



SAND2005-2938C

A Modified Perspective of Decision Support in C²

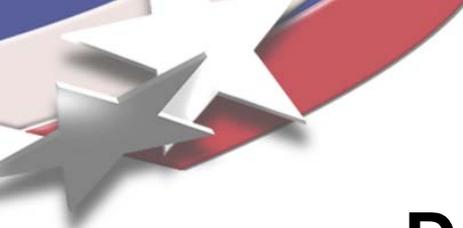
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Briefing Outline

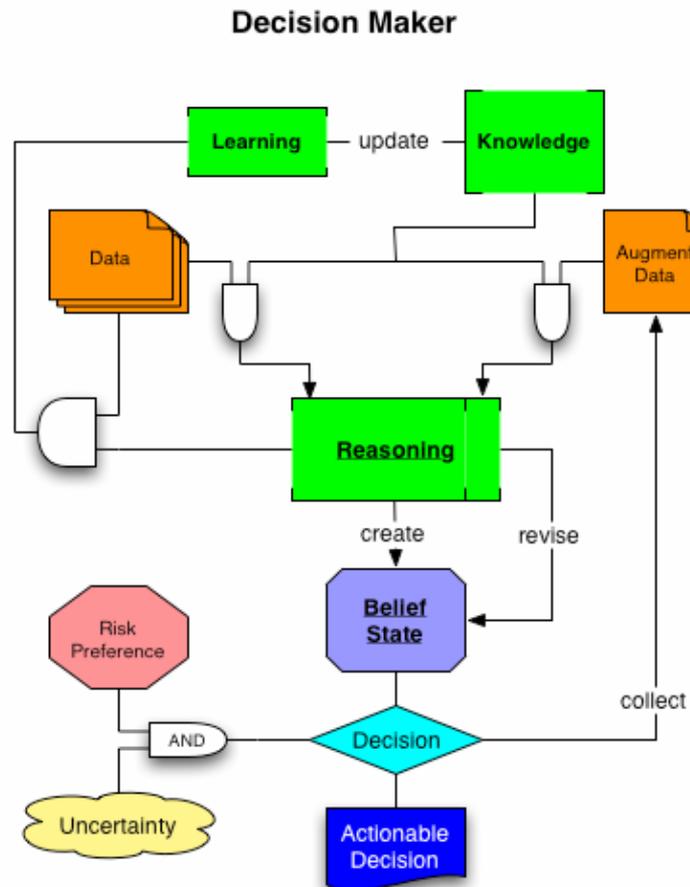
- **Decision Making Paradigm**
- **Problem Domain**
- **Solution Concept**
- **Technologies**
 - **Peircean Reasoning**
 - **Knowledge Representation**
 - **Modal Logics**
 - **Neo-cortical Model**
 - **Co-evolutionary Models**
- **Wrap-up**



Decision Making Fundamentals

- **Knowledge**
 - Tactical skills, technical understanding, adversarial capabilities, capabilities of his force, etc.
- **Data / Information**
 - Adversarial disposition of forces (numbers, locations), weather, terrain, etc.
- **Belief**
 - Convolution of knowledge and information.
 - Basis for situational projections
 - Basis for decisions
 - Influenced by
 - Data / information uncertainty
 - Risk aversion

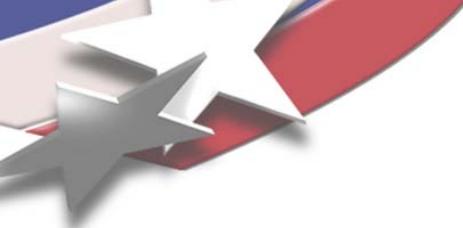
Command & Control Model





Problem Domain

- **IED Threat Space.**
 - **IRA bombing campaign analogue.**
 - **Antagonists adjusting to each others tactics.**
 - **Not amenable to “pattern matching” technologies.**
- **Problem is a multi-sided game in which all sides evolve a dominant strategy.**
 - **i.e. co-evolutionary game theory with n evolving players.**

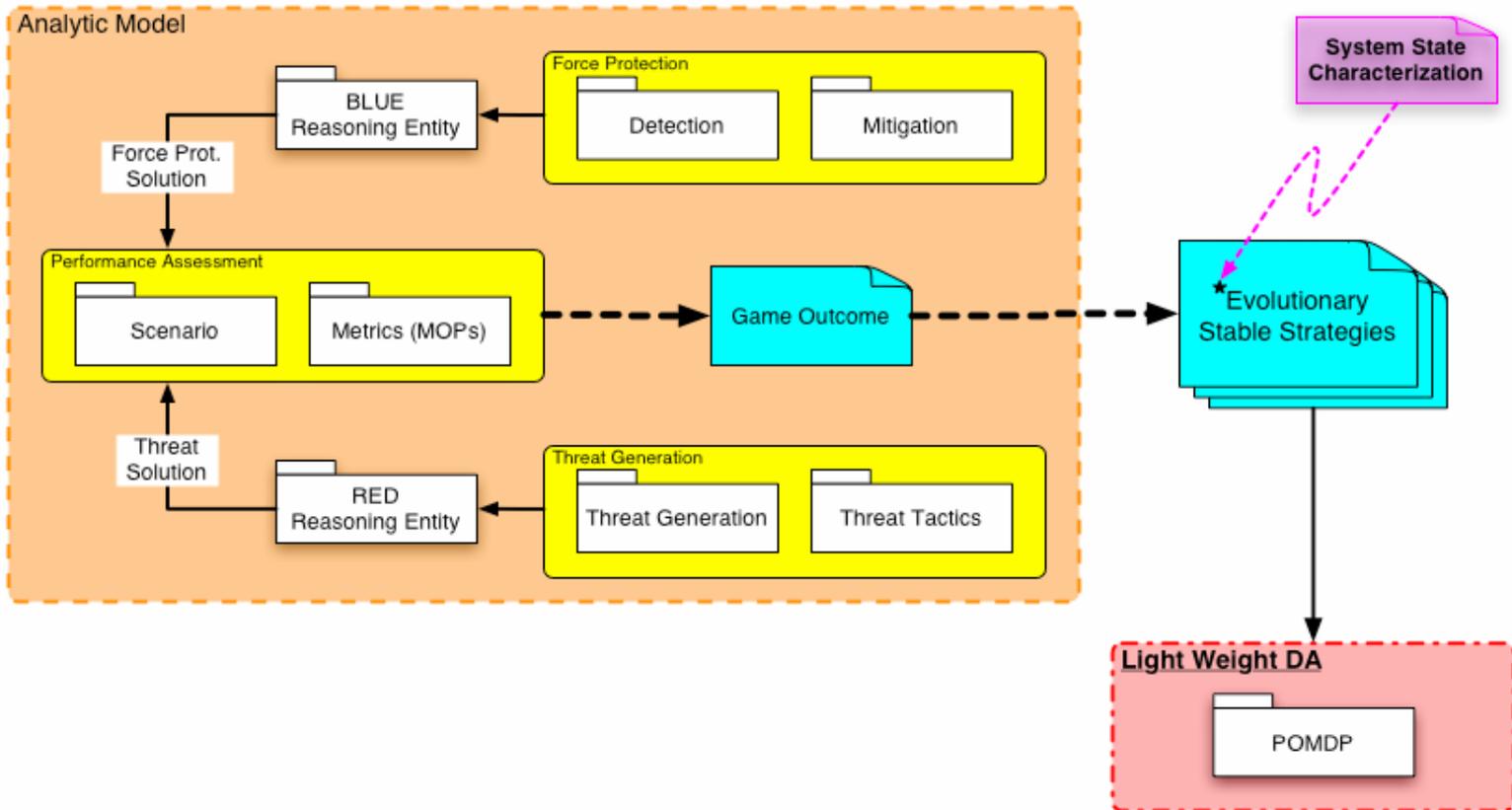


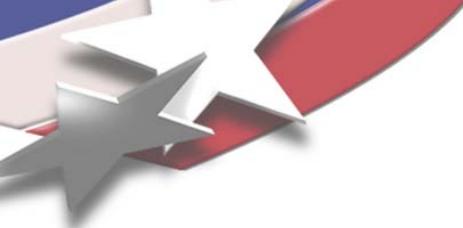
Solution Concept

- **Co-evolutionary framework**
- **Reasoning Engines**
 - **Modified evolutionary game theoretic**
 - **Peircean reasoning**
 - **Abduction, deduction, & induction**
- **Knowledge Representation**
 - **Formal Concept Analysis (FCA)**
 - **Strong mathematical foundations**
 - **Ordered set theory, lattice theory**

Architectural Graphic

Game Theoretic Environment



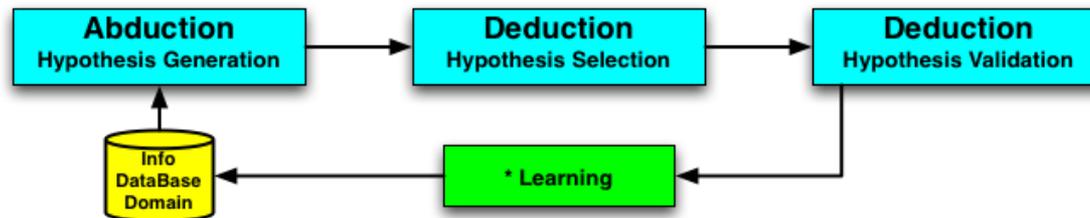


Technologies

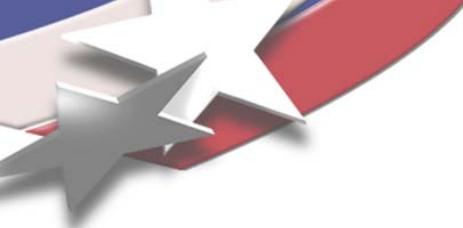
- **Peircean Reasoning**
 - Logic of reasoning
 - Reasoning operators
- **Knowledge Representation**
- **Modal Logics**
- **Hawkin's Neo-cortical Model**
 - Physical manifestation of philosophically based Peircean reasoning.
- **Co-evolutionary Models**
- **Fusion**

Reasoning consists of the formulation of a hypothesis through abduction, from which a series of experiments are postulated using deductive techniques. The results are inductive evidence used to verify or confirm the hypothesis.

Peircean System of Reasoning



* Basic Peircean Model with Ed Nozawa's cognitive interpretation.



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.

Peircean Reasoning Logic

Components of Peircean Reasoning

Deduction

$$\begin{array}{l} \text{Any } M \text{ (} \begin{array}{c} \text{is} \\ \text{is not} \end{array} \text{) } P \\ \text{(} \begin{array}{c} \text{Any} \\ \text{Some} \end{array} \text{) } S \text{ is } M \\ \bullet \bullet \text{(} \begin{array}{c} \text{Any} \\ \text{Some} \end{array} \text{) } S \text{ (} \begin{array}{c} \text{is} \\ \text{is not} \end{array} \text{) } P \end{array}$$

Induction

$$\begin{array}{l} \text{Any } M \text{ (} \begin{array}{c} \text{is} \\ \text{is not} \end{array} \text{) } P \\ \text{(} \begin{array}{c} \text{Any} \\ \text{Some} \end{array} \text{) } S \text{ (} \begin{array}{c} \text{is not} \\ \text{is} \end{array} \text{) } P \\ \bullet \bullet \text{(} \begin{array}{c} \text{Any} \\ \text{Some} \end{array} \text{) } S \text{ is not } M \end{array}$$

Abduction

$$\begin{array}{l} \text{(} \begin{array}{c} \text{Some} \\ \text{Any} \end{array} \text{) } S \text{ (} \begin{array}{c} \text{is} \\ \text{is not} \end{array} \text{) } P \\ \text{(} \begin{array}{c} \text{Any} \\ \text{Some} \end{array} \text{) } S \text{ is } M \\ \bullet \bullet \text{Some } S \text{ (} \begin{array}{c} \text{is} \\ \text{is not} \end{array} \text{) } M \end{array}$$



Reasoning Operators

J.S. Mill's Canons

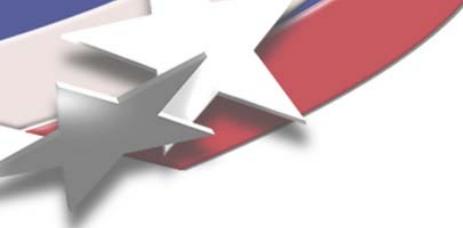
Method of Agreement

Method of Differences

Indirect Method

Method of Residues

Method of Concomitant Variations



Knowledge Representation

- **Formal concept analysis**
 - **Mathematical foundations**
 - **Ordered set theory**
 - **Lattice theory**
 - **Transformations of concepts into other dimensions**
 - **Galois transformation**
 - **Kuznetsov's chemical grouping research**
 - **Readily extensible**

Alternative FCA Representations

- **Formal Concept Analysis**
 - Context is expandable.
 - E.g. “Animals”
 - Orthogonal dimension of a context can capture different functionality.
 - IED: construction, detection, mitigation.

- **Lattice or Matrix representation**
 - Columns represent features
 - Rows represent concepts

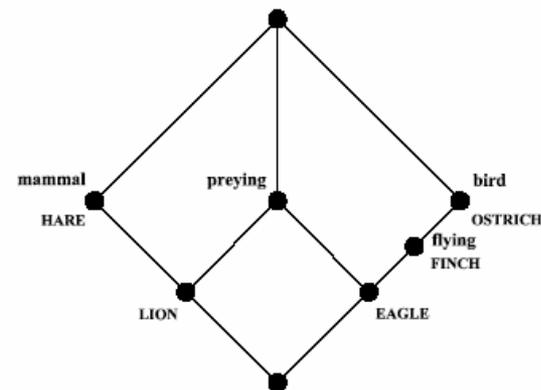
Note: Lattice reading rule:

- Object possess attributes above it, if there are lines connecting the object and attribute.
- E.g. Lion attributes {preying, mammal}

Feature Matrix

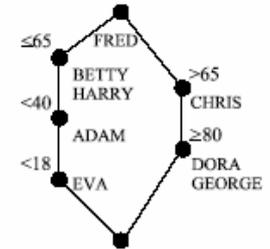
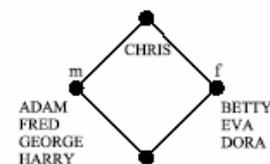
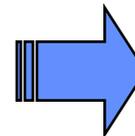
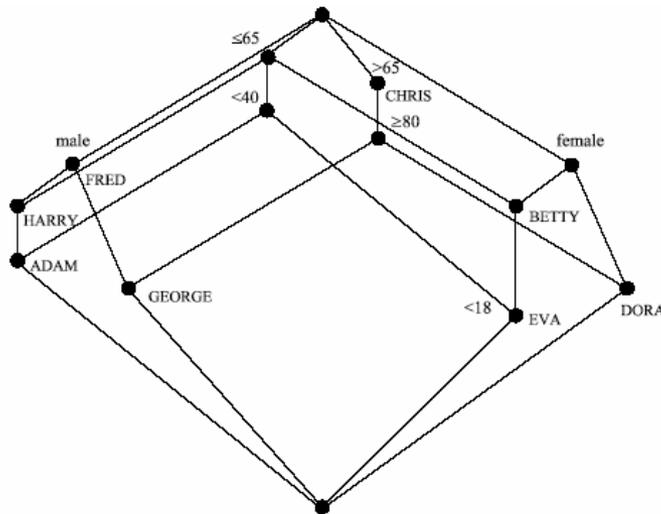
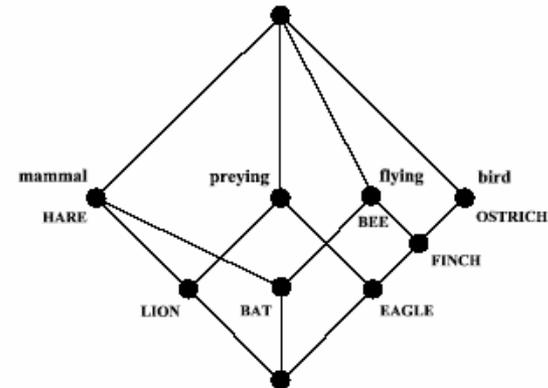
Animals	Preying	Flying	Bird	mammal
Lion	x			x
Finch		x	x	
Eagle		x	x	
Hare				x
Ostrich			x	

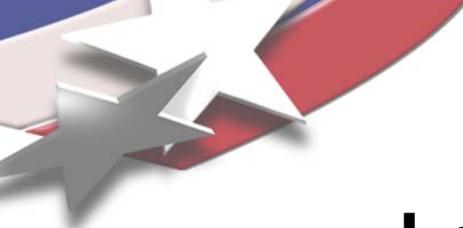
FCA Lattice



Unique Strengths of FCA

- **Extensible**
 - New Information can be integrated into existing lattice.
 - Addition of Bat & Bee
- **Decomposable or modular**
 - Male-female & age
- **Mathematical foundations in Lattice Theory**





Logic's Role in Information Ops

- **Provides a framework for operations on and with information.**
 - **Algebra / Calculus of information combinatorics.**
 - **Defines permitted operations and transformations.**
- **Multiple Logics.**
 - **Modal logics address many dimensions of information.**
 - **Knowledge, belief, morality, time.**
- **Provide a basis for revision and update.**



Sample Modal Logics

- **Modal Logics Applicable to Information processing**
 - (theoretical basis for information operations / functionality!)
- **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

Logic / Reasoning

- **Logic foundations**

- **K** ~ Knowledge
- **B** ~ Belief
- \Box = ~ “logically valid”
- α, β represent blocks of information/knowledge
- \perp ~ logical contradiction

- **Update and Revision**

- Principles 7-11
- Contraction & expansion operators
 - “-”, “+”, “*”
 - “* “ expansion under consistency

(Consistency)

(Veridicality of Positive Introspection)

(Veridicality of Negative Introspection)

(Positive Introspection)

(Negative Introspection)

Veridicality of Knowledge

$$(1) \models K(\alpha \rightarrow \beta) \rightarrow (K\alpha \rightarrow K\beta)$$

$$(2) \models B(\alpha \rightarrow \beta) \rightarrow (B\alpha \rightarrow B\beta)$$

$$(3) \models K\alpha \rightarrow \alpha$$

$$(4) \models K\alpha \rightarrow B\alpha$$

$$(5) \text{ if } \models \alpha, \text{ then } \models K\alpha$$

$$(6) \text{ if } \models \alpha, \text{ then } \models B\alpha$$

$$(7) \neg B\perp$$

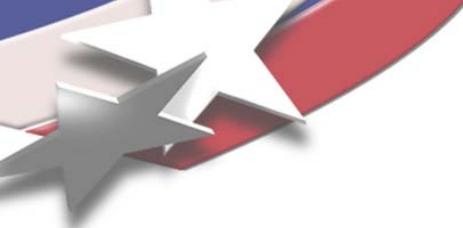
$$(8) BB\alpha \rightarrow B\alpha$$

$$(9) \neg B\perp \rightarrow (B\neg B\alpha \rightarrow \neg B\alpha)$$

$$(10) B\alpha \rightarrow BB\alpha$$

$$(11) \neg B\alpha \rightarrow B\neg B\alpha$$

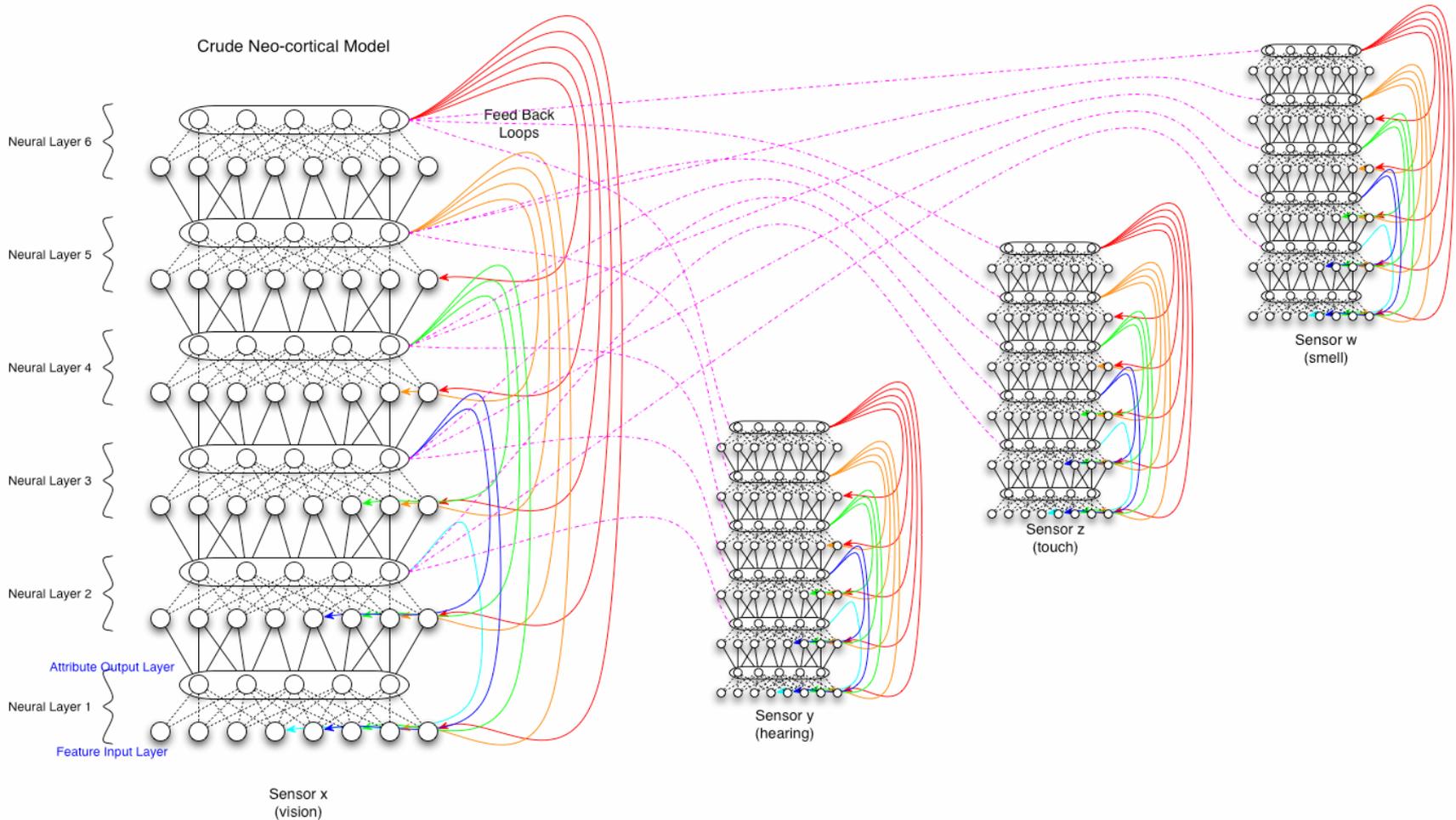
Ref. Lindstroem & Rabinowicz



Neo-Cortex Model

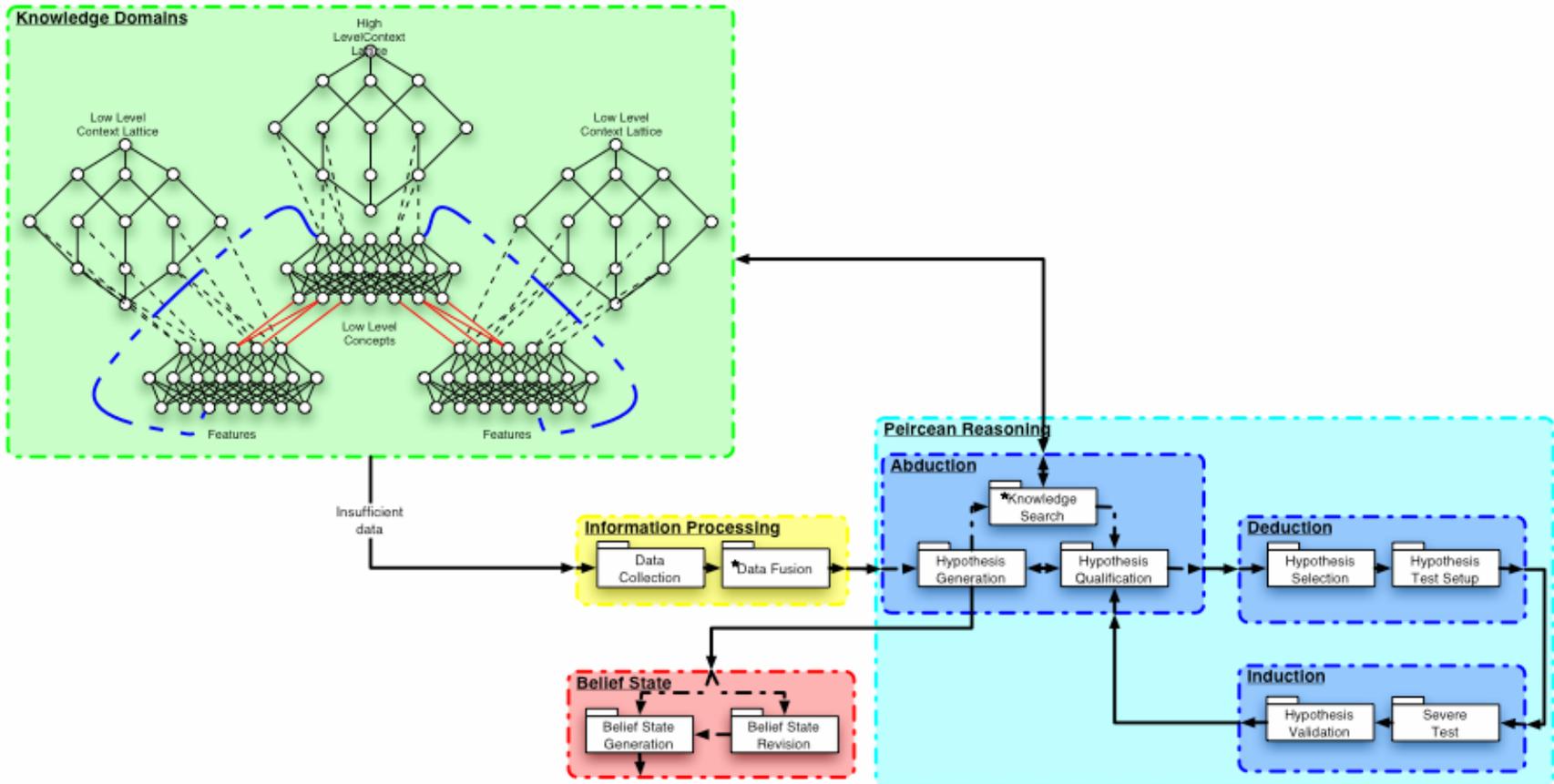
- **Abstraction Levels**
- **Feed Back Loops**
- **Linkage Between Regions**
- **Parallels to Peircean Reasoning**
- **Architecture(?)**

Neo-Cortical Model (Hawkins)



Architecture for Reasoning

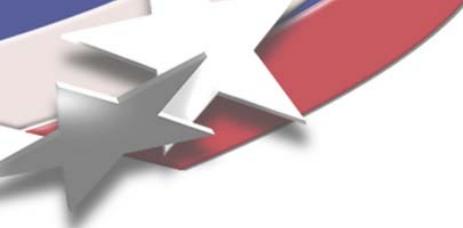
Hybridization of J. Hawkins concept of the neo-cortex, NEAT neural net technology, and formal concept analysis (FCA)





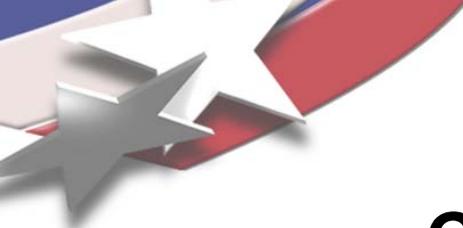
Game Theory

- **Essentials of Game theory**
 - **Non cooperative game.**
 - **With pure and mixed strategies.**
 - **Game is played one time.**
 - **Can have many players.**
 - **Payoff matrix defines results.**
 - **Payoff matrix provides a basis for selecting game strategies.**
 - **Nash equilibrium.**
 - **Characteristic that emerges in mixed strategy games.**



Evolutionary Game Theory

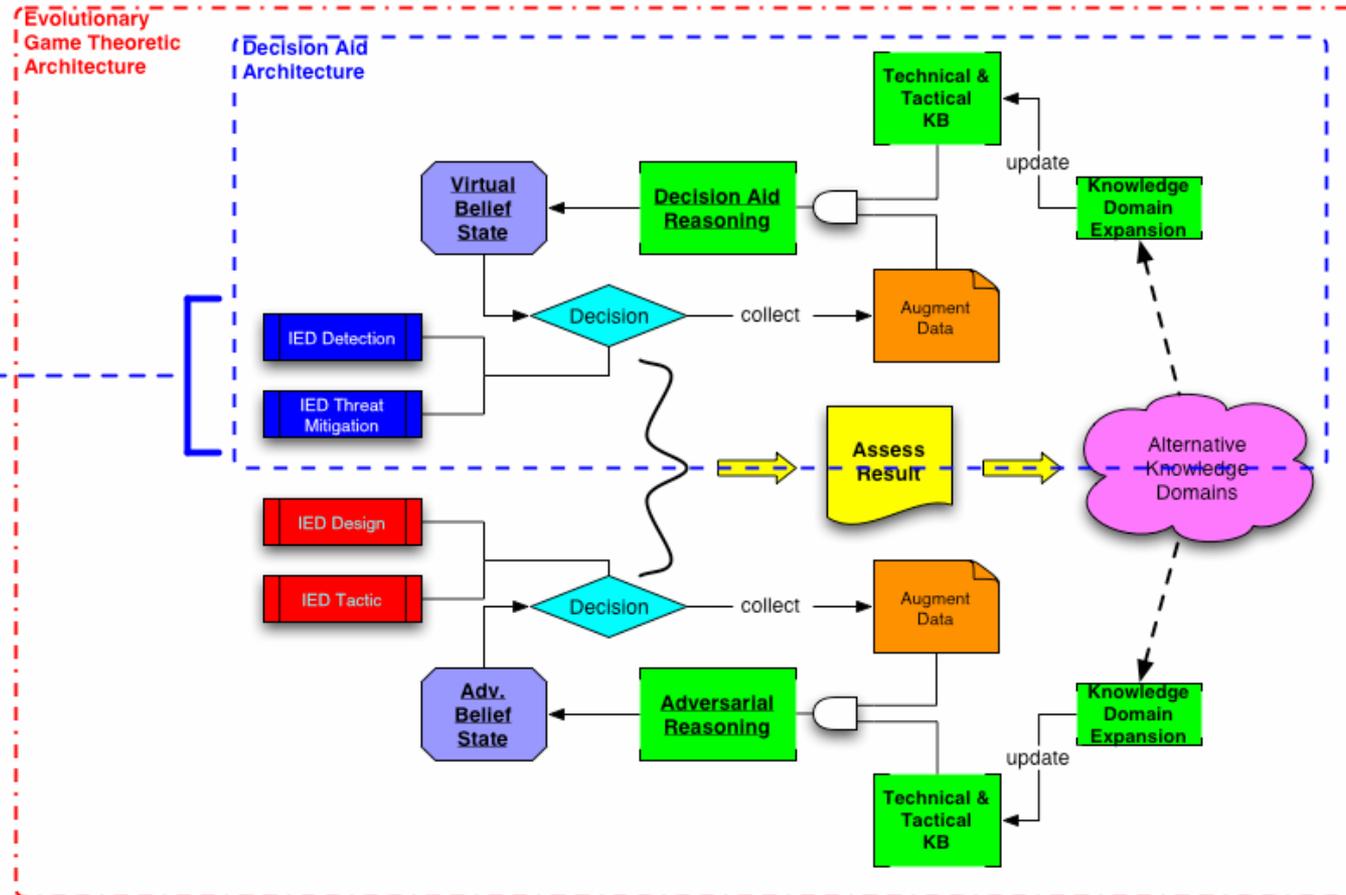
- **Essentials of Evolutionary Game theory.**
 - Non cooperative game.
 - Played many times.
 - “Players” are randomly drawn from a population.
 - Each member of the population can have a unique strategy.
 - Evolutionary process impacts the population from which players are drawn.
 - No guarantee that the ultimate strategy will lead to a Nash equilibrium.

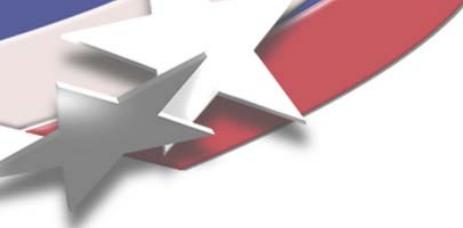


Co-Evolutionary Game Theory

- **Multi-sided game in which all sides evolve a dominant strategy.**
 - Is evolutionary game theory with n evolving players.
- **Objective**
 - Provide basis for an automated system to search for optimal solutions against adaptive opponents.

Architectural Graphic





Fusion

The foundations of fusion system designs must be rooted in an understanding of and the replication of human reasoning.



Fusion Systems

- **Elements required of a DA, support Fusion Solutions**
- **Theoretical Foundations of Fusion**
 - **Peircean Based Reasoning**
 - Provides the basis for tailoring fusion design solutions.
 - **Modal Logics**
 - Defines the “algebra/calculus” of information combinatorics.
 - **Knowledge Representation (FCA)**
 - Defines the “currency” of information operations.
 - **Neural Paradigms (J. Hawkins)**
 - Provides a basis for architectures needed for fusion solutions.
- **Fusion Levels**
 - **Conventional definitions**
 - An arbitrary construct based on the information pyramids.
 - **Generic interpretation**
 - Enables solutions custom fitted to functional requirements.
 - Abduction, deduction, induction, pragmatism,...



Conclusion(s)

- **Systems View of Decision Aid Design.**
 - Identified relatively untapped research domains.
 - Identified a decision making construct for use in the design process.
 - Identified fundamental deficiencies in our approaches for dealing with massive information infusion.
- **We must move beyond reactive solutions.**
 - The abductive component is imperative in the domains of unconventional warfare and current terrorist environments.
- **We have found a potential approach that links the physical with the philosophical.**
 - In the process we believe we have identified the model which needs to be applied in the design of data and information fusion systems.



Backup Slides



Information has “value” when convolved with a system.

Information possesses temporal and spatial value or worth.

The dynamics of information can not be assessed isolated from the system employing that information.

Philosophically, in isolation can information have value?



Information Fundamentals

- **Information / data functionality.**
 - It is: collected, transported, transformed, stored and utilized.
- **Information has “value”**
 - Information is temporally and spatially dependent.
- **Information supports the command decision making process.**
 - When convolved with knowledge it forms the basis of a belief state which provides the foundation for decisions.
- **Information is a systems integration medium.**
 - Complex combat systems exhibit this characteristic.



Why Bother With Modal Logic ?

Algebraic Rules

Distributive Law ???

$$\left. \begin{array}{l} 3x+1 = 7 \\ \text{or} \\ 3(x+1) = 7 \end{array} \right\} \longrightarrow x = 2$$

Associative Law ???

$$\left. \begin{array}{l} (x + 2) + 1 = 6 \\ \text{or} \\ x + (2 + 1) = 7 \end{array} \right\} \longrightarrow \begin{array}{l} x = 3 \\ \text{and} \\ x = 4 \end{array}$$

Are you ready to fly on a plane designed under these “rules”?



Peircean Philosophical Contributions

- **Reasoning Model (Peirce)**
 - **Model of scientific inquiry**
 - **Technical systems engineering model defined in MIL-STD499A**
 - **Abduction (Analogic), Deduction, Induction**
 - **Peirce’s “semeiotic”**
 - **Grammar**
 - **The study of what must be true for signs**
 - **Critical Logic**
 - **The study of the conditions of the proper use of signs**
 - **Formal Rhetoric**
 - **The study of the formal conditions under which signs can be communicated, developed, understood, and accepted**