AN AGENT-BASED MODEL SIMULATION OF MULTIPLE COLLABORATING MOBILE AD HOC NETWORKS (MANET)

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Presentation Outline

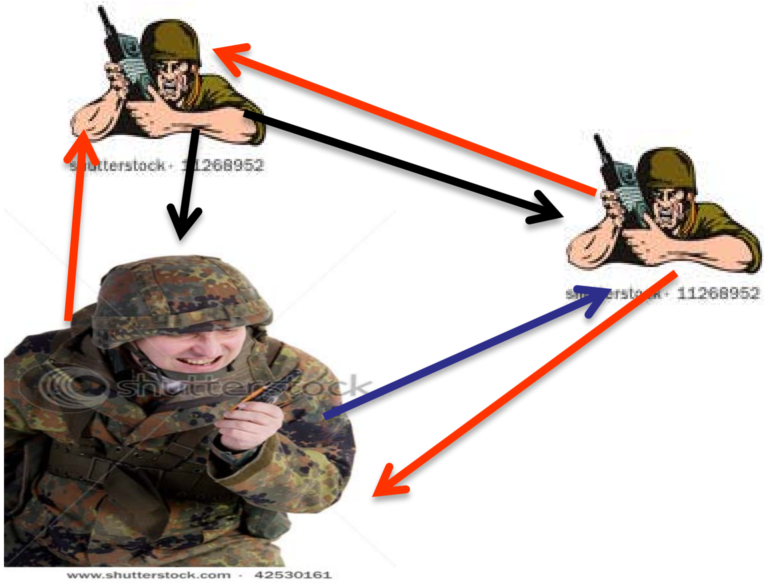
1. Background
2. Research Motivation
3. Approach
4. Modeling & Simulation
5. Simulation Results
6. Summary and Conclusions

BACKGROUND

MANET: A popular acronym for Mobile Ad hoc NETwork

Figure 1. Radio Set SCR-300-A. In Use, Viewed From Right Side.

- ✓A MANET is an autonomous collection of mobile users that communicate over relatively bandwidth constrained wireless links.
- ✓Since the nodes are mobile, the network topology may change rapidly and unpredictably over time.
- ✓ The network is decentralized, where all network activity including discovering the topology and delivering messages must be executed by the nodes themselves, i.e., routing functionality will be incorporated into mobile nodes.
- ✓A hybrid of human-machine- or machine-machine- system



BACKGROUND

- Mobile
  - Random and perhaps constantly changing
- Ad-hoc
  - Not engineered
- Networks
  - Elastic data applications which use networks to communicate

Ad hoc networks:

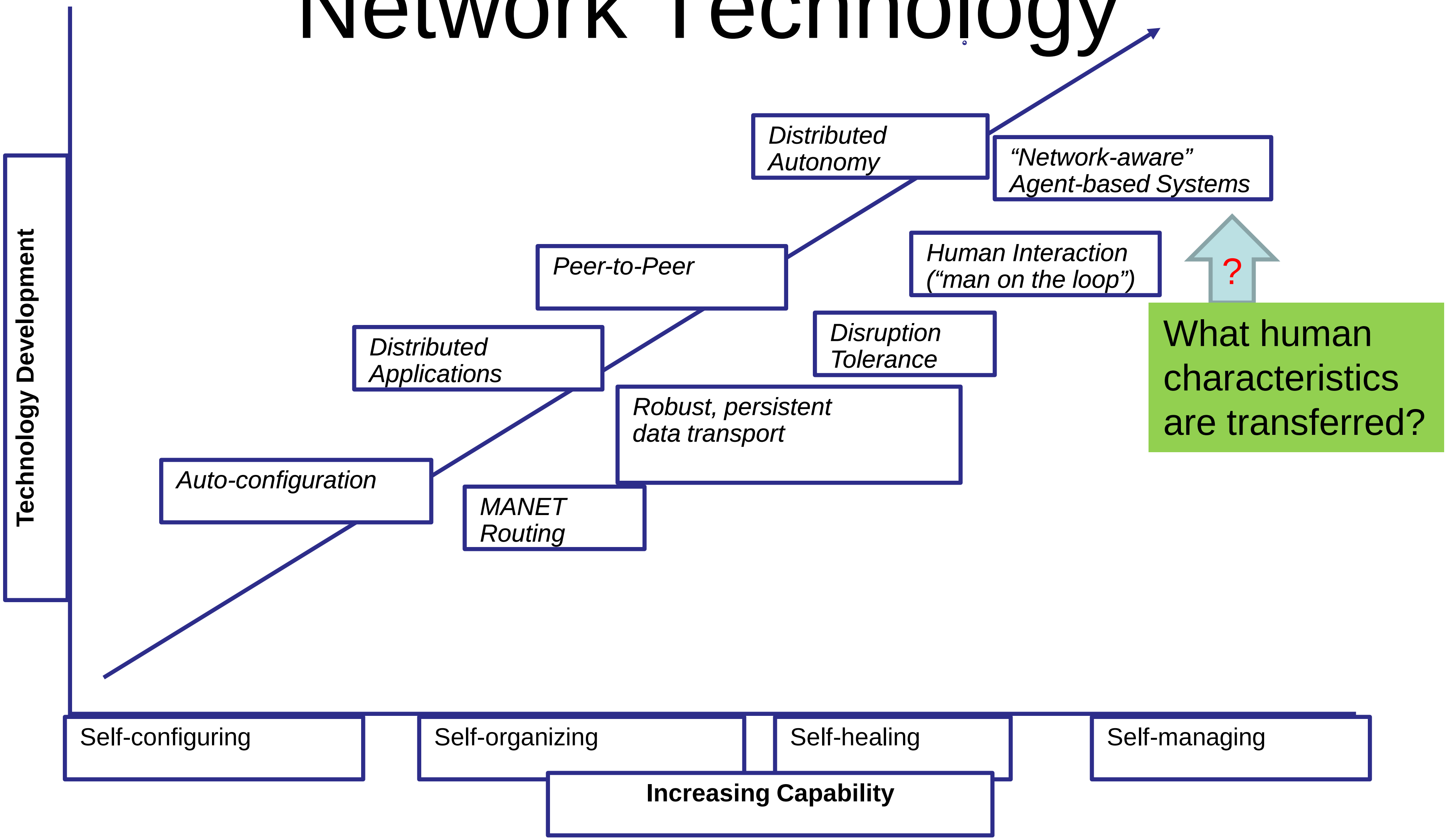
Do not need backbone infrastructure support

Are easy to deploy

Useful when infrastructure is absent, destroyed or impractical

- Interconnected collection of wireless nodes
- Nodes enter and leave over time
- Nodes also act as routers; forward packets
- No pre-established network infrastructure
- No centralized administration
- Communication using BlueTooth and WAP

Envisioned Evolution of Network Technology



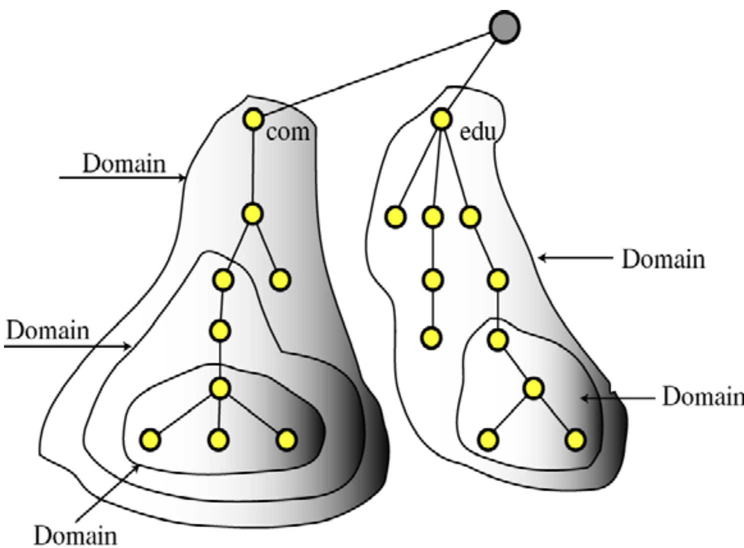
From : Brian Adamson, NRL

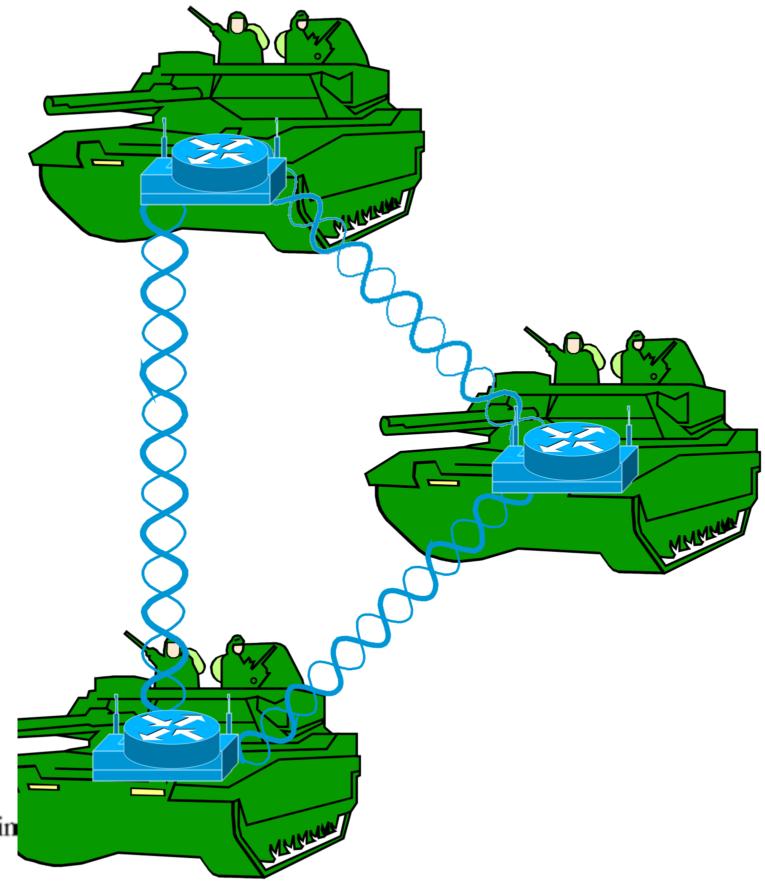
Many Applications of MANET

- Personal area networking
  - cell phone, laptop, ear phone, wrist watch
- Military environments
  - soldiers, tanks, planes
- Civilian environments
  - taxi cab network
  - meeting rooms
  - sports stadiums
  - boats, small aircraft
- Emergency operations
  - search-and-rescue
  - policing and fire fighting

Military applications

- Combat regiment in the field
  - Perhaps 4000-8000 objects in constant unpredictable motion…
- Intercommunication of forces
  - Proximity, function, plan of battle
- Special issues
  - Low probability of detection
  - Random association and topology





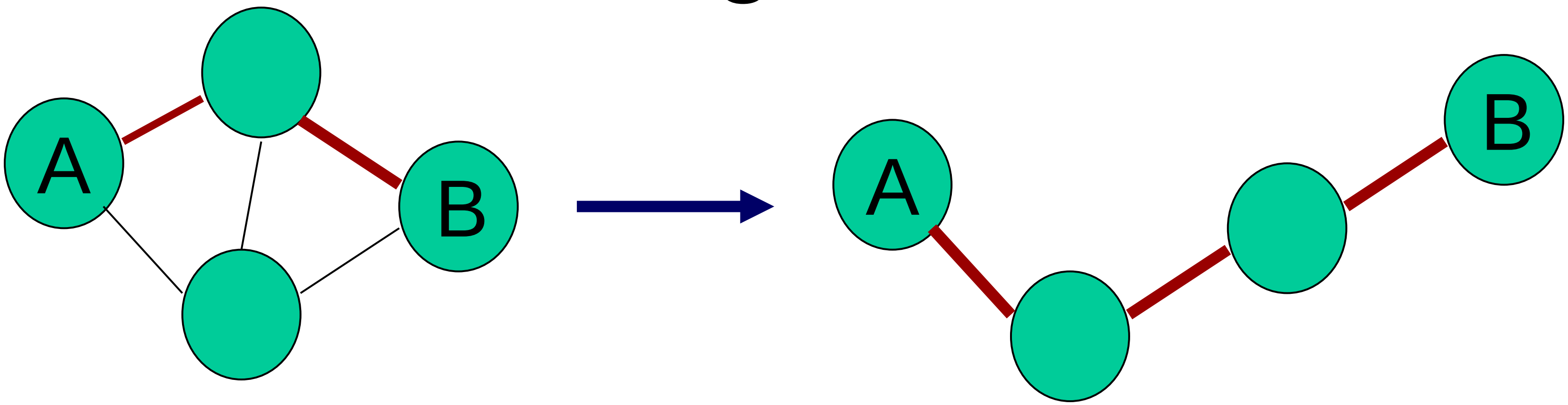
Challenges in Mobile Environments

- Limitations of the Wireless Network
  - packet loss due to transmission errors
  - variable capacity links
  - frequent disconnections/partitions
  - limited communication bandwidth
  - Broadcast nature of the communications

- Limitations Imposed by Mobility
  - dynamically changing topologies/routes
  - lack of mobility awareness by system/applications

- Limitations of the Mobile Computer
  - short battery lifetime
  - limited capacities

Challenges Continue



- Dynamic Topologies and node memberships
- Bandwidth constraints
- Many Transmission Errors
- Energy-constrained operation

Community Attention to Manets

- Routing/ packet scheduling
- *Reliability*
- *Lethality*
- *Energy consumption and longevity*
- *Vulnerability*
- *Mobility*
- *Security*
- *Survivability*

Motivation

- MANET as a human-machine system
- MANETOLOGY: Develop a network theory for human-machine system (with MANET = machine)

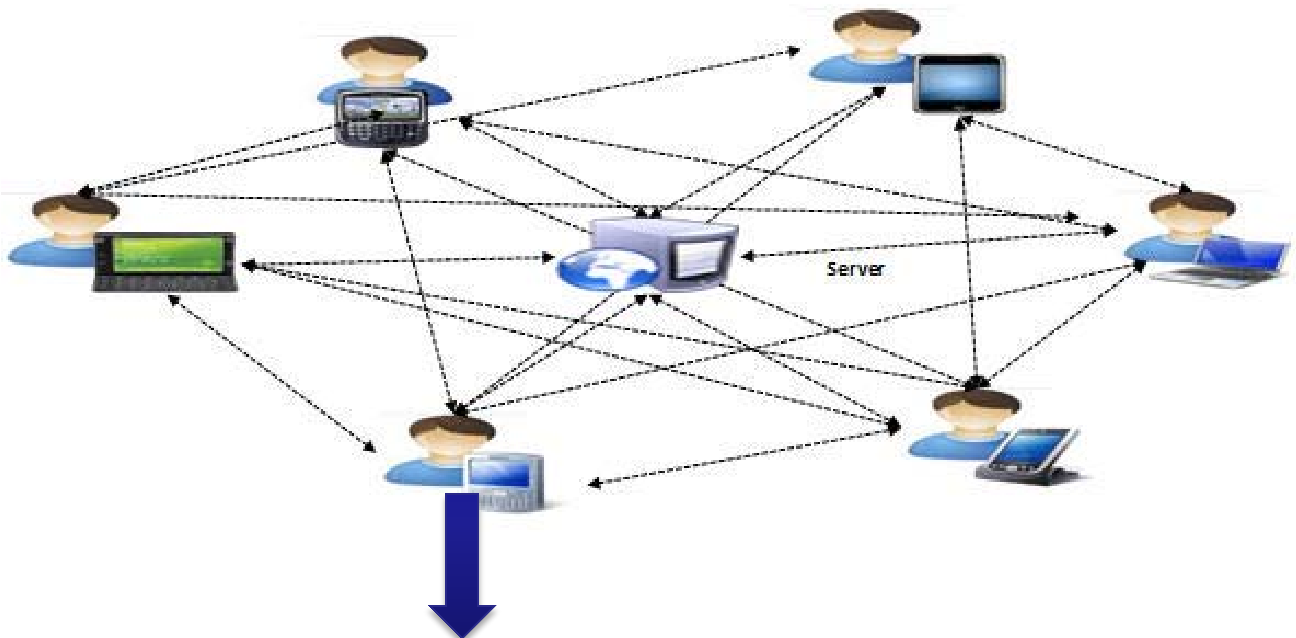
1. Allows for modeling of fundamental human characteristics in intelligent agent-based networks.
2. Allows for representation framework for CSTS
3. Advance cognitive network theory for modeling and simulation

Question: Does agent-based MANET performance (measured by vulnerability) affected by human traits like behavior, perception, and cognition abilities?

INFLUENCING FACTORS FOR MANETOLOGY

(1) Emergence – the notion that the interaction of a technological, cognitive, social, and ecological system will give rise to a collective pattern of behaviors that differ remarkably from the presumed behaviors from each of the sub-systems;
(2) Dynamic – the notion that behavior change is situated in time and space giving rise to temporal and spatial behaviors, respectively;
(3) Spiral model – the notion that due to the interaction of multiple behaviors, resultant system behaviors are non-linear, and understanding information flow and their functions are mediated through a continuous spiral feedback model;
(4) Self-organized – the notion that agents that have intelligence can adapt and re-organize their behaviors for planning during contingencies;
(5) Distributed cognition – the notion that each agent in the system share, the same goal and seamlessly distribute what they know with each other;
(6) Sensemaking – the notion that agents can reduce equivocal information to a common metric for use in an intended goal execution, and collectively seek prospective information for coping with future state changes (Huang & Chang, 2006);
(7) Agitative states – the notion that agents for military M&S will operate under stress levels which have the effect of diminishing the full functioning of the agent's performance such as reduction of awareness and attention.

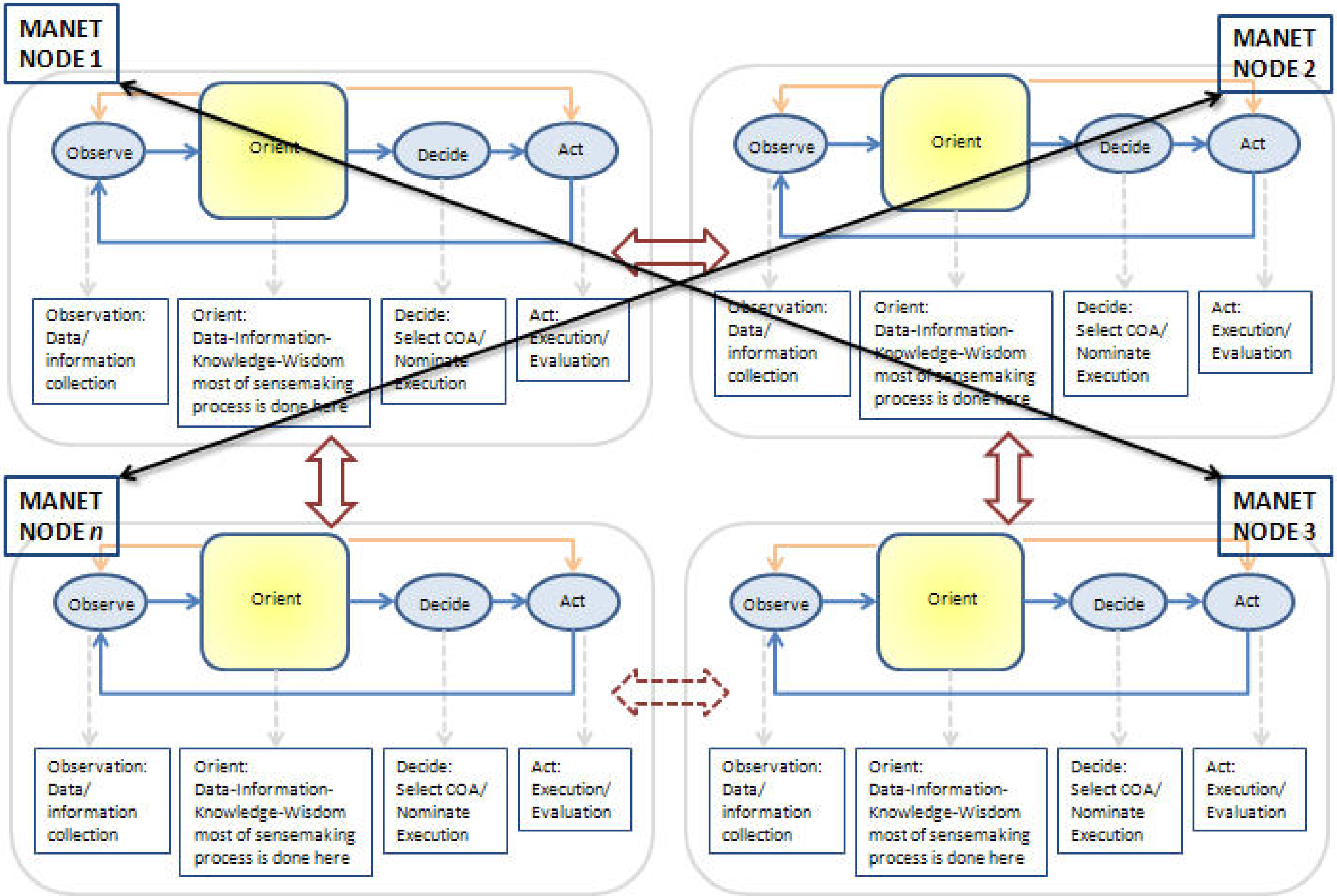
APPROACH—MANET AS A COGNITIVE SOCIO-TECHNOLOGY SYSTEM (CSTS)



At each node, the human activities are to Observe, Orient, Decide, Act

	MANET device	Human
MANET device	Instructions and rules Automated behaviors	Model-based predictions and look-up table
Human	User-interface, visual tools	Social-based: dialogs and communication

APPROACH—MANET AS A COGNITIVE SOCIO-TECHNOLOGY SYSTEM (CSTS)

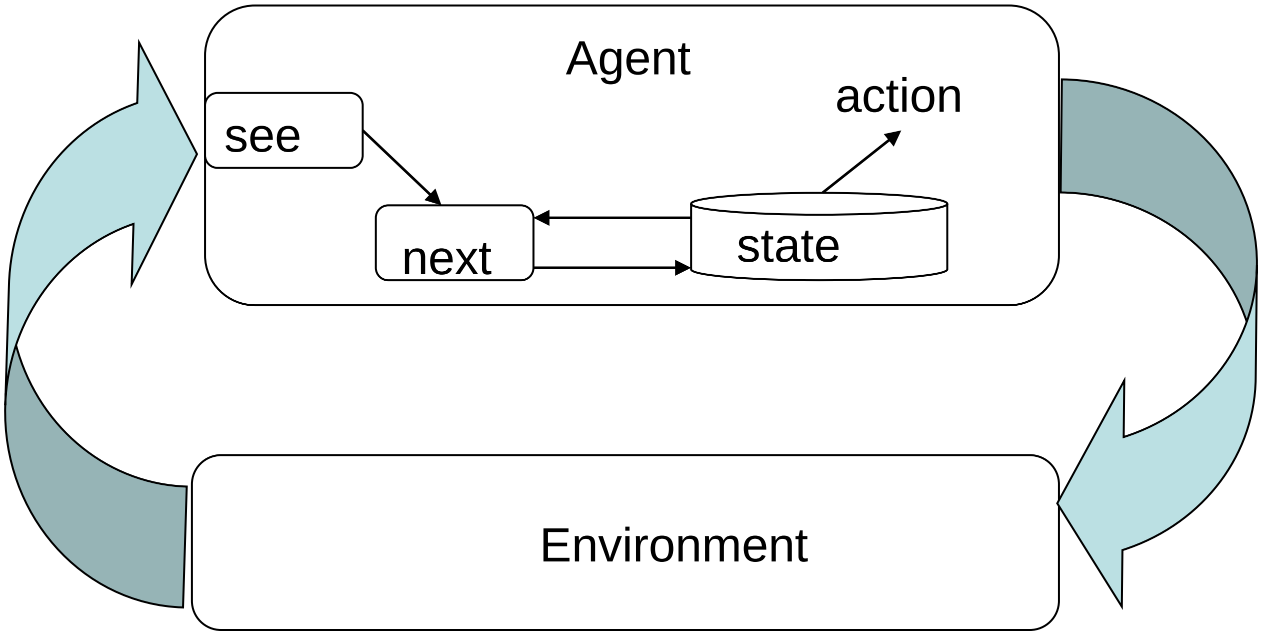


The OODA model was developed by Boyd (1987)

APPROACH—MANET AS A COGNITIVE SOCIO-TECHNOLOGY SYSTEM (CSTS): Why Agents

(a) cope with complex interaction of multiple behaviors;
(b) capable of analyzing complex adaptive information;
(c) cope with contingencies under emergence behaviors and events;
(d) recognize opportunities in a spatio-temporal manner;
(e) seek satisficing and plausible (good enough) solutions when confronted with unexpected situations with uncertain and equivocal information;
(f) represent as much as is feasible the various dimensions of expert knowledge in the domain problems

APPROACH: Agents in MANET

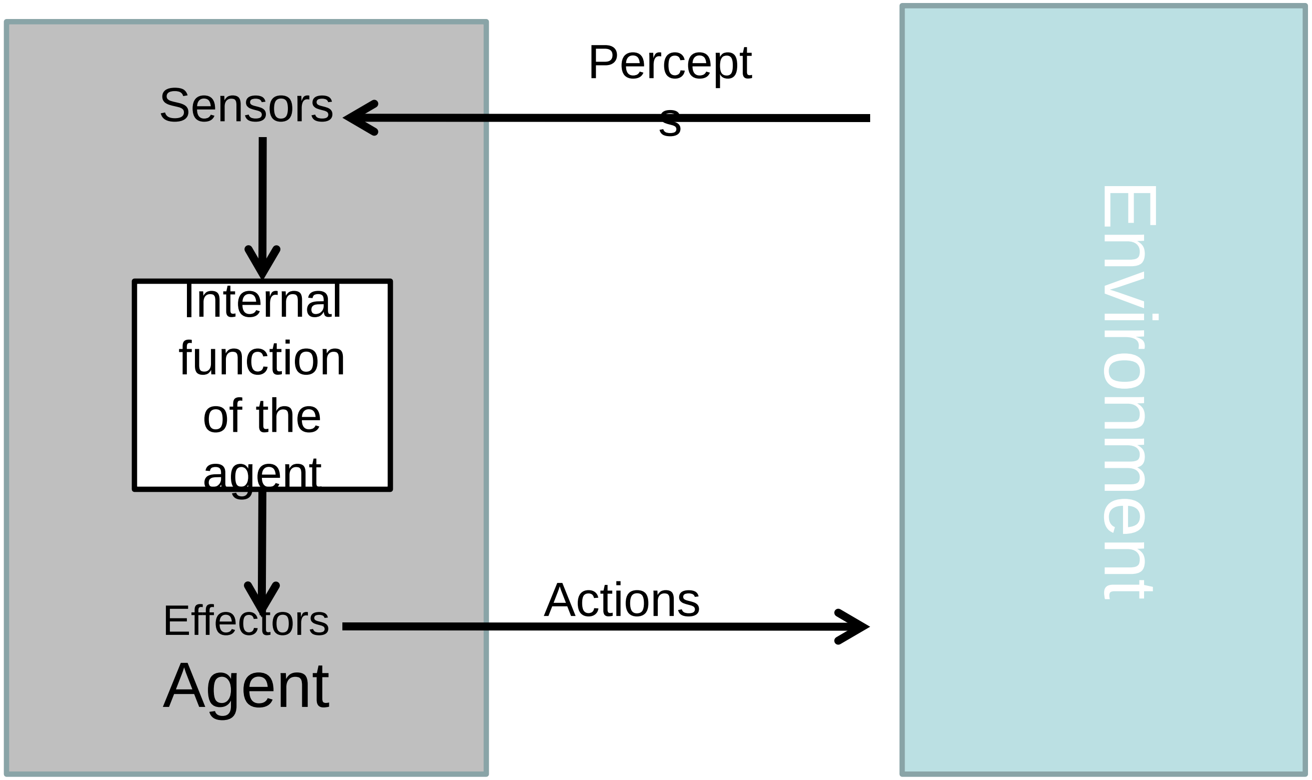


Assume the basic principle of a Rational Agent: For each possible percept sequence, a rational agent should select an action that is expected to maximize its performance measure, given the evidence provided by the percept sequence and whatever built-in knowledge the agent has.

Intelligent Agents: Theory and Practice

Michael Wooldridge **Nicholas R. Jennings**

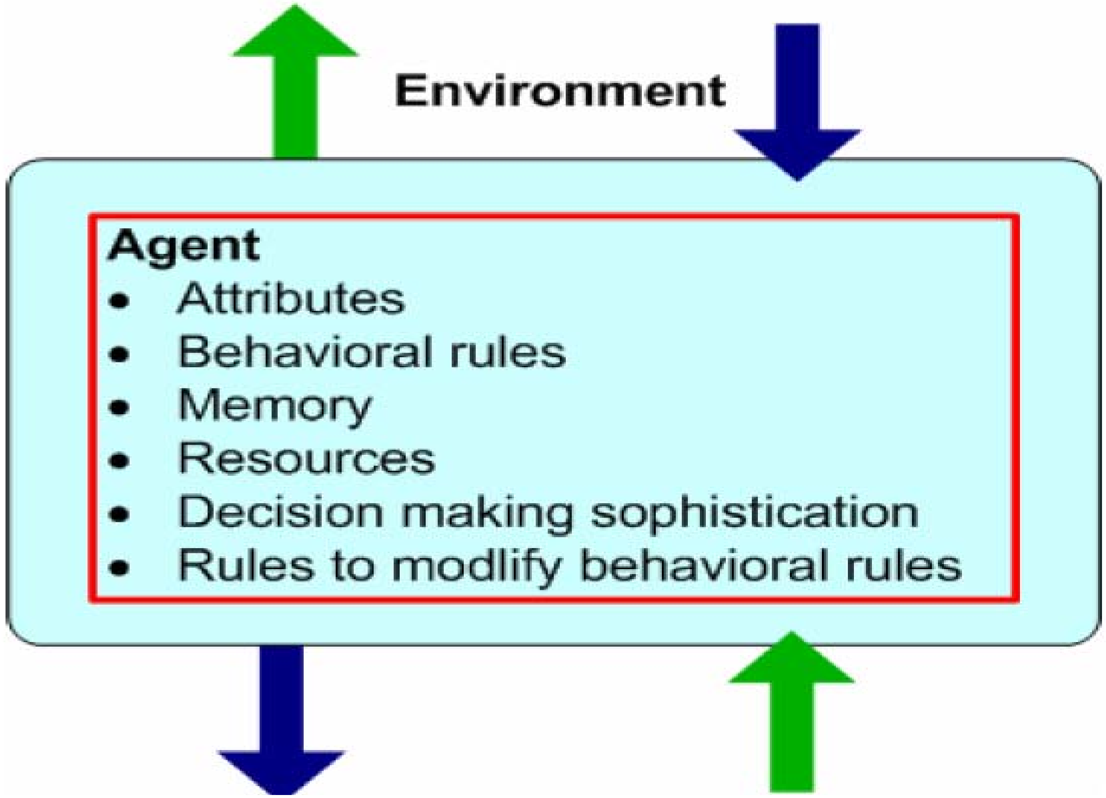
APPROACH: Agents in MANET



Russell & Norvig (2003). Artificial Intelligence: A Modern Approach; Prentice Hall.

Agents can perform actions in order to modify future percepts so as to obtain useful information (information gathering, exploration).

APPROACH: Modeling Representation

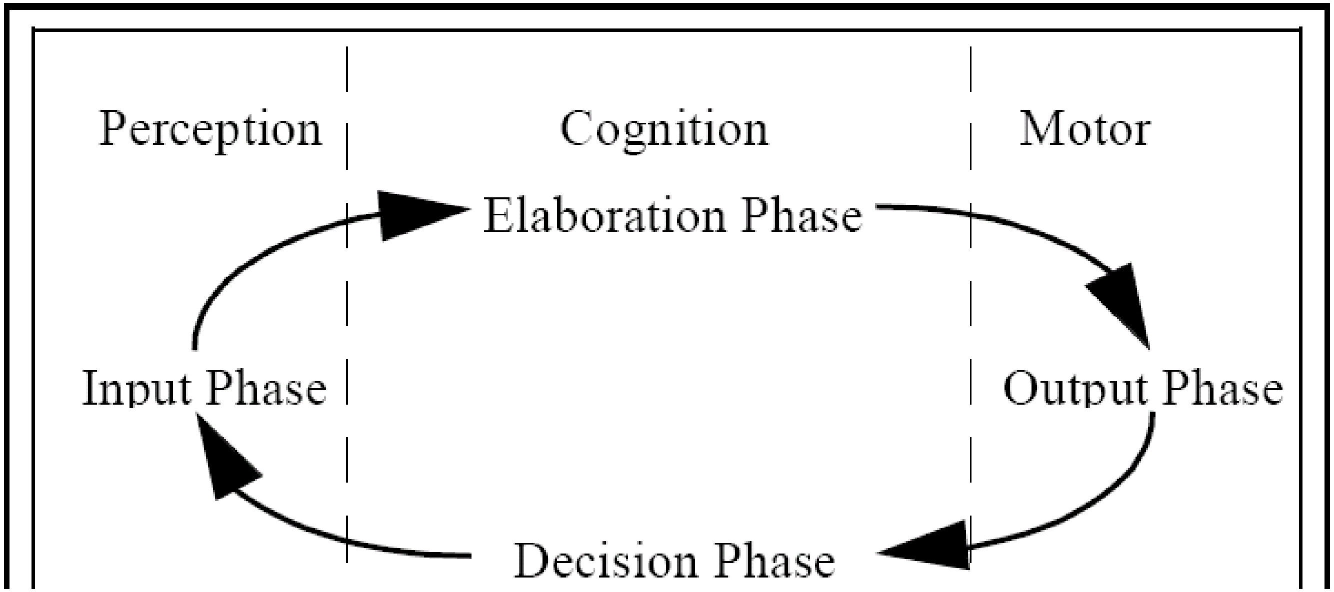


TUTORIAL ON AGENT-BASED MODELING AND SIMULATION

Charles M. Macal
Michael J. North

Each agent interacts (directly or indirectly) with one or more aspects of an environment.

APPROACH: Modeling Representation



Proc. of 8th Conference on Computer Generated Forces and Behavioral Representation, Orlando, FL, May 1999

Modeling Perceptual Attention in Virtual Humans

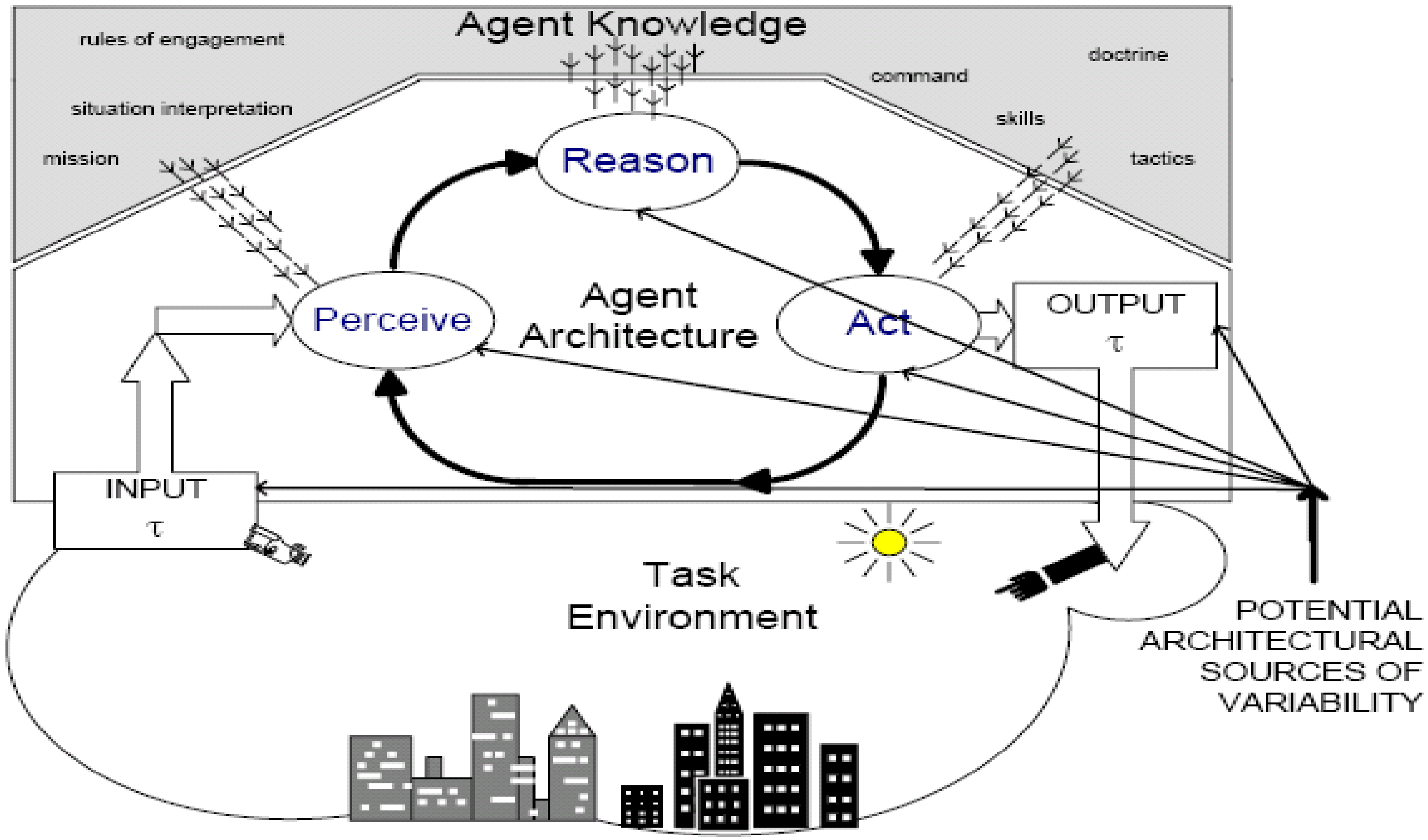
Randall W. Hill, Jr.

<u>Agent Environments</u>

Fully vs. Partially Observable (Accessible vs. inaccessible)
Deterministic vs. Stochastic (non-deterministic)
Episodic vs. Sequential (non-episodic)
Static vs. dynamic
Discrete vs. continuous

APPROACH: Modeling Representation

Variability in human behavior most often arises from
complex interactions among the many mental and



Presented at: Behavior Representation in Modeling & Simulation Conference (BRIMS). May, 200

Variability in Human Behavior Modeling for Military Simulations

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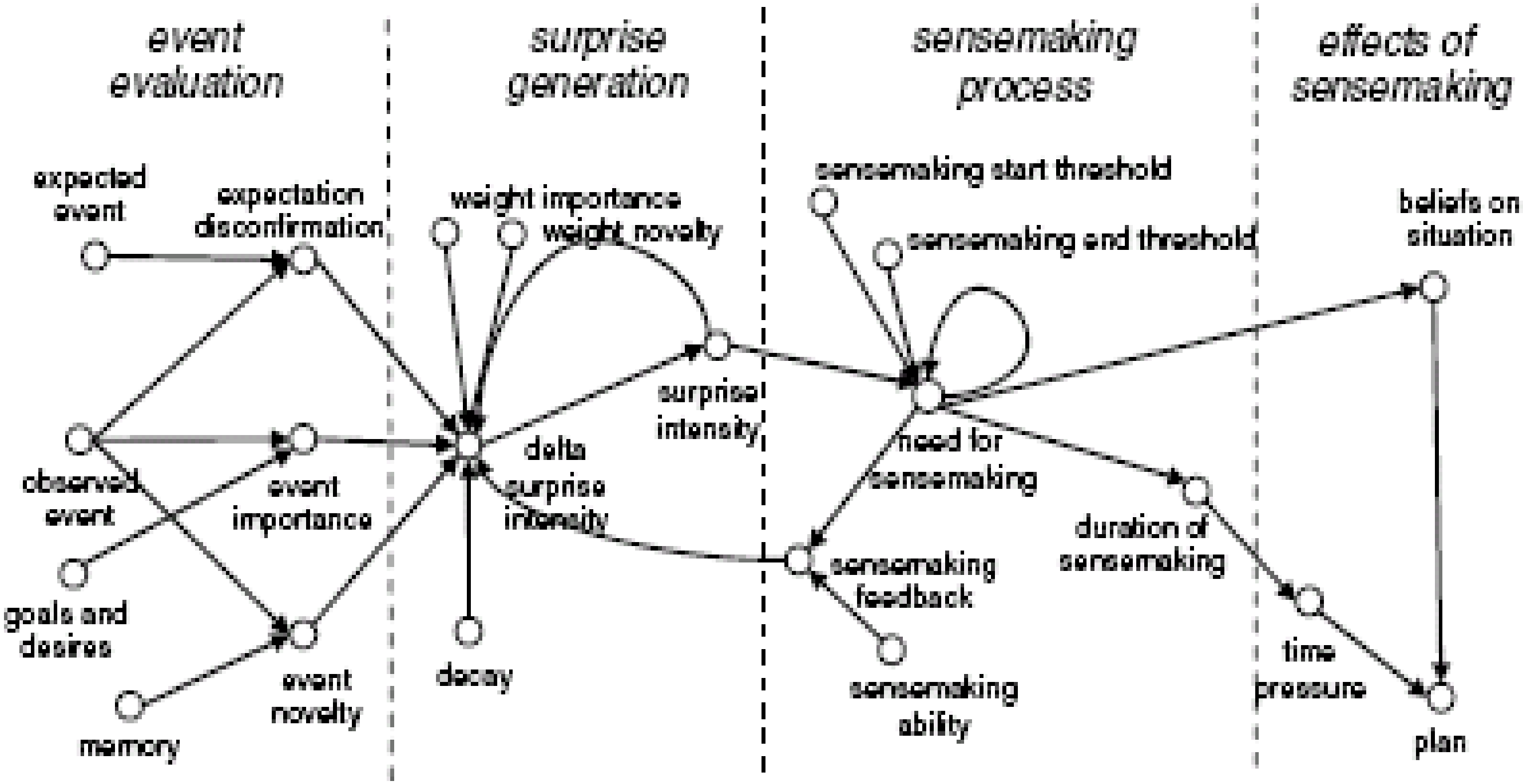
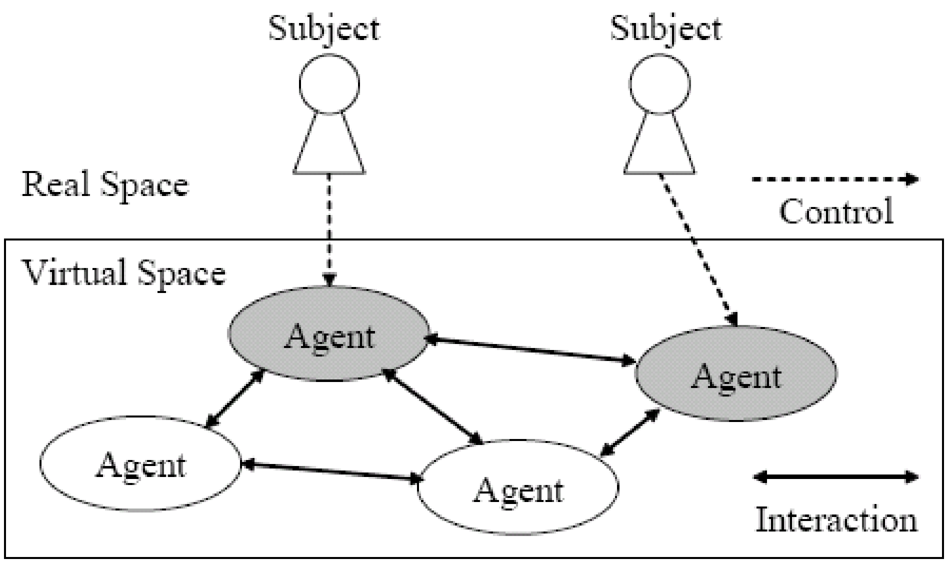
APPROACH: How We Do It



A Computational Model on Surprise and Its Effects on Agent Behaviour in Simulated Environments

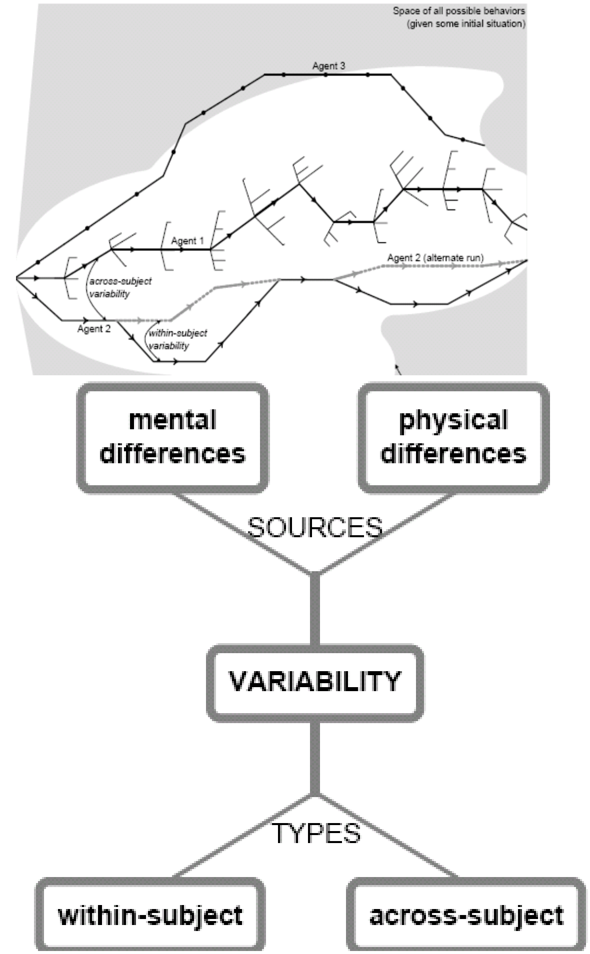
Robbert-Jan Merk

APPROACH: Considering Behavior



Modeling Human Behavior for Virtual Training Systems

Yohei Murakami and **Yuki Sugimoto** and **Toru Ishida**
Department of Social Informatics, Kyoto University



Presented at: Behavior Representation in Modeling & Simulation Conference (BRIMS). May, 200

Variability in Human Behavior Modeling for Military Simulations

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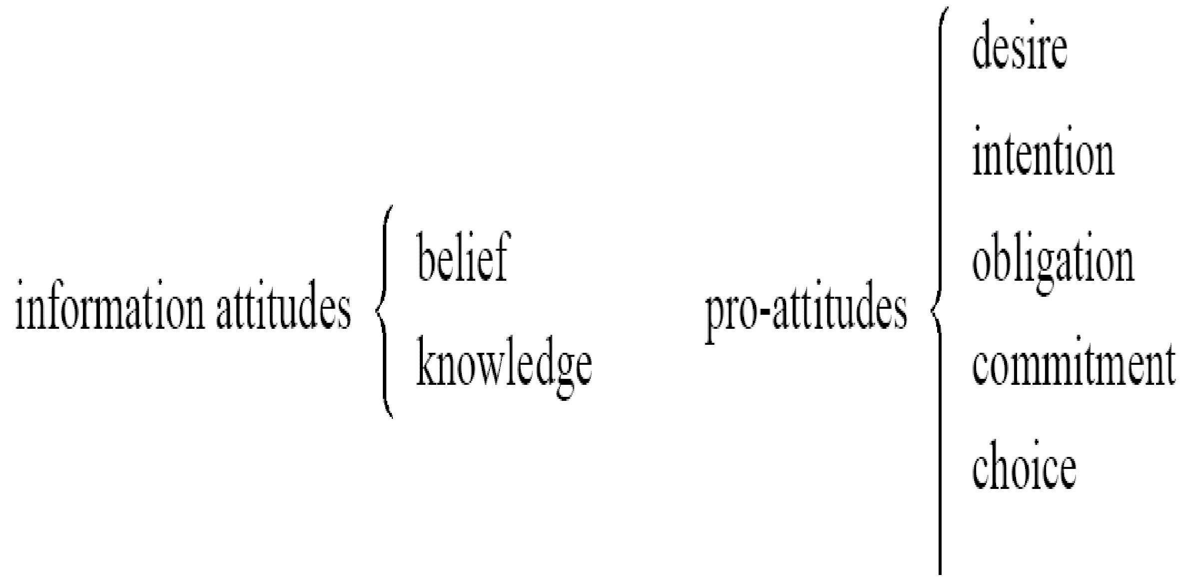
APPROACH: Modeling Behavior



Intelligent Agents: Theory and Practice

Michael Wooldridge   Nicholas R. Jennings

An agent is completely specified by the <u>agent function</u> mapping percept sequences to actions. We use a model-based reflex agent function paradigm for the prototype simulation.

PEARL SIMULATION ARCHITECTURE

Predict, **E**nvision, **A**nticipate, **R**eason, and **L**earn (PEARL)

Scenarios.

SOAP (Simulation Of Agent Perception);
SOAC (Simulation Of Agent Cognition);
SOAS (Simulation Of Agent Socio-culture); and
SOAB (Simulation Of Agent Behaviors).

KANAN: **Knowledge action repository** ↔

SOAP: Perception of Environment (Level 1 SA)

SOAC: **Agent cognition of the problem space** ↔

SOAB: Simulation model for Agent behaviors

SOAS: **Social and cultural cognition** ↔

An agent function can have one or all of:
Simple reflex agents: If the world is X then action Y
Model-based reflex agents: what representation describes the situation?
Goal-based agents: For situation X what should I do to achieve Y?
Utility-based agents: If I do X for situation Y, my satisfaction is Z ≥ Ω

SIMULATION (Has a Suite of 36 Major Algorithms)

SAMPLE Behavior Adaptation Algorithms

1. **Agent ID**

2. **Time :** The time agent's properties reported to the command node.

3. **Roles** : Agent's role assigned by Command Node.

4. **Physical Location (X,Y,Z)** : Agent's Current Location on the Real Map(Google Map). (Z= Zoom level)

5. **Behavior_F** : get from 'probability of failure' received from agent node (min + (max – min)*rand()) .

6. **Behavior_A** : get from 'probability of attack' received from agent node (min + (max – min)*rand()) .

7. **Behavior_AD** : Adaptability when there is enemy attack.

$$(y_{adap} = (2 / (1+e^{-kf(h,c)})) - 1$$

$k = 1$, $f(h,c)$ = Trapezoidal Fuzzy Number using hostility(h) and capability(c) level

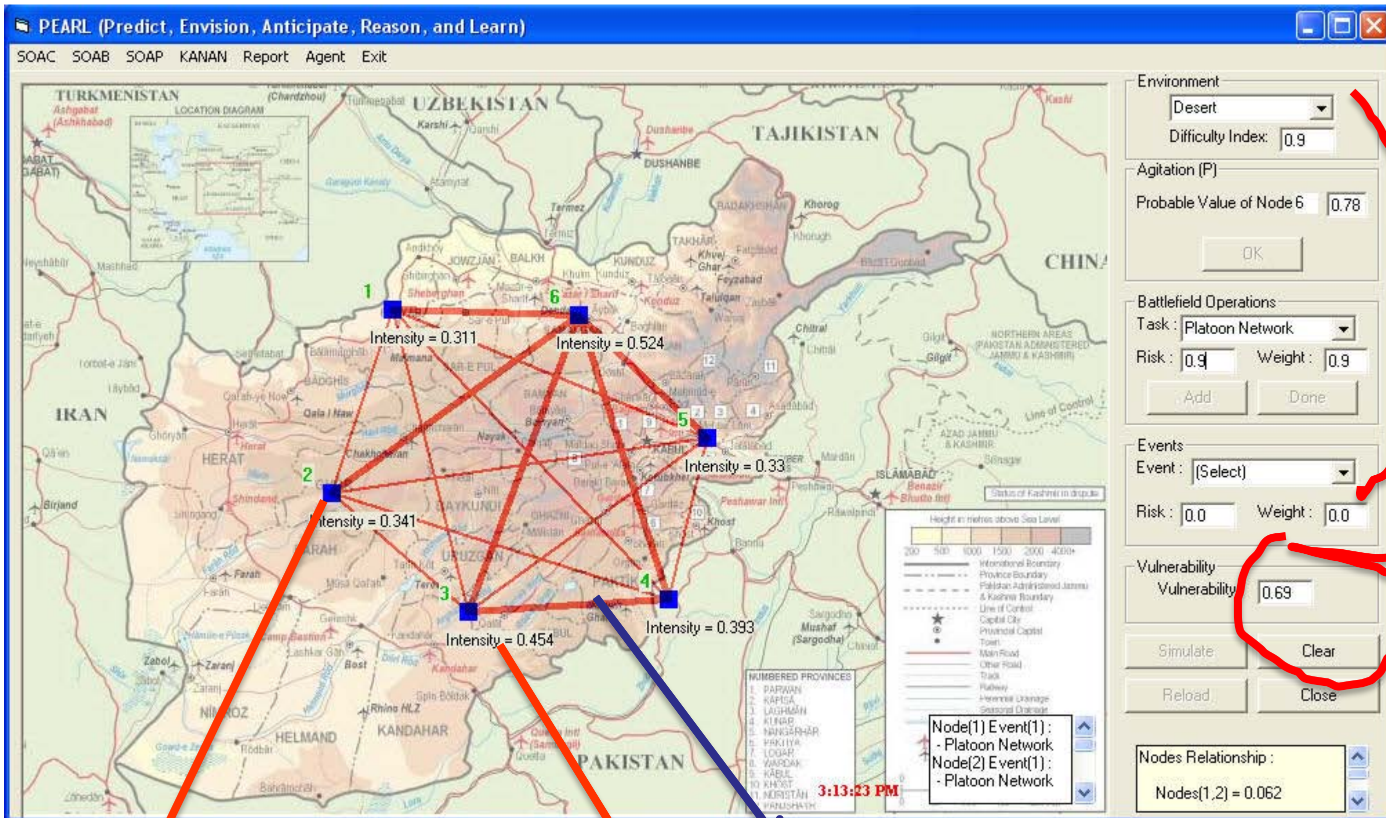
if $y_{adap} < 0$ then : Agent is Not **Adaptive**
if $0 <= y_{adap} < 0.4$ then : Agent is **Sluggishly Adaptive**
if $0.4 < y_{adap} <= 1.0$ then : Agent is **Adaptive**

8. **Perception** : get from 'Situation Awareness ability' received from agent node (min + (max – min)*rand()) .

if $0.5 < SA <= 1.0$ then : **Recognize**
if $0.0 <= SA < 0.5$ then : **Fail**

9. **Learning : (reinforcement learning, discounted time learning)**

SAMPLE SIMULATION RESULTS



Input parameters

Vulnerability of network during simulation = 69%

Arc size defines frequency of node- to- node interaction

Sample network topology (A MANET with 6 nodes; allowed number of nodes is arbitrary)

Sample node intensity (45.6%) calculated as aggregated parameter effects: task difficulty, interaction requirements, perception of environment, personality type, etc.

SIMULATION RESULTS

SOAC Stat.

System Status at Time = 5

Enemy Activity

	Freq.
1. Intruding	12
2. Spying	18
3. Listening to Communication	6
4. Attacking (Network)	12
5. Mimicking	12

C2 Activity

	Freq.
1. Information Flow	12
2. Network Behavior	18
3. Intruder	12
4. Discrepancy	18
5. Device Failure	6
6. Communication Failure	18

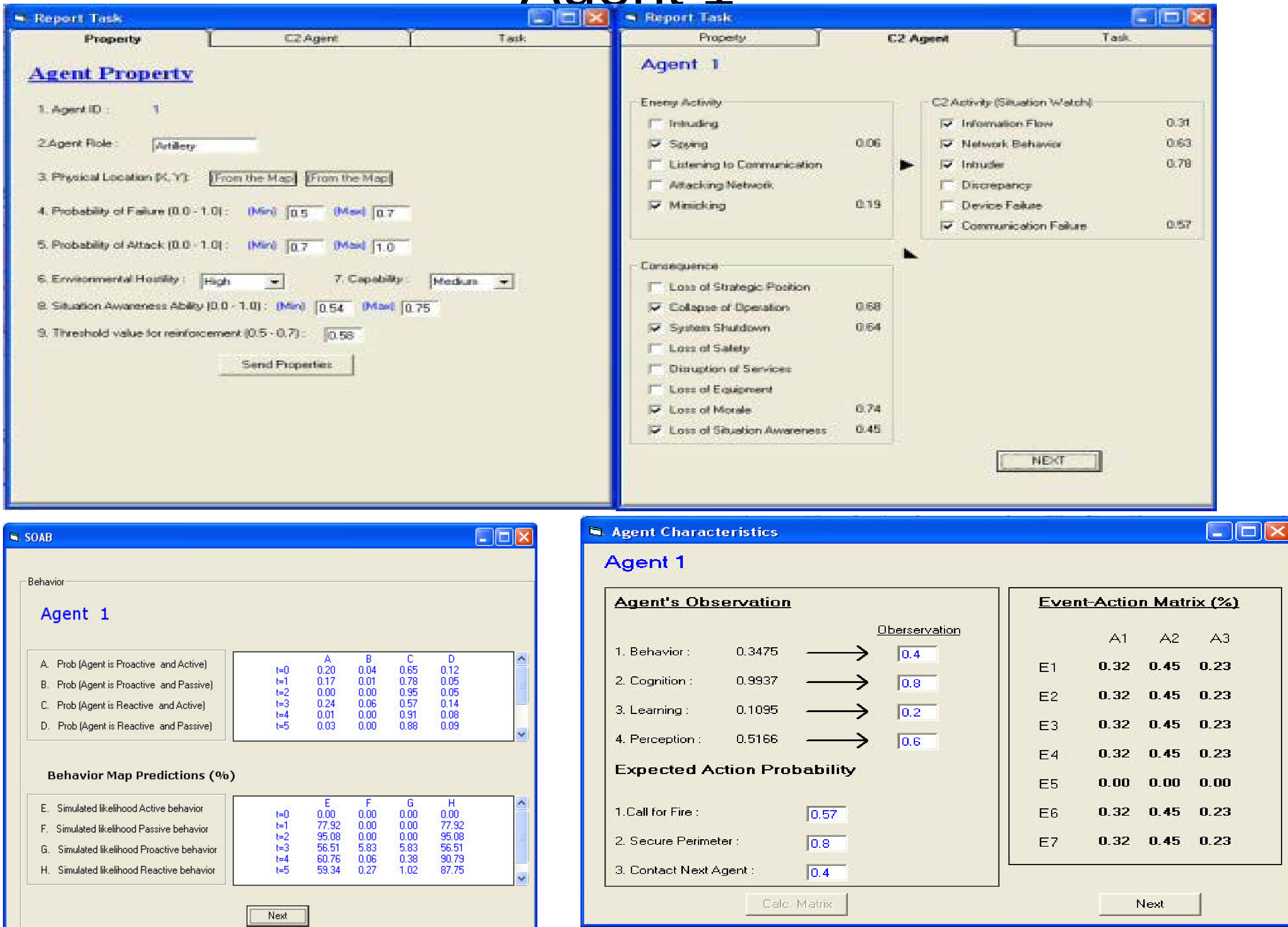
Cause (Frequency)

	C1	2	3	4	5	6
1. Critical Changes in Node Behavior	0	3	3	3	4	5
2. Degradation in Information	0	1	4	2	4	2
3. Loss of Information	0	1	3	2	1	3

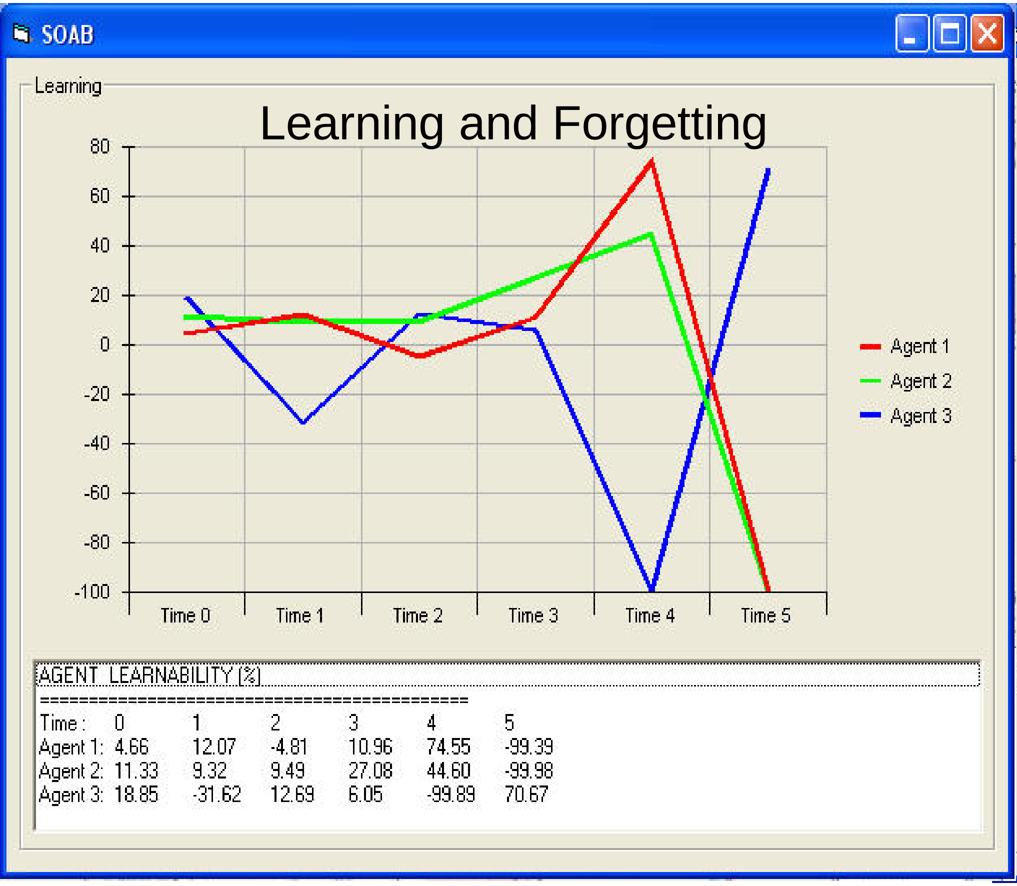
Consequence (Affected Nodes)

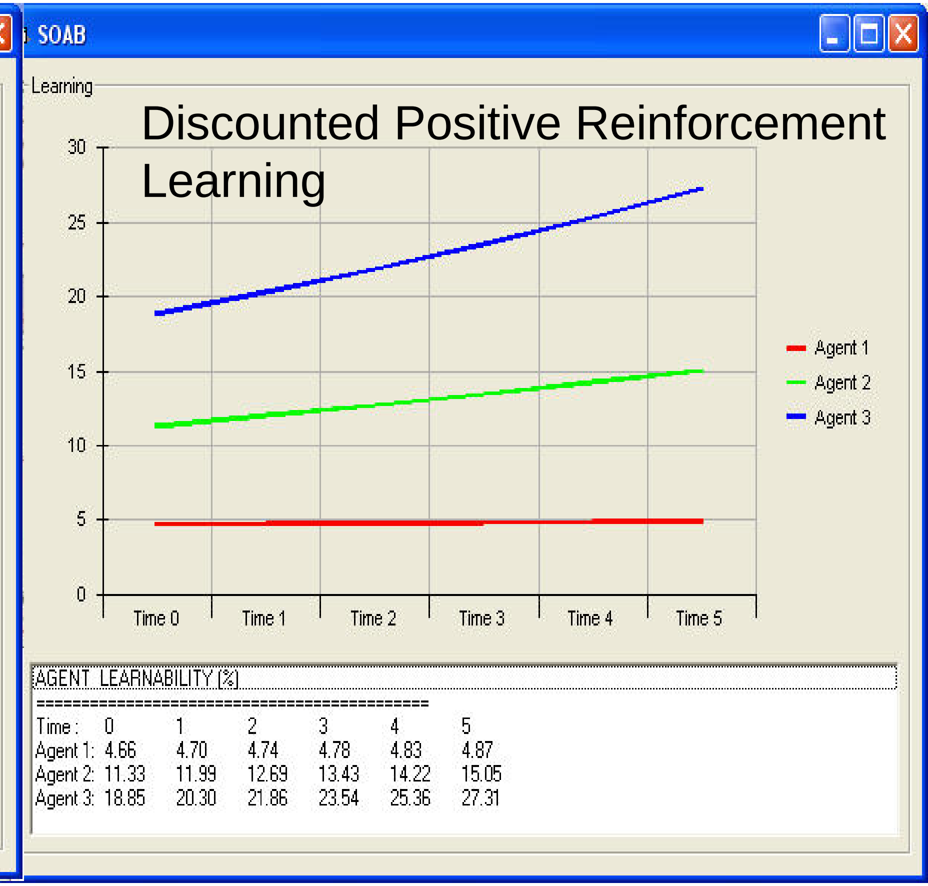
	Total Freq.	C1	2	3	4	5	6
1. Loss of Strategic Position	14	☑	☑	☑	☑	☑	☑
2. Collapse of Operaion	16	☑	☑	☑	☑	☑	☑
3. System Shutdown	11	☑	☑	☑	☐	☑	☑
4. Loss of Safety	13	☑	☑	☑	☑	☑	☑
5. Disruption of Services	19	☑	☑	☑	☑	☑	☑
6. Loss of Equipment	19	☑	☑	☑	☑	☑	☑
7. Loss of Morale	20	☑	☑	☑	☑	☑	☑
8. Loss of Situation Awareness	18	☑	☑	☑	☑	☑	☑

SIMULATION RESULTS: Sample Output – Agent 1



SIMULATION RESULTS: Agent Learning Profiles

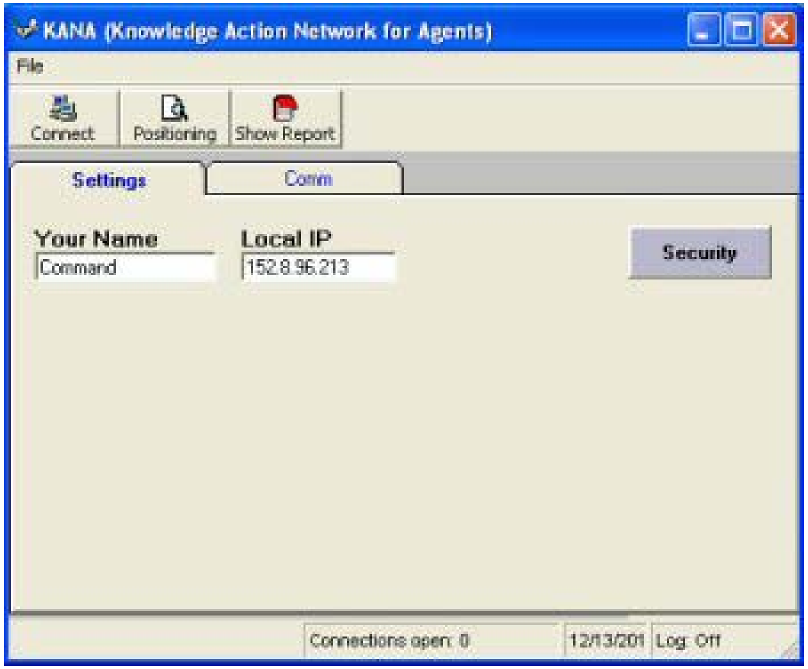




Forgetting is triggered by task conditions that disable rational and deliberate mental models –forcing the agent to ignore (or forget) routine processes.

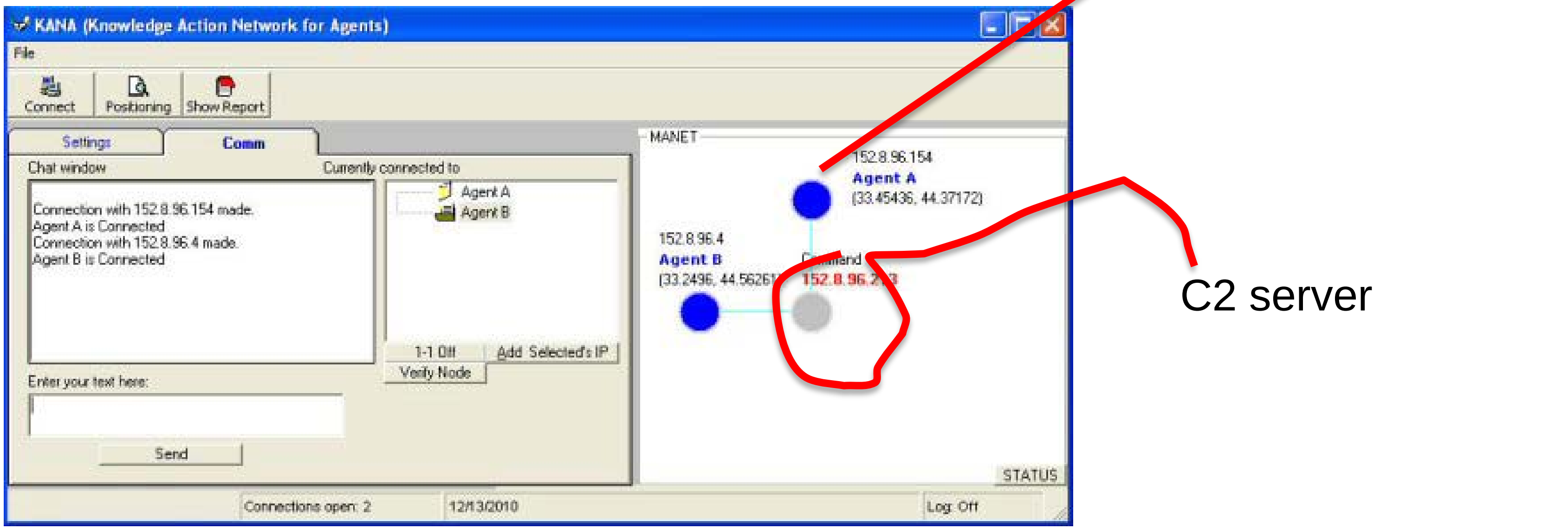
Positive reinforcement is earned by an incremental credit awarded to an agent for routinely achieving an intended goal.

APPLICATION OF SIMULATION RESULTS

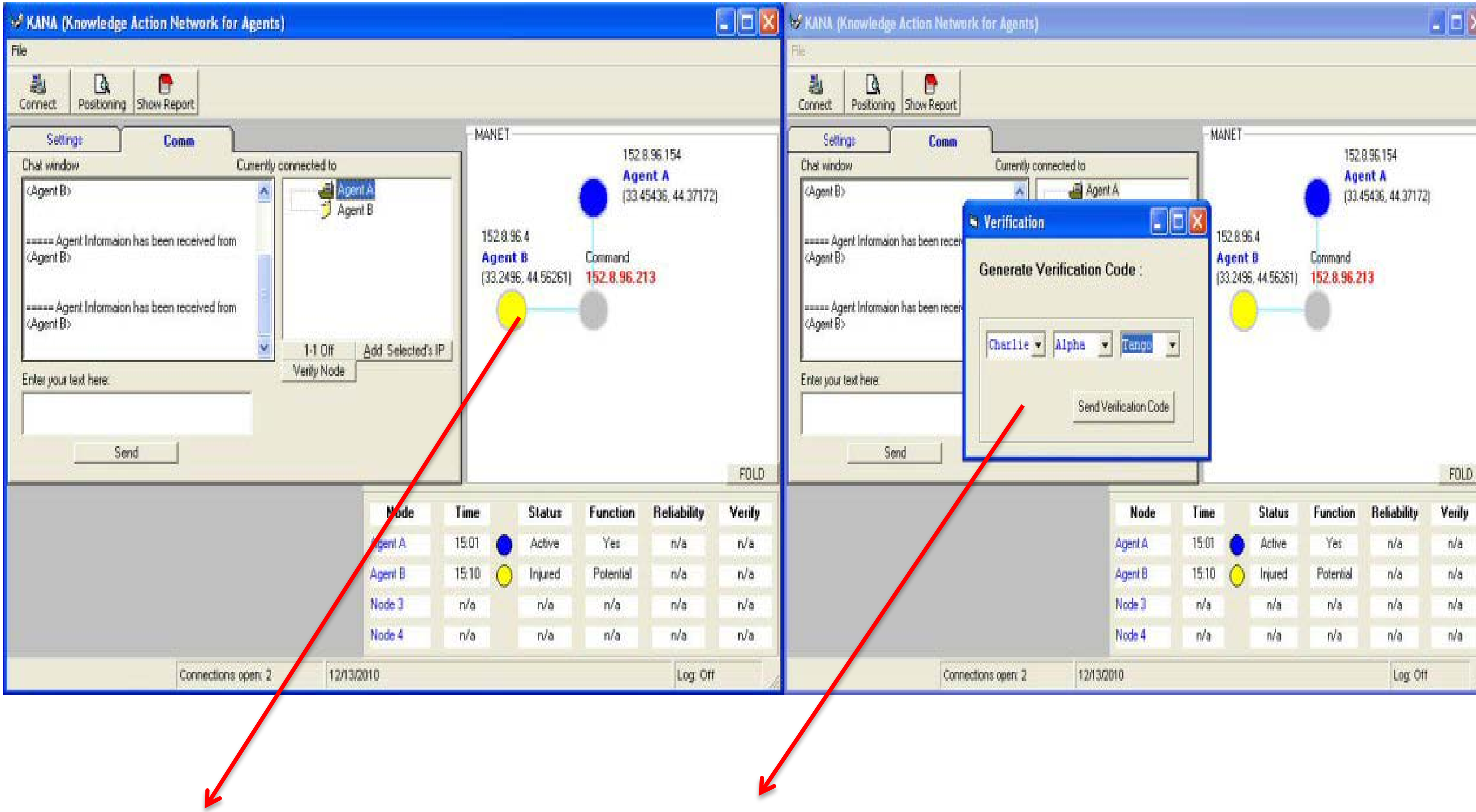


A prototype 3-node MANET with
1 C2 Server
2 field MANET agents

Log-in control by IP address.



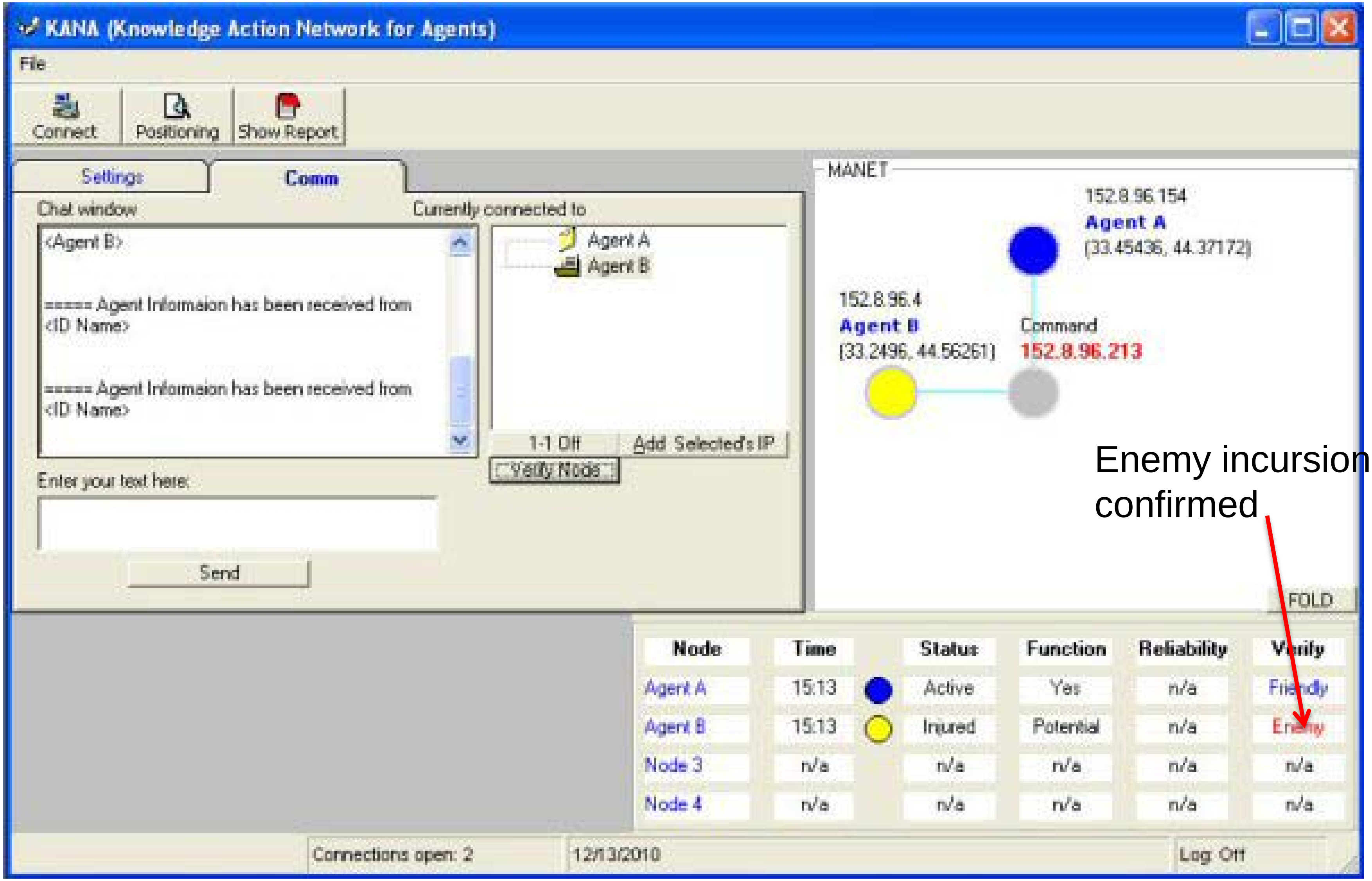
APPLICATION OF SIMULATION RESULTS



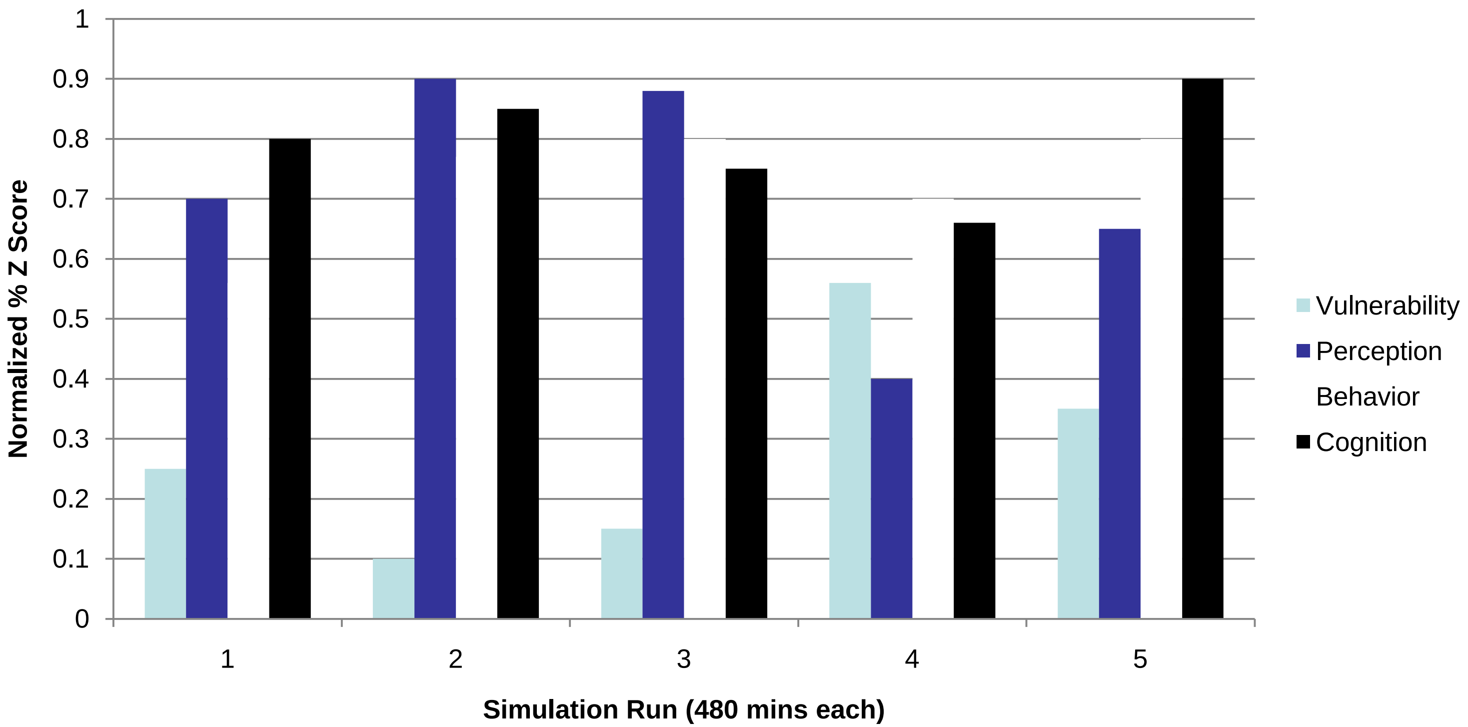
Human injury reported by agent at MANET node 2

Injury report verification by C2 server to avoid enemy mimicking node 2 behavior or status

APPLICATION OF SIMULATION RESULTS



SIMULATION RESULTS (Agent 1)



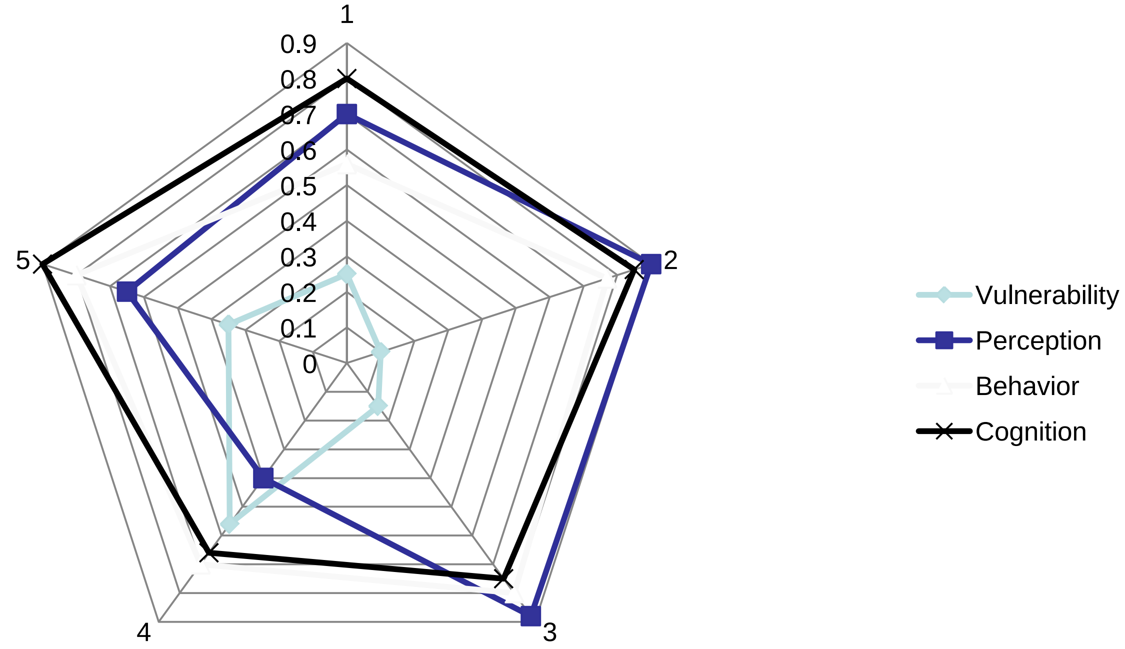
	Vul	Percep	Behavior	Cognition
Vul		-0.991	-0.198	-0.512
Percep			0.319	0.509
Behavior				0.54
Cognition				

Pearson Correlation for Simulated Period

SIMULATION RESULTS (Agent 1)

Radar Plot of Average Normalized % Scores (low = 0.0, high = 1.0)

- ✓Agent cognition more influential.
- ✓Cognition correlates positively with perception and behavior.
- ✓Decreased vulnerability = increased scores in cognition, behavior, and perception



Vulnerability	Perception	Behavior	Cognition
0.25	0.7	0.56	0.8
0.1	0.9	0.77	0.85
0.15	0.88	0.8	0.75
0.56	0.4	0.7	0.66
0.35	0.65	0.8	0.9

SUMMARY AND CONCLUSION

1. Modeling MANET as a cognitive socio-technical system.
2. MANET players considered collaborative agents:
3. Applied network science to capture MANET nodes as cognitive agents
4. Inject human cognitive and behavioral traits into agent-based modeling and simulation
5. Use OODA model and sensemaking paradigms to drive non-deliberate behavior of agents as rational entities (model-based functions).
6. Experiment with positive reinforcement learning (with incremental gain over time), and learning with forgetting caused by task changes).

SUMMARY AND CONCLUSION

7. Baseline Research Question: Does an agent-based MANET performance (measured by vulnerability) affected by human traits like behavior, perception, and cognitive abilities?

   (a) As agents gain and exhibit increasing perception of the problem situation, show positive rational behaviors, and gain expertise (cognition), MANET nodes are less likely to show high vulnerability during a mission.

   (b) Agents exhibit cognition, perception and behavior traits that are positively correlated.

   (c) Agents exhibit more human cognitive traits in solving problems (learning and forgetting co-exist).

SUMMARY AND CONCLUSION

8. Have demonstrated the utility of the model for use in training:
   - ✓ MANET node performance statistics.
   - ✓ Human performance as orchestrated by system interactions.
   - ✓ Levels of collaboration/ information sharing during system level mission.

9. Embellish PEARL model with other agent functional algorithms; extend to system-of systems modeling; compare performance.
10. Conduct field test to measure effects on survivability, vulnerability, lethality, and system reliability.