Cloud Robotics: (and the Future of Distributed Intelligence)

James Kuffner

Google Research

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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
Autonomous Grasping & Manipulation (2000-2011)
Sampling-Based Planning with Rapidly-exploring Random Trees (RRTs)

q<sub>new</sub>  
q<sub>target</sub>  
q<sub>goal</sub>  
q<sub>init</sub>  
q<sub>near</sub>

“RRT-Connect” [Kuffner, LaValle ICRA ’00]
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)

OpenRAVE: Open-source Robotics and Animation Virtual Environment

http://openrave.programmingvision.com/
- OR -
http://www.sourceforge.net/
keyword: “openrave”
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
Mean Images of Induced Pose Sets

CMU PhD thesis: Rosen Diankov
Planning With Constraints
Whole-body Constrained Planning

Simultaneous Constraints and Goal Sampling
Using TSR chains

[ Berenson, Chestnutt, Srinivasa, Kagami, Kuffner, *Humanoids2009* ]
Search-based Artificial Intelligence

MOORE'S LAW


1,000,000,000 100,000,000 10,000,000 1,000,000 100,000 10,000 1,000

Intel® 486™ Processor
Intel® Pentium® II Processor
Intel® Pentium® III Processor
Intel® Pentium® IV Processor
Intel® Pentium® M Processor
Intel® Pentium® Pro Processor
Intel® Pentium® Processor
Intel® 80486 Processor
Intel® 8086 Processor

James Kuffner  (CMU/Google)
Cloud Robotics and the Future of Distributed Intelligence
IROS2011 Workshop: Knowledge Representation for Autonomous Robots
AI and Google

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

Larry Page
The Rise of Cloud Computing
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
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/uploads
  – 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-to-Speech

- Recognition
- Translation
- Synthesis

Alex Waibel’s group (CMU & KIT)
• Statistical Machine Translation

http://translate.google.com/

Translate over 50 languages

From:Japanese▼  To:English▼  Translate

Type text or a website address or translate a document.

Do more with Google Translate

Stumbled across a foreign website?
Download Google Chrome, a fast and secure web browser with built-in translation.

Linguists, robots or aliens? Learn about the technology behind Google Translate and how you can help us improve.

Reach an international audience. Add translated captions to your YouTube videos.

Wish your Norwegian fans could read your blog? Install the Google Translate Element for easy 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 $\rightarrow$ Objects/Domain Info $\rightarrow$ Usage Instructions $\rightarrow$ Behaviors/Motor Skills

“Contact Ryan”
“I Need a Helicopter Pilot Program...”
Build your own cellbot!

- AppInventor interface for Android phones and tablets
- http://www.cellbots.com/
- http://www.cloudrobotics.com/
- ADK (Accessory Development Kit) for Android
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.oftc.net.

rosjava was announced publicly during the Cloud Robotics tech talk at Google I/O 2011.