Overview

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- Adaptive Behavior in ALCSs
  - Ideas and possibilities
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Anticipatory Learning Classifier Systems: An Introduction

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Based on material provided by Dr. M.V. Butz

ALCS: Introduction

- What is an ALCS?
  - Adaptive agent
  - Learns anticipatory model of an environment
  - Exploits model for adaptive behavior
- How does it work?
  - Interaction with some problem/environment
    - Perception of environment through situations
    - Manipulation by actions
  - Learn to anticipate effects while interacting (online learning)
  - Optimize behavior exploiting the evolving anticipations

ALCS: Environmental Interaction

ACS2

- Rule learning system
- Evolves a set of rules (= a population of classifiers)
- Each rule includes
  - Condition C
  - Action A
  - Effect part E
- Each rule explicitly anticipates something like:
  “I anticipate that executing action A under conditions C in my environment will cause the effect E”
- Population represents an environmental model

Classifier Structure

- Each classifier includes
  - Condition, Action, Effect (the anticipation)
  - Mark (situational properties of states in which anticipation was wrong)
  - Quality (accuracy of anticipation)
  - Reward prediction (expected reinforcement)
Learning the Model

- How is the model represented?
  - Population of classifiers
- What model do we want to learn?
  - A compact model that is able to accurately anticipate the effects of each available action in all possible situations in the environment
  - Complete, accurate, and compact environmental model
- How do we learn the model?
  - Evolutionary process evolves population of classifiers
Anticipatory Learning Process

• Basic Idea:
  – Exploit feedback as much as possible
  – Generate more specialized rules where necessary

• Background:
  – Psychological learning theory of anticipatory behavioral control
    • Primary learning process: Action-effect relations
    • Secondary process: Differentiation of conditions

• How does it work?
  – Evaluation of quality q
  – Update mark in case of wrong anticipation
  – Generation of specialized offspring:
    • No correct classifier present: Covering
    • Over-general classifier: Specialization of condition

• What does it do?
  – Covering of all situation-action-effect cases
  – Evaluation of classifiers
  – Specialization of over-general classifiers

> A directed evolutionary specialization mechanism

Genetic Generalization

• Given:
  – Continuous knowledge-based specialization of over-general classifiers (by anticipatory learning process -ALP)
  – Over-specialization due to ALP (various reasons for that)
  – Partly over-generalized complete and accurate environmental model (represented by classifier population)

• Goal:
  – Evolution of accurate, complete, and compact environmental model

• Basic Idea:
  – Use genetic mechanism to optimize / condense environmental representation
  – Implement a genetic generalization pressure

> A genetic generalization mechanism

ALP and GG Model Learning

ACS2: Basic Adaptive Behavior

• What do we have?
  – Evolving environmental model represented by classifiers
  – Reward prediction in each classifier

• How is behavior adapted?
  – Reinforcement learning
  – Modified Q-learning mechanism
  – Policy forming directly in evolving model
  – Policy dependent on a model
Anticipatory Adaptive Behavior

- Basic Idea: Exploit anticipations for further adaptation
- Exploitation Possibilities:
  - Faster Model Learning
    - Action planning towards unknown regions
    - Action selection bias towards unknown effects
  - Enhanced Reinforcement Learning
    - Mental Acting (internal reinforcement updates)
    - Look-ahead Action Selection (anticipating before acting)
  - Reasoning
    - Planning
    - Utility states

Faster Model Learning: Basic Idea

- Low level approach by action selection
- Choose actions with unknown results
- Implementing “curiosity”
- Choose biased selection with probability $p_{ab}$ and random action selection otherwise
- Two approaches:
  1. Action delay bias
  2. Knowledge array bias

Faster Model Learning: Realization

1. Action Delay Bias
   - Select an action with the longest delay
   - Enhance classifiers with time stamp recording last application time
   - Select an action of classifier with lowest time stamp (= longest delay)
2. Knowledge Array Bias
   - Select action with least knowledge about effect
   - Compute knowledge about consequences (average of classifier quality)
   - Select action with the lowest average quality (= least knowledge about consequence)

Adaptive Behavior in ACS

More Distinct Adaptation

- Behavior represented as reward prediction
- Basic Idea:
  - Exploit knowledge in environmental model
  - Adapt behavior further
- Methods:
  - Lookahead action selection
    - Anticipate using the model
    - Adjust behavior according to anticipation
  - Mental acting
    - Connect classifiers in model
    - Adjust reward predictions internally

Adaptive Behavior in ACS

More Distinct Adaptation: Tasks

- Psychological experiment with rats
- Normal reinforcement learning not able to solve the problem
- Non-generalizing model learner (e.g., Dyna) not able to solve the problem

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Use of Anticipations: Perspectives (1/2)

- Intentional mechanisms
  - Anticipation of voluntary results before action.
  - Intentioned viewed as the anticipation of action effects.
- Motivations
  - Options trigger motivations
  - Motivations trigger action selection
Use of Anticipations: Perspectives (1/2)

- Attention
  - Attention is usually task-related
  - Intentions & Motivations trigger attention
  - Selective attention
  - Preparatory attention
- Reactive mechanisms
  - Faster response due to anticipation of stimulus, response and effect
  - Unexpected changes can be detected faster

Summary

- Anticipatory learning classifier systems build generalized environmental models online
  - Model allows anticipatory processes
  - Better adaptive behavior by model exploitation
  - Anticipations control behavior
- ACS2 represents its model with a population of condition-action-effect classifiers
- Model can be exploited to improve
  - Model learning itself
  - Adaptation to problem

Conclusions

- Anticipations control our behavior
- Anticipations need to be used in intelligent (learning) systems
- Further adaptive possibilities:
  - Intentional mechanisms
  - Motivations
  - Attention
  - Faster reactive behavior
  - Faster & better adaptation