Natural Computation and Behavioral Robotics

Brains, Minds and Mechanisms

Overview

- How do we model brain ?
- How do we model behavior ?
- System-Theoretic approaches
- Memory and Behavior
- How general are these models ?
- Food for thought

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Brains and Minds

"Black-Box" approach: something we cannot explain

"Brain-as-Computer": brain is the device and mind is the logic (s/w)

"Behavioral" model: translate input-output transitions into pure mathematical models for describing the state-space machine

Modeling Behavior:

- Stimulus-Response patterns (state-space models)
  - Investigate Response in relation to Stimulii
- Cognitive Sciences (functional-physiological analysis)
  - Explain how and why the brain creates Response

"What is mind? No matter. What is matter? Never mind..." – Descartes

System-Theoretic Approach

- Stimulii: system input (sensor data)
- State: internal variables (feelings, energy, ...)
- Response: system output (decisions/actions)
- Transition: analytical mathematical model for calculating output (Response) from input (Stimulii) and current status (State).

Cellular Automata: model the system as a transition graph and move from one state to another based on current input and status.

Signal Processing: model the system as a set of differential equations to calculate output as a solution for the current state.

Approach I: Cellular Automata

Model description:

G : {S,V} = directional graph that describes the model's states (nodes) and transitions (vectors) for the CA

D : {I} = sensor data affect the final choice between multiple transitions from the current state (node).

$$CA\{S(k),V(k),I(k)\} \rightarrow CA\{S(k+1),V(k+1),I(k+1)\}$$

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Approach II: Signal Processing

Model description (linear):

X = current internal state {X(0) = initial state}

U = current external input

Y = current system output

Y(k) = H * X(k)	"action"
X(k+1) = F * X(k) + G * U(k)	"transition"
U(k+1) = U(k) + K * X(k)	"feedback"

Examples of Behavioral Models

Approaches similar to CA:

- Rule-based knowledge systems (E.S.)
- Fuzzy Rules
- Graph Search methods

Approaches similar to SP:

- Classic Automatic Control (linear models)
- Hidden Markov Models (probability-based CA)
- Pattern Recognition (ANN, SVM, ...)

Memory and Behavior

Memory

- The means of describing past experiences and the properties of the environment
- Also keeps track of previous states and transitions
- Large memory leads to “smart” but cumbersome agents
- Small memory leads to “dummy” but adaptive agents

CA: memory is the path that led to the current state

SP: memory is the residuals in the differential equation

How general are CA and SP?

- Linearity: The transitions in both the CA and the SP are deducted only from the most recent (previous) state.

- What about more complex behavior ?
- What about non-stationary behavior ?
- How “smart” can an artificial agent become ?

Proofs of generalization

- For CA, Computational Theory has proven that anything that is computable can be computed by the Universal Turing Machine (UTM), which is equivalent to a Universal CA.
  - Caution: see the Godel's and the Halting problem theorems
- For SP, Statistical Learning (Vapnik) has proven that, given an appropriate transformation of the input via a functional (kernel), any arbitrary mapping between input and output can be realized by a linear discriminant function (see: SVM).
  - Caution: The real problem is finding the appropriate kernels

Food for thought

- What about using “analog” (0...1) computers instead of “digital” (0 or 1) ?
- What is “intelligent” behavior? Can it be described by a CA or SP model ?
- Is there a difference between “true” intelligence (human?) and “simulated” intelligence (computer) ?
- How are “feelings” described in these models ?
- Is Godel’s theorem a proof against “strong” A.I. ?

P.C. – Readings

- John L. Casti, “Reality Rules II: Picturing the World in Mathematics – The Frontier”, John Wiley & Sons, 1997. [see: ch.6]
- John L. Casti, “Behaviorism to Cognition: A System-Theoretic Inquiry into Brains, Minds and Mechanisms”, in Real Brains & Artificial Minds, Elsevier, 1987.