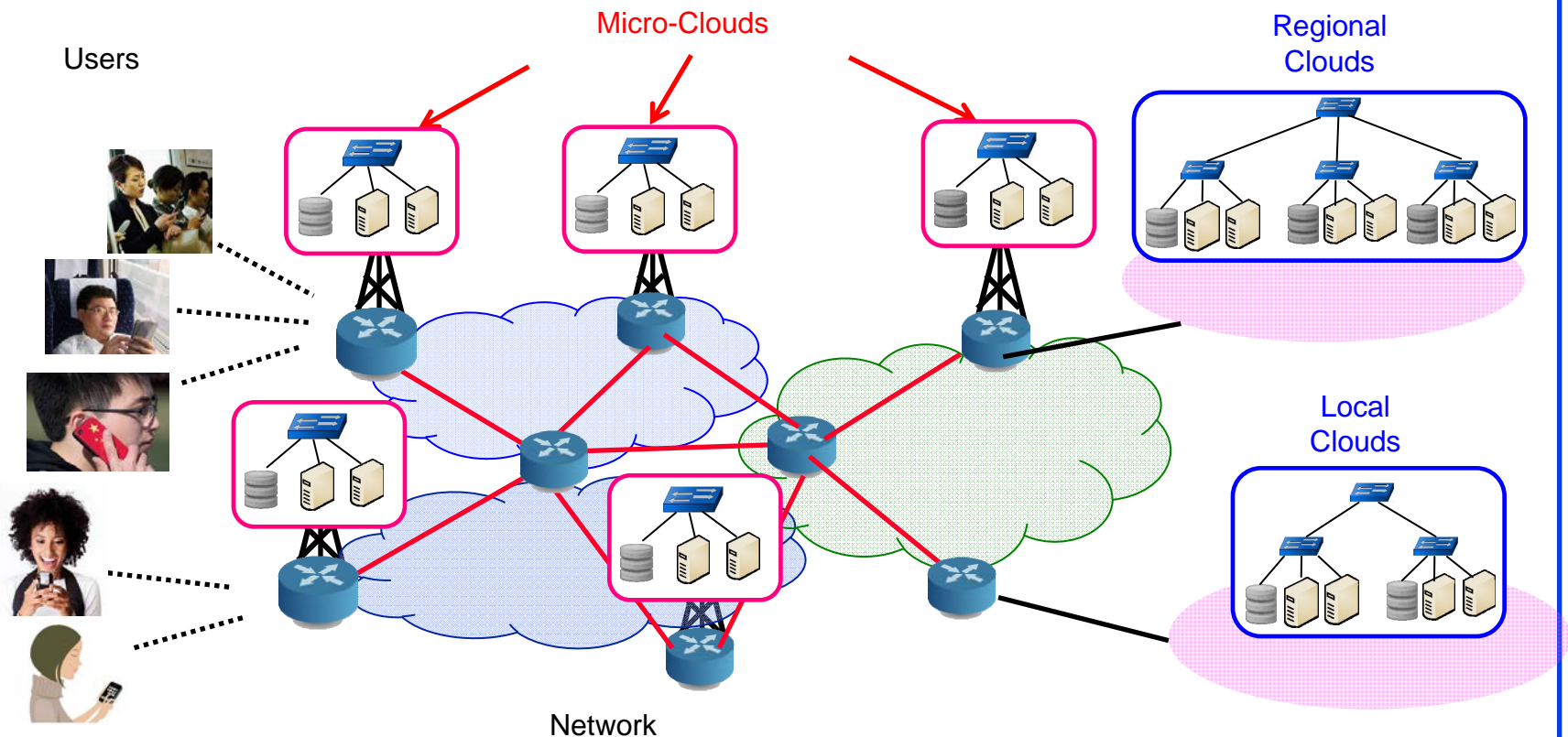
Trend: Computation in the Edge

- To service mobile users/IoT, the computation needs to come to edge \Rightarrow Micro-cloud on the tower \Rightarrow Mobile-Edge Computing

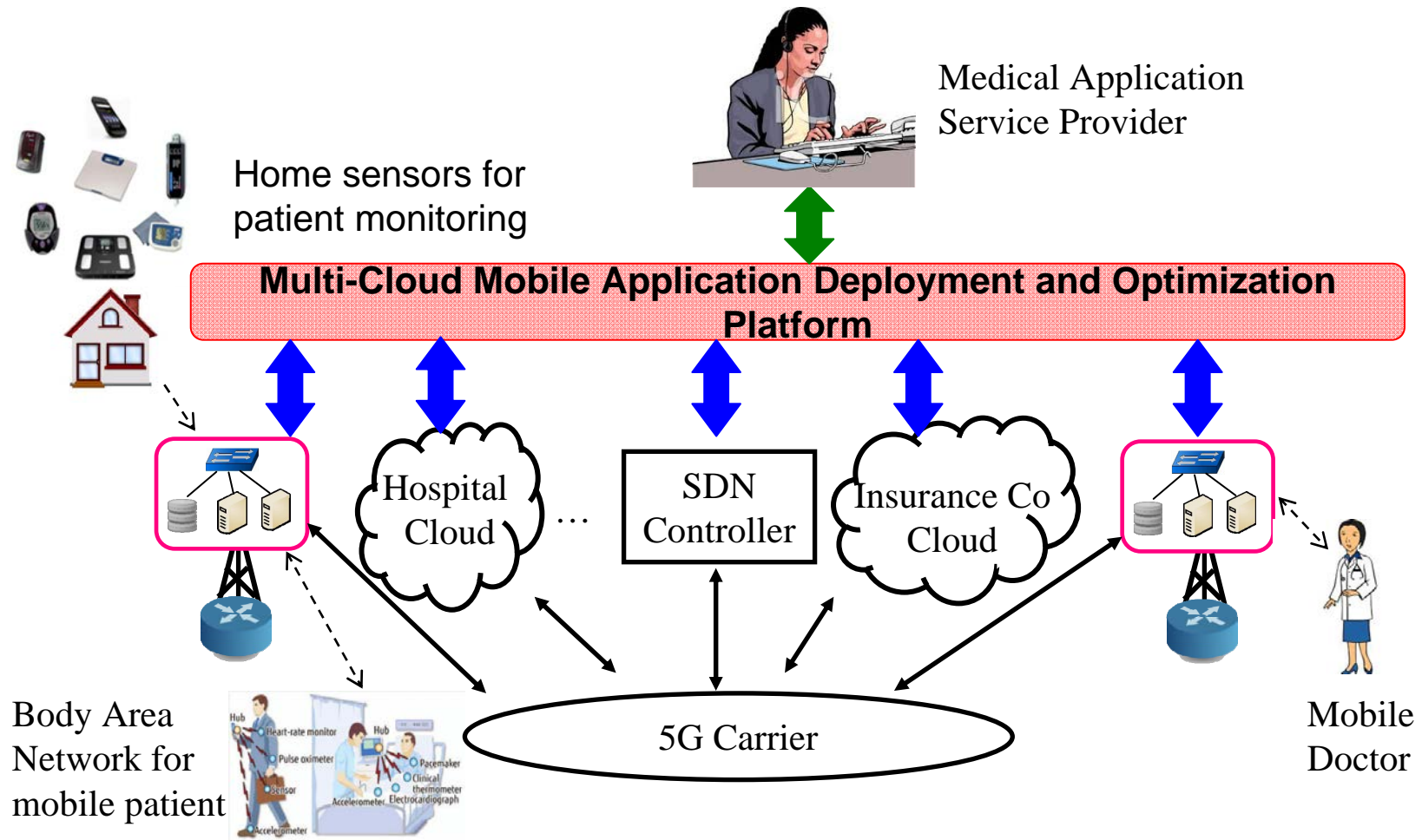


Trend: Multi-Cloud

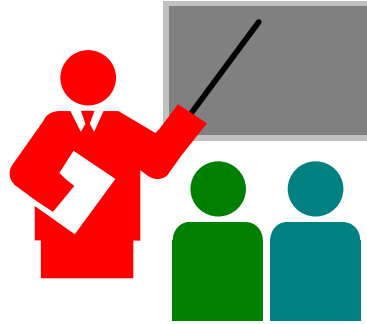
- Larger and infrequent jobs serviced by local and regional clouds \Rightarrow Fog Computing



Mobile Healthcare Use Case



Summary



1. Smart \neq High-Speed Computation,
Smart \neq Big Data Storage,
Smart = Networked
2. Computation is moving to the Edge
 \Rightarrow Fog Computing
 \Rightarrow Multi-Cloud/Inter-Cloud
3. Our MCAD abstracts/virtualizes the cloud interfaces
and allows automated management of security and
other policies of multi-cloud applications

Happy Birthday



Prof. Jerry Cox

Scan This to Download These Slides



Raj Jain

<http://www.rajjain.com>