Reexamining Information Fusion—Sensemaking--Decision Making Inter-dependencies; Again
New Perspectives on Fusion’s Contribution to Mission Effectiveness

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Outline

• Making Decisions: one model: OODA
• Information Fusion: operations, purpose, model, and boundaries
• Closed Loop Situation Management
• Models of Sensemaking and Interfaces to Fusion
• Dual-process Decision-Making Processes
• Fusion Support to Intuitive Decision-Making
• Dealing with Temporal Effects
• Situation Mgmt as Stochastic Adaptive Control
• The Critical Role of Resources
• Summary
Observe-Orient-Decide-Act
OODA LOOP Interdependencies

- Observe
- Orient
- Decide
- Act

IMPORTANT INTERDEPENDENCIES
Limited Holistic Studies and Analyses
<10 papers addressing Fusion & DM at last 4 ISIF Conf.

Foraging-Sensemaking

Various Analytics

Information

Implicit Guidance & Control

Implicit Guidance & Control

Unfolding Circumstances

Outside Information

Unfolding Interaction With Environment

Feedback

Feedback
Basic Role of Fusion: Adaptive Situation Estimation

- One means to satisfy user information needs for decision/analysis support, i.e., most frequently inserted to support human user
Data/Information Fusion Functional Model
(Jt. Directors of Laboratories (JDL), 1993)

- Point and Standoff Sensors
- Data Sources
- Intel Sources
- Air Surveillance
- Surface Sensors
- Standoff Sensors
- Space Surveillance

Level 0 Processing
- Sub-object Data Association & Estimation

Detection Tracking ID
- Combinatorial Optimization
- Linear/NL Estimation
- Statistical
- Knowledge-based/AI/ML
- Control Theoretic

Aggregation Behavior Events
Lethality Intent Opportunity

Sensor Mgmt
Process Mgmt
Refinement

Data Base Management System
- Support Database
- Fusion Database

Methods:
Detection Tracking ID
Aggregation Behavior Events
Lethality Intent Opportunity

INFORMATION FUSION PROTOTYPE
JEM
JWARN3
GCCS

Detection
Tracking
ID
Aggregation
Behavior
Events
Lethality
Intent
Opportunity
Level 0
Processing
Sub-object Data Association & Estimation

Level 1 Processing
Single Object Estimation

Level 2 Processing
Situation Assessment

Level 3 Processing
Threat/Impact Assessment

Level 4 Processing
Adaptive Process Refinement

Data Base Management System
- Support Database
- Fusion Database

- Support Database
- Fusion Database

Methods:
- Combinatorial Optimization
- Linear/NL Estimation
- Statistical
- Knowledge-based/AI/ML
- Control Theoretic
Fusion Information Framework
A Functional Framework for discussions regarding technology and issues

SYSTEMS ENGINEERING CHALLENGE:
DEFINE THE ROLE OF THE DF PROCESS

SYSTEM WIDE INTERFACES AND DEPENDENCIES

Abstraction Layers
Awareness
Significance
(Information relevant to mission goals)
Level 3

Information
Object & Event Relationships
(Data in context)
Level 2

Data
Observables
Level 0/1

Fusion

Resources

Platforms
Sensors
Weapons
Sources
People

Warfighter

Objects

Methods

Level 3

Object & Event Relationships
(Data in context)

Plans

Low

Inference

Abstraction Layers

Dynamic Re-plan

Tasks

Level 2

Process Refine (Lvl 4)

Threats

Situations

Level 3

Significance
(Information relevant to mission goals)

Level 0/1

Awareness

SYSTEMS ENGINEERING CHALLENGE:
DEFINE THE ROLE OF THE DF PROCESS
Situation Management* and Fusion

**Presumed Known or computable**

\[ \Delta S = \hat{S} - S_{desired} \]

**NOTE:** \( \hat{S} = S_{true} \pm \varepsilon \)

**Fusion Levels 0-3**

- Level 0: Perception-Sensing Mgmt
- Level 1: Comprehension
- Level 2: Decision-Making Process
- Level 3: Fusion

**Fusion Level 4**

Perception-Sensing Mgmt

**Situation Management**

- Situation Acquisition
- Situation Memory
- Situation Learning

**Past Situation**

Investigative SM

**Predictive SM**

Future Situation

**Situalional Estimator**

**Comprehension**

Deliberative Situation Control Loop

Events

Subsumption-Based Control Loop

**Sensing**

**Problem Solving**

 Plans

Affecting

**Situation Awareness**

**Situation Resolution**

**Generate Feasible (Effective) Options**

Maps Feasible Actions to Resource-bounded ability to achieve \( \Delta S \rightarrow 0 \)
Automated Information Fusion Processes

Contemplative System 2

Multisource, Multi-Level Information Fusion

Common Referencing

Alert/Anomaly

Multispectral Agile Sensing

Soft and Unstructured Data

State Estimation (L0,L1,L2,L3)

Adaptive Process Refinement

Current Situation Estimate

Projected Situation Estimate

Alert/Anomaly

Decision (COA) Selection

Available Resources

Dynamic Optimal Resource Selection

(Modified) COA/Task Execution

C2

Final Projected Sit Estimate

Desired Situation

YES

No Action

NO

Dec-Mkg Mode-switching Criteria

Intuitive System 1 Decision Making

Hybrid Decision Making

Policy Cmd Authority Mission Plan

DATA – to- ACTION

DATA – to- DECISION

REAL SITUATION

[COA]

Foraging-Sensemaking

Current Situation Estimate

Projected Situation Estimate

Alert/Anomaly

Decision Option Formulation

Decision Evaluation

Decision (COA)

Available Resources

Dynamic Optimal Resource Selection

(Modified) COA/Task Execution

C2

Final Projected Sit Estimate

Desired Situation

YES

No Action

NO

Dec-Mkg Mode-switching Criteria

Intuitive System 1 Decision Making

Hybrid Decision Making

Policy Cmd Authority Mission Plan

DATA – to- ACTION

DATA – to- DECISION

REAL SITUATION

[COA]
Foraging and Sensemaking—Process Models [C4, 5]


Dependency: IF Adaptive to Foraging-Sensemaking

Multisource, Multi-Level Information Fusion

- Common Referencing
- Data Association

Multisource, Multi-Level Information Fusion

Associated Evidence
- State Estimation (L0, L1, L2, L3)

Aggregated State Estimates

IF Reprocessing per Analyst Modifications

Modified Output

Schema/Mental Model Management

Framing/Reframing Support

Adaptive Estimation Support

Analyst API

12
And a few Nobel-Laureate Viewpoints:

--Simon (1978): Bounded Rationality
--Kahneman (2002): Psychology of judgment
 (see also: Thinking Fast and Slow)
--Roth (2012): decision-making and matching supply (resources) to demand (reqmts)

Multiple Systems in Decision Making
A Neurocomputational Perspective
Michael J. Frank, Michael X. Cohen, and Alan G. Sanfey
Current Directions in Psychological Science, 18, 2, 2009
Analytic and Intuitive Decision-Making

FM 5-0 defines IDM as "Intuitive decision making is the act of reaching a conclusion that emphasizes pattern recognition based on knowledge, judgment, experience, education, intelligence, boldness, perception, and character."

Naval Doctrine Document 6 also acknowledged the role of IDM: "The intuitive model credits an experienced commander with the ability to grasp the situation in its entirety, an ability sometimes called coup d’oeil. (from the French, “stroke of the eye”)."

AND FM 5-0 that says "The two approaches to decision making are rarely mutually exclusive."

NavDoc6 comments: "Each model of decision making has its strengths and weaknesses; which is better depends on the nature of the situation, particularly on the time and information available."

(c) 2021 by Dr. P. Croskerry

Croskerry, P., A Universal Model of Diagnostic Reasoning, Academic Medicine, Vol 84, No 8, Pp1022–8, 2009


Klein Recognition-primed Decision Models, Army Res Inst Note 96-36
Fusion Support to Intuitive Decision-making

- High OpTempo, Time-pressured; Recognition-primed, Intuitively guided

- Some Fusion support implications:
  - Fast—eg Anytime methods
  - Fast Augmentation of human DM
    - Case-based Techniques

- Process Management Issues
  - Fusion Processes thus have Multiple Modalities
    - Intuitive, Analytic Modes: On Demand? Always ON? Managed?
Anytime and Case-based Methods

• **Anytime algorithms** are algorithms that exchange execution time for quality of results, but have certain properties*, e.g.,:
  – Measurable quality
  – Consistency
  – Diminishing returns
  – Interruptible….other

• **Case-based Reasoning** is “reasoning based on remembering”; two modes are: interpretive CBR and problem-solving CBR
  – Interpretive ~ assess similarity of current problem to past/stored problem
  – Problem-solving ~ uses prior cases to suggest solutions that might apply to new circumstances

* Not every algorithm that trades execution time for quality of results is necessarily an anytime algorithm.
Time Dependency: Regarding Time and Situation-managing Actions

- **Delays:**
  - To perceive the Estimated Situation
  - To develop Course of Action Options
  - To evaluate those Options
  - To decide and implement the chosen Action
  - For the Action to affect the Situation

- Call this "ΔT"

- Then we should have had the Situational estimator forward *project/predict S | ΔT*

- A Role for L2/L3 Info Fusion—note that **Uncertainty grows with forward projection** (must be accounted for in Action-taking)

  - *can we anticipate ΔT* as a reqmt onto the Fusion process??

There is a corresponding extrapolation process needed to extend the decision preferences from dealing with the “Now” situation to those addressing the extrapolated Situational Estimate
Sensemaking-DM Interdependencies for SA
Situational “Signal Processing”, Thresholding, and Decision Process Initialization

- Situational model
- Situational estimator (Fusion)
  ~“Situation Composition”

Systemic Model
Error
Estimator Error

Situation Completeness

Time

“Situational Detection”
“the situation is occurring or has begun”

“Situational Awareness”
“core situational elements related to decision-making are Present”

“Best Situational Estimate”
“this situational estimate fully satisfies situational Model criteria”

Decision Process Initialization?
User-selectable??

(Presumably)
Decreasing Confidence
But addtl Time

(Presumably)
Increasing Confidence
But less Time
Dependency: Situation Mgmt as Stochastic Adaptive Control

Fusion Processes

\[ \hat{S} \]

Compute

\[ \Delta S = \hat{S} - S_{\text{desired}} \]

Fusion Processes

\[ \hat{S} \]

- Random Set approach
- Event Sequence Edit
- Graph Similarity
- L2 DA Metrics
- Directly in “Action Quanta”--TBD

“Performance Index” Statistical Difference Metric ~ “SDM”, w Variance

Warrants Action?

Commander’s Intent
Variance of SDM ~ Significant?
Policy, ROE’s, etc
Context
Other

YES

Define Action Goals (How much of \( \Delta S \) wants to be changed?)

DM Nominates Candidate COA-Outcome set; Decision Problem Starts

“Reality/Policy” Loop of Pirolli, Card SM Model
• E.g., If Situation Representation is a graph:
  – **Maximum common subgraph** – identifying the ‘largest’ isomorphic subgraphs of two graphs.
  – **Minimum common supergraph** – identifying the ‘smallest’ graph that contains both graphs.
    • Analogous to Graph Matching
  – **Edit distance** – given a cost function on edit operations (e.g. addition/deletion of nodes and edges), determine the minimum cost transformation from one graph to another.
Dependency: Situation Representation: Graphical Methods --Dependence on Resource Inventory--

Predefined Inventory of Feasible $\Delta S$'s, given a priori Resources, Actions

Semantic Entities

Inter-entity Relationships

“Actionable Quanta” of the Situation
• General Research Objectives:
  – Solve the problem of re-assigning resources in response to dynamic changes in mission conditions that in part involve Fusion
  – Establish an extensible Math-Programming modeling framework to handle a wide variety of task types and resource capabilities.
  – Currently using std Integer Pgmmg algorithm to find an optimal soln for small-med size problems—uses LP-Solve freeware

• Specific Optimization Objectives
  – Maximize overall mission effectiveness.
    • Priority values for each mission component.
    • Effectiveness values for each resource when performing a mission component.
    • Target time slices (early/middle/late).
    • Impose penalty for using $\pm \delta$ time windows.
  – Minimize changes to initial assignments.
    • Penalty for changing order.
    • Penalty for changing times.
  – Minimize the distance travelled for each resource.
    • Provide reasonable solution.
• Decision-making Frameworks
  – Sequential, Dynamic
    • Dynamic: Control/convergence-oriented (eg Situation Management)--Interdependent decisions; constraining effects
    • Sequential: Diagnostic; Observe-Act; Information-seeking
    • IF system feedback/decision sequence cycling important
    • See Taxonomy at Edwards* and Leong
  – Distributed/Collaborative/Group
    • Consensus-formation; opinion pools, argumentation schemes
Summary

• Information Fusion, Sensemaking, and Decision-Making are Interdependent
  – IF is an information-providing process primarily supportive of SM with implications for DM
  – DM is a multimodal information-exploiting process leading to action
  – The role of and optimization of Resources also not well integrated into IF process design
  – IF operates within a meta-process control paradigm that has to be developed at the systemic level

• Limited research on these interdependencies
  – Systemic approach required
  – Various research initiatives needed to address these shortfalls
7. Kahneman, D., A perspective on judgment and choice: mapping bounded rationality, American psychologist 58 (9), 2003