Retrospective Self-Adaptation of Domain Knowledge via Perceptually-Grounded Semantics

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FreeCiv

- Turn-based multiplayer strategy game

- Massive number of game states and many (compound) actions

- Interrelated subgoals (technology, population growth, military...)

![FreeCiv gameplay screenshot](image-url)
Object-level Reasoning of a FreeCiv Playing Agent

1. Play FreeCiv Turn
2. Select Compound Action
   - Set Tax Rates
   - Set Research Goals
   - Set City Production
   - Move Units
   - Manage Citizens
   - Set Government
3. Select and Move Unit
   - Select Unit
   - Select Unit Action
     - Move Settler Unit
       - Select Settler Unit Role
       - Select Settler Unit Action
         - Make Improve Terrain Move
         - Select Improve Terrain Action
     - Move Military Unit
       - Select Military Unit Role
       - Select Military Unit Action
         - Make Build City Move
         - Select Build City Action
Reflective Learning

- If the reflective layer detects that the agent has performed suboptimally, how to correct?

- Our group’s research theme: View the agent as an abstract device, with a task-level design and a method-level teleology

- Endow the agent with a declarative self-model of its design/teleology

- Use the self-model for agent self-analysis (structural credit assignment) and self-adaptation.
Autognostic

- Retrospective adaptations only, for some classes of problems.
- Autognostic's reflective layer reasons over a process-oriented self model in conjunction with a trace of failed reasoning to localize and repair faults.
- Strouli, E. & Goel, A. K. AAAI-96, IJCAI-97
Reflective Evolutionary Mind

- REM handles retrospective and proactive adaptations, again for certain classes of problems.
- Retrospective adaptation is similar to Autognostic.
- Proactive adaptation uses a description of a new problem plus background knowledge such as transformative operators.
Reflective Evolutionary Mind

- In some cases faults cannot be precisely identified, then an external technique (e.g. RL) is used to complete the adaptation.

Reflection on object-level knowledge

- What if a metareasoning process such as REM or Autognostic identifies a primitive task as the source of error?

- Primitive tasks are those that are directly implemented by object-level knowledge.

- Want reflective process to then descend into the task and reason about the knowledge.

- Take as an example the primitive 'select city build action' task.
City Location Quality Subproblem

- Predict shield (resource) production of a potential city over time
Object-level domain knowledge representation

- A commonly used pattern of hierarchical classification is “structured matching” (Bylander, et al., 1991)
- In structured matching, state features are progressively aggregated and abstracted
- Structured matching is efficient – linear in space and inference time with respect to input dimension
FreeCiv City Location Quality Knowledge Structure

- city_quality
  - shield_start
  - shield_growth
  - shield_utilization
    - shield_development_efficiency
    - shield_potential
  - shield_food_coincidence
  - population_happiness
  - population_growth
    - food_start
    - sufficient_squares
    - food_growth
      - food_development_efficiency
      - potential_food
    - fresh_water
Domain Characterization

- Task: Compositional Classification
- There is a set of “empirically determinable” features that share mutual information amongst themselves, and with the class label
- Assume a known independence structure
- Some features are only determinable after classification, and may have some cost
Empirical Verification Procedures

- REM and Autognostic provide theories of the kind of knowledge needed for metalevel reasoning over process – but what metaknowledge is needed for metareasoning over object-level knowledge?

- Use metaknowledge that grounds the semantics of object-level knowledge in perception.

- Can be exploited by the reflective layer to perform diagnosis over the object-level knowledge hierarchy.
Learning

- Exploit the empirical determinability of the represented features
- Learning technique used within nodes is flexible, as is the internal knowledge representation
- Different learning progressions based upon other design choices and problem characteristics; in all cases the EVPs are key in assigning fault to specific nodes.
Experimentation

- Rote “table update” learners, neural networks and kNN learners have been placed within nodes in our knowledge structures.

- We have experimented in synthetic domains, as well as in the FreeCiv example described, financial prediction and sports prediction.

- Some positive results with several domain/learner configurations, please see papers for detail.
Metareasoning Architecture

- Ground-level actions may be in service of reflective layer diagnosis; thus the metareasoning level may in some cases drive action selection.
Meta-knowledge here takes the form of an explicit representation of object-level knowledge semantics via connection to ground level percepts.
Metareasoning Architecture

- Meta-knowledge is distributed over object-level knowledge structures, not confined to separate metareasoning level representations.
Conclusion

• As metaknowledge in the form of goals can be used by a metareasoner to reflect on an agent's object-level process, metaknowledge in the form of grounding of concept semantics in perception can be used to reflect effectively on an agent's object-level knowledge.

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