Cloud – Enabled Humanoids: (and the Future of Distributed Intelligence)

James Kuffner

The Robotics Institute
Carnegie Mellon University
Humanoid Motion Planning (1995-2011)

- 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
Self-driving Cars

- A total of more than 145,000 autonomous miles
- 10 high-complexity routes of roughly 100 miles each without human intervention.
Autonomous Grasping & Manipulation
(2000-2010)
RAVE: Online Manipulation Planning (2001)
Stable Grasp Generation

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

CMU PhD thesis: Rosen Diankov
Feasible Grasp Generation
Automatic Regrasping (2006)

Object-Specific 6D Pose Extraction

• Modeling Object Pose Error

CMU PhD thesis: Rosen Diankov
Whole-body Constrained Planning

Simultaneous Constraints and Goal Sampling Using TSR chains

[ Berenson, Chestnutt, Srinivasa, Kagami, Kuffner, *Humanoids*2009 ]
Model of Computation

INPUT  Computer Program  OUTPUT

Robot / World changes

ROBOTICS

SENSE

“Model of the world” Robot / World State

PLAN

Motor Commands (behaviors, pos/vel, torques)
Cloud Computing

• Documents “live” in the cloud (backed up and accessible anywhere)
• Netbook
• Supercomputing: (Heavy CPU or data-intensive processing handled by distributed network)
“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

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

• RoboEarth

• Cloud Robotics at Google I/O (May 2011)
Enabling Factors

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

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

- Statistical Machine Translation
Translation in the Cloud
Cross-Language Search

Google - restaurant reviews antwerp

Translated search

Translated results for restaurant reviews antwerp - My language: English

Dutch: restaurant reviews antwerpen - Edit
French: critiques de restaurants d'Anvers - Edit

Antwerp Restaurant Restaurants in Antwerp Belgium...
Translated from: Dutch
Write a review...Nice Greek restaurant in a beautiful place near Antwerp Kathedraal green place...Restaurant Name: WOK OF ANTWERP...

Antwerpen Restaurant Restaurants in Antwerpen Belgie...
Schrijf een review...Leuk Grieks restaurant op een mooie plek in Antwerpen vlakbij kathedraal groenplaats...Restaurant naam: WOK VAN ANTWERPEN...

www.antwerpenrestaurants.be/review.php

Pasta & Vino Restaurant Antwerp, Restaurants in Antwerp
Translated from: Dutch
Brunello 41 reviews. Food: 7 Control: 6 Atmosphere: 7. (13-10-2008). We have a lovely lunch at this cozy restaurant. Antwerp is our favorite city...

In the Shadow of the Cathedral Review Antwerp Best Restaurant...
Translated from: Dutch
In the Shadow of the Cathedral restaurant review by 10Best. This restaurant serves great food best Antwerp is one of the best places to eat in Antwerp.

Restaurant reviews, cookbooks and culinary shop weblog | Special Bite
Language Coverage

- 2006: Released our first Statistical Machine Translation Languages (project “Rosetta”)
- Today, cover nxn translation in 51 languages (2,550 pairs)
  - More than 98% of internet users (including all official EU languages)
  - First commercially available system for fa, iw, af, etc.

<table>
<thead>
<tr>
<th>Year</th>
<th>Languages</th>
</tr>
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<tbody>
<tr>
<td>2001</td>
<td>French, Italian, Spanish, Portuguese, German, Chinese, Japanese, Korean</td>
</tr>
<tr>
<td>2004</td>
<td>3rd Party RBMT, Arabic, Russian, Chinese (S), Chinese (T), Dutch, French, German, Spanish, Portuguese, Japanese, Korean</td>
</tr>
<tr>
<td>2006</td>
<td>Google SMT(3), Arabic, Chinese (S), Chinese (T), Dutch, French, German, Greek, Italian, Korean, Japanese, Russian, Spanish, Portuguese</td>
</tr>
<tr>
<td>2007</td>
<td>Google (13), Arabic, Bulgarian, Catalan, Chinese (S), Chinese (T), Croatian, Czech, Danish, Dutch, Filipino, Finnish, French, German, Greek, Hebrew, Hindi, Indonesian, Italian, Japanese</td>
</tr>
<tr>
<td>2008</td>
<td>Google (35), Arabic, Bulgarian, Catalan, Chinese (S), Chinese (T), Croatian, Czech, Danish, Dutch, Filipino, Finnish, French, German, Greek, Hebrew, Hindi, Indonesian, Italian, Japanese, Korean, Latvian, Lithuanian, Norwegian, Polish, Portuguese</td>
</tr>
<tr>
<td>2009</td>
<td>Google (51), Afrikaans, Albanian, Arabic, Belarusian, Bulgarian, Catalan, Chinese (S), Chinese (T), Croatian, Czech, Danish, Dutch, Estonian, Filipino, Finnish, French, German, Greek, Hebrew, Hungarian, Hindi, Indonesian, Irish, Italian, Japanese, Korean, Latvian, Lithuanian, Macedonian, Malay, Maltese, Norwegian, Persian, Polish, Portuguese, Romanian, Russian, Slovak, Slovenian, Spanish, Swahili, Swedish, Thai, Turkish, Ukrainian, Vietnamese, Welsh, Yiddish</td>
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Speech-to-Speech

- Recognition
- Translation
- Synthesis

Alex Waibel’s group (CMU & KIT)

Conversation Mode on Android
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...”
Al and Google

"The ultimate search engine will understand everything in the world."

Larry Page
ROS on Android

http://code.google.com/p/rosjava/

rosjava is the first pure Java implementation of ROS.

From ROS.org: ROS is an open-source, meta-operating system for your robot. It provides the services you would expect from an operating system, including hardware abstraction, low-level device control, implementation of commonly-used functionality, message-passing between processes, and package management.

Developed at Google in cooperation with Willow Garage, rosjava enables integration of Android and ROS compatible robots. This project is under active development and currently alpha quality software. Please report bugs and feature requests on the issues list.

To get started, visit the Welcome page of the wiki.

Still have questions? Check out the ros-users discussion list, post questions to ROS Answers with the tag "rosjava," or join #ROS on irc.freenode.net.

rosjava was announced publicly during the Cloud Robotics tech talk at Google I/O 2011.
Build your own cellbot!

- AppInventor interface for Android phones and tablets
- [http://www.cloudrobotics.com/](http://www.cloudrobotics.com/)
- ADK (Acessory Development Kit) for Android
Android-Based Robots

- App Inventor for Android and LEGO Mindstorms NXT
- NASA CubeSat Project
- Willow Garage TurtleBot with ROS on Android
Google/Hasbro Project Phonedox

Summary

• Planning requires “models” of the world to be useful.
• Cloud Robotics means models are distributed across cloud computers.
• Cloud Robotics enables cheaper, lighter, and “smarter” robots
• A rapidly evolving infrastructure already exists.
• Creating a “shared knowledgebase” for robots will enable a robot revolution…
  – Deep knowledge and information about the world
  – Robot experiences / user interactions / learned skills