# Simulation-based Multi-hazard Decision Support

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# Simulation-based Multi-hazard Decision Support

Introduction

Aseismic Design and Retrofit

Aseismic Decision Support

Multi-hazard Decision Support

Summary

# Simulation-based Multi-hazard Decision Support

## Overall Objective

Enhance community resilience to extreme events

## Characteristics

- Multidisciplinary
- Uncertainty, ambiguity and risk
- Spatial and temporal dimensions
- Finite resources
- Unlimited possibilities

} Complex Problems → Robust Solutions

# Simulation-based Multi-hazard Decision Support

## Research Objective

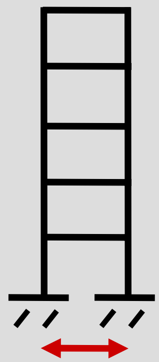
**Develop a computational decision support framework for critical infrastructure and facilities that**

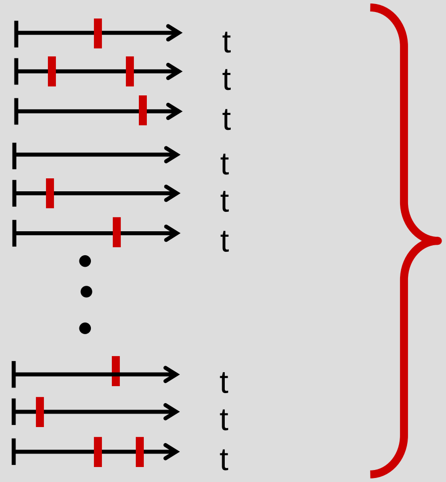
- **Provides flexibility to include a broad range of models and simulation software**
- **Incorporates both engineering and sociotechnical aspects**
- **Allows consideration of a variety of extreme events**
- **Seeks robust solutions to complex problems**

**Focus initially on critical care facilities and healthcare networks under seismic hazards**

# Aseismic Structural Design and Retrofit

Design
A

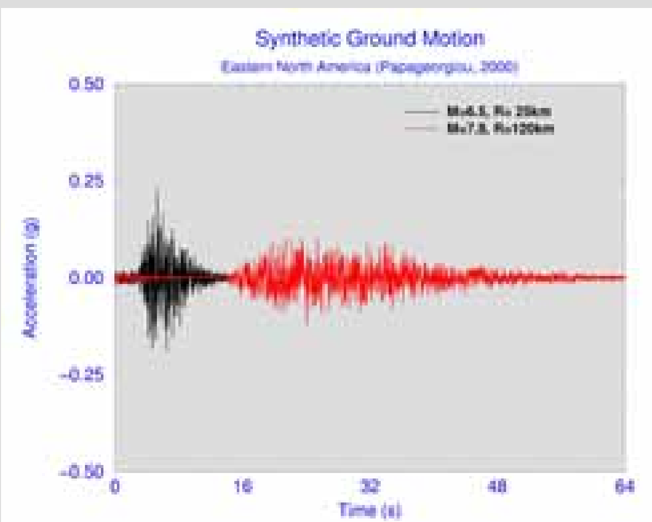


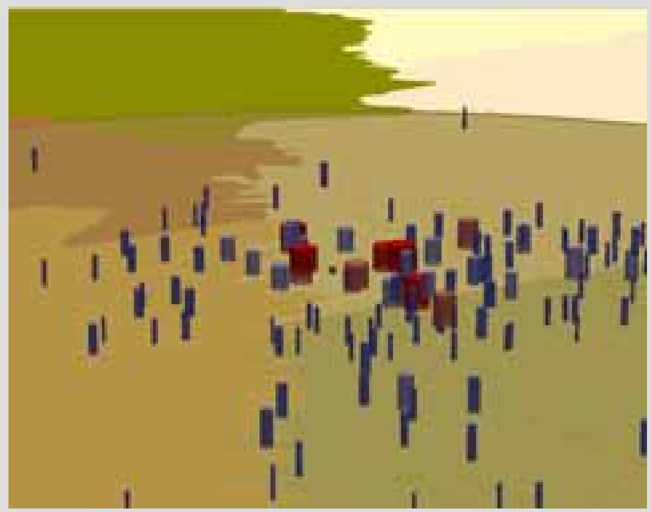



Utility of
Design A

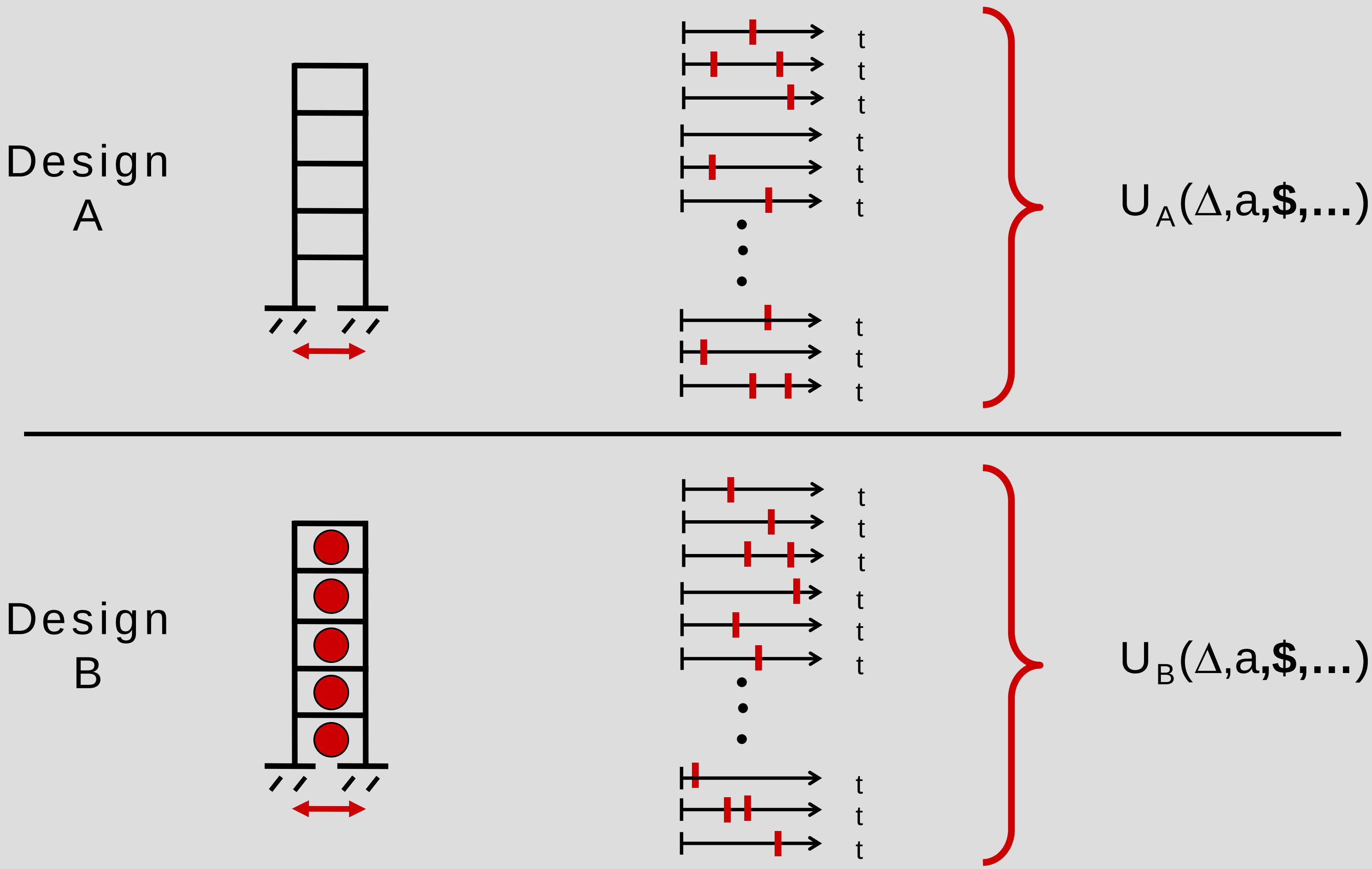
$U_A(\Delta, a, \$, \ldots)$

Resilience
Metric



# Aseismic Structural Design and Retrofit



# Aseismic Structural Design and Retrofit

## Difficulties

**Many potential design solutions exist**

**How does one determine Designs A and B?**

## Simulation-based Design

**Define utility function** U

**Identify space of possible design solutions** S

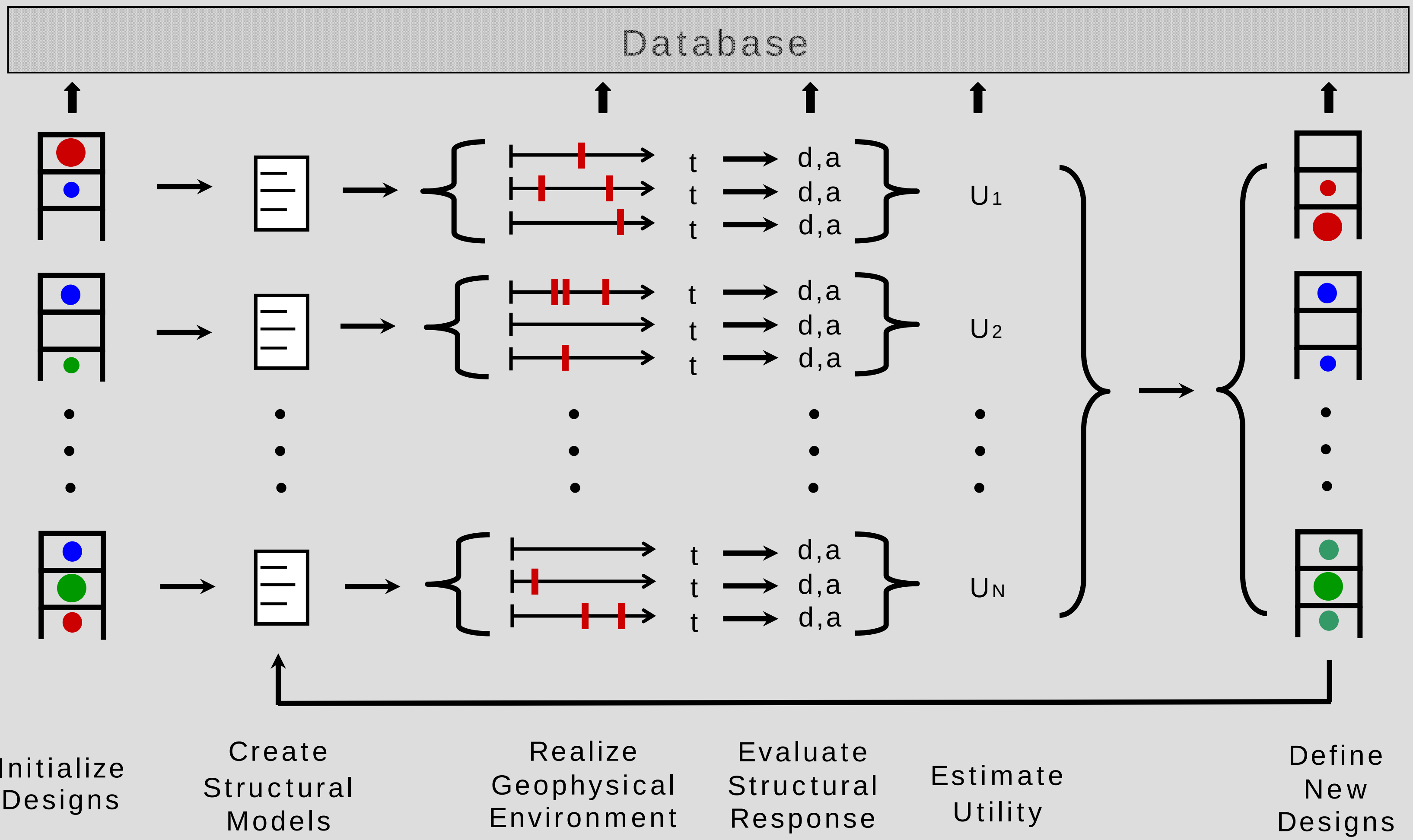
**Identify/develop appropriate simulation algorithms to evaluate** U **for all possible design solutions in** S

**Utilize systematic method to find robust designs**

↓

**Genetic Algorithms (Holland, 1975)**

# Evolutionary Aseismic Design and Retrofit



# Evolutionary Aseismic Design and Retrofit
## Features

**Passive damper options include both rate-independent (metallic) and rate-dependent (viscous and viscoelastic) devices**

**Nonlinear models for base structure and passive elements using lumped parameter representations**

**Uncertain seismic environment or fixed ensemble of ground motions**

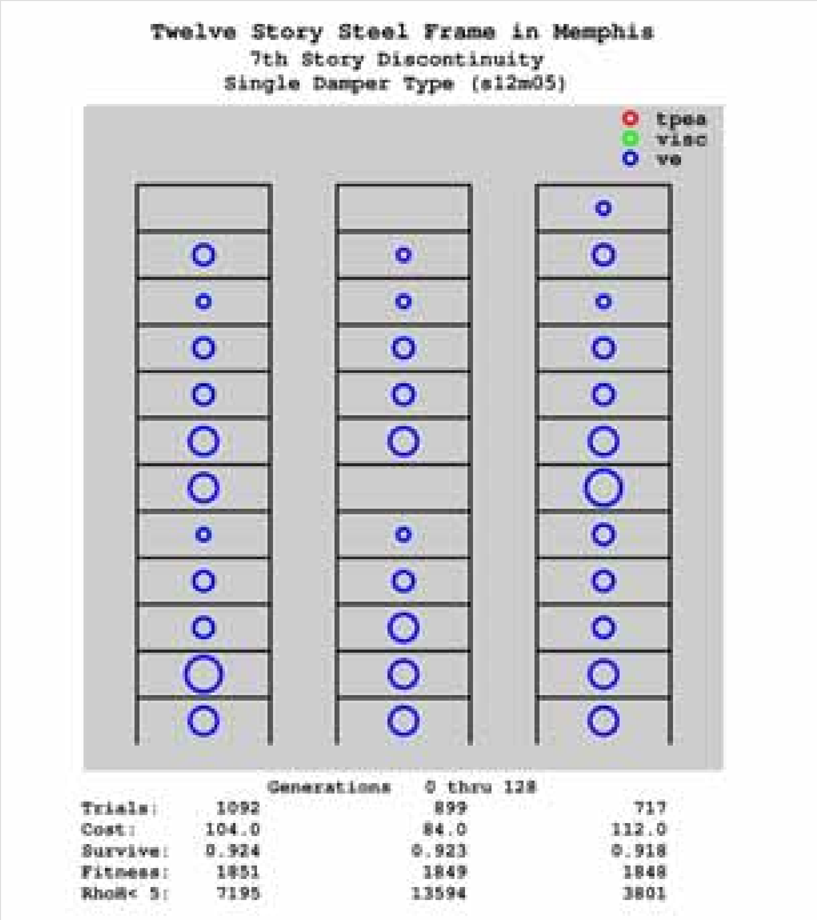
**Transient dynamic analysis to evaluate seismic response**

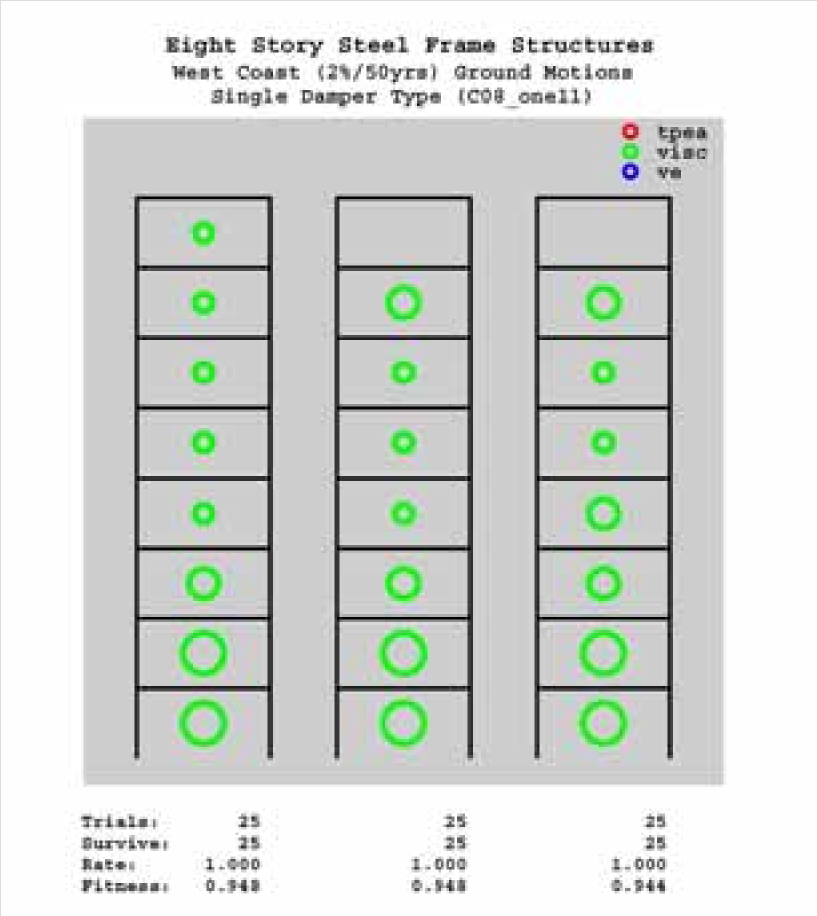
**Structural fitness (or utility) depends upon:**

- **Satisfactory levels for interstory drift and total acceleration**
- **Performance of non-structural components**
- **Damper cost**
- **Risk aversion index**

# Evolutionary Aseismic Design and Retrofit

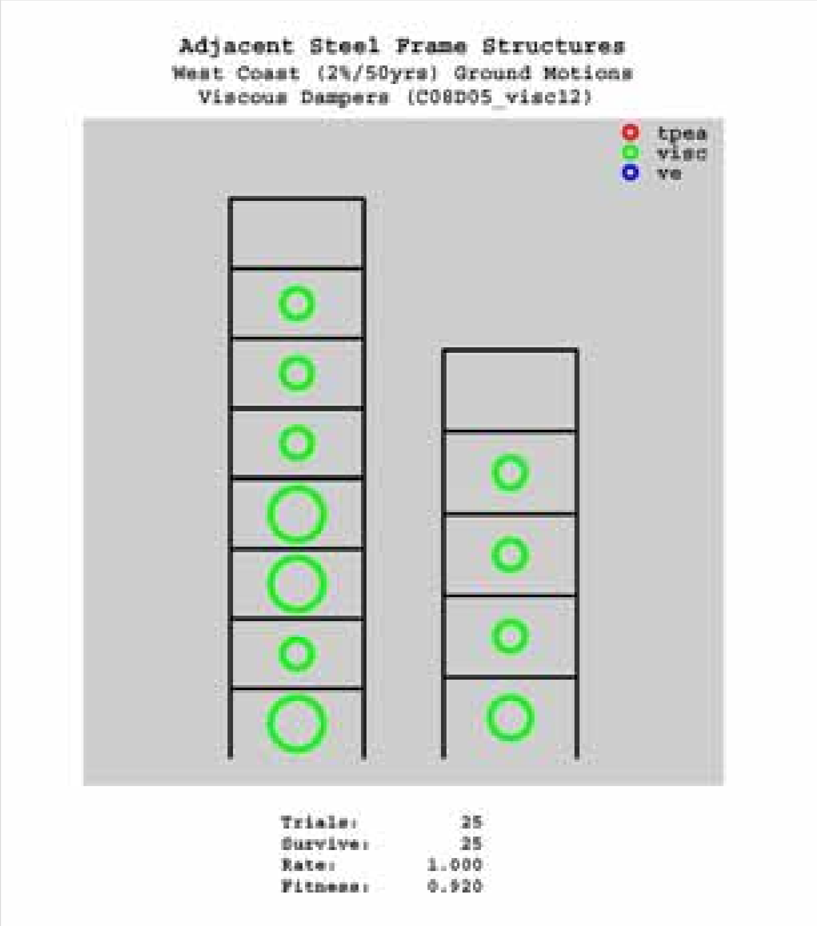
## Examples

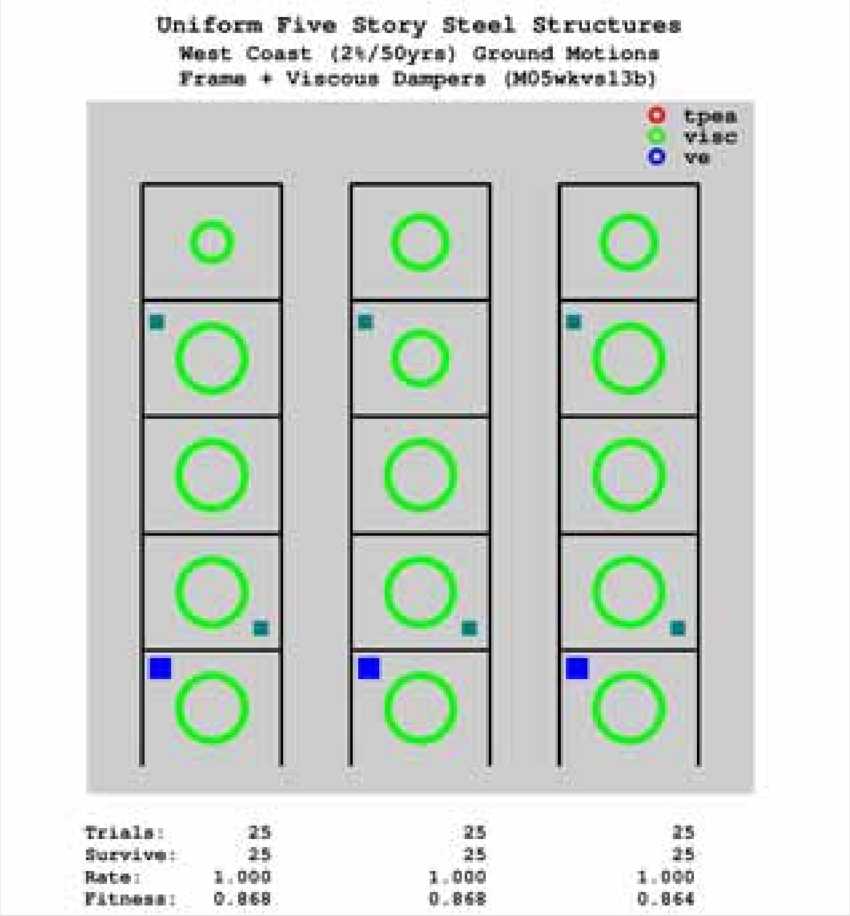


# Evolutionary Aseismic Design and Retrofit

## Examples




**For more details, please see poster by Seda Dogruel**

# Healthcare Organizations
## (Petak-Alesch, 2004)

**Existence of robust engineering solutions is not sufficient**

**Retrofit selected only if critical care organization:**

- **Believes that a solution exists to reduce the risk**
- **Believes that it is in its best interest to act**
- **Finds a solution compatible with its mission**
- **Has the capacity to implement the solution**
- **Perceives the seismic risk**

**Temporal dimension of decision-making process also is important**

**Can simulations provide useful information to this decision-making process? What models would be appropriate?**

# Aseismic Decision Support

**Simulation-based Approach**

**Define utility function U for organization**

**Identify space of possible policy sets S**

**Identify/develop appropriate simulation algorithms to evaluate U for all possible policy sets in S**

**Utilize genetic algorithm to evolve robust policy sets**

↓

**Evolutionary Aseismic Decision Support**

# Evolutionary Aseismic Decision Support

## Critical Care Formulation

**Utility Function**

- Building & equipment; Monetary assets
- Patients served
- Accumulated damage; Patient-days lost

} Resilience Metric

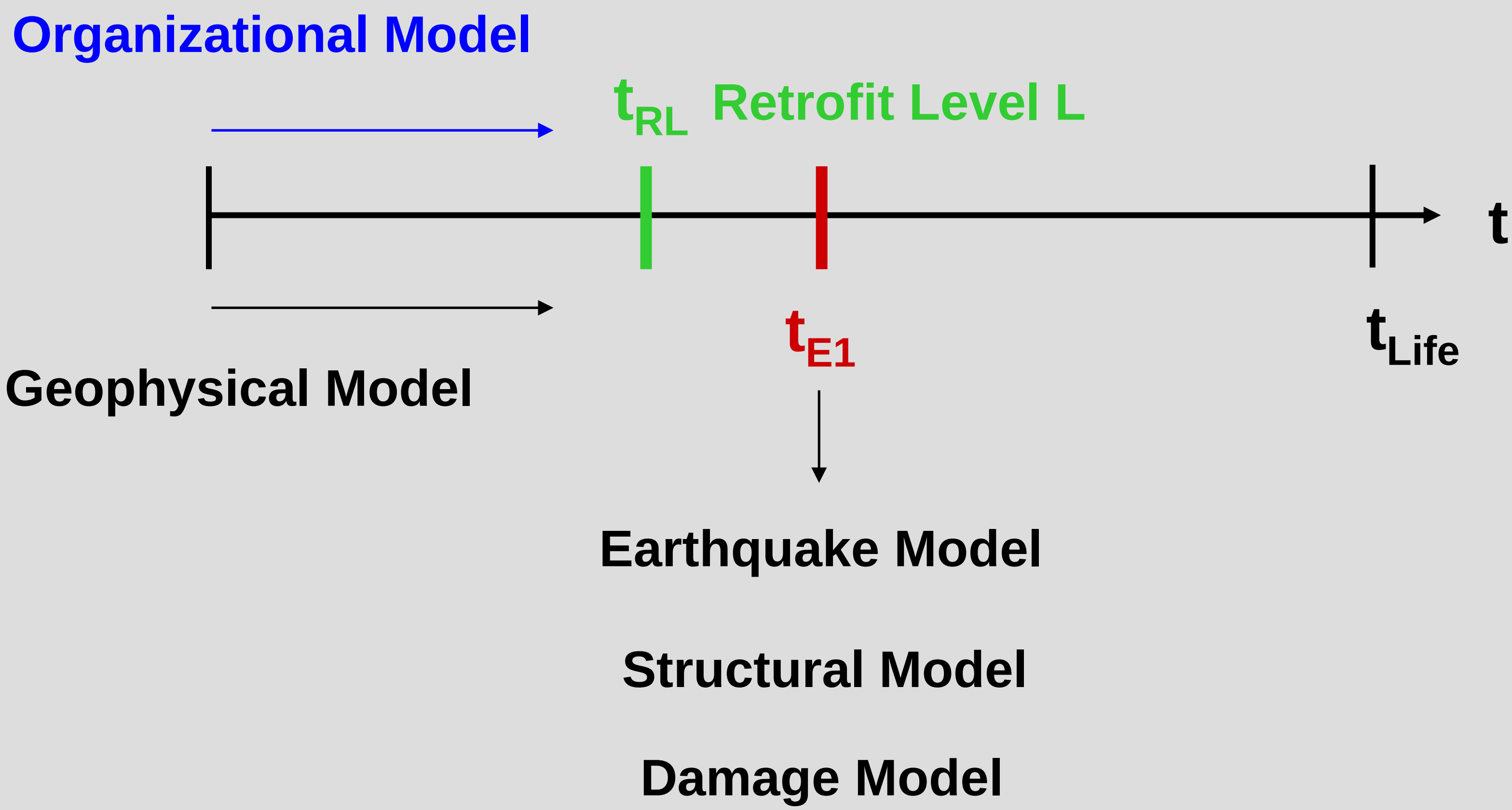
**Decision Space**

- Policy 1: Seismic Retrofit
  - Evaluation frequency, Retrofit criteria, Retrofit level
- Policy 2: Building & Equipment Investment
  - Investment coefficient, B/P target ratio, Monetary asset threshold
- Policy 3: Facility Status
  - Open/close decision, Alternative function

# Evolutionary Aseismic Decision Support

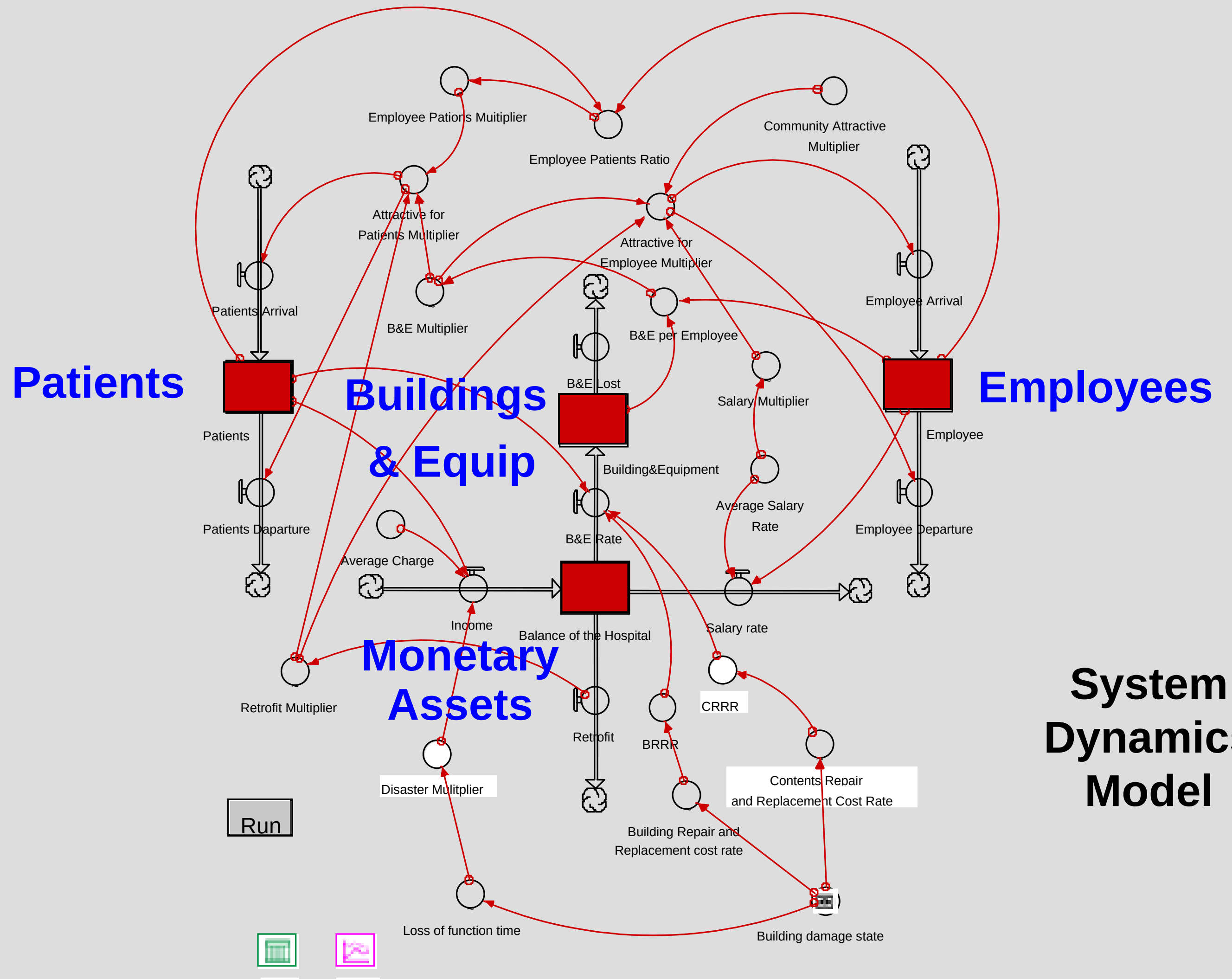
## Critical Care Formulation

**Single Realization over Time**



# Organizational Model of Hospitals

## Initial Formulation




System Dynamics Model

# Organizational Model of Hospitals

## Initial Formulation

**System Dynamics (Forrester, 1961, 1969)**
**Population Dynamics (May, 1973)**

**Primary Variables:**

- **Patients (P)**
- **Employees (E)**
- **Buildings & Equipment (B)**
- **Monetary Assets (M)**

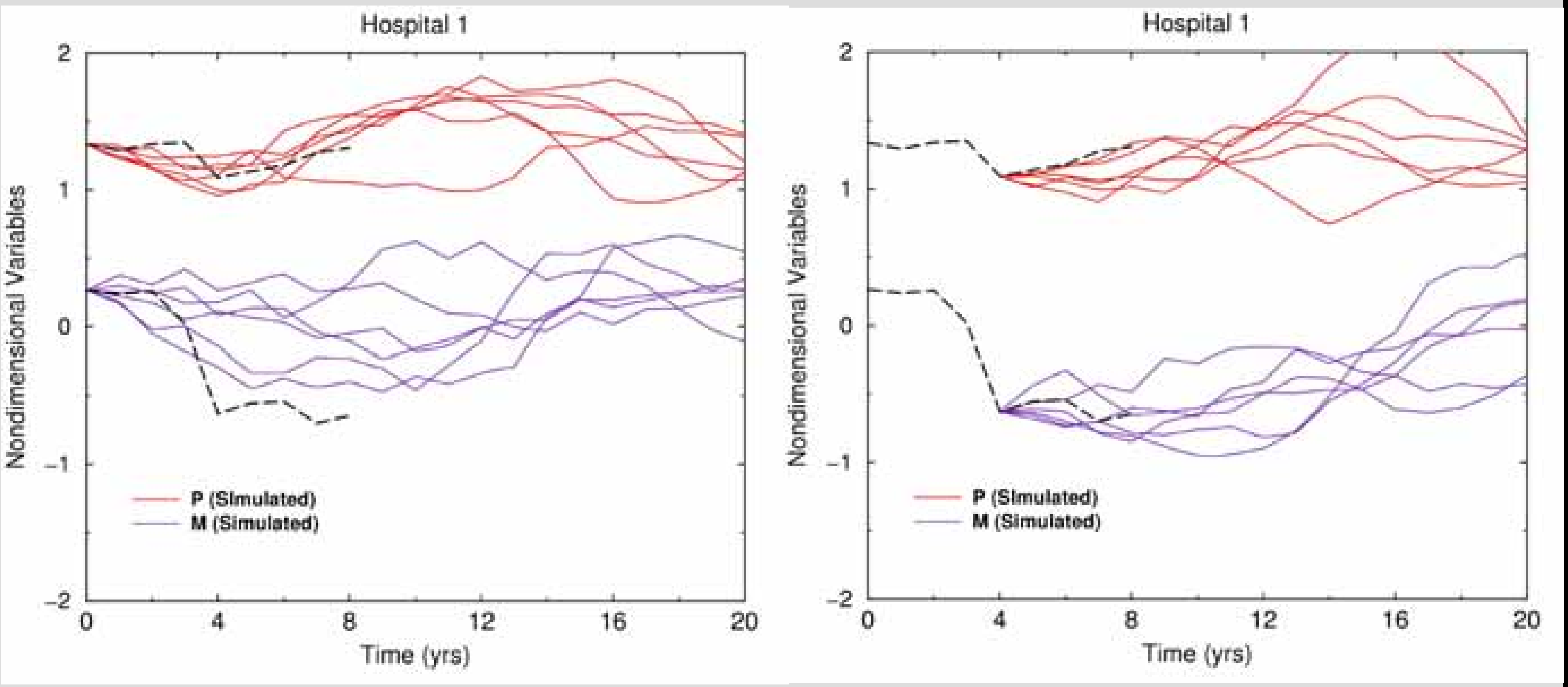
$$d\,\mathbf{X} = \mathbf{f}(\mathbf{X}, t)\,dt$$

**Key Ratios:**

- **E/P**
- **B/P**

**Parameter estimation based upon OSHPD database**

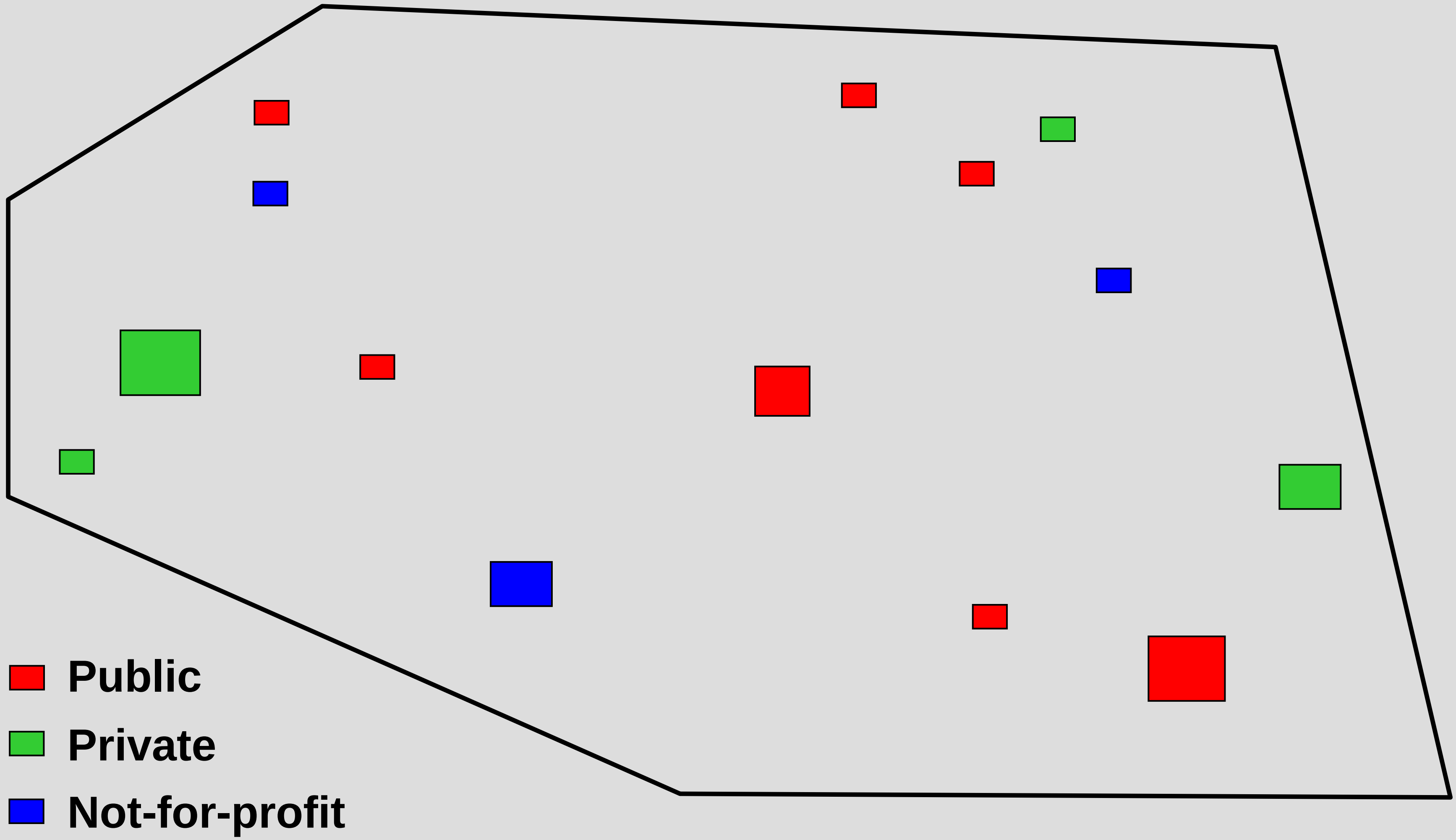
# Organizational Model of Hospitals
## Initial Formulation




**For more details, please see poster by Yufeng Hu**

# Spatial Distribution of Hospitals

## Regional Policy Formulation



# Evolutionary Aseismic Decision Support
## Regional Policy Formulation

**Utility Function**

**Patients served; Economic activity**
**Accumulated damage; Patient-days lost**

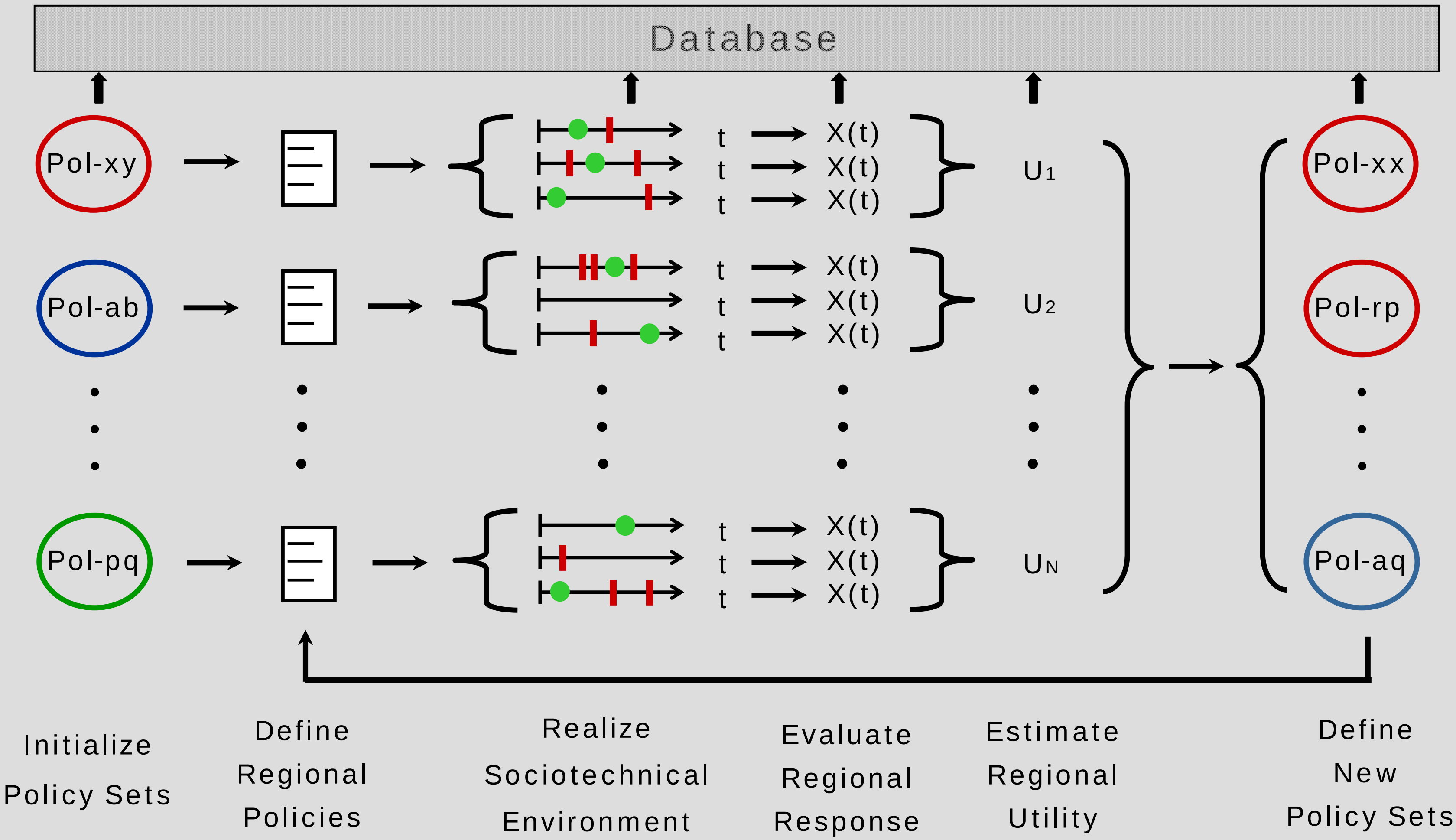
} Resilience Metric

**Decision Space**

**Policy 0: No retrofit regulation**
**Policy 1: Mandated retrofit wo/financial support**
**Policy 2: Mandated retrofit w/financial support**
**.**
**.**
**.**
**Policy n: Optional retrofit w/incentives Z phased in with time schedule X**

# Evolutionary Aseismic Decision Support

## Regional Policy Formulation

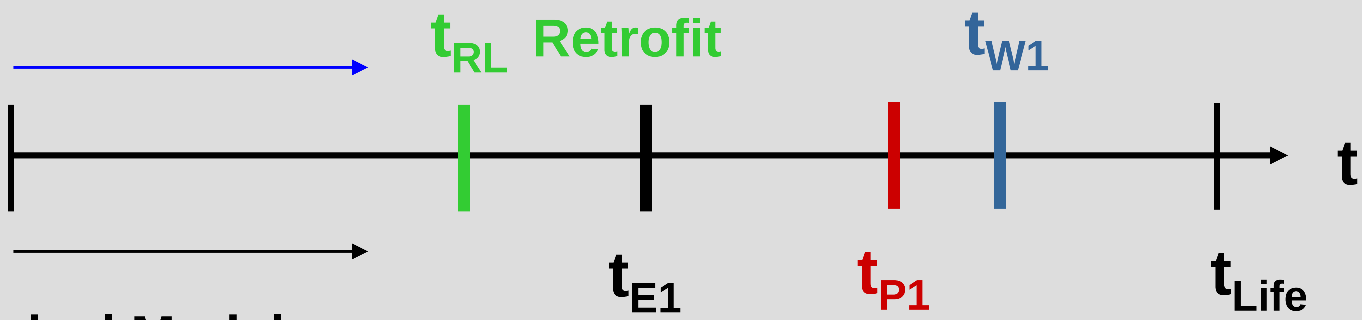



Multidisciplinary Center for Earthquake Engineering Research

# Multihazard Decision Support
# Aseismic Decision Support

## Single Realization over Time

Organizational Model




Geophysical Model

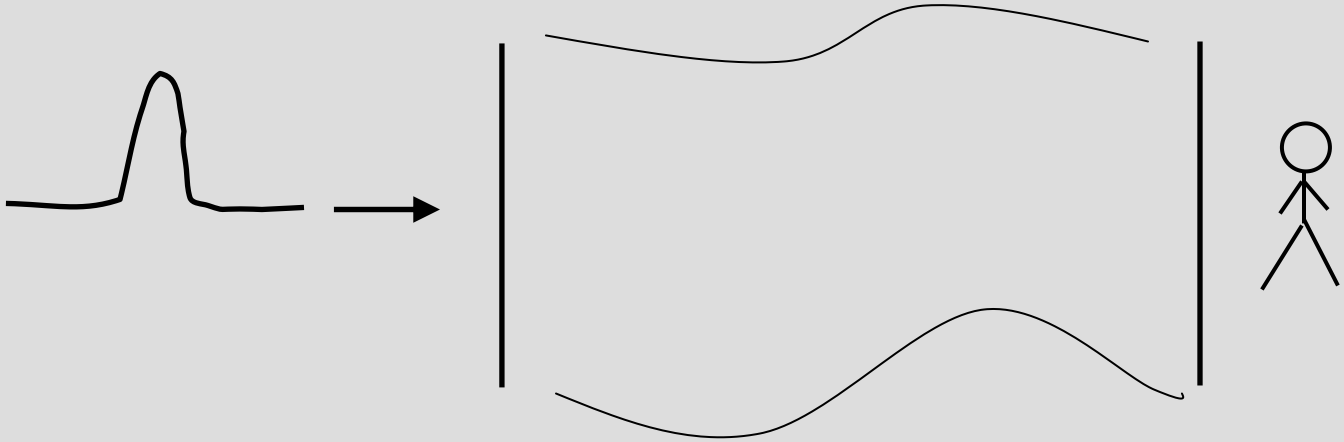
Meteorological Model

Extreme Events: Earthquake Model

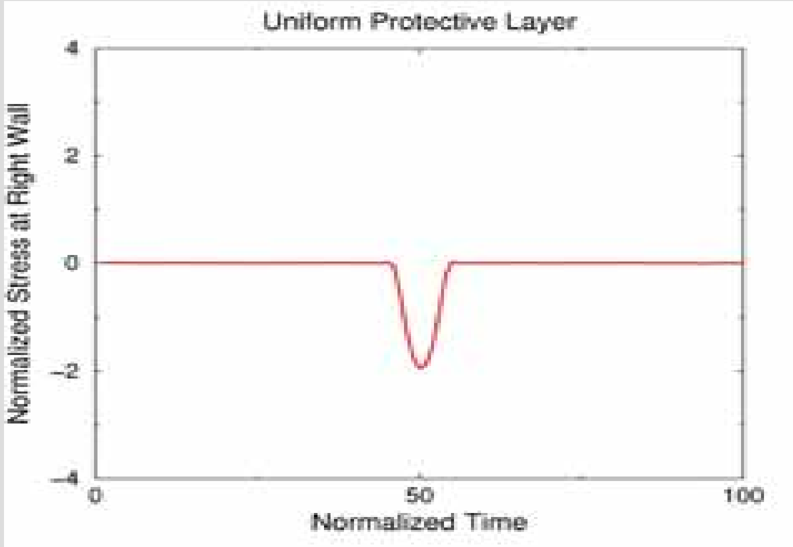
Wind Model

Sociopolitical Model [e.g., SB1953]

# Evolutionary Protective System Design
## (Aref et al.)

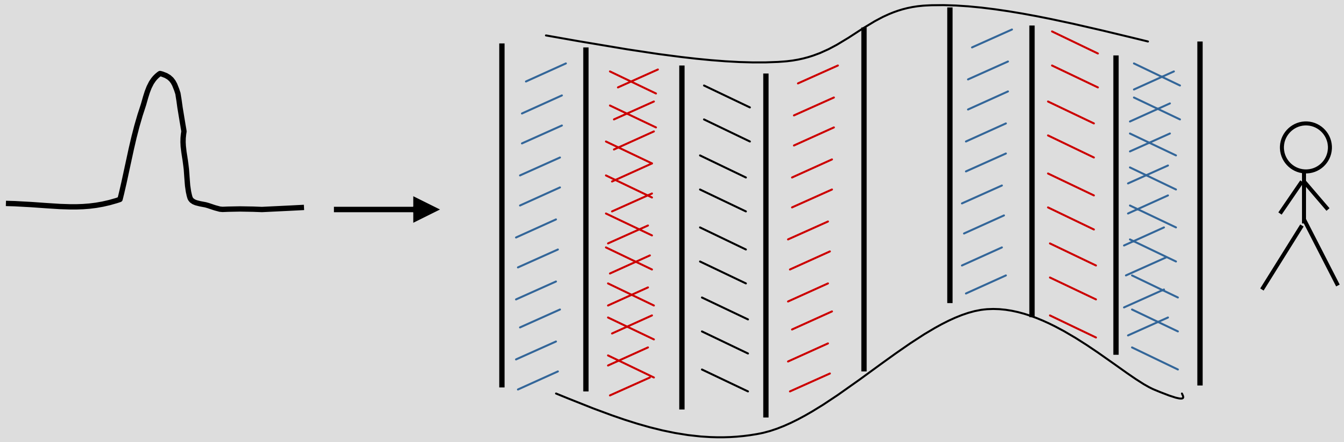


**Elastodynamic Wave Propagation via Boundary Element Method**



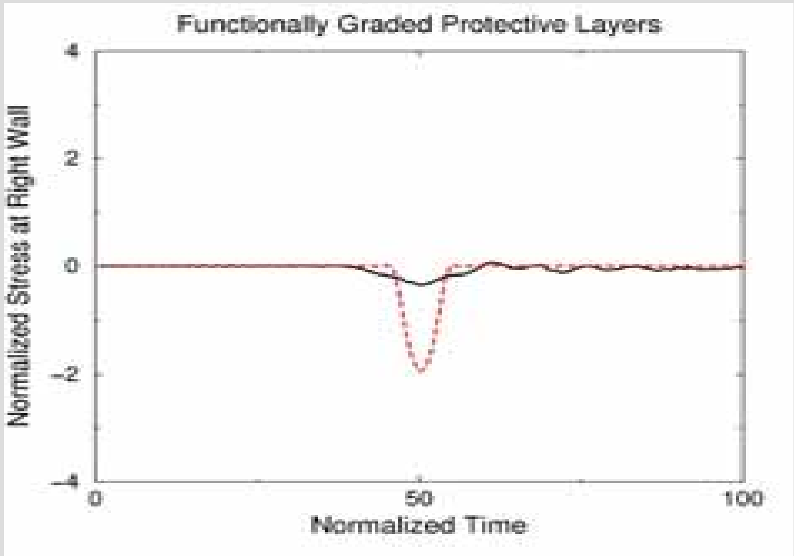
# Evolutionary Protective System Design

(Aref et al.)



**Elastodynamic Wave Propagation**

**Genetic algorithm to select material layers**



# Simulation-based Multi-hazard Decision Support

Summary

## Overall Approach

**Define utility function** U

**Identify space of possible solutions** S

**Identify/develop appropriate simulation algorithms to evaluate** U **for all possible solutions in** S

**Utilize genetic algorithms to evolve robust solutions**

# Simulation-based Multi-hazard Decision Support

Summary

## Framework is flexible

- Applicable to a broad range of extreme event design and decision processes
- Extendable to incorporate more advanced models and analysis tools

## Approach is encouraging

- Consistently produces robust aseismic structural designs in either uncertain or fixed environments
- Holds promise to provide guidance in the overall sociotechnical decision-making process
- Computational requirements are manageable

# Simulation-based Multi-hazard Decision Support

**Thank you!**