ARROYO CENTER

Measuring the Value of High Level Fusion

April 2004

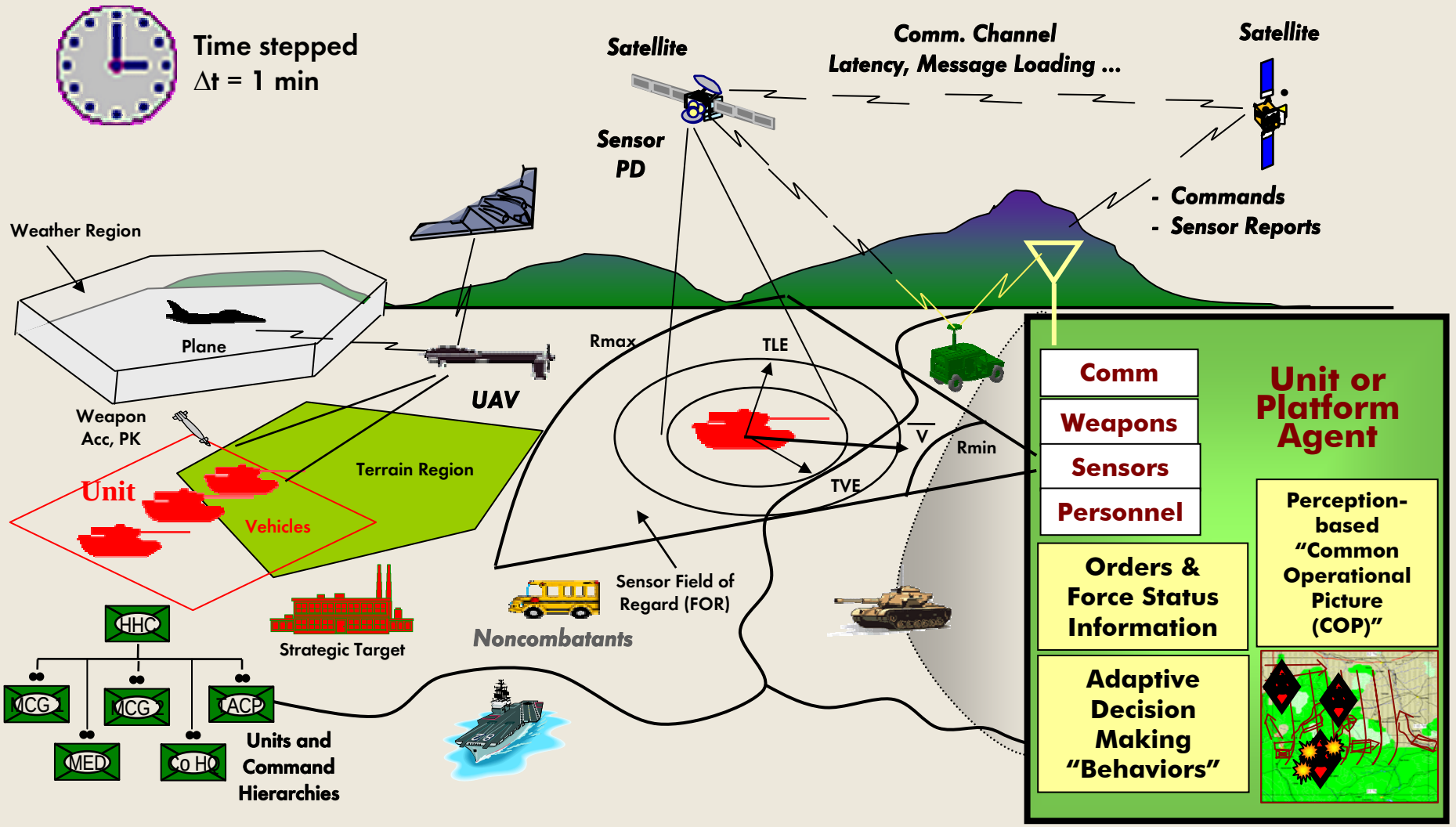
Problem: Weak Analytical Linkage Between Intelligence, Surveillance, and Reconnaissance (ISR), C2, Communications and Operational Outcomes

- Fusion representations are limited
  - ✓ Targeting – Objects (Level 1 Fusion)
  - ✗ Understanding – Relationships, Capability & Intent, Projection (Levels 2 & 3 Fusion)
- Command and control is basic
  - ✓ Rapid planning – Scripts and decision tables
  - ✗ Deliberate planning – Dynamic resource allocation and course of action (COA) selection based on perceived benefits of projected outcomes

This Briefing Has Two Objectives

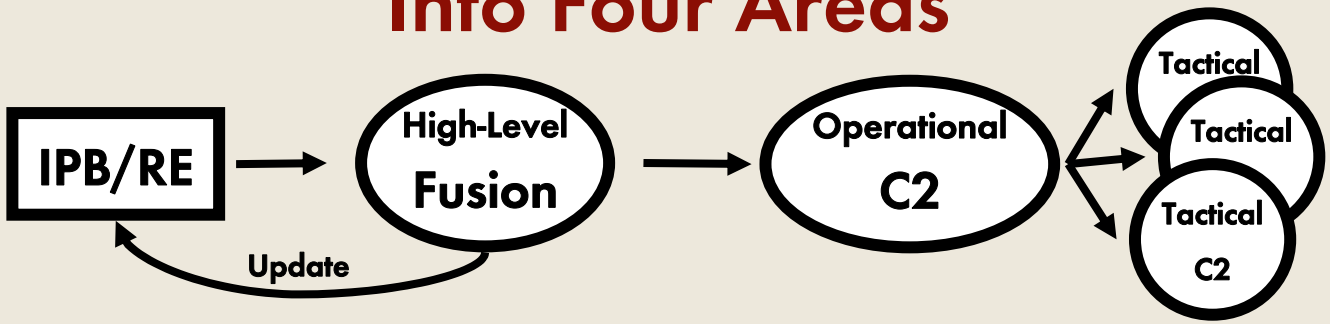
- Describe our approach to modeling high-level fusion
  - to improve support for analysis of C4ISR and Network Enabled Warfare (NEW) issues
  - for use in constructive simulations
    - Initially the Ground C4-ISR Analysis Model (GCAM)
    - AWARS, COMBAT XXI
    - Eventually JWARS?
  - in collaboration with the Army and others
    - G2, TRAC, USAIC & FH, G3, AIMP, AMSO, AMSAA, CAA
    - ASD/NII, Dstl, MITRE, LSI
- Introduce FY04 plans to transfer our representations to Army analysis organizations
  - AWARS (TRAC FLVN) looks feasible and developers are willing
  - COMBAT XXI (TRAC WSMR), CAA, …

GCAM/SEAS* Is A Stochastic, Agent Interaction-Based, C4-ISR Unit- and Platform-Level Simulation in a Theater Context



*Ground C4-ISR Analysis Model / System Effectiveness Analysis Simulation

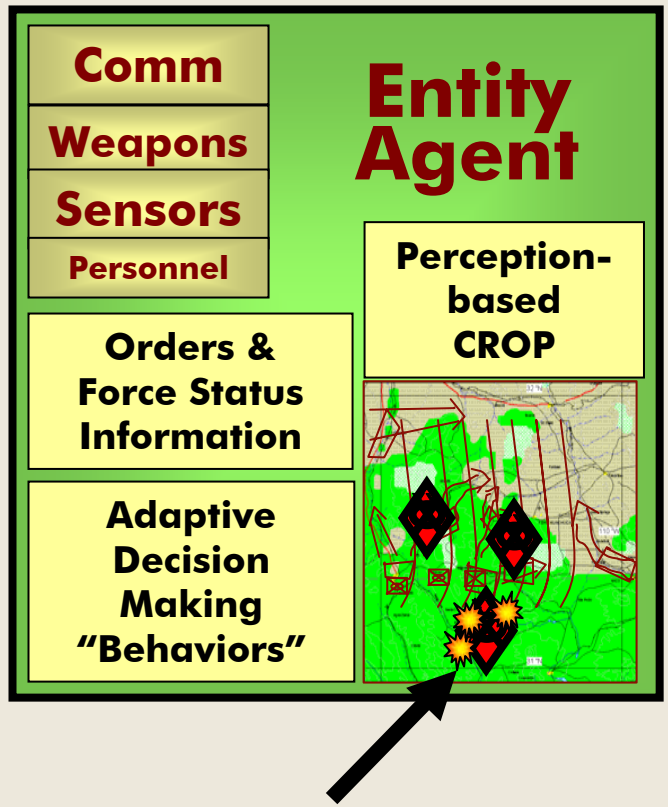
Improved Representations and Algorithms Fall Into Four Areas



1. IPB/Running Estimate (RE) representation
   - Enhanced Common Relevant Operational Picture (CROP)
   - Capacitated planning network
2. High-level fusion – Knowledge Matrix
   - ASD/NII DSC *Multiple Intelligence Fusion Study*
   - Stochastic and Deterministic versions
3. Operational C2 – Deliberate planning using genetic algorithm to search n-sided game payoff space
   - Klein's *Recognition Primed Decision (RPD) Model*
4. Tactical C2 – Rapid planning using probabilistic pattern matching
   - Moffat's *Bayesian Decision Making and Catastrophes*

GCAM Entities Maintain a CROP of IPB/RE Elements, Raw, and Fused Sensor Observations

- Each observation enters/leaves CROP through:
  - Detection/BDA by sensors
    - Onboard
    - Via communications channels
  - Fusion behaviors
- Each element the IPB/RE is represented as an entity in GCAM
  - Locations, status, and behaviors governed by current IPB/RE
    - Sensed by IPB sensor
  - Disseminated over communications channels
  - Updated by fusion process

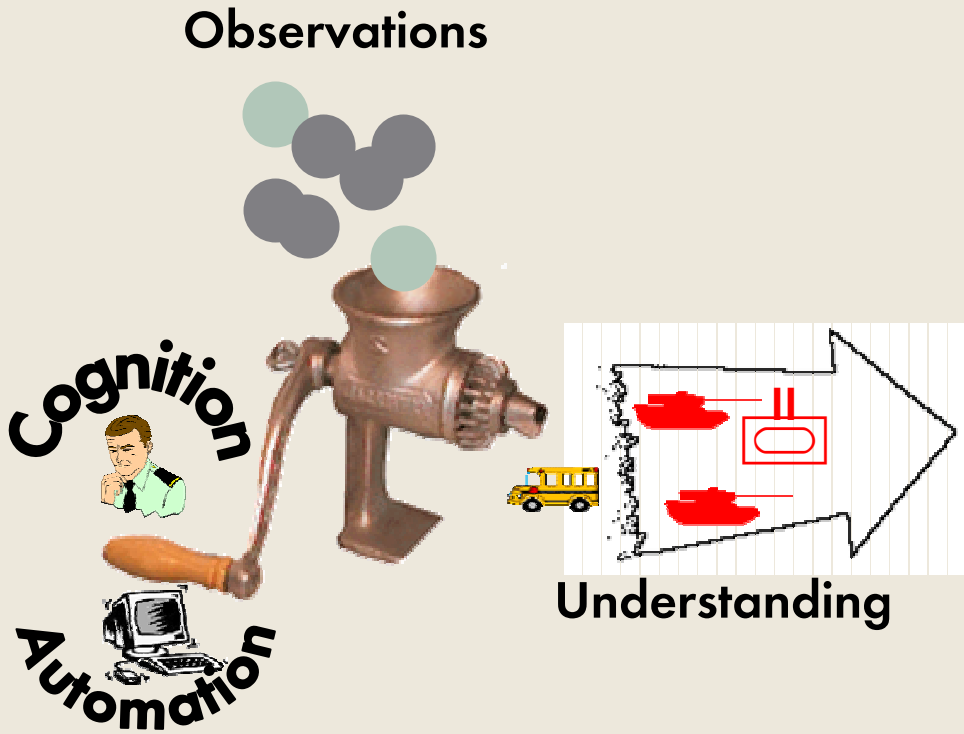


"IPB/RE grease board"

Observations Are Fused to Enable Understanding

"Fusion is a series of processes performed to transform observational data into more detailed and refined information, knowledge, and understanding. These processes, by their very nature, involve both automation and human cognition."

Fusion White Paper, Final Coordinating Draft, DCD CAR, USAIC, Fort Huachuca, AZ, Dated 28 April 2004



Knowledge Matrix† (KM) Captures Information Quality of Fusion Process

- In tabular form – Cell entries are likelihoods that the quality (error) of the observations exceeds (is less than) the cell description (threshold)
- Four types of battlefield entities
  - **Infrastructure** and facilities (buildings, roads, bridge etc.)
  - Pieces of **equipment** (tanks, trucks, etc.)
  - **Aggregates** (units, collections, organizations, etc.)
  - Structured relationships such as an **order of battle (OOB)**
- Derived from
  - target and environment
  - sensor and process characteristics (variances)
    - graphical representations (ellipses)
  - expert opinion

†*Multiple Intelligence Fusion Study*, Keithley, ASD/C3I DSC, 2000

Knowledge Matrix Bin Descriptions

	Type of Knowledge					
Quality Level	Location	Track	Identity	Activity	Capability	Intent
Highest 5	5 Meters	Vectors & Patterns	Specify Object & Parent	Precise Actions	All Elements	All Long & Short-term Objectives
High 4	10 Meters	Vectors	Specify Object	Many Specific Actions	Many Details	Major Objectives
Medium 3	20 Meters	General Speed & Direction	Classify (Wheeled, Tracked)	Identifiable Actions	Some Details	Primary Objectives
Med-Low 2	100 Meters	Toward or Away	Distinguish (Vehicle, Structure)	Single Identifiable Action	General Information	General Objectives
Low 1	1 Kilometer	Stationary or Not	Discriminate	Unidentifiable Action	Minimal Information	Single Objectives
Lowest 0	10 Kilometers	Detect	Detect	Detect	Detect	Detect

Based on *Multiple Intelligence Fusion Study*, Keithley, ASD/C3I DSC, 2000

KM Entries Are Perceived Likelihoods That the Bin Error Threshold is Not Exceeded

Increasing Information Quality (Confidence)

Quality	Loc	Track	ID	Act	Cap	Int
5	0	0	0	0	0	0
4	0.3	0	0	0	0	0
3	0.8	0	0	0	0	0
2	0.9	0.7	0.9	0	0	0
1	0.95	0.9	0.95	0	0.9	0
0	0.99	0.95	0.98	0	0.92	0
-1	1.0	1.0	1.0	1.0	1.0	1.0

Increasing Error (Ignorance)

Implicit values in bottom row (Quality Level –1) are always 1.0

Generation of Sensor Observations from Truth, KM, & Ignorance

Truth

Quality	Loc	Track	ID	Act	Cap	Int
5	0	0	0	0	0	0
4	0.3	0	0	0	0	0
3	0.8	0	0	0	0	0
2	0.9	0.7	0.9	0	0	0
1	0.95	0.9	0.95	0	0.9	0
0	0.99	0.95	0.98	0	0.92	0
-1	1.0	1.0	1.0	1.0	1.0	1.0

Knowledge Matrix (G)

$U \cong \text{Uniform}(0,1)$

Ignorance

$G(v) = \text{Prob}[\varepsilon \leq v]$

$\varepsilon = G^{-1}(U)$

Observation

Error

$X = f(\text{Truth}, \varepsilon)$

- Perception based only on X (not truth)
- G & U associated with X through out simulation

Fusion Process Steps

- Age KM to account for latency
  - "half life" calculation
- Determine fusion candidates
  - Locations "close enough"
  - Consistent identities
  - Knowledge "good enough"
    - Correlation Algorithm
- Combination
- Hierarchical association
- Inference

Stochastic KM Combination

ISR Sensor Report Observation$_1$

U_1= (0.75, 0.84, 0.1, 0.6, 0.52, 0.3)

Quality	Loc	Track	ID	Act	Cap	Int
5	0	0	0	0	0	0
4	0.3	0	0	0	0	0.9
3	0.8	0	0	0	0	0.9
2	0.9	0.7	0.9	0	0	0.9
1	0.95	0.9	0.95	0	0.9	0.9
0	0.99	0.95	0.98	0	0.92	0.9
-1	1.0	1.0	1.0	1.0	1.0	1.0

$=G_1$

CROP Observation$_2$

U_2= (0.38, 0.24, 0.4, 0.52, 0.48, 0.3)

$G_2=$

Quality	Loc	Track	ID	Act	Cap	Int
5	0	0	0.1	0.3	0	0
4	0.2	0	0.6	0.4	0	0
3	0.7	0	0.8	0.5	0.7	0
2	0.9	0.7	0.9	0.6	0.8	0.3
1	0.95	0.8	0.95	0.7	0.9	0.4
0	0.99	0.9	0.98	0.8	0.92	0.5
-1	1.0	1.0	1.0	1.0	1.0	1.0

Fused Observation

$G_{\text{"Fused"}} \cong 1-(1-G_1)(1-G_2)$

$U_{\text{"Fused"}} \cong 1-(1-U_1)(1-U_2)$ $[1-\ln\{(1-U_1)(1-U_2)\}]$

$G_{Fused}=$

U_F= (0.56, 0.62, 0.13, 0.49, 0.40, 0.16)

Quality	Loc	Track	ID	Act	Cap	Int
5	0	0	0.1	0.3	0	0
4	0.44	0	0.6	0.4	0	0.9
3	0.94	0	0.8	0.5	0.7	0.9
2	0.99	0.91	0.99	0.6	0.8	0.93
1	.998	0.98	.998	0.7	0.99	0.94
0	.999	.998	.999	0.8	.994	0.95
-1	1.0	1.0	1.0	1.0	1.0	1.0

This report has ~20 meter error, for an MBT moving forward, with identifiable activity, some specific capability and a known objective and intent

Nuggets May Occur Infrequently, But Fuse Easily

CROP

Quality	ID	Act	Cap	Int
5	0.4	0.3	0.2	0.1
4	0.6	0.5	0.4	0.3
3	0.7	0.6	0.6	0.5
2	0.9	0.7	0.7	0.6
1	0.95	0.8	0.8	0.7
0	1.0	1.0	1.0	0.8
-1	1.0	1.0	1.0	1.0

EQ = 3.6, 2.9, 2.7, 2.0

Nugget*

Quality	ID	Act	Cap	Int
5	0.6	0.3	0.2	0.1
4	0.7	0.5	0.4	0.4
3	0.8	0.6	0.6	1.0
2	0.9	0.7	0.7	1.0
1	0.95	0.8	0.8	1.0
0	1.0	1.0	1.0	1.0
-1	1.0	1.0	1.0	1.0

EQ = 4.0, 2.9, 2.7, 3.5

After combination step simulated decision-makers use improved information

Quality	ID	Act	Cap	Int
5	0.76	0.51	0.36	0.19
4	0.82	0.75	0.64	0.58
3	0.94	0.84	0.84	1.0
2	0.99	0.91	0.91	1.0
1	.998	0.96	0.96	1.0
0	1.0	1.0	1.0	1.0
-1	1.0	1.0	1.0	1.0

EQ = 4.5, 3.9, 3.7, 3.8

*Special Orders 191, Gen R. E. Lee, Battle of Antietam

Fusion Summary

- We have implemented a representation of fusion in our C4ISR simulation (GCAM)
  - Elegant – Simple structure, easy to program and use
  - Malleable – structure is able to capture the results of wide range of fusion processes
  - Implicit – does not replicate the fusion process
    - Availability of data and rules is TBD (but enough should exist)
  - Joint pedigree
- Transfer to other constructive simulations
  - Description the algorithms improving
  - Amount of transference will depend on representation of ISR in candidate simulation
    - Stochastic preferred but deterministic is acceptable
    - Full capability may require entity-based (vs. aggregate) simulation
- We need your criticism and assistance