Using Gaming and Agent Technology to Explore C2

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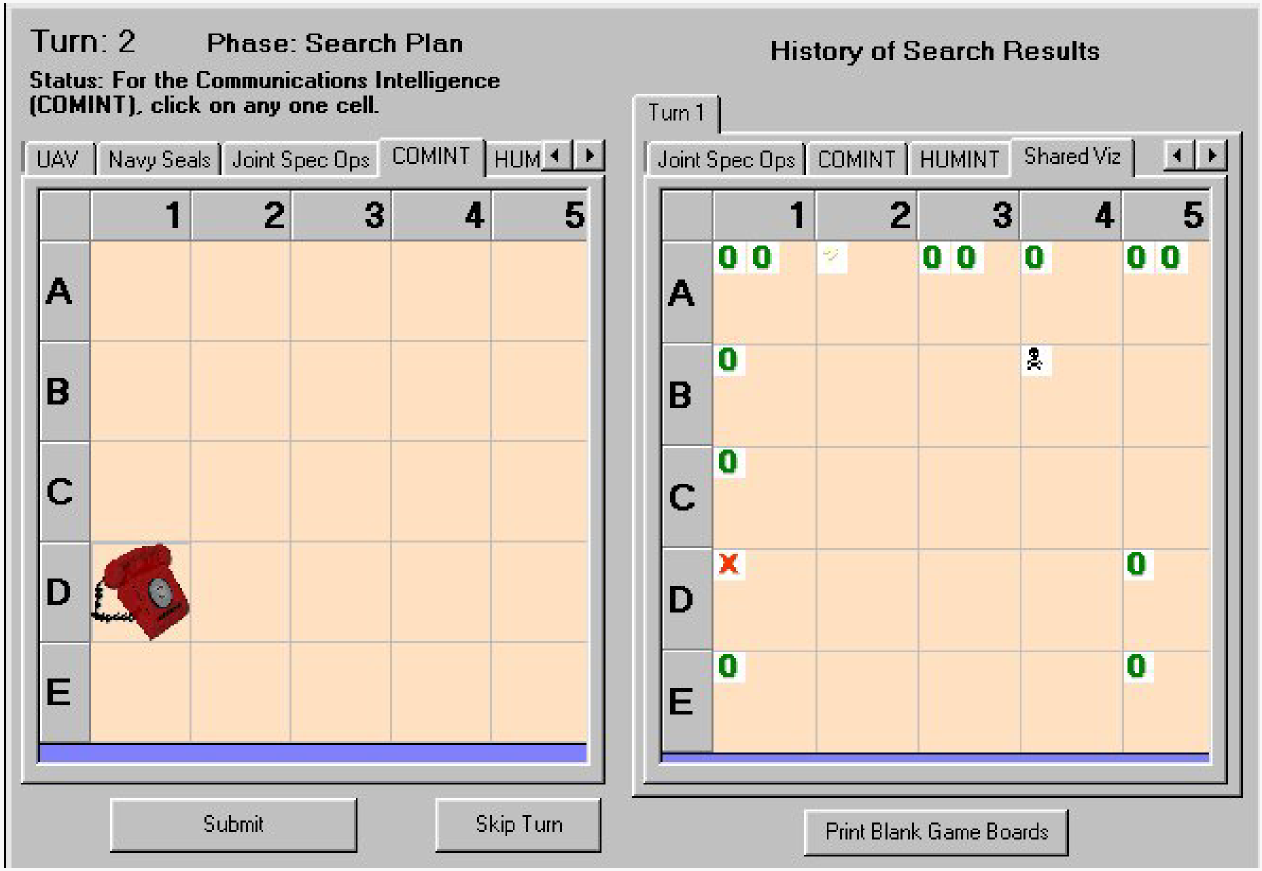
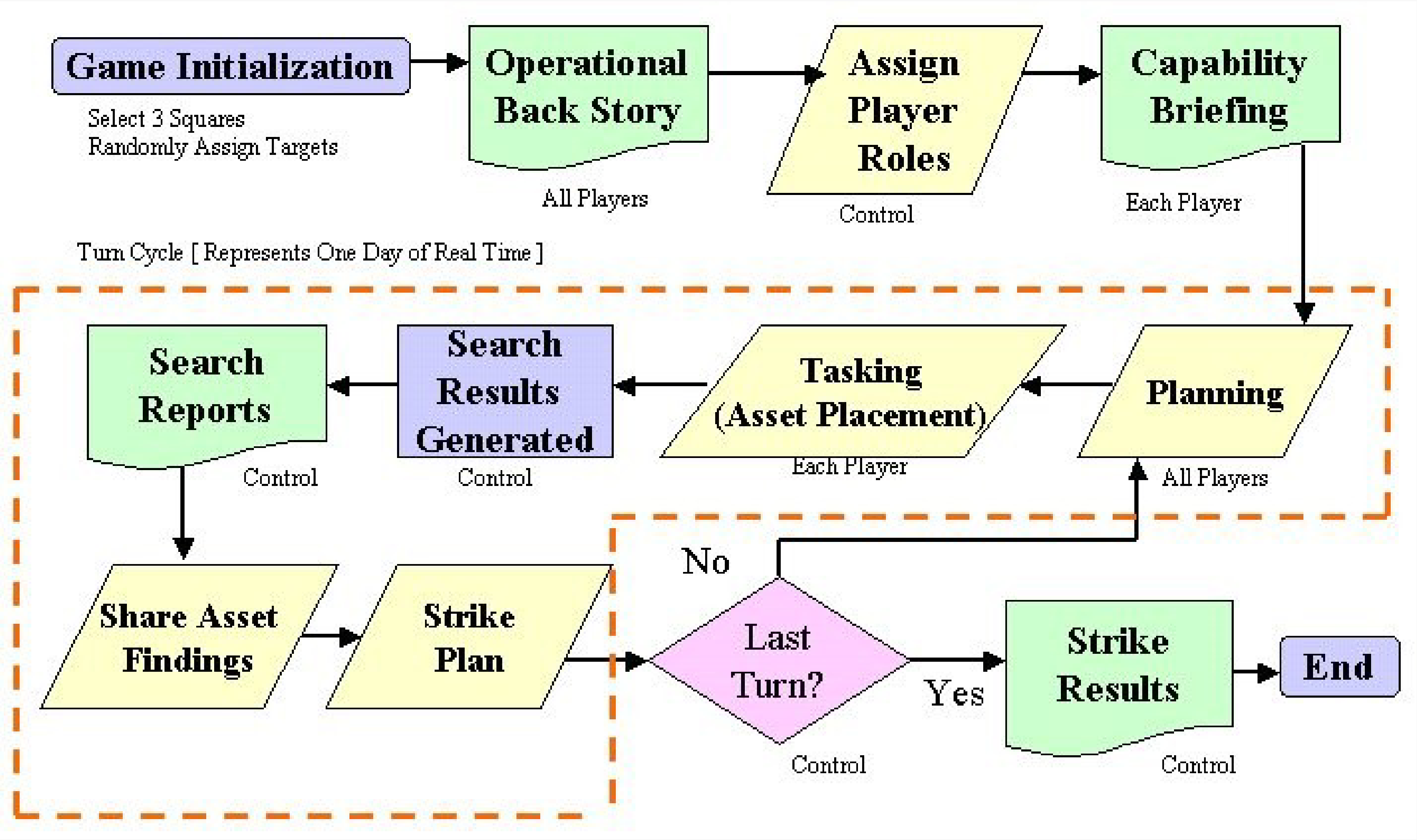
Summary

- We can create distillation games that capture the key elements in the OODA loop
- We can use such games to create experiments that are amenable to statistical design and analysis
- We can use game-playing agents and genetic algorithms to explore vast C2 decision spaces
- We can use human games to validate findings, suggest adjustments, and identify new areas for exploration
- We can integrate agent and human games in experimental campaigns to address fundamental issues systematically

SCUDHunt sample gameboard





Game Initialization
Select 3 Squares
Randomly Assign Targets
Operational Back Story
All Players
Assign Player Roles
Control
Capability Briefing
Each Player
Turn Cycle [Represents One Day of Real Time]
Search Reports
Control
Search Results Generated
Control
Tasking (Asset Placement)
Each Player
Planning
All Players
Share Asset Findings
Strike Plan
No
Last Turn?
Control
Yes
Strike Results
Control
End

Experimental measurements

Shared Situational Awareness (SSA) score- overlap in assessment of launcher locations among team members, irrespective of whether understanding is right or wrong

SSA score = Ratio of the total number of recommended target squares by all players to total number of unique squares designated

Example: Perfect SSA: All 4 team members vote for the same 3 squares = 12/3 = 4
Lowest score: All 4 team members vote for 3 different squares = 12/12 = 1

Experimental measurements

Accuracy (ACC) score - Do team members (or individual players) actually find the launchers?

ACC = ratio of nominated squares that actually contained SCUD launchers to the total number squares nominated

Example: Perfect team ACC: 4 players vote for the same 3 squares containing launchers = 12/12 = 1.

Lowest ACC: Team does not identify any launcher squares, then their score is 0 / 12 (or some other large number) = 0

We also compute individual player ACC

Experiment/Year	Conducted by	For	Experimental Variables
Experiment #1; 2000	ThoughtLink and CNA	DARPA	Availability of visualization, type of communication
Data Mining of Experiment #1; 2001	ThoughtLink	Joint C4ISR Decision Support Center	Data mining of original experiment for quality of decisions
Experiment #2; 2002	George Mason University	Army Research Institute	Training on own or all assets, mode of communication
Experiment #3; 2002	Naval War College, CNA, ThoughtLink	Naval War College	Command method, type of visualization
Experiment #4; 2002	ThoughtLink, Naval War College, CNA	Joint C4ISR Decision Support Center	Quality of information, type of visualization
Experiment Meta-Analysis; 2002	ThoughtLink	Joint C4ISR Decision Support Center	Meta Analysis of four *SCUDHunt* experiments

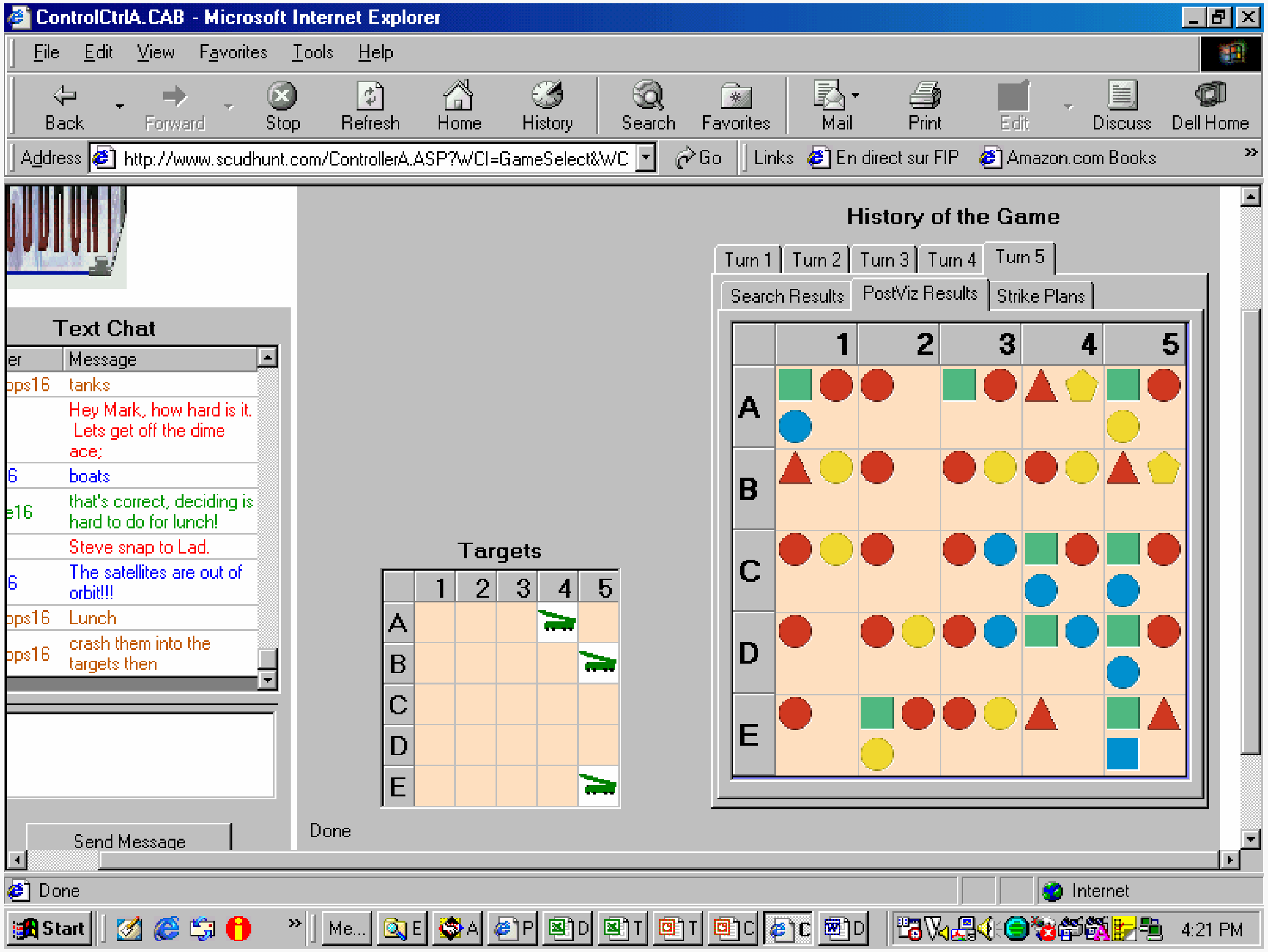
Key results from human experiments

- Quality of information affects ACC more than it affects SSA
  - SSA can be built on bad info, so providing COP is not a cure-all
- ACC and SSA are related
  - From meta-analysis, 50% of variance in ACC can be accounted for by knowing SSA
- Communication matters, but mode of communications doesn't
  - Chat/voice/shared visualization were similar, in terms of effect on SSA
- What doesn't matter
  - Duration of games
  - Amount of text chat

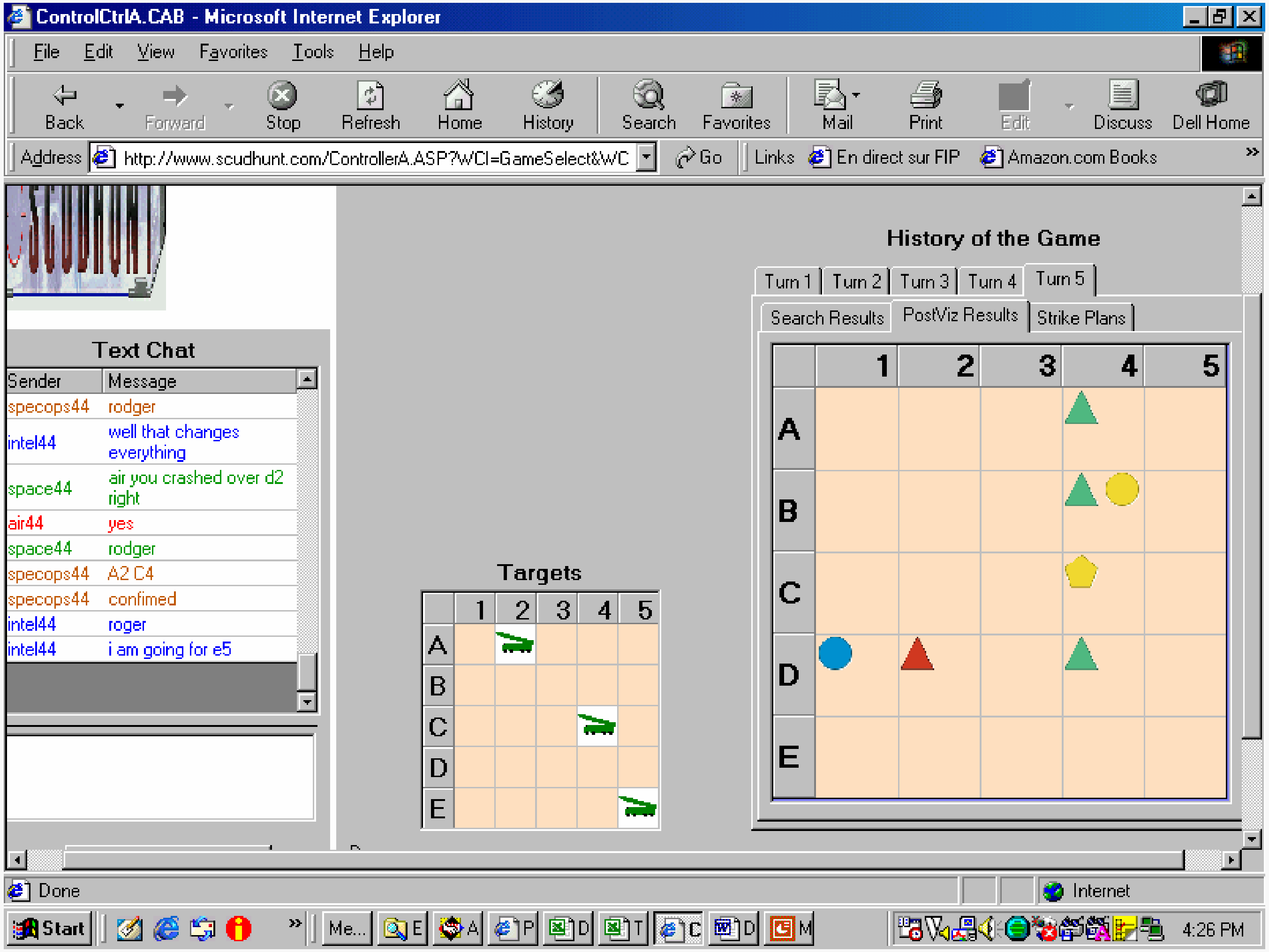
Key results from human experiments

- Teams matter but we’re not sure what is most important
- Teams differ in:
  - Understanding that asset reliability descriptions were critical to success
  - Value placed on timeliness vs. accuracy
  - Degree of integration of their team strategy
  - Leadership style

Team 1's final post viz game - turn 5



Team 4’s last post viz game - turn 5



Sample team 3 chat – DSC 2002

Player ID	Message
space35	SPACEto col. 3.
specops35	with your assets up to the ne, I can send the seals across to D2 and joint spec ops up to d5
specops35	Both spec ops will be within search range of E3/E4
air35	maybe spec ops can clear out row E. I'll take manned air over row A and the uav down col 4 so that next space pass will give us corroboration
specops35	I could send the seals down to E2 vs D2 next, but both air and space had e2 clean
specops35	Air, are you thinking Joint Spec ops to E4 this round vs D5
space35	What is level of conf that INTEL is right about E5 (that SEALs chickened out?)?
air35	yes, because you can always move to D5 on a diagonal, right?
intel35	Where is JOint Spec ops starting from? Can they do E4 this turn and D5 next?
intel35	Comint is VERY good at saying a space is Clear
specops35	Yes to intel, they start back in E5. the Koronans ability to hide scuds is low, I think Joint Spec Ops hit that low probability of koronan security with no scud.
specops35	So seals to D2, Joint Spec Ops to E4 this rnd.
space35	Concur.
air35	sounds good
intel35	6 of one, half dozen of another

Sample team 4 chat – DSC 2002

Player ID	Message
intel41	spec ops check out a3
specops41	i am going to check out B2 and E5
intel41	humint checking out b2
space41	which row you guys want me
space41	i'll check row 4
intel41	no scud in b2
space41	4 poss in row 4
specops41	ok i am in a3 and e4
air41	uav killed on e5
specops41	no info in either
intel41	disregard my prob scud in a3 then, my bad
specops41	final go
intel41	this is the search plan that counts
specops41	we know that there is one in C2
intel41	prob in d5, but not sure

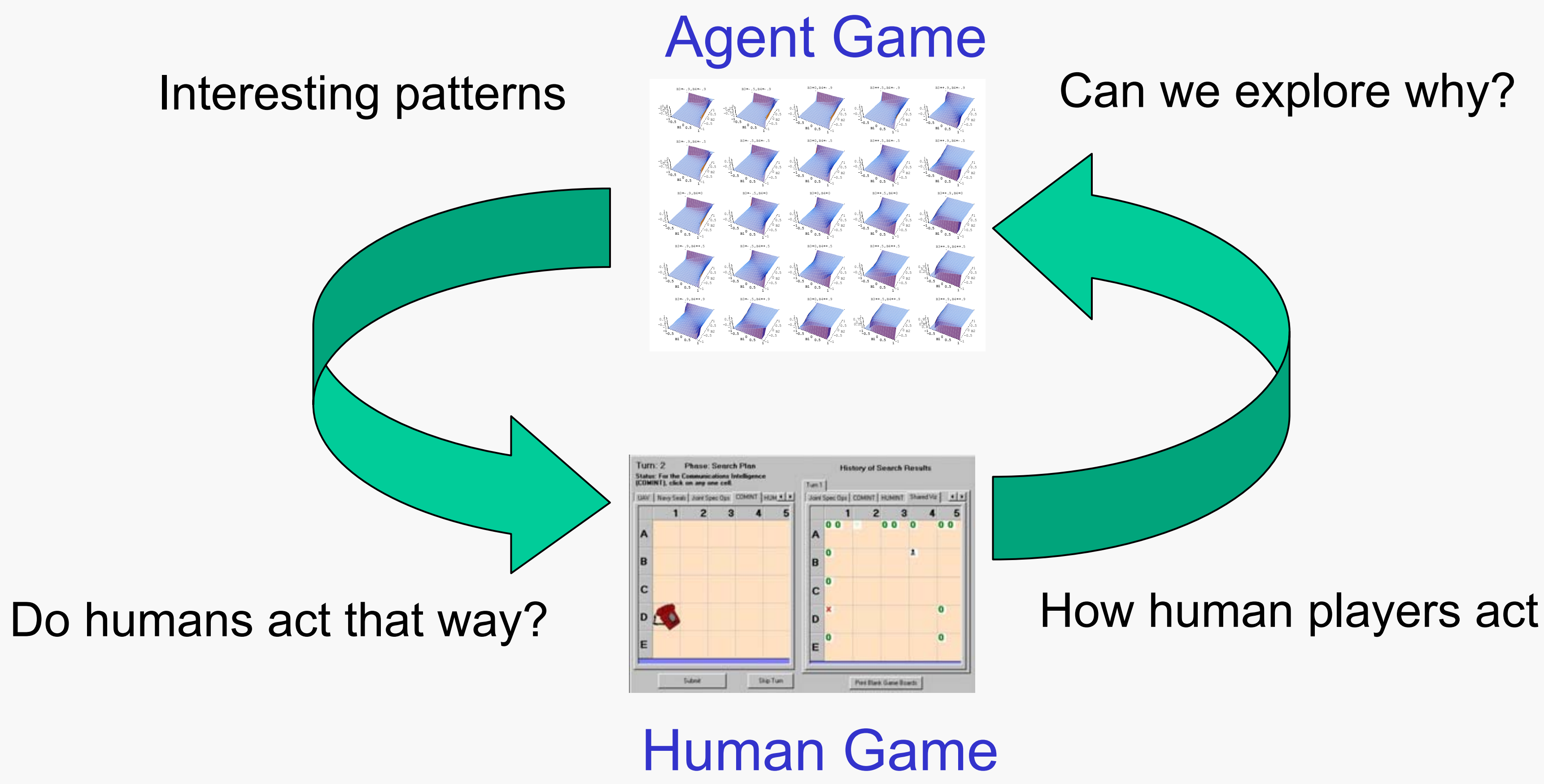
Team 2 chat – NWC 2002

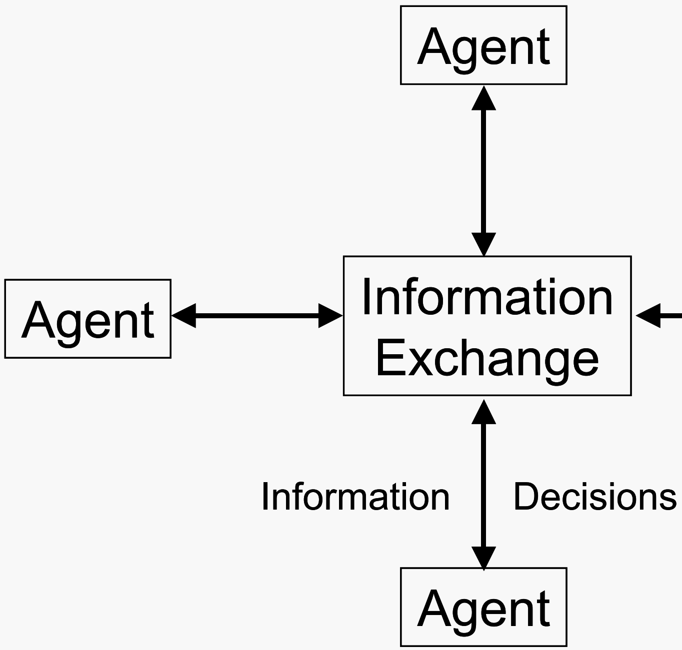
Game	Player	Chat Message
401	intel25	what areas do we not have covered this turn?
401	air25	i dont know
401	specops25	I'll check out B3 but I think intel was there already, only place checked once though
401	air25	just slap joint in somewhere and we will hope that we made good decisions

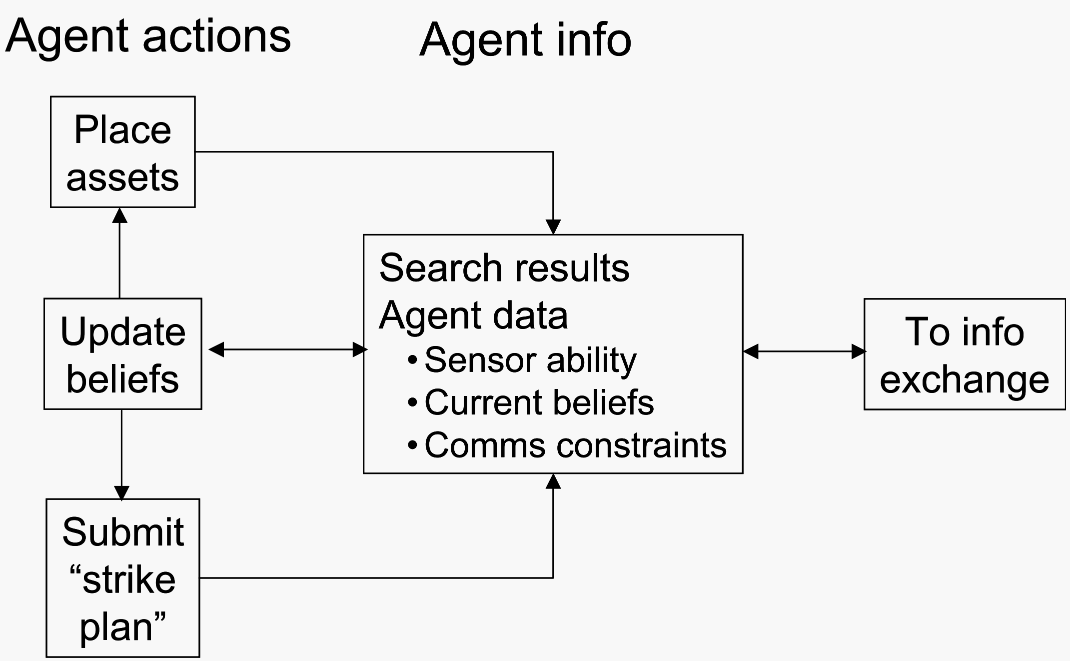
Team 5 chat - last turn – NWC 2002

Seq-uence	**Player**	**Chat Message**
8224	Space56	Definite Negatives: A1, A3, A4, A5, B1,2,3,4,C2,3,4,D2,4,E2,4
8225	Space56	a3 and a4...both nothing
8226	Space56	Probable Negatives (3 no): C1, D1, E1, E3, (2 no): D3
8227	Space56	Mixed: D5 (1 pos, 3 neg)

Integrating human and agent games




Agent
Agent
Information Exchange
Agent
Information
Decisions
Agent


Agent actions
Agent info
Place assets
Search results
Agent data
• Sensor ability
• Current beliefs
• Comms constraints
Update beliefs
To info exchange
Submit "strike plan"

The key components of the model include representations of each agent’s:

- *Belief Matrix*, the strength of the agent’s belief that a target is, or is not, present in a specific grid square
- Interpretation of sensor reports and how they change his belief value for the grid squares
- Trust of other agents and how that affects the way he integrates the information they provide into his own belief calculations
- Strike-plan logic, the determination of which targets to recommend for strike
- Sensor-placement logic, the process of deciding where to place the agent’s sensors to maximize some “fitness function” representing the various, possibly competing, motivations an agent may have as he decides how to allocate his search effort.

SSA scores, human-based experiment

Team	Game 1	Game 2	Game 3	Game 4	Game 5	Game 6	Mean
1	2.09 (B)	1.89 (E)	1.92 (A)	2.00 (C)	1.82 (F)	2.15 (D)	1.98
2	2.00 (D)	3.00 (A)	4.00 (E)	4.00 (B)	4.00 (C)	4.00 (F)	3.50
3	2.50 (A)	4.00 (F)	2.60 (D)	1.86 (E)	1.82 (B)	1.82 (C)	2.43
4	2.60 (F)	3.00 (C)	2.56 (B)	2.00 (D)	3.50 (A)	1.82 (E)	2.58
5	3.00 (E)	2.40 (B)	2.17 (C)	3.00 (F)	2.40 (D)	1.88 (A)	2.47
6	4.00 (C)	3.25 (D)	3.20 (F)	4.00 (A)	2.50 (E)	4.00 (B)	3.49
Treatments	A: QOI High, Shared viz		C: QOI Med, Shared viz		E: QOI Low, Shared viz		
	B: QOI High, Post viz		D: QOI Med, Post viz		F: QOI Low, Post viz		

Team	Game 1	Game 2	Game 3	Game 4	Game 5	Game 6	Mean
1	3.25 (B)	3.40 (E)	4.00 (A)	4.00 (C)	3.00 (F)	4.00 (D)	3.61
2	3.40 (D)	3.50 (A)	3.50 (E)	2.40 (B)	4.00(C)	2.67 (F)	3.24
3	3.12 (A)	4.00 (F)	4.00 (D)	2.67 (E)	3.40 (B)	3.50 (C)	3.45
4	4.00 (F)	4.00 (C)	4.00 (B)	3.12 (D)	3.75 (A)	3.75 (E)	3.77
5	3.25 (E)	2.17 (B)	3.25 (C)	4.00 (F)	4.00 (D)	3.50 (A)	3.36
6	32.60 (C)	4.00 (D)	4.00 (F)	4.00 (A)	3.86 (E)	3.850 (B)	3.66
Treatments	A: QOI High, Shared viz		C: QOI Med, Shared viz		E: QOI Low, Shared viz		
	B: QOI High, Post viz		D: QOI Med, Post viz		F: QOI Low, Post viz		

SSA scores, agent-based experiment

ANOVA of SSA scores for human-based experiment

	Sum of squares	Degrees of freedom	Mean square	F statistic	p-value
Team (row)	11.48	5	2.30	5.25	0.003
Game (column)	0.37	5	0.07	0.17	0.97
Treatment	2.90	5	0.58	1.33	0.29
QOI	0.84	2	0.42	0.96	0.40
Med/Low - High	0.84	1	0.84	1.91	0.18
Med - Low	0.0001	1	0.0001	0.0002	0.99
Visualization	0.46	1	0.46	1.06	0.32
Interaction	1.60	2	0.80	1.83	0.19
Error	8.75	20	0.44		
Total	23.50	35			

	Sum of squares	Degrees of freedom	Mean square	F statistic	p-value
Team (row)	1.18	5	0.24	0.83	0.54
Game (column)	1.10	5	0.22	0.77	0.58
Treatment	1.73	5	0.35	1.22	0.34
QOI	0.55	2	0.27	0.97	0.40
Med/Low - High	0.12	1	0.02	0.41	0.53
Med - Low	0.43	1	0.001	1.53	0.23
Visualization	0.06	1	0.06	0.22	0.64
Interaction	1.12	2	0.56	1.98	0.16
Error	5.67	20	0.28		
Total	9.68	35			

ANOVA of SSA scores for agent-based experiment

Accuracy scores, human-based experiment

Team	Game 1	Game 2	Game 3	Game 4	Game 5	Game 6	Mean
1	0.35 (B)	0.41 (E)	0.44 (A)	0.67 (C)	0.5 (F)	0.43 (D)	0.47
2	0.67 (D)	0.92 (A)	0.67 (E)	1.00 (B)	1.00 (C)	0.67 (F)	0.82
3	0.15 (A)	1.00 (F)	0.62 (D)	0.23 (E)	0.35 (B)	0.60 (C)	0.49
4	0.62 (F)	0.80 (C)	0.39 (B)	0.67 (D)	0.86 (A)	0.45 (E)	0.63
5	0.33 (E)	0.67(B)	0.77 (C)	0.83 (F)	0.75 (D)	0.27 (A)	0.60
6	1.00 (C)	0.62 (D)	0.50 (F)	1.00 (A)	0.50 (E)	1.00 (B)	0.77
Treatments	A: QOI High, Shared viz		C: QOI Med, Shared viz		E: QOI Low, Shared viz		
	B: QOI High, Post viz		D: QOI Med, Post viz		F: QOI Low, Post viz		

Team	Game 1	Game 2	Game 3	Game 4	Game 5	Game 6	Mean
1	0.38 (B)	0.41 (E)	0.33 (A)	0.67 (C)	0.33 (F)	0.67 (D)	0.47
2	0.65 (D)	0.38 (A)	0.38 (E)	0.75 (B)	0.33 (C)	0.06(F)	0.42
3	0.32 (A)	1.00 (F)	0.40 (D)	0.00 (E)	0.31 (B)	0.43 (C)	0.41
4	1.00 (F)	0.50 (C)	0.67 (B)	0.32 (D)	0.73 (A)	0.47 (E)	0.61
5	0.69 (E)	0.38 (B)	0.31(C)	0.25 (F)	0.67 (D)	0.38 (A)	0.45
6	0.62 (C)	0.67 (D)	0.00 (F)	0.67 (A)	0.30 (E)	0.14 (B)	0.40
Treatments	A: QOI High, Shared viz		C: QOI Med, Shared viz		E: QOI Low, Shared viz		
	B: QOI High, Post viz		D: QOI Med, Post viz		F: QOI Low, Post viz		

Accuracy scores, agent-based experiment

ANOVA of accuracy scores for human-based experiment

	Sum of squares	Degrees of freedom	Mean square	F statistic	p-value
Team (row)	0.62	5	0.12	4.58	0.006
Game (column)	0.26	5	0.05	1.93	0.14
Treatment	0.69	5	0.14	5.17	0.003
QOI	0.54	2	0.27	10.12	0.0009
Med/Low - High	0.38	1	0.38	14.09	0.001
Med - Low	0.16	1	0.16	6.16	0.02
Visualization	0.0002	1	0.0002	0.009	0.92
Interaction	0.15	2	0.075	2.80	0.08
Error	0.54	20	0.03		
Total	2.10	35			

	Sum of squares	Degrees of freedom	Mean square	F statistic	p-value
Team (row)	0.19	5	0.04	0.73	0.61
Game (column)	0.33	5	0.07	1.027	0.31
Treatment	0.47	5	0.09	1.81	0.16
QOI	0.44	2	0.22	4.20	0.03
Med/Low - High	0.20	1	0.20	3.89	0.06
Med - Low	0.24	1	0.24	4.50	0.05
Visualization	0.003	1	0.003	0.06	0.80
Interaction	0.03	2	0.02	0.30	0.74
Error	1.04	20	0.05		
Total	2.04	35			

ANOVA of accuracy scores for agent-based experiment

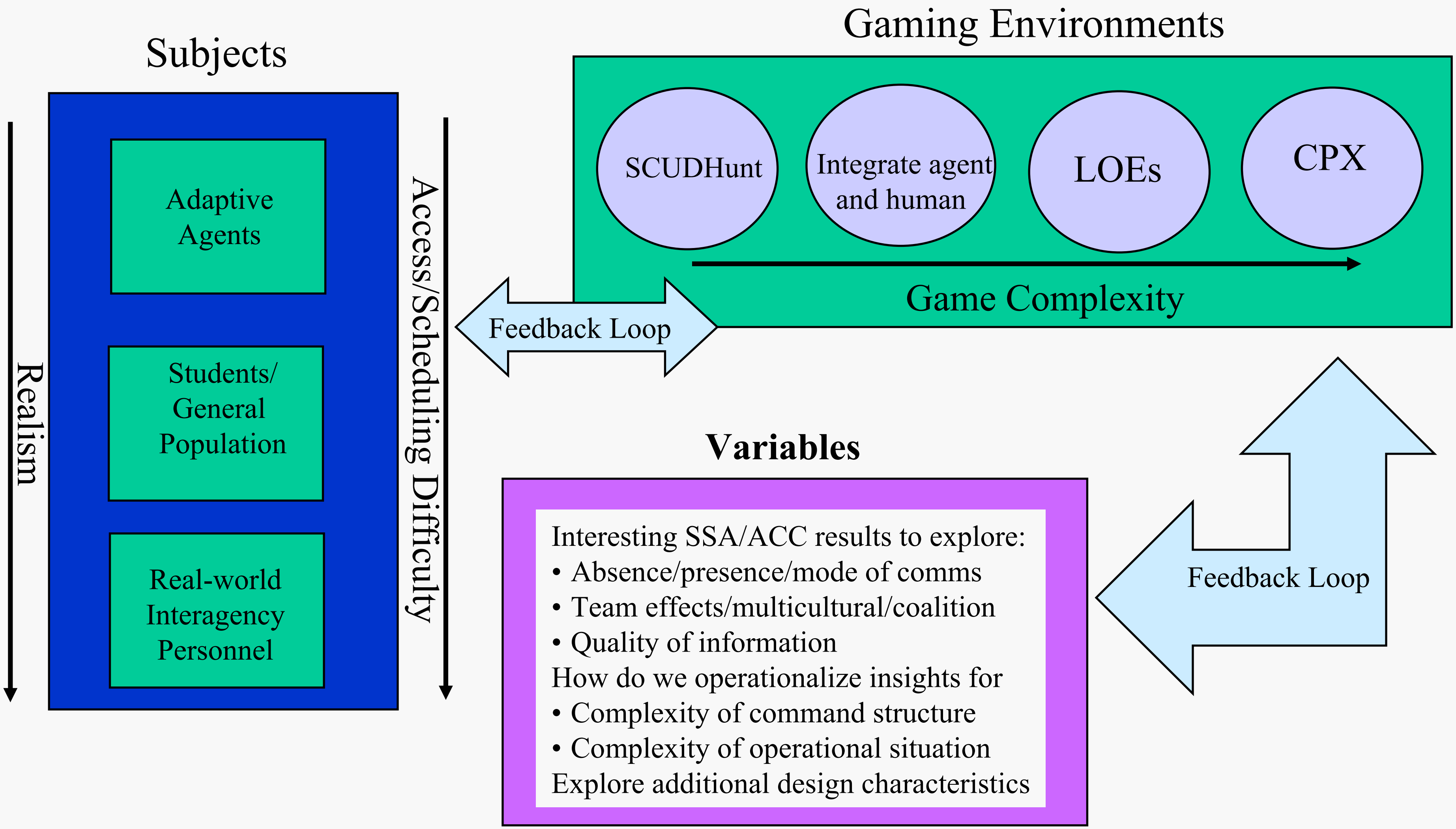
Questions for further research

- The causality conundrum: does high SSA lead to high quality, or does high quality produce high SSA?
- How does adding complexity change the problem (thinking OPFOR, terrain cues)?
- What information do teammates exchange to produce effective SSA and good decisions?
- What attributes of players and teams relate to higher quality scores?
- What is the role of leadership in building SSA and improving quality of decisions?

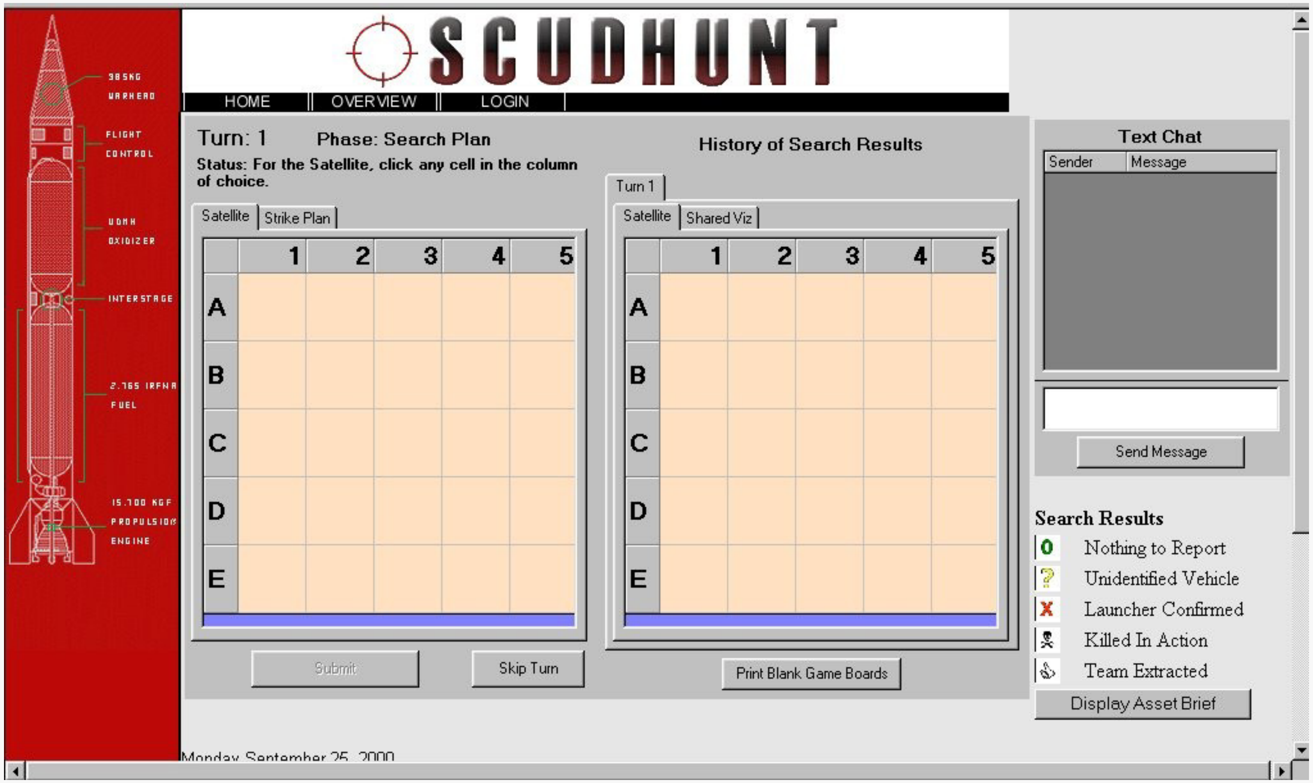
Summary . . . so far!

- We can create distillation games that capture the key elements in the OODA loop
- We can use such games to create experiments that are amenable to statistical design and analysis
- We can use game-playing agents and genetic algorithms to explore vast C2 decision spaces
- We can use human games to validate findings, suggest adjustments, and identify new areas for exploration
- We can integrate agent and human games in experimental campaigns to address fundamental issues systematically

C2 campaign plan



To play SCUDHunt for yourself, go to:
www.scudhunt.com



To read SCUDHunt papers go to:
www.thoughtlink.com/publications.htm

Agent basics

- State of the game
  - *Belief-matrix*, $-1 \leq B_{ij} \leq +1$
- Agent characteristics (~ “Personality”)
  - *Interpretation of sensor reports*
  - *Trust (of other agents)*
  - *Strike Plan Logic*
  - *Sensor Placement Logic*

Agents and sensors

- Interpretation of sensor reports
  - *Sensor-Report:Launcher-Correlation Matrix:*

    β_{RS} = *Agent's belief that launcher is at coordinate for which sensor S has reported R*
  - *Sensor Reliability Estimate Matrix:*

    $\mathcal{R}_{RS}$ = *A's estimate of the reliability of sensor S's report R*

    $0 \leq \mathcal{R}_{RS} \leq 1$

Sensor placement

- Sensor Placement Logic
  - Dogma Threshold, $0 \le B_{Dogma} \le 1$:
    - ✓ *If $B_{ij} \ge B_{Dogma}$ then A places a “launcher is definitely here” marker at site (i,j)*
    - ✓ *If $B_{ij} \le - B_{Dogma}$ then A places a “launcher is definitely not here” marker at site (i,j)*
  - Sensor Placement Fitness Function:

$$F_S(t) = \begin{cases} w_{MCov} * (\text{number of sites covered at time } t) \\ + w_{CCov} * (\text{total number of sites covered at least once for times } t < t) \\ + w_{FCov} * (\text{minimal number of sites that can be covered at time } t+1) \\ + w_{GBel} * (\text{belief gain throughout battlefield at time } t) \\ + w_{LBel} * (\text{belief at site } i, j \text{ at time } t) \end{cases}$$

Trust and beliefs

- Trust (of other agents)
  - *Agent↔Agent Trust Matrix:*

  $0 \leq T_{AB} \leq 1$

  $T_{AB} = 0$*: agent A mistrusts everything agent B tells it*

  $T_{AB} = 1$*: agent A believes everything agent B tells it*

- Belief Update:
  - Own Sensors: $B_{own} = \mathscr{R}_{RS} \cdot \beta_{RS}$
  - Linked Sensors: $B_{linked} = T_{AB} \cdot \mathscr{R}_{RS} \cdot \beta_{RS}$ *or* $B_{linked} = T_{AB} \cdot B_{L,ij}$,

    where $B_{L,ij}$ *is the belief matrix of agents linked to A*

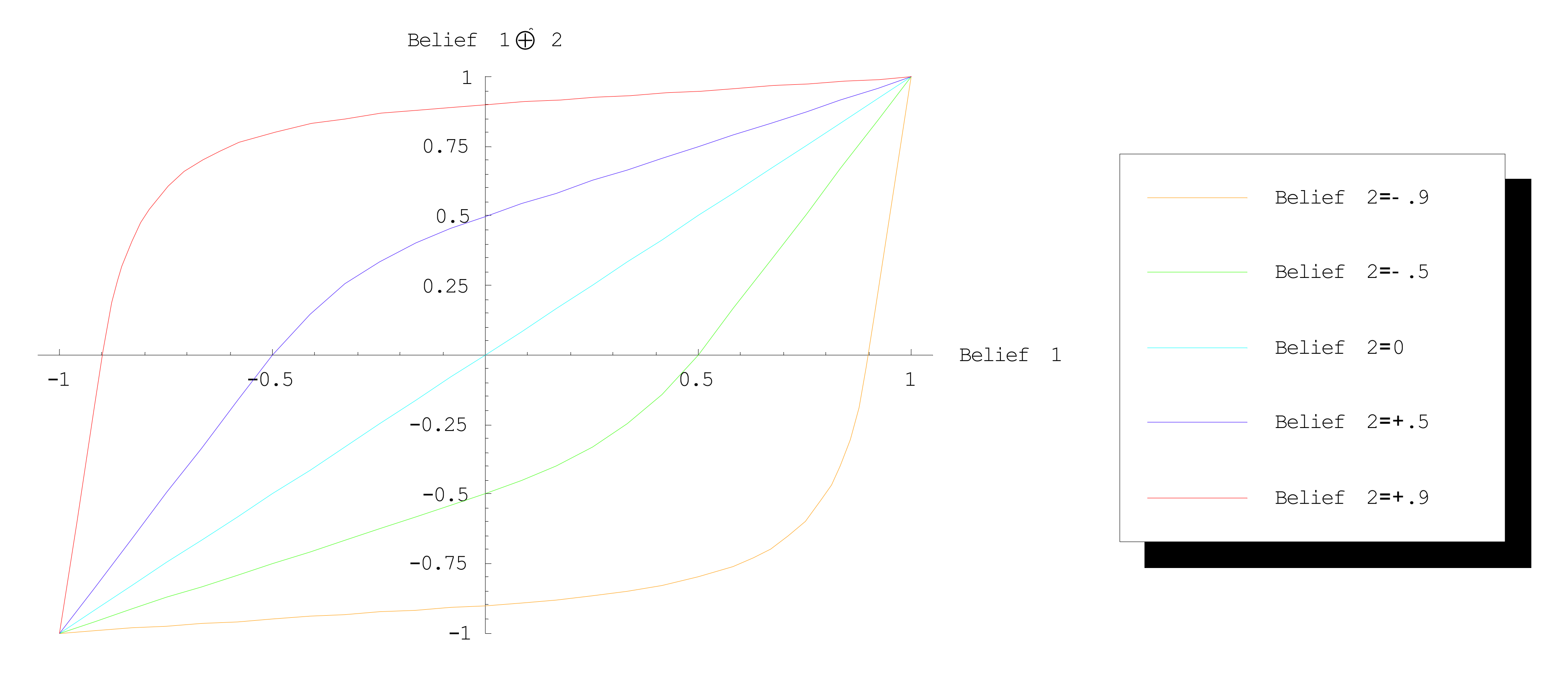
Updating beliefs

- Belief Update (using Durkin fuzzy-sum):

  $B_{ij}(t+1) = B_{ij}(t) \oplus B_{own}(t) \oplus B_{linked}(t)$, where

$$B_1 \oplus B_2 = \begin{cases} B_1 + B_2(1 - B_1), \text{ if } B_1, B_2 > 0, \\ B_1 + B_2(1 + B_1), \text{ if } B_1, B_2 < 0, \\ (B_1 + B_2)/(1 - Minimum\{|B_1|, |B_2|\}) \end{cases}$$

Durkin sums


Belief 1 ⊕̂ 2
1
0.75
0.5
0.25
-0.25
-0.5
-0.75
-1
-1
-0.5
0.5
1
Belief 1
Belief 2=-.9
Belief 2=-.5
Belief 2=0
Belief 2=+.5
Belief 2=+.9

Agents and strike plans

- Strike Plan Logic
  - Select top N_{Strike} ranking sites:

…such that $|B_{ij}| \geq B_{threshold}$

where $0 \leq B_{threshold} \leq 1$ *is A's Threshold Belief Strength*

$B_{threshold} \approx 0 \leftrightarrow$ *A is easily convinced*

$B_{threshold} \approx 1 \leftrightarrow$ *A is stubborn*