Life In a World of Ubiquitous Sensing

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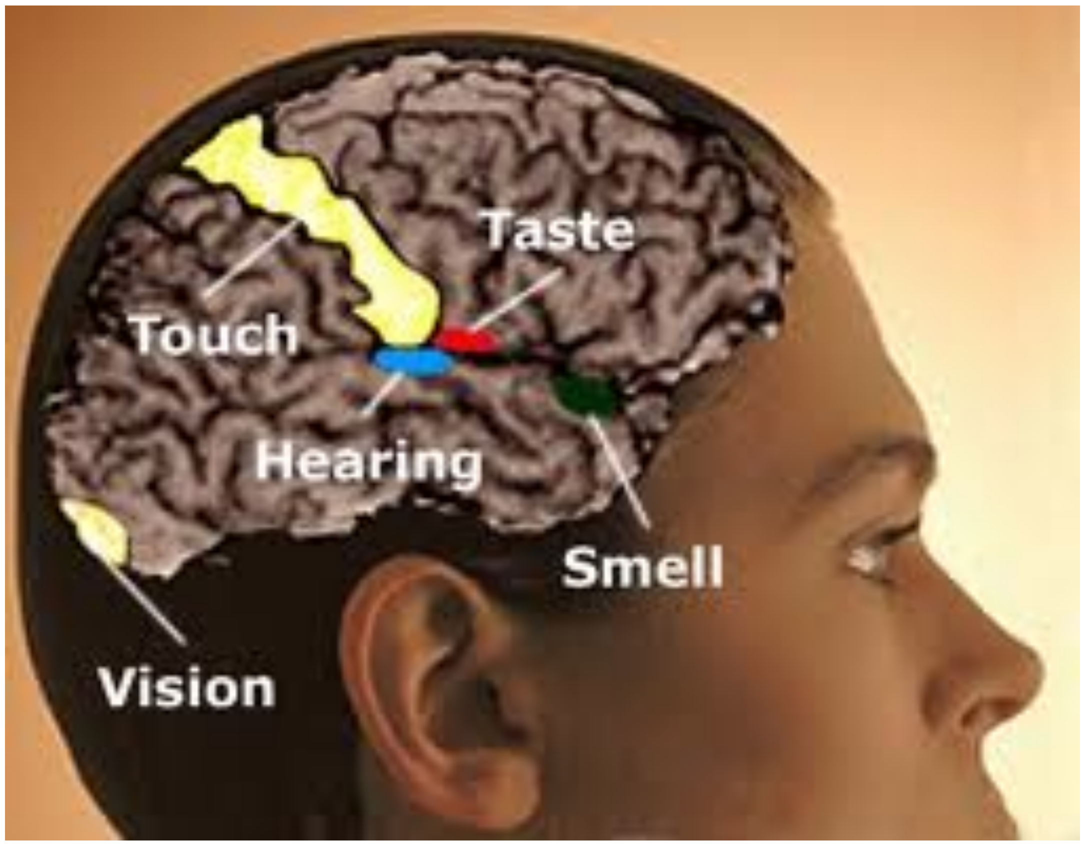
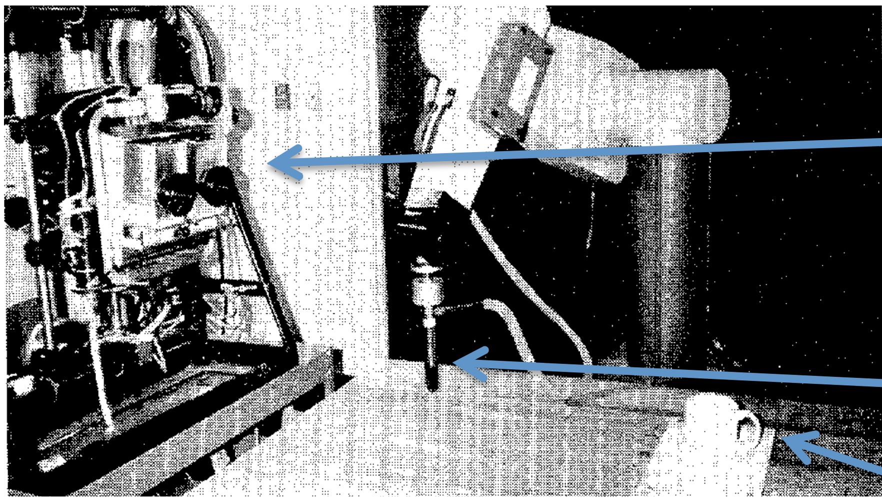
To Sense or Not To Sense

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



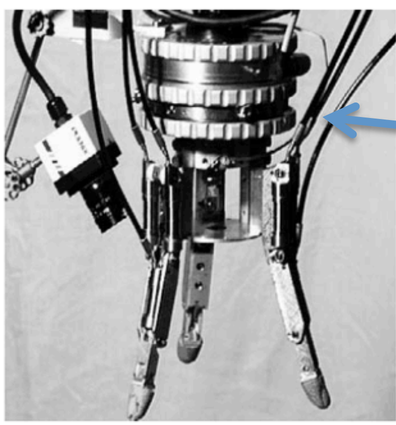
Grasp Lab, ca. 1985

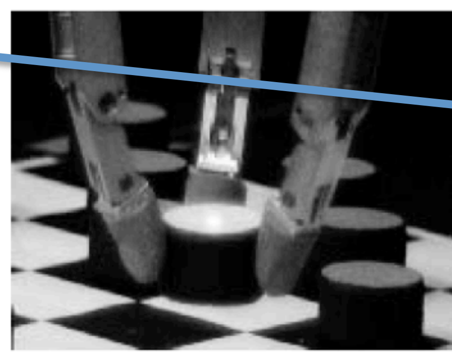
Stereo cameras

Tactile sensor

Cup Bolted to the table

Force





DLR, ca. 1985

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

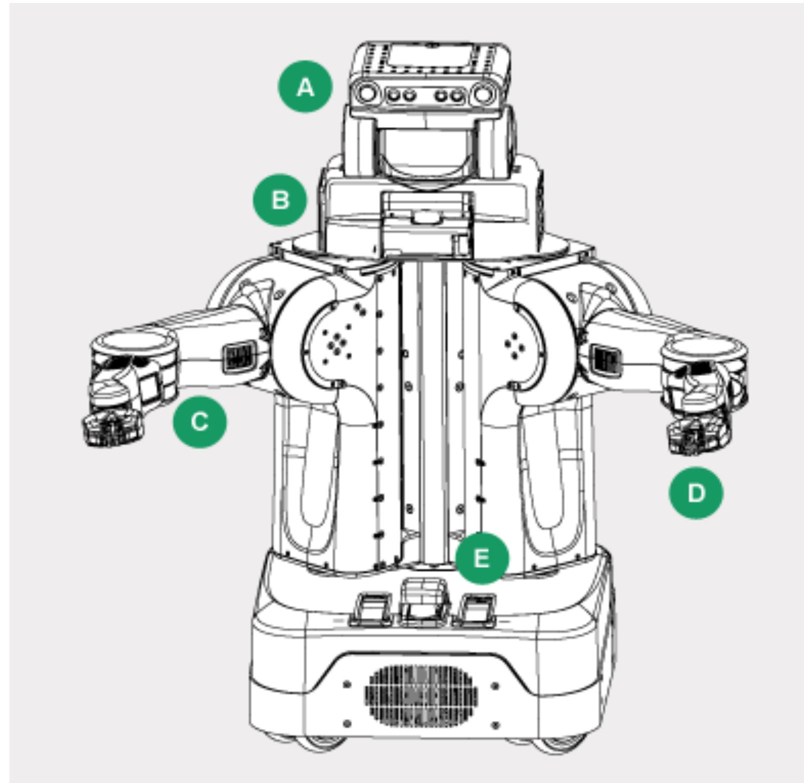
Three-Axis Accelerometer

Fingertip Pressure Sensor Arrays (**NOT on SE**)

Calibration LED

E Base

Hokuyo UTM-30LX Laser Scanner



Not Just On Robots

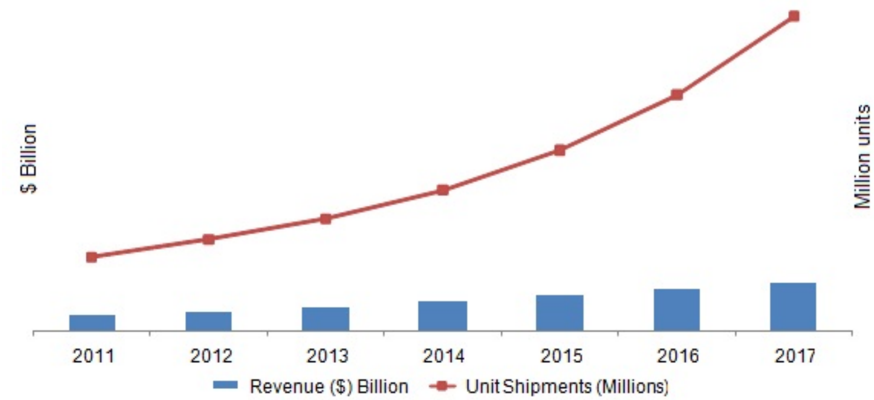
iPhone 5s in-built sensors

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

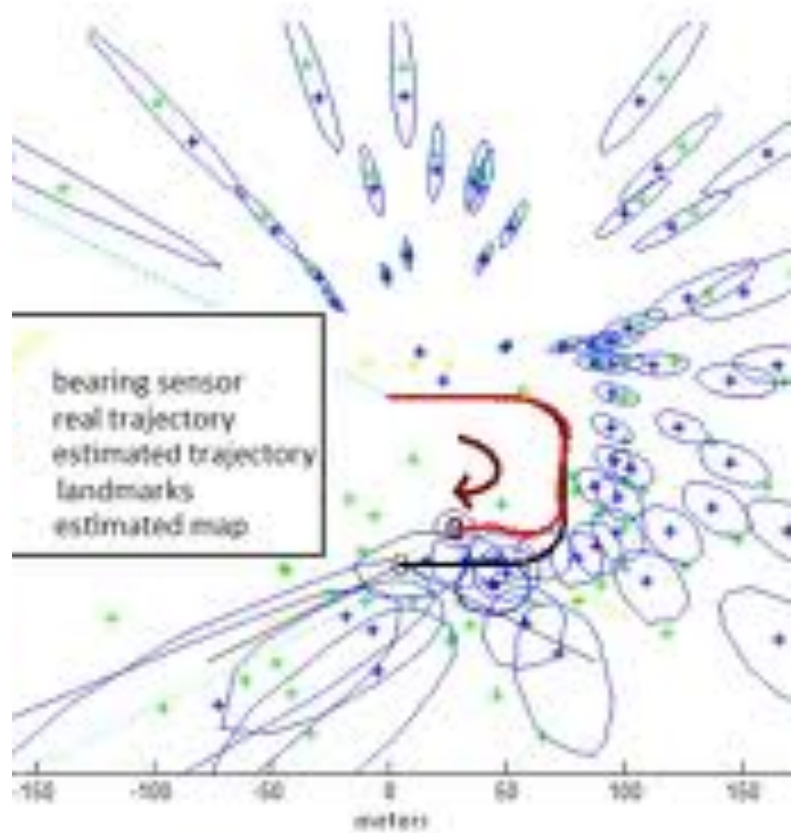


Networked Surveillance Cameras

Consumer-grade RGBD for gaming

Algorithms Depend on Data

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



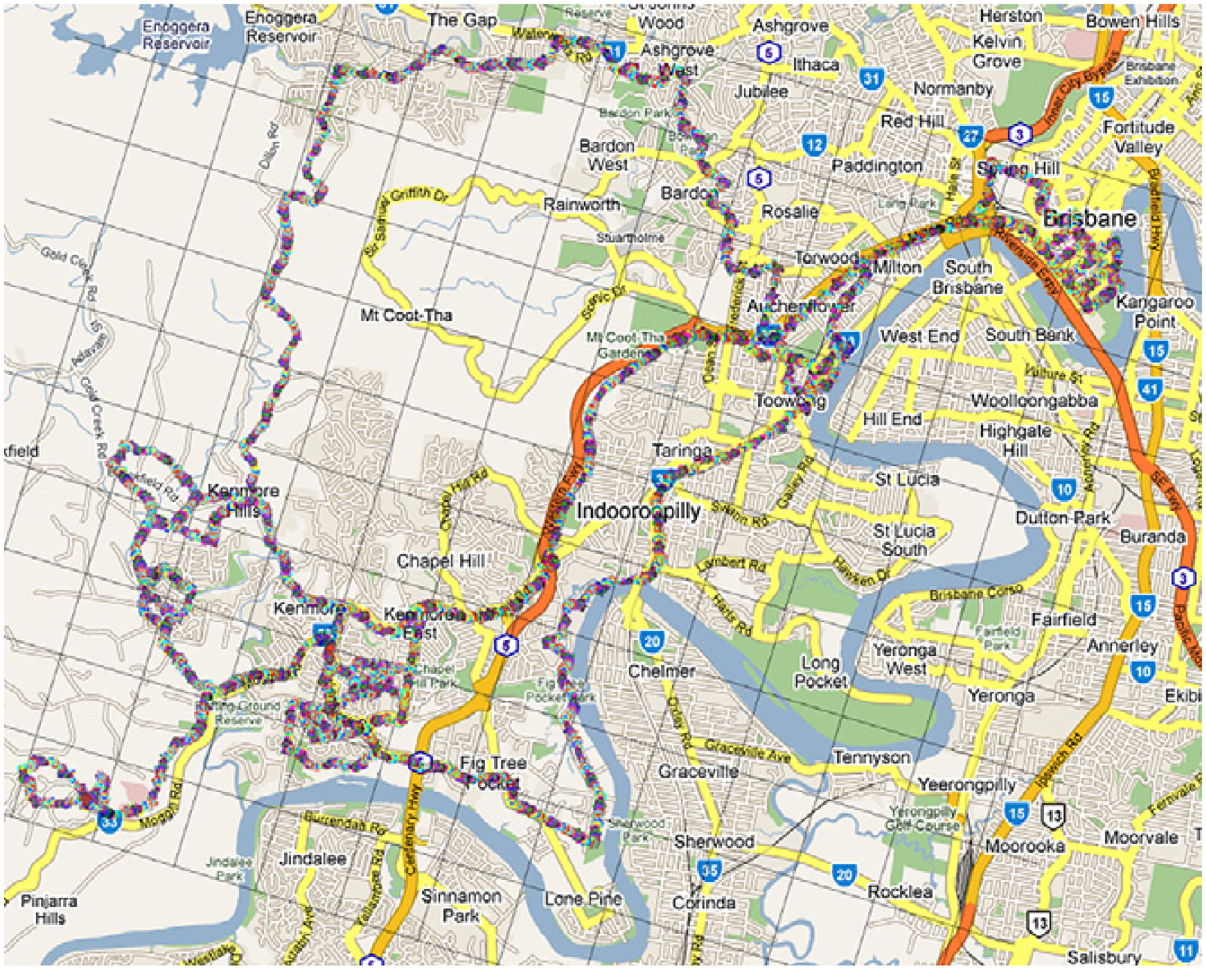
From Sound to Light

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).

Video courtesy Dieter Fox

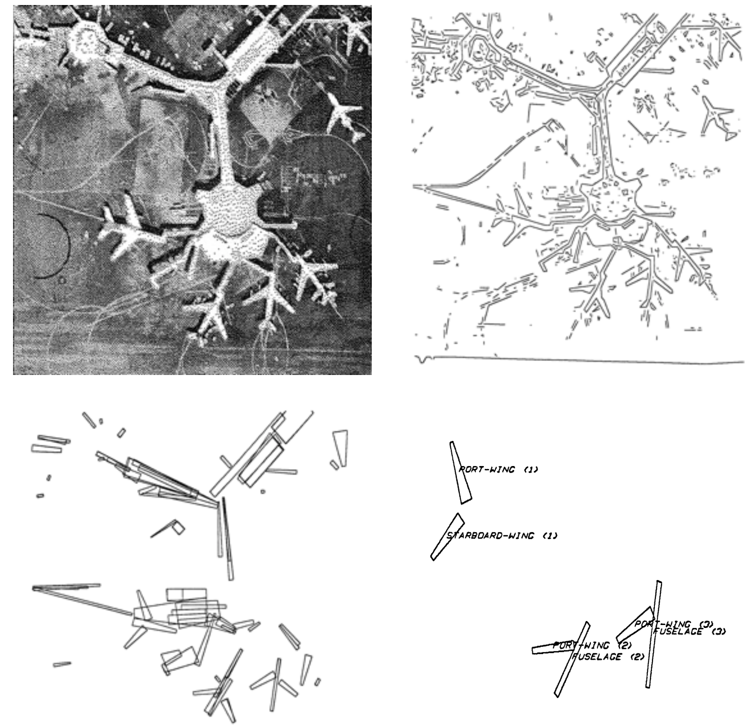
The Power Algorithmic Innovation



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

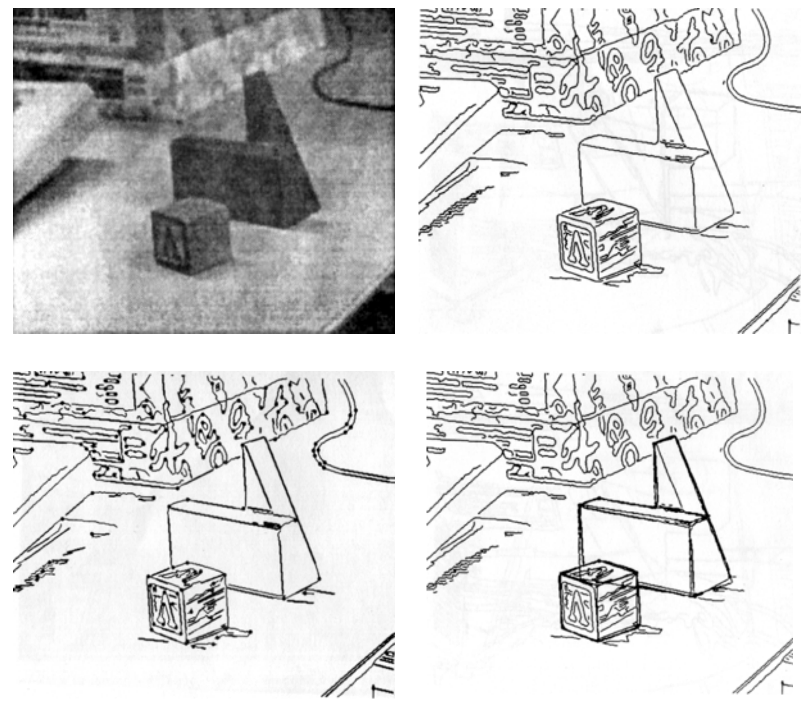
- The 70’s – AI reasoning
  - 1 object



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

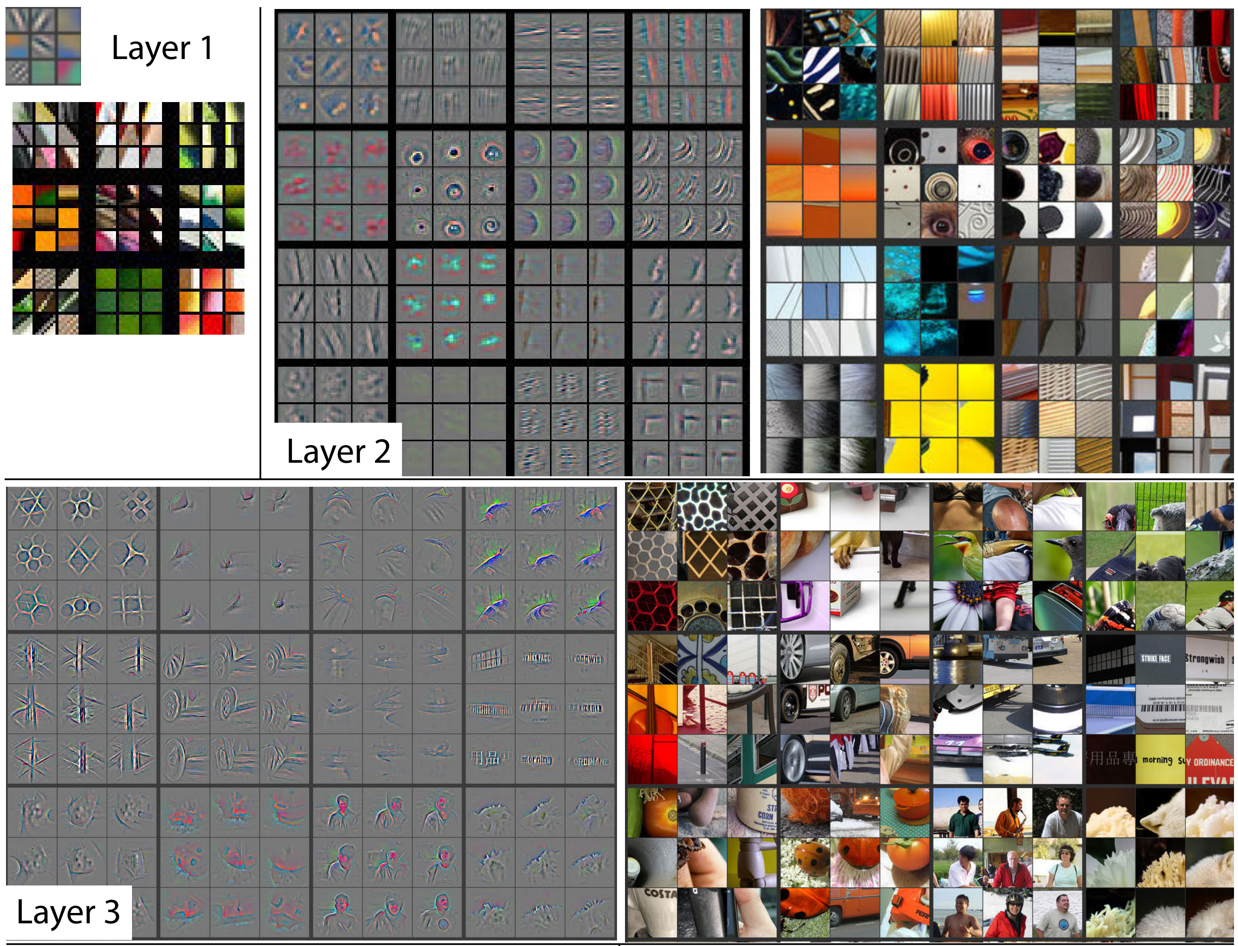
- The 70's – AI reasoning
- The 80's – Geometry
- The 90's – Appearance
- The 00's – Keypoints
  - 100's of objects
  - Real-world conditions
  - Highly scalable

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

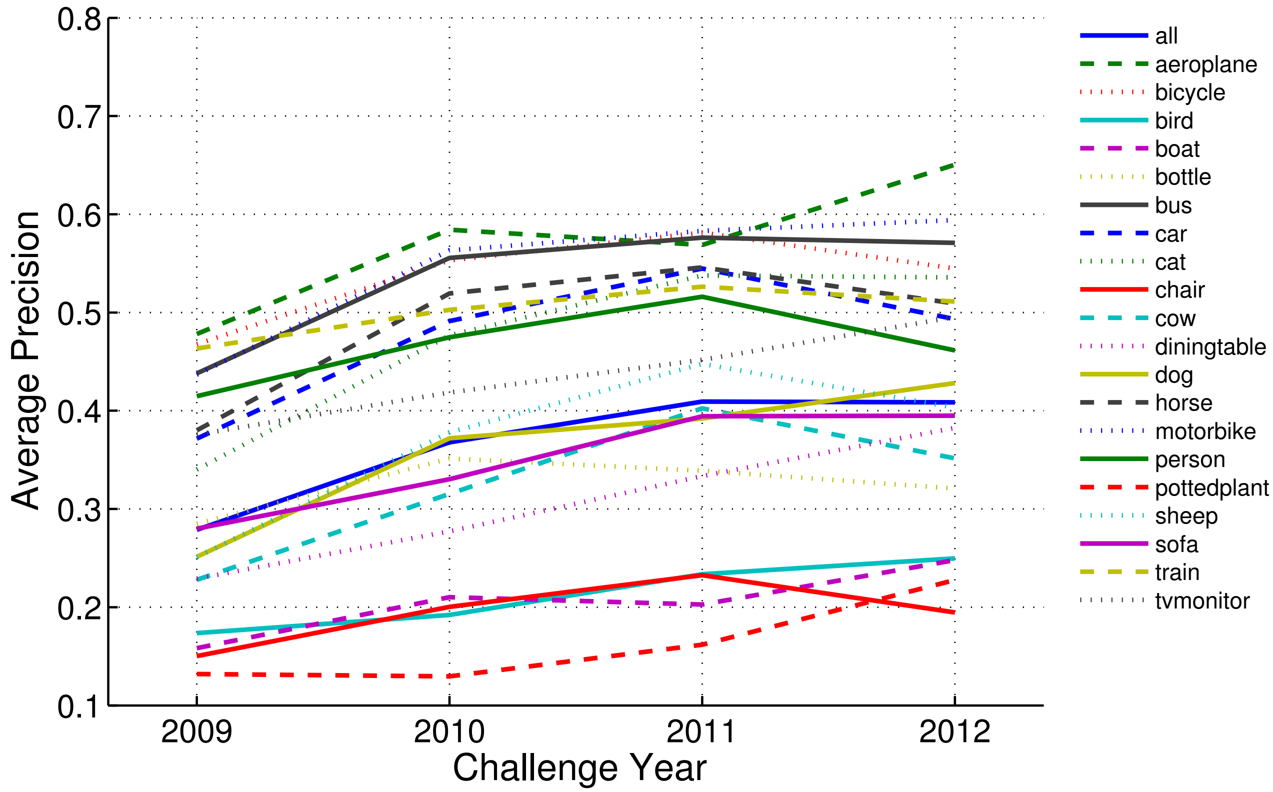
(38k citations since 2004)

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

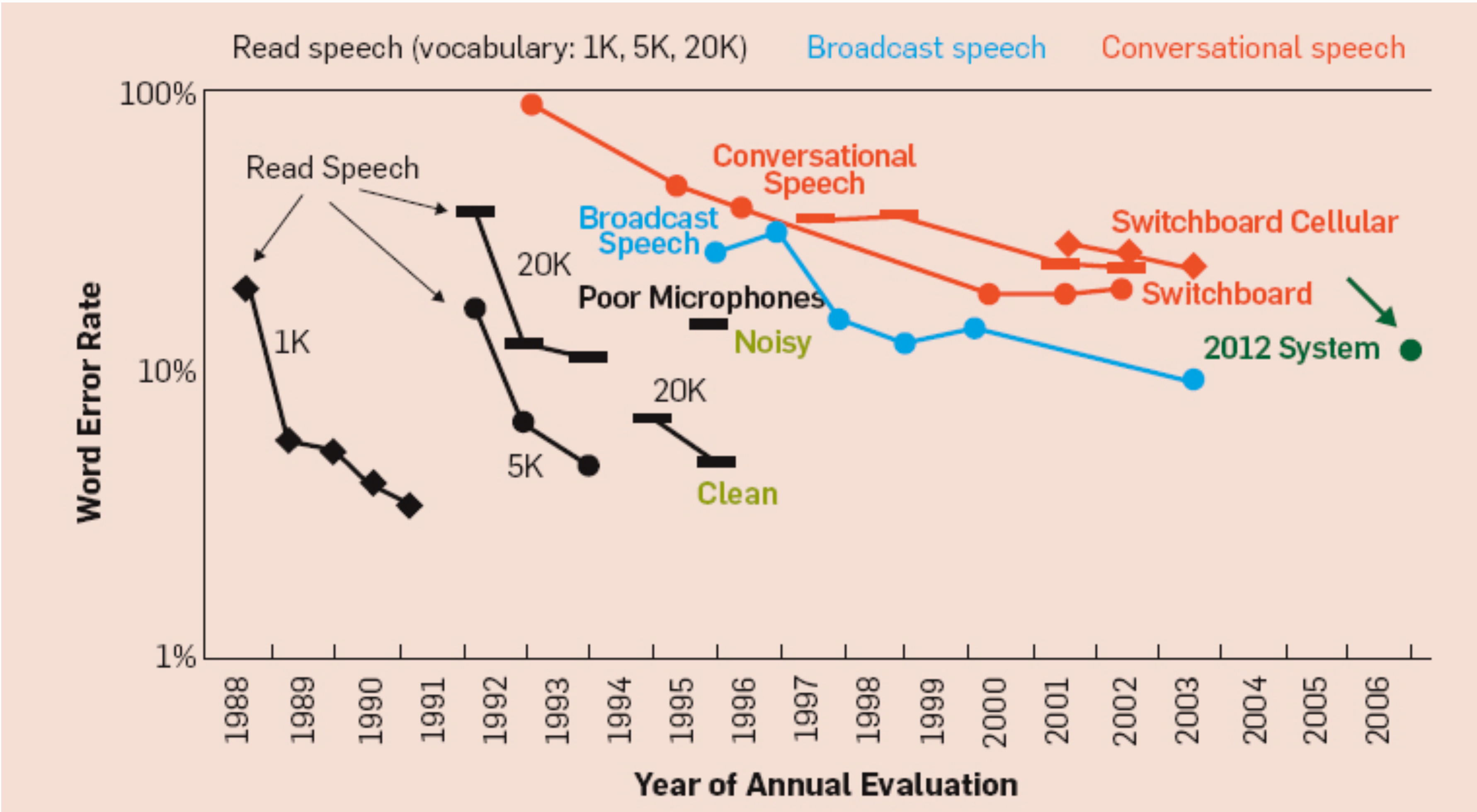


The PASCAL Visual Object Classes Challenge - a Retrospective

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

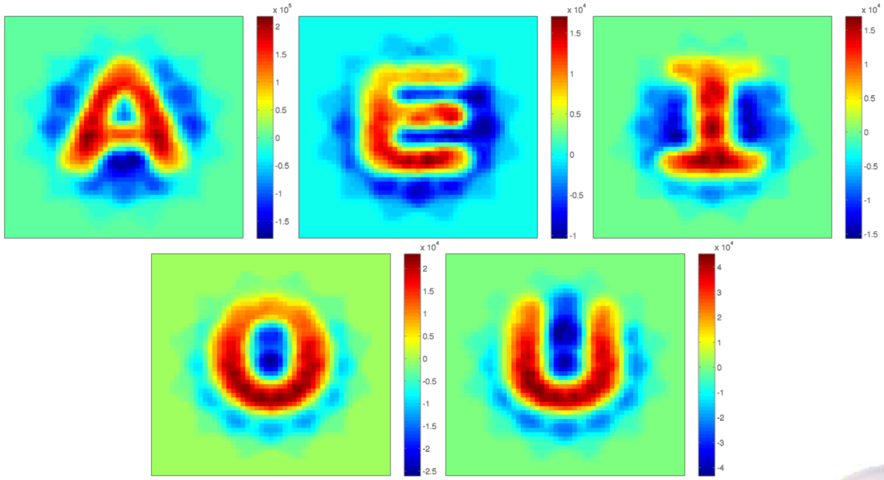
Speech

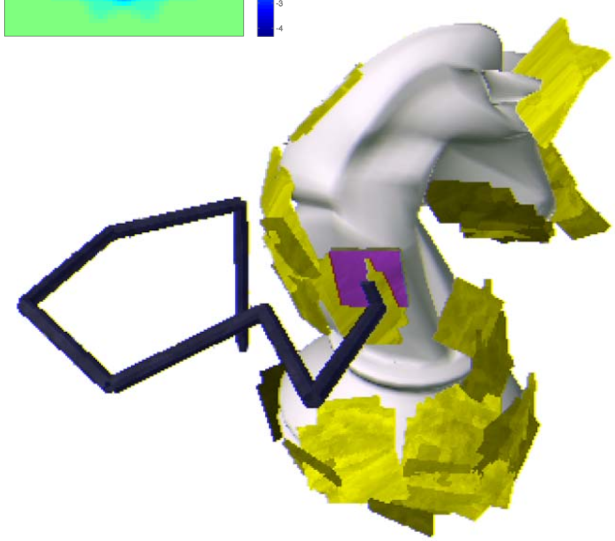


Huang, Xuedong, James Baker, and Raj Reddy. "A historical perspective of speech recognition." *Communications of the ACM* 57.1 (2014): 94-103.

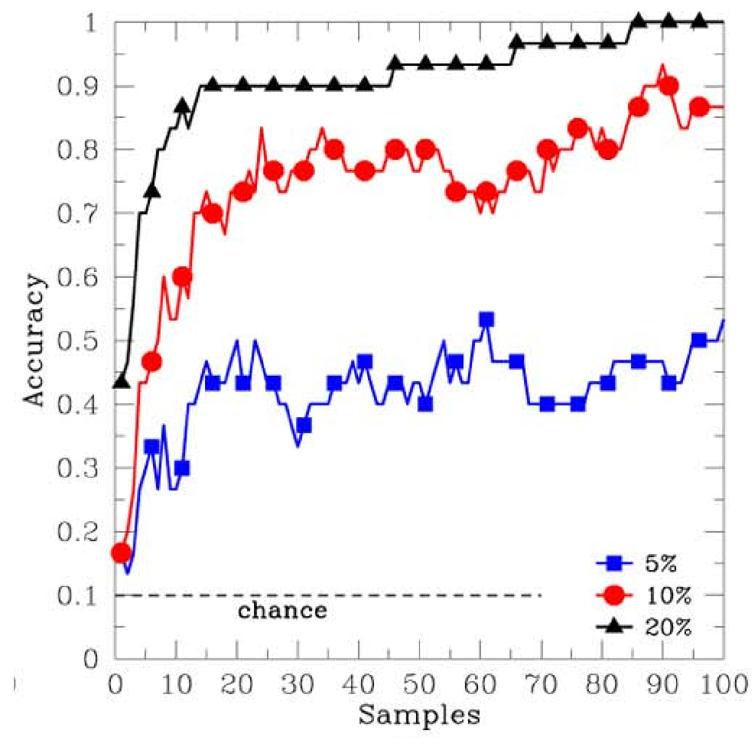
Tactile and Force Too!

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





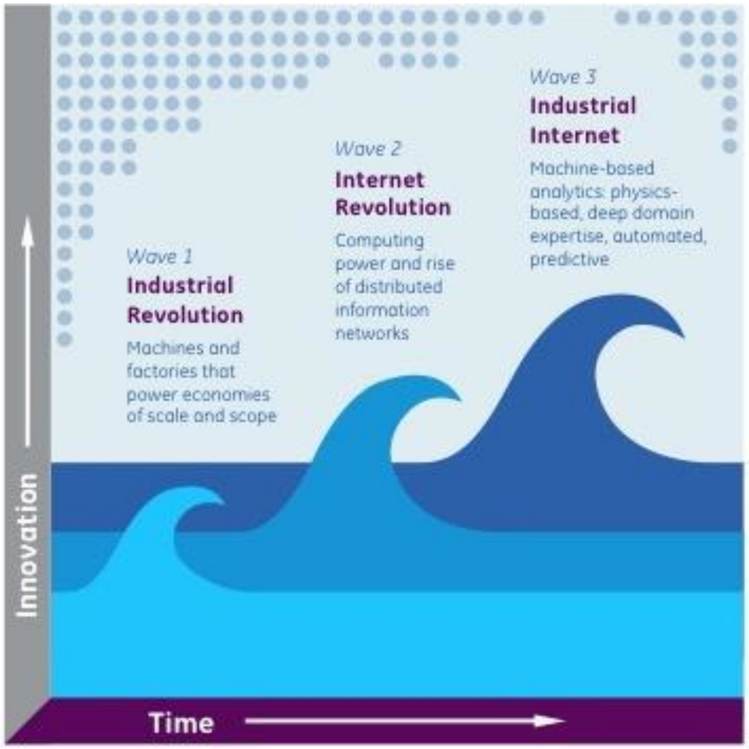
(a)



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?

CIRL Computational Interaction and Robotics Laboratory

The Built Environment: Electrical Devices

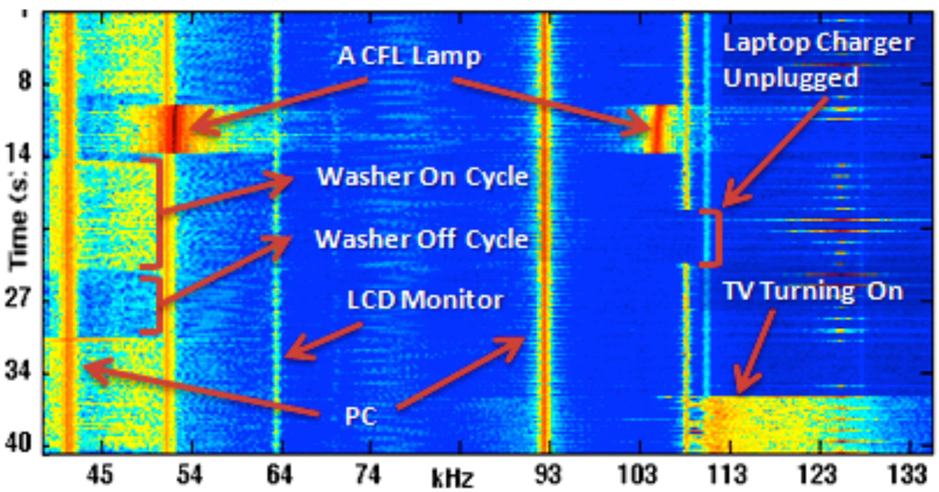


Figure 2: Frequency spectrogram showing device actuation in a

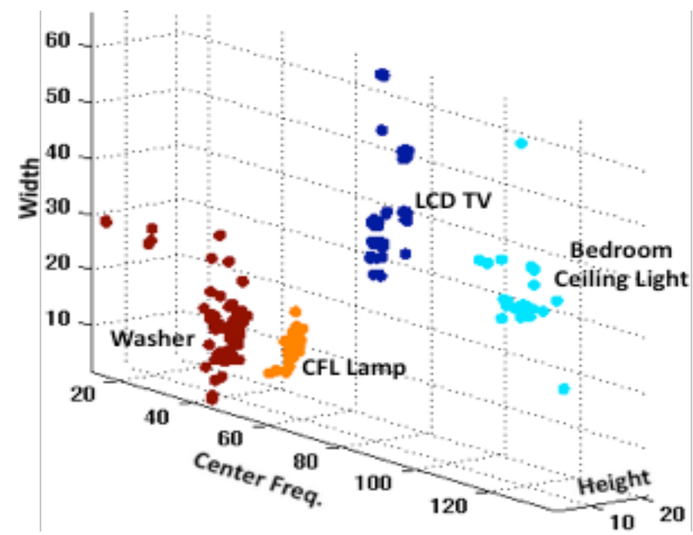


Figure 8: Variation of features over 6 months for four devices shown in the feature space. Note that no cluster overlaps.

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

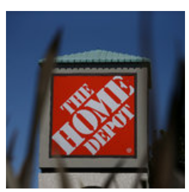
Where are my kids?
Is someone watching TV?
Is my 2 year old near the stairs!
Did I leave the stove on?
Is someone unexpected in the house?
Who has the car?

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