Constructing Representations through Iterated Relational Learning

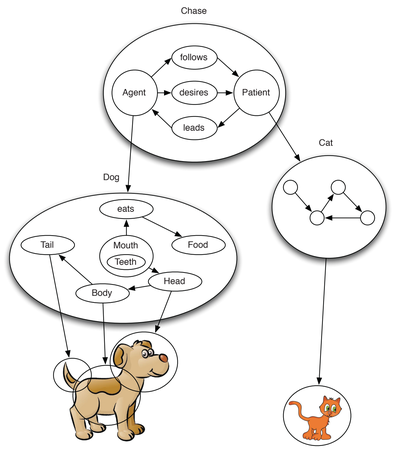
James Foster
James.M.Foster@colorado.edu
Fabián Cañas Matt Jones
canas@colorado.edu mcj@colorado.edu

Introduction

- Analogy allows discovery of new stuctural regularities in the environment
- Compare two scenarios and form a schema from their common structure
- Proposal:
  - These new concepts can then support further learning
  - Act as elemts in higher order relations
  - Iterated process of relational learning can lead to sophisticated abstract concepts

A Unified View of Objects and Relations

- Models of analogy ground representations in atomic object concepts
- Most objects actually have substructure
- Relational system among component subprocesses, capabilities, etc.
- Implications:
  - Many object concepts are products of iterated analogical learning
  - Extended relational hierarchies: Where can analogy gain a foothold?



Lessons from prior research

- MAC/FAC (Forbus, Gentner & Law 1995)
  - Distinguishes feature-based search from structural alignment
  - Feature vectors can drive paralell search and memory retrieval
  - Structural alignment acts on relational systems; Slow, WM intensive
- DORA (Doumas, Hummel & Sandhofer 2008)
  - Models relational predication as schema acquisition
  - Schemas can be elements of higher-order structures but remain relational systems
  - Shortcomings:
    - Representations only have meaning when grounded at a primitive level
    - Intrinsic capacity limitaion prevents model operating far above primitive level

Relational Consolidation

Concepts transition from explicit relational systems to atomic features/objects
- Acquisition of an atomic concept to stand in for a relational system
- Episodic memory consolidation is a special case.

- Extension of MAC/FAC
- Relational consolidation gives relational systems the status of features

- Consequences of relational consolidation:
  - Enables driect memory retrieval
  - Automatic detection without role binding, alignment, or WM demands
  - Allows consolidated concept to play a role in yet higher-level relations (Clark 2006)
  - Acts as a foothold for analogies on yet-higher-order structures
    - Reduces complexity of representation on which structural alignment acts

A Model of Hierarchical Analogical Learning

1. Relational representations constructed through dynamic role binding
2. Analogical comparison through structural alignment (Gentner, 1983)
3. Schema induction by intersection discovery (Hummel & Holyoak, 2003)
4. Schema Refinement through world-schema analogies (Doumas et al., 2008)
5. Relational consolidation
6. Iteration to construct hierarchies of increasingly abstract concepts

Technical Approach

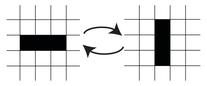
- Explore long-term dynamics of analogical learning and relational consolidation
- Complex environments with emergent hierarchical structure
- Test for autonomous discovery of useful higher-order relational concepts

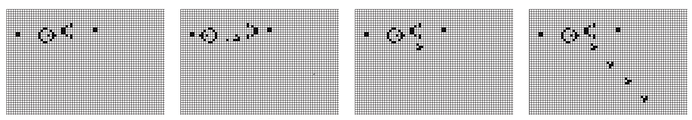
Model

Representational Assumptions
- Objects and relations are the same class of entities
  - Each capable of participating in external relations
  - Has a set of roles which can be bound to its components
  - Defines a structured system of relations among its components
- Scenarios (non consolidated relational systems) represented as graphs
  - Collections of objects bound to each other's roles (1)

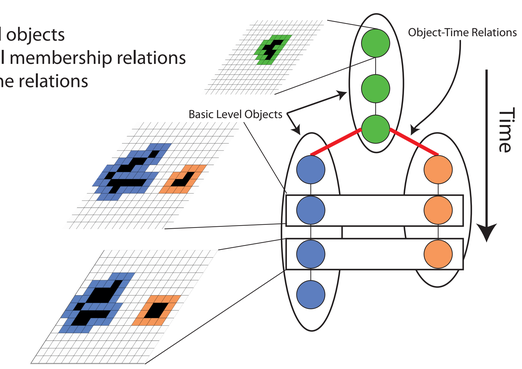
Process Assumptions
- Analogy via structural alignment (2)
  - Search for mapping to maximize paralellism and systematicity
  - Continuous dynamics of mapping weights (Larkey & Love 2003)
- Schema induction via intersection discovery (3)
  - New graph created comprising common structure of analogy participants
- Schema refinement (4)
  - Schema-world analogies generate sparser schemas
  - Incidental elements are removed
- Consolidation (5)
  - Define a new class of objects corresponding to a schema
  - One role for each element in schema
  - Instances of schema induce tokens of new class, bound to elements
  - Tokens eligible to play roles in other relations (6)

Test Domain

Conway's Game of Life
- Cellular Automaton
  - World is a grid whose state evolves according to simple rules
- Different seed patterns exhibit interesting properties:
  - Stable objects 
  - Periodicity 
  - Infinite Growth
  - ***Hierarchical emergent structure***



Starting representation
- Parse into basic-level objects
  - Segmentation within each time slice
  - Linking slices based on overlap
- Four types of entities
  - Cells
  - Basic-level objects
  - Object-cell membership relations
  - Object-time relations

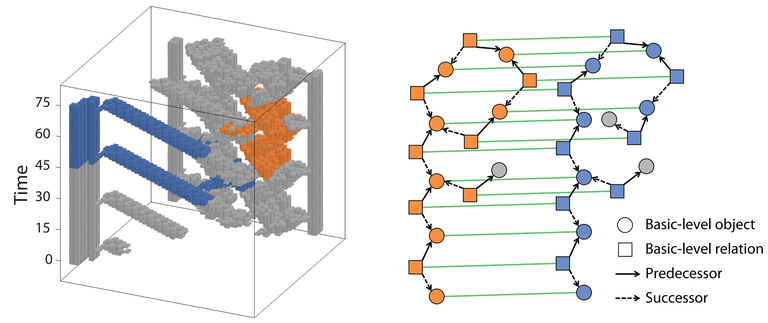


Goals

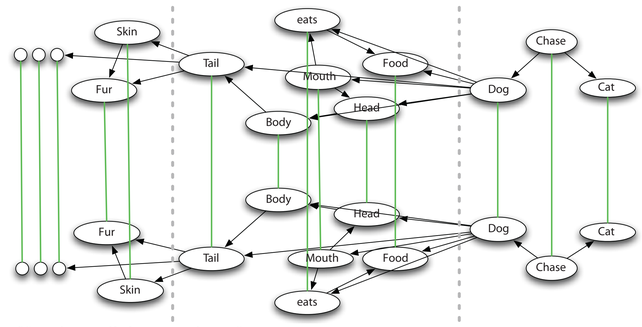
- Can model discover objects and relational systems in Life?
- Can model discover different types of objects?
- Can its concepts become more sophisticated with iterated consolidation?

Preliminary Results

- Model discovers analogies
- Abstracts beyond cellular representation
- Interesting long-term dynamics of schema refinement



Discussion and Further Conjectures



Pathology of "analogy all the way down"
- Mapping matched objects should lead to mapping all substructure
- Relevant even to simple analogies
- Active representation only includes maximal concepts
- Role of attention in determining resolution

Discovery of relations at new levels
- Emergence: objects form structures not anticipated from their components
- Configurations of relations among components, discovered and schematized via analogy

Analysis vs. synthesis
- Basic level is intermediate in scale (not minimal)
- How to discover substructure of initially atomic concepts
- Supposition of borrowed structure, instantiated with anonymous tokens

Basic-level relations
- Embodiment
- Conceptual learning as progressive abstraction from one's point of view

Neurological grounding
- Parieto-frontal construction of active relational representations
- Hippocampal storage
- Consolidation: Feed-forward training of detection by temporal cortex
- Gradient of abstraction within temporal cortex
- Closes the loop – new representations available as elements of new relations

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