Abstraction Strategies for Complex Hybrid Systems

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Abstract

We propose a general method of designing two-sorted reasoning systems, inspired by synthetic differential geometry. The goal is to explore a suggested new discipline in abstraction engineering to address vexing problems that involve human-machine interaction. Two examples are used, addressing Parkinson's Disease and cyberwar. The goal in both is the design of an 'autonomous analyst' as a human aid for advanced and meta-reasoning.

Introduction

Some problem domains are best addressed by devising a two-sorted reasoning system. These systems often consist of a primary or target reasoner and a meta-system that reasons about the target reasoner. A convention has the former on the right-hand side (RHS) of statements and the latter on the left-hand side (LHS). We consider two-sorted systems where the RHS usually is a conventional system that reasons about and/or models the world, and the LHS is abstracted from the RHS, using different types and operators. Typically, the LHS is a 'categoric logic'; this differentiates between systems of a similar construction where the two reasoners share types, connectives and a basis in set theory. For our purposes, we classify second-order, modal and introspective logics together as candidates for RHS systems but not LHS.

Our research group addresses problems that would benefit from a two-sorted approach, many of which are defined by the need for integrated human/machine reasoning. In particular, we are looking toward a facility to enhance human understanding of agile, adaptable human-machine systems.

Prior approaches to this problem domain have been exotic, computationally costly, incomplete, or narrowly focused. Therefore, a need exists for solutions that supply practical advantage that might come from a two-sorted approach, where these are managed by abstracting to more apt spaces.

For these types of problems, we suggest a new discipline, 'abstraction engineering,' is required in part to indicate where a two-sorted approach may be beneficial and what the nature of the LHS may be.

This paper takes a first step toward such an engineering discipline by defining a set of pressing problems, and reviewing techniques applied in similar domains. We report initial conclusions for solutions to our problem domains, balancing effectiveness, cost, human intuitiveness and generality. We do not attempt a survey of logics and topological analyses.

Problem Domains

Candidate problem domains tend to fall into two categories, both addressing deficiencies in the RHS, resulting from inherent constraints of logic, challenging source information, or extended reasoning ambition.

- In 'category 1,' the user has a "god's eye view" with access to the systems on both the right and left hand sides.
- Category 2 users have access to only the RHS, where any LHS entities and dynamics must be converted to RHS equivalents, however lossy.

Category 1

The LHS can 'see' elements in the RHS and dynamically re-engineer them for effects that would be difficult or costly otherwise. The user has access to both sides, and uses mechanisms from each where appropriate. Applications include:

- Reasoning over information, perhaps at scale, that is ontologically heterogeneous using the LHS to dynamically modify ontologies based on situated governance.
- Reasoning over communications to effectively encrypt and intrusively decode them.
- Reasoning to develop coherent theories of the bio-mechanisms among overlapping human-biome systems: their signal, channel, and effect fabrics.

- Reasoning to enable an 'autonomous analyst' to dynamically reconfigure mixed autonomous/human systems for optimized or constrained behaviour, for example, enterprise management or military command and control.
- Design of dynamic reasoners for electronic warfare where the physics of the involved systems are mixed with strategic and tactical intents, including deception.
- Reasoning over RHS systems with the intent of mastering influence and effect, with perhaps unseen control. Our category 1 example is this kind, addressing a cyberwarrior primarily concerned with managing provocateurs by thwarting their intent. This includes traditional cyber-intrusion and weaponised narrative.

Category 2

The RHS can use elements from the LHS to better perform tasks that would be impossible without the expanded LHS-enabled abstraction space. The user is limited to the RHS reasoning system and employs the two-sorted technique to escape the limits of closed world reasoning. Applications include:

- Reasoning over information at massive scale where collections are gathered as LHS tokens to be reasoned over conventionally and optionally resolved.
- Reasoning systems that provide an interface between the central nervous system and bionic devices. The complex signal fabric of the Central Nervous System is presumed to be best characterised by LHS dynamics.
- Support for narrative reasoning within new media systems, managing overt and hidden metaphors and retroactive reinterpretation.
- Reasoning simultaneously over both reductionist and system models of complex systems like human bodies. System 'imperatives' and signals will be LHS tokens that may be resolvable by RHS means (in our example case, drugs). Our category 2 example is this type, examining Parkinson's Disease (PD) with the intent of devising pharmaceutical interventions.

Generally, both categories are applications where a human or human-assisted analyst needs to understand and engineer a system that is modelling and acting on the world. Targets of specific interest are intelligent queries over large, heterogeneous and incomplete data sources; causal signal modelling in biomedical systems; and, enterprise optimisation with non-ergodic decision spaces and unknown futures.

A Common Model of Ontological Zones

A common model is used in the examples, with interacting 'ontological zones' each with unique abstractions but with underlying common type systems:

- The presented environment.
- The reaction of the agents governed by the model. In category 1 cases, these agents have access to LHS dynamics.
- A number of zones capturing the dynamics of the world(s) involved.
- The interpreted, perceived or engineered result.

The basic problem is to accept the world(s) in the first of these (the presented environment), and effect a suitably changed world in the last (the result).

Strategies

We will leverage a number of strategies. Synthetic differential geometry is expected to inform the design of practical LHS systems, given an understanding of required type dynamics. A novel understanding of narrative dynamics will inform the theory of science we employ, based on a preference for ontic realism. Traditional agent models will be accommodated on the RHS, but a new model of agent governance will be devised for LHS dynamics based on functor-defined reactive functions[1].

The paper will be accessible to non-mathematical readers, but it will follow a formal mathematical development.

[1] A functor maps between two or more categories, being the most useful relation for our purposes.