SEAri Short Course Series

Course: PI.26s Epoch-based Thinking: Anticipating System and Enterprise Strategies for Dynamic Futures

Lecture: Lecture 11: Temporal Properties ("ilities")

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Systems Engineering Advancement Research Initiative

[PI.26s] Epoch-Based Thinking: Anticipating System and Enterprise Strategies for Dynamic Futures

Lecture 11
Temporal Properties ("ilities")

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PROFESSIONAL EDUCATION

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Outline

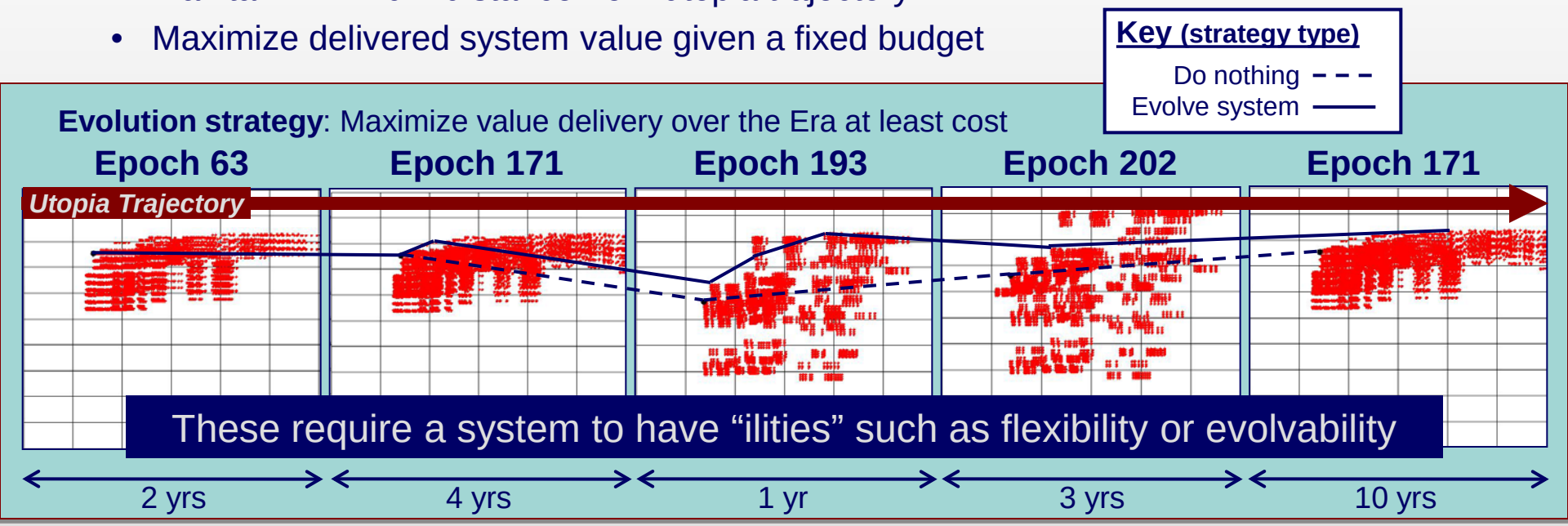
- Defining the need for changeable systems
- Changeability definition and framework
- Metrics for changeability
- Valuing changeability

Using Eras to Evaluate System Evolution Strategies

Propose time-based system evolution strategies that sustain / maximize stakeholder value delivery

Example strategies include:

- Maintain minimum distance from utopia trajectory
- Maximize delivered system value given a fixed budget



Epoch-Era Analysis can be used to determine system designs and transition strategies that deliver the highest value over the entire system lifecycle or within a particular context

The Dynamic Value Problem

- Designers and architects often face changes in…
  - User needs
  - Available technologies
  - Political and technical contexts
- Classical "scenario analysis" can be too opportunistic, qualitative, or sparse
- Solutions must be able to deliver value in spite of changes in context and needs
  - Example strategies:
  - Develop "Changeable" solutions (*i.e.,* use "ilities' in architecture)
  - Develop "Versatile" solutions (*i.e.,* build in "extra" value)
- Precise definitions and methods of characterization are needed in order to incorporate and design for "ilities"

How can "ilities" become an active consideration during architecting and design exercises?

Need for "ilities"

Washington, DC in June 2004

- According to Dr. Marvin Sambur, former Asst. Sec. of USAF for Acquisitions, "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 these *operational "ilities"*

*Adapted from Ross, A., Rhodes, D., and Hastings, D., "*Defining System Changeability: Reconciling Flexibility, Adaptability, Scalability, and Robustness for Maintaining System Lifecycle Value*,"* INCOSE Int'l Symposium 2007, San Diego, CA, June 2007

What are the “ilities”*?

- Relate to structure, operation, time-based quality, or new ability of a solution
- Example categories of ilities
  - Structural (often independent of context/use)
    - E.g., Modularity, implementability
  - Operational (dependent on context/use)
    - E.g., Survivability
  - Either structural or operational
    - E.g., Changeability, flexibility, adaptability, agility, scalability, modifiability, robustness
  - Relevant in a lifecycle context
    - E.g, Evolvability, sustainability

All “-ilities” are not equivalent in essence, definition, or representation

*There were 61 “-ilities” on Wikipedia as of April 24, 2008.

Defining Some “ilities”

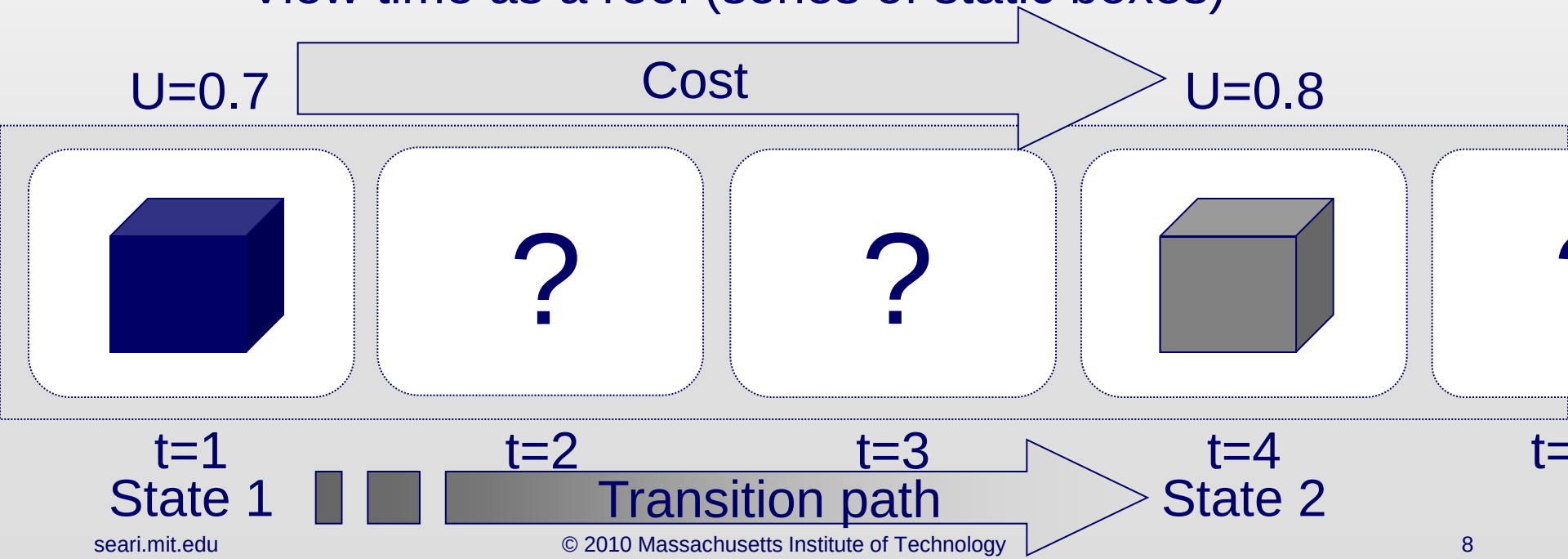
robustness	ability of a system to maintain its level and set of specification parameters in the context of changing system external and internal forces
versatility	ability of a system to satisfy diverse needs for the system without having to change form (measure of latent value)
changeability	ability of a system to alter its form—and consequently possibly its function—at an acceptable level of resource expenditure
flexibility	ability of a system to be changed by a system-external change agent
adaptability	ability of a system to be changed by a system-internal change agent
scalability	ability of a system to change the current level of a system specification parameter
modifiability	ability of a system to change the current set of system specification parameters
survivability	ability of a system to minimize the impact of a finite duration disturbance on value delivery
value robustness	maintaining value delivery in spite of changes in needs or context

Desiring Change: Changeability

To assess change, three things must be defined

1. State 1
2. State 2
3. Transition path from 1 to 2

View time as a reel (series of static boxes)



A Cross-Cutting "ility": Changeability*

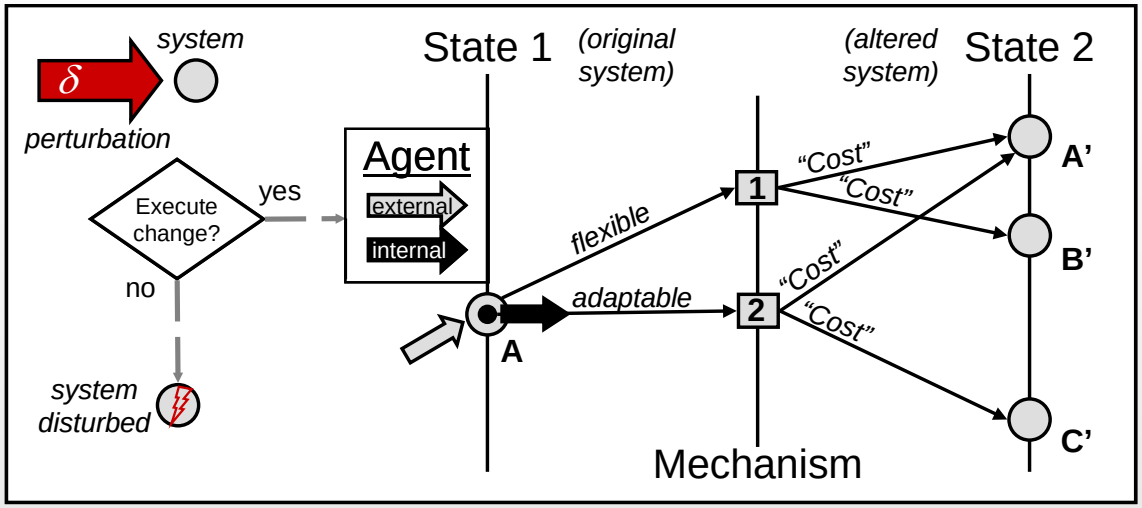
- What is needed for (intended) change?
  - Presence of an "actor" (for intent)
  - Defined by differences…
  - Necessity of time…
- Three aspects to change process
  - Change <u>agent</u> ("who" caused change, force instigator)
  - Change <u>effect</u> (what changed, "State 2 – State 1")
  - Change <u>mechanism</u> (how changed, including "cost")

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

*Ross, A.M., Rhodes, D.H., and Hastings, D.E., "Defining Changeability: Reconciling Flexibility, Adaptability, Scalability, Modifiability, and Robustness for Maintaining Lifecycle Value," *Systems Engineering*, Vol. 11, No. 3, pp. 246-262, Fall 2008.

Framework for Assessing and Designing for Changeability

Change pathway: Perturbation-Agent-Mechanism-Effect

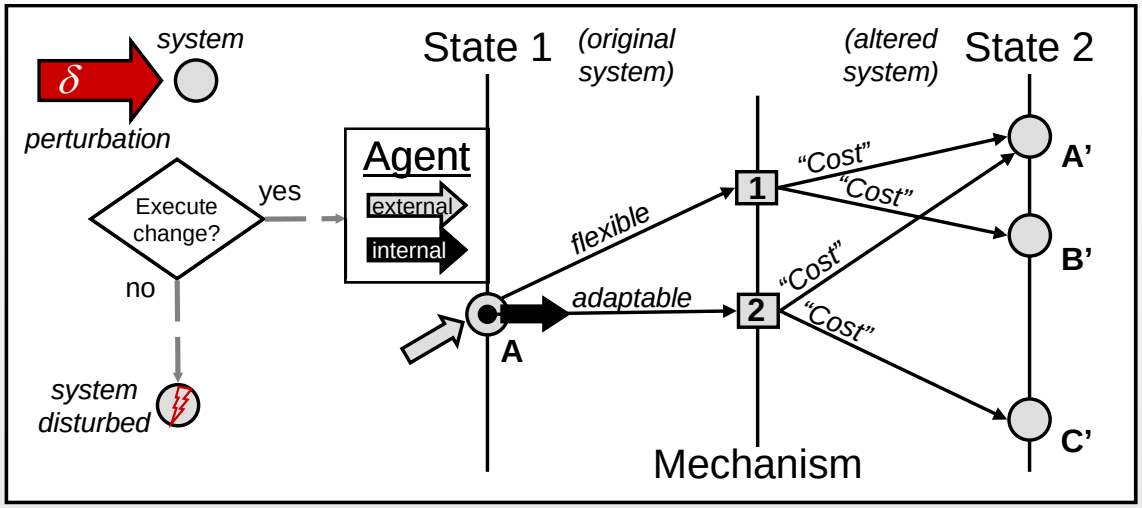


At least two questions can be asked regarding degree of changeability

1. Can a system be changed or change itself?
   - Capability question; pursue structural and operational strategies
   - Key metrics: number of destination end states, time/cost to achieve change
2. Does the change result in a "better" system?
   - Value question; analyze context-dependent performance and perceptions
   - Key metrics: utility loss/gain over time, aggregate value delivery/availability

Framework Example

Change pathway: Perturbation-Agent-Mechanism-Effect

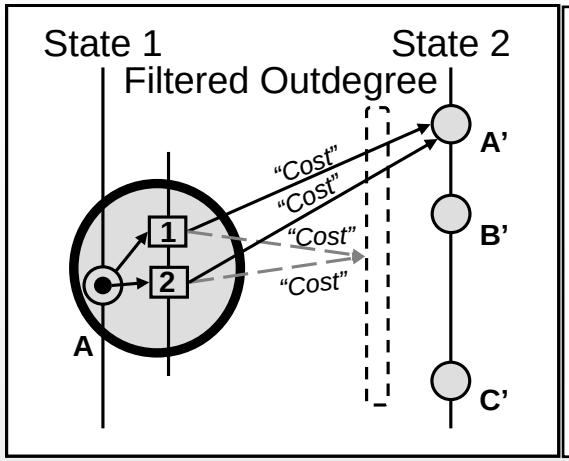


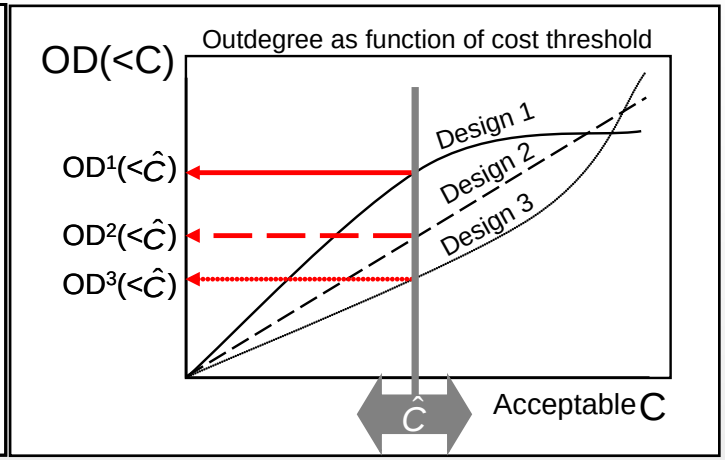
Perturbation	*System*	Agent	Mechanism	Effect
δ	○	internal / external	1 / 2	○ A' ○ B' ○ C'
Δ technology	Sat. constellation	Program manager	Swap payloads	New capability
Δ business model	Aircraft fleet	Autonomous software	Redefine operations	Enhanced survivability
Δ enemy	Training system	Warfighter	Combine assets	Cost-efficiency gains

Framework helps to structure thinking about changeability, including creative generation of strategies, as well as quantification

Changeability Metrics

If perturbations or desired end states are unknown

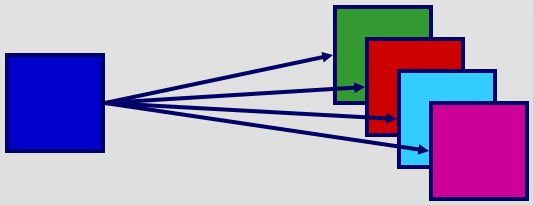




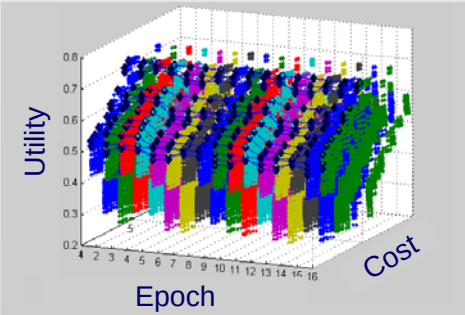
Filtered outdegree is a metric of acceptable changeability (incl. adaptability). Outdegree function shows differential degree of changeability across "willingness to pay" cost/time thresholds

Future context must be known in order to evaluate goal end state and value of end state

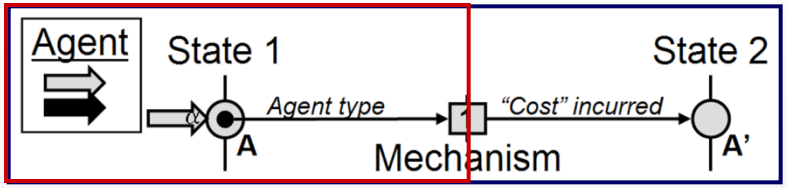
"Epoch-based thinking" can be used to structure anticipatory scenario analysis

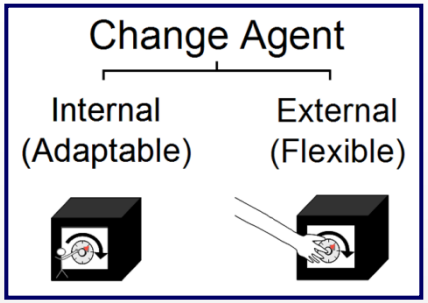


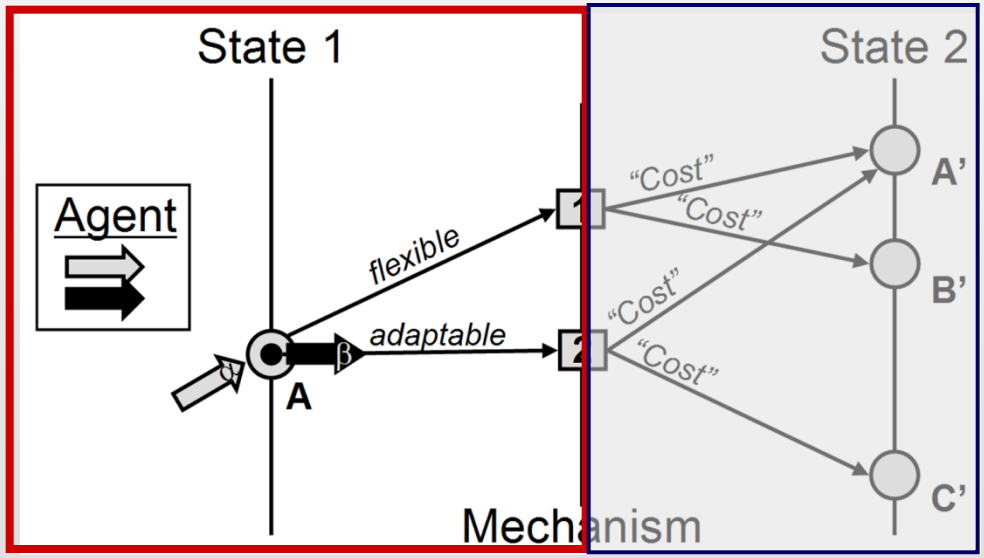
Today Possible futures (epochs)



Agent of Change: Flexibility vs. Adaptability

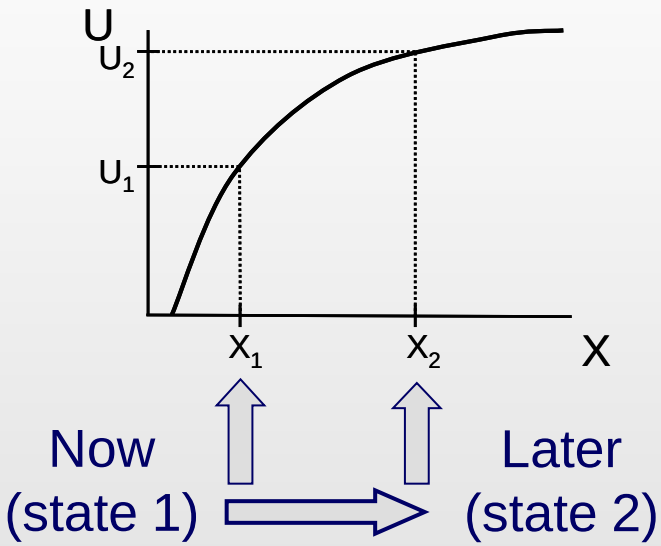


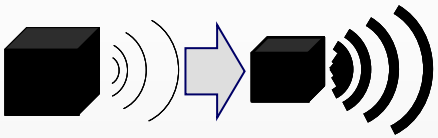




Key difference between flexibility and adaptability is defined by boundary of solution (i.e., what is "internal" vs. "external"?)

Effects of Change: Scalability





Change in parameter level

"Scalable"

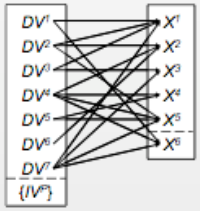
A box can be quantified in terms of *scalable in X^i*

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

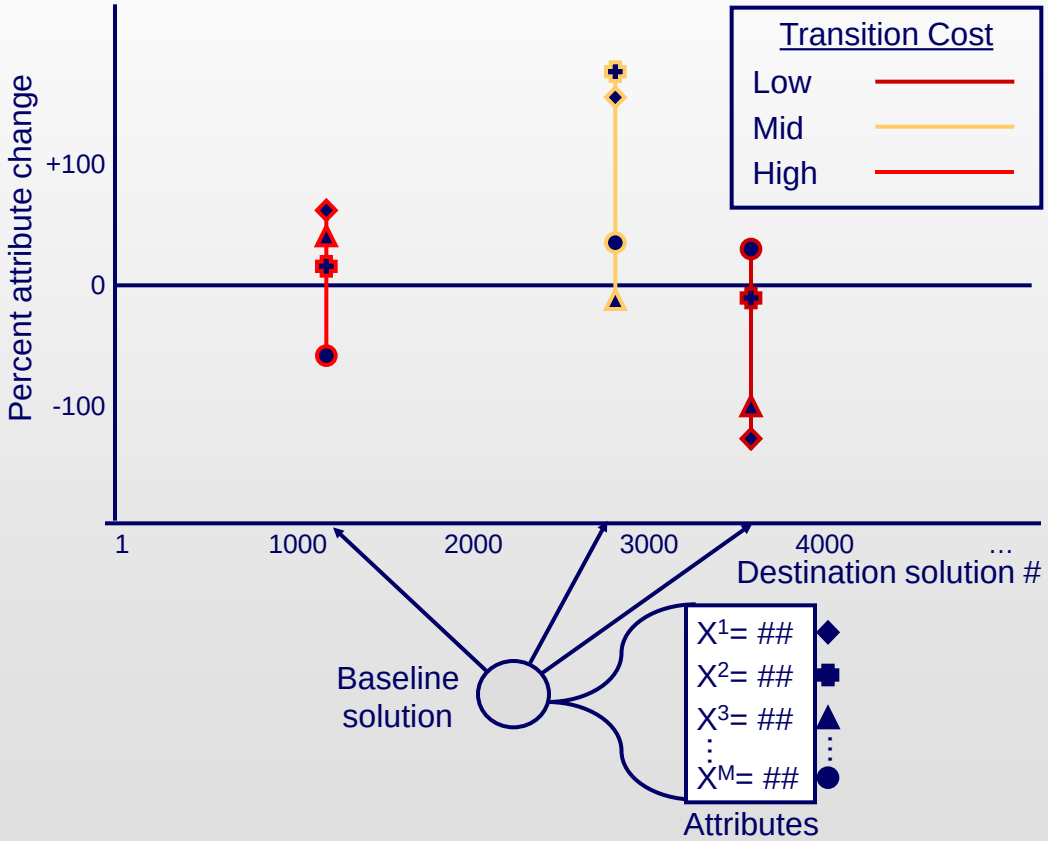
Caution on Scalability

Attribute scaling

Coupled



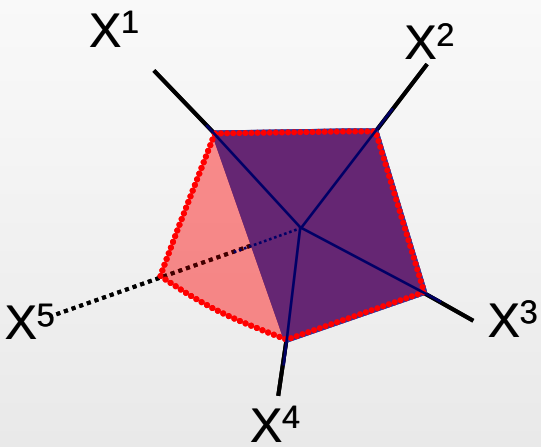
Coupled design results in scaling up and down across parameters when changing designs



The more complex the solution, the more coupled it likely is, the more unintended "scaling" effects may occur

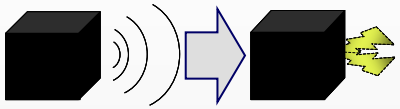
Scalability is multi-dimensional and destination dependent

Effects of Change: Modifiability



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

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



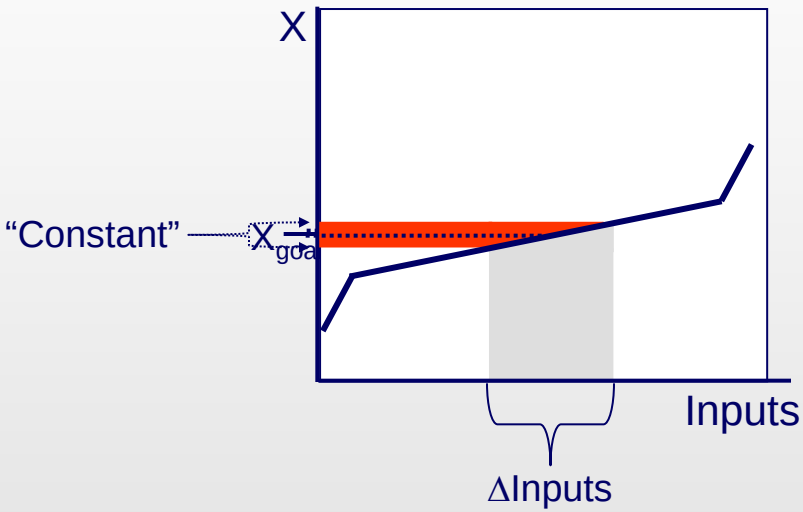
Change in parameter set

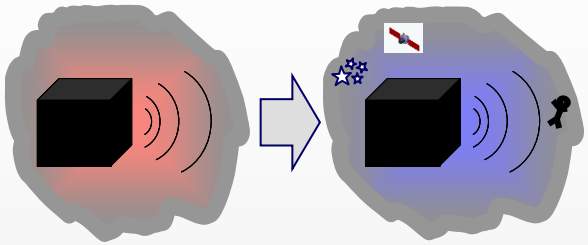
"Modifiable"

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?)

Effects 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"?)

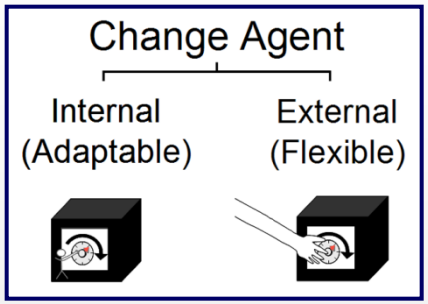
Change Agents and Effects

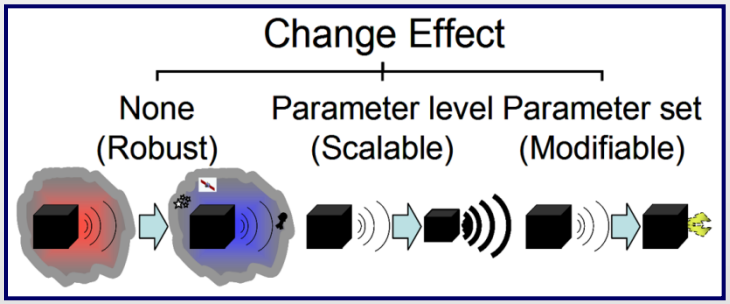
Changeability

Change
agent origin

+

Change effect

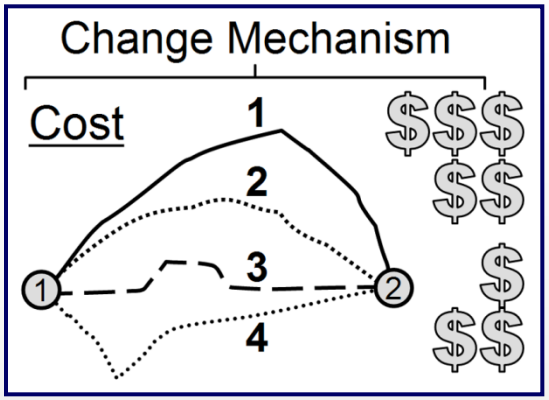




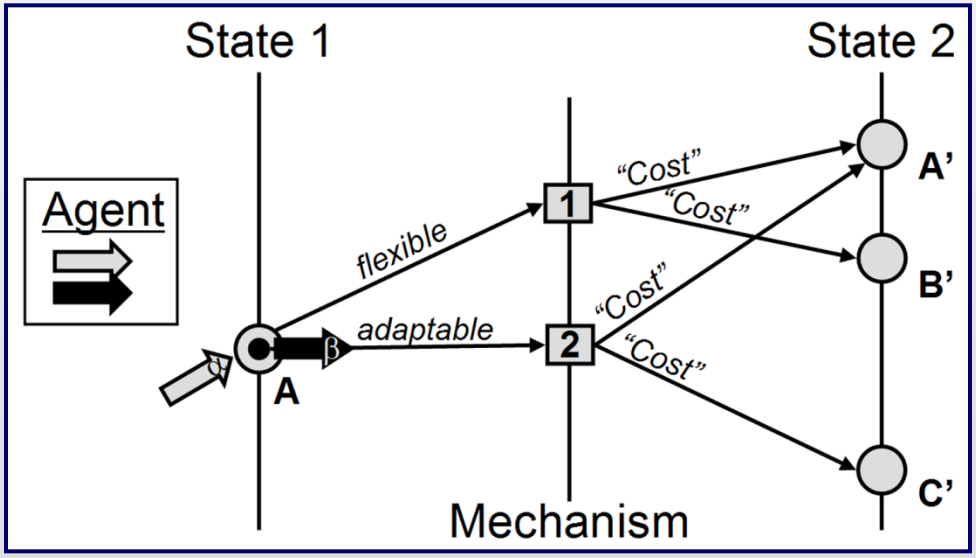
Change agents and effects are used to classify the change type… what about change mechanisms?

Mechanisms

There are many possible paths to achieve desired change



A given mechanism may require internal or external change agents



Mechanisms are the means by which the change takes place

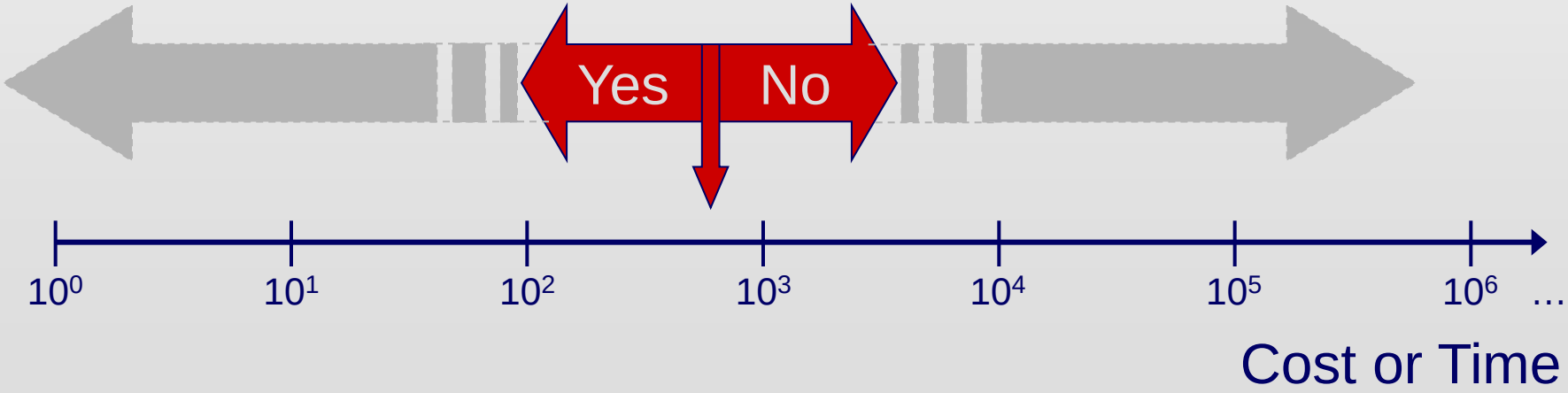
Determining Changeability

The Question: Is the enterprise _____?

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

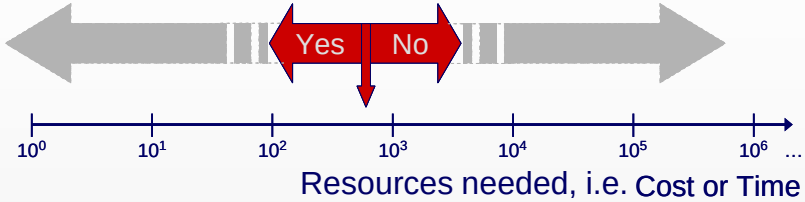
The Answer: It depends!

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



Specifying Changeability

1. Specify subjective acceptability scale



2. Specify origin of change agent

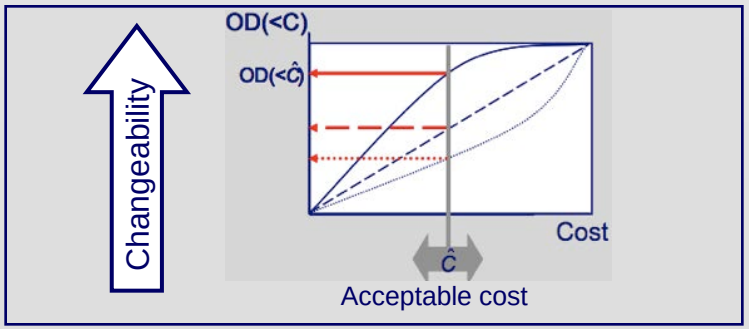
Change agent: External (Flexible), Internal (Adaptable),

3. Specify desired change effect

Desire change			Desire no change		
_____ in	_____ for	_____	_____ in	_____ to	_____
"ility"	metric	resource	"ility"	metric	perturb.
Scalable	X^i	Cost	Robust	X^i	ΔDV
Modifiable		Time		Rank (Pareto Efficient)	ΔConstraints
				Cost/Time	ΔConst.
					ΔPreference set

Evaluating changeability

4. Perform architecture evaluation (changeability metrics)



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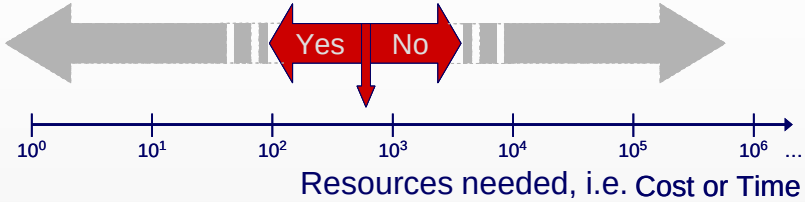

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Modifiable		Time		Rank (Pareto Efficient)	ΔConstraints
				Cost/Time	ΔConst.
					ΔPreference set

Example formulation of an operational ility statement

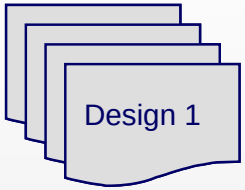
The system shall be _____ (change agent type) flexibly or adaptably _____ (change effects) scalable, modifiable in _____ (system parameter) for less than _____. (resources)

Accounting for “ilities”

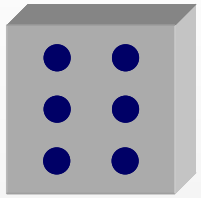
- Benefits of “ilities”:
  - Enterprises can continue to produce value in uncertain future
  - Robust/Versatile enterprises create greater expected value (Net Present Value or NPV) in the presence of uncertainty
  - ***Options*** *enable* changeable enterprises
- Costs of “ilities”:
  - Direct cost (cost of robustness / cost to exercise options)
  - Cost of hooks (cost to purchase option)
  - Lost utility or added cost (compromise cost)
- Example valuation methods for “ilities”
  - Real Options Analysis
  - Tradespace Networks
  - Outdegree Assessments

There is a difference between whether something is “flexible” or “valuably flexible”

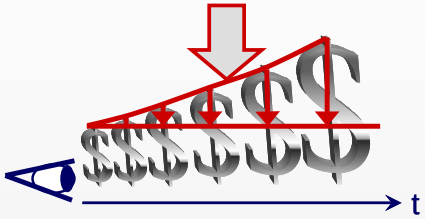
Using Real Options



Designs: Choices (technical, programmatic and operational)



Dice: The uncertain future state of the system/context



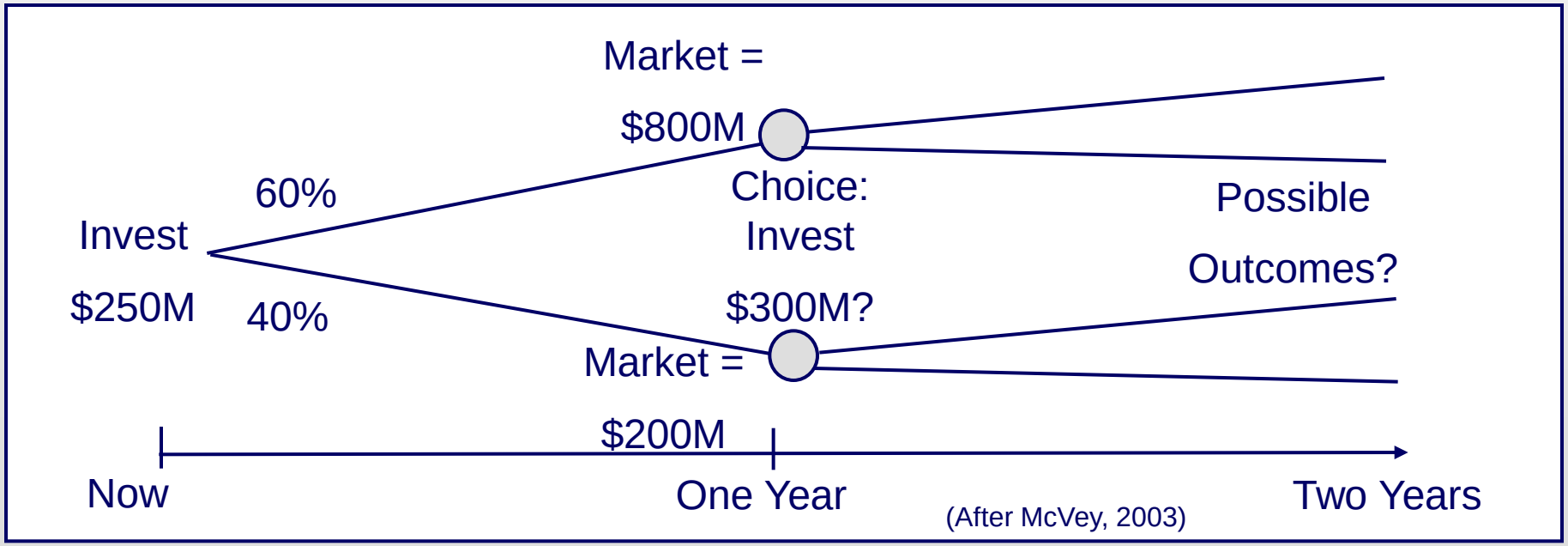
Discounting: Reducing the value of future benefits/costs as perceived today

*Shah, N.B., Viscito, L., Wilds, J.M., Ross, A.M., and Hastings, D.E., "Quantifying Flexibility for Architecting Changeable Systems," 6th Conference on Systems Engineering Research, Los Angeles, CA, April 2008.

Accounting for the Value of Changeability - Real Options

Simple example:

- Costs $250M to initiate a project, and an additional $300M after one year to complete
- The market has a 60% chance to yield $800M in income, but a 40% chance to yield only $200M. Market conditions will be known in one year

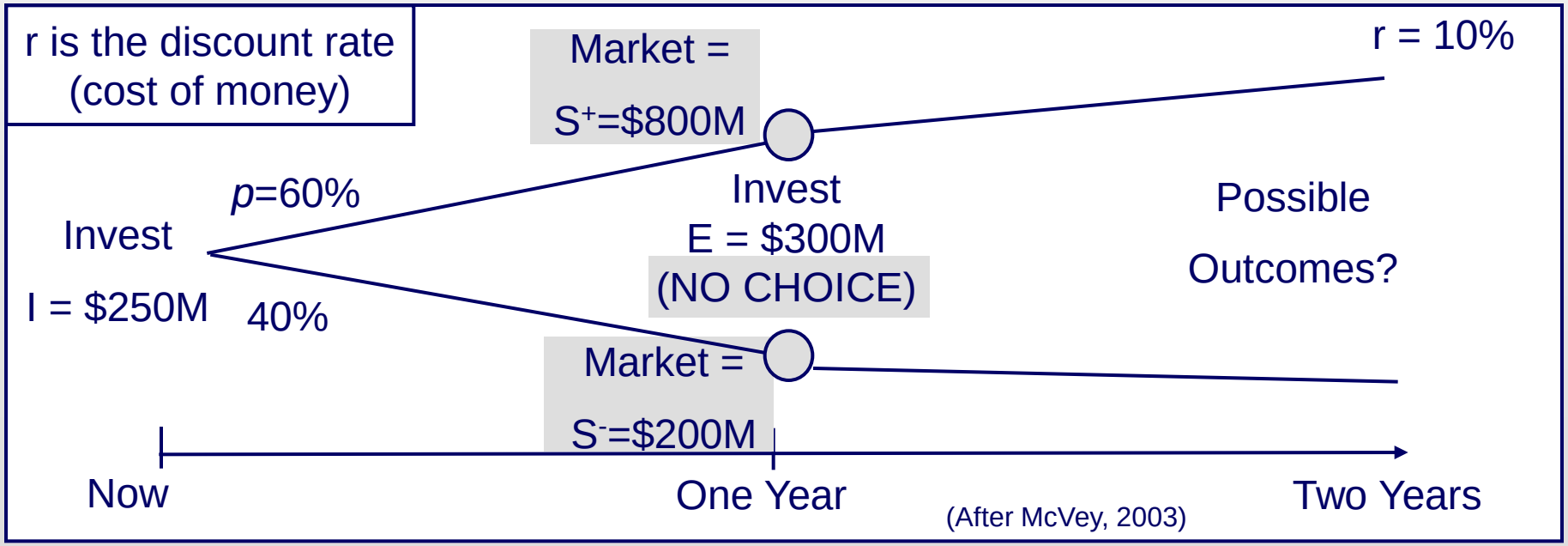


(After McVey, 2003)

Accounting for the Value of Changeability - NPV

Without *options*, must commit to investing the $300M. Calculate Net Present Value (NPV):

$$NPV = p\frac{(S^{+}-E)}{1+r} + (1-p)\frac{(S^{-}-E)}{1+r} - I = -14$$

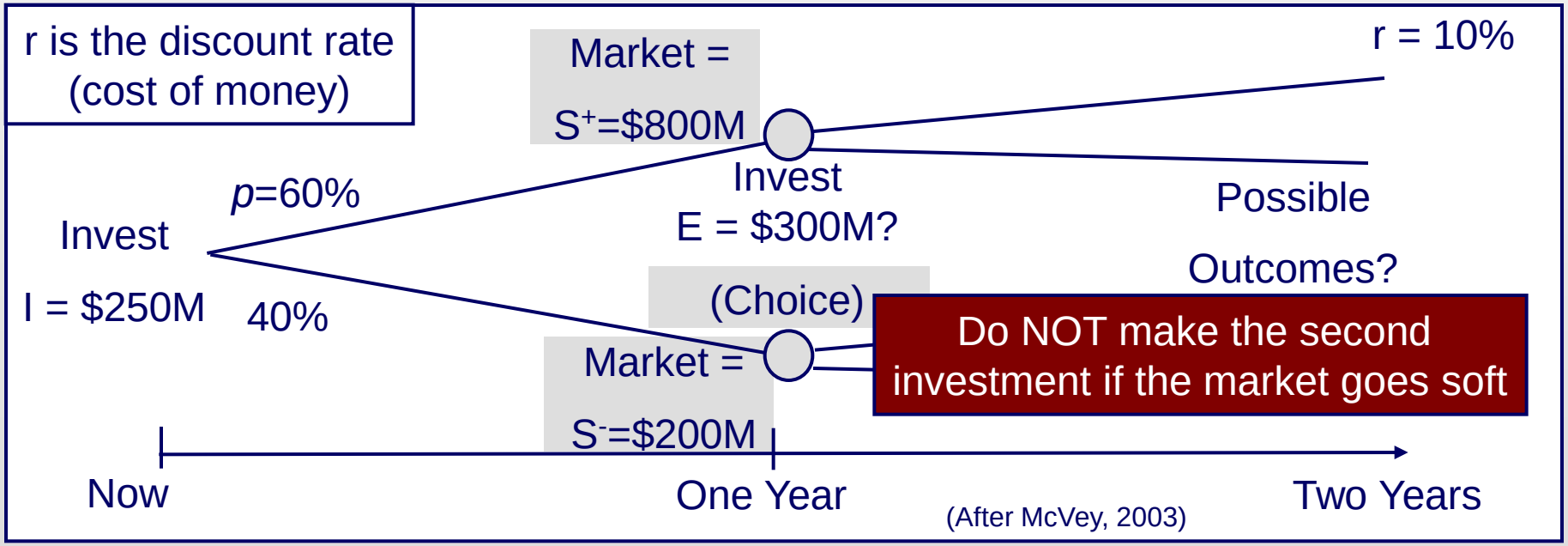


(After McVey, 2003)

Accounting for the Value of Changeability - DTA

With *options*, choose to commit (or not) the $300M. Calculate using Decision Tree Analysis (DTA):

$$DTA = p\frac{\max(S^{+} - E, 0)}{1+r} + (1-p)\frac{\max(S^{-} - E, 0)}{1+r} - I = +23$$



(After McVey, 2003)

Real Options Analysis (ROA)

- The ability to choose after a year was an *option*. It's value was

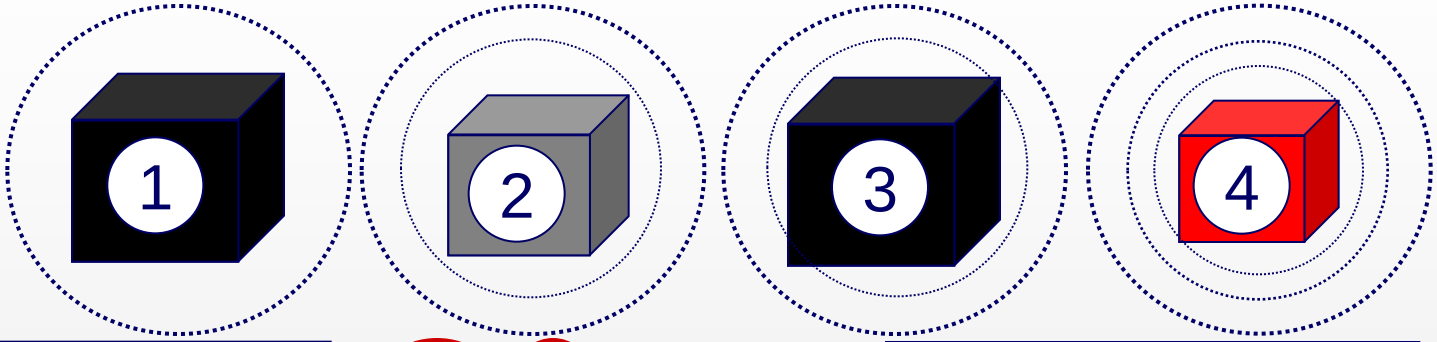
  DTA-NPV = 23-(-14) = $37M

- Changeable designs give us options to respond to changing conditions and markets
- Changeability can be valued with ROA, but must be able to characterize three D's:
  1. Distribution of uncertainty,
  2. Design choices, and
  3. Discounting of future costs and benefits to present

If the three D's are unknown or not agreed upon, the "value" of changeability cannot be used as a decision metric

The Pursuit of Value Robustness

Example: Picking the "best" options



Preferences t=1

Attribute	k_i
Size	0.5
Loudness	0.2

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

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

big>small

loud>quiet

Change?

Preferences t=2

Attribute	k_i
Size	0.5
Loudness	0.2

Attribute "priority"

New

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

Versatile solutions or changeable solutions can each achieve value robustness

Designing for Value Robustness

Mindshift: recognize dynamic contexts and fallacy of static preferences—the inevitability of "change"

- Two primary strategies:
  - Matching changeable solutions to changing needs leads to sustained success
  - Creating versatile solutions with latent value leads to sustained success
- Methods for increasing ***Changeability***
  - Increase number of paths (change mechanisms)
  - Lower "cost" or increase acceptability threshold (alter apparent changeability)
  - Changeability can be used as an explicit and consistent metric for designing solutions
- Methods for increasing ***Versatility***
  - Increase number of displayed fundamental or combinatorial system attributes
  - Decrease "cost" for displaying or hiding attributes

Designed for changeability or versatility across an era, systems & enterprises will be empowered to become value robust, delivering value in spite of context and expectation changes