



Life In a World of Ubiquitous Sensing

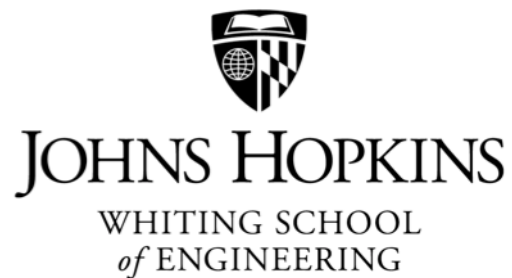
Gregory D. Hager

Professor and Chair, Computer Science

Director, Computational Interaction and Robotics Laboratory

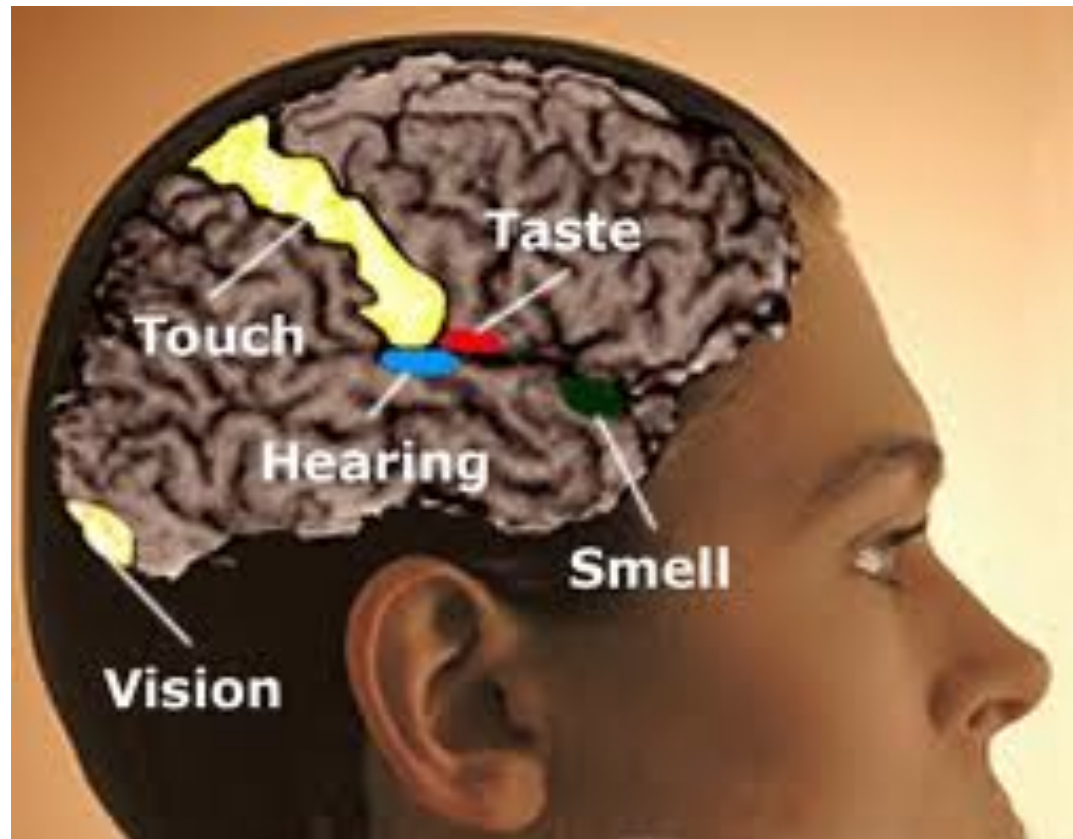
The Johns Hopkins University

hager@cs.jhu.edu

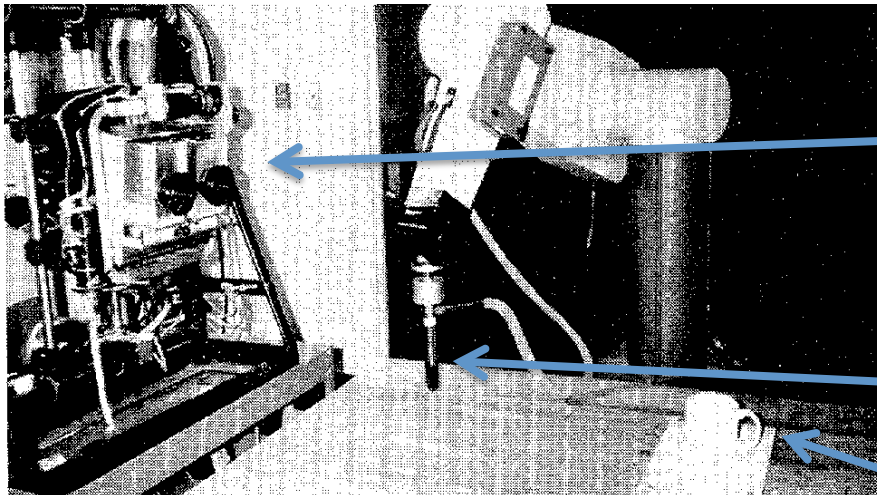


To Sense or Not To Sense

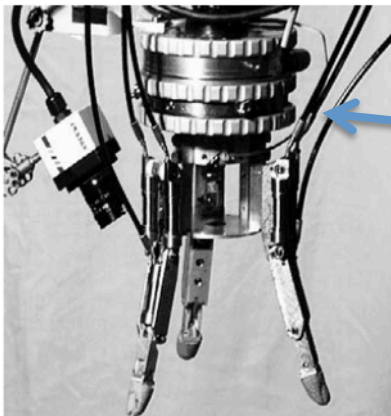
Why would I add a camera – it costs me money, my robot is slower and it makes more mistakes?



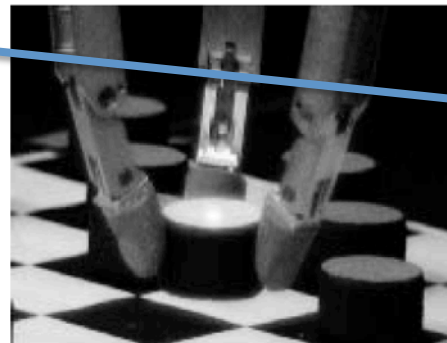
Sensors Used to be a Scarce Resource



Grasp Lab, ca. 1985



DLR, ca. 1985



Stereo cameras

Tactile sensor

Cup Bolted
to the table

Force



Scarce No Longer!

Sensors

A Head

Microsoft Kinect
5-Megapixel Global Shutter
Color Gigabit Ethernet
Camera (1-Megapixel **on SE**)
Environment Stereo
Camera: Wide-Angle Global
Shutter Color Stereo
Ethernet Camera (**NOT on SE**)
Manipulation Stereo
Camera: Narrow-Angle
Global Shutter Monochrome
Stereo Ethernet (**NOT on SE**)
LED Texture Projector
Triggered with Narrow-Angle
Stereo Camera (**NOT on SE**)

B Above the Shoulders

Tilting Hokuyo UTM-30LX
Laser Scanner
Microstrain 3DM-GX2 IMU

C Forearm

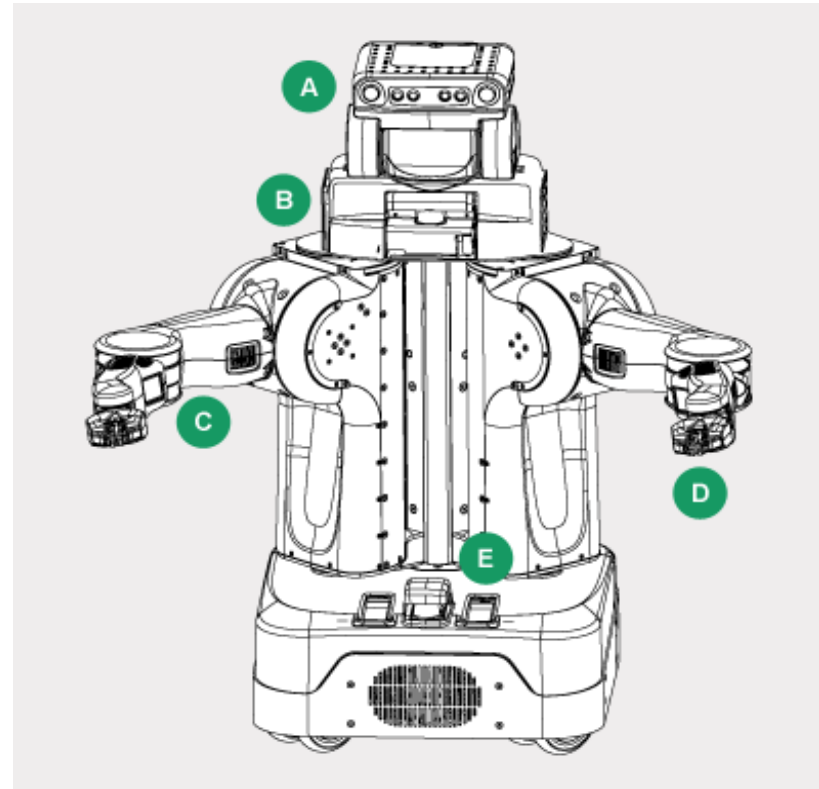
Global Shutter Ethernet
Camera

D Gripper

Three-Axis Accelerometer
Fingertip Pressure Sensor
Arrays (**NOT on SE**)
Calibration LED

E Base

Hokuyo UTM-30LX Laser
Scanner



Not Just On Robots

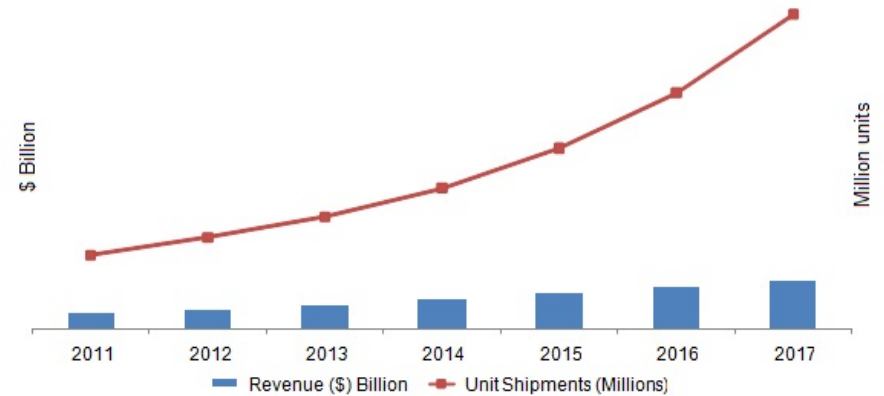
iPhone 5s in-built sensors

2014

- Proximity Sensor
- Motion sensor / accelerometer
- Ambient light sensor
- Moisture Sensor
- Gyroscope sensor
- Fingerprint sensor
- M7 motion coprocessor

2019?

- ECG
- Blood pressure
- Glucose
- Mood
- Heart rate/HRV
- Fatigue
- Blood biomarkers



Networked Surveillance Cameras

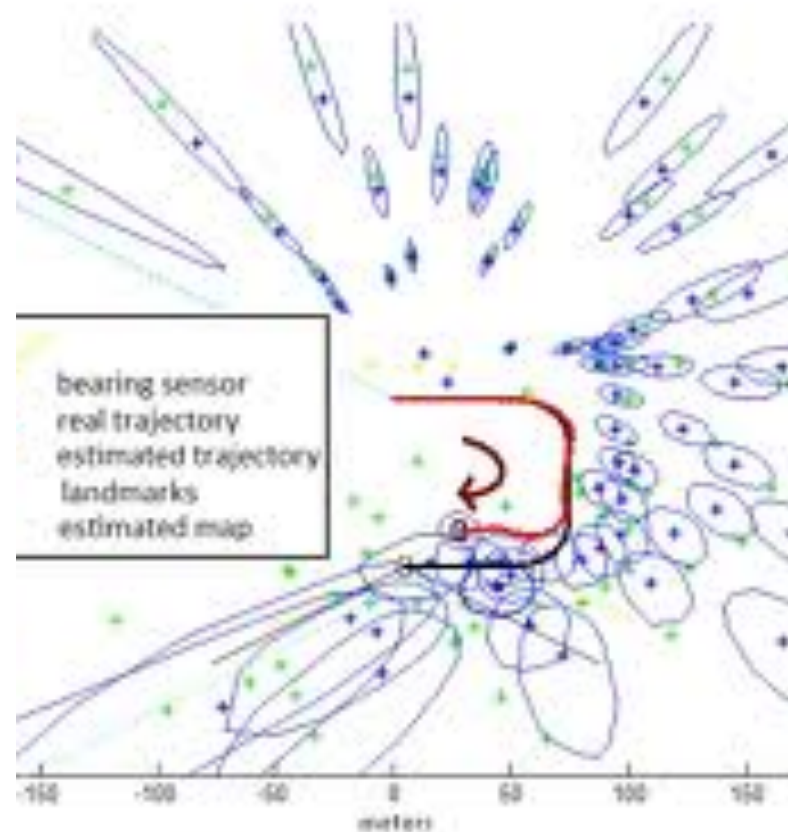


Consumer-grade RGBD for gaming



Algorithms Depend on Data

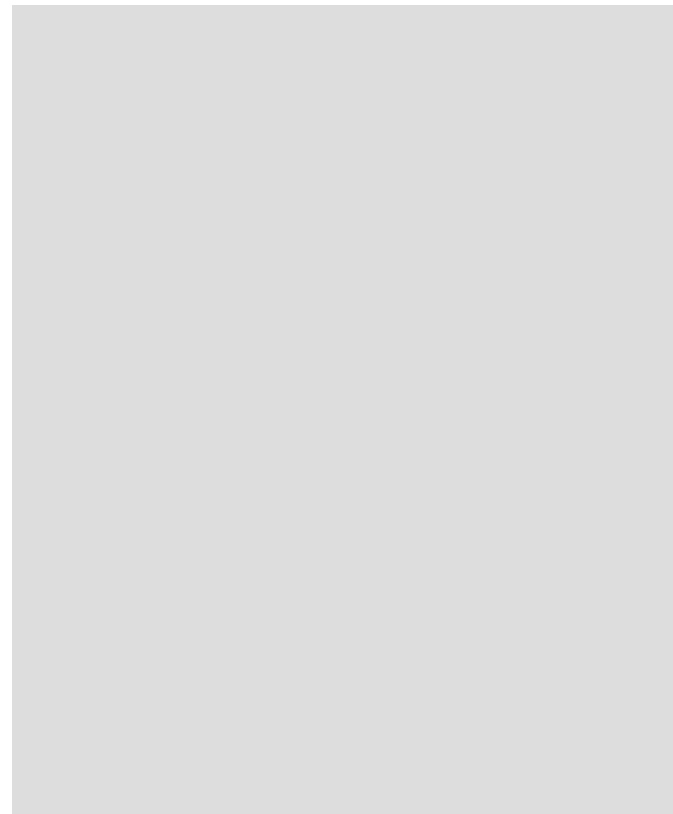
Estimating uncertain spatial relationships in robotics. Smith, Self, Cheeseman, 1990
Uses Kalman filters from Sonar



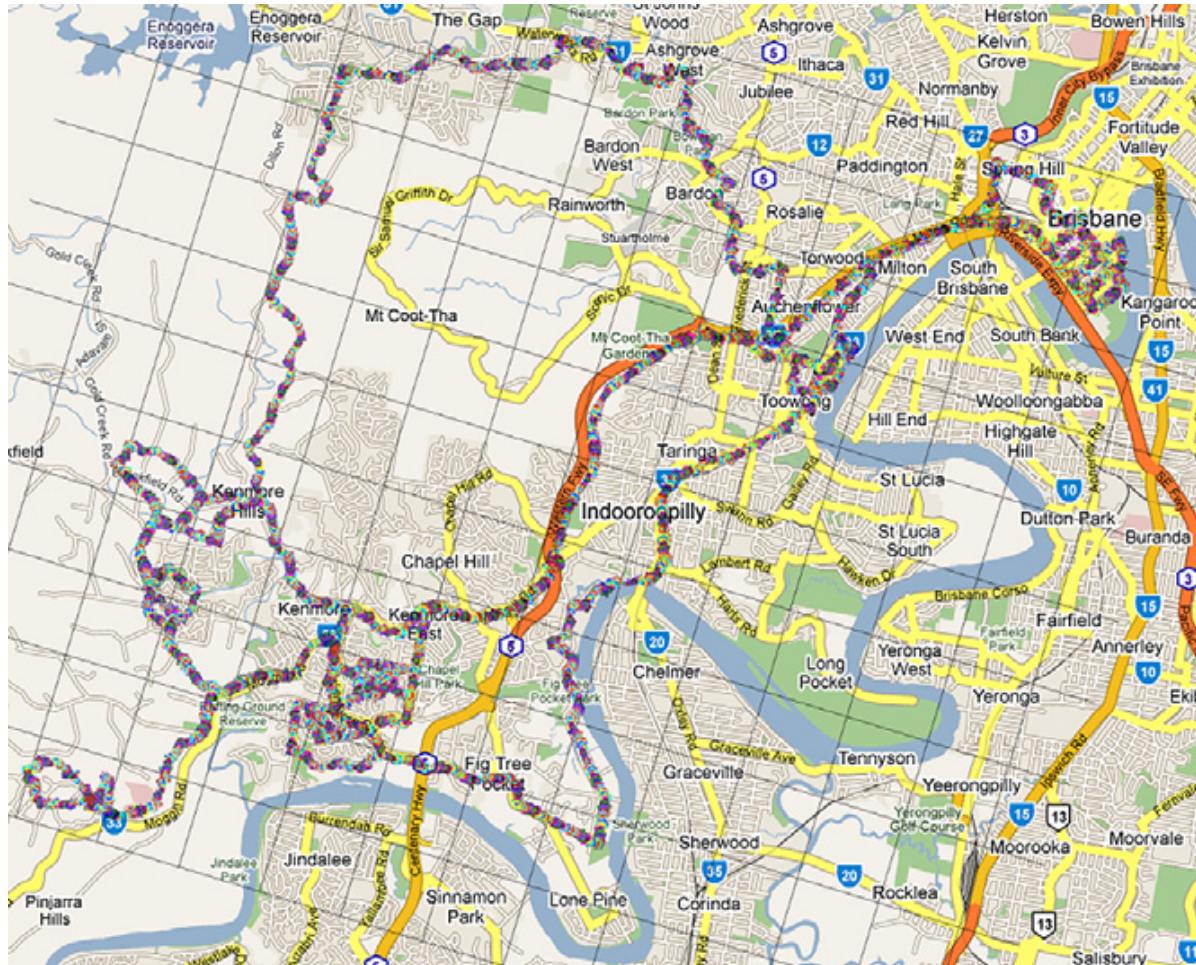
From Sound to Light

Montemerlo, Michael, et al. "FastSLAM: A factored solution to the simultaneous localization and mapping problem." *AAAI/IAAI*. 2002.

Fox, Dieter. "KLD-sampling: Adaptive particle filters and mobile robot localization." *Advances in Neural Information Processing Systems (NIPS)* (2002).



The Power Algorithmic Innovation

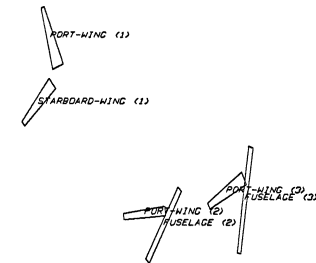
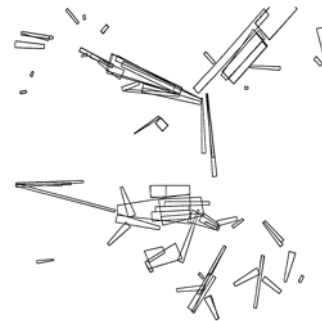
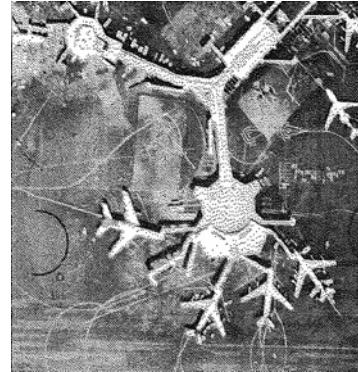


M. Bosse and R. Zlot, Keypoint Design and Evaluation for Place Recognition in 2D Lidar Maps, Robotics and Autonomous Systems, 57(12), December 2009.



Object Recognition

- The 70's – AI reasoning
 - 1 object

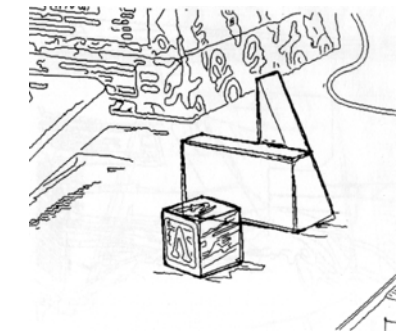
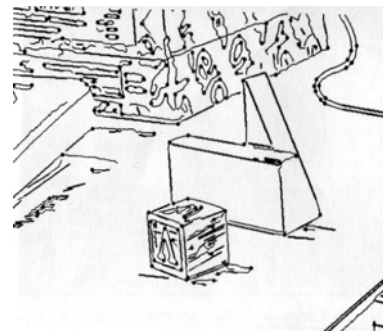
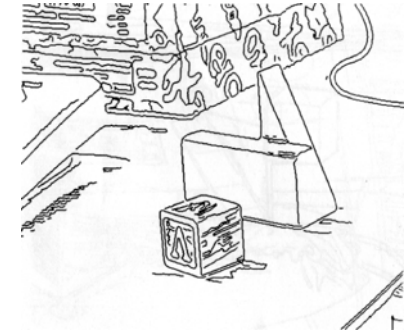
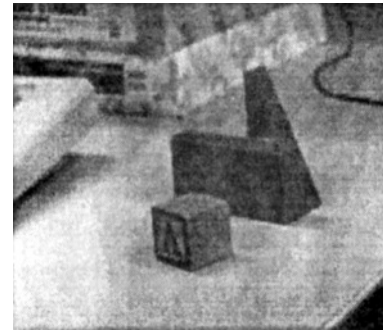


Brooks, Rodney A. "Symbolic reasoning among 3-D models and 2-D images." *Artificial intelligence* 17.1 (1981): 285-348.



Object Recognition

- The 70's – AI reasoning
- The 80's – Geometry
 - 10 objects



Courtesy Dan Huttenlocher



Object Recognition

- The 70's – AI reasoning
- The 80's – Geometry
- The 90's – Appearance
 - 10's of objects
 - COIL 100 database



Murase, Hiroshi, and Shree K. Nayar. "Visual learning and recognition of 3-D objects from appearance." *International journal of computer vision* 14.1 (1995): 5-24.



Progress is Not Continuous

- The 70's – AI reasoning
- The 80's – Geometry
- The 90's – Appearance
- The 00's – Keypoints
 - 100's of objects
 - Real-world conditions
 - Highly scalable



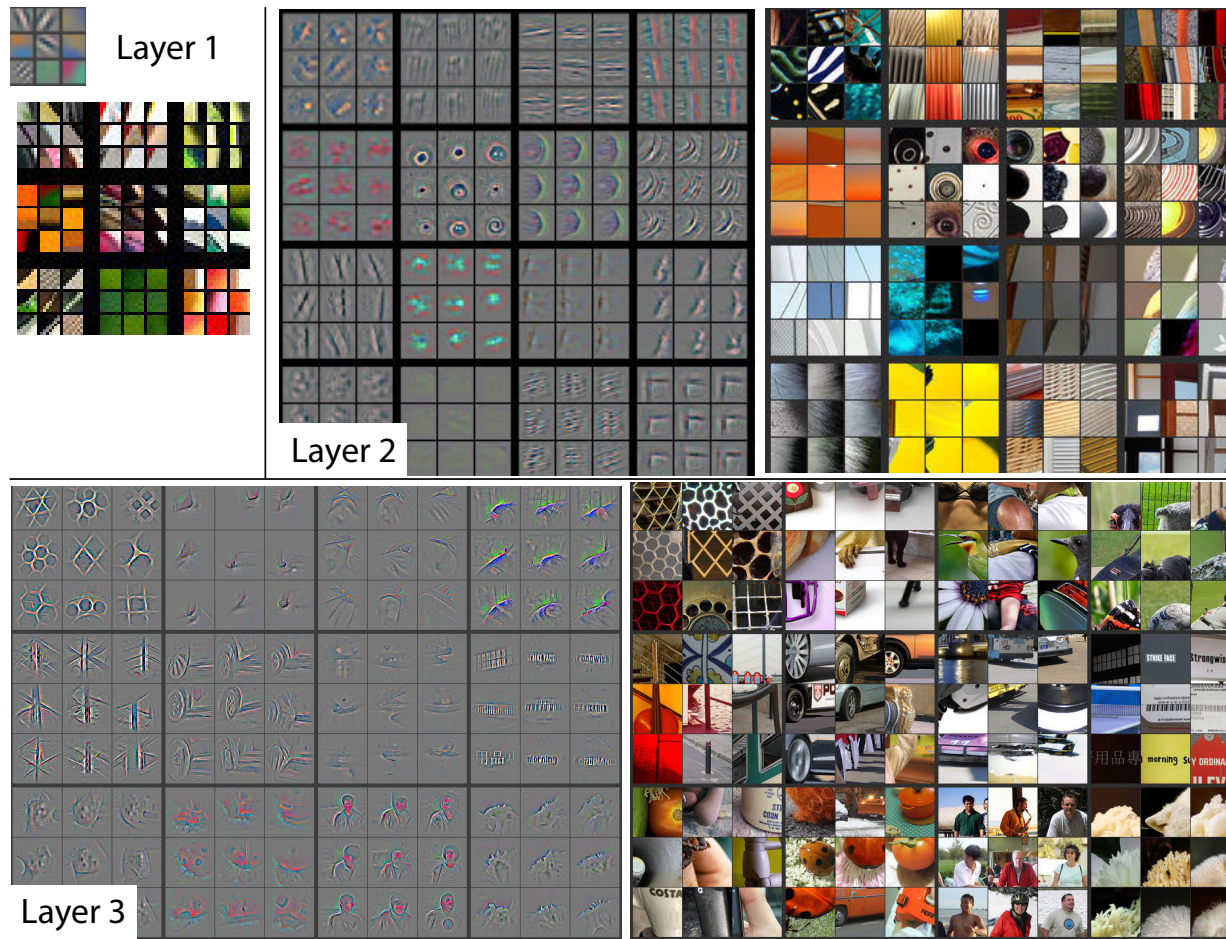
Lowe, David G. "Distinctive image features from scale-invariant keypoints." *International journal of computer vision* 60.2 (2004): 91-110.

(38k citations since 2004)

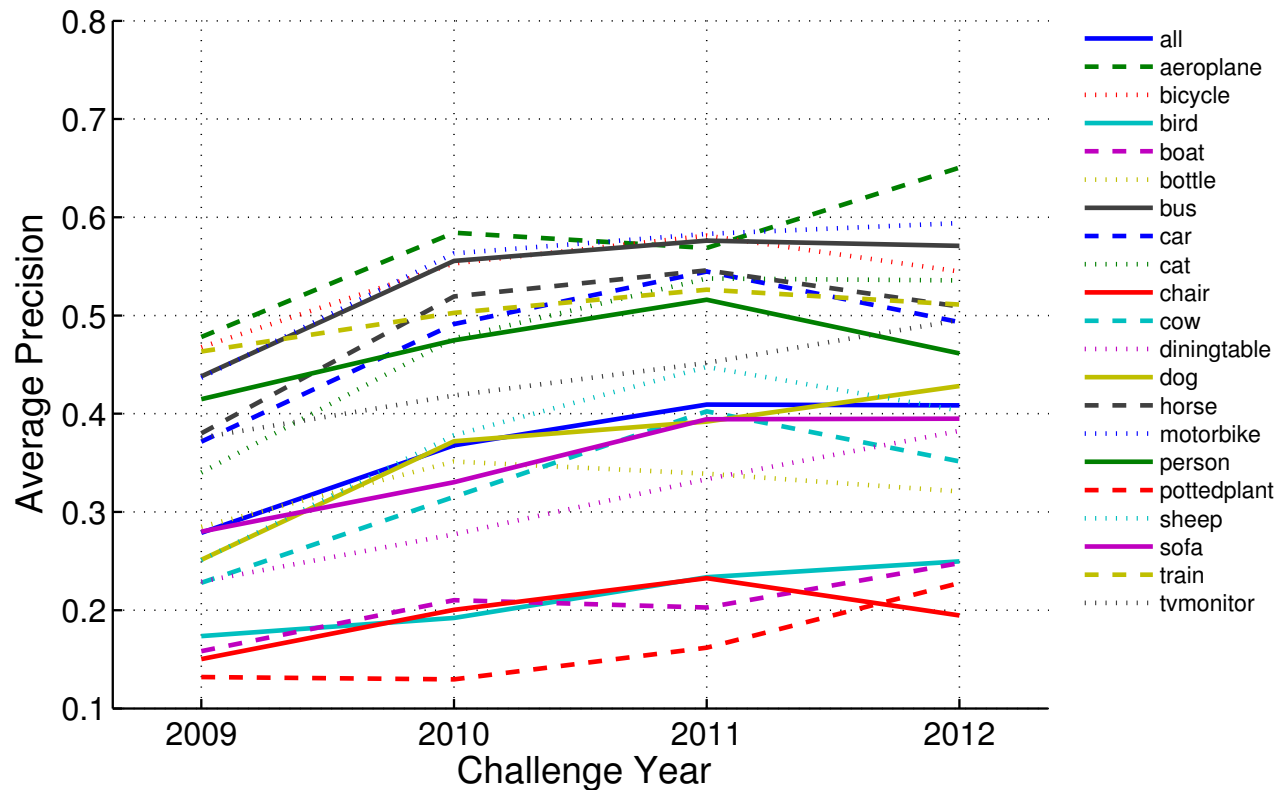


Categories: The Power (Challenge!) of Data

Zeiler, Matthew D., and Rob Fergus. "Visualizing and understanding convolutional neural networks." *arXiv preprint arXiv:1311.2901* (2013).



Community Benchmarking Efforts



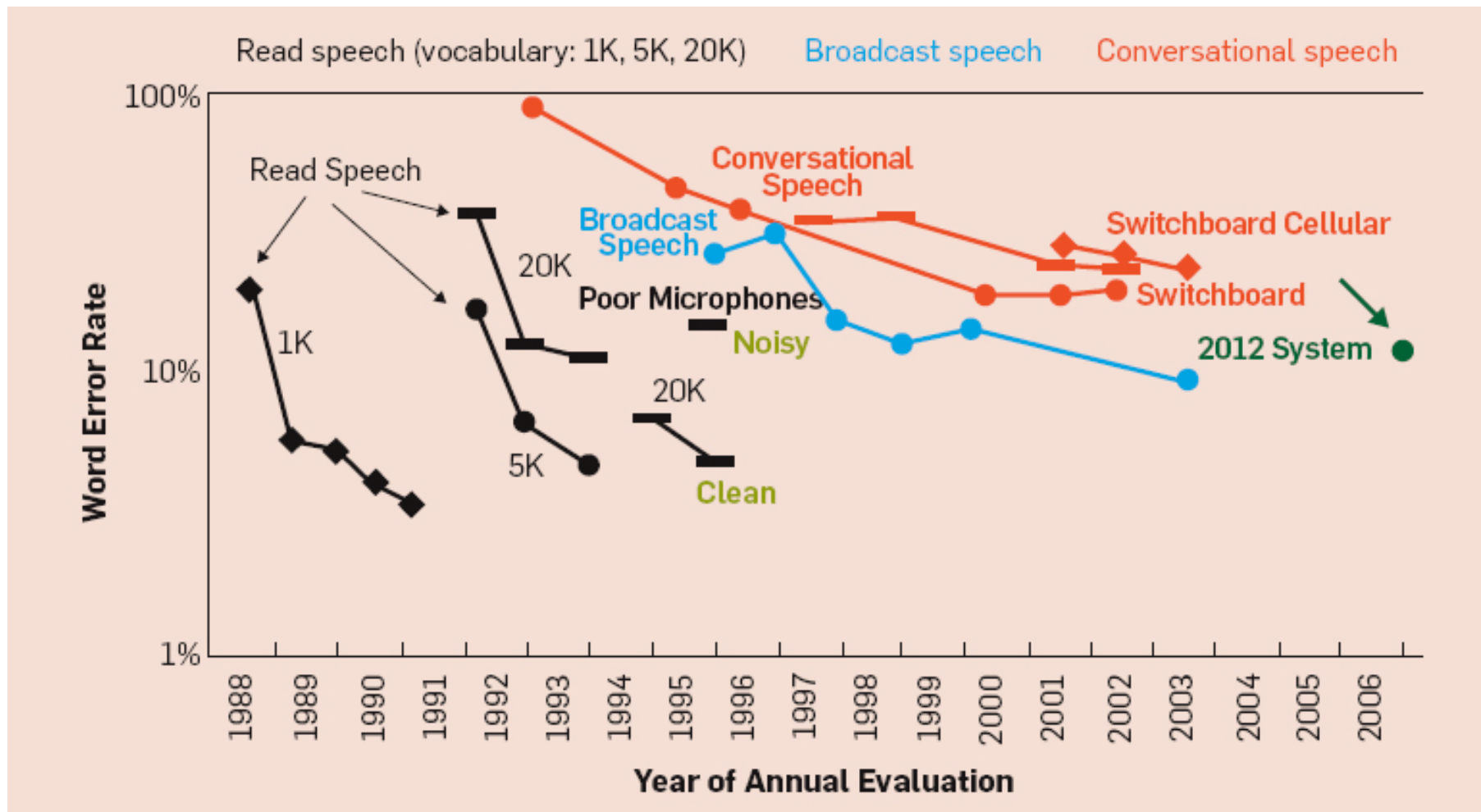
The PASCAL Visual Object Classes Challenge - a Retrospective

Everingham, M., Eslami, S. M. A., Van Gool, L., Williams, C. K. I., Winn, J. and Zisserman, A.

Accepted for International Journal of Computer Vision, 2014



Speech



Huang, Xuedong, James Baker, and Raj Reddy. "A historical perspective of speech recognition." *Communications of the ACM* 57.1 (2014): 94-103.



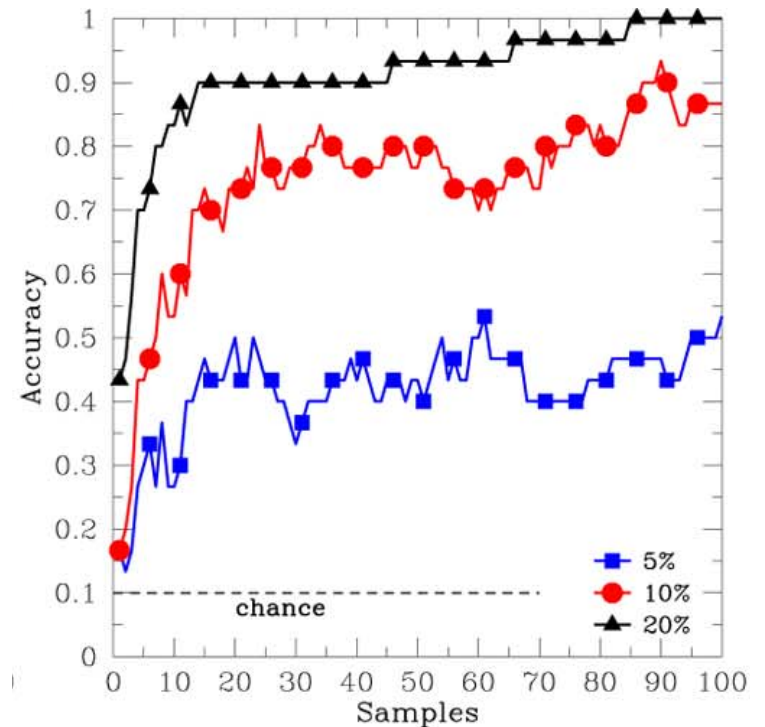
Tactile and Force Too!

Pezzementi, Zachary, et al. "Tactile-object recognition from appearance information." *Robotics, IEEE Transactions on* 27.3 (2011): 473-487.



(a)

IROS 2014, Gregory D. Hager

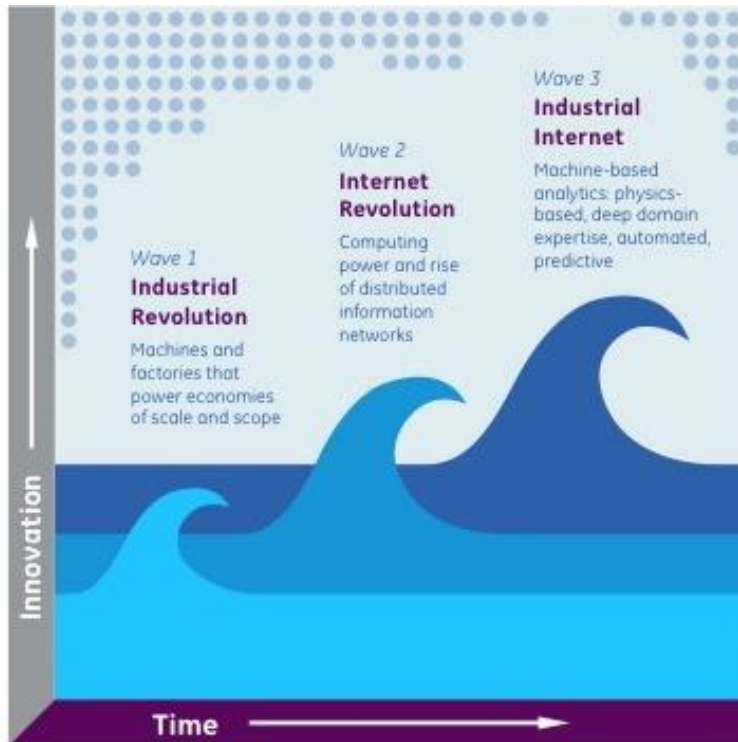


Economics Drives Technology

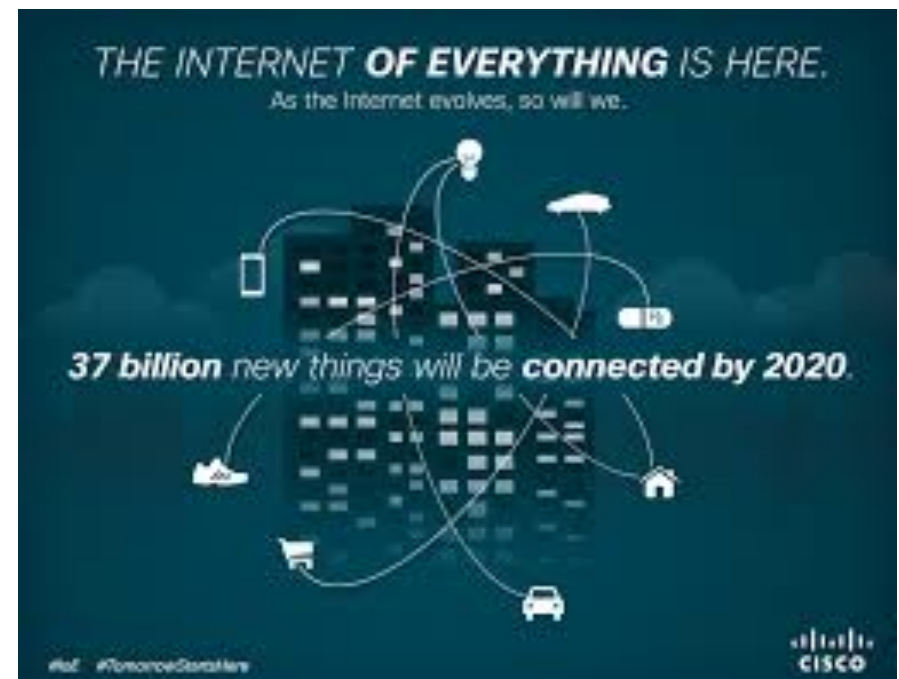
The density *at which the cost per transistor is the **lowest*** doubles every (year, 18 months, 2 years).



Gordon Moore



Source: GE



Source: CISCO



The Future: Sensing in Everything?



ubicomplab

UNIVERSITY OF WASHINGTON

Professor Shwetak N. Patel
<http://ubicomplab.cs.washington.edu>

<p>SpiroSmart</p> <p><small>Spirometry from a mobile phone</small></p> <p>CoughSense</p> <p><small>Automatic, ambulatory cough monitoring from a mobile phone</small></p> <p>ElderCare</p> <p><small>Activity recognition for in-home elder care</small></p> <p>Mobility Rehabilitation</p> <p><small>Location tracking for mobility impaired people</small></p> <p>Lullaby</p> <p><small>Capture and access for the sleep environment</small></p>	<p>ElectriSense</p> <p><small>Whole-home, single-point sensing of disaggregated electricity usage</small></p> <p>HydroSense</p> <p><small>Whole-home, single-point sensing of disaggregated water usage</small></p> <p>GasSense</p> <p><small>Whole-home, single-point sensing of disaggregated gas usage</small></p> <p>InnerSol</p> <p><small>Automatic monitoring and management of plants</small></p> <p>Stick-on Power Meter</p> <p><small>End-user-deployable, whole-house, contactless power sensor</small></p>	<p>InGen</p> <p><small>Self-powered haptic feedback device</small></p> <p>SNUPI</p> <p><small>Ultra-low-power wireless sensor network utilizing powerlines</small></p> <p>Static Electric Field Sensing</p> <p><small>Ultra-low-power human body motion sensor using static E-field sensing</small></p> <p>Barometric Harvesting</p> <p><small>Harvesting energy from pressure and temperature changes</small></p>	<p>GripSense</p> <p><small>Using built-in sensors to detect hand posture and pressure on phones</small></p> <p>LightWave</p> <p><small>Using compact fluorescent lights as sensors</small></p> <p>HeatWave</p> <p><small>Thermal imaging for surface user interaction</small></p> <p>uTouch</p> <p><small>Sensing touch gestures on uninstrumented LCDs</small></p> <p>WalkType</p> <p><small>Using the accelerometer to improve typing on touchscreens while walking</small></p> <p>Humantenna</p> <p><small>Sensing gestures using the body as an antenna</small></p>
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Health sensing

Sustainability sensing

Low-power sensing

Novel interaction techniques



The Built Environment: Electrical Devices

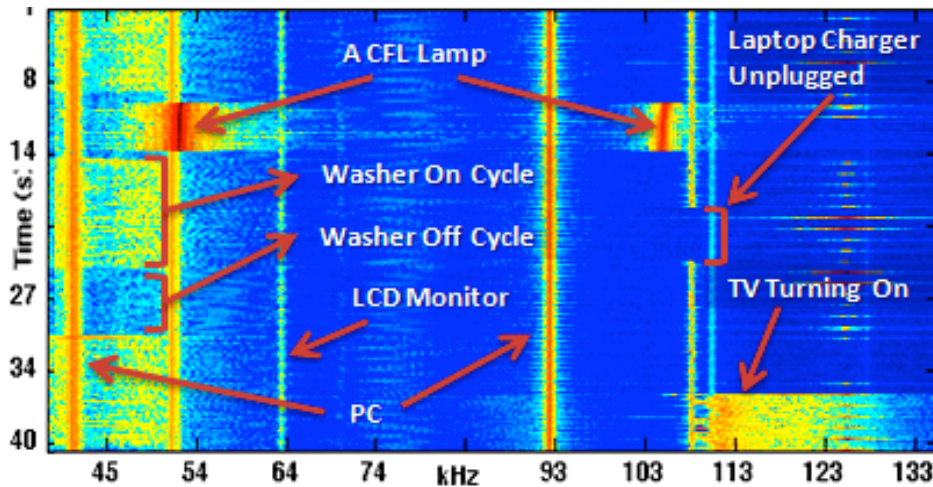


Figure 2: Frequency spectrogram showing device actuation in a

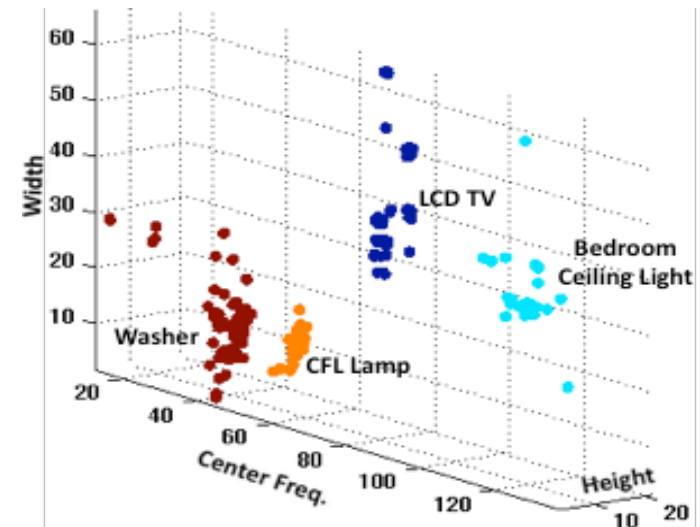


Figure 8: Variation of features over 6 months for four devices shown in the feature space. Note that no cluster overlaps.

Gupta, S., Reynolds, M.S., Patel, S.N. ElectriSense: Single-Point Sensing Using EMI for Electrical Event Detection and Classification in the Home. In the *Proceedings of UbiComp 2010* (Sept. 26-29, Copenhagen, Denmark), ACM, New York, 2010, pp. 139-148.



Some Challenges:

Make Sensing Disappear

- Create an open “plug and play” sensing environment
 - Organize around ontology and information, not data



Some Challenges:

Create Information Abstractions

- Create “information APIs” that can answer context-relevant questions



Where are my kids?
Is someone watching TV?
Is my 2 year old near the stairs!
Did I leave the stove on?
Is someone unexpected in the house?
Who has the car?



Challenges: Implications for Society

- How do we know what information we're sharing and with whom?
- What can be **inferred** and by whom and for what?
- What privacy and security abstractions are practical for systems that operate in the physical world?



[Home Depot Data Breach Could Be the Largest Yet](#)

"This is not how you handle a significant **security breach**, nor will it provide any sort of confidence that **Home Depot** can solve the problem going ...

September 08, 2014 - By Nicole Perlroth - Technology - Print Headline: "Home Depot Data Breach Could Be the Largest Yet"



In Summary

- Think expansively – healthcare, home, workplace
- Think generally – fundamental concepts that apply widely
- Think openly – the more we share, the better we become

