Introduction to Cognitive Robotics

Module 7: Cognitive Architectures

Lecture 4: The CRAM cognitive architecture: design principles

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www.vernon.eu

CRAM

- CRAM: Cognitive Robot Abstract Machine
- Hybrid cognitive architecture (symbolic and sub-symbolic representations and processes)
- Introduced by Michael Beetz in 2010
  - developed significantly since then based on several research projects
- Designed to address robot manipulation tasks in everyday activities
  - tasks that would typically be carried out by people in household settings, e.g. in a kitchen.

The Robot Household Marathon aka the EASE Robot Day Demonstrator

Gayane Kazhoyan, Simon Stelter, Ferenc Balint-Benczedi,
Franklin Kenghagho Kenfack, Sebastian Koralewski and Michael Beetz

Everyday Activity Science and Engineering
www.ease-crc.org

Artificial Intelligence

Universität Bremen

https://www.youtube.com/user/agkiunibremen

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Design Principles

Implicit-to-explicit manipulation: “fetch the spoon and put it on the table”

Vaguely-stated high-level goal → Specific low-level motions required to accomplish the goal

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Mapping is accomplished using a generative model:
Tightly-coupled symbolic and sub-symbolic knowledge representations
of the robot, tasks it is performing, objects it is acting on and environment in which it is operating

Design Principles

Implicit-to-explicit manipulation: “fetch the spoon and put it on the table”

Vaguely-stated high-level goal → Specific low-level motions required to accomplish the goal

Requested by another agent or self-generated

Constraints at the general high-level are propagated to the low-level execution in the mapping

Success in accomplishing the goal is evaluated in the same space as that in which the goal was formulated, i.e. the perceptual space

Design Principles

CRAM focusses on abstract specification of robot actions that are underdetermined

- The action specifications are framed in terms without all knowledge required to complete the action

  e.g "fetch the milk and pour it in the bowl"

- The knowledge required to complete the action is resolved at run-time during plan execution
- by querying in real-time a multi-element knowledge-base
  - Prior knowledge
  - Current world states
  - Robot's sensorimotor state

Design Principles

The control program is stated as a generalized action plan

- One plan for each category of underdetermined action description, e.g. fetch, place, pour, cut, ...
- The plan can be executed
- The plan can be reasoned about and transformed
    - Self—programming
    - Development and self-improvement through automatic generation of new plans

Design Principles

The control program is stated as a generalized action plan

Generalized Action Plan → Motion Plan

This is the key concept in CRAM

3-step refinement process:
contextualization
Identify the values of the parameters to the motion plan that maximize the likelihood that the associated body motions successfully accomplish the desired action

The motion parameter values are provided by the generative model

Design Principles

The control program is stated as a generalized action plan

Generalized Action Plan → Motion Plan

This is the key concept in CRAM

The motion parameter values are provided by the generative model

Equivalent:

- Perform an underdetermined action description
- Execute (i.e. interpret) a generalized action plan
- Resolve a high-level action designator in a generalized action plan (explained in next few slides)

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Control strategies in object manipulation tasks

J Randall Flanagan[1], Miles C Bowman[1] and Roland S Johansson[2]

The remarkable manipulative skill of the human hand is not the result of rapid sensorimotor processes, nor of fast or powerful effector mechanisms. Rather, the secret lies in the way manual tasks are organized and controlled by the nervous system. At the heart of this organization is prediction. Successful manipulation requires the ability both to predict the motor commands required to grasp, lift, and move objects and to predict the sensory events that arise as a consequence of these commands.

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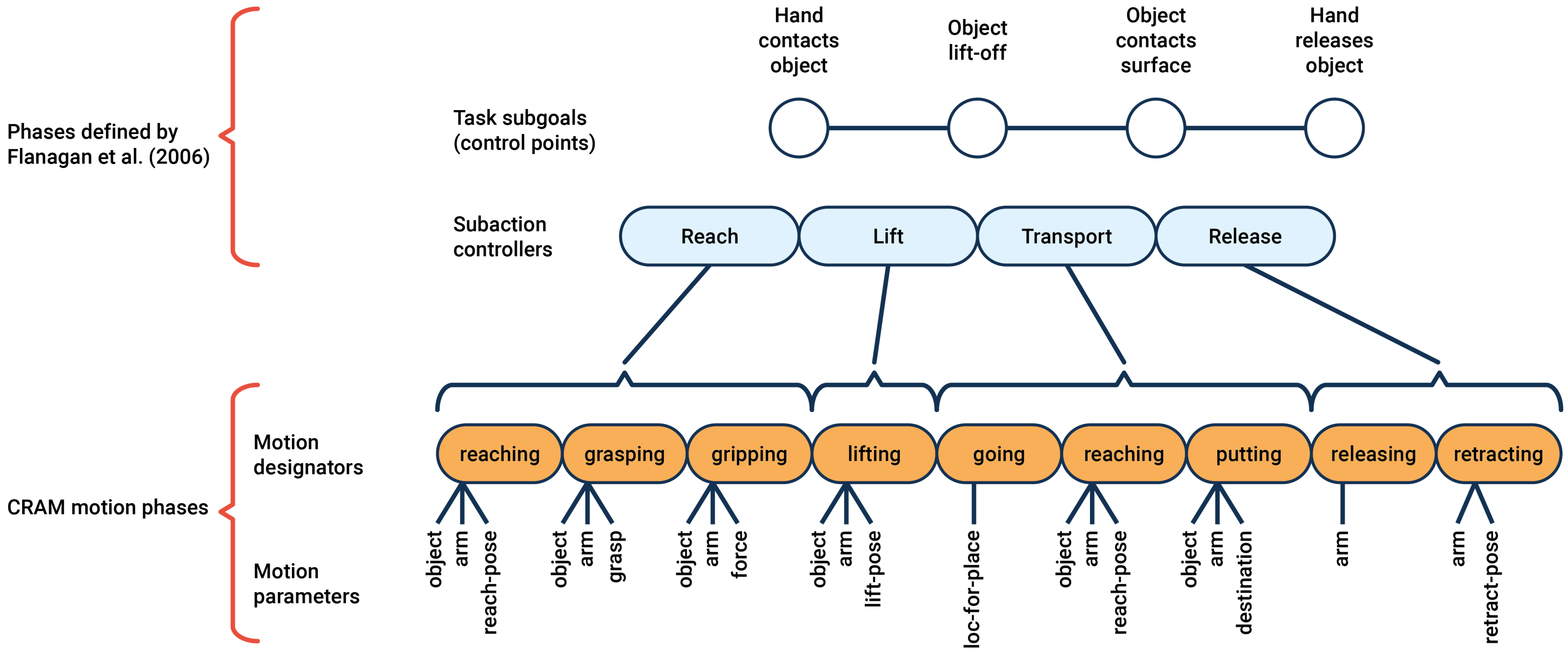
and another object or surface. Importantly, these contact events give rise to discrete and distinct sensory events, each characterized by a specific afferent neural signature. Because these sensory events provide information related to the functional goals of successive action phases, they have a crucial role in the sensory control of manipulations. In object manipulation, the brain not only forms action plans in terms of series of desired subgoals but also predicts the sensory events that signify subgoal attainment in conjunction with the generation of the motor commands. By comparing predicted sensory events with the actual sensory events, the motor system can monitor task progression and adjust subsequent motor commands if errors are detected. As discussed further below, such adjustments involve parametric adaptation of fingertip actions to the mechanical properties of objects, triggering

J Randall Flanagan, Miles C Bowman, and Roland S Johansson. Control strategies in object manipulation tasks. *Current opinion in neurobiology*, 16(6):650–659, 2006.

Motion Plan



J Randall Flanagan, Miles C Bowman, and Roland S Johansson. Control strategies in object manipulation tasks. *Current opinion in neurobiology*, 16(6):650–659, 2006.

Recommended Reading

M. Beetz, L. Mösenlechner, and M. Tenorth. CRAM – A Cognitive Robot Abstract Machine for Everyday Manipulation in Human Environments. In IEEE/RSJ International Conference on Intelligent Robots and Systems, pages 1012–1017, Taipei, Taiwan, October 2010.

M. Beetz, D. Beßler, A. Haidu, M. Pomarlan, A. Kaan Bozcuoglu, G. Bartels, "KnowRob 2.0 – A 2nd Generation Knowledge Processing Framework for Cognition-enabled Robotic Agents", In International Conference on Robotics and Automation (ICRA), Brisbane, Australia, 2018.