Cloud-Enabled Humanoid Robots

James Kuffner

### *The Robotics Institute*
Carnegie Mellon University

(currently working at Google Research)

Digital Human Research Center (AIST)

Humanoid Motion Planning (1995-2010)

- Stanford University
  1995-1999

- University of Tokyo
  JSK Lab
  1999-2001

- Carnegie Mellon University
  The Robotics Institute
  2001-*present*

- Digital Human Research Center (AIST)
  2001-*present*

H5   H6   H7   Asimo   HRP2   HRP3
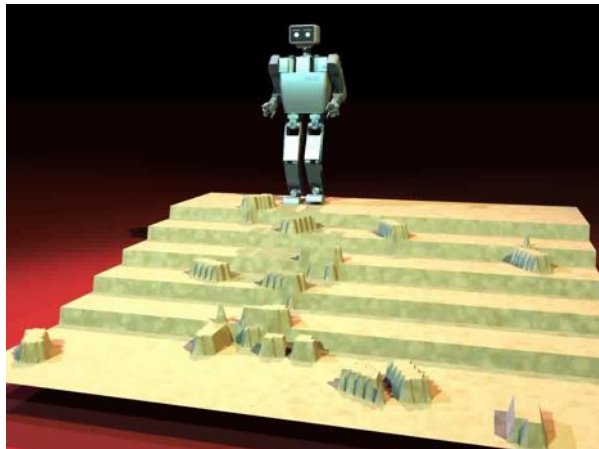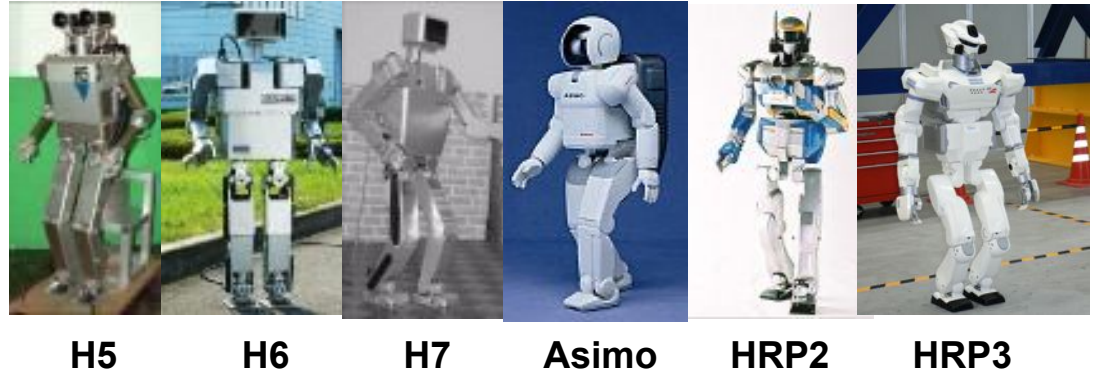
Self-driving Automobiles

Science

WORLD	U.S.	N.Y. / REGION	BUSINESS	TECHNOLOGY	SCIENCE	HEALTH	SPORTS	OPINION

SMARTER THAN YOU THINK

Google Cars Drive Themselves, in Traffic

Ramin Rahimian for The New York Times

Dmitri Dolgov, a Google engineer, in a self-driving car parked in Silicon Valley after a road test.

By JOHN MARKOFF
Published: October 9, 2010

MOUNTAIN VIEW, Calif. — Anyone driving the twists of Highway 1 between San Francisco and Los Angeles recently may have glimpsed a Toyota Prius with a curious funnel-like cylinder on the roof. Harder to notice was that the person at the wheel was not actually driving.
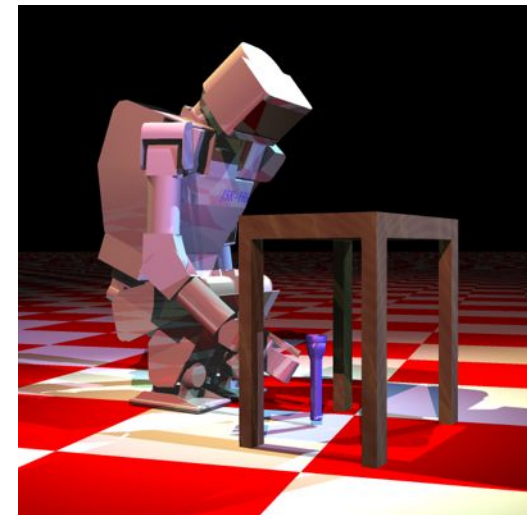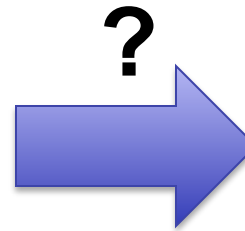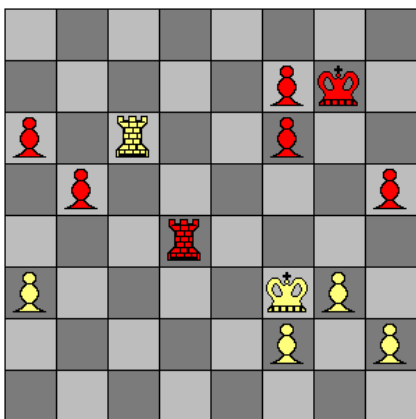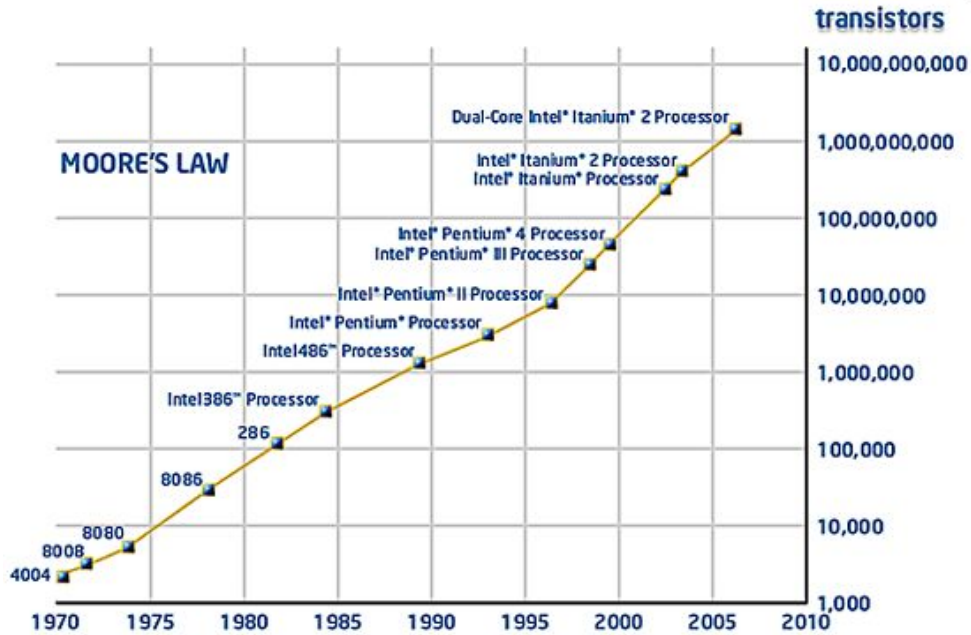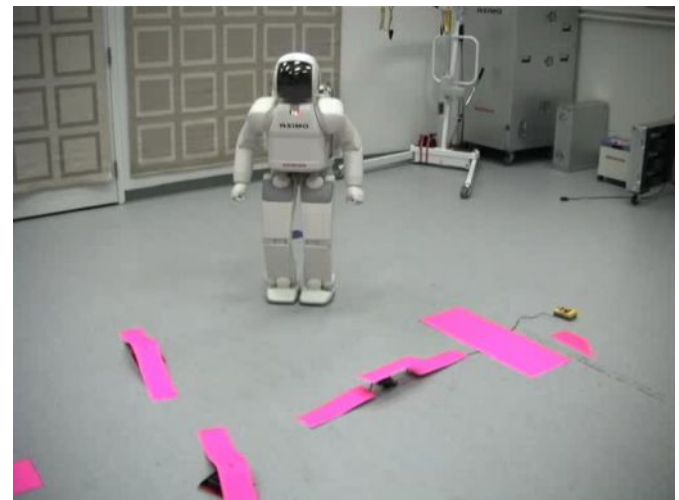
RECOMMEND

TWITTER

COMMENTS (85)

SIGN IN TO E-MAIL

Search-based Artificial Intelligence

transistors

Dual-Core Intel® Itanium® 2 Processor

MOORE'S LAW

Intel® Itanium® 2 Processor
Intel® Itanium® Processor

Intel® Pentium® 4 Processor
Intel® Pentium® III Processor

Intel® Pentium® II Processor

Intel® Pentium® Processor

Intel486™ Processor

Intel386™ Processor

286

8086

8080
8008
4004

GARRY KASPAROV   DEEP BLUE

?

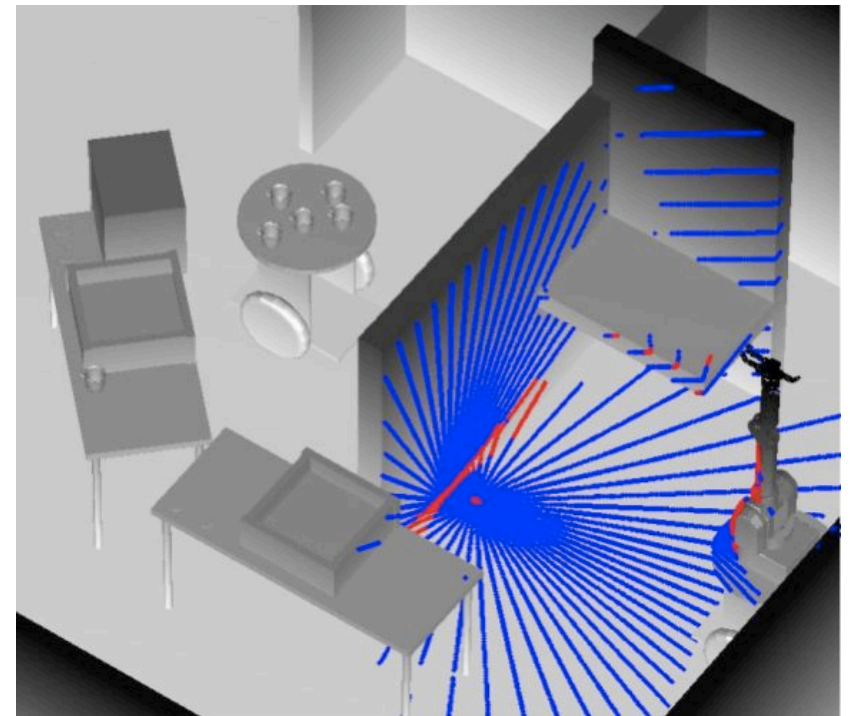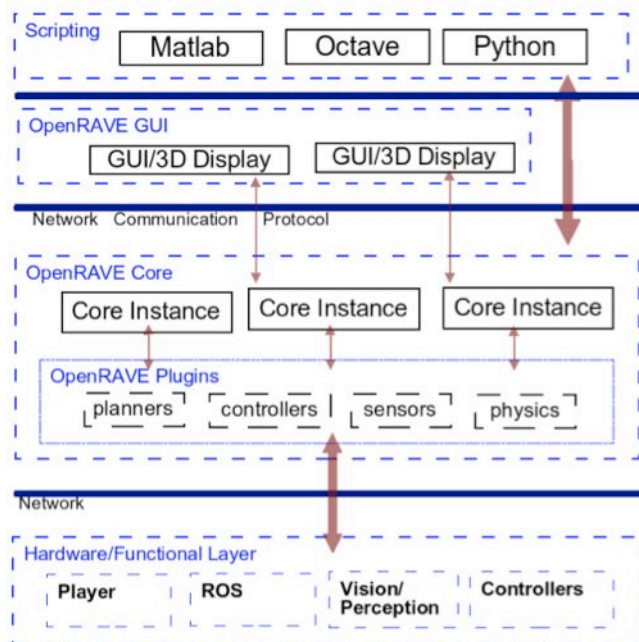# Autonomous Humanoid Navigation: "Footstep Planning" (2000-2009)
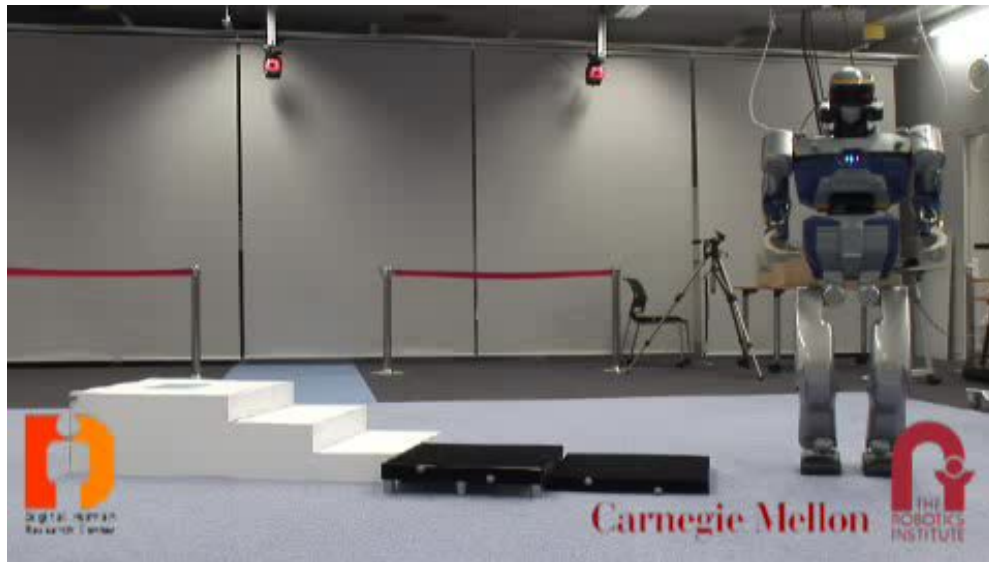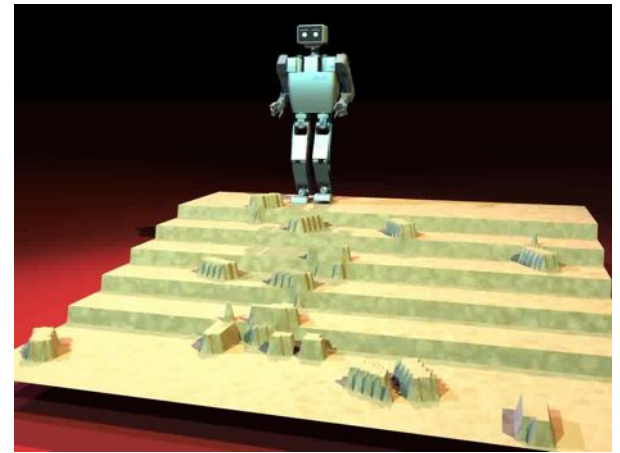
Autonomous Grasping & Manipulation (2000-2010)

INITIAL   FINAL
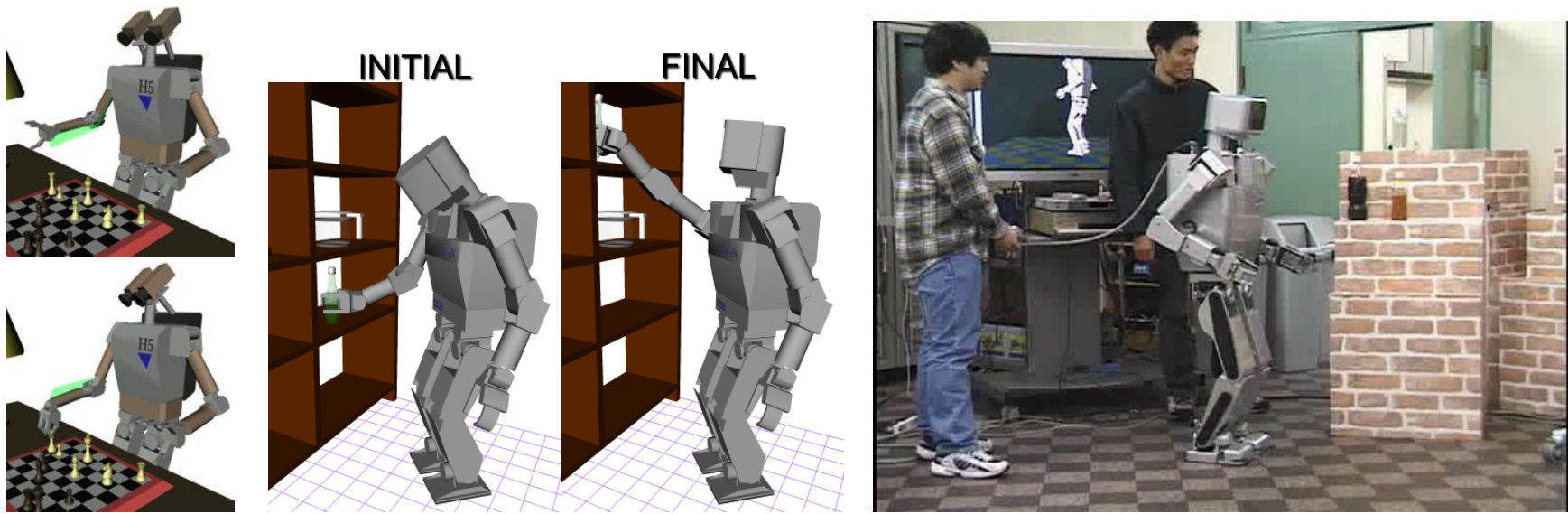
OpenRAVE : Open-source Robotics and Animation Virtual Environment

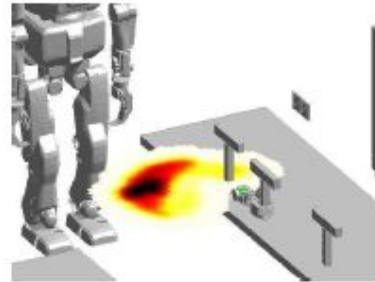**OpenRAVE**

http://openrave.programmingvision.com/
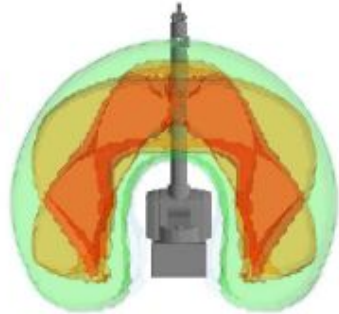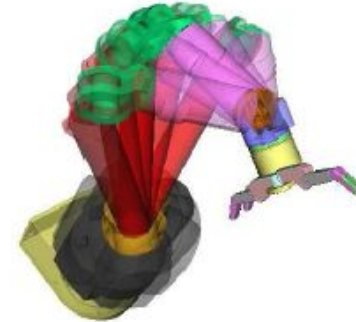- OR -
http://www.sourceforge.net/
keyword: "openrave"

Robot Knowledge Database
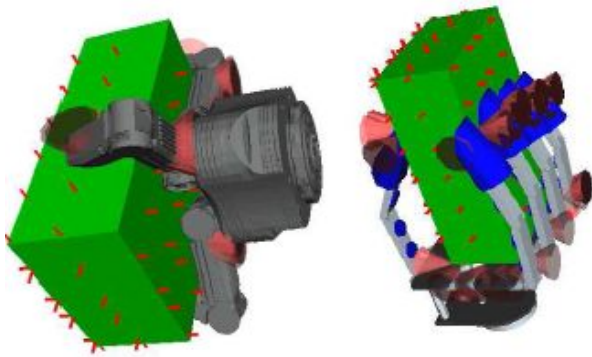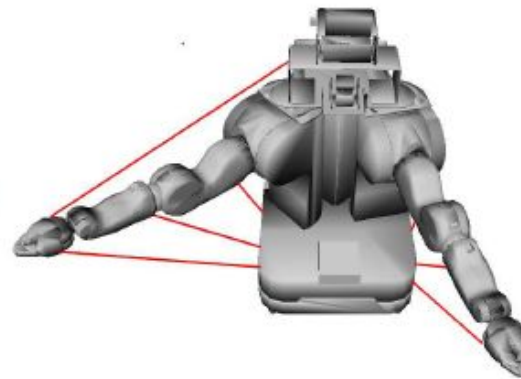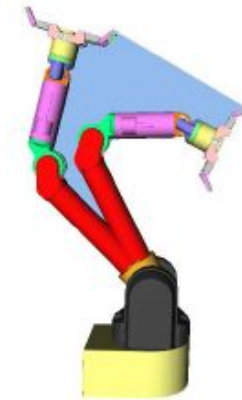
reachability

base placement

inverse kinematics

Grasping

self-collision

distance metrics

CMU PhD thesis: **Rosen Diankov**

Grasp Configuration Sampler

CMU PhD thesis: **Rosen Diankov**
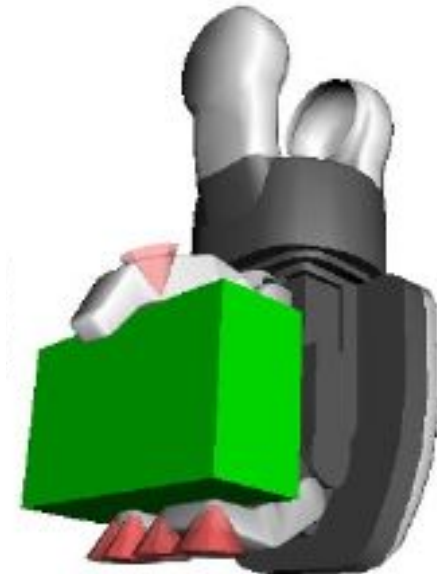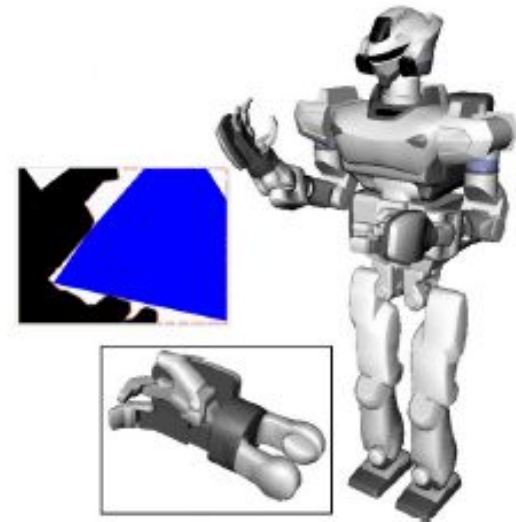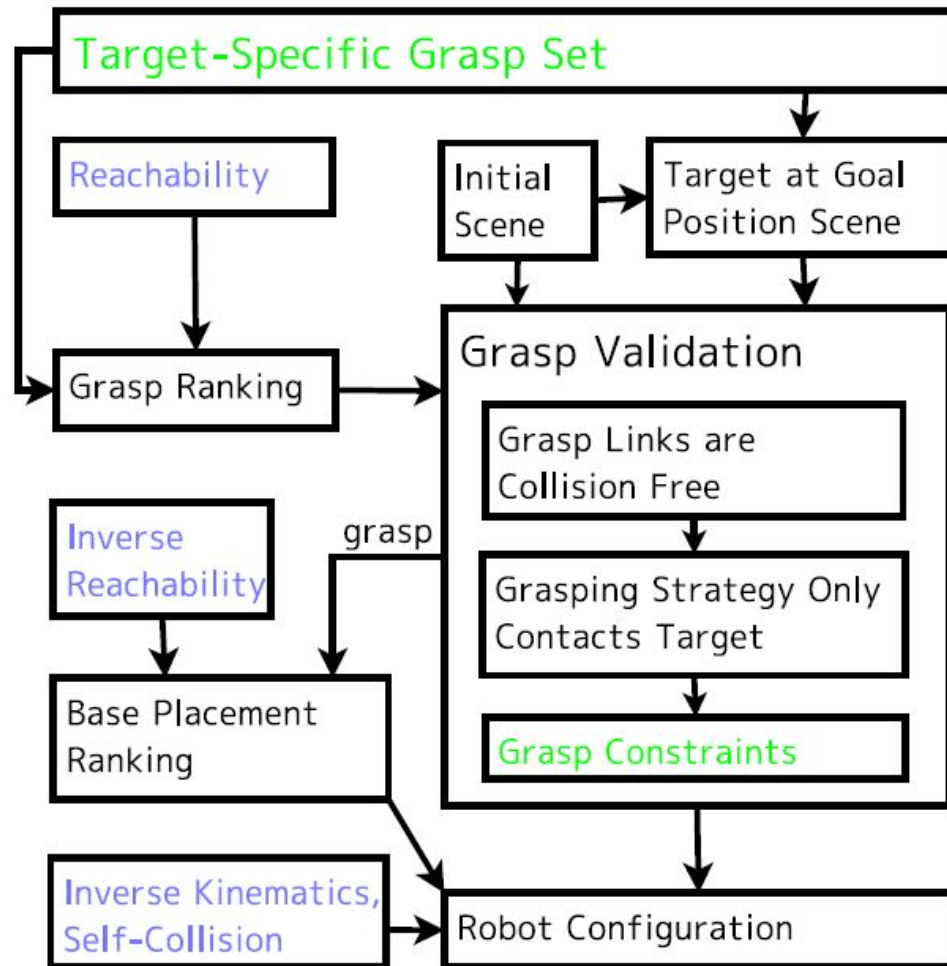
Stable Grasp Generation

1. Approach Target   2. Close Fingers   3. Compute Contacts

CMU PhD thesis: **Rosen Diankov**
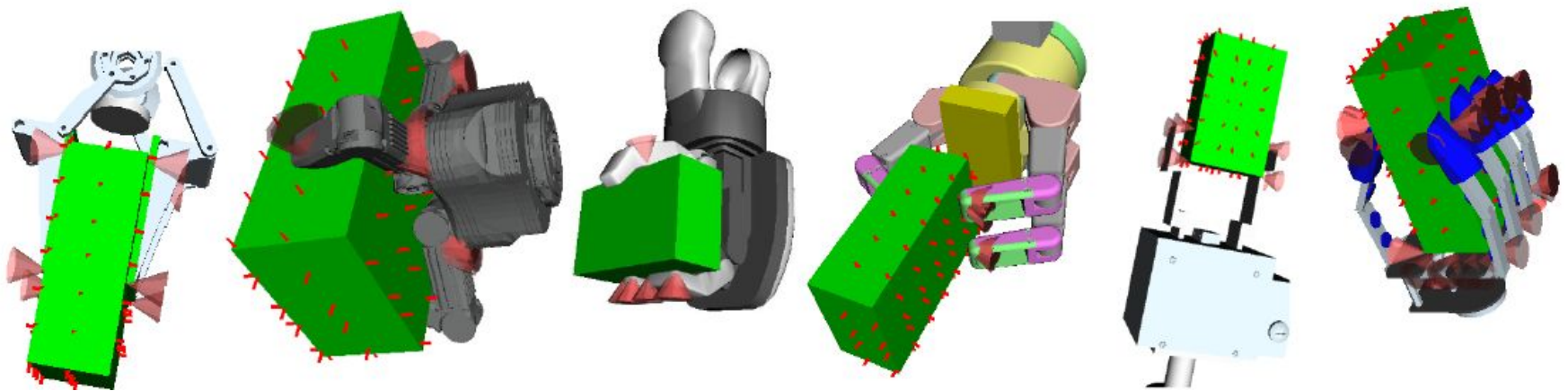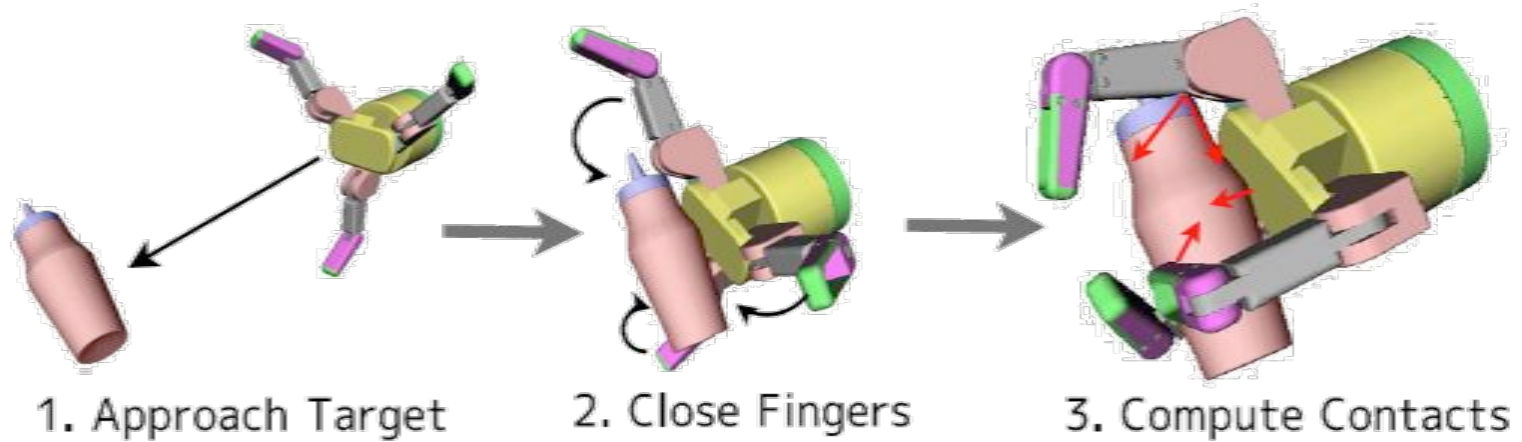
Precomputed Reachability

- **Given the robot's position, where can the arm reach?**

CMU PhD thesis: **Rosen Diankov**
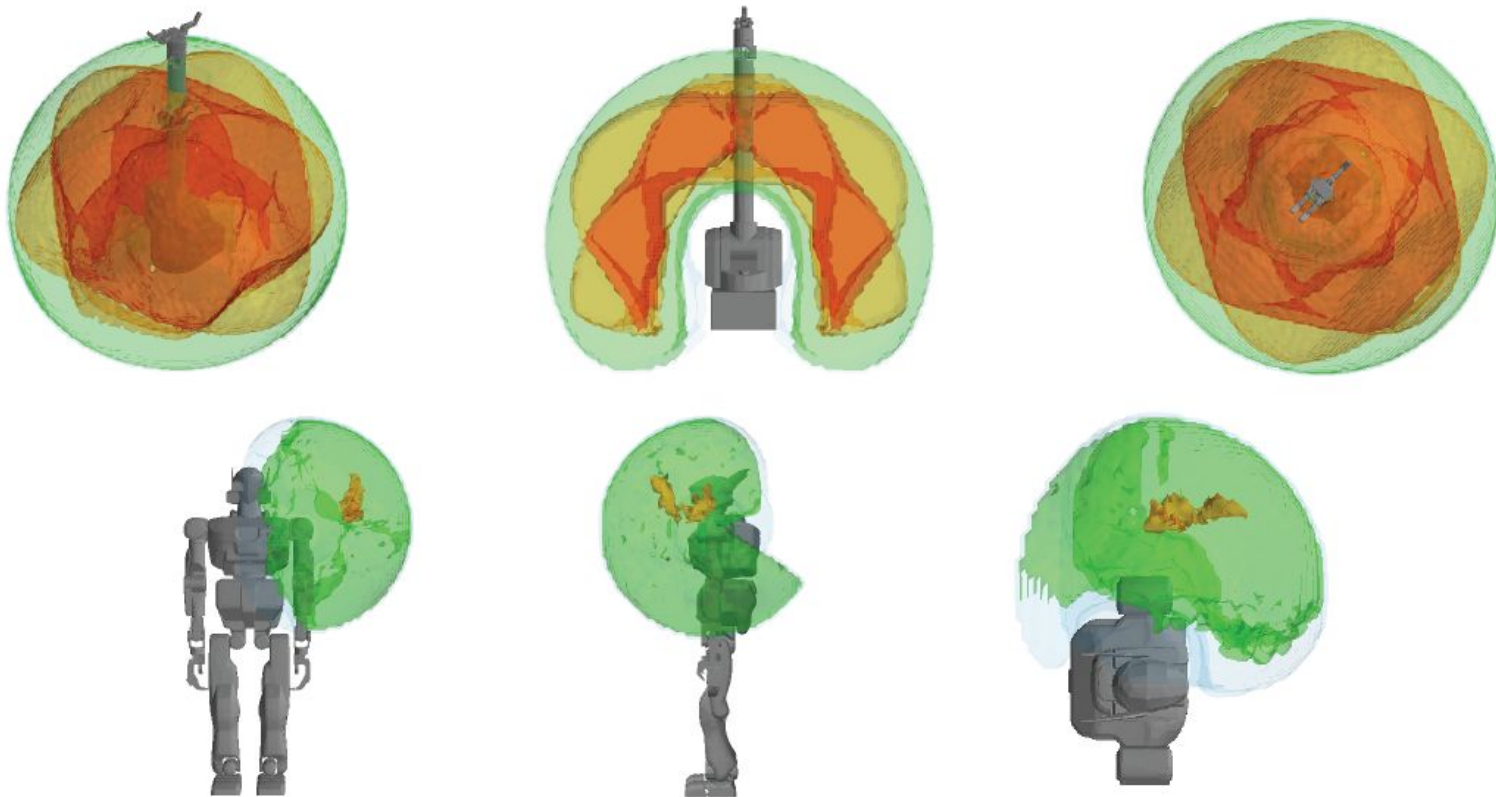
Object-Specific 6D Pose Extraction

- ## Modeling Object Pose Error

CMU PhD thesis: **Rosen Diankov**

Pose Sets due to a Curve

CMU PhD thesis: **Rosen Diankov**

James Kuffner (Google) - Humanoids2010 Workshop "What's Next" – Cloud-Enabled Humanoid Robots
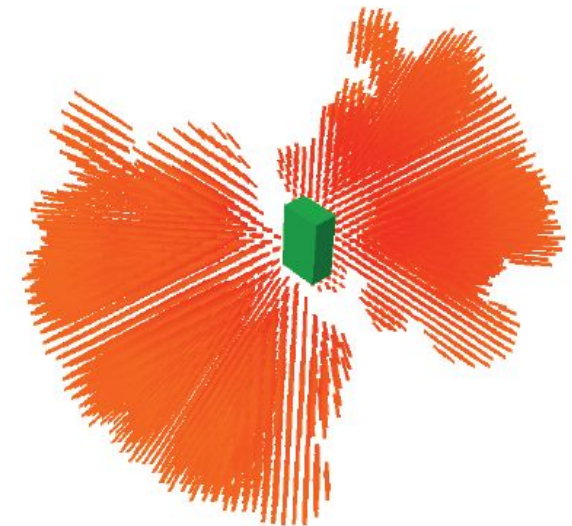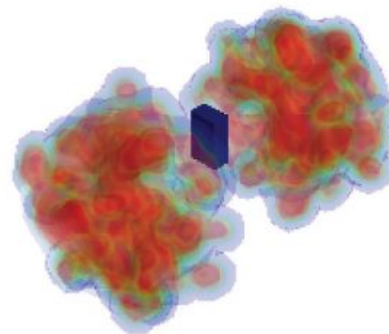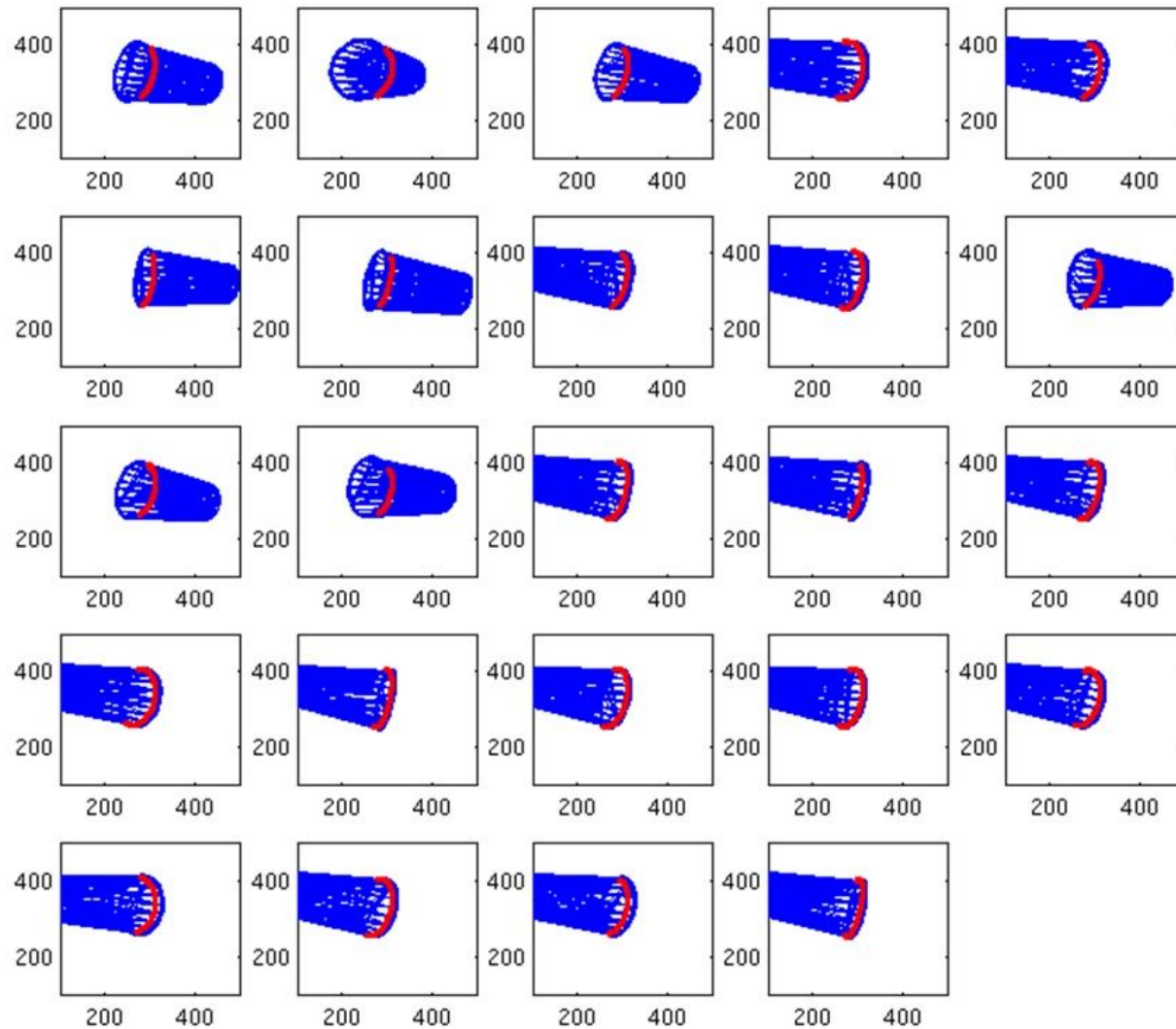
Mean Images of Induced Pose Sets

CMU PhD thesis: **Rosen Diankov**
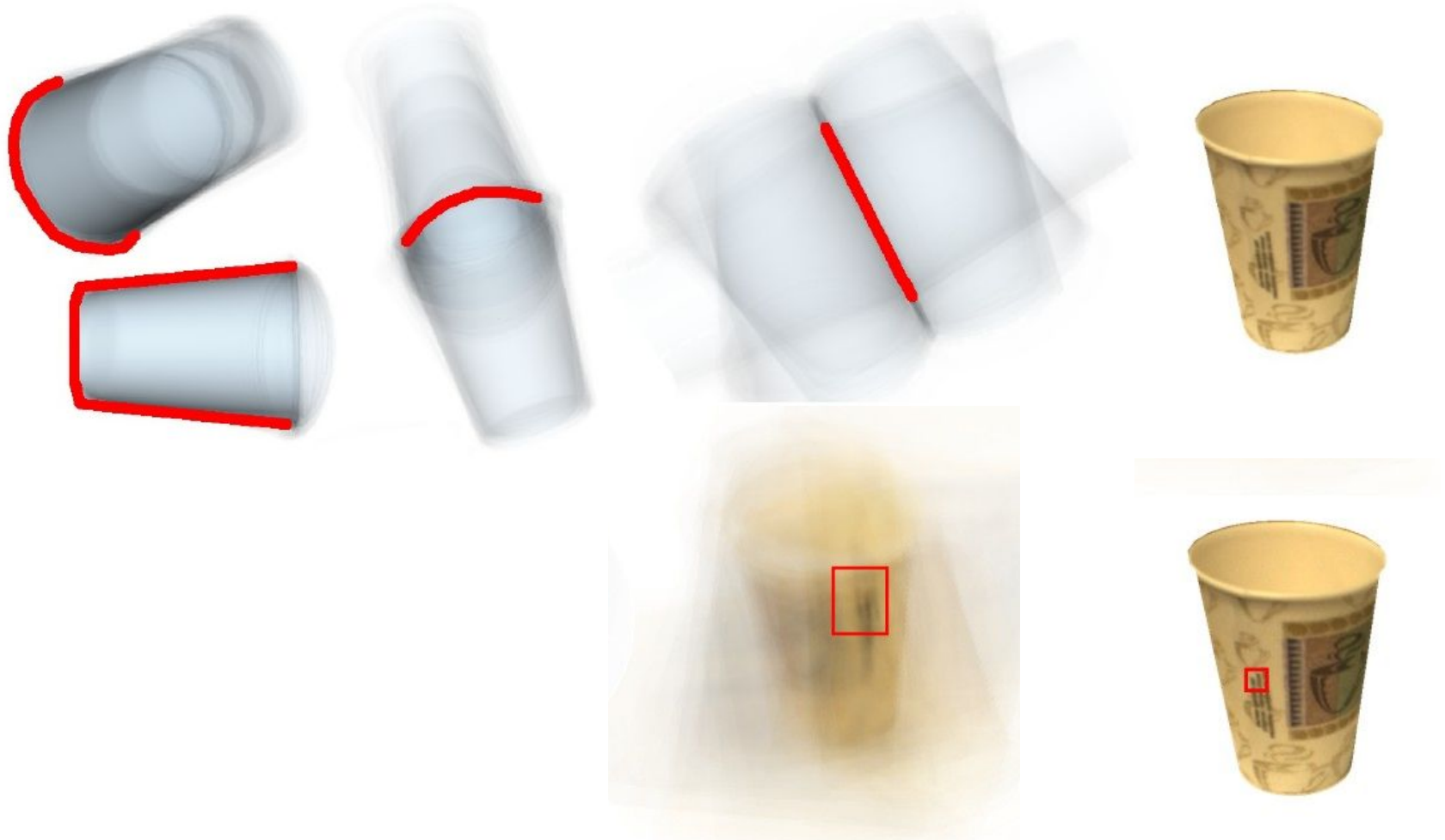
Cloud Computing

- ## Documents "live" in the cloud
  (backed up and accessible anywhere)

- ## Netbook

- ## Supercomputing:
  (Heavy CPU or data-intensive processing handled by distributed network)

Client Computer

Control Node

Database (Storage)

Computer Network

Application Servers
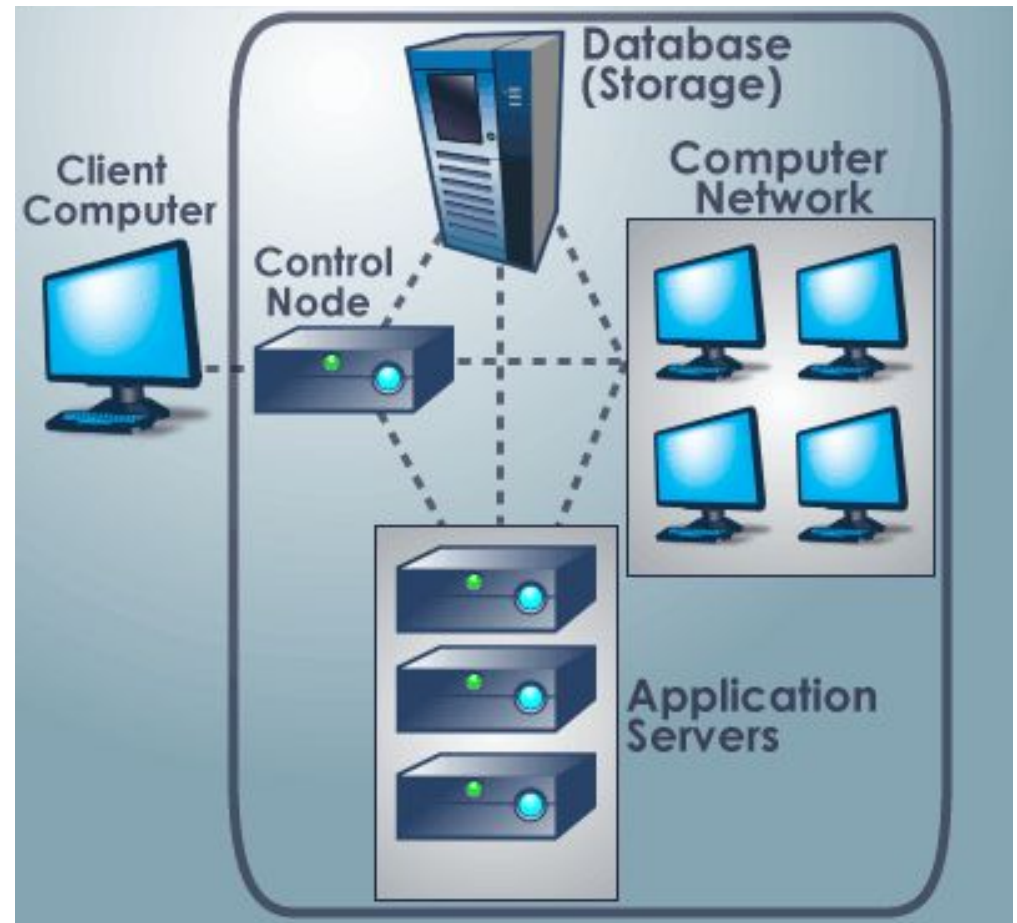
Today's Headline News

With Chrome OS, Google Doubles Down on the Cloud

By Michael Calore, Webmonkey ✉   December 7, 2010 | 3:23 pm | Categories: Cool Apps, Web Tech

SAN FRANCISCO — Google unveiled a beta version of its Chrome OS and an early test version of its branded netbook Tuesday morning, a big bet by the search giant to help drive computing to the cloud — and to the popular web-based services that are its bread and butter.

Google's release of the new OS, related but separate to its mobile OS Android, comes after a year of development and at a time when cloud computing — and the simpler machines that access applications on distant servers rather than running them on a hard drive — seems to have passed a sort of tipping

"Remote-Brain" Robots

- Physical separation of Hardware (motors & sensors) and Software (high-level processes)
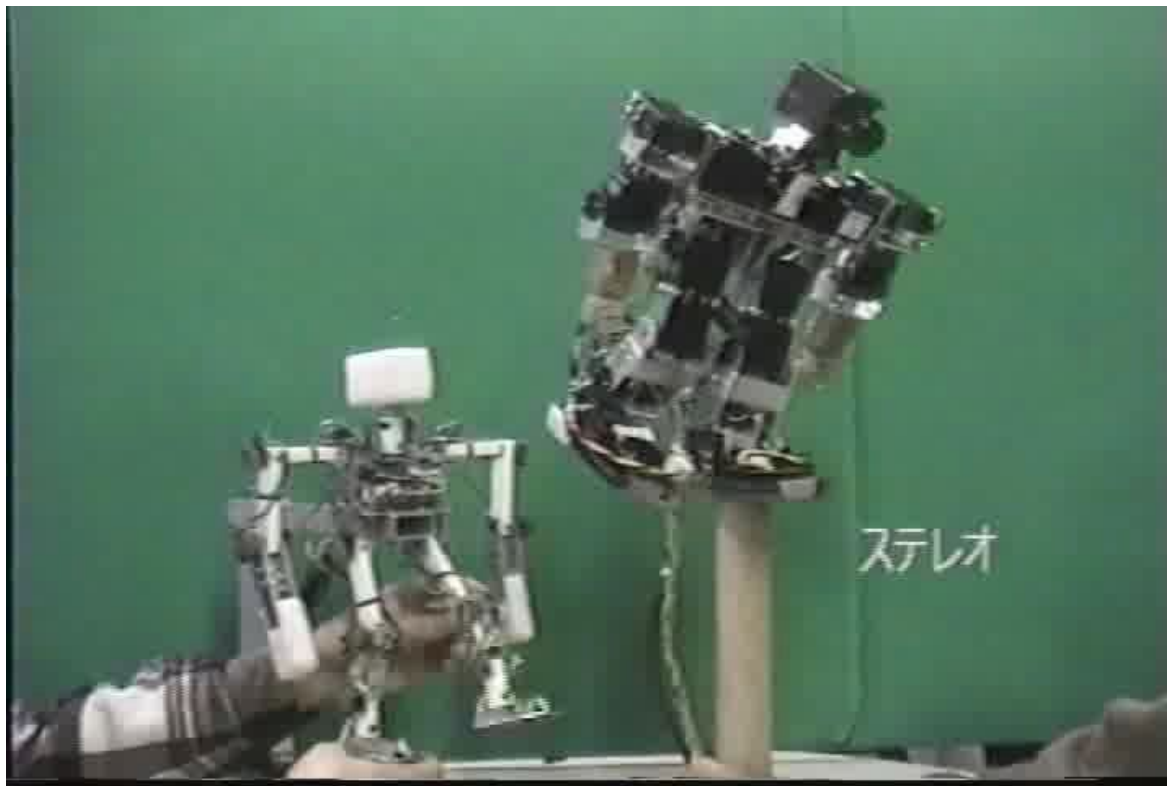
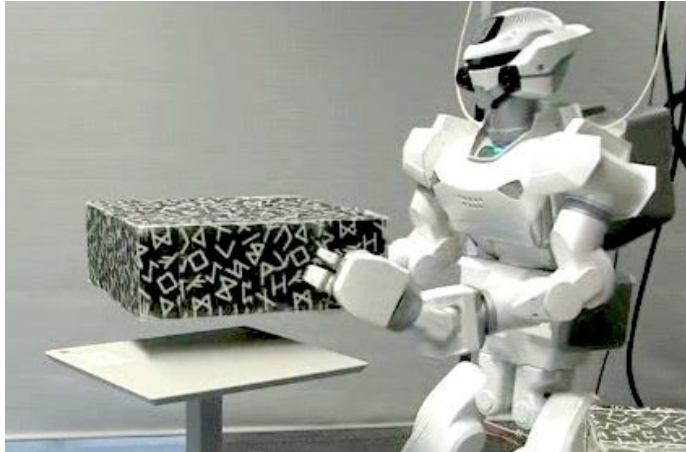JSK (U.Tokyo) mini-Humanoids (1990s)

Relationship to Teleoperation

- Human acts as the "remote-brain"

- Not suitable for all tasks

- Issues:
  - Latency
  - Data Bandwidth

NAIST-Hand I

Cloud-Enabled Robotics
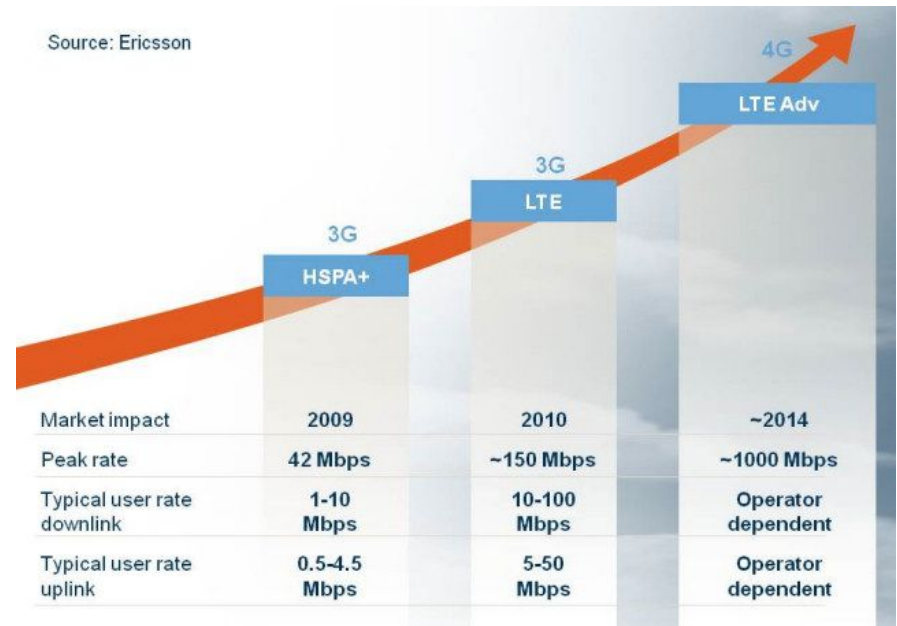

HRP3 (AIST/Kawada)

Google DataCenter

- ## Recent proposals:

  "DAvinCi: A cloud computing framework for service robots" [Arumugam, et. Al. , ICRA 2010]

  – Hadoop cluster with ROS communication infrastructure

  – FastSLAM map/reduce

Enabling Factors

- ## Wireless networking:
  - Fast
 - Reliable
  - Ubiquitous
  - Sufficient bandwidth

(e.g: Mobile Broadband
64 kbps to 150 Mbps
in 10 years = 2400x)

STANDARD	Rated maximum range (feet)	Frequency	Maximum speed
802.11a	25 to 75	5 GHz	54 mbps
802.11b	100 to 150 indoors 300 outdoors	2.4 GHz	11 mbps
802.11g	100 to 150 indoors 300 outdoors	2.4 GHz	54 mbps

Source: Ericsson

	4G
	LTE Adv
3G	
LTE	
3G	
HSPA+	

|			
Market impact	2009	2010	~2014
Peak rate	42 Mbps	~150 Mbps	~1000 Mbps
Typical user rate downlink	1-10 Mbps	10-100 Mbps	Operator dependent
Typical user rate uplink	0.5-4.5 Mbps	5-50 Mbps	Operator dependent

Benefits of "Cloud Robotics"

- ## Provides a shared knowledge database
  - Organizes and unifies information about the world in a format usable by robots

- ## Offloads heavy computing tasks to the cloud
  - Cheaper, lighter, easier-to-maintain hardware (akin to desktop PC vs. a thin-client "netbook")
  - Longer battery life
  - Less need for software pushes/updates
  - CPU hardware upgrades are invisible & hassle-free

- ## Skill / Behavior Database
  - reusable library of "skills" or behaviors that map to perceived task requirements / complex situations.
  - Data-mining the history of all cloud-enabled robots
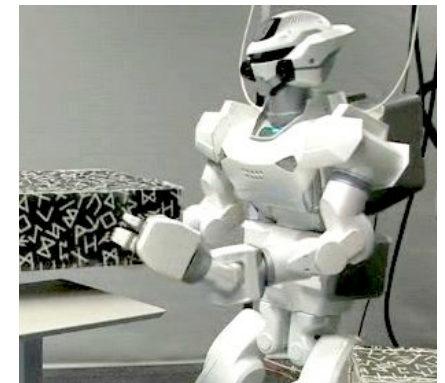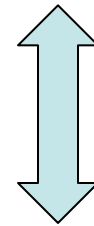
Example: Perception

- Cloud-enabled Object Recognition
  - e.g. "Google Goggles"
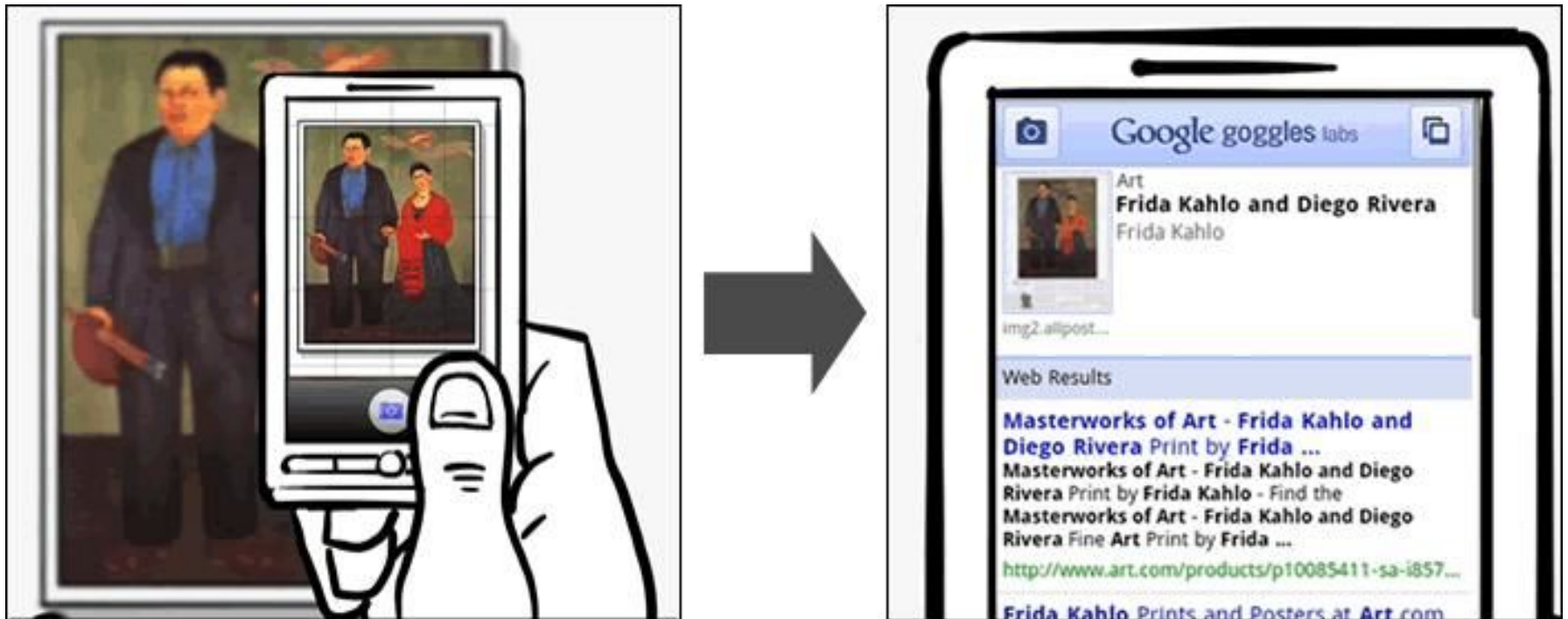
"Robot" Goggles

- Upload image(s) → Download Semantics
  - Object name
  - 3D model, mass, materials, friction properties
  - Usage instructions (function, how to grasp, operate)
  - Context / Domain knowledge

ARMAR III (KIT)

Example: Speech

- Recognition
- Translation
- Synthesis

Alex Waibel's group (CMU & KIT)

http://translate.google.com/
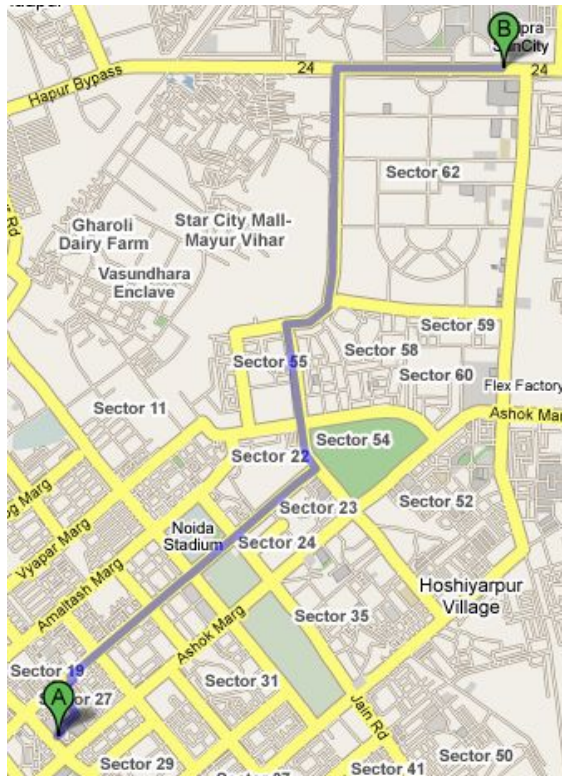
- ## Statistical Machine Translation

Example: Maps & Localization

- Shared, highly-detailed maps of the world stored in the cloud

- Updates/ changes can be published and immediately used
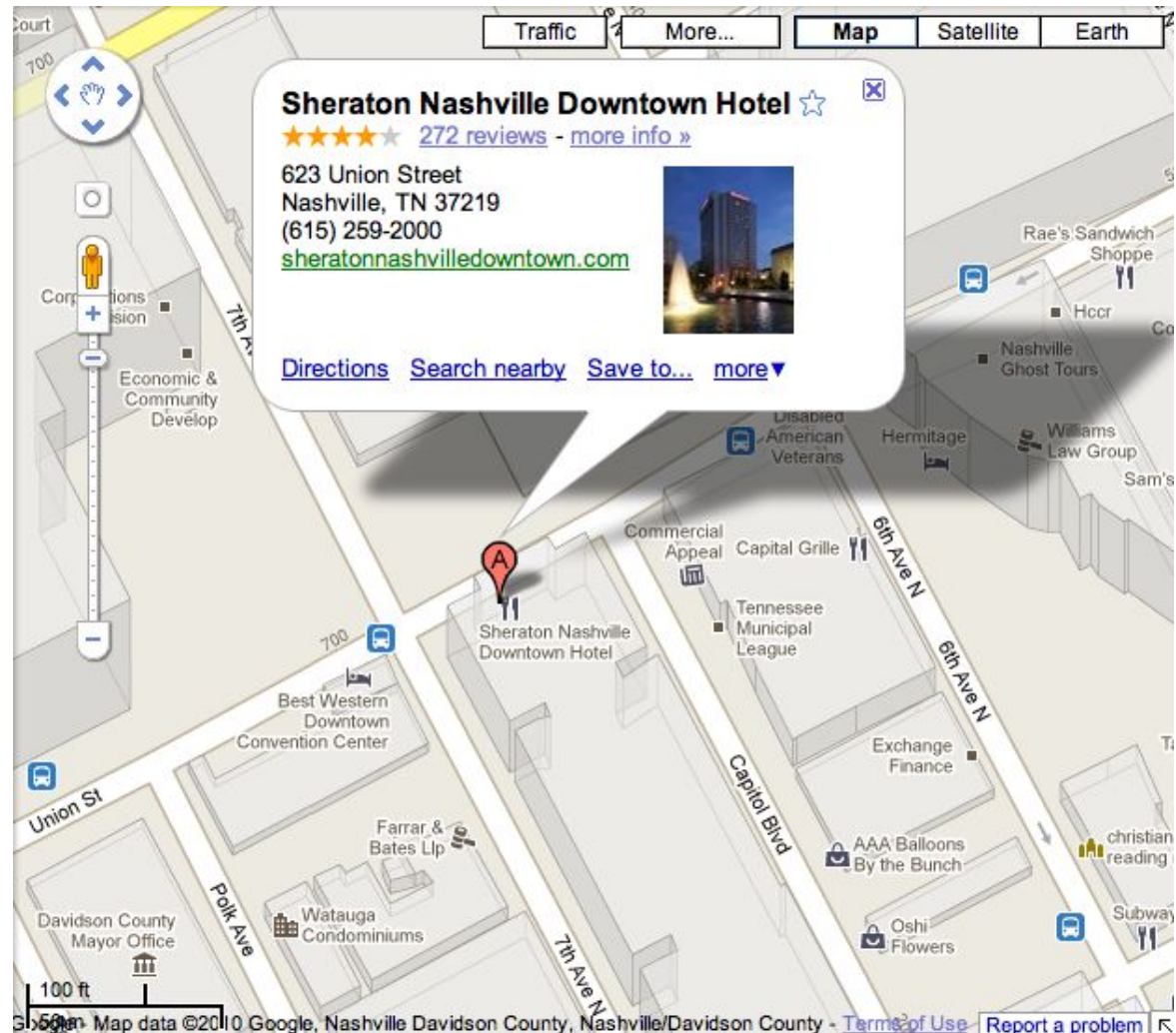
Example: Planning

- ## Navigation

- ## Difficult task or motion planning problems solved in the cloud
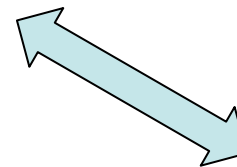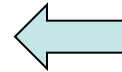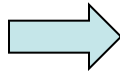 *(e.g "God's Number")*
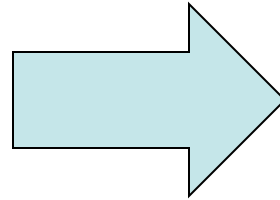

- 43,252,003,274,489,856,000 positions
- 35 CPU-years used

Example: Skills

- An "App Store" for robots
- Task → Objects/Domain Info → Usage Instructions → Behaviors/Motor Skills

"Contact Tamim"

"I Need a Helicopter Pilot Program…"

Summary

- Cloud computing can enable cheaper, lighter, "smarter" robots

- The infrastructure exists and is rapidly evolving in terms of performance and accessibility

- Create a "shared knowledgebase" for robots

  – Information about the world

  – Robot experiences / history / behavior outcomes / learned skills can all be published or data mined.