*I*rreducible *S*emi-*A*utonomous *A*daptive *C*ombat (ISAAC): An *Artificial-Life* Approach to Land Combat (U)

*"War is ... not the action of a living force upon lifeless mass ... but always the collision of two **living forces**."* - Carl von Clausewitz, *On War*

Andy Ilachinski

Presenters

- 1LT Esref Mert
  - Background
- LTJG Askin Ercetin
  - ISAAC
- Capt. Erik Jilson
  - ISAAC Runs
- LTJG Mustafa Dinc
  - EINSTein

1TLT Esref Mert

- Complex Systems & Complexity Theory
- Adaptive Agents & Modeling Complex Systems
- Battlefield as a complex system
- Combat Simulations
- LEs
- Muilt-Agent Systems

Complex Systems & Complexity Theory

A **complex system** is a dynamical system composed of many non-linearly interacting elements (e.g., a society, an economy, or the human immune system, warfare) and complex organisms do not exhibit behaviors in group they may not exhibit individually.

Interactions among the elements will change the system over time, and such changes can not be attributed to any single rule or explanation.

Complexity theory aims to both develop ways to solve complex systems problems as well as identify the principles of complex systems.

continued…

Complexity theory is basically thinking and seeing the world from a different perspective;

- From a Newtonian and Cartesian paradigm of viewing the world as:

  * Clockwise universe

  * Inherently mechanical

  * Predictable, rational and reductionist

-To viewing the world as:

  * Flowing

  * Adapting

  * Nonlinear

  * Holistic.

More on Complex Systems..

* Two features of the complex systems making them complex in common sense:

1- non-linearity of the system

2- type of interactions between other elements of the system

* Within complex systems, we can further sub-divide into systems that are ***adaptive*** and ***non-adaptive.***

Adaptive Agents & Modeling Complex Systems

Adaptive agents

- computer programmed entities
- can sense their respective environment
- can act upon what they sense
- can adapt the environmental changes

Adaptive agent theory was first demonstrated in 1995 by Chris Langton, who is considered by many to be the founder of Artificial Life.

continued…

Adaptive agents are often used to simulate complex systems, and used in complexity research to study issues that are too complex to address any other way.

In adaptive agent simulations there is no central controller; individual agents self organize into larger units , which are themselves agents.

The battlefield is a scene of constant chaos. The winner will be the one that best controls that chaos, both his own and that of his enemy.

-Napoleon

Battlefield as a complex system

It is regarded for sure that military conflicts, particularly land combat, possess all of the characteristic features of complex adaptive systems:

- Nonlinear Interactions
- Nonreductionist
- Emergent Behavior
- Hierarchical Structure
- Decentralized Control
- Self-organization
- Nonequilibrium Order
- Adaptation
- Collectivist Dynamics

continued…

Simulations that have been done using Complex Adaptive Systems in land combat simulations stands for the theory that land combat can be modeled as a complex adaptive system.

(Adaptive) Multi-Agent Simulations → Interactive, conceptual laboratory for exploring self organized emergent behavior in combat.

Combat Simulations

In 1914, F.W.Lanchester introduced a set of coupled ordinary differential equations as models of attrition in modern warfare.(Lanchester Equations-LEs)

Since then, LEs have been fundamental mathematical models for most modern theories of combat attrition.

LEs: - intuitive

- easy to apply

LEs

* Most existing models remain Lanchesterian in nature with the driving factor being force-on-force attrition.

*LEs are applicable under a strict set of assumptions:

- homogeneous forces
- continuous engagement
- firing rates are independent of opposing force levels
- firing rates are constant in time
- units are aware of everything about opposing units

continued…

•Shortcomings with Lanchesterian combat models:

- modeling combat as a deterministic process
- requiring knowledge of “attrition-rate coefficient
- inability to account for different effects of weapons
- failure to account for terrain
- lacking the spatial degrees of freedom

Summarizing: idealizing the combat much in the same way as Newton’s laws idealize the real chaos -and complexity- ridden physics of the world

continued…

Two significant drawbacks to using LEs to model land combat:

1- LEs are unable to account for any spatial variations of forces (i.e. no link is established between movement and attrition)

2- LEs do not incorporate the human factor in combat (i.e. the psychological an/or decision making capability of the human combatant)

Modeling today's combat

Today's vision of combat:

* Small, highly trained, well-armed autonomous teams working in concert, continually adapting to changing conditions and environments.

To address these shortcomings in existing conventional models, we are exploring developments in complex systems theory- particularly the set of multi-agent based simulation tools developed in the artificial life community.

MAS Simulations

The motivation of MAS-based simulations is to explore alternative non-Lanchesterian description of combat.

MAS simulations takes a bottom-up, synthesis approach to the modeling of combat, vice the more traditional, aggregated models' top-down or reductionist approach.

The philosophy of Adaptive MAS simulations: A toolbox for identifying, exploring, and possibly exploiting emerging collective patterns of behaviors on the battlefield.

Fundamental MAS Combat Simulations:

* ISAAC (A. Ilachinsky, 1997)
* EINSTein
* JACOB
* ARCHEMIDES

LTJG Askin Ercetin

- ISAAC
- ISAACA
- 2D Battlefield
- Initial State
- ISAAC Personality
- Move Selection
- Meta Rules
- Command and Control
- Combat
- Combat Logic Enhancements

ISAAC

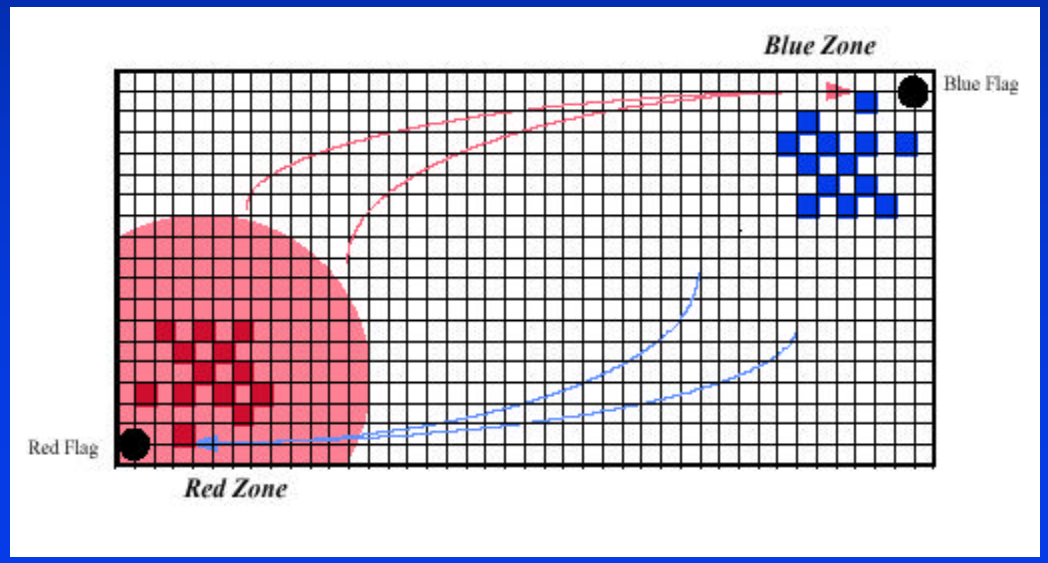
- Developed by Dr. Andy Ilachinski (CNA- Center for Naval Analysis)
- Sponsored by CNA and ONR
- One of the first military research projects to attempt to model land combat using agent-based simulation techniques
- Goal was to take a bottom-up approach to the modeling of combat, vice the more traditional top-down, or reductionist view
- First phase consisted of developing a “proof-of-concept” multiagent-based simulation of land combat

ISAACA

- Basic element is an ISAACA = ISAAC Agent
  - Represents primitive combat unit (infantryman, tank, etc.)
- Each ISAACA is equipped with:
  - **Rules :** A default internal rule set specifying how to act in a generic environment (i.e. doctrine)
  - **Goals :** Goals directing behaviors (i.e. mission)
  - **Sensors :** Generating an internal map of environment
  - **Adaptive Mechanism :** Internal mechanism to alter behavior and/or rules

2D Battlefield

- Battlefield is represented by a two dimensional lattice of discrete sites.
- Each site may be occupied by only one ISAACA or flag



Initial State

- Either user specifies formations of red and blue ISAACAs, or
- ISAACAs are placed randomly around a user specified site
- Flags are generally positioned in diagonally opposite corners
- A typical goal for an ISAACA is to reach the enemy flag located in the opposite corner

More on ISAACA

- Each ISAACA exists in one of three states:
  - Alive, Injured, and Dead
- Each ISAACA has some range characteristics
  - Sensor range , fire range , comms range, movement range, etc.
- Injured ISAACAs may have different personalities from when they were alive
- An injured ISAACA's ability to shoot enemy is 1/2 of its ability when alive

ISAAC Personality

- The personality represents an internal value system that determines how an individual ISAACA responds to local information
- Each ISAACA is equipped with a 6-component personality weight-vector
  - $W = (W_1, W_2, W_3, W_4, W_5, W_6)$ $-1 <= W_i <= 1$ $\mathrm{Sum}(\mathrm{Abs}(W_i)) = 1$
- The personality vector may be state depended or its components may be negative

ISAAC Personality

Personality Weight	Attaches relative value to...
W_1	alive friendly ISAACAs
W_2	alive enemy ISAACAs
W_3	injured friendly ISAACAs
W_4	injured enemy ISAACAs
W_5	own flag
W_6	enemy flag

ISAAC Personality

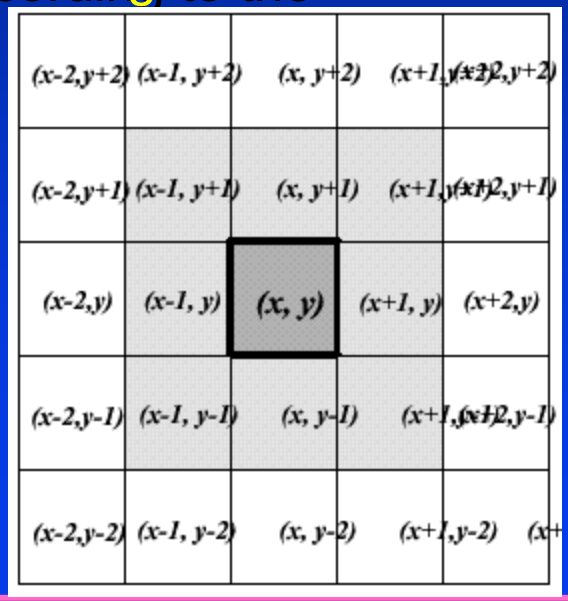
- A personality is defined by assigning a weight to each of the six kinds of information
- A fairly aggressive ISAACA:
  - (1/20, 5/20, 0, 9/20, 0, 5/20)
- An ISAACA that wants to move away from everything:
  - (-1/6, -1/6, -1/6, -1/6, -1/6, -1/6)

Move Selection

- Personality weight vector is used to rank each possible move according to a penalty function

- Penalty function measures the total distance that the ISAACA will be from other ISAACAs and flags, each weighted according to the appropriate component of the personality vector

$$
\begin{aligned}
Z(x,y) = \; & w_1 \, s_{\text{red}}^{-1} \, N_{\text{alive red}}^{-1} \sum_{\text{alive red; i}} d[i;(x,y)] \quad + \\
& w_2 \, s_{\text{blue}}^{-1} \, N_{\text{alive blue}}^{-1} \sum_{\text{alive blue; i}} d[i;(x,y)] \quad + \\
& w_3 \, s_{\text{red}}^{-1} \, N_{\text{injured red}}^{-1} \sum_{\text{injured red; i}} d[i;(x,y)] \quad + \\
& w_4 \, s_{\text{blue}}^{-1} \, N_{\text{injured blue}}^{-1} \sum_{\text{injured blue; i}} d[i;(x,y)] \quad + \\
& w_5 \, d_{\text{new}}[\text{red flag};(x,y)] \,/\, d_{\text{old}}[\text{red flag};(x,y)] \quad + \\
& w_6 \, d_{\text{new}}[\text{blue flag};(x,y)] \,/\, d_{\text{old}}[\text{blue flag};(x,y)] \quad ,
\end{aligned}
$$



Move Selection

- A penalty is calculated for each possible move
- The actual move is the one that incurs the least penalty
- If two or more cells gets the same smallest penalty value at the same time, then ISAAC randomly selects the actual move from among the candidate moves

Meta Rules

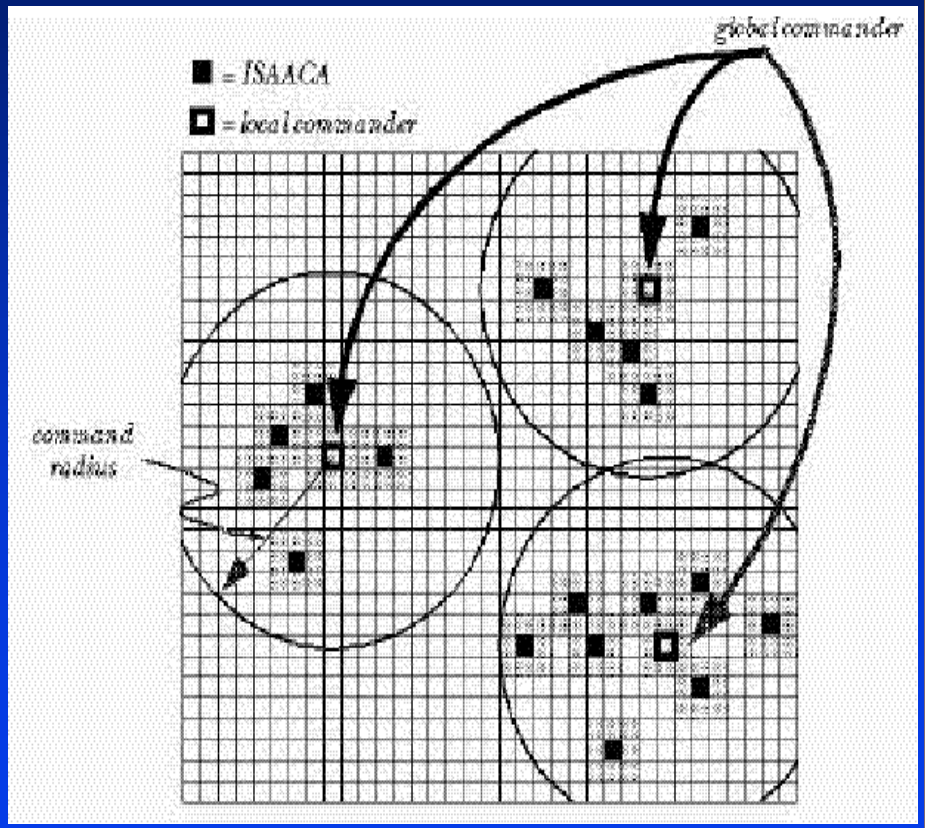
- An ISAACA personality may be augmented by a set of meta-rules that tell it how to alter its personality according to the environmental conditions
- Three meta-rules are used:
  - **Advance:** advance towards enemy flag if and only if the number of surrounding friendlies exceeds a given threshold

Meta Rules

- **Cluster :** stop moving towards surrounding friendlies if the number of friendlies exceeds a given threshold
- **Combat :** move towards and engage the enemy if and only if the difference between friendly and enemy force strengths exceeds a given threshold

Command and Control

- In its simplest run mode there is no C2.
- User has an option of defining C2 hierarchy
  - Global Commander
  - Local Commander
  - ISAACA



Combat

- The single shot probabilities are provided by the user
- In each run, every ISAACA has an opportunity to “fire” at all enemy ISAACAs within the fire range
- If an ISAACA is shot by the enemy, its current state is degraded
- Once “dead”, that ISAACA is permanently removed from further play

Combat

- The user has the option of limiting the number of simultaneously engageable enemy targets

- If this option is selected, and the number of enemy ISAACA's within an ISAACA's fire-range exceeds a user defined threshold number, then N ISAACAs are randomly chosen from among the ISAACAs in this set

Combat Logic Enhancements

- Basic combat logic may be enhanced by three additional functions:
  - **Defense :** gives ISAACA the ability to withstand a number of hits before having their state is degraded
  - **Reconstitution :** adds a provision for previously injured ISAACs to be reconstituted to their alive state
  - **Fratricide :** adds an element of realism to ISAAC combat by making it possible to inadvertently “hit” friendly forces

Capt. Erik Jilson

- ISAAC Run Modes
- Sample Behavior
- Samples 1-5
- Payoffs to Using a Multi-Agent Based Model

ISAAC Run Modes

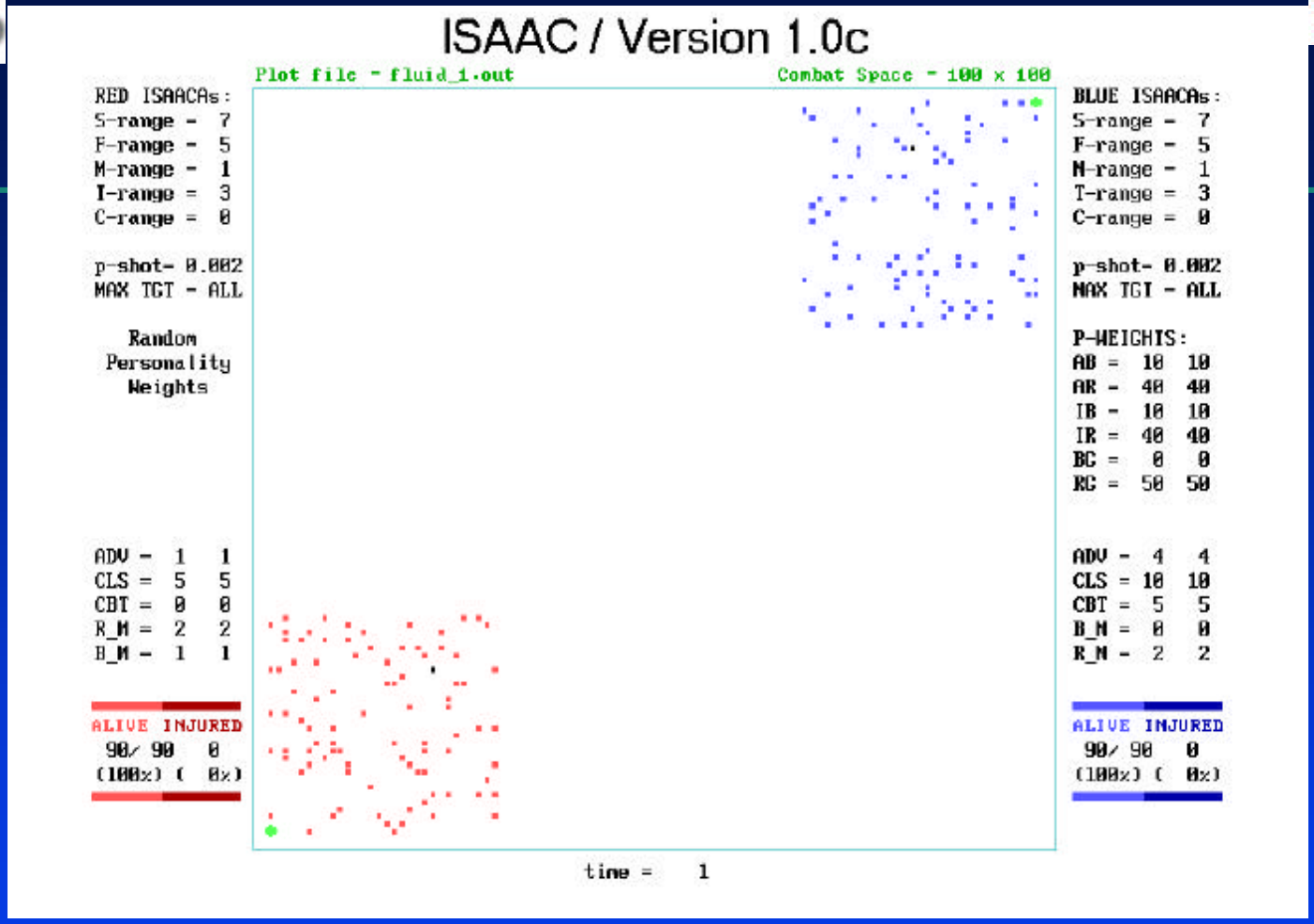
- Interactive Mode – 'on-the-fly' changes, purely graphical, good for "What if?" scenarios
- Data-Collection Mode –
  - Time series w/ various change in quantities
  - Keep track of certain measures
  - Also generate behavior profiles on 2D slices of parameter space
- Genetic Algorithm "Evolver" Mode – breed for "best" suited for well-defined mission against fixed foe

Sample Behavior

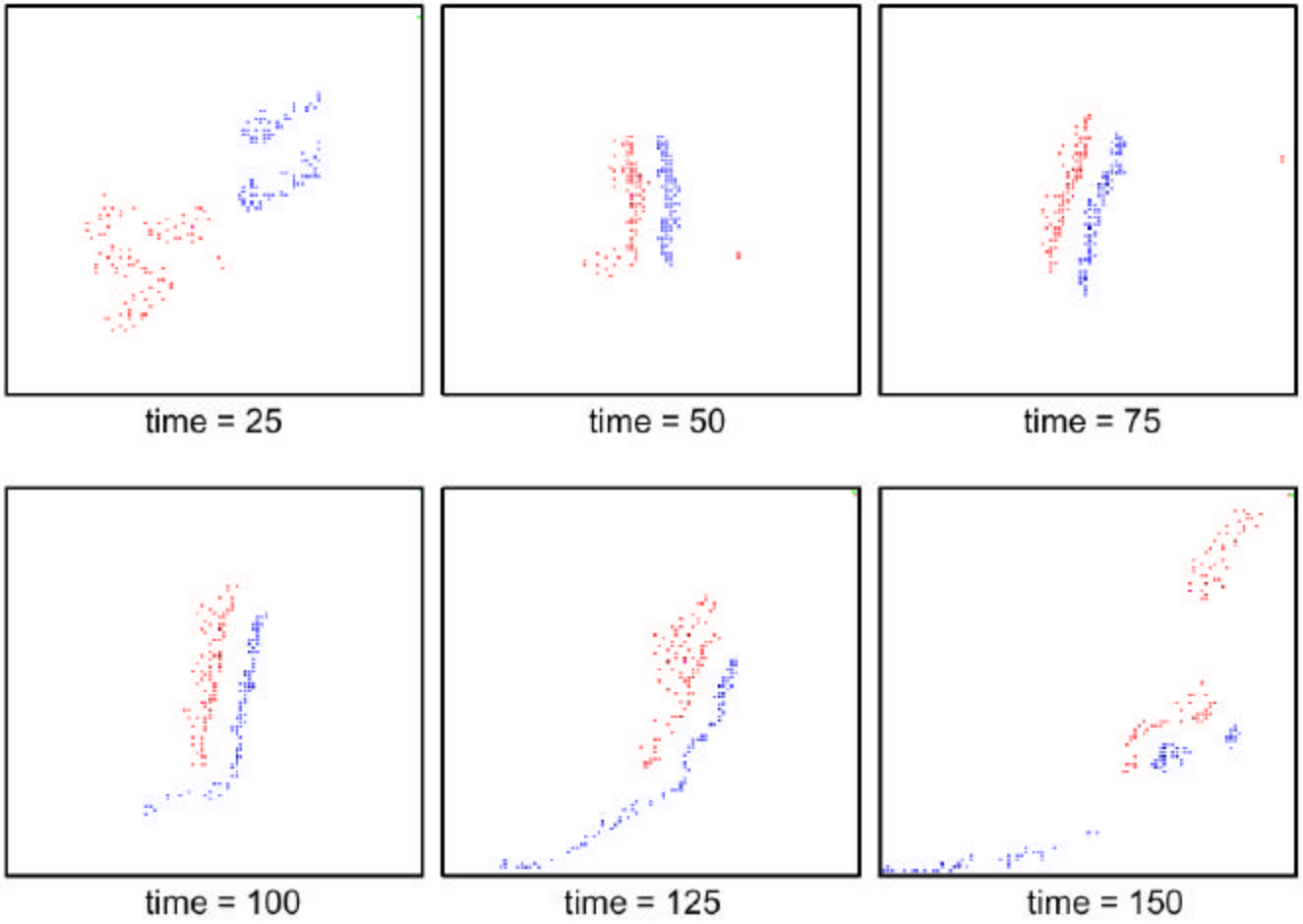
- ***Examples of emergent behaviors***
  - Forward advance
  - Frontal attack
  - Retreat
  - Containment
  - Flanking Maneuvers

Sample Behavior (cont.)

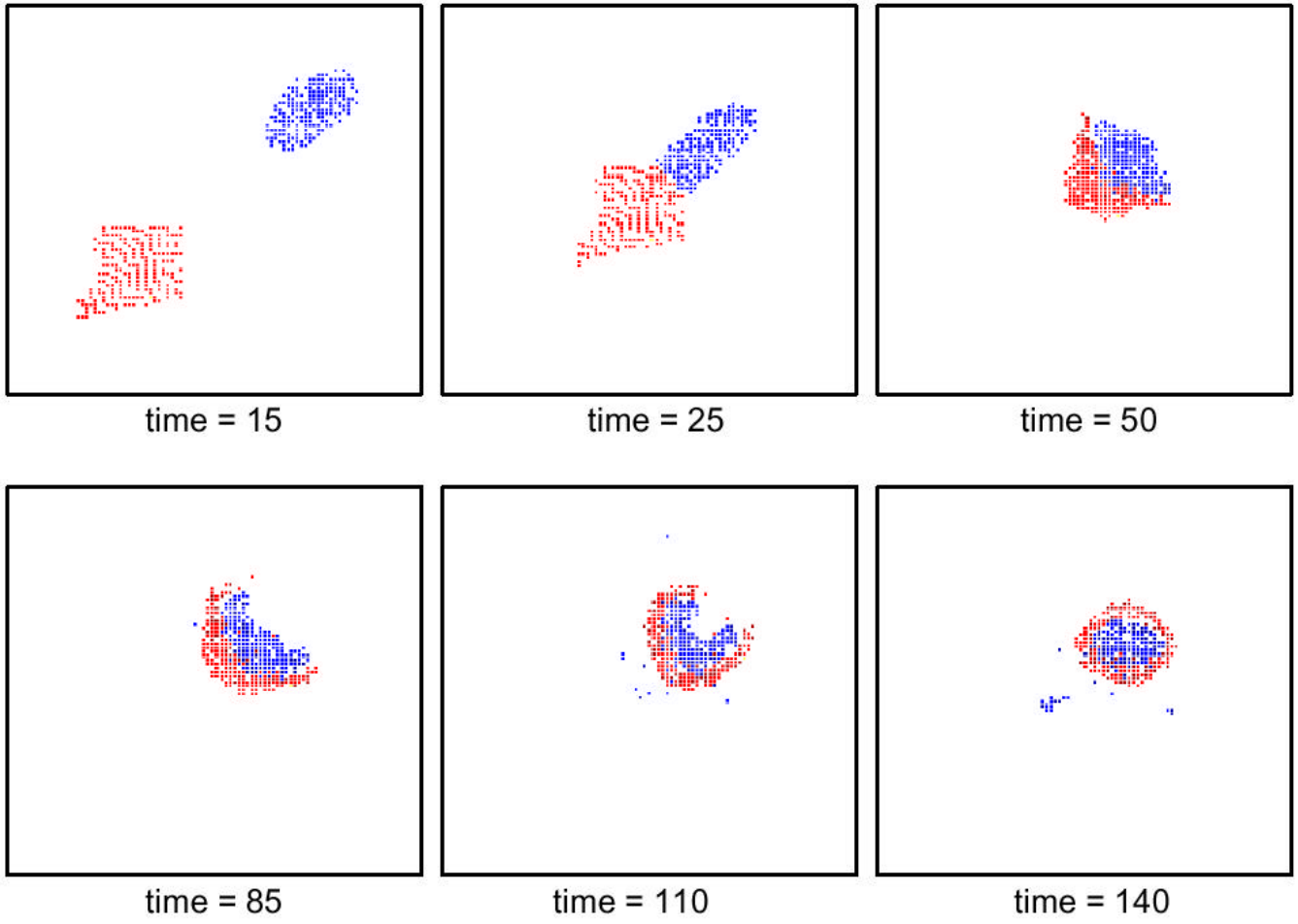
- Behavior that appears to involve some form of "intelligent" division of red and blue forces to deal with skirmishes
  - This is especially common in genetic algorithm modes
  - These are no hard wired, but emergent property of a decentralized and nonlinear local dynamics.



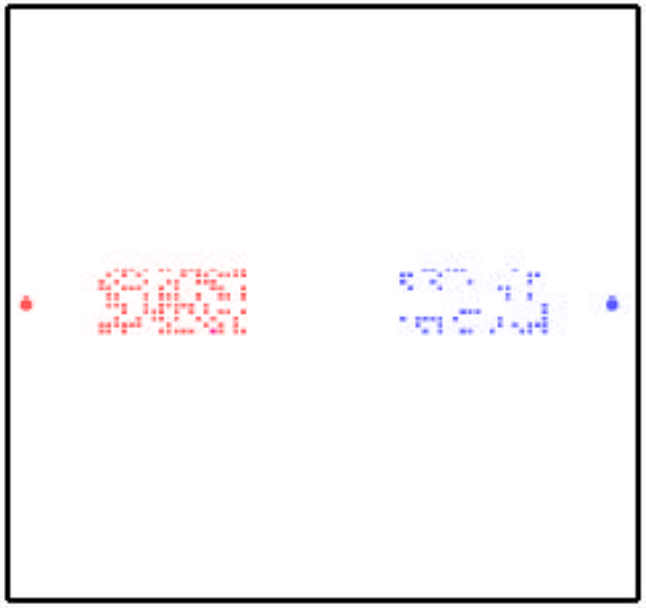
Sample 1: Fluid-like “Collisions”



Sample 1: Fluid-like “Collisions”

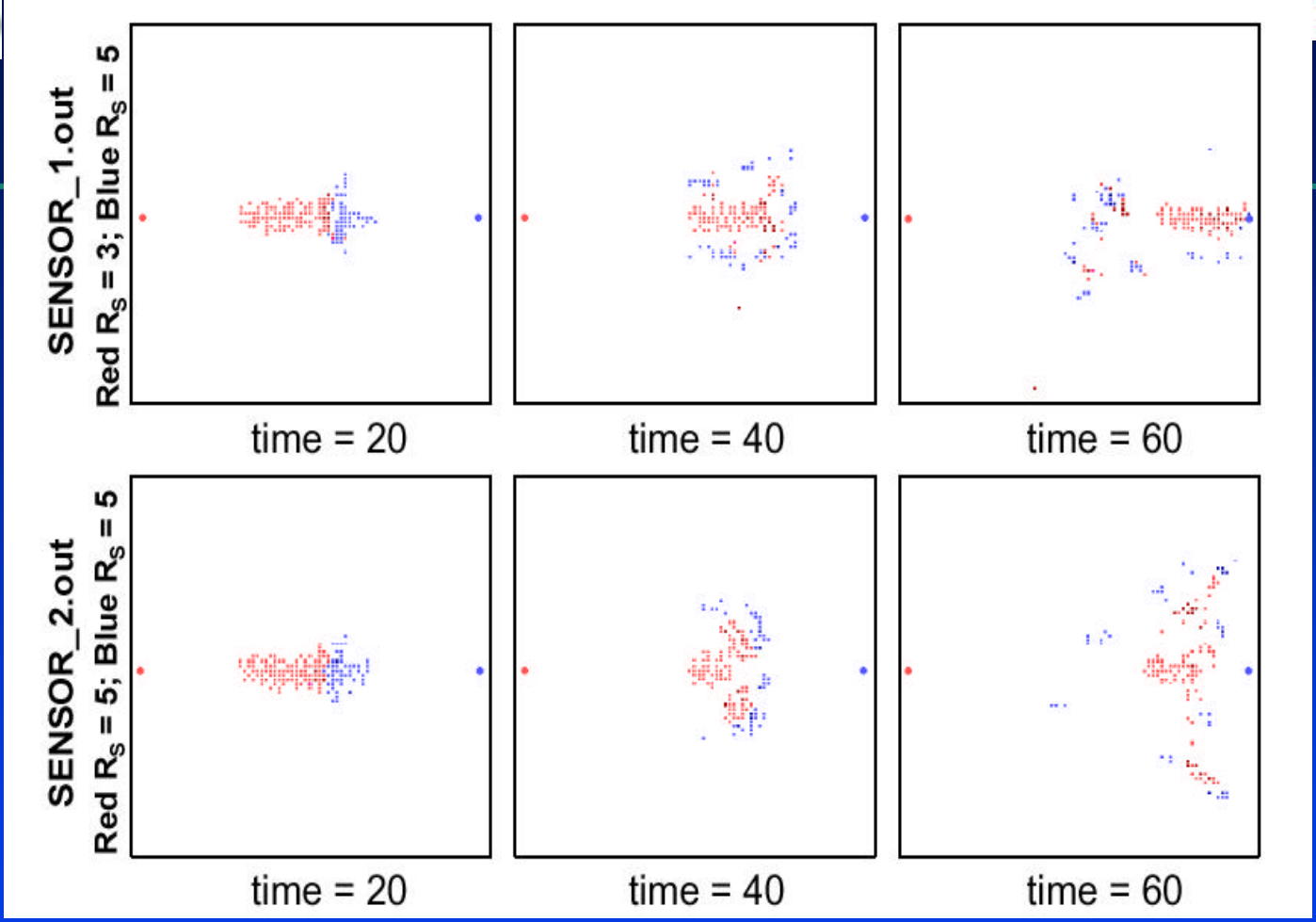


Sample 2: Red “Encircles” Blue

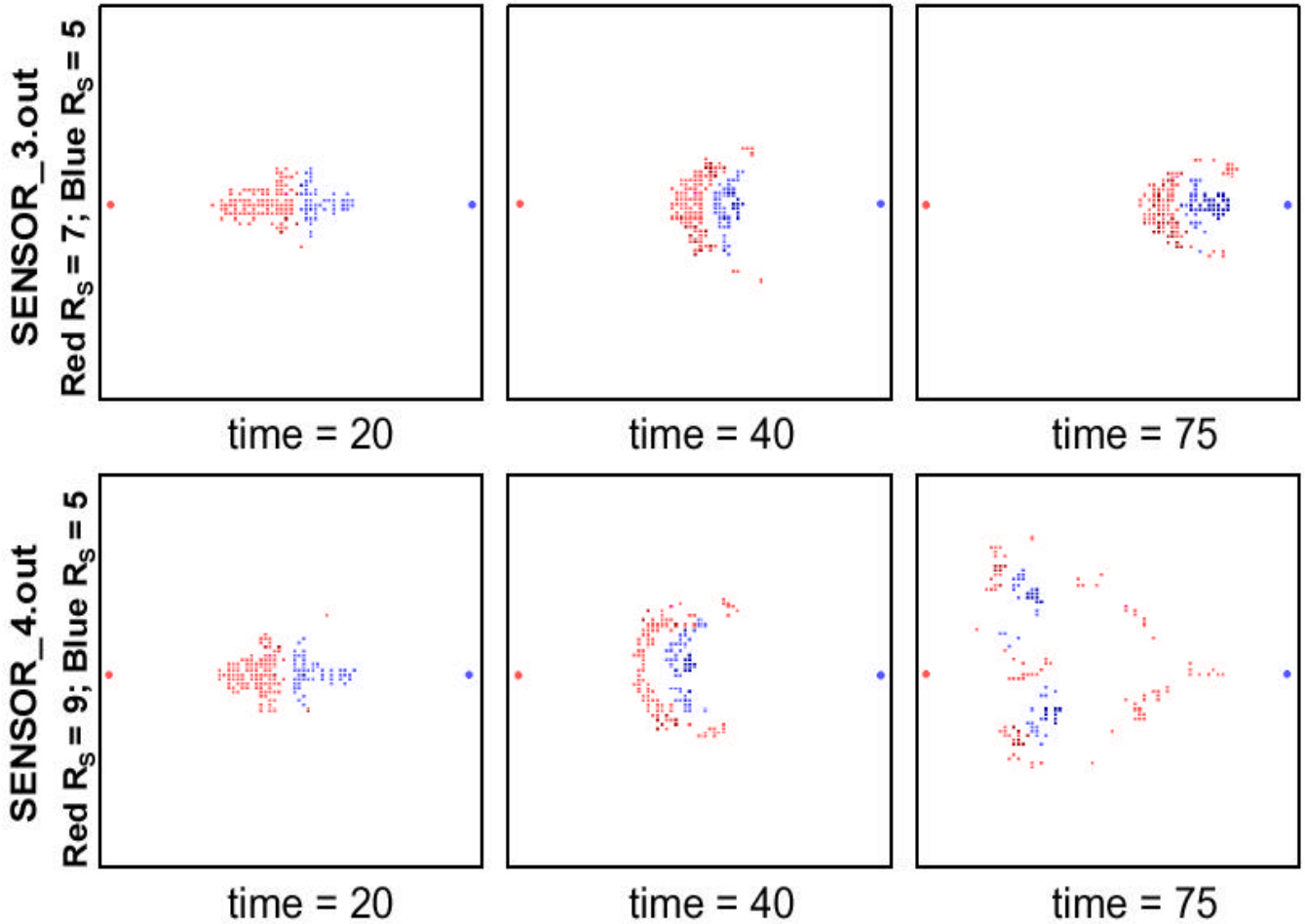


Initial State

Sample 3: Non-Monotic Behavior



Sample 3: Non-Monotic Behavior



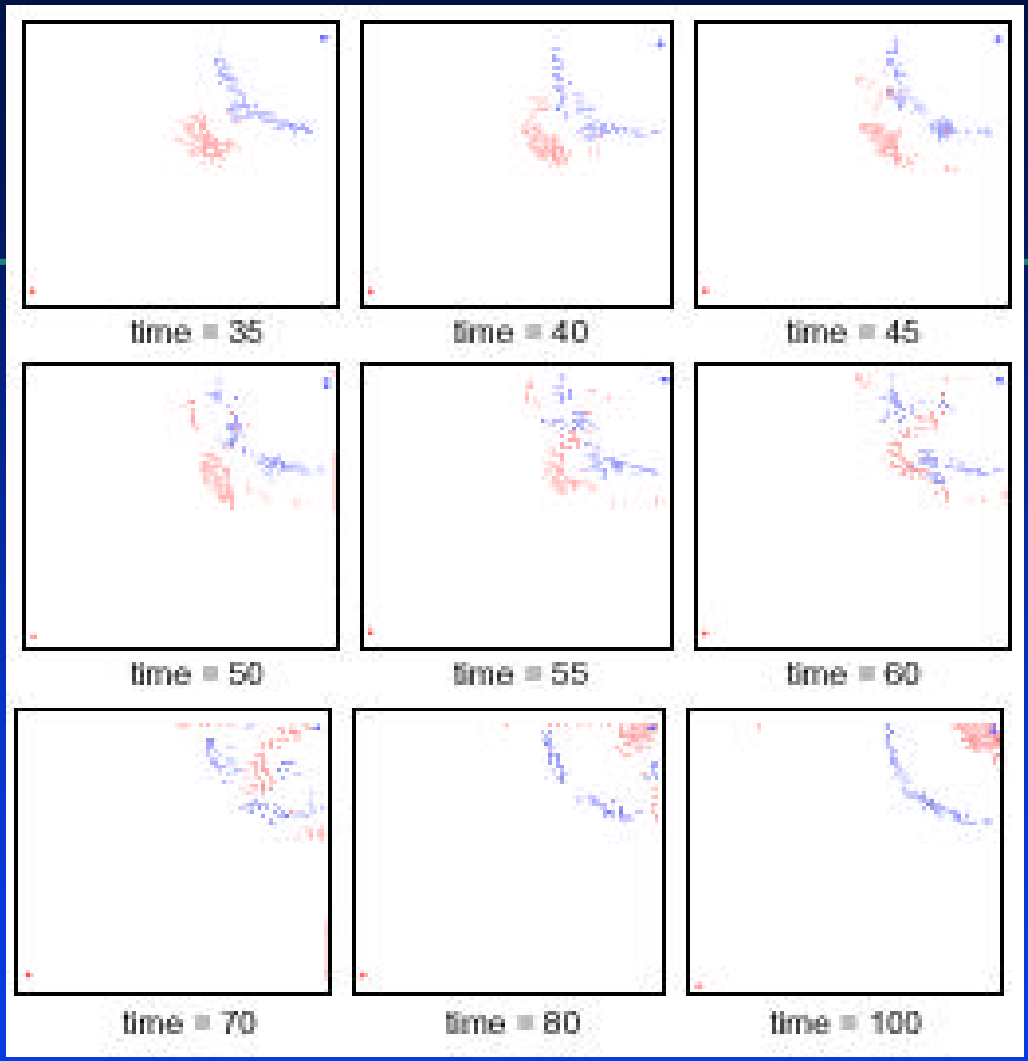
Sample 3: Non-Monotic Behavior

Sample 4: Genetic-Algorithm-Bred "Tactics"

Genetic Algorithms(GA) - Knowledge that "parents" gain is passed on to "offspring"

- Red personality is "bred" using a GA to fine "best" personality to perform:
  - Get as many red forces near blue's flag as possible while minimizing red casualties.

(This personality was bred using a pool of 75 different personalities and averaging over 25 random initial conditions for each generation)

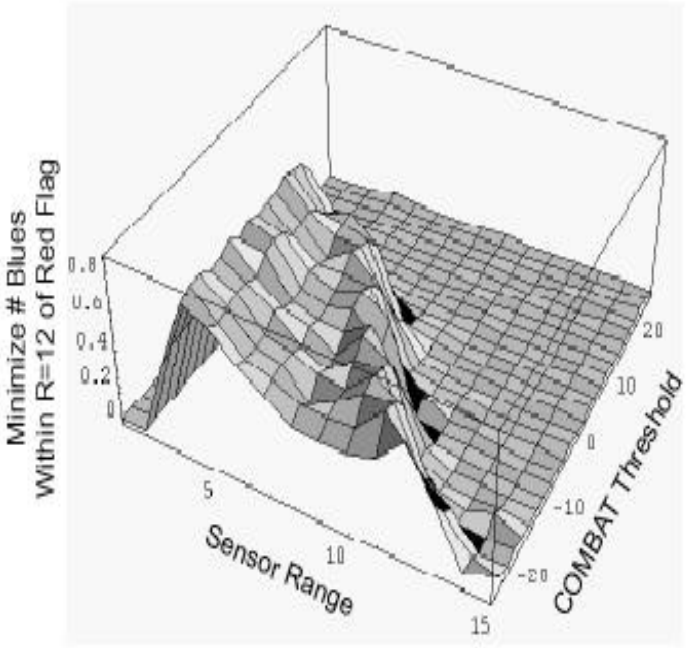


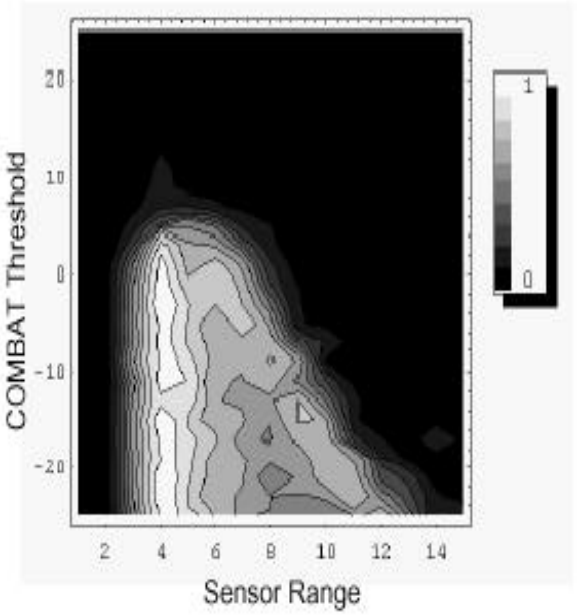
Sample 4: Genetic-Algorithm-Bred “Tactics”

Sample 5: 2D-Slice of N-dim Parameter Space

- Demonstrates ISAACs ability to sample a 2D "slice" of a very large N-dimensional parameter space.
- Red's defensive capability is probed
- Fitness function is defined so red's fitness ≈ 1
  - When red kills all (or most) of the blue ISAACAs that approach the red flag

Blue attacks with ***w*** = (10,40,10,40,0,50); Sensor = 4; Fire = 3; COMBAT = -3; p = 0.005
Red defends own flag with ***w*** = (10,40,10,40,0,0)
Mission Fitness = *minimize number of blues within R=12 of red flag*

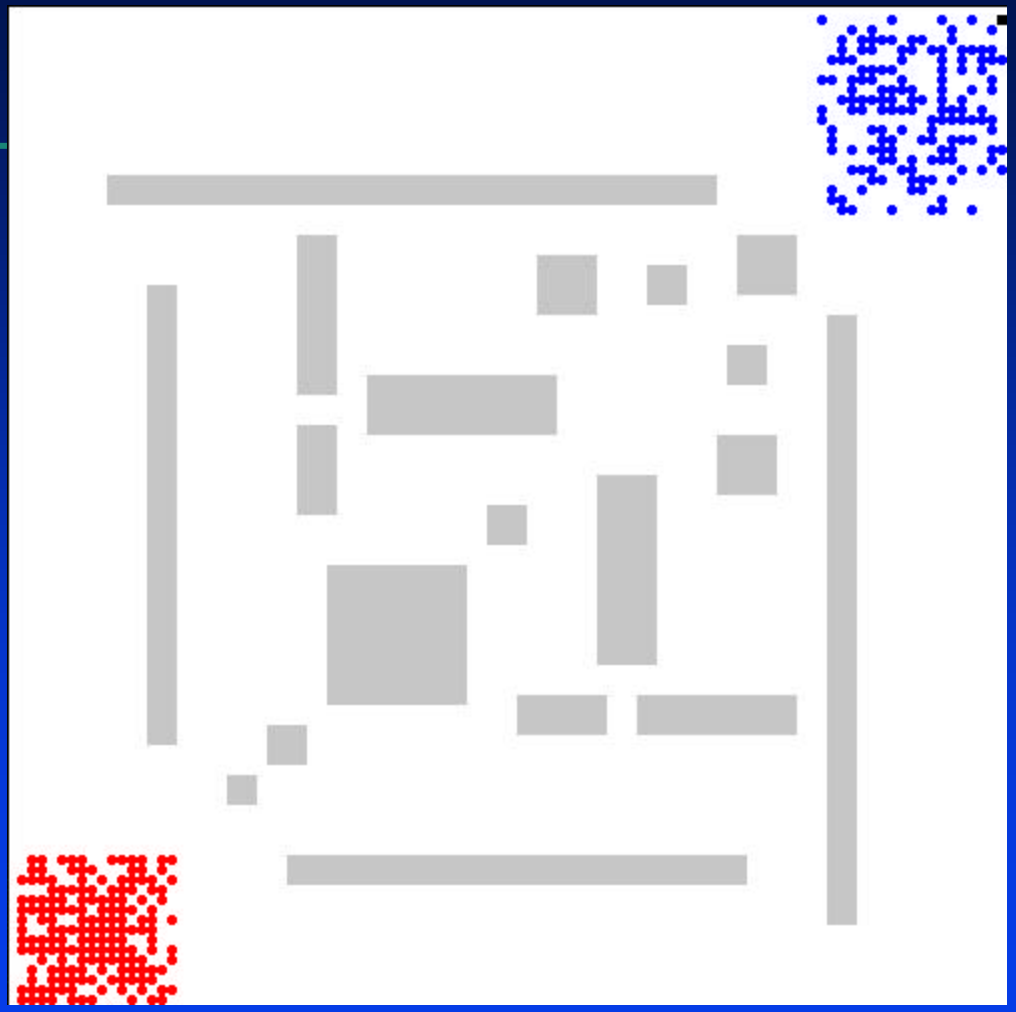




Sample 5: 2D-Slice of N-dim Parameter Space

Notional Terrain

There are two squads per side: squad 1 consists of 100 agents, squad 2 consists of 50 "elite" agents (that can move quicker and are more potent offensively). Gray blocks represent impenetrable terrain-blocks that agents can see through but cannot traverse (i.e. lava pits).



Payoffs to Using MultiAgent Based Models

- Traditional Models – the equilibrium state is explicitly solved for and declared the "battle outcome."
- Agent Models (ISAAC) – focuses on understanding the kinds of emergent patterns that might arise while the overall system is out of (or far from) equilibrium.
  - MultiAgent Based Models not to be used for prediction, but enhanced understanding.

Payoffs to Using MultiAgent Based Models

ISAAC designed to …

- Assess the value of information (sensor range, ...)
- Explore qualitative characteristics of combat (unit cohesion, morale, leadership)
- Examine patterns of combat behavior
- Look at how two sides co-evolve

Payoffs to Using MultiAgent Based Models

ISAAC provides a natural arena in which to explore the Clausewitzian "fog-of-war"

- Uncertainties
- Inaccuracies of intelligence data
- Time-delays in reporting information

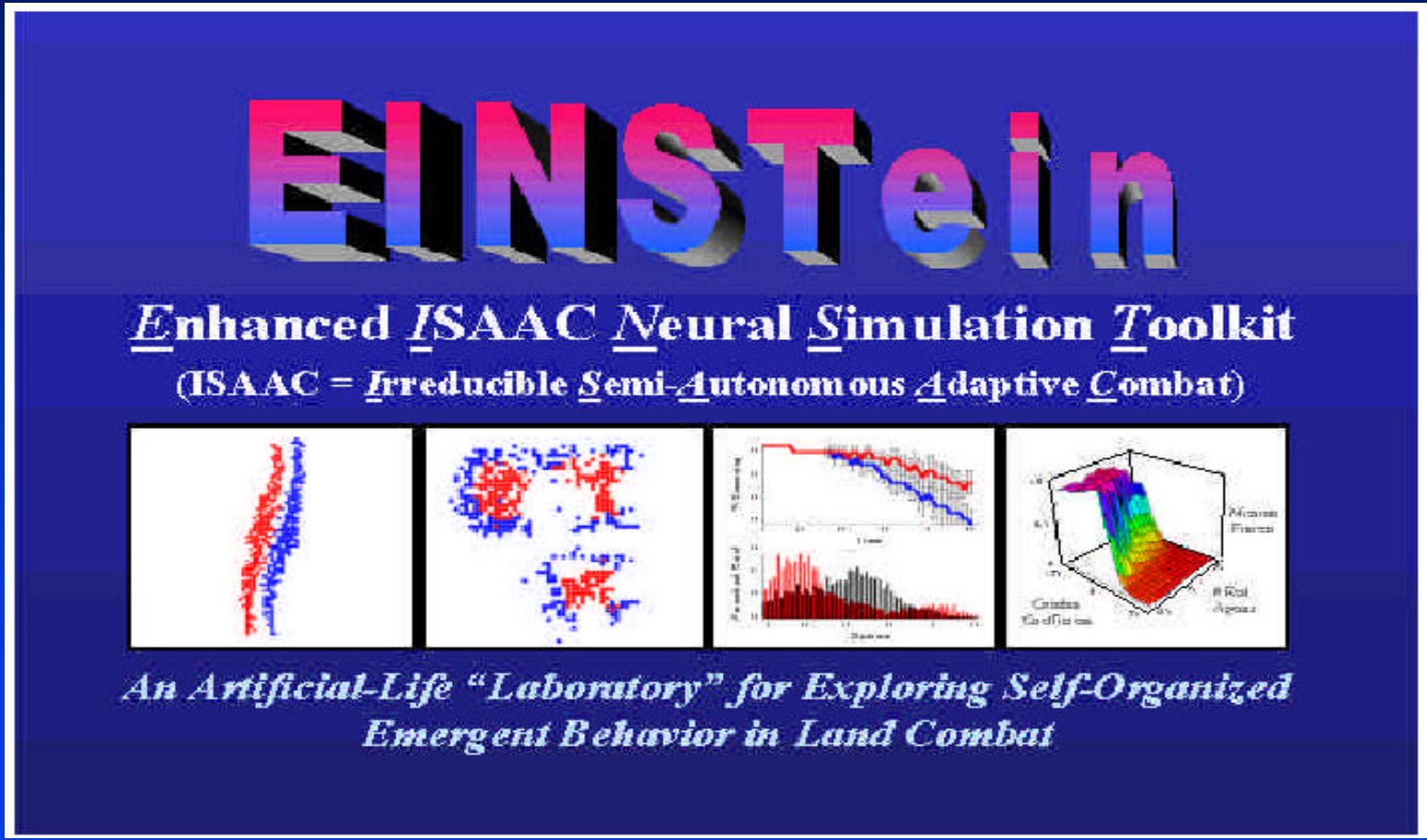
ISAAC can explore force and/or weapon mix

Re-examine traditional measures of combat effectiveness

LTJG Mustafa Dinc

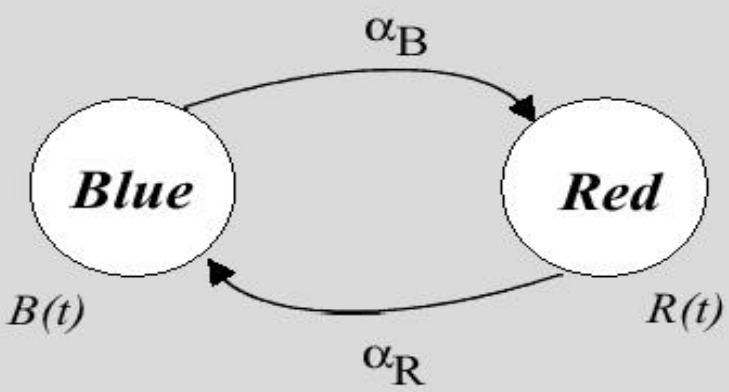
- EINSTein
- Questions

EINSTein


EINSTein
Enhanced ISAAC Neural Simulation Toolkit
(ISAAC = Irreducible Semi-Autonomous Adaptive Combat)
An Artificial-Life "Laboratory" for Exploring Self-Organized Emergent Behavior in Land Combat

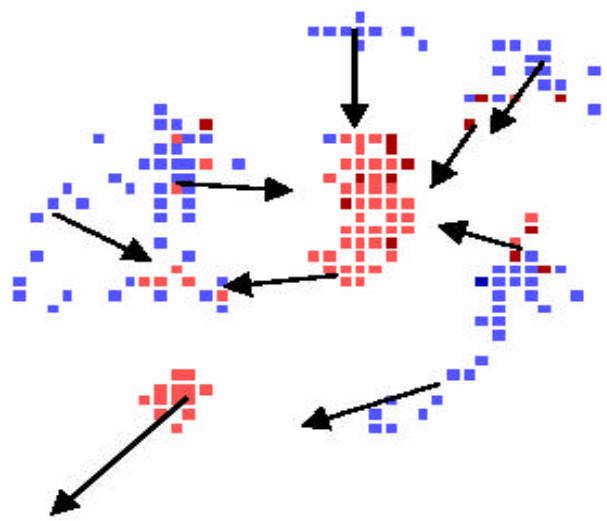
EINSTein

Lanchester Equations



$$\begin{cases} \dfrac{dR}{dt} = -\alpha_B B(t), & R(0) = R_0 \\ \dfrac{dB}{dt} = -\alpha_R R(t), & B(0) = B_0 \end{cases}$$

Goals, local interactions, motivations, personality, adaptation, ...



EINSTein

Phase-I (ISAAC)

Explore emergent collective dynamics (Micro-Rules Macro-Behavior)

Phase-II (EINSTein)

Self-contained "laboratory" for exploring

evolution of self-organized collective behavior from

primitive local dynamics

Phase-III (…?)

(Open-ended?) co-evolution of intelligent autonomous agents

Towards a fundamental grammar of combat…?

EINSTein

The key idea building combat

- ✓ "up from the ground up" by using
- ✓ complex adaptive agents as primitive agents
- ✓ focusing on the global co-evolutionary patterns of behaviors
- ✓ that emerge from the collective non-linear local dynamic of these primitive agents.

EINSTein

- EINSTein (Enhanced ISAAC Neural Simulation Toolkit) is a ambitious follow-on project that takes lessons learned from ISAAC, and
  - incorporates much more functionality, as well as
  - a windows-based development environment.

EINSTein

- EINSTein is a simple multi-agent-based "toy models" of land combat
- are being developed to illustrate how certain aspects of land combat can be viewed as emergent phenomena resulting from
  - ✓ the collective,
  - ✓ nonlinear,
  - ✓ decentralized interactions among notional combatants.

EINSTein

Basic element is an Agent

– Represents primitive combat unit (infantryman, tank, etc.)

- Each agent is equipped with:
  - Doctrine: A default internal rule set specifying how to act in a generic environment
  - A hierarchical rule set, consisting of orders passed down echelon via

EINSTein

- A global rule set that determines combat attrition and reinforcement
- Mission: Goals directing behavior
- Situational Awareness: Sensors generating an internal map of environment
- Adaptability: An internal mechanism to alter behavior and/or rules

EINSTein

EINSTein includes:

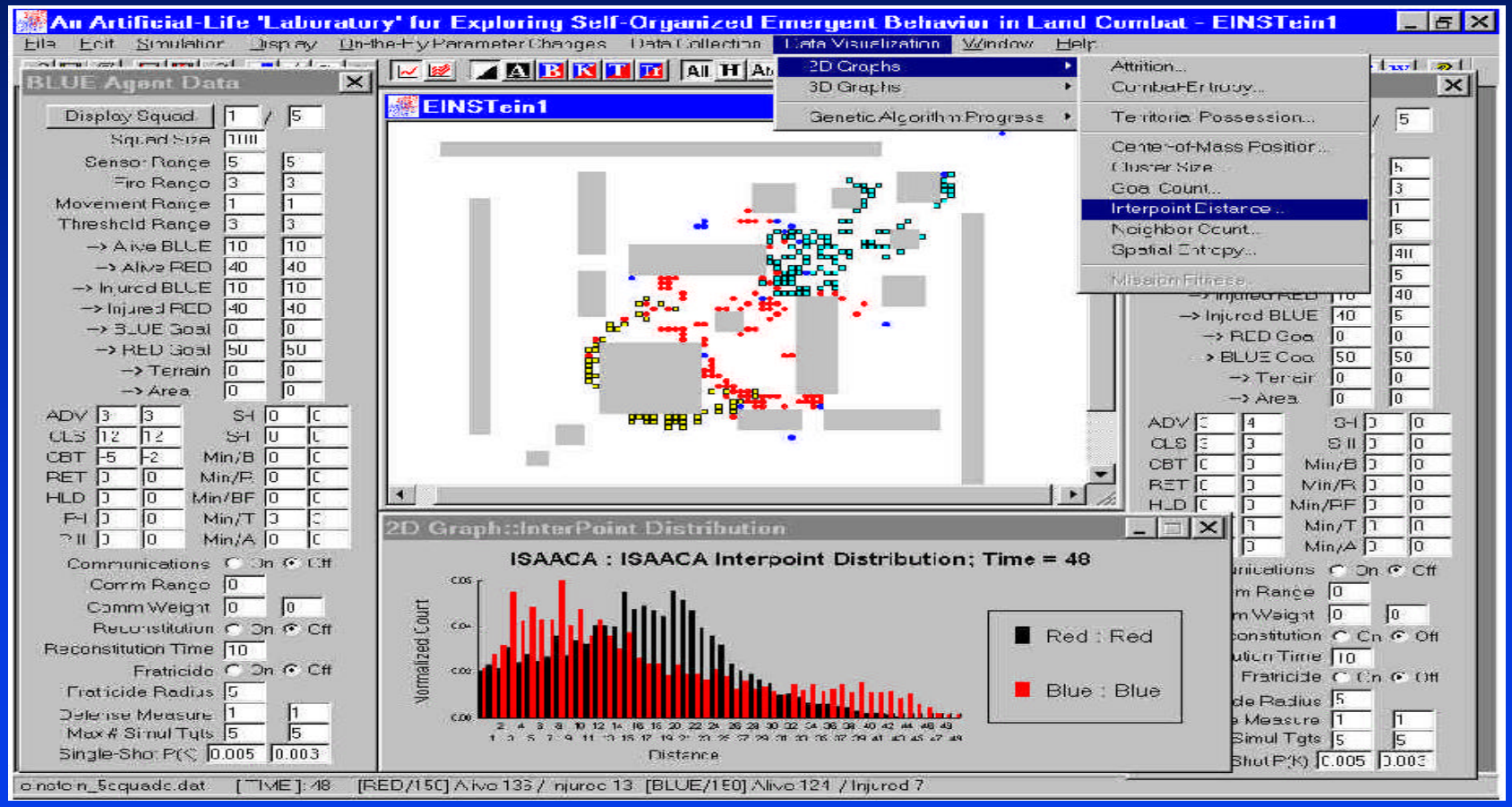
- A fully integrated Windows 95 GUI front-end
- An object-oriented C++ code base (compared to ISAAC's plain vanilla ANSI-C source)
- Context-dependent and user-defined agent behaviors (i.e., personality scripts)
- On-line genetic algorithm, neural-net, reinforcement-learning, and pattern recognition toolkits.

EINSTein

EINSTein includes cont.:

- Data collection and multi-dimensional visualization tools
- On-line chaos-data/time-series analysis tools
- On-line mission-fitness co-evolutionary landscape profiles.

EINSTein::Graphical User Interface



EINSTein vs. ISAAC

Show Word Document

EINSTein Web Site

http://www.cna.org/isaac

Questions…

Q - List three of the common features of land combat and complex adaptive systems.

A -

- Nonlinear Interactions
- Nonreductionist
- Emergent Behavior
- Hierarchical Structure
- Decentralized Control
- Self-organization
- Nonequilibrium Order
- Adaptation
- Collectivist Dynamics

Questions…

Q – Is ISAAC a high-resolution or low-resolution model

A – High-resolution

Q – What are the three META rules

A – Advance

Cluster

Combat

Questions…

Q – Multi-Agent Systems provide:

a. Enhanced Understanding

b. A Look at emergent patterns during combat

c. A prediction of the outcome

d. a and b

e. c

A – d

Questions…

Q – What came first EINSTein or ISAAC

A – ISAAC

??????