BECCA—A Brain Emulating Cognition and Control Architecture

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BECCA—A Brain Emulating Cognition and Control Architecture

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BECCA

• BECCA is a biomimetic approach to achieving human-like reasoning, perception, learning, and movement control in machines

• Capabilities
  – Learning complex, unmodeled systems and patterns (data fusion)
  – Predicting future events based on prior experience
  – Identifying novel patterns and concepts
  – Generalizing knowledge and applying it to unfamiliar situations (symbolic reasoning)

• It has two core algorithms
  – S-Learning
  – Context-Based Similarity
Overview

S-Learning
Rotary Robot
Reaching
Grasping

Context-Based Similarity
Natural Language Processing
Perception

Applications

Brain-Emulating Cognition and Control Architecture

Agent -> Planner -> World

- New experiences
- Current condition
- Update
- Query
- Report
- Train
- Report of actions

Experience Classifier

Effects of actions

Operational Diagram
Working Assumptions

- Sensor and control information
  - are passed in “episodic” fashion, quantized in time,
  - are discretized in magnitude,
  - are treated as categories, i.e. extrapolation and interpolation does not occur explicitly.
- Allows very general application
S-Learning Algorithm

• **S-Learning (sequence learning)**
  - records observed sequences and uses them
    • to make control decisions and
    • predictions about future events

• **Algorithm outline**
  - 1. If a sequence ends in a goal, remember it.
  - 2. If a sequence correctly predicts a goal, strengthen it.
  - 3. If a sequence incorrectly predicts a goal, weaken it.
S-Learning: Rotary robot

- Simulation of a one degree-of-freedom rotary pointer robot,
  - Sensor quantized in 10° increments
  - Movement by 10° increments
- S-Learning demonstrated the ability to learn and predict hard nonlinearities
- S-Learning performed optimally even in the presence of
  - Scrambled sensor conditions
  - Gain reversals
  - Stochastic movement errors
  - Random time delays
- No explicit model of the system was provided—its workings were discovered by S-Learning
S-Learning: Reaching simulation

- Two degree-of-freedom robot reaching simulation
  - Approximately human parameters used for inertia, movement characteristics, and sensing capabilities
- Robot learned to reach a fixed target at an arbitrary position in the plane
- Demonstrated *generalization*
  - Learning in one task was applied to a second task
  - This, despite the complete separation of the sensory representations of the two tasks
- *No explicit model of the system was provided*—its workings were discovered by S-Learning
S-Learning: Grasping simulation

- Three degree-of-freedom robot grasping simulation with rich sensors:
  - Coarse vision
  - Coarse position
  - Contact pressure

- Robot learned to reach a fixed target at a given position in the plane
- Learned to coordinate grasp with motion to grab target

*No explicit model of the system was provided* — its workings were discovered by S-Learning
Context-Based Similarity (CBS)

**Definitions:**
- **$\mathcal{E}$** *Key event(s).* The subjects of the comparison. This can be one or more events.
- **$\rho_e$** *Key pattern.* Any pattern containing $\mathcal{E}$.
- **$\alpha$** *Prefix.* The portion of $\rho_e$ that precedes $\mathcal{E}$.
- **$\omega$** *Postfix.* The portion of $\rho_e$ that follows $\mathcal{E}$.
  - i.e.: $\rho_e = [\alpha \mathcal{E} \omega]$
- **$\lambda_{\mathcal{E}}$** *Key library.* The set of all $\rho_e$.
- **$\tau_{\mathcal{E}}$** *Term set.* The set of all $\mathcal{E}$ occurring between a given $\alpha$ and $\omega$.
- **$\sigma_{\mathcal{E}}$** *Synonym set.* The set of events similar to $\mathcal{E}$.

**States that occur in a given context are related.**
- The semantic content of a state or event is defined by its surroundings.
Context-Based Similarity (CBS)

- Underlying concept: Events are similar if they occur in identical contexts.
  - Context refers to the surrounding events that precede and follow a given event of interest.
- CBS finds the word “great” and the phrase “very large” to be similar because they are preceded and followed by the same word(s), i.e. they are in identical contexts.
CBS: Natural Language Processing

- After reading 25 million words, CBS performed synonym extraction (finding sets of words that occurred in contexts identical to a seed word)
- No part-of-speech tags were given
  - In fact, CBS did not do anything that was specific to English, text, or language in general. It would have handled position and force data the same way.
- Plausible synonym groups were created
- Illustrates bootstrapped association of categorically separate inputs

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CBS: Concept formation

- Formulating the concept of the object <vehicle> by compiling specific examples
- Repeated sequences of 1) a static video background, 2) a dynamic video component created by a moving vehicle, 3) detected motion, and 4) detected sound allow the “synonym group” or concept of <vehicle> to be formed.
Formulating the higher-level concept <barrier> using previously developed concepts
Repeated sequences of 1) a proximity detection event, 2) a instance of one of several previously discovered concepts, 3) forward motion, and 4) collision detection allow the meta-concept of <barrier> to be formed.
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Humanoid robot control

- Physically interact with humans
- Learn to manipulate unfamiliar objects
- Acquire spoken language
- Learn complex perceptuo-motor tasks
- Create high-level abstractions
- Make predictions about future events
- Use reasoning to achieve goals
- Solve poorly-posed problems
- Generalize experience to novel situations
Multi-vehicle cooperative control

- Learn from experience
  - Individual vehicles
  - The cooperative as a whole
- Make predictions about unfamiliar environments
- Create conceptual symbols
- Find cross-domain patterns
- Use symbolic reasoning to interpret complex data
- Explore hypothetical situations

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Multi-media data mining

- Make predictions
- Create conceptual symbols
- Identify arbitrary patterns in large multi-modal data sets
- Use symbolic reasoning to interpret complex data
- Explore hypothetical situations
- Identify unusual or “red flag” situations