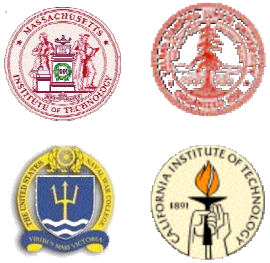


A Framework for Understanding Uncertainty and its Mitigation and Exploitation in Complex Systems

Prof. Daniel Hastings - MIT
Dr. Hugh McManus - Metis Design

Space Systems, Policy, and Architecture Research Consortium
A joint venture of MIT, Stanford, Caltech & the Naval War College
for the NRO

©2004 Massachusetts Institute of Technology

SSPARC

Problem

- Growing body of work on uncertainty
  - Conventional (technical) uncertainties
  - Market and strategic environment
  - Budget and policy decisions
  - Management and team dynamics
- New tools for handling them
  - Trade space analysis
  - Modularity
  - Real options and portfolio theory
- National awareness of need for advanced attributes
  - Robust, flexible, evolutionary systems called for
  - Confusion about what these terms mean

Need a unified look at these issues

©2004 Massachusetts Institute of Technology

SSPARC

A Framework for Discussion

Uncertainties

- Lack of Knowledge
- Lack of Definition
- Statistically Characterized Variables
- Known Unknowns
- Unknown Unknowns

Risks/ Opportunities

- Disaster
- Failure
- Degradation
- Cost/Schedule (+/-)
- Market shifts (+/-)
- Need shifts (+/-)
- Extra Capacity
- Emergent Capabilities

Mitigations/ Exploitations

- Margins
- Redundancy
- Design Choices
- Verification and Test
- Generality
- Upgradeability
- Modularity
- Tradespace Exploration
- Portfolios&Real Options

Outcomes

- Reliability
- Robustness
- Versatility
- Flexibility
- Evolvability
- Interoperability

<Uncertainty> causes <Risk> handled by <Mitigation> resulting in <Outcome>

Four categories, from uncertainty in nature to resulting system

Breakdown each into broad classes

©2004 Massachusetts Institute of Technology

SSPARC

Current Techniques: Risk Analysis

Uncertainties

- Lack of Knowledge
- Lack of Definition
- Statistically Characterized Variables
- Known Unknowns
- Unknown Unknowns

Risks/ Opportunities

- Disaster
- Failure
- Degradation
- Cost/Schedule (+/-)
- Market shifts (+/-)
- Need shifts (+/-)
- Extra Capacity
- Emergent Capabilities

Mitigations/ Exploitations

- Margins
- Redundancy
- Design Choices
- Verification and Test
- Generality
- Upgradeability
- Modularity
- Tradespace Exploration
- Portfolios&Real Options

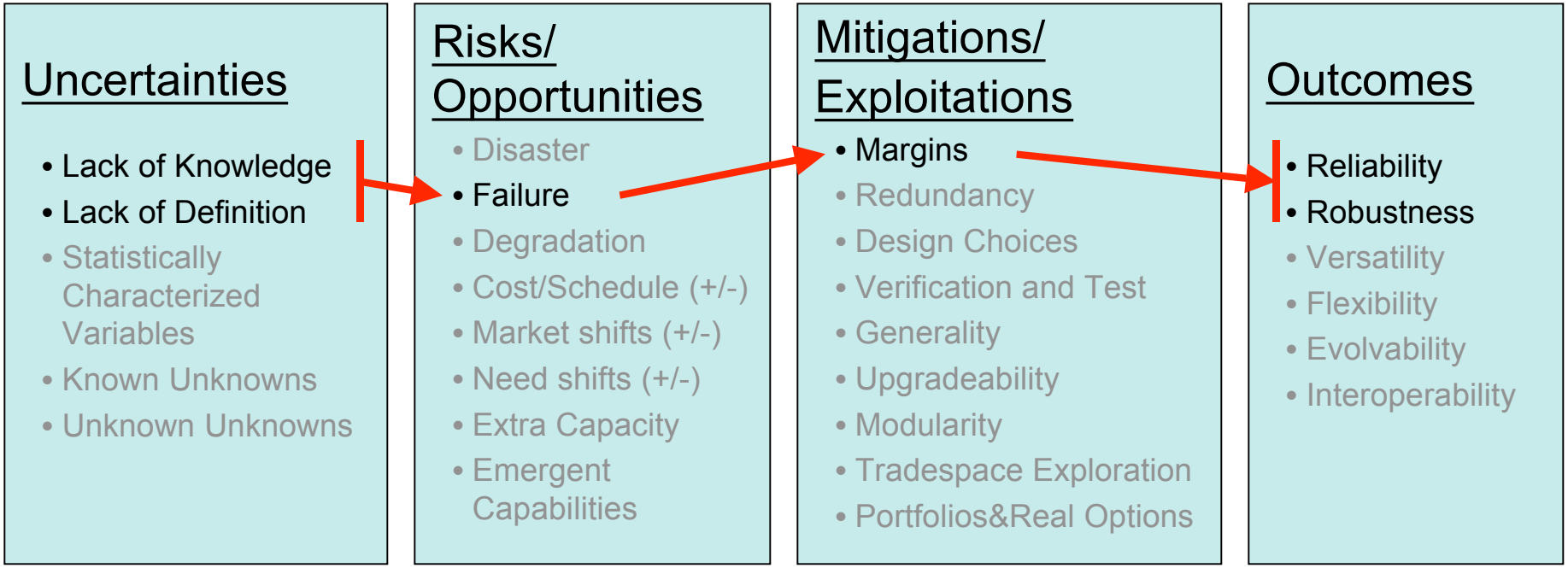
Outcomes

- Reliability
- Robustness
- Versatility
- Flexibility
- Evolvability
- Interoperability

©2004 Massachusetts Institute of Technology

SSPARC

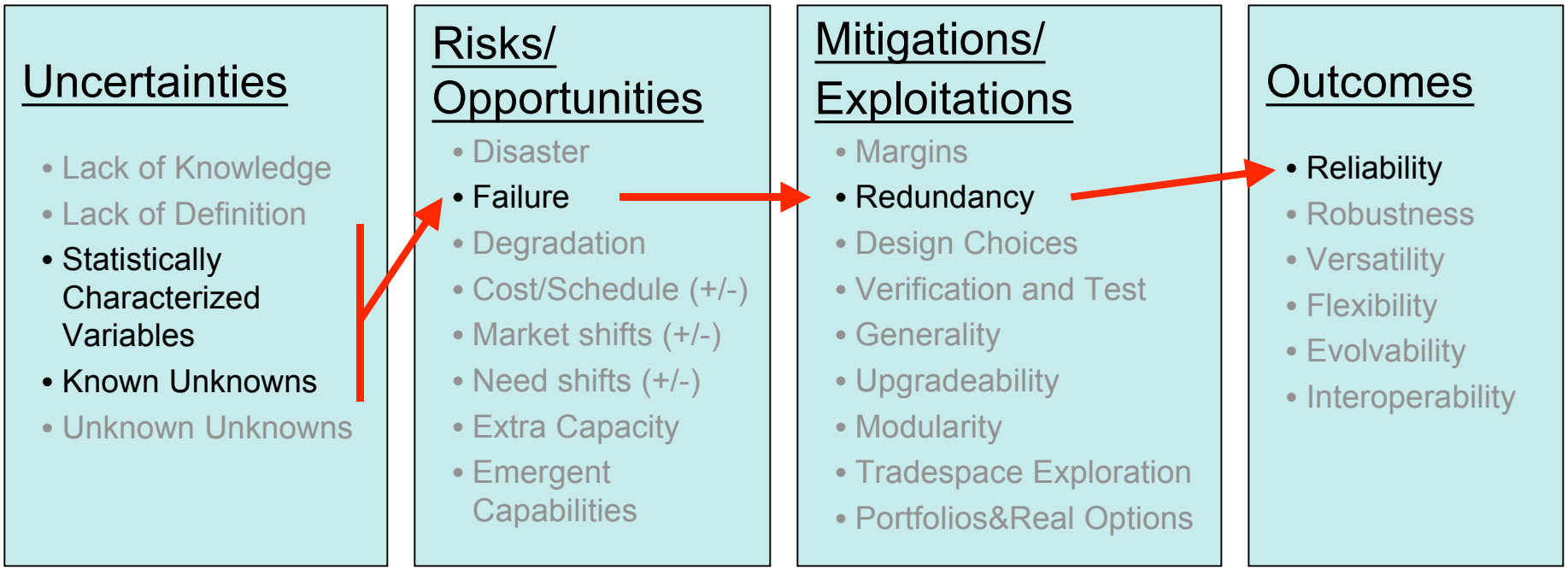
Current Techniques: Margins



©2004 Massachusetts Institute of Technology

SSPARC

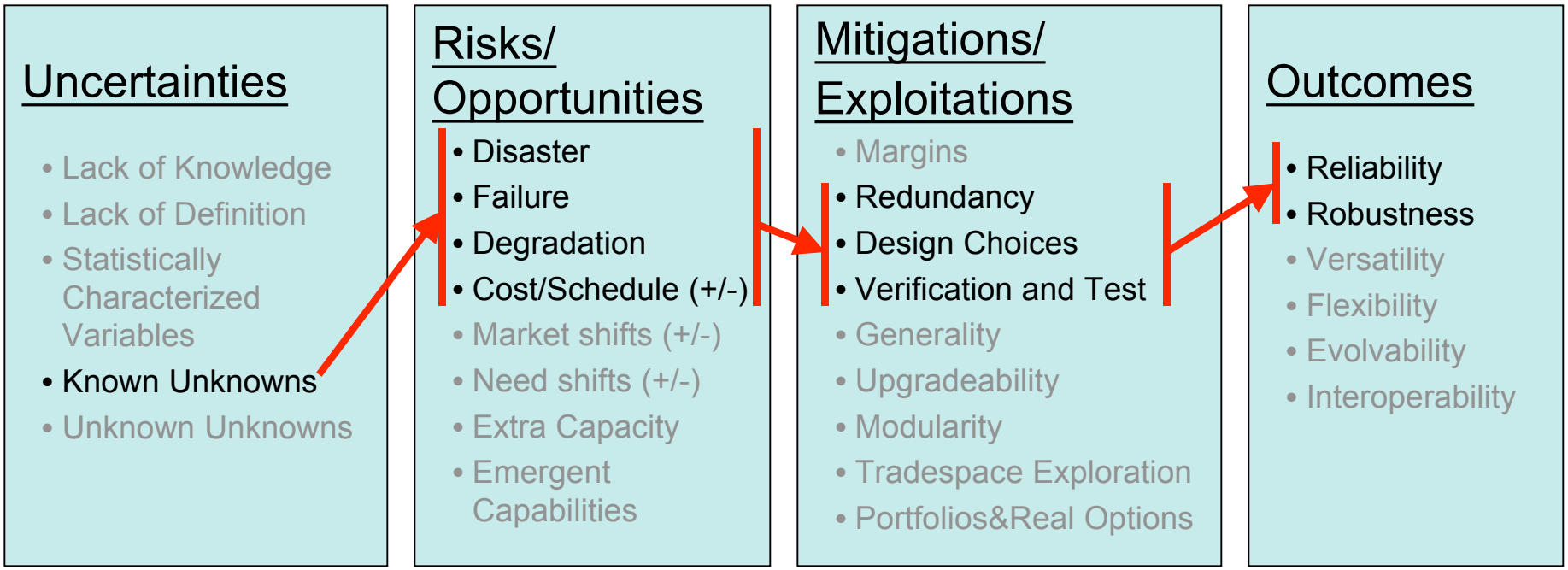
Reliability Engineering



©2004 Massachusetts Institute of Technology

SSPARC

Risk Management



©2004 Massachusetts Institute of Technology

Architecture Trade Space Exploration

A process for understanding complex solutions to complex problems

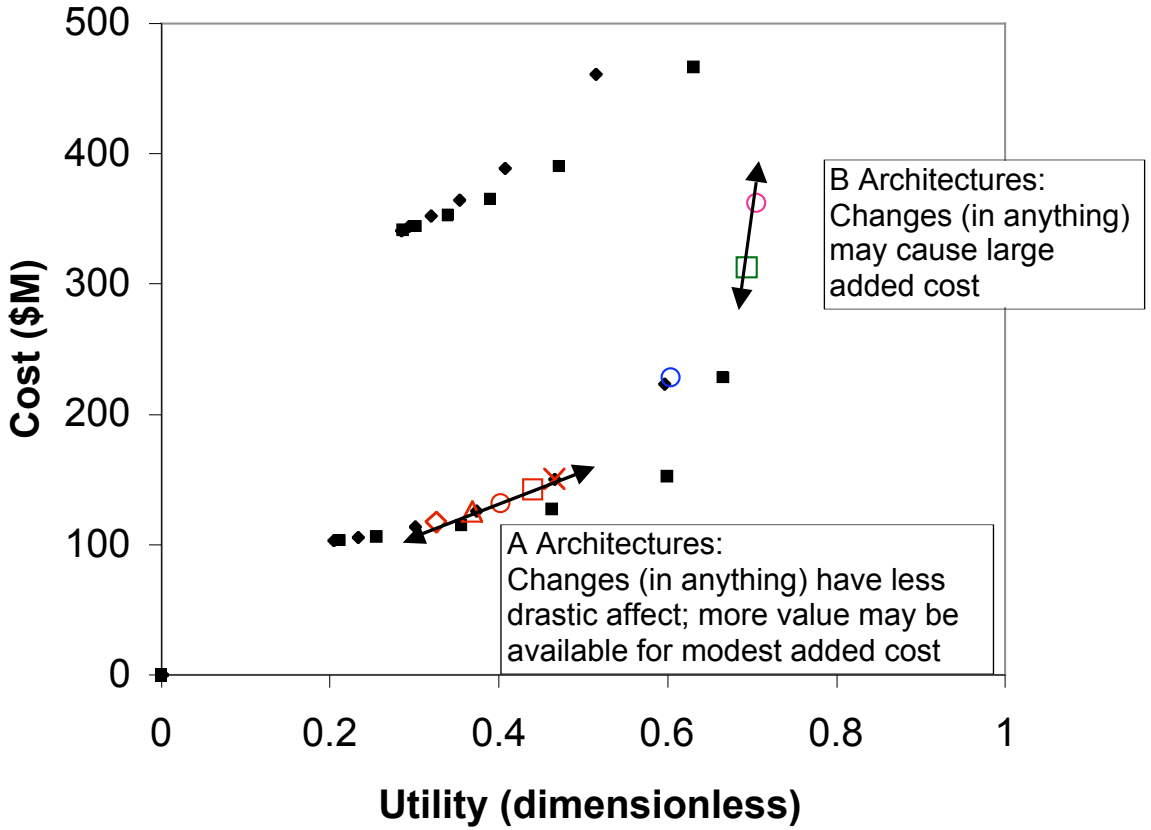
- Model-based high-level assessment of system capability
- Ideally, *many* architectures assessed
- Avoids optimized *point solutions* that will not support evolution in environment or user needs
- Provides a basis to explore technical and policy *uncertainties*
- Provides a way to assess the value of *potential* capabilities

Allows informed “upfront” decisions and planning

©2004 Massachusetts Institute of Technology

SSPARC

Emerging tools: Tradespace Exploration

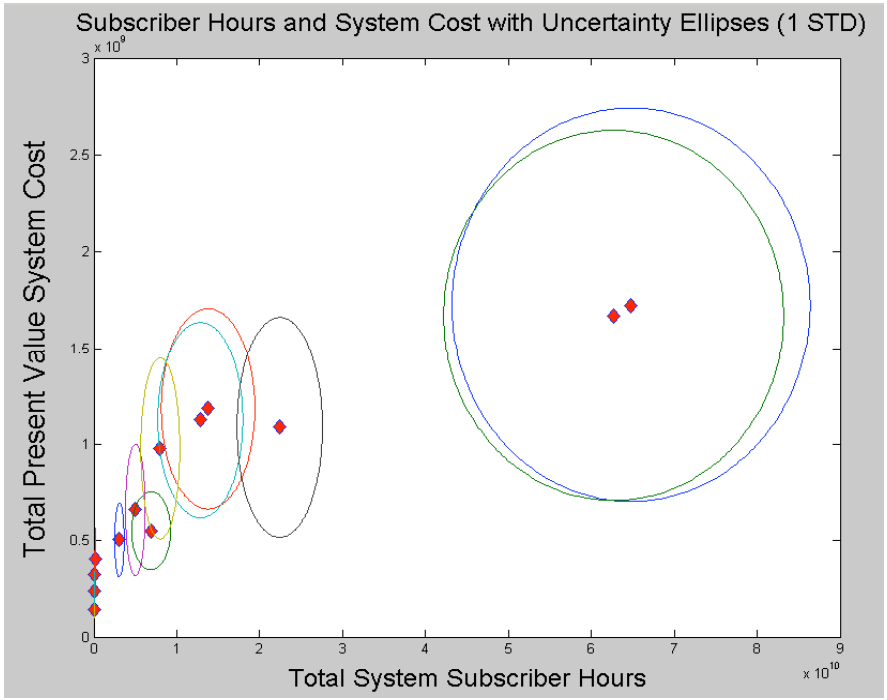


- Look at thousands of architectures with simulation models
- Often learn a lot by simple examination

©2004 Massachusetts Institute of Technology

SSPARC

Tradespace Exploration with Uncertainties



- *Explicitly* look at sensitivity of models to uncertainties
- Uncertainties can be market (shown), policy, or technical
- Mitigate with portfolio, real options methods

©2004 Massachusetts Institute of Technology

Advanced Desired Attributes

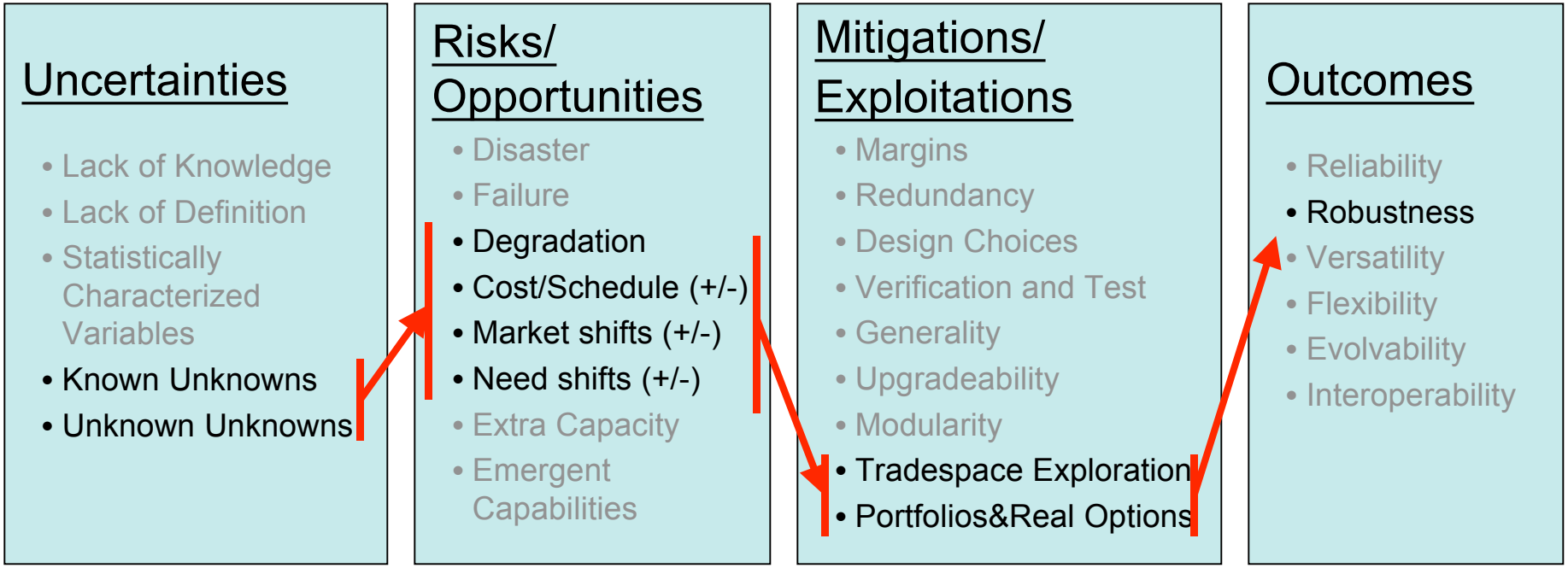
- **Reliability:** *Probability that the system will do the job it was asked to do (i.e. will work).*
- **Robustness:** *Ability of the system to do its basic job in unexpectedly adverse environments.*
- **Versatility:** *Ability of the system, as built/designed, to do jobs not originally included in the requirements definition, and/or or to do a variety of required jobs well.*
- **Flexibility:** *Ability of the system to be modified to do jobs not originally included in the requirements definition.*
- **Evolvability:** *Ability of the system to serve as the basis of new systems (or at least generations of the current system) to meet new needs and/or attain new capability levels.*

Much confusion in both terminology and real needs

©2004 Massachusetts Institute of Technology

SSPARC

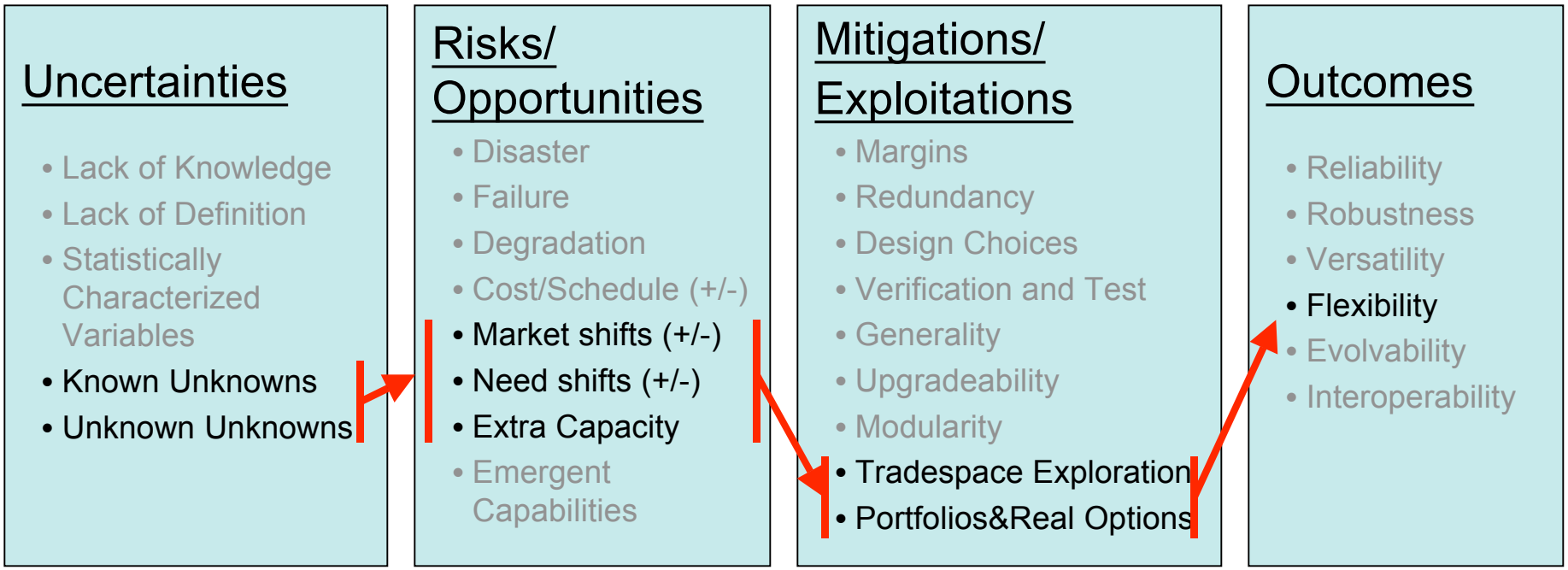
Using Tradespace Exploration



©2004 Massachusetts Institute of Technology

SSPARC

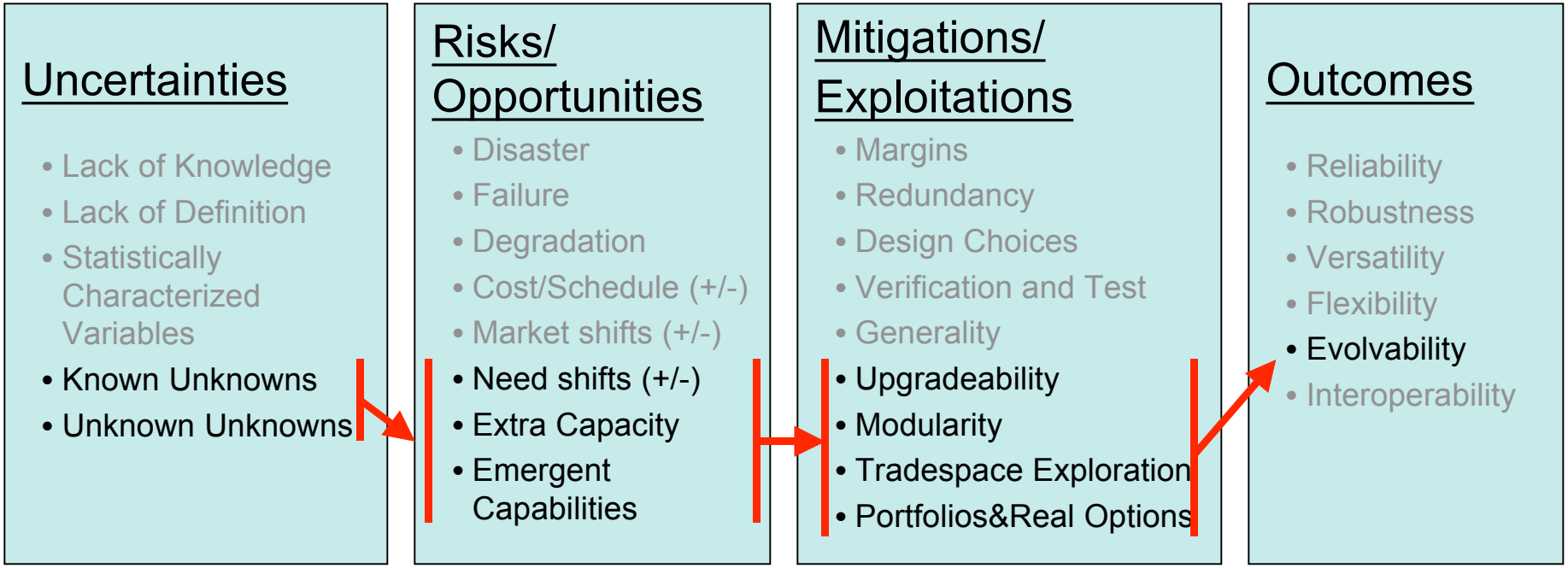
Exploiting Uncertainty via Flexibility



©2004 Massachusetts Institute of Technology

SSPARC

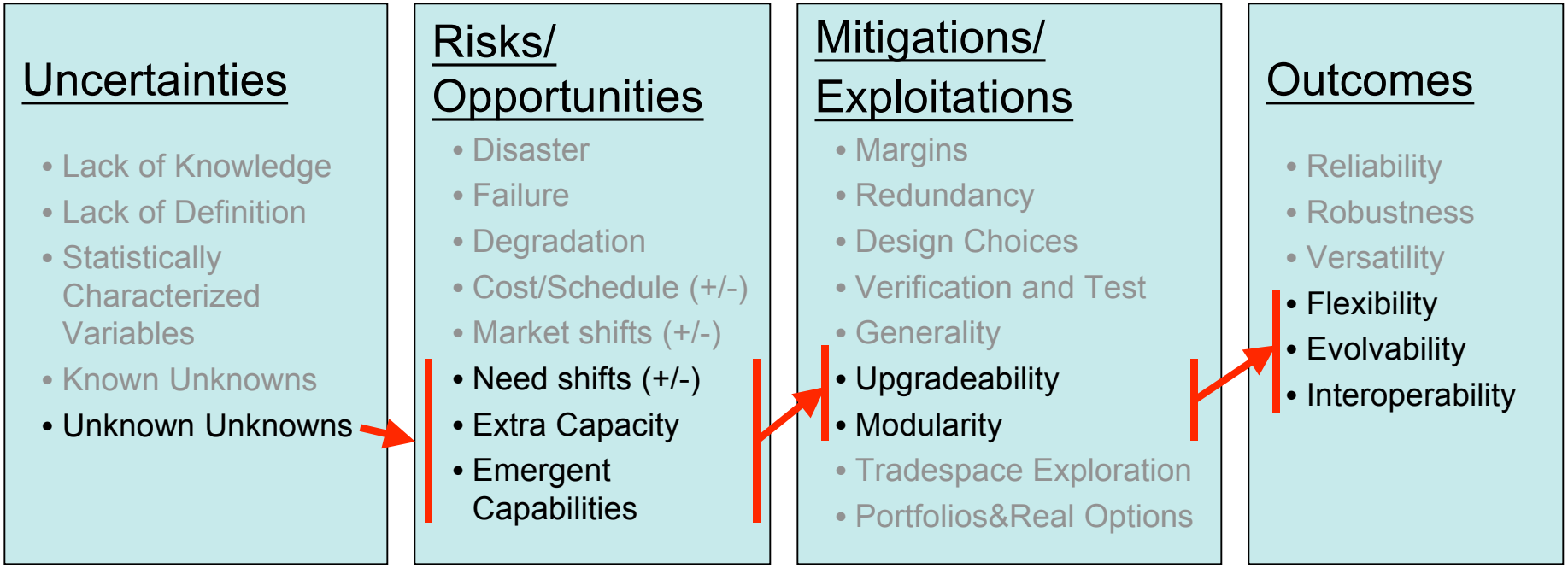
Living in an Uncertain World: Evolutionary Aquisition



©2004 Massachusetts Institute of Technology

SSPARC

Assessing Technologies: Modular Satellites?



©2004 Massachusetts Institute of Technology

Summary

- Framework puts a large number of problems, tools, and needs in context.
- Potential exists for systematically managing, mitigating and even exploiting most types of uncertainty
  - Mature methods and powerful tools occupy the upper (left) of the framework
  - Qualitative methods (e.g. risk management) occupy the center
  - The bottom (right) is covered by new methods
- As engineering systems expands to address new kinds of uncertainties and new desired system attributes, new methods must mature and enter general practice

©2004 Massachusetts Institute of Technology