Exploring Edge Organizations for Network Centric Operations

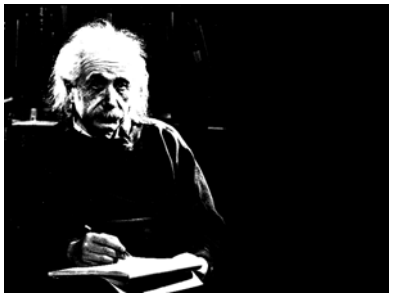
Adam Forsyth – Referentia Systems
Susan Sanchez – Naval Postgraduate School
Hong Wan – Purdue University
Kok Meng Chang – DSTA, Singapore
Paul Sanchez – Naval Postgraduate School

Outline

- Introduction
- Project Albert and Data Farming
- Experimental Design
- Framework for Investigation
- Future Direction

Project Albert and Data Farming

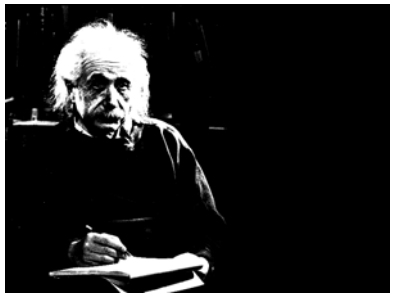
What is Project Albert?



"If we knew what we were doing, it would not be called research, would it?"

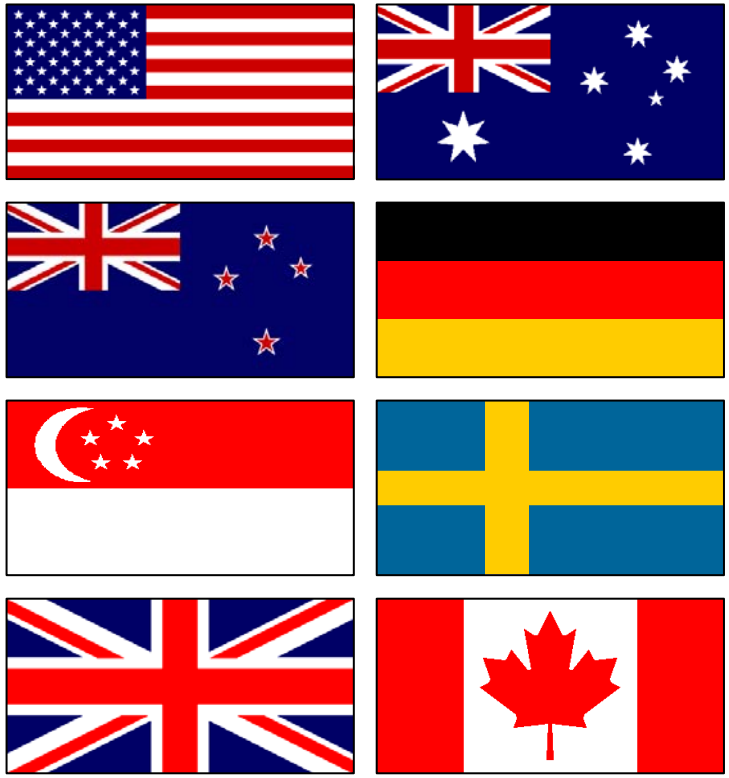
- Question-based USMC initiative based at the Marine Corps Warfighting Lab
- Focuses on aspects of modeling and simulation where traditional operations research techniques are deficient
  - Non-linearity
  - Intangibles
  - Co-evolution

Who is Project Albert?

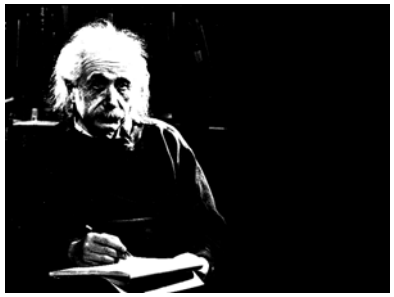


"I am neither especially clever nor especially gifted. I am only very, very curious."

- Project Albert is a multi-national collaboration
  - United States
  - Australia
  - New Zealand
  - Germany
  - Singapore
  - Sweden
  - Great Britain
  - Canada



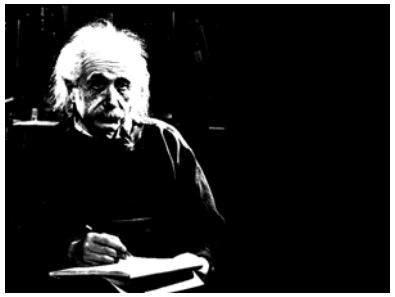
Why do we need Project Albert?



"A theory can be proved by experiment; but no path leads from experiment to the birth of a theory."

- A major problem when trying to understand and model problems in the defense domain is "irreducible complexity"
- Project Albert takes a different approach to these problems
  - Approach based on the emerging science of complex systems
  - Relies on building simple, distillation models
  - Focuses on the interactions between components
  - Use MHPCC's massive computing power to fully explore the landscapes of possible outcomes
  - Rapidly generates insights into problems

Data Farming



"As far as the laws of mathematics refer to reality, they are not certain, as far as they are certain, they do not refer to reality."

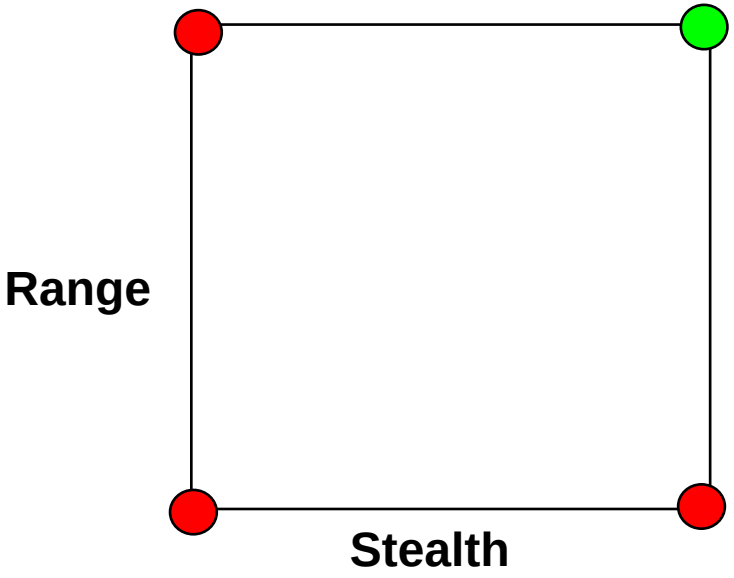
- Non-linear systems such as crowds can be highly sensitive to initial conditions and parameter settings
- Data Farming is a meta-technique to fully explore the landscape of possible outcomes from a model across a wide range of initial conditions
- Data Farming gives the decision maker insight into what are the possible outcomes, not just an estimate of the most likely outcome

Design of Experiments

Why designs are needed: a simple example

Unless we examine many factors at many levels simultaneously:

- We limit the insights possible (can't look for "interactions" or "thresholds" - places where interesting things happen for specific combinations of factors) so...
- ...we only tell part of the story, and...
- ...we have fewer chances for surprises!



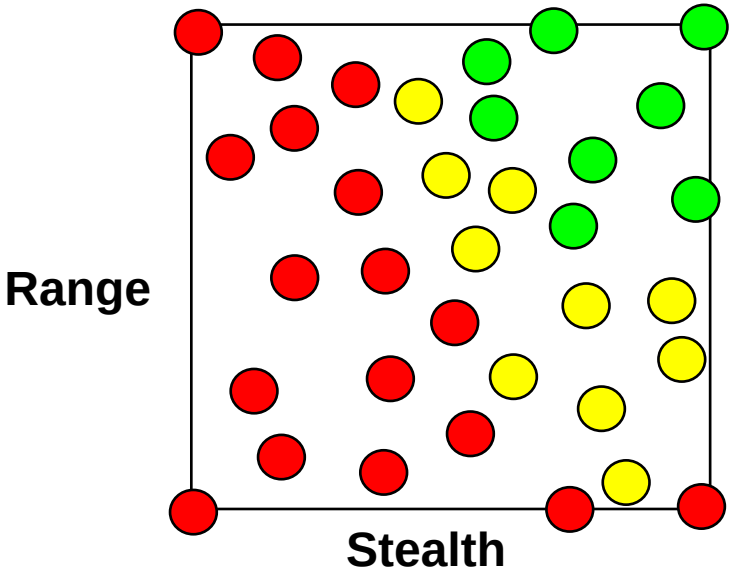
Example: which is more important, stealth or range?

Stealth	Range	Kill
Low	Low	No
Low	High	No
High	Low	No
High	High	Yes

Why designs are needed: a simple example

Unless we examine many factors at many levels simultaneously:

- We limit the insights possible (can't look for "interactions" or "thresholds" - places where interesting things happen for specific combinations of factors) so...
- ...we only tell part of the story, and...
- ...we have fewer chances for surprises!



Ex: which is more important, stealth or range?

Stealth	Range	Kill
Low	Low	No
Low	High	No
High	Low	No
High	High	Yes

Why *efficient* designs are needed!

How many runs will you need? A few comparisons...

# factors	10^k factorial	5^k factorial	2^k factorial
1	10	5	2
2	10^2 = 100	5^2 = 25	2^2 = 4
3	10^3 = 1,000	5^3 = 125	2^3 = 8
5	10^5 = 100K	5^5 = 3,125	2^5 = 32
10	10^10 = 10 billion	5^10 = 9,765,625	2^10 = 1,024
20	*Don't even think about it!*	5^20 = 95 trillion	2^20 = 1,048,576
40		5^40 = 9100 trillion trillion	2^40 = 1.1 trillion

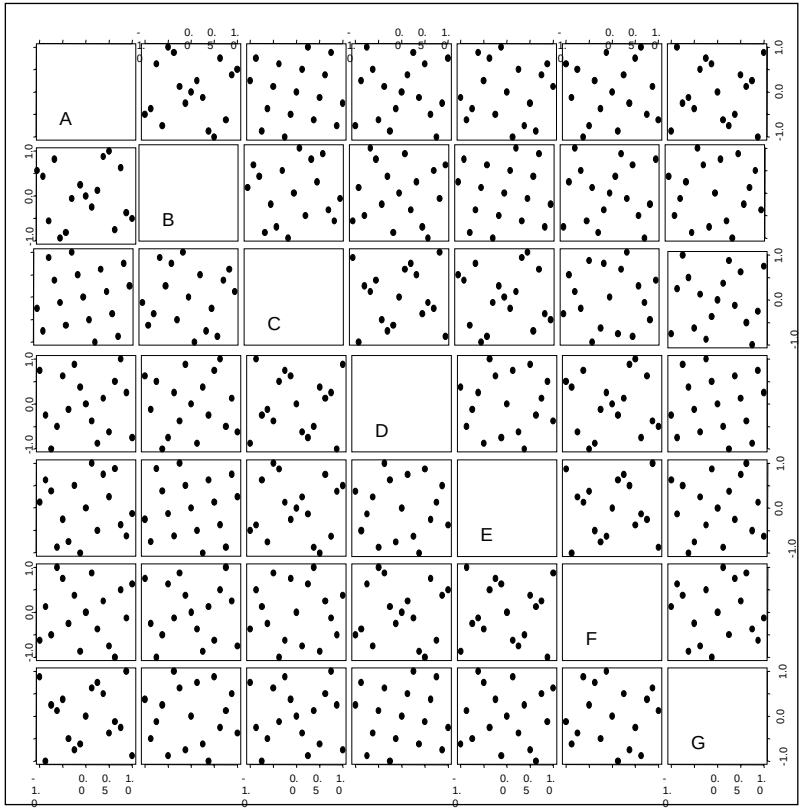
In contrast, structured nearly orthogonal Latin hypercube (NOLH designs) require

- 17 runs for 2-7 factors (up to 17 levels/factor)
- 33 runs for 8-11 factors (up to 33 levels/factor)
- 65 runs for 12-16 factors (up to 65 levels/factor)
- 129 runs for 17-22 factors (up to 129 levels/factor)
- 257 runs for 23-29 factors (up to 257 levels/factor)

Random LH designs can be generated for arbitrary combinations of # factors (*k*) and # runs (*n*) as long as *n* >= *k*.

A good all-purpose design

- Nearly Orthogonal Latin Hypercubes

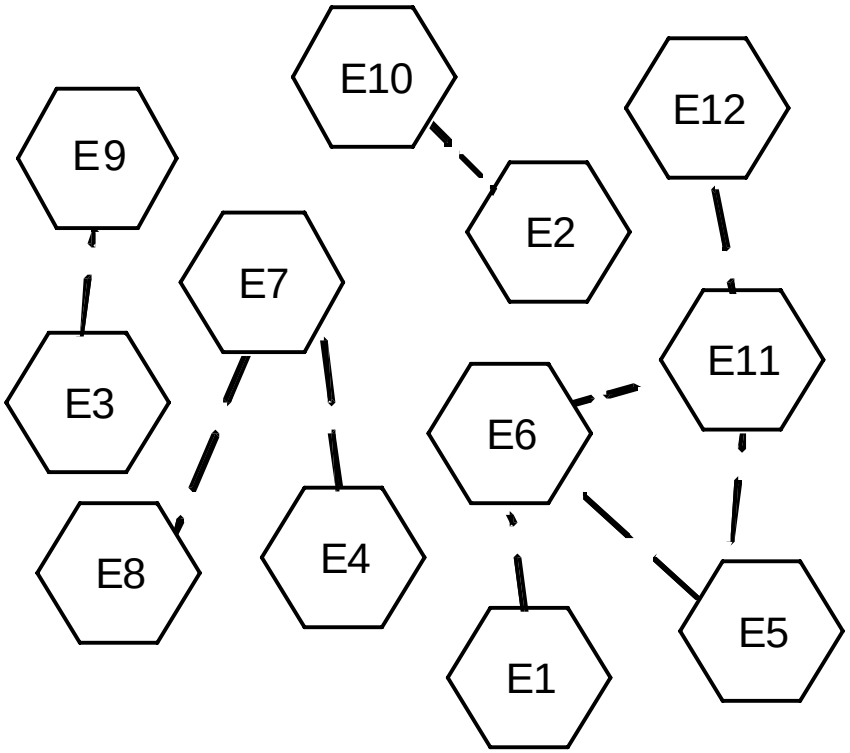


- The pairwise projections for exploring 7 factors with only 17 design points show
  - Orthogonality (no pairwise correlations)
  - space-filling behavior (points fill the sub-plots)

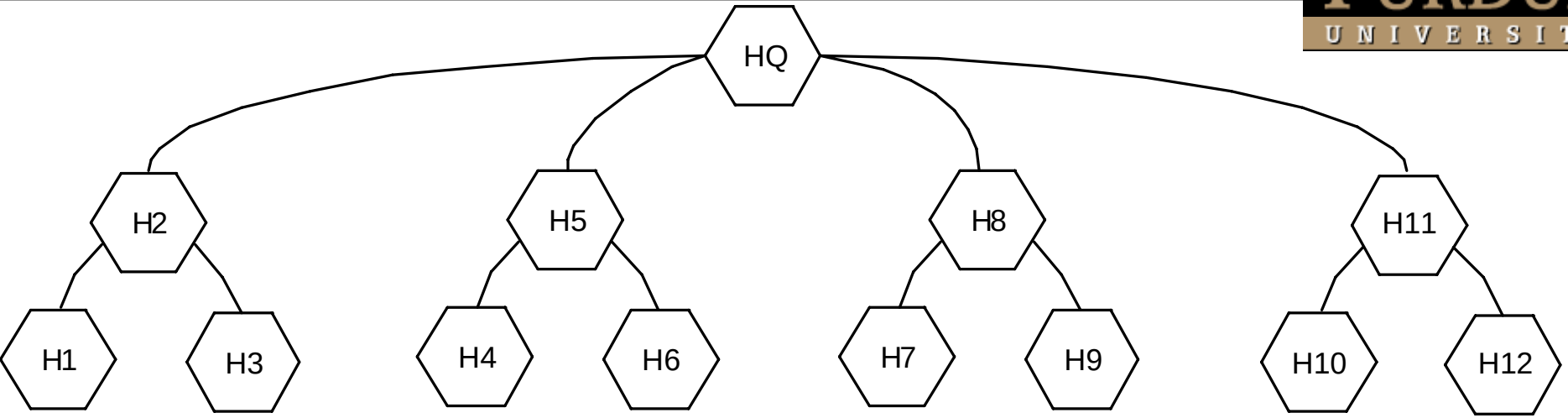
- **17 total design points!**

Framework for Investigation

Framework For Investigation



A momentary snapshot of an edge organization



The hierarchical organization used in our study

The Task

- Information Gathering Task based on Physical Experiment
- Agents must discover the *who, what, where* and *when* of an adversary attack by discovering a set of information factoids
- Factoids contain information about one of the aspects of the puzzle, and factoids may contain untrue (negative) information

Attributes of Intelligence Gathering Task

- The Intelligence Gathering task can be characterized by the following attributes:
  - Total amount of information available for discovery
  - Total amount of negative information
  - Total number of factoids available
  - Total number of negative factoids
  - Rate at which factoids are discovered
  - Solution threshold

Agent Behaviors

Edge Organization

- Common portal for agent to post factoids
- All agents can access this portal
- “Push and smart pull” approach
- Agents can work on any part of task
- When an agent discovers a factoid it can:
  - Hoard
  - Share with selected peers
  - Post to common portal
- Leadership is emergent

Agent Behaviors

Hierarchical Organization

- Common portal for agents to post factoids
- Agents can only discover factoids according to their specialized type
- Primary task of the agent is to discover factoids and pass these factoids it to their leader
- Leadership structure fixed

Measures of Effectiveness

- Problem is solved when sufficient information is accumulated for each of the factoid types
- Two typical MOE's
  - Time required to solve task
  - Information distribution at completion of task
- Other performance indicators
  - Does leader emerge?
  - Identity of any emergent leader
  - Identities of agents that solve individual components
  - Identity of winner – agent that solves task first

Future Direction

- Adapt model such that degree of centralization is a parameter, rather than just pure edge or pure hierarchical structures
- Put the model into the context of network-centric warfare
- Leverage advances in experimental design methodologies (such as Controlled Sequential Bifurcation) to determine the important factors in the experiment

Questions?