Redesigning the ICARUS Architecture to Model Social Cognition

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Research Objectives

We aim to develop a unified theory of the human cognitive architecture that supports:

• Representing and reasoning about others’ mental states
• Flexible inference and problem solving in this context
• Structural learning that supports these processes

The research project’s significance lies in its potential to:

• Improve accounts of human reasoning and learning
• Support agents/robots that interact effectively with humans

We have included ideas from the earlier ICARUS architecture but addressed some of its key limitations.
Recent Accomplishments

During the past year, our team’s accomplishments have included:

- Extending our model of incremental abductive inference to:
  - Use a more distributed, reified encoding of relations and unifications
  - Incorporate knowledge and beliefs about norms and anomalies
- Implementing / testing a complementary model of questing answering
- Extending our account of flexible problem solving to:
  - Organize search through an OR tree with alternative branches
  - Encode each node as an elaboration of its parent and inherit the rest
  - Handle problems stated as goals, tasks, or their combination
- Improving our model of flexible execution and interleaving to:
  - Operate over the new encoding for hierarchical plans
  - Support more effective revision of these plans when needed

Together, these support our aims to produce a more complete account of human cognitive abilities.
Abductive Inference in UMBRA

In previous years, we have developed UMBRA, an account of everyday reasoning that assumes inference:

• Draws conclusions not only about the environment but also about other agents’ mental states;
• Involves abductive generation of explanations via introduction of default assumptions;
• Operates in an incremental fashion to process observations that arrive sequentially; and
• Proceeds in a data-driven manner because understanding arises from observations about agents’ activities.

We have tested UMBRA on a variety of plan recognition tasks, some involving social interaction.

*Meadows, Langley, & Emery, PAIR 2013*
Extensions to UMBRA

In the previous year, we extended UMBRA to support embedded structures used in reasoning about mental states.

In the past year, we redesigned and reimplemented UMBRA from scratch to incorporate:

• A more distributed (Davidsonian) notation for relations / events
• Knowledge about norms that do not require any explanation
• Marking of assumed norms and detected anomalies
• Reified encoding of unifications to track equality constraints

These changes should lead the system to make fewer incorrect default assumptions and recover from others.

*Meadows, Langley, & Emery, ACS 2014*
We have also developed a complementary module – PHOS – for answering questions that:

• Operates over the *same explanatory structures* as UMBRA
• Also relies on *incremental abductive inference* with defaults
• Proceeds in a *query-driven* rather than a data-driven manner
• May require *multiple attempts* before generating a response
• *Alters the explanation* and influences answers to later questions

Experiments revealed *depth-of-processing* effects; more effort by UMBRA reduced the effort PHOS required.

*Meadows, Heald, & Langley, CogSci 2015*
At the previous review, we reported modules for problem solving and execution that:

- Operate over hierarchical decompositions of problems
- Cycle through stages that inspect / manipulate these structures
- Encode strategies as domain-independent control rules
- Including ones for interleaving planning and execution

We demonstrated that both modules support a variety of familiar strategies from the literature.

We also tested them, and their combination, on a number of task domains, including ones that involved social planning.

*Pearce, Meadows, Langley, & Barley, AAAI 2014*
A problem consists of a set of state literals and goal literals; a solution decomposes it into subproblems with operators.

In social settings, state and goal literals include descriptions of others’ beliefs and goals.
In the past year, we have revised the problem-solving module, now renamed HPS, so that it:

- Organizes search as an OR tree with alternative branches
- Encodes each node as an elaboration on its parent
- Stores only altered elements and inherits the rest
- Retains dependency information to support plan revision
- Handles problems stated as goals, tasks, or in combination

These extensions let the system solve tasks that its predecessor could not.

HPS retains the ability to mimic many different problem-solving strategies.

*Pearce, Bai, Langley, & Worsfold, TR 2015*
The Space of Partial Plans

HPS searches an OR space in which each node denotes a partial plan that elaborates on its parent.

Here the system has found a solution (E12) by following the highlighted path from E1.
We have also extended the plan execution module, now renamed HPE, so that it:

- Operates over the new encoding for hierarchical plans
- Supports more effective revision of plans when needed
- Including the ability to execute generic HTNs reactively

HPE retains capacity to reproduce many strategies for execution such as open-loop vs. closed-loop control.

Together, HPS and HPE also support a variety of strategies for interleaving problem solving with execution.

*Bai, Pearce, Langley, Barley, & Worsfold, ACS 2015*
Experiments with different interleaving strategies suggest their effectiveness varies with environmental characteristics.
The problem solver, HPS, passes control to the plan executor, HPE, to carry out a (possibly partial) plan.

If HPE finds conditions unexpectedly violated during execution, it passes control back to HPS for replanning.
Although this project has ended, a new effort will build on the results we have achieved to:

• Extend the architectural framework’s representational power
• Modify its mechanisms to operate over these extended structures
• Make strategic knowledge conditional on situational features

Our emphasis will be on supporting greater *adaptability* and thus increased *autonomy* in intelligent agents.

This work will draw on our results with social cognition, but we do not plan to extend those abilities.
In this talk, I presented elements of a new architectural framework that addresses ICARUS’ limitations by:

- Representing mental states in terms of embedded beliefs and goals
- Incorporating modules for incremental abduction that enable:
  - Data-driven generation of explanations for observed behavior
  - Query-driven use of these explanations to answer questions
- Including modules for problem solving and execution that:
  - Construct plans by decomposing problems into subproblems
  - Use meta-level rules to create and execute plans with different strategies
  - Support alternative strategies for interleaving planning with execution

These elements provide the building blocks for a new cognitive architecture that will support more autonomous agents.


Cooperative Development

Our research on this project has benefited from results produced on a number of other efforts:

• Commitments to hierarchical concepts / skills borrowed from initial ICARUS architecture developed under ONR funding;

• Representation of mental states developed jointly with ONR MURI project at CMU;

• Ideas on abductive inference co-developed with W. Bridewell in ONR MURI work at Stanford.

These efforts have let us make more rapid progress than would have been possible otherwise.
The research project’s budget, by federal fiscal year, is:

- FY2012: $118K
- FY2013: $179K
- FY2014: $182K
- FY2015: $60K

No DURIP were awarded in relation to this project.
End of Presentation