Fusion Sub-System Design

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Briefing Topics

- Relationship of Reasoning & Cognition
  - Decision Making Paradigm
- Data / Information Fusion
  - Architecture (Hawkins Neocortical Paradigm)
- Supporting Technologies:
  - Formal Concept Analysis (FCA)
  - Temporal Concept Analysis
  - Peircean Reasoning
  - Modal Logic
- Status
Cognition vs. Reasoning

- **Cognition:**
  - Is the function associated with the acquisition, storage, representation and utilization of information.

- **Reasoning:**
  - Is the function to discern what is unknown from a position of what is known.
    - Reasoning is fundamental to human decision making, it is endemic in everything we do.
      - Reasoning can be a skilled application of the scientific method or a process flawed in its method, and/or data. (Peirce’s fixation of belief; tenacity, authority, …)
  - Reasoning is a product of Cognition.
Belief and Decision Making

- Beliefs “…guide our desires and shape our actions.” C.S. Peirce
  - Peirce believes “doubt” in the fuel that drives the engine of inquiry.
- Inquiry employs the mechanisms of reasoning to mitigate doubt.
- These perspectives on belief and reasoning provide the basis for a “decision making” paradigm.
Decision Making

- The convolution of data and knowledge form the basis of a belief state.
- Belief may be revised by assimilating new data, or updating the knowledge base.
- Given a belief state, actions taken are conditioned by the decision maker's degree of risk aversion and uncertainty or doubt at the time of the decision.
Data / Information Fusion

- The decision making model has an intrinsic fusion functionality.
- This functionality is founded on the mechanics to reasoning.
- Design of virtual fusion systems must consider reasoning as a fundamental function of fusion.
  - Failure to include this in the design is a major design failure.
Architecture
The intersection of philosophy and engineering

- Hawkins neocortical model
  - 6 neural layers.
    - Provides an abstraction mechanism.
  - Feedback loops between all layers.
    - Activate “expectation” mechanisms (prediction)
  - Linkage between functional regions.
    - Multi-sensor capabilities.
- A physical manifestation of Peircean reasoning.
Design Implementation

Automated & Deliberate Processes

Detail of the Deliberate Processes

Reasoning System Information Process Flow

- Problem Domain
- Intel / Data
- Knowledge Base
- Working Context
  - Disjunctive Logic
  - Non-monotonic Logic
    - Paraconsistent Logic
  - Knowledge "ether"
- Knowledge Operators (JSM)
- Augmented JSM Operators
  - Temporal Logic
- Temporal Logic
- Doxastic Logic
- Epistemic Logic
- Belief State
- Hypotheses

Collect validation data

Data collection

Objectives

Decision Engine

Belief State Cache

Decision Control

Hawkins NeoC Model / Base

Peircean Reasoning

Reasoning PKG

Knowledge Operators

Knowledge Base PKG

Knowledge Representation / Base

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Briefing Topics

- **Relationship of Reasoning & Cognition**
  - Decision Making Paradigm

- **Data / Information Fusion**
  - Architecture (Hawkins Neocortical Paradigm)

- **Supporting Technologies:**
  - **Formal Concept Analysis (FCA)**
    - Knowledge representation
  - **Temporal Concept Analysis**
    - Knowledge representation in a temporal domain
  - **Peircean Reasoning**
    - Belief state generation/revision
    - Hypothesis generation
  - **Modal Logic**
    - Belief revision, knowledge update, temporal reasoning, etc.

- **Status**
Formal Concept Analysis (FCA)

Based on Ordered Set Theory

\[ \mathcal{K}_{FC} = (G, M, I) \]

G & M represent sets of “objects” and “attributes”
I is a binary relation between sets G & M

Fundamental operator ( )’

\[ (A)' = \{ m \in M | (g, m) \in I \text{ for all } g \in A \} \]

\[ (B)' = \{ g \in G | (g, m) \in I \text{ for all } m \in B \} \]

Natural extension of attributes into a real valued domain.
Fuzzy set theory provides the mathematical transformation.
Temporal Concept Analysis

- Natural extension of FCA (Wolff, Neouchi)
  - Approach adds second set of edges (directed)
  - Identify state trajectories and terminal states.
- Our approach takes a modified view of systems / states.
  - Systems possess temporally dependent attributes.
  - Permits robust application of the most effective technology.
  - Potentially enables “reuse” of Mill’s operators.
Modified “state” Perspective

- “snapshots” provide different views of included attributes.
  - FCA identifies 2 hypotheses.
  - Temporal matching narrows the hypotheses

- Potential temporal technologies:
  - Markov techniques
  - Bayesian technologies
  - Temporal extension of FCA
Peircean Reasoning

- Peirce’s “method of scientific inquiry”.
  - Abductive component adds unique capabilities.
- Initial set of knowledge operators based on “Mill’s Canons”.
  - Method of Agreement
  - Method of Differences
  - Indirect Method
  - Method of Residues
  - Method of Concomitant Variations
Peirce’s Reasoning Model

- Deduction
  - The argument which shows a necessary connection between premises and the conclusion.
    - Logical deduction has its basis in mathematical reasoning.

- Induction
  - Draws a rule from the results of sample cases.
    - Three types: crude, quantitative, and qualitative.
      - Crude: Denying an event because it seldom happens.
      - Quantitative: Arguments based on a random sample.
      - Qualitative: Involves the verification or confirmation of a hypothesis.

- Abduction
  - The formulation of hypotheses, the process by which we arrive at plausible explanations of unique events.

- Analogic
  - The formulation of hypotheses through analogy.
Modal Logics

- Modal logic is the calculus of information processing
  - Address many dimensions of information operations.
    - Knowledge, belief, morality, time

- Epistemic Logic
  - Basis for treatment of Knowledge
    - Tactical, Operational, Strategic skills

- Doxastic Logic
  - Basis for treatment of Belief
    - Decision making

- Deontic Logic
  - Basis for the handling of moral issues
    - ROEs

- Temporal Logic
  - Dealing with temporal aspects of information
Status

- We have:
  - Defined a model of fusion.
    - Uses a human based fusion construct.
  - Validation of the hybrid technology integration is progressing.
    - Shooting for a 70% solution.
  - A non-traditional view of system states is being employed to maximize technology effectiveness.

- We must:
  - Explore modal logics in greater detail.
  - Assess and expand the knowledge operator sets.
    - Consider; process reasoning, conceptual reasoning, causal reasoning, ...

- Implications:
  - Changes the information architecture, inverted conduit sizing.
  - Impact on sensor design, potentially focus sensing on higher level abstractions.
Backup Slides
Logic / Reasoning

- Logic foundations
  - $K \sim$ Knowledge
  - $B \sim$ Belief
  - $\models \sim$ "logically valid"
  - $\alpha, \beta$ represent blocks of information/knowledge
  - $\bot \sim$ logical contradiction

- Update and Revision
  - Principles 7-11
  - Contraction & expansion operators
    - $\cdot \cdot \cdot$, $+ \cdot \cdot \cdot$, $\cdot \cdot \cdot \cdot$
    - $\cdot \cdot \cdot \cdot \cdot$ expansion under consistency

Veridicality of Knowledge

1. $\models K(\alpha \rightarrow \beta) \rightarrow (K\alpha \rightarrow K\beta)$
2. $\models B(\alpha \rightarrow \beta) \rightarrow (B\alpha \rightarrow B\beta)$
3. $\models K\alpha \rightarrow \alpha$
4. $\models K\alpha \rightarrow B\alpha$
5. if $\models \alpha$, then $\models K\alpha$
6. if $\models \alpha$, then $\models B\alpha$
7. $\neg B\bot$
8. $BB\alpha \rightarrow B\alpha$
9. $\neg B\bot \rightarrow (B\neg B\alpha \rightarrow \neg B\alpha)$
10. $B\alpha \rightarrow BB\alpha$
11. $\neg B\alpha \rightarrow B\neg B\alpha$

(Consistency)
(Veridicality of Positive Introspection)
(Veridicality of Negative Introspection)
(Positive Introspection)
(Negative Introspection)

Ref. Lindstroem & Rabinowicz