Stable Configurations for Cooperation in Complex Agents with Minimal Communication

or

Where Should Complexity Go?

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Synopsis

• General Concept: People worry too much about communication in MAS and not enough about the agents themselves.

• Evidence: Animals are complex but their communication is simple.

• Special Concept: There is a trade-off between the amount of social structure required in a (primate) society and the capacity for conflict resolution (Flack and de Waal).
Outline

- Communication vs. Behavior Complexity
- How to Build Complex Agents
- Example: Socializing Without Communicating
- A Little More on Social Organization
Why Should Communication be Limited? (in Nature)

- In a complex dynamic environment, an agent has best access to its own opportunities and dangers.

- Signals must persist for multi-tasking agents to reliably observe them $\Rightarrow$ no rapid or detailed instructions.

- Perception is unreliable $\Rightarrow$ signals must be distinct $\Rightarrow$ not many different ones.

- Evolution favors behavior uniform within species and advantageous to conspecifics $\Rightarrow$ high-level reference sufficient.
Do These Criteria Apply to Artificial Agents?

- Yes if communication is limited (e.g. by distance) or highly time-critical (e.g. in Robocup).
- If they don’t, maybe we are discussing distributed intelligence in one agent, rather than a real multi-agent system (MAS).
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Start with Modular Intelligence

- Modules are relatively simple to design (or evolve).
- Provide the control for agent’s actions (expressed and/or internal),
- the perception required for that control, and
- the memory required for perception or control.

This extends Behavior-Based AI (Brooks 1986, 1991) to be more like Object-Oriented Design. A little like Fodor (1983) but no central processor, less encapsulation.
Add Arbitration for Resource Conflicts

- Hierarchical Reactive Plans
  - help limit search, and
  - provide state on decisions (to defeat dithering).

- Support three types of action-selection problems:
  - Some things need to be checked at all times: drives.
  - Some only need considering in particular contexts: competences.
  - Some things reliably follow from others: action patterns.
Arbitration is not Fully Centralized Control
Behavior-Oriented Design (BOD) Methodology

- Initial Decomposition
- Cyclic Development

(Bryson & Stein IJCAI 2001, Bryson MIT AI PhD 2001)
Initial Decomposition

1. Specify (high-level) what the agent will do.
2. Describe activities as sequences of actions. **reactive plans**
3. Identify sensory and action primitives from these sequences.
4. Identify the state necessary to enable the primitives, cluster primitives by shared state. **behaviors**
5. Identify and prioritize goals or drives. **drive collection**
6. Select a first behavior to implement.
Cyclic Development

• Scale the system.
  – Code behaviors and/or plans.
  – Test and debug code.

• Simplify the design.
  – Revise the specifications.
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# Basic Social Behaviors

<table>
<thead>
<tr>
<th></th>
<th>Navigate</th>
<th>Groom</th>
<th>Explore</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>state</strong></td>
<td>x, y, size, name</td>
<td>drive-level</td>
<td>drive-level</td>
</tr>
<tr>
<td></td>
<td>focus-of-attn</td>
<td>partner</td>
<td>direction-of-interest</td>
</tr>
<tr>
<td><strong>actions</strong></td>
<td>approach</td>
<td>groom</td>
<td>choose-new-location</td>
</tr>
<tr>
<td></td>
<td>unentangle</td>
<td>choose-partner</td>
<td>wait</td>
</tr>
<tr>
<td></td>
<td>do-it</td>
<td>engage</td>
<td></td>
</tr>
</tbody>
</table>
untangle (tangled?)

groom (C) (want-to-groom?)

explore (C) (want-novel-loc?)

wait (T)

life (D)

choose-partner

choose-explore-target

explore-that-a-way

lose-target

align

approach

groom

untangle
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<td><strong>state</strong></td>
<td>$x, y, size$</td>
<td>drive-level, partner</td>
<td>drive-level</td>
</tr>
<tr>
<td></td>
<td>name</td>
<td>groomed-by</td>
<td>direction-of-interest</td>
</tr>
<tr>
<td></td>
<td>focus-of-attn</td>
<td>groomed-at</td>
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<td>unentangle</td>
<td>choose-partner</td>
<td>wait</td>
</tr>
<tr>
<td></td>
<td>do-it</td>
<td>tolerate, notify</td>
<td></td>
</tr>
</tbody>
</table>
No Communication  
Wait on Groom  
Wait on Approach  

Percentage Waking Time in Activity  

[2*se, p< .05]  
[mean, N=16]  
grooming  
trying to groom  
untangling

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- No Communication
- Wait on Groom
- Wait on Approach

<table>
<thead>
<tr>
<th>Activity</th>
<th>Percentage Waking Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Communication</td>
<td>Highest</td>
</tr>
<tr>
<td>Wait on Groom</td>
<td>Middle</td>
</tr>
<tr>
<td>Wait on Approach</td>
<td>Lowest</td>
</tr>
</tbody>
</table>

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Legend:
- [2*se, p< .05]
- [mean, N=16]
- grooming
- trying to groom
- untangling
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A Little More on Social Organization

- Related primate species have differing degrees of hierarchical vs. egalitarian social orders.
- The ones that are more egalitarian have more reconciliation strategies and reconcile more frequently.
- Weird analogy: Kind of like token ring vs. ethernet.
- Egalitarians fight more, but with less severity.
- Some strategies can be learned, other seems innate.
- Goal of modeling effort.
Summary

• General Radical Concept: Maybe if things communicate much they aren’t really agents in a MAS, but are modules in an agent.
• Less Radical Concept: Maybe we should worry more explicitly about software engineering.
• Special Radical Concept: Maybe studying primate social organization will be useful to MAS research.
Acknowledgements

• Much of this work was done on DAML funding under the supervision of Lynn Andrea Stein, of Olin College of Engineering.

• Primate society conceptualizing done in collaboration with Jessica Flack of Emory University.
[Talk Boundary]
Is BOD Biologically Plausible?

• Elements in BOD
  – Behaviors: Neocortex
  – Action Selection: Basal Ganglia, Periaqueductal Gray Matter
  – Drive Collection: Amygdallic System

• Other Possible Additions
  – Smoothing and Interpolation (Cerebellum?)
  – Episodic Memory (Hippocampus?)
Revising the Specification: State

• Prefer the simplest.
  1. Control State
  2. Deictic State
  3. Specialized State (learning)
  4. Meta-State (learning to learn)

• Exceptions:
  – Eliminate Plan Redundancy
  – Reduce Plan Complexity
Revising the Specification: Control

• Prefer the simplest.
  – Single Primitive > Sequence
  – Sequence > BRP
  – Control State > Variable State

• Exceptions:
  – Want part of primitive ⇒ sequence.
  – Sequence elements repeated, skipped ⇒ BRP.
  – Use variable state to:
    * Replace lots of triggers.
    * Generalize control state.
Example
Control State Only

walk ⇒ (left-feeler-hit) ⇒ avoid-obstacle-left
      ⇒ (right-feeler-hit) ⇒ avoid-obstacle-right
      ⇒ walk-straight

avoid-obstacle-left ⇒ ⟨walk backwards → walk right → walk left⟩
avoid-obstacle-right ⇒ ⟨walk backwards → walk left → walk right⟩
Deictic State as Well

Avoid-hit, feeler-hit, compensate-avoid $\xrightarrow{\text{deictic-avoid}}$ hit-left $\xrightarrow{\text{feeler info}}$

walk $\Rightarrow \left(\begin{array}{c} \text{(feeler-hit)} \Rightarrow \text{avoid-obstacle} \\ \Rightarrow \text{walk-straight} \end{array}\right)$

avoid-obstacle $\Rightarrow \langle\text{walk backwards} \rightarrow \text{avoid hit} \rightarrow \text{compensate avoid}\rangle$
Specialized State (rather than Deictic)

- back-up, find-way
- store-obstacle
- specialized-avoid
- local-map
- feeler info

walk ⇒

(feeler-hit) ⇒ store-obstacle back-up
⇒ find-way
Learning

- Learning in Behaviors

- Learning of Plans
  - Search
  - Evolution
  - Imitation

- Learning Behaviors
  - Existing work is one behavior in BOD.
  - Learning dynamical models (e.g. Hogg, Brand)
A Simple Behavior

screeching
A Behavior with State

- screeching
- screeching-now?
- pulse-duration
Behaviors with Perception

- screeching
- screeching-now?
- pulse-duration
- known, liked
- recognize
- familiarity-levels
- affinity-levels
Behaviors that Aren’t Objects

- face recognizer
- identity
- screeching
- screeching-now?
- pulse-duration
- known, liked
- recognize
- familiarity-levels
- affinity-levels
Behaviors with Processes and/or Triggers

**action selection**

inhibit

**face recognizer**

identity

screeching

screeching-now?

pulse-duration

inhibit-STM

recognize

familiarity-levels

affinity-levels

known, liked
Some Things Follow: Action Patterns

⟨get a banana → peel a banana → eat a banana⟩
Another Representation:
Production Rules

(have hunger) $\Rightarrow$ get a banana
(have a banana) $\Rightarrow$ peel a banana
(have a peeled banana) $\Rightarrow$ eat a banana
Are Production Rules Better than Action Patterns?

(have hunger) ⇒ get a banana
(have a banana) ⇒ peel a banana
(have a peeled banana) ⇒ eat a banana
No — A Sequence is State

\[\langle \text{get a banana from left} \rightarrow \text{pass a banana to right} \rangle\]

(left neighbor offers banana) $\Rightarrow$ get a banana from left

(have a banana) $\Rightarrow$ pass a banana to right
Basic Reactive Plans: State + Flexibility

(hungry) ⇒ (full) ⇒ goal

( have a peeled banana) ⇒ eat a banana
( have a banana) ⇒ peel a banana
⇒ get a banana

Many different expressed plans (sequences of behavior) are determined by one reactive plan.
Drive Collections:
BRPs for Environment Monitoring

\[ \text{life} \Rightarrow \langle (\text{something looming}) \Rightarrow \text{avoid} \rangle \langle \langle (\text{something loud}) \Rightarrow \text{attend to threat} \rangle \langle (\text{hungry}) \Rightarrow \text{forage} \Rightarrow \text{lounge around} \rangle \]
How Hard is Learning Everything?