2011 SEArri Annual Research Summit

**Research Topic**
“Using Serious Gaming to Experience Dynamic Uncertainties and Illities”

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Cambridge, MA
Massachusetts Institute of Technology
Designing for a Dynamic World

- SEAr is has a decade of research on designing “value robust” systems
- Specifically targets the high leverage *early concept phase*
- Methods and metrics inform selection of promising concept designs for further analysis
- Uses exogenous uncertainties to frame the need for the ability of a system to respond to *perturbations*

Systems developed in a dynamic world must accommodate shifts in context and needs (epoch) across their lifespan (era)

Success for modern systems is strongly determined by being able to respond to perturbations on appropriate timescales
Many possible contexts and needs may unfold in the future, impacting actual and perceived system utility and cost. "Epoch-based thinking" can be used to structure anticipatory scenario analysis.

**Example triggers for epoch shifts impacting a system**
- Change in political environment
- Entrance of new competitor in market
- Emergence of significant new or changed stakeholder need(s)
- Policy mandate impacting product line, services or operations
- New threat environment with non-state actors using improvised attacks

Categories of uncertainties can aid in thinking about key changing factors:
*E.g., Resources, Policy, Infrastructure, Technology, End Uses ("Markets"), Competition, etc.*
### Related “ilities”

**Changeability and Survivability**

<table>
<thead>
<tr>
<th><strong>value robustness</strong></th>
<th>ability of a system to maintain value delivery in spite of changes in needs or context</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>changeability</strong></td>
<td>ability of a system to be intentionally altered in form or operations, and consequently possibly in function, at an acceptable level of “cost”</td>
</tr>
<tr>
<td>flexibility</td>
<td>ability of a system to be altered by a system-external change agent</td>
</tr>
<tr>
<td>adaptability</td>
<td>ability of a system to be altered by a system-internal change agent</td>
</tr>
<tr>
<td><strong>survivability</strong></td>
<td>ability of a system to minimize the impact of finite-duration disturbances on value delivery</td>
</tr>
<tr>
<td>susceptibility</td>
<td>reduction of the likelihood or magnitude of a disturbance</td>
</tr>
<tr>
<td>vulnerability</td>
<td>satisfaction of minimally acceptable value level during and after disturbance</td>
</tr>
<tr>
<td>resilience</td>
<td>timely recovery to an acceptable value level after a disturbance</td>
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</tbody>
</table>

A *valuably changeable* system is one that can be intentionally altered, typically in response to a perturbation (such as a change in context), in order to improve its value.
Ten Years of Research on Methods and Metrics

Methods for Value-Centric Analysis

- Multi-Attribute Tradespace Exploration
- Epoch-Era Analysis

VASC
1. Set up data for epoch-era analysis
2. Identify designs of interest
3. Define rule usage strategies
4. Multi-epoch changeability analysis
5. Era simulation and analysis

Likelihood of Design E executing each transition rule across a 10 year era (per strategy)

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Rule 1</th>
<th>Rule 2</th>
<th>Rule 3</th>
<th>Rule 4</th>
<th>Rule 5</th>
<th>Rule 6</th>
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<tr>
<td>MaxU</td>
<td>N/A</td>
<td>N/A</td>
<td>100.0%</td>
<td>88.2%</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>MaxEff</td>
<td>N/A</td>
<td>N/A</td>
<td>100.0%</td>
<td>97.1%</td>
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<tr>
<td>Survive</td>
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<td>94.9%</td>
<td>0.0%</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>MaxP</td>
<td>N/A</td>
<td>N/A</td>
<td>96.8%</td>
<td>31.5%</td>
<td>N/A</td>
<td></td>
</tr>
</tbody>
</table>

Era (long run) analysis
Multi-epoch (short run) analysis

Exploring Fuzzy Pareto Shap of designs of interest for a strategy

Name Strategies
Maximize Utility
Maximize Efficiency
Survive
Maximize Profit

Change Mechanisms

Each tradespace represents a fixed context/needs
Each point represents a feasible solution

Many epoch data sets

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Ten Years of Research on Methods and Metrics

Methods for Value-Centric Analysis

- Multi-Attribute Tradespace Exploration
- Epoch-Era Analysis

RSC consists of seven processes:
1. Value-Driving Context Definition
2. Value-Driven Design Formulation
3. Epoch Characterization
4. Design Tradespace Evaluation
5. Multi-Epoch Analysis
6. Era Construction
7. Lifecycle Path Analysis

VASC
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It takes graduate students over a year to begin to really apply some of this…
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SEArI's goal is to impact practice, so we need to find a better way to teach the research
Tackling Problems using “Games”

There is growing interest in using the medium of games for learning how to solve both complex and complicated problems.

Is this an applicable medium for SEArri research?
The Four Freedoms of Play

• Freedom to Experiment
• Freedom to Fail
• Freedom to Try on Identities
• Freedom of Effort

From Scot Osterweil of The Education Arcade, “Keeping the Play in Learning Games”, 6/9/2011
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Learning

Fun

From Scot Osterweil of The Education Arcade, "Keeping the Play in Learning Games", 6/9/2011
A game is a problem-solving activity, approached with a playful attitude
Schell 2008, pg 37

- Entertainment
- “Edutainment” = “Serious” games
- Education
- Simulations
  - Management flight simulators
  - Aircraft flight simulators
(Aldrich 2009)

Whether stated goal is to teach a lesson or to escape reality, the main purpose of games is to create an “experience” in the mind of the player

Monopoly: Classic family board game by Hasbro; buy and sell properties in Atlantic City

Windfall: a strategy game about building wind farms to create clean energy profitably. Persuasive Games (http://www.persuasivegames.com)

Microsoft Flight Simulator X: Gold Edition: Experience realistic flights with day/night and weather effects, multiplayer races and over 80 missions worldwide
Game Design is both Art and Engineering


Four Basic Elements of a Game

- **Mechanics**
  - Procedures and rules of a game
  - Describe the goals, how players can and cannot try to achieve them, and what happens when they try

- **Story**
  - Sequence of events that unfolds in a game
  - Linear and pre-scripted, or branching and emergent

- **Aesthetics**
  - How a game looks, sounds, smells, tastes, and feels
  - Has most direct impact on game experience

- **Technology**
  - Any materials and interactions that make a game possible, such as paper and pencil, plastic chits, or high-powered lasers
  - Is the medium in which aesthetics take place, in which mechanics occur, and through which a story is told

(Schell 2008), pp 39-43
More than Just “Play”

Transformation and Responsibility

- **Good for us**
  - Emotional maintenance
  - Connecting
  - Exercise
  - Education
    - Facts
    - Problem Solving
    - New Insights
    - Curiosity

- **Bad for us**
  - Violence
  - Addiction

- **Responsibility**
  - Intend to do good

- **Being accountable**
  - Do no harm

Games are a powerful medium that creates (potentially transforming) experiences in players

Miller's pyramid of learning in (Schell 2008), pp 445
Summer Project Motivation

- Summer 2009 (updated 2010)
  - VisLab created as means to “experience” the data
  - Users have fun while gaining insight and learning
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• Summer 2011
  – Find a way to develop a “game” to teach, clarify, simulate SEArri constructs
  – And be fun!
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GOAL: Develop interactive games for accelerated insights into dynamic system strategies using six SEArI constructs (“design” choices, utilities, costs, epochs, eras, and “ilities”)
High Level Project Goals

*Interactive Games for Accelerated Insights into Dynamic System Strategies*

**Goals**

- To develop a “game” to let players better understand the “ilities” and the effects of changing contexts & needs on valuation
- To develop useful visual and interactive constructs to communicate short run and long run scenario analysis using SEArri constructs
- To be able to gather player game data (to compare how users “optimize” and make decisions in this dynamic decision environment to strategies derived through SEArri algorithms)
- To have a software platform that enables easy modification to demonstrate the universality of the problem type across various system problem applications

*These goals were presented at the summer project kickoff meeting*

*A game is a problem-solving activity, approached with a playful attitude.*

Schell 2008, pg 37
3 Methods and 6 Constructs for Summer Project

SEARI METHODS AND CONSTRUCTS
SEArri Methods

• The following **methods** were developed by SEArri:

1. **MATE** (Multi-Attribute Tradespace Exploration)  
   (sometimes just “TSE”)
   • Guides the exploration of many design choices (tradespace) in terms of benefits and costs to different stakeholders

2. **EEA** (Epoch-Era Analysis)
   • Analyzes short run and long run impacts of changing contexts and needs on design(s)

3. **RSC** (Responsive Systems Comparison)
   • Combines MATE and EEA into 7 process structured method

• The methods generate and manipulate the constructs

SEArri methods seek to improve the way engineers and decision makers generate, characterize, evaluate, and select “design” choices in a dynamic world
SEAriv Constructs

The following constructs form the core “elements” for the summer project:

1. “design” choices
2. utilities
3. costs
4. epochs
5. eras
6. “ilities”
“Design” Choices

Decisions on a “design” alternative that is in the control of the “Designer”
- Can be on entire alternative or aspect(s) of an alternative
- Can be done during generation or selection of alternatives
- Can be done initially or later in the “lifecycle”

Design Space
> Manipulator Mass
  - Low (300kg)
  - Medium (1000kg)
  - High (3000 kg)
  - Extreme (5000 kg)
> Propulsion Type
  - Storable bi-prop
  - Cryogenic bi-prop
  - Electric (NSTAR)
  - Nuclear Thermal
> Fuel Load - 8 levels

Related Concepts: designs, design vectors/variables, concepts, configurations, alternatives, choices, selections
The benefit accrued from a “design” choice

- Is subjectively defined, varying by person
- Can be multi-criteria
- Can vary over time

Related Concepts: attributes, single attribute utility, multi-attribute utility, benefits, criteria, score, performance, rewards, effectiveness
The expended resources for a design choice to achieve the utilities

- Can be incurred initially, over time, and at end of life
- Can be multi-criteria (not necessarily dollars)
- Often subject to constraints (such as budgets and schedules)

**Cost Space**

\[ C = c_w M_w + c_d M_d \]

**Space Tug**

- Dollar cost
  - Dry mass
  - Fuel cost
- Simple parametric model

**Related Concepts:** costs, dollars, budget, time, schedule, expenses, resources, effort, penalties
Epochs

The short run period of “fixed” context and expectations for a choice
• Defined by factors outside of “Designer” control (uncertainties played out)
• Can be many possible epochs
• Concept is relative to defined “fixed” factors that may vary in the future

Categories of key uncertainties → epochs
Available resources, Policy, Infrastructure, Technology, End Uses (“Markets”), Competition, etc.

Related Concepts: epochs, epoch variables, short run, contexts, expectations, futures, uncertainties

Space Tug

> Expectations
  – Rescue mission
  – Military mission
  – Tender mission
  – Space Debris Collector
  – Tech Demo
  – Refueler

> Technology
  – Cost of propulsion
  – Mass density

DARPA Orbital Express
Eras

The long run, time-ordered sequences of epochs
- Represents “path-dependency” of uncertain future timelines
- Allows for strategy development of choices over time
- Concept is relative to defined “fixed” factors that may vary in the future

Space Tug

Sequence of epochs
1. Demonstration
2. Comsat Servicer
3. Orbital Infrastructure
4. Orbital Rescue

Related Concepts: eras, epoch ordering, long run, contexts, expectations, futures, uncertainties
“ilities”

The ability of a choice to change over time or not need to change over time
• Usually defined in reference to a perturbation (e.g. disturbance → survivability)
• Can be regarded in terms of “degree of” and “value of” each “-ility”
• Usually require an embedded “option” or “mechanism” to execute with costs

Space Tug

Each “-ility” corresponds to a particular aspect of the choice over a particular range; multiple “ilities” can co-exist or conflict

Related Concepts: ilities, real options, change mechanisms, changeability, flexibility, adaptability, scalability, modifiability, robustness, survivability
Layered Architecture

The high level architecture consists of the game, engine, and database.

This summer's goal was to develop the engine and the game.
Game Conceptual Flow

Introduce Stakeholders

Research

Design

Operations

Results

(Minigames)
Game Architecture Outline

Free Play → Story Mode

Options
- Difficulty
- # epochs in era
- # DMs
- Scoring goals

META Story

Level 1 → Level 2 → Level 3 → Level N

Increasing difficulty, exposure to constructs

App specific data (e.g., story, graphics)

DB input

Increasing difficulty, exposure to constructs
Brief Game Outline

Introduce

Stakeholders

Operations

Research

Design

Results

(Minigames)

(seari.mit.edu 352011 SEAri Research Summit © 2011 Massachusetts Institute of Technology)
Brief Game Outline

Introduce Stakeholders

Research

Design

Operations

Results

(Minigames)
Brief Game Outline

Introduction

Stakeholders

Operations

Research

Design

Results

(Minigames)

Welcome to Free-play mode.

Your goal is to create a design that will please The Surveyors.

A design in operation will earn you valuable diamonds.

A design in the process of building will give you coins.

Coins are less valuable but still let you know that the Surveyors are still interested.

Your progress will be considered for a medal at the end.

Narration

Name: Prayma

Weight 0.49

Preferences Focus: DeltaV.

Context

Description

The condition of this epoch is:

TechLevel 2.0
Brief Game Outline

Introduce Stakeholders

Research

Design

Operations

Results

(Minigames)
Brief Game Outline

Introduce

Stakeholders

Operations

Research

Design

Results

(Minigames)
Brief Game Outline

1. Introduce
2. Stakeholders
3. Research
4. Design
5. Operations
6. Results
7. (Minigames)
Brief Game Outline

Introduce Stakeholders

Research

Design

Operations

Results

(Minigames)
Research Minigame 1
Hit the Pareto

**Goal:** Propose a design as close as possible to Pareto Frontier, within constraints

**Gameplay:** Make a design given an epoch

**Constraints:** Maximum cost and minimum utility, depends on difficulty level
Hit the Pareto Interface

**Epoch description**
(prefs, context, constraints)

**Design Variables**
(Choose the design you want to “test”)

**Attempt Medals**
(Three attempts, each scored with medals)

**Tradespace Plot**
(Shows Pareto Front, constraints, and all attempts)

**Attribute Levels**
(length=relative importance, colored by fill %)
Hit the Pareto Scoring

• Points
  – Based on Fuzzy Pareto Number
  – Normalized to 1000

• Failures
  – Infeasible: Not following constraints
  – Invalid: Negative Utility

• Medals
  – Depends on points and difficulty level
  – E.g. for medium level:

<table>
<thead>
<tr>
<th>Medal</th>
<th>Fuzzy Point Range</th>
<th>Point Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gold</td>
<td>0-3</td>
<td>800-1000</td>
</tr>
<tr>
<td>Silver</td>
<td>4-6</td>
<td>550-800</td>
</tr>
<tr>
<td>Bronze</td>
<td>6-10</td>
<td>200-550</td>
</tr>
<tr>
<td>Wood</td>
<td>&gt;10</td>
<td>0-200</td>
</tr>
</tbody>
</table>
Research Minigame 2
Destroy Your Design

Goal: Discover a three-epoch era where your level design will achieve poorly

Gameplay: Construct a difficult to survive era

Constraints:
- Up to 3 decision makers who have a preference set in each epoch
- One context for each epoch
- Up to 2 disturbances for each epoch (order matters!)
Destroy Your Design Interface

Constructed Era Description
The goal is to achieve the *lowest fraction remaining utility* possible, which is determined by the ratio of the utility of current design over maximum achievable utility of the era.

<table>
<thead>
<tr>
<th>Medal</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gold</td>
<td>$0% \leq \text{remaining utility} &lt; 10%$</td>
</tr>
<tr>
<td>Silver</td>
<td>$10% \leq \text{remaining utility} &lt; 25%$</td>
</tr>
<tr>
<td>Bronze</td>
<td>$25% \leq \text{remaining utility} &lt; 50%$</td>
</tr>
</tbody>
</table>

Success ratio = fraction of remaining utility
Brief Game Outline

Introduce Stakeholders

Research

Design

Operations

Results

(Minigames)
Brief Game Outline

Introduce Stakeholders

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Results

(Minigames)
Evaluation Screen
Era View

- Directly follows Operations (Mission)
- Layout
  - Timeline
  - Tabs

Visually organizes Mission by Era, Epoch, Days (Scrollable)
Easily cipher through to see Era/Epoch specific data

Era Tab
- Scoring
  - Total Earnings
  - Surveyor Appeal
  - Bonus
  - Medal Earned
- Graph
  - Visual diagram
  - View More option
• **Epoch Tab**
  - Point / Utility Distribution among each decision maker
  - Options to view disturbances / executions
  - Audio of decision maker based on performance
Evaluation Screen
Overall Scoring

Scoring

- **Total Earnings**
  - Diamonds: Effective Utility in Operations
  - Coins: Basic Utility in Design

- **Surveyor Appeal**
  - Percentage that player pleased all decision makers
  - Averages all DMs with “Thumbs Down” weighted more

- **Bonus**
  - Cost Efficiency
  - Uptime
  - Change Mechanisms
  - Research

- **Medal**
  - Averages above three percentages with maximum possible value
  - Type:
    - Gold
    - Silver
    - Bronze

Four categories shown in Era tab:

- **Compares cost of design to that on the Pareto Line**
- **Percentage in era when design is valid in operations**
- **Compares design effective utility before and after execution**
- **Averages points and high scores achieved in minigames**
Discussion

• Inheritance of VisLab software was key
• Development is just demonstration, low level of maturity
  – One spiral, little play testing
  – Still a promising product, showing potential for vision
• This game currently demonstrates only one “skin” (i.e., “SpaceTug”) that can be applied to the engine
• Designed with extensibility in mind, especially in the mini games
• Further work would vastly improve gameplay experience
• Learning occurs for both developers and players

The game and engine were developed such that students can pick up this project in future efforts
Contributions

• Experience teaching SE Ari concepts to a non-SE, younger audience
• A serious game that looks at complex systems engineering from many perspectives
  – Tradespace Exploration – Hit the Pareto
  – Identifying Weaknesses – Destroy Your Design
  – Era Analysis – Operations Mode
• Pioneering the use of serious games in systems engineering
• Experience using game constructs to illustrate SE Ari constructs
• Extensible architecture (engine) for future game development

The SE Ari Summer Project was a successful multi-disciplinary exercise in using new methods to communicate SE Ari research

Hopefully to be continued…