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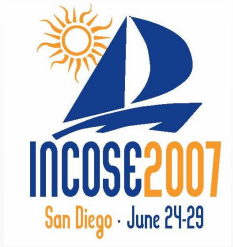
MIT esd



SEA RI

Systems Engineering Advancement Research Initiative

9.4.3 Defining System Changeability: Reconciling Flexibility, Adaptability, Scalability, and Robustness for Maintaining System Lifecycle Value

Dr. Adam M. Ross, Dr. Donna H. Rhodes, and Prof. Daniel E. Hastings

INCOSE International Symposium
Session 9, Track 4
Wednesday, June 27, 2007

Meeting Customer Needs

- Goal of design is to create value (profits, usefulness, happiness, etc…)
- Requirements capture a mapping of needs to specifications to guide design

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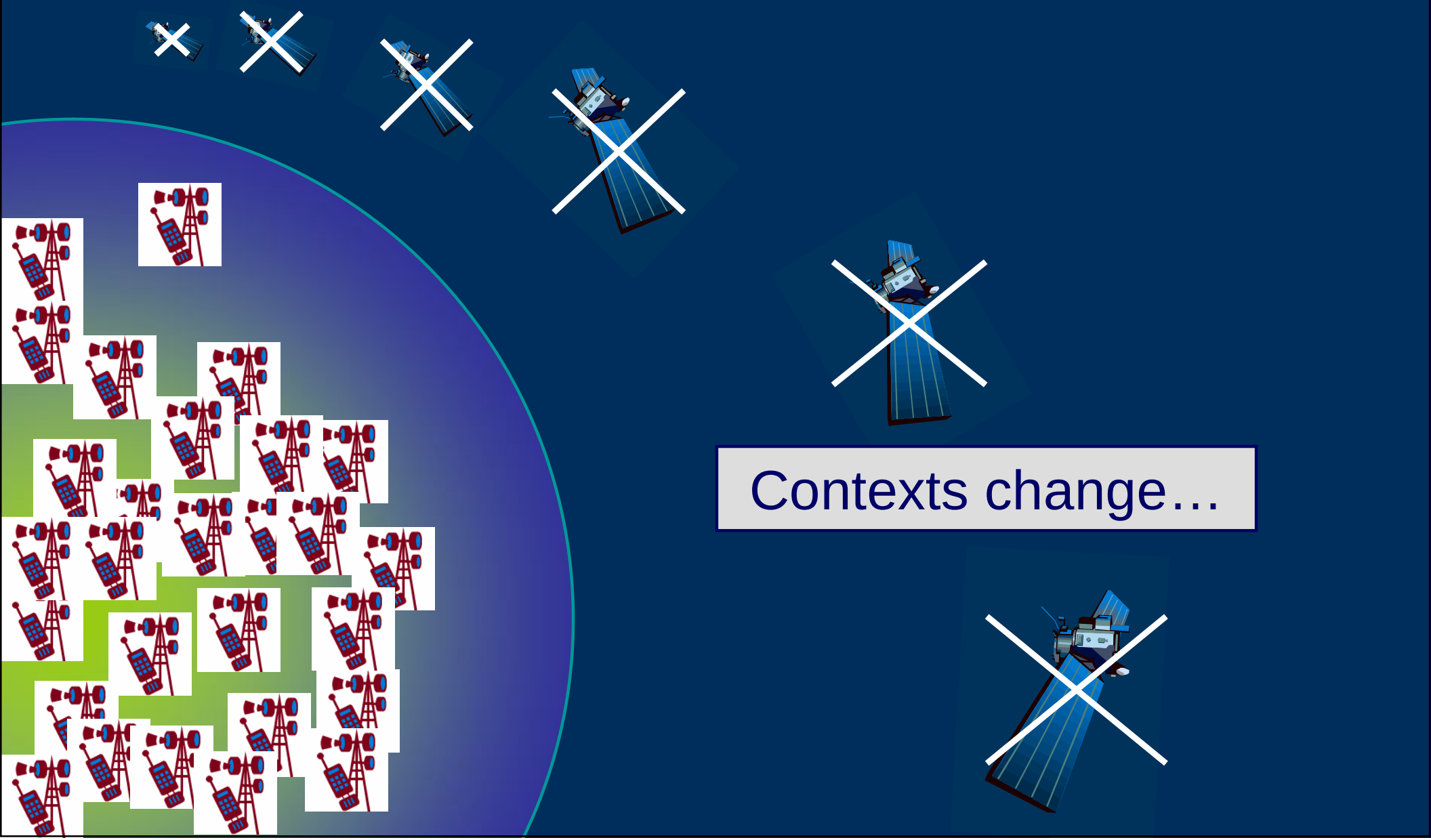
Deploying a “Valuable” System…



Meeting Customer Needs (cont.)

- Goal of design is to create value (profits, usefulness, happiness, etc…)

- People change their minds…
- To continue to deliver value, systems may need to change as well…

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LAI/AF Systems Engineering for Robustness Workshop

Washington, DC in June 2004

- According to Dr. Marvin Sambur, "Systems Engineering for Robustness" means developing systems that are…

  - Capable of *adapting* to changes in mission and requirements
  - *Expandable/scalable*, and designed to accommodate growth in capability
  - Able to *reliably* function given changes in threats and environment
  - Effectively/affordably *sustainable* over their lifecycle
  - Developed using products designed for use in various *platforms* and systems
  - Easily *modified* to leverage new technologies

- "Robustness" scope expanded beyond classical robustness …
- Experts questioned…
  - What does it mean?
  - How can it be measured/analyzed?
  - Who is going to pay for it?

How can designers account for this new "robustness"?

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Changeability = New "Robustness"?

- What is change?
  - Defined by differences…
  - Necessity of time…
- Three aspects to change process
  - Change agent ("who" caused change, force instigator)
  - Change mechanism (how changed, including "cost")
  - Change effect (what changed, "State 2 – State 1")

All things change, but some things are more "changeable" than others

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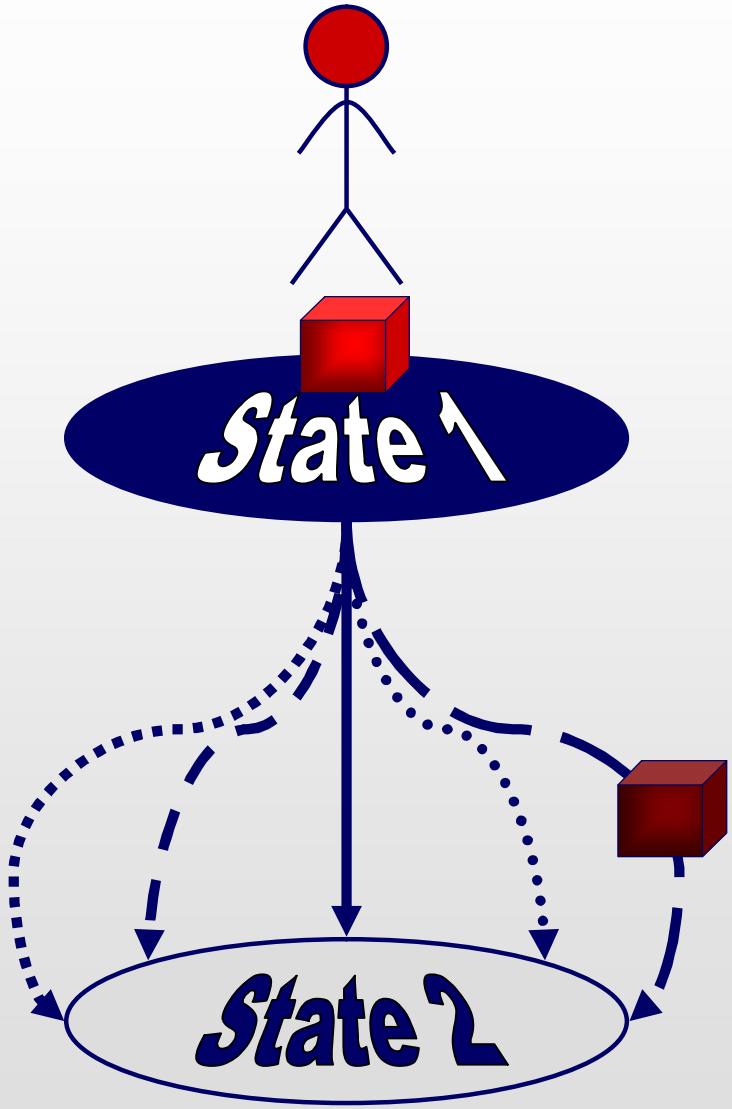
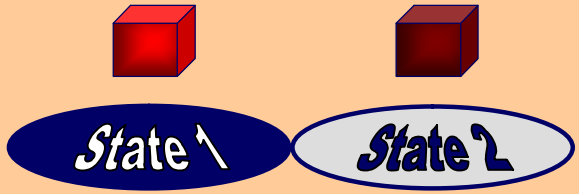
The Aspects of Change



Change Agent

Change Mechanism

Change Effect



Change aspects can be used to classify the change type…

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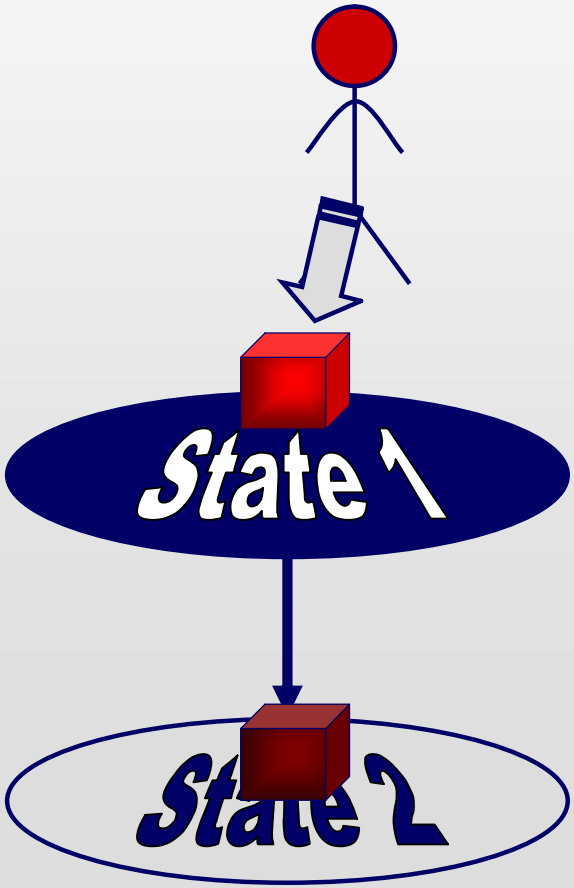
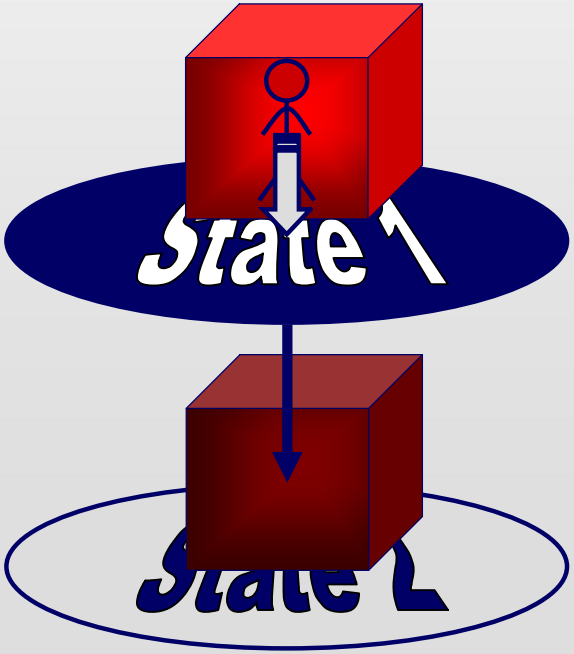
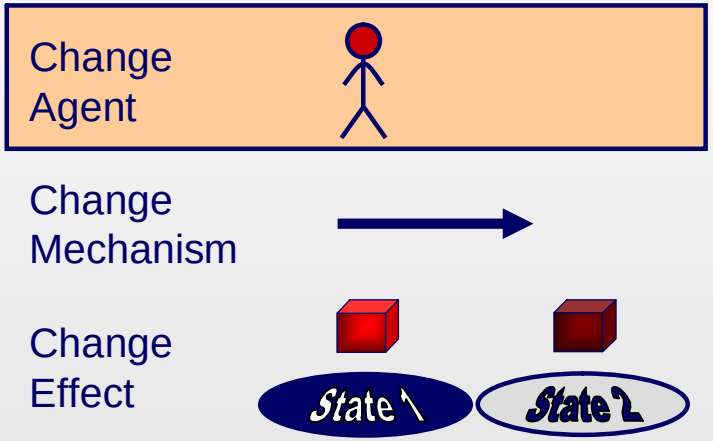
Flexibility vs. Adaptability: Change Agent Origin

Flexible Change-type (Outside System)



Adaptable Change-type (Inside System)





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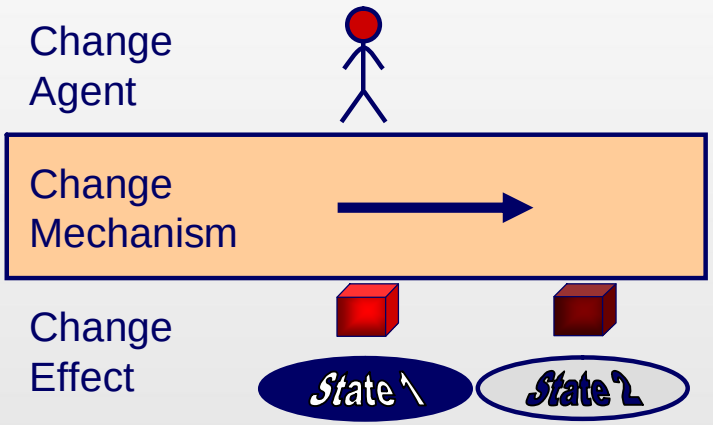
How to Change: Change Mechanism

Will revisit in a few slides



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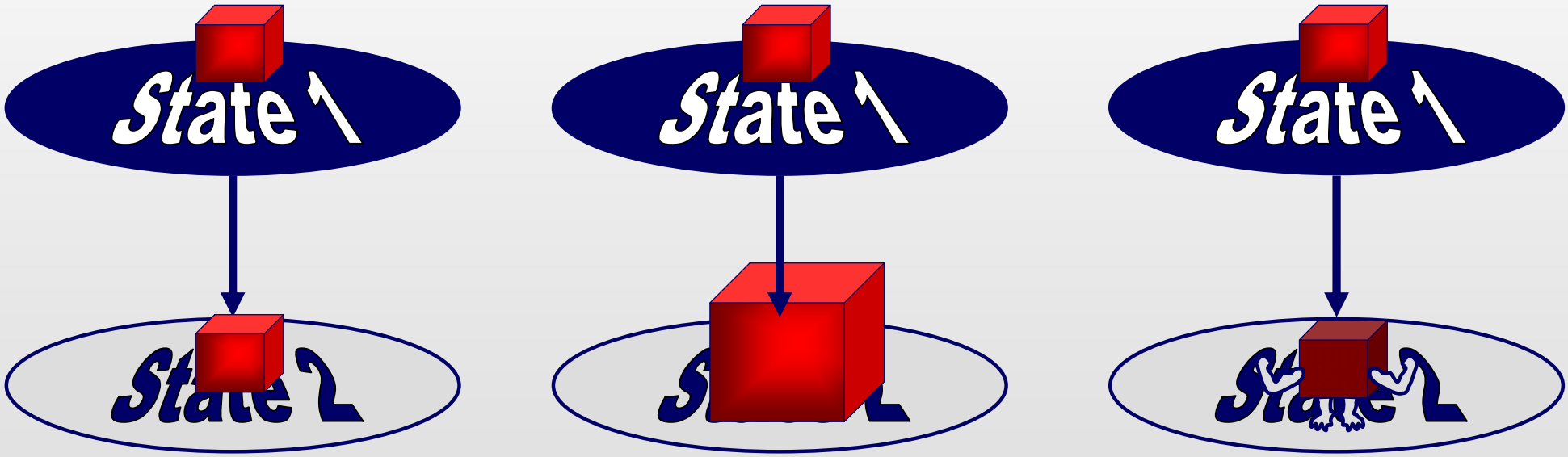
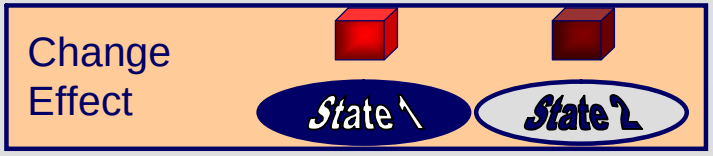
Robustness, Scalability, Modifiability: Change Effect

Robust (No change)	Scalable (Parameter level)	Modifiable (Parameter set)



Change Agent

Change Mechanism



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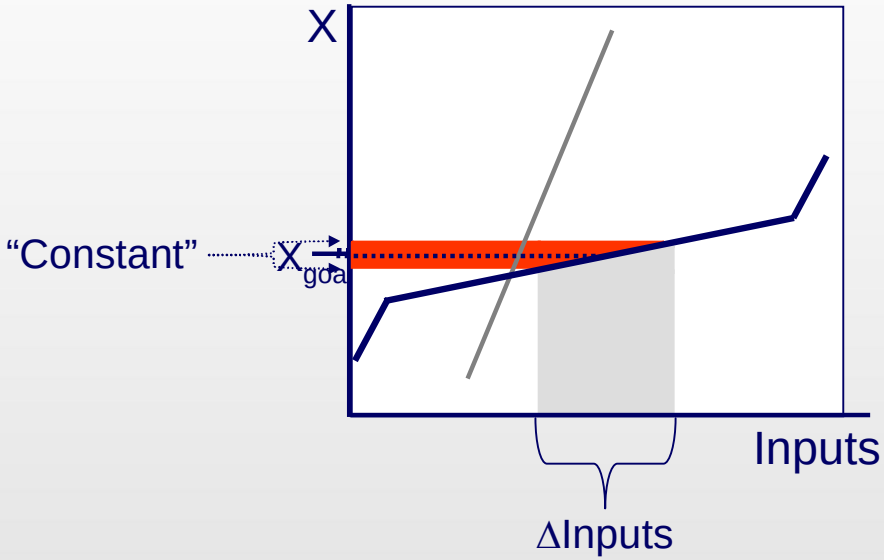
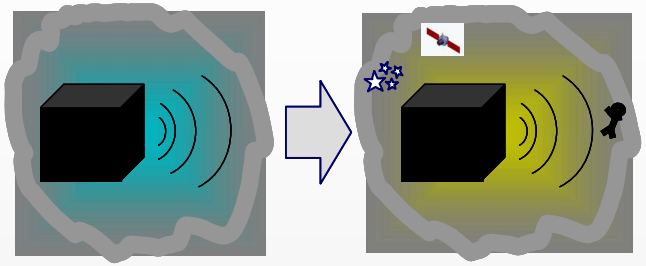
Types of Change: Robustness





No change in perceived value

"Robust"

A box can be quantified in terms of *robust in X^i to "Input" change*

(i.e., can X^i remain "constant" over range of "Input"?)

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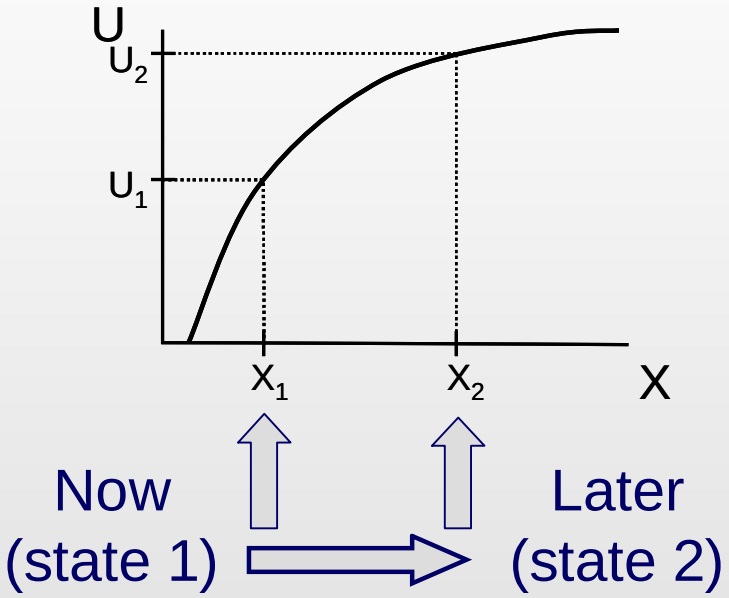
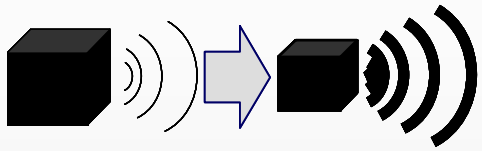
Types of Changes: Scalability





Change in parameter level

"Scalable"

A box can be quantified in terms of *scalable in* X^i

(i.e., can X^i be changed from X^i_1 to X^i_2?)

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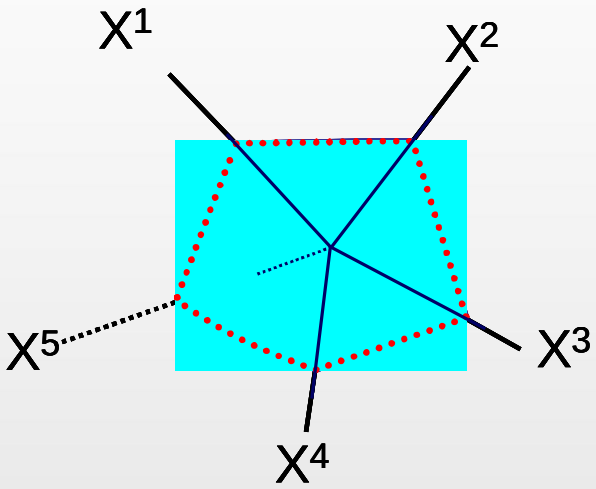
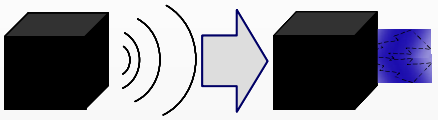
Types of Changes: Modifiability





Change in parameter set

"Modifiable"

A box can be quantified in terms of *modifiable in* X^i

(i.e., can X^i be added to or deleted from the parameter set?)

Now (state 1) ⇨ $U=f(X^1,X^2,X^3,X^4)$

Later (state 2) ⇨ $U'=f(X^1,X^2,X^3,X^4,X^5)$

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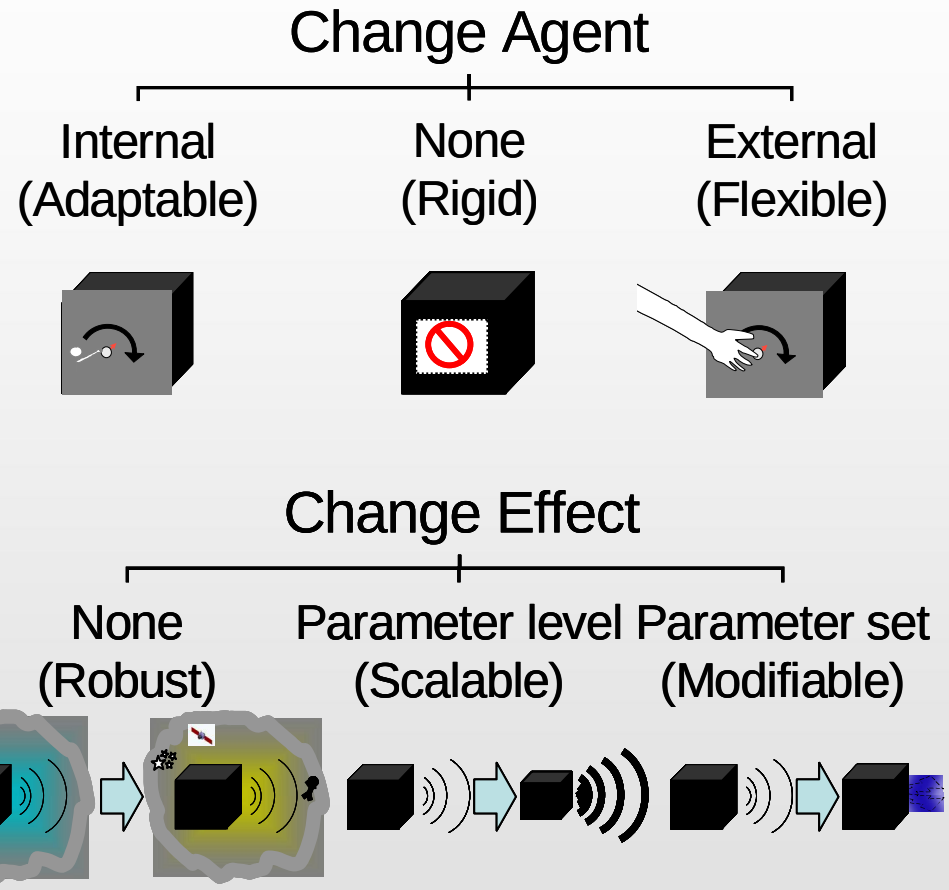
Change Agents and Effects

Changeability

Change agent origin

+

Change effect type



Change agents and effects are used to classify the change type… what about change mechanisms?

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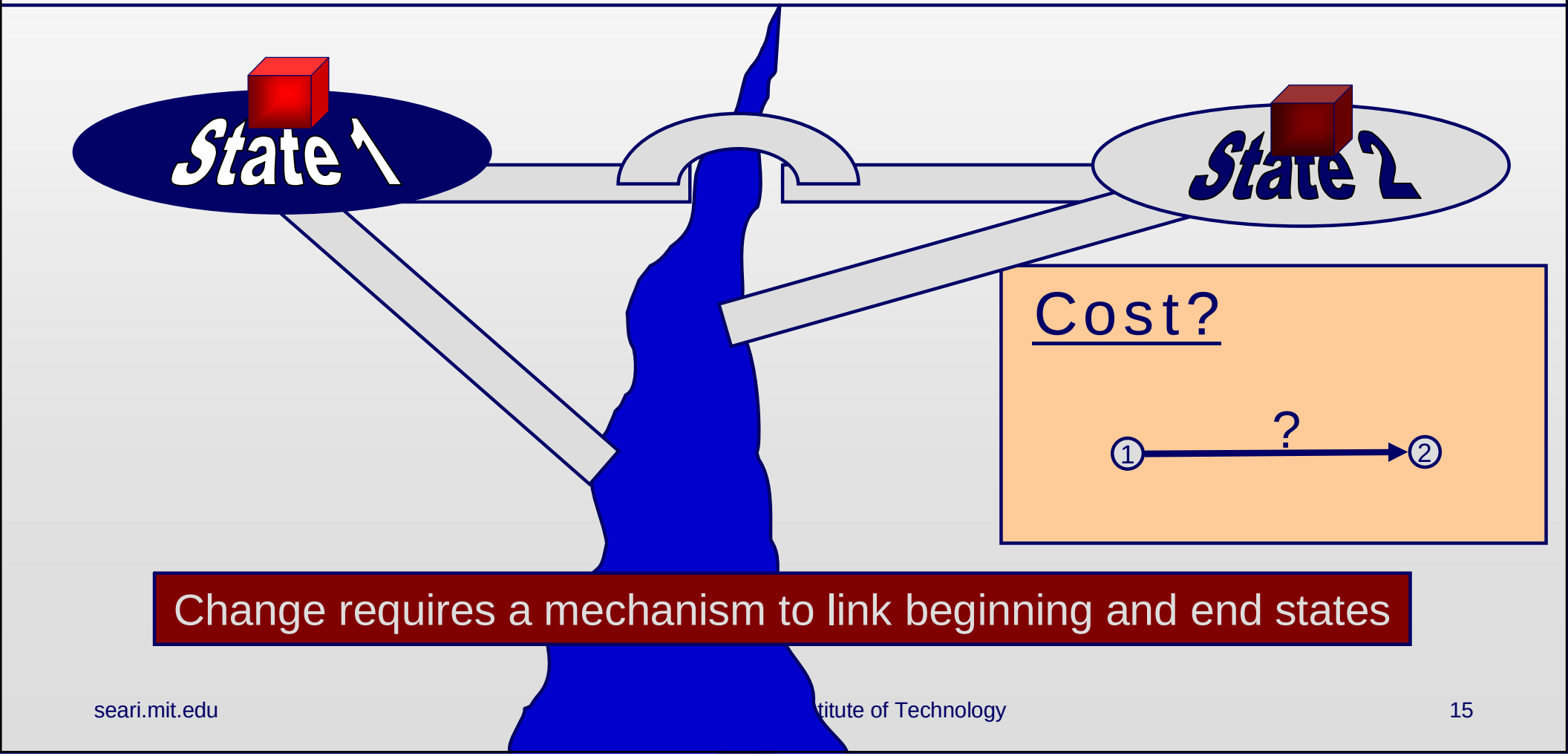
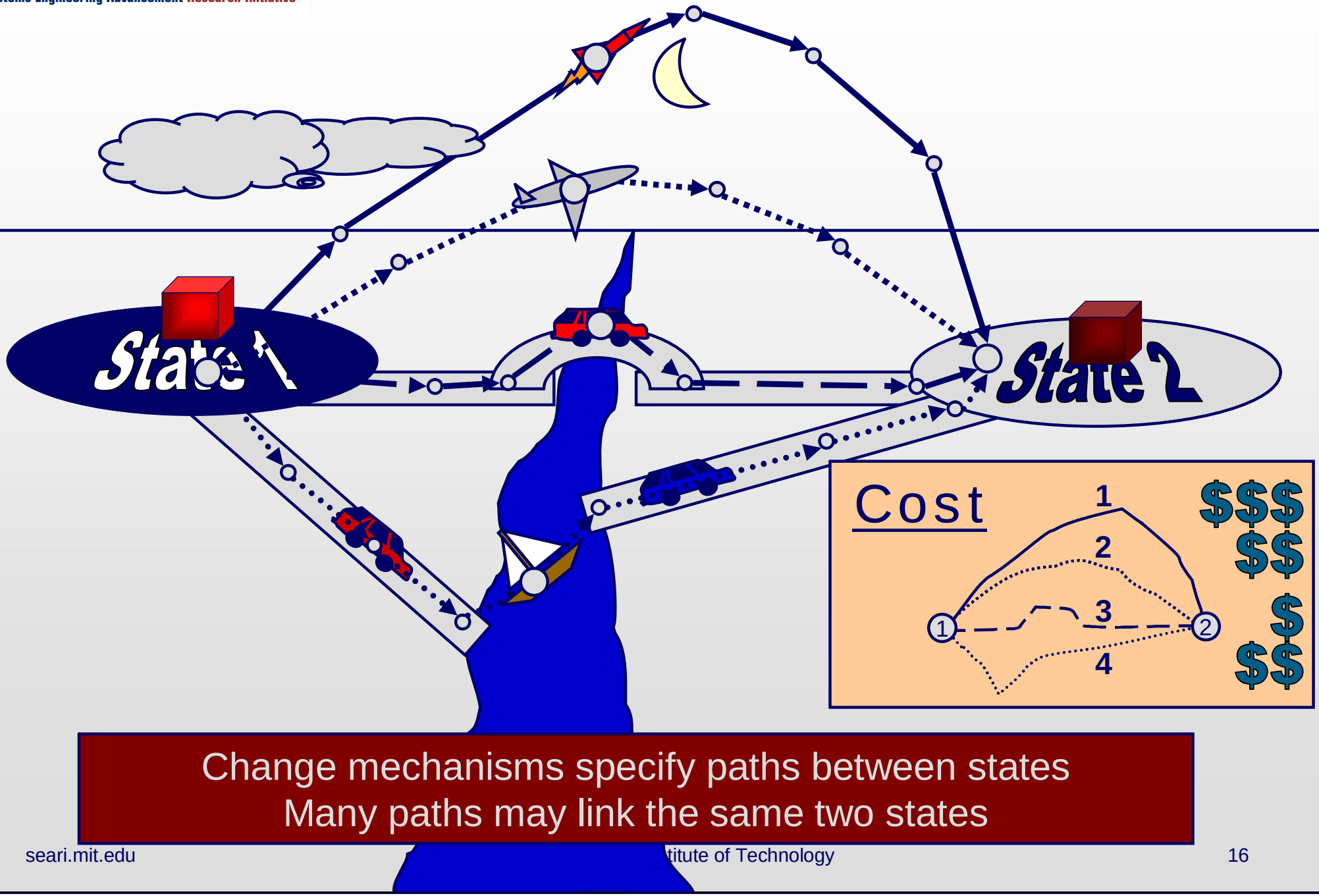
Change Mechanism



Change requires a mechanism to link beginning and end states

Change Mechanism



Change mechanisms specify paths between states
Many paths may link the same two states

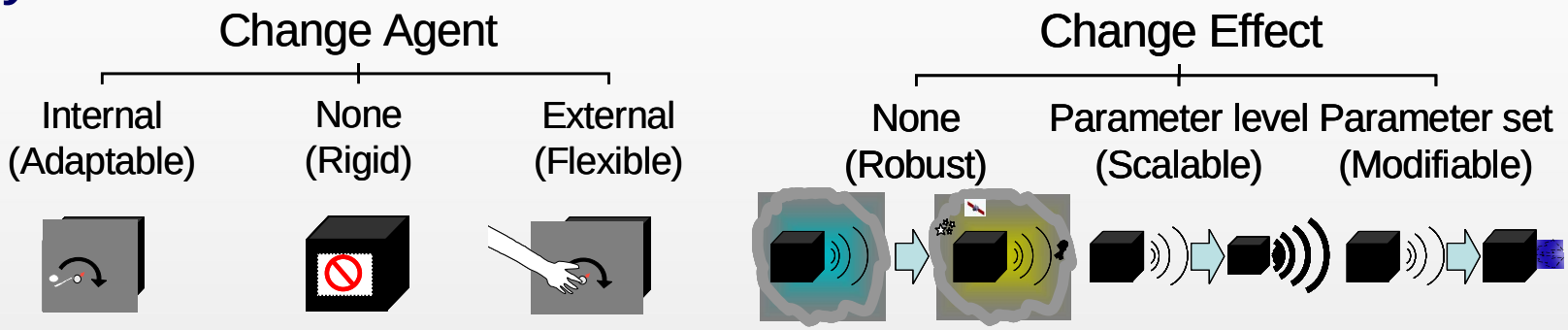
Change Summarized

Changeability

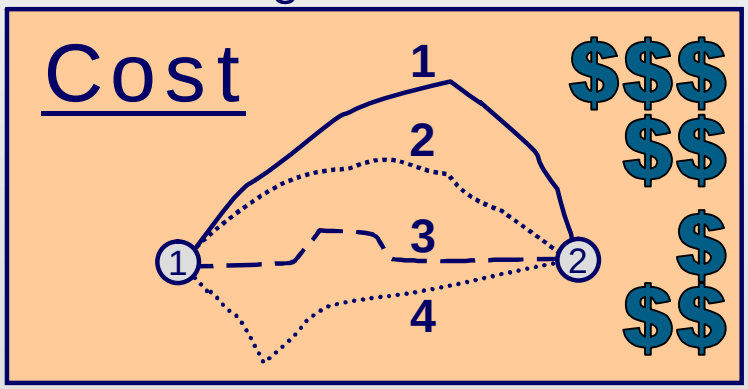
Change type

+

Ways to change



Change Mechanism



Number of mechanisms is a partial measure of changeability

Now that changeability is defined… how can it be used to evaluate systems?

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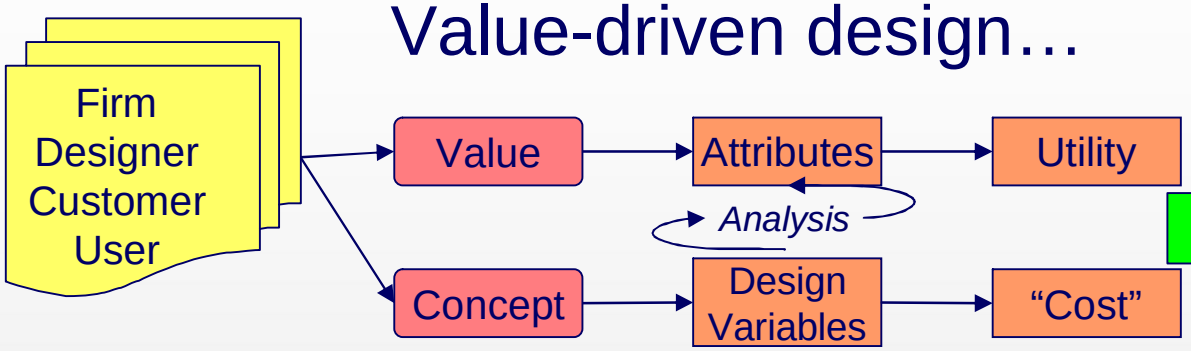
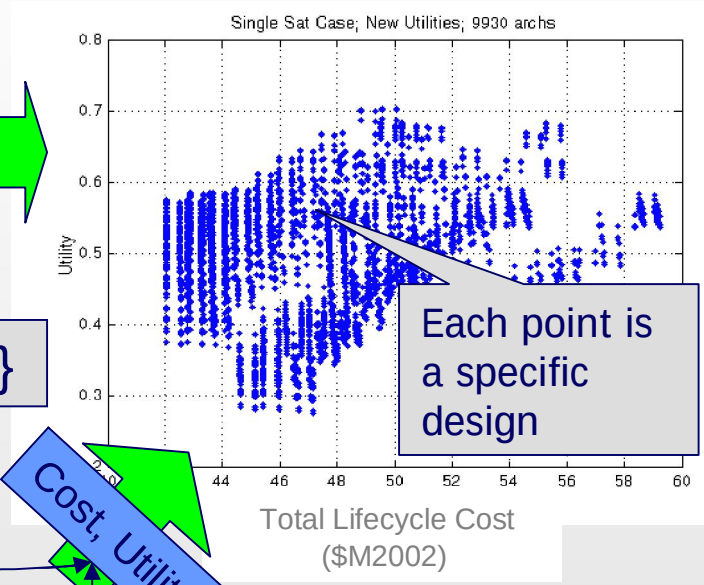
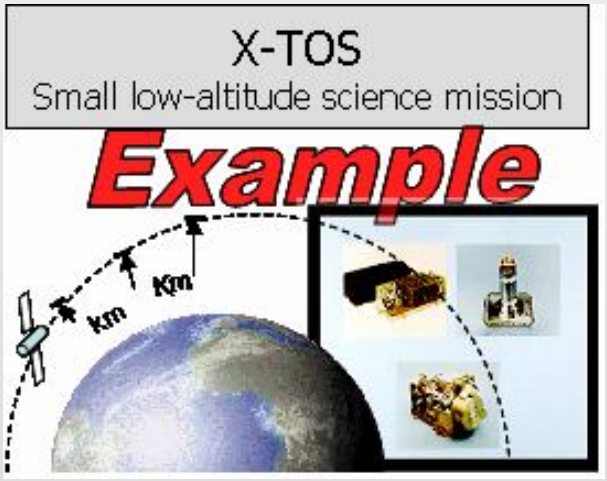
Tradespaces Defined

Value-driven design…





Tradespace: {Design,Attributes} ←→ {Cost,Utility}



DESIGN VARIABLES:
Design trade parameters

Orbital Parameters
- Apogee Altitude (km)
- Perigee Altitude (km)
- Orbit Inclination (deg)

Spacecraft Parameters
- Antenna Gain
- Communication Architecture
- Propulsion Type
- Power Type
- Total Delta V

ATTRIBUTES:
Design decision metrics
- Data Lifespan (yrs)
- Equatorial Time (hrs/day)
- Latency (hrs)
- Latitude Diversity (deg)
- Sample Altitude (km)

Assessment of cost and utility of large space of possible system designs

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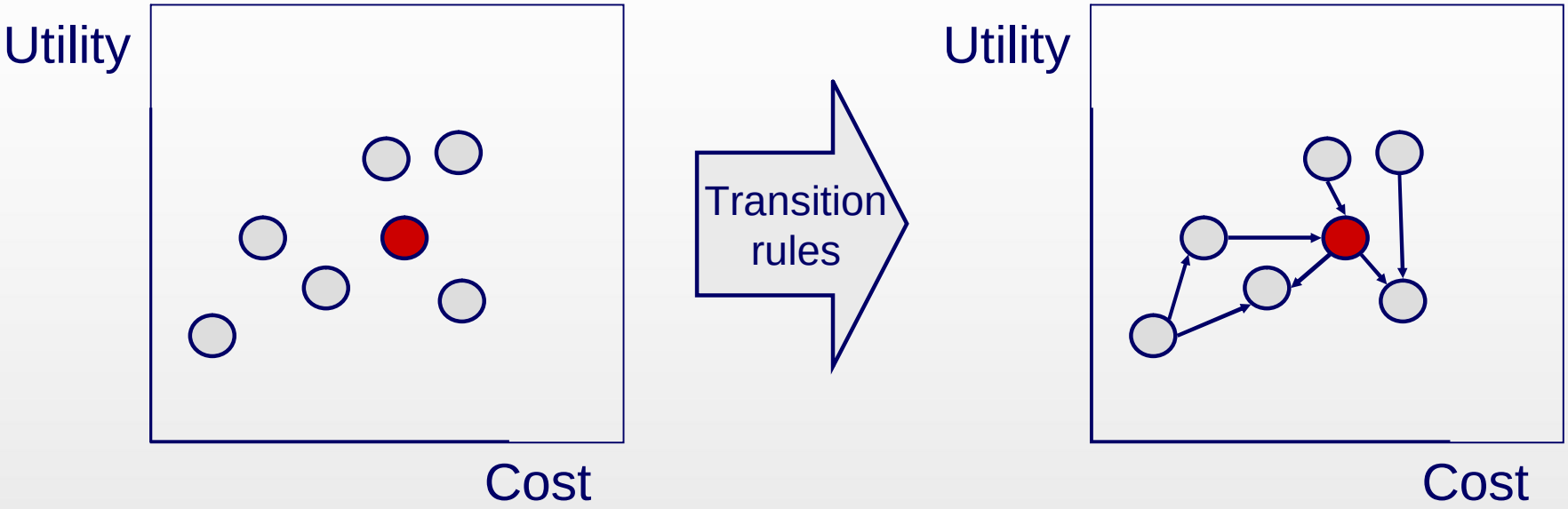
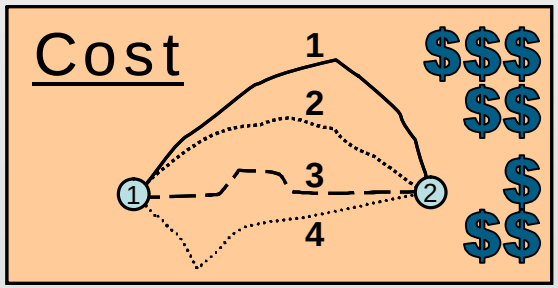
Tradespace Networks



Tradespace designs = nodes

Applied transition rules = arcs



Transition rules are mechanisms to change one design into another
The more outgoing arcs, the more potential change mechanisms

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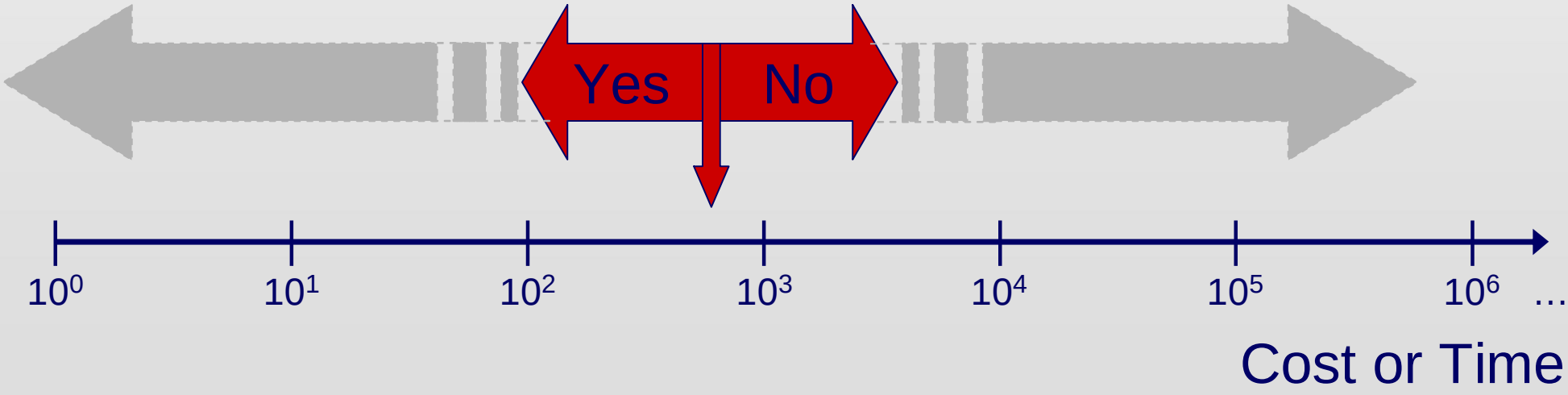
Determining Changeability

The Question: Is the system _____?

(Flexible, Adaptable, Robust, Scalable, Modifiable, Changeable, Rigid, etc…)

The Answer: It depends!

The question of changeability is partly subjective:
Is the "cost" for change acceptable?



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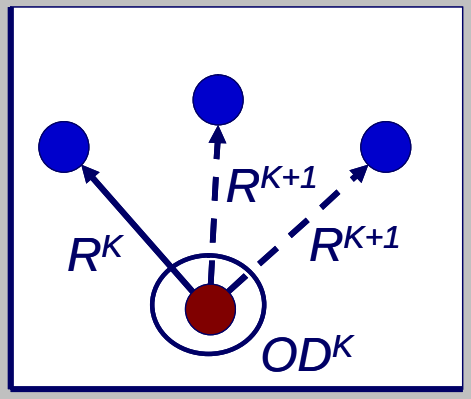
Changeability Metric: Filtered Outdegree

objective

Outdegree

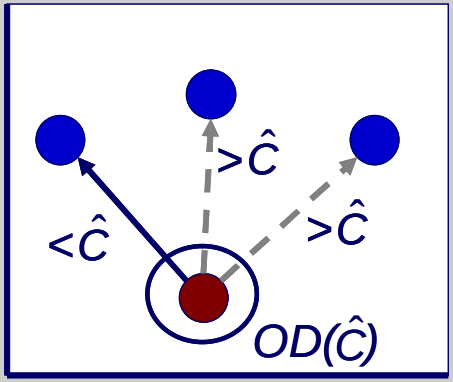
outgoing arcs from a given node



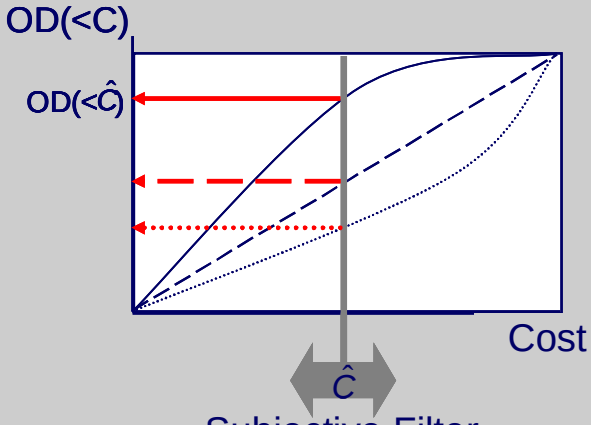
subjective

Filtered Outdegree

outgoing arcs from design at acceptable "cost"
(measure of changeability)



Outdegree



Subjective Filter

Filtered outdegree is a measure of the apparent changeability of a design

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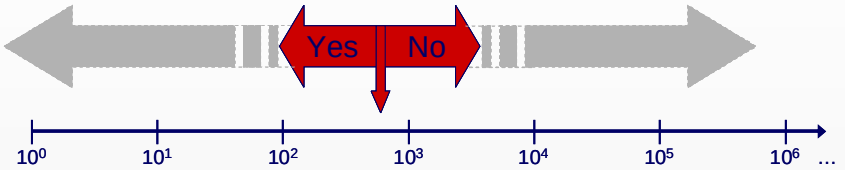
Putting it all Together: Assessing Changeability

1. Specify subjective acceptability scale



2. Specify origin of change agent

Change agent: External (Flexible), Internal (Adaptable), None (Rigid)

3. Specify desired change effect

Desire change

_____ in _____ for _____

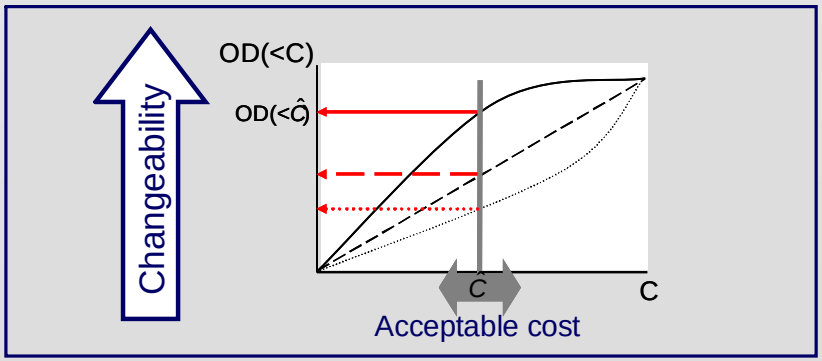
"ility"	metric	resource
Scalable	X^i	Cost
Modifiable		Time

Desire no change

_____ in _____ to _____

"ility"	metric	perturb.
Robust	X^i	ΔDV
	Rank (Pareto Efficient)	ΔConstraints
	Cost/Time	ΔConst.
		ΔPreference set

4. Perform dynamic tradespace analysis (calculate changeability metrics)



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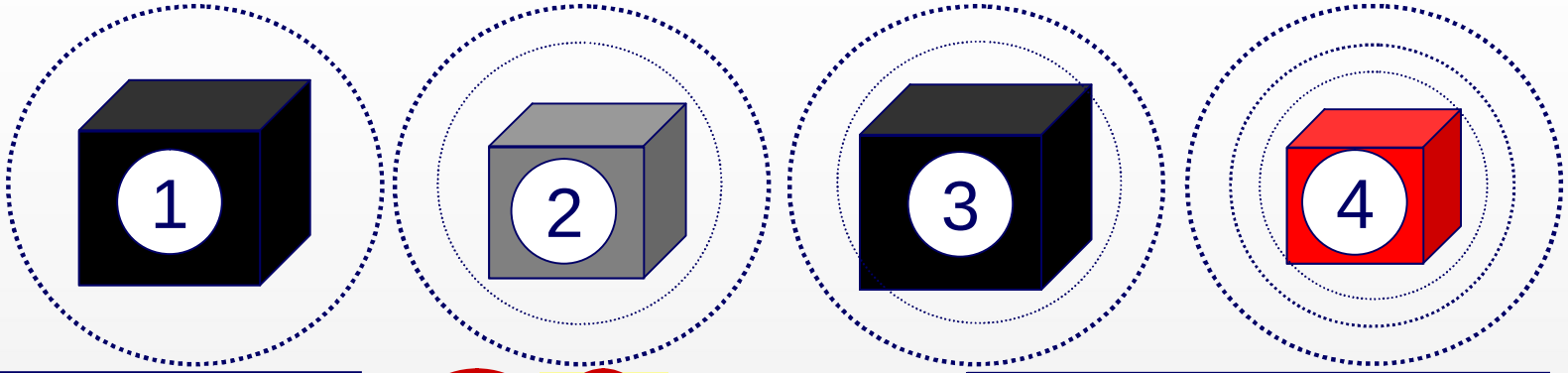
Ex: Desiring "No" Change:
Value Robustness



Preferences t=1

Attribute	k_i
Size	0.5
Loudness	0.2

Choose 3

U(3)>U(2)>U(1)>U(4)

U(4)>U(2)>U(3)>U(1)

big>small

loud>quiet

red>gray>black

Change?

Preferences t=2

Attribute	k_i
Size	0.5
Loudness	0.2
Color	0.6

Attribute "priority"

New

Choose 4

If switching costs are high, option 2 may be better choice (i.e. robust in value)

Clever designs, or changeable designs can achieve value robustness

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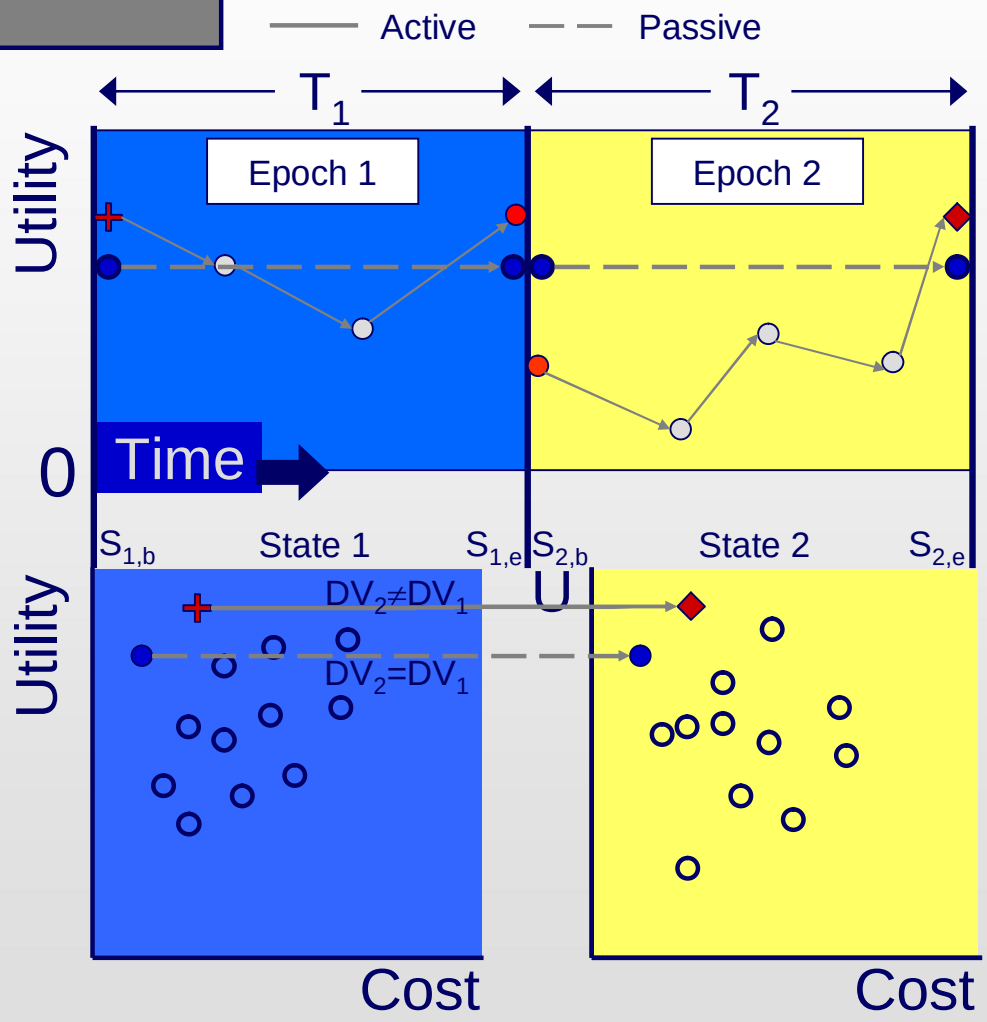
Achieving Value Robustness

Research suggests two strategies for "Value Robustness"

New Context Drivers

- External Constraints
- Design Technologies
- Value expectations

1. Passive
   - Choose "clever" designs that remain high value
   - Quantifiable: Pareto Trace number
2. Active
   - Choose changeable designs that can deliver high value when needed
   - Quantifiable: Filtered Outdegree



Value robust designs can deliver value in spite of inevitable context change

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Conclusion

- Change includes three aspects
  - Change agent
  - Change mechanism
  - Change effect
- Change taxonomy links agents and effects
- Change mechanism drives filtered outdegree
- Quantifiable filtered outdegree couples both objective and subjective measures
- Changeability can be used as an explicit and consistent metric for designing systems

Designed for changeability, systems will be empowered to become value robust, delivering value in spite of context and preference changes

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Thank you for your attention!

Any questions?

For further details on topic please see:

Ross, Adam M., Managing Unarticulated Value: Changeability in Multi-Attribute Tradespace Exploration. Cambridge, MA: MIT. PhD in Engineering Systems. 2006.