SEAri Short Course Series

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

Lecture: Lecture 2: Concepts and Constructs for Epoch-based Thinking

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

Lecture 2
Concepts and Constructs for Epoch-Based Thinking

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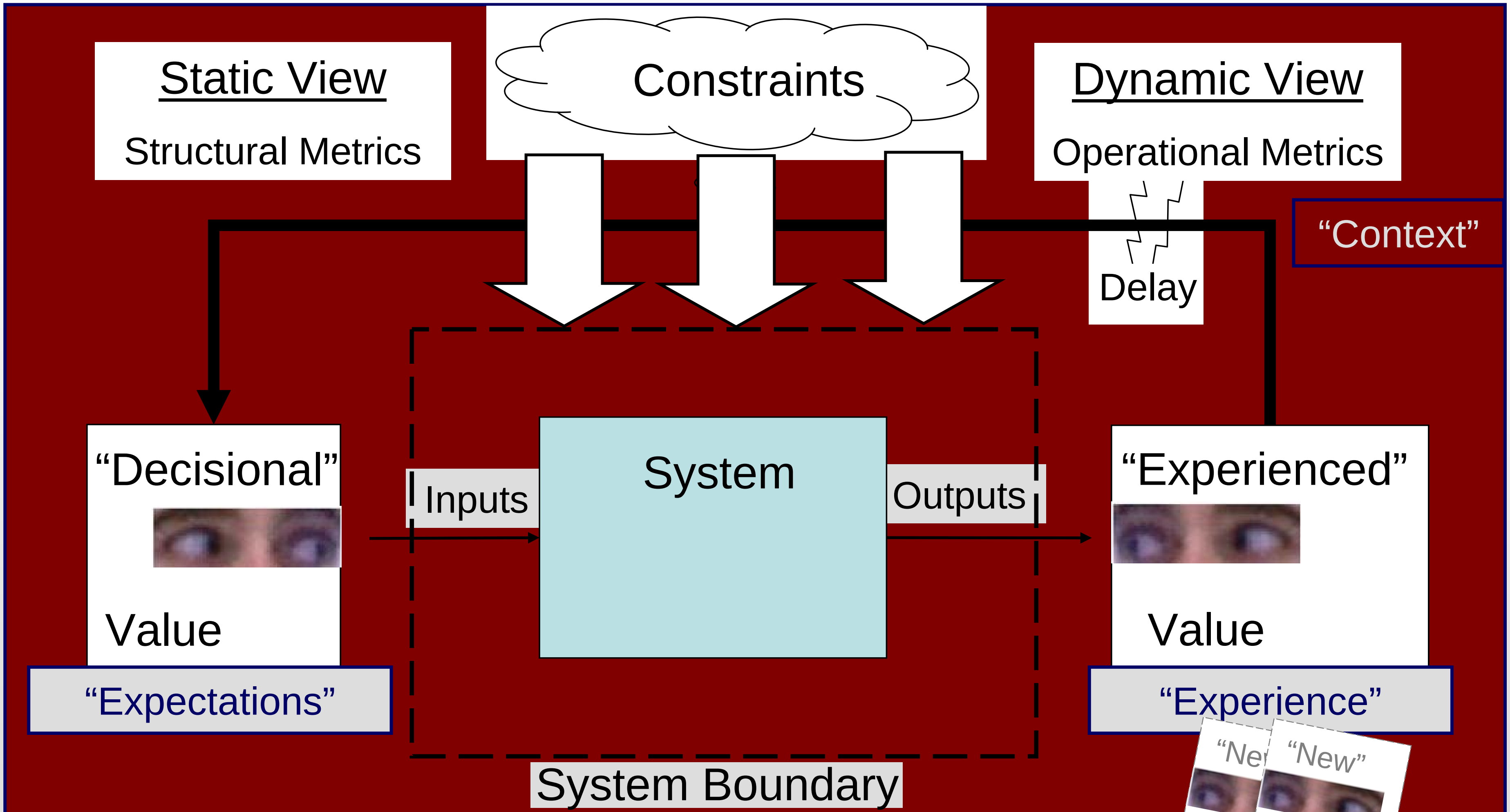
Outline

- Dynamic context and needs
- Context defined
- Temporal importance
- Introducing the “Epoch”
  - Representation
  - Characteristics
  - Potential Uses
- Using quantification

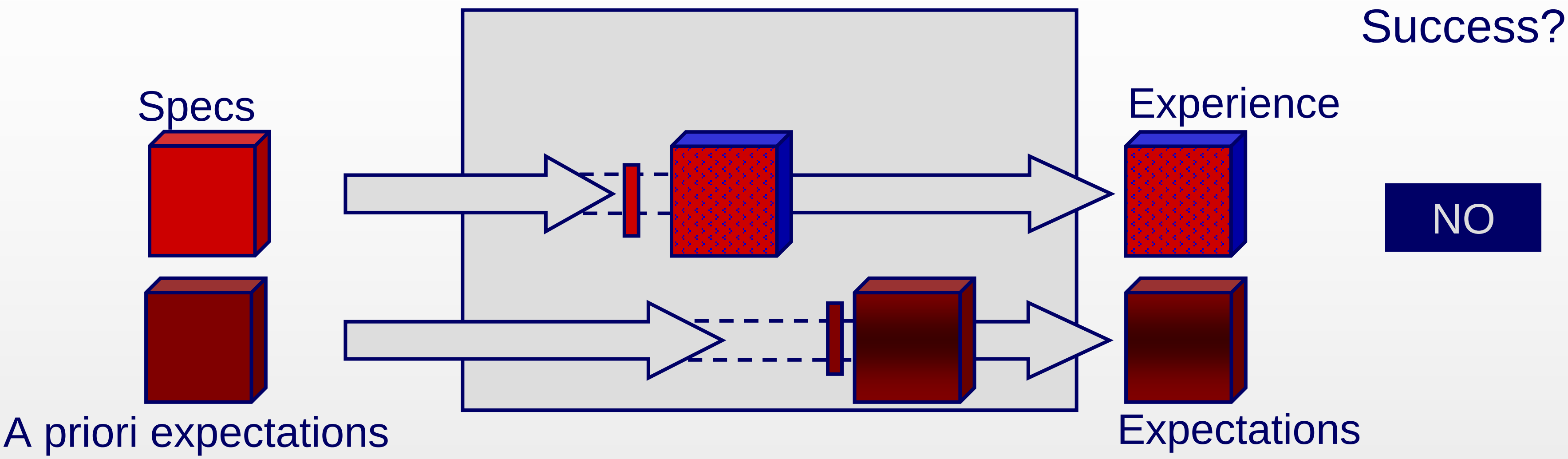
Dynamic System Context: Value Lenses



"Decision", "Experienced", and "Remembered" Utility from (Kahneman and Tversky 2000)

***Discussion of "structural" versus "operational" metrics in (Giachetti et al. 2003)*

What is Context?



- Context includes forces exogenous to system
  - "Other" stakeholder expectations
  - Operating environment
  - Policy constraints
  - Available technologies
  - Competitors in market
  - Etc…
- System success depends on system performance within a given *context*
- In order to ensure success, designers must consider context beyond traditional "operating environment" (classical robust design)

What is Context?

GENERAL

- The interrelated conditions in which something exists or occur (Merriam-Webster)

ENGINEERING SYSTEMS

- The constraints and environment that exists at and beyond the “system” boundary. Often the context is imposed or out of the control of the designer and must be treated as an exogenous variable in the design endeavor (Ross, 2006)

ORGANIZATIONAL BEHAVIOR

- Stimuli and phenomena that surround and thus exist in an environment external to the individual, most often at a different level of analysis (Mowday and Sutton, 1993)

“The Many Faces of Context” -- from field of organizational behavior

- Context as salience of situational features
  - Salient factors heighten sensitivity but neither sufficient nor necessary to characterize context
- Context as situational strength
- Context as a cross-level effect
  - Situational variables at one level of analysis impact variables at another level
- Context as bundle of stimuli
  - A set of factors when considered together, can sometimes yield a more interpretable and theoretically interesting pattern than any of the factors would show in isolation (Rousseau and Fried, 2001)
- Context as an event
- Context as a shaper of meaning
- Context as a constant

(source: Johns,G., 2008)

Contextual Aspect

Requires understanding of complexities/uncertainties stemming from:

- external environment in which system operates
- relevant stakeholder needs as driven by this environment

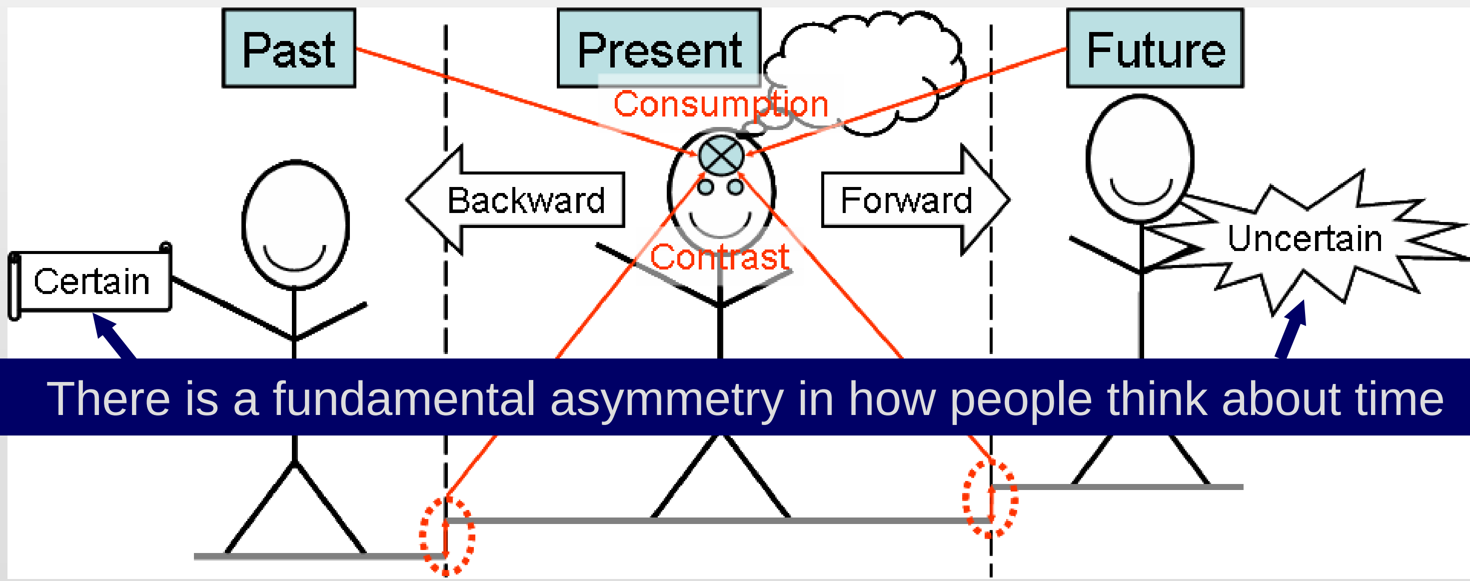
Relates to understanding system in a period of fixed context and needs

- context shifts may occur as related to political, economic, threat, cultural, policy, and market factors
- exogenous factors drive design decisions, yet are typically not fully elaborated and considered

Traditional systems engineering includes defining system boundaries, external entities, and external interfaces in system context diagrams. Also described in documents such as operational concept documents or capability description documents. While highly useful, these provide descriptive information rather than an analytic capability.

Choice over Time*

Backward effect	Forward effect	Result
Consumption		Prefer to consume in present to maximize creation of good memories, overall want to maximize creation of extremely positive memories
Contrast		Create good memories that cannot be compared to present, create stream of improving experiences to remember improvement (present superior to any summary of past)
	Consumption	Put off good experiences to maximize savoring, continually improve, take bad experiences now
	Contrast	Continually improve or remain constant in present state so that future does not look too much better than present (reduce discontent with present)



There is a fundamental asymmetry in how people think about time

* Based upon Loewenstein, George and Jon Elster, Eds. (1992). Choice Over Time. From "Utility from Memory and Anticipation." New York, Russell Sage Foundation. p.213-234

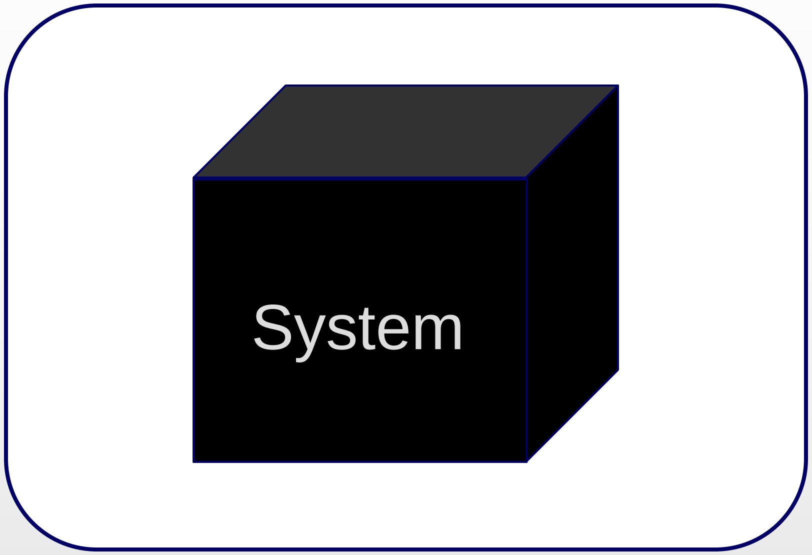
Temporal Aspect

- Temporal aspect of systems is critically important, but remains undertreated in engineering practice
- Use of system scenarios is most typical method used in systems engineering, but largely "illustrative"
- Necessary to characterize changes over time
- Addresses time-based properties such as survivability or adaptability of the system over its lifespan

Over two decades ago, Hall discussed the importance of an environmental forecast ….. "a forecast is daunting because it encompasses a comprehensive description of the environment from before the time of conception of a new system, through every period of its lifecycle, to its ultimate demise".

A.D. Hall, *Metasystems Methodology*, Oxford, England, Pergamon Press, 1989

Traditional Perspective



- Does my System…
  - have good requirements? (stable, achievable, verifiable, etc. across many use-cases, stakeholders, and environments)
  - meet the requirements?
- Does my System program have acceptable…
  - cost, schedule, risk, etc…?

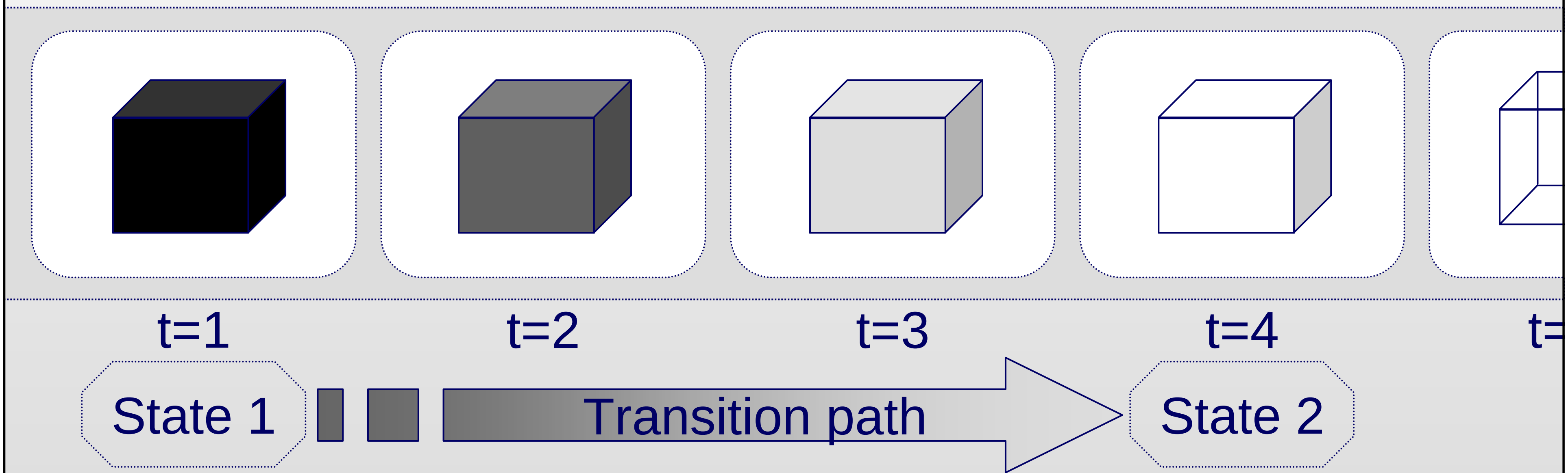
Changes are considered to be "bad"

Inherently a "static" perspective, but methods bias us in this direction

From Static to Dynamic Views

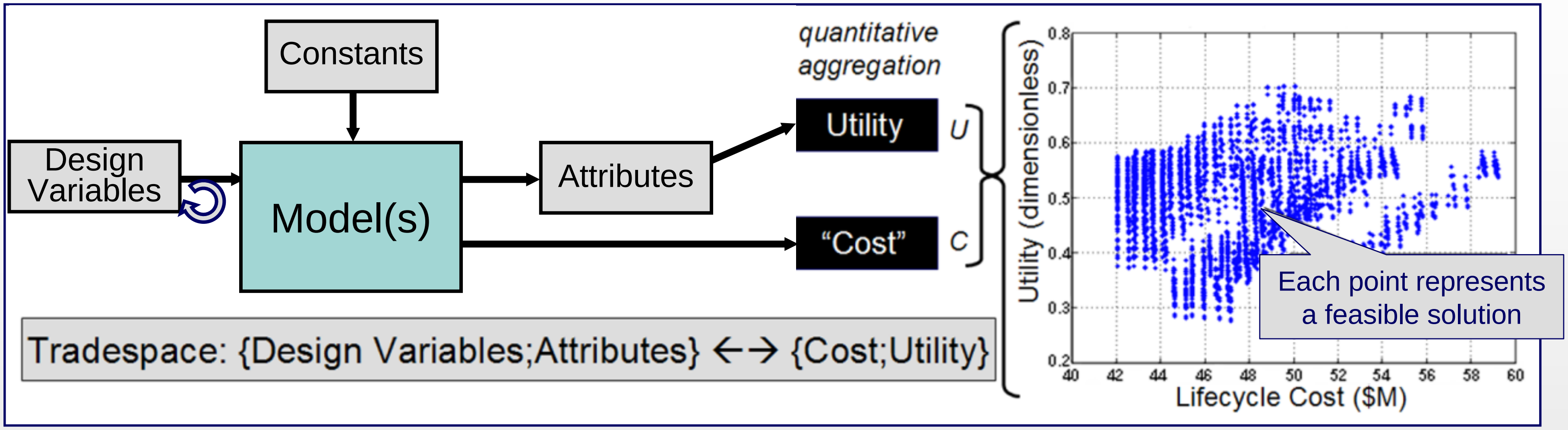
If classical approaches bias us in the direction of a static perspective, how can we move closer to a dynamic reality?

View time as a movie reel (series of static boxes)



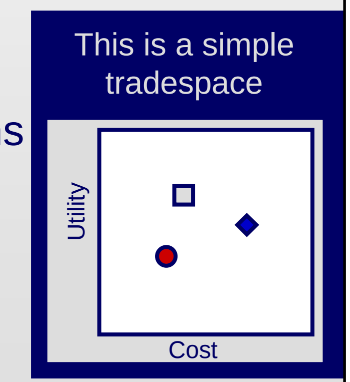
A string of static analyses can approximate dynamic analyses, in the limit

Supporting Construct: Tradespaces



Compares many designs on a common, quantitative basis

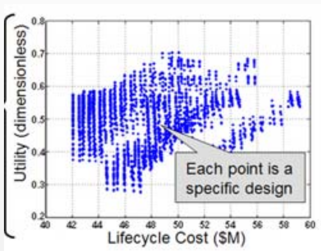
- Maps design space onto stakeholder value (attributes→ utility = "benefit")
- Uses models to assess many designs, avoiding limits of local point solutions
- Simulation can be used to account for design uncertainties (*e.g.*, cost, schedule, performance uncertainty)



<u>Typical goal:</u> maximize aggregate benefit (utility) and minimize aggregate cost (lifecycle cost)

Value-based assessments allow for comparison of many different alternatives

Epochs: Discretizing Contexts and Needs



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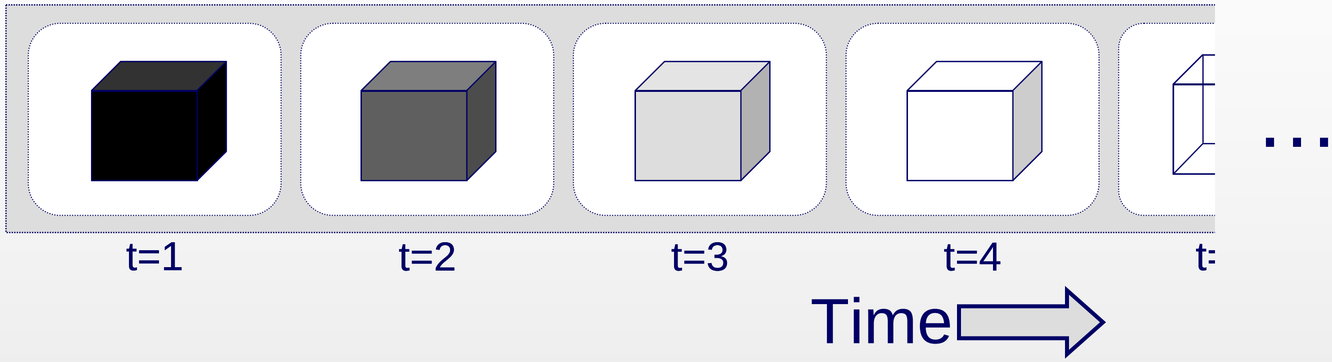


Epoch

Time period with a fixed "context" and needs

Fixed: Constraints, design concepts, available technology, and expectations (attributes and utility function)

One Epoch: short run
Multiple Epochs (System Era): long run

Epoch Purpose

Partition problem into series of short run problems

Legend:

T_i: Duration of Epoch i

$S_{i,b}$,$S_{i,e}$: System State at beginning,end of Epoch i

Continuity of States: $S_{i,e}$=$S_{i+1,b}$

An “Epoch” as a Snippet of Time

Definition of Epoch

Time period with a fixed context and needs; characterized by static constraints, concepts, available technologies, and articulated expectations

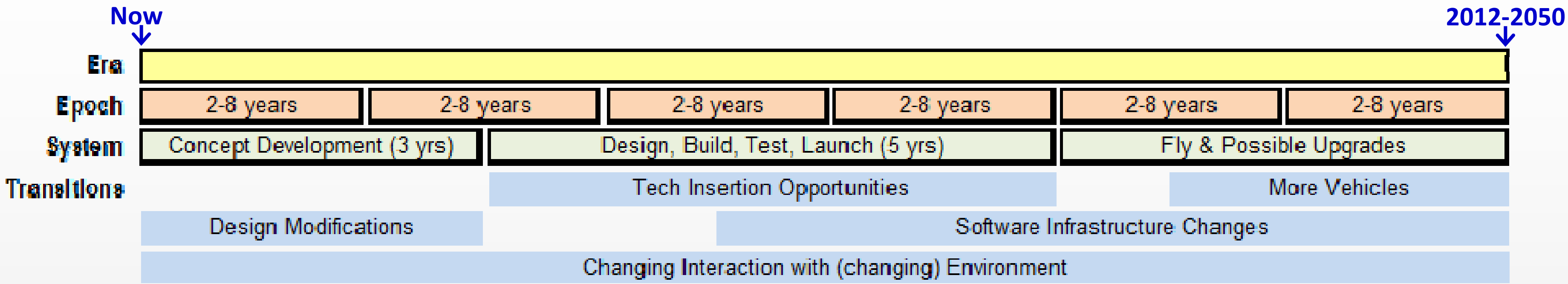
System success depends on the system meeting *expectations* within a given *context*

can change! can change!

Epoch-based Thinking

Using the concept of “epoch” to generate and consider a large number of possible future contexts and needs facing a system, along with short term and long term strategies for maintaining a successful system across epochs

Natural Value-Centric Time Scales



- Shift in contexts occur more frequently than typical system development timelines (e.g., budgets, leadership changes, new stakeholder needs)
- Often "***time scales***" are dictated by programmatic guidelines or arbitrary dates
- Context-derived "***natural***" ***time scales*** may compete with the "artificial" program time scales imposed on a system
  - Alignment of planets (e.g. Mars every 780 days)
  - New administration (e.g. presidential every 4 years)
  - New technology (e.g. Moore's law: 24 months
- "***Value-centric***" ***time scales*** focus on dynamic factors that impact the ***value proposition*** for the system (e.g. the metrics that define "success")

By considering natural value-centric time scales and how systems could respond across the lifecycle, one can begin to <u>anticipate</u> value robust systems that maintain value delivery over time

Using an "Epoch"-based framework is not new…

Era

Variable:

- Environment
- "Systems"
- Value

Epoch Shift

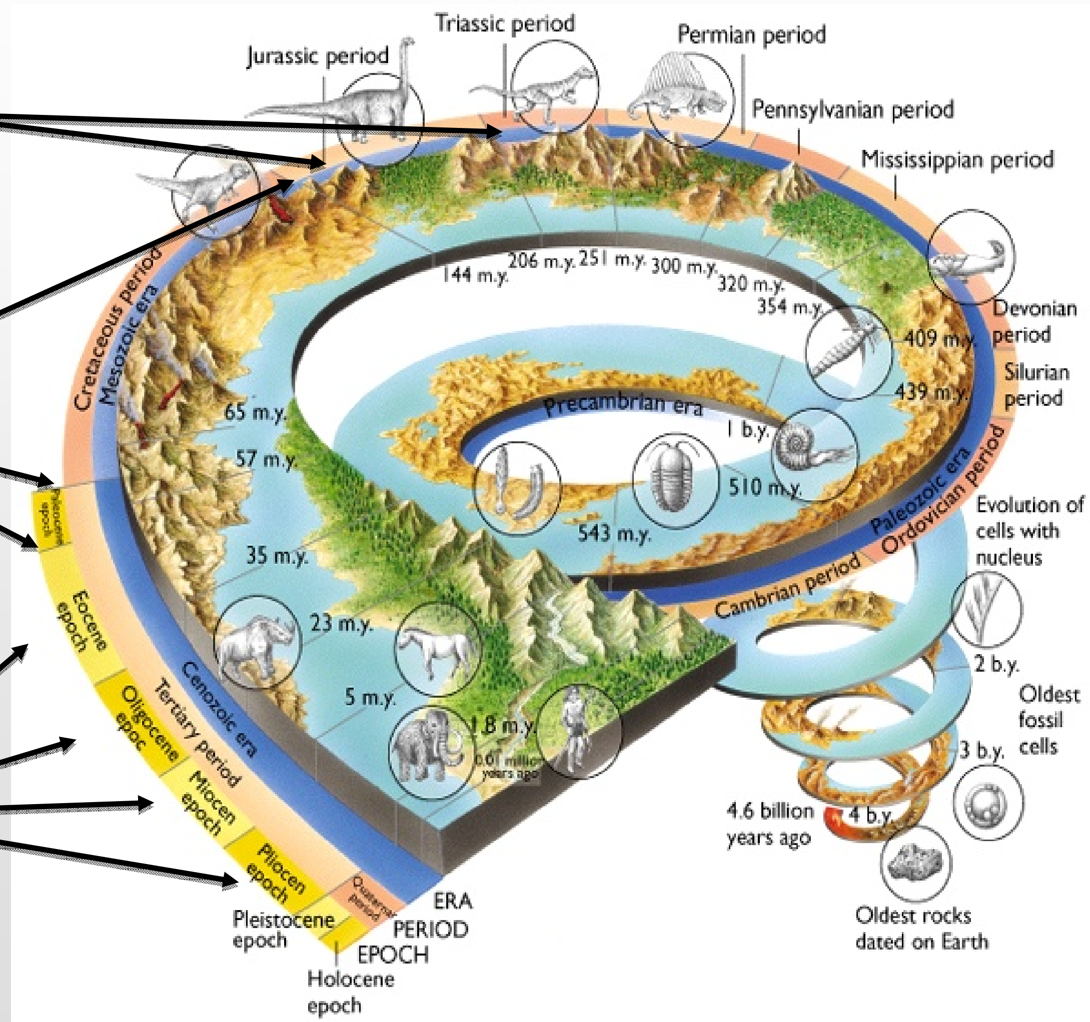
Change in:

- Environment
- "Systems"
- Value

Epoch

Fixed:

- Environment
- "Systems"
- Value



(Slide courtesy of Andrew Long, Booz Allen Hamilton, 2010)

SEA RI
Systems Engineering Advancement Research Initiative

Epoch Characterization

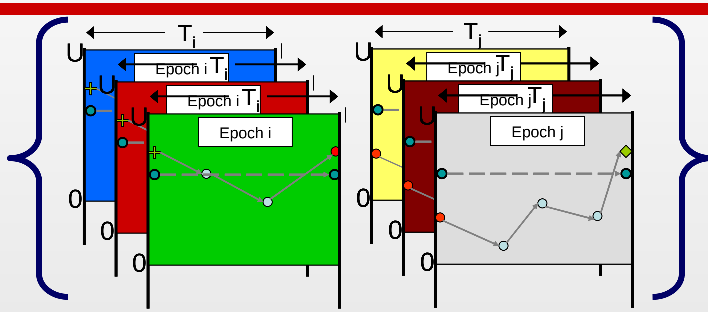
Definition of Epoch:

Time period with a fixed context and needs; characterized by static constraints, concepts, available technologies, and articulated attributes (Ross 2006)

Define Epochs

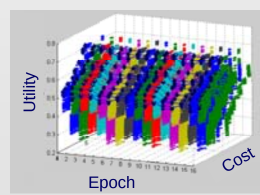
Potential Contexts

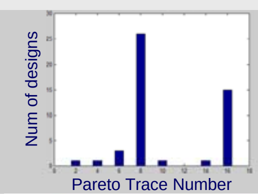
Potential Needs

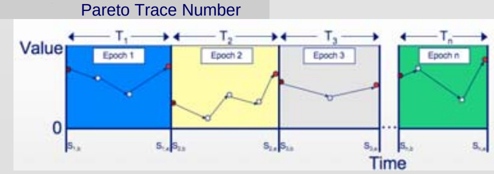


Multi-Epoch Analysis

Era Construction







Parameterize future contexts for generating and sampling scenarios

Capturing Information

- Each Epoch has specific quantities associated with it
- Definition of these quantities concretizes a given "context"
- Used as guidance for analyst-developed models

Analysis for X-TOS System Era – Epoch n	
Epoch Identifier	**Description**
Epoch Name	The descriptive name for the epoch, for example: ***X-TOS Initial Operating Scenario***
Epoch Duration	Finite duration for the epoch, for example: five years, or until system context change
Epoch Goal	Overall goal for epoch, for example: **Find Maximum Utility Design At** $S_{i,e}$
Constraints	**Description**
Resource	All of the resource related constraints including time, financial, manpower, and others, for example: *Must spend less than $100M over 5 years*
Political	The political related constraints which may be by formal policy or implicit, for example: *Must not use foreign launch vehicle*
Market	Market constraints including limitations imposed and windows of opportunity
Physical	Physical system constraints including limits by physical laws, spatial limits, etc.
Operational	The operational constraints in regard to system performance and other operating considerations, for example: *Must provide less than 5 Gbps downlink data rate*
Other	Any other constraints not enumerated in the previous categories.
Constants	**Description**
Constant Variable Set {CON}	The set of design variables that is constant within this epoch.
Controllable	The constants which are controllable by the designer.
Uncontrollable	The constants which are beyond the control of the designer.
Preference Space	**Description**
Decision Maker set, {DM}	The set of decision makers for the epoch, for example: *system user*
Number of DM {DM}	The number of decision makers for the epoch, for example 1
Attribute set, $\{X^M_{ij}\}$:	Attribute set for the epoch, defined for each decision maker i. For example: {Data Lifespan, Latitude Diversity, Equator Time, Latency, Sample Altitude}
Attribute Priorities, $\{k^M_{ij}\}$:	The priorities on a scale of 0 to 1, defined for each decision maker, for example: [0.3,0.125,0.175,0.1,0.425]
Single attribute utility curves, $U_j(X_j)$:	Single attribute utility curves for the epoch for each decision maker.
Multi-attribute utility curve, $f(U(k_j,U_j))$: *MAUF*	Multi-attribute utility curves for the epoch for each decision maker.
Changeability Cost threshold, $\hat{C}$:	The highest level change cost that a decision maker is willing to accept, for example $50M
Changeability Time threshold, $\hat{t}$:	Changeability acceptable time threshold of a decision maker; this varies if making decision for short term (this epoch only) or longer term (multi-epochs).
Design Space	**Description**
Design variable set, $\{DV^N\}$:	The set of design variables for the epoch, For example {Inclination, Apogee Altitude, Perigee Altitude, Communication Arch, Total DeltaV, Propulsion Type, Power Type, Antenna Gain}
Baseline design, DV_{base}:	Baseline design from the previous epoch; if this is first epoch then there is no baseline.
Path-enabling variable set, $\{IV^P\}$:	The variable set whose purpose is to enable new paths in the epoch tradespace, lowering transition cost or adding paths.
Transition rule set, $\{R^K\}$:	Rules for how to change design variable values, where change in one may result in change in another. For example, R1: Plane Change (burn on-board fuel to alter inclination), R2: Apogee Burn (burn on-board fuel to alter apogee), etc.
Cost function, F_c *(CON, DV, IV)*	The cost function for the design, based on the constants, design variables, and the path enabling variables, for example mass-based cost-estimating relationships.
Model	**Description**
Scenario	Visual and descriptive scenario, developed by Team ABC
Model(s) to be used, F_{XM}	The model(s) to be used, for example X-TOS code version 1.1 developed by Team XYZ.

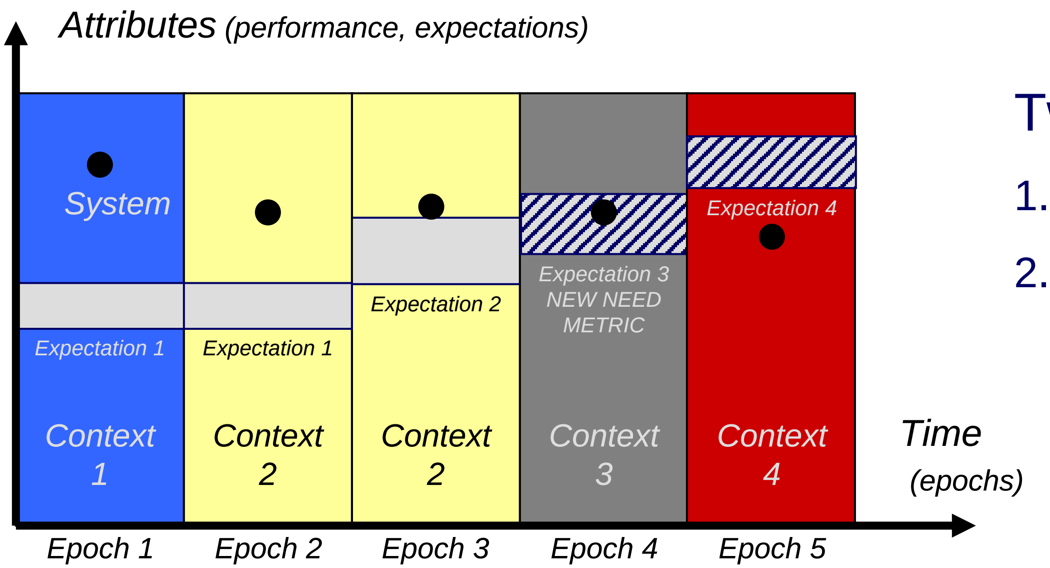
Ross, A.M., and Rhodes, D.H., "Using Natural Value-centric Time Scales for Conceptualizing System Timelines through Epoch-Era Analysis," INCOSE International Symposium 2008, Utrecht, the Netherlands, June 2008

The Dynamic Value Problem

- System 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
- Systems must be able to deliver value in spite of changes in context and needs
  - Strategy one: "Changeable" systems (*i.e.,* use "ilities" in architecture)
  - Strategy two: "Versatile" systems (*i.e.,* build in "extra" value)
- Structured method needed for collecting information to characterize and evaluate systems across a wide variety of possible futures

How can alternatives be evaluated across changing contexts and needs?

Storyboarding with Epochs

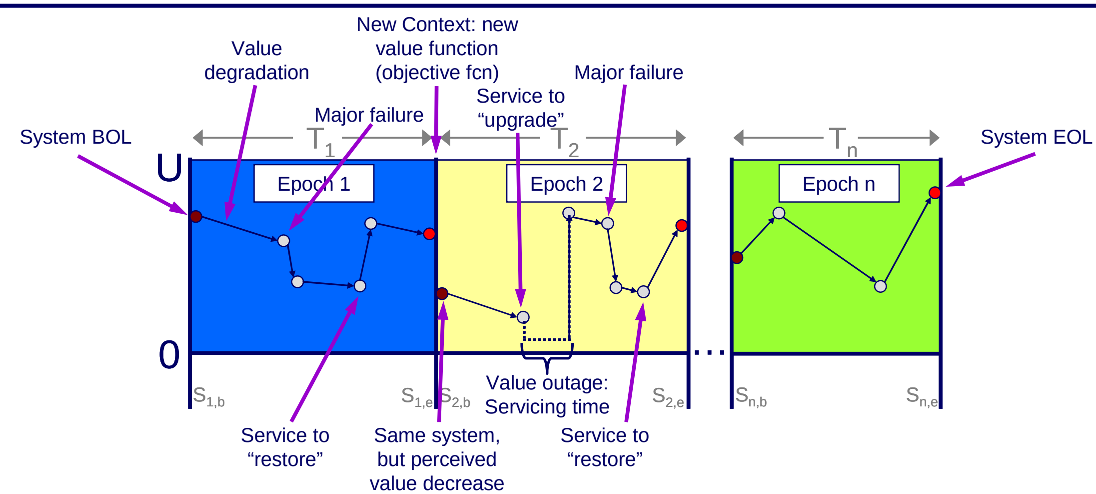


Two aspects to an ***Epoch***:

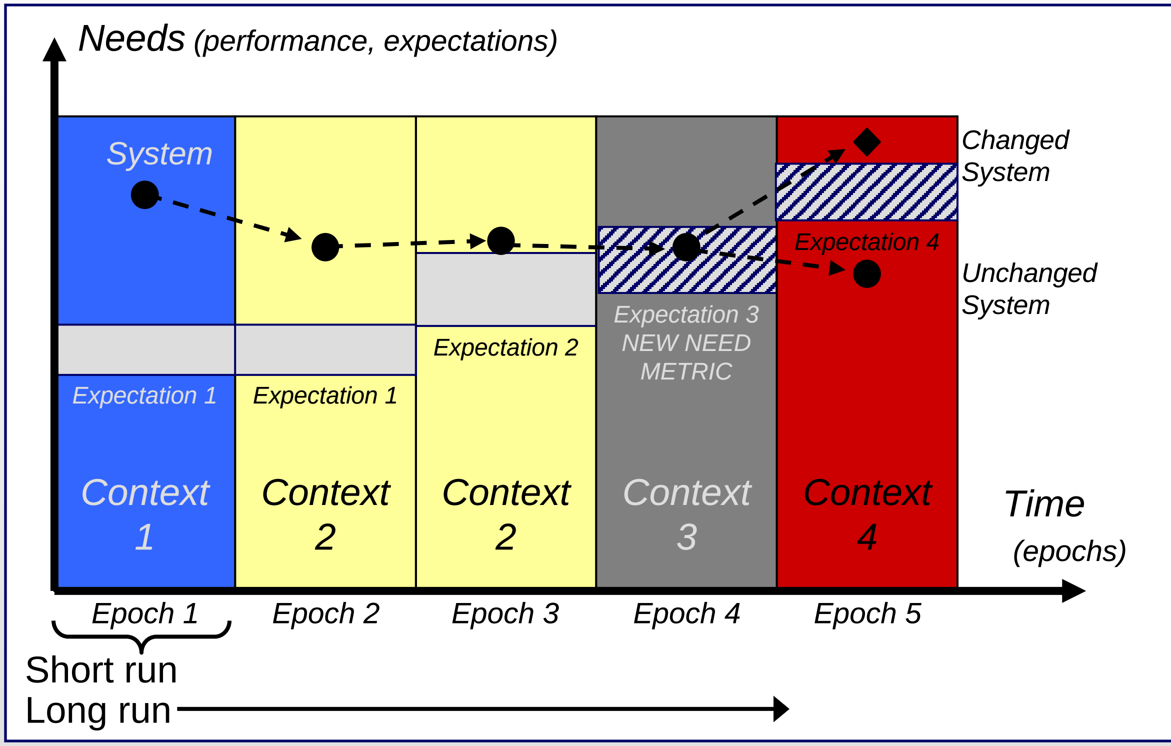
1. Needs (expectations)
2. Context (constraints including resources, technology, etc.)

Needs: …
+
Context: …

Example system: Serviceable satellite



Using Epochs for Proposing Time-Based Strategies



Epoch:

Time period with a fixed context; characterized by static constraints, design concepts, available technologies, and articulated attributes (Ross 2006)

Legend
- System
- System Trajectory
- Expectations

(Ross and Rhodes 2008)

Discretization of change timeline into short run and long run enables analysis

What Can Change: Short Run and Long Run Analysis

In economics, the *short run* is the decision-making period during which at least one input factor is considered fixed

Example: lease on facility (commitment can vary 6 mos to 10 yrs or more)

The *long run* is the decision-making period considered when all inputs are variable

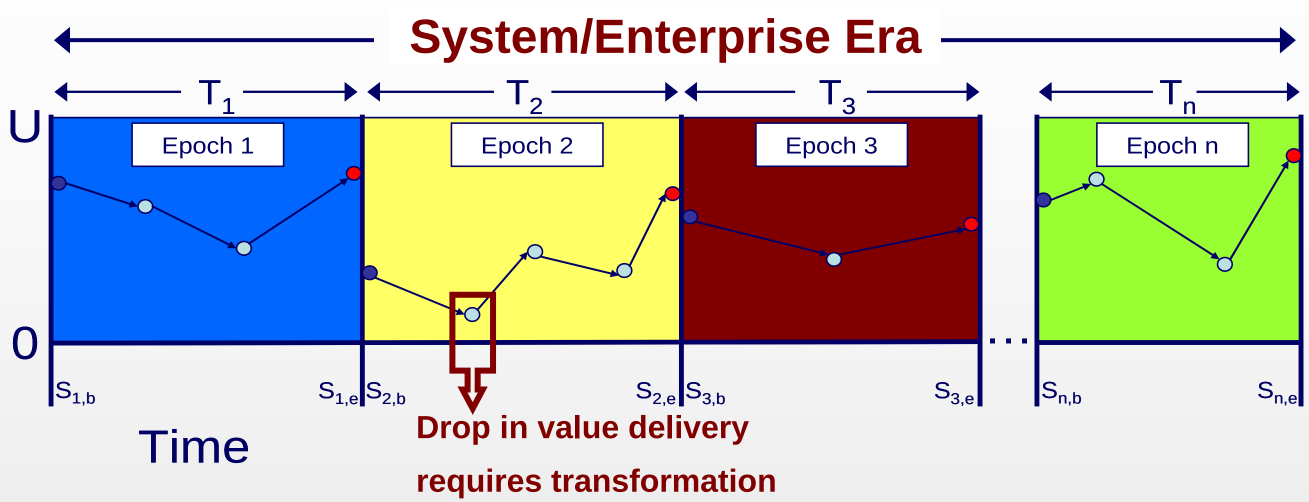
Implication: in short run, optimize subject to fixed constraints; in long run, make strategic decisions to shift possibilities

	Short run		Long run	
	Fixed factors	**Variable factors**	**Fixed factors**	**Variable factors**
Economic Analysis	Input factors such as labor, capital equipment, regulations, knowledge	Quantity demanded, quantity supplied, dollars and time spent	none	all
Engineering Analysis	Objectives, constraints, stakeholder set, technology, concepts	Design chosen, dollars and time spent, perceived value	none	all

Natural analogy from economics to engineering leverages years of methodological validation

Value Delivery Across Epoch Shifts

Epoch is a time period for which context and expectations are fixed



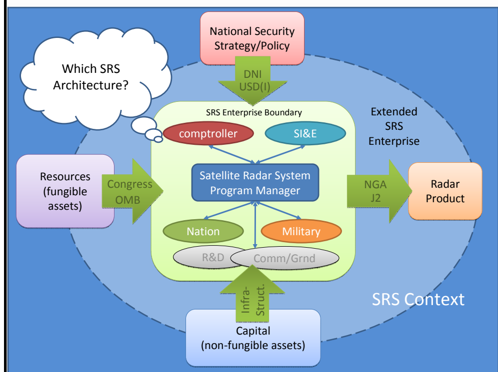
Example triggers for epoch shift impacting system/enterprise

- Change in political environment
- Entrance of new competitor in market
- Emergence of significant new/changed stakeholder need
- Policy mandate impacting product line, services or operations

Categories of epoch variables can aid in thinking about key changing factors

E.g. Resources, Policy, Infrastructure, Technology, End Uses ("Markets"), Competition, etc.

Parameterizing Contexts: Epoch Variables



Enterprise scoping exercise informed the types of "epoch variables" encountered by program

– Enumerate hundreds of contexts

– Analogous to design variables

Epoch Vector

Category	Variable Name	Definition	Range
Capital	**Technology Level**	Includes constants for spacecraft (ex. radar and bus) available technology	**Level 1 (Low),** equiv. TRL = 9 technology **Level 2 (Med),** equiv. TRL = 6 technology **Level 3 (High),** equiv. TRL = 4 technology
	Comm. Level	Availability of ground stations and space-based relay options	**Level 1** – No Backbone + AFSCN Ground Sites **Level 2** – WGS + AFSCN Ground Sites **Level 3** – TSAT + AFSCN+ Ground Sites
	AISR	Availability of AISR assets	Yes / No
Radar Product	**Target list**	Defines the target areas of interest along with target RCS variations	**Op plan 9:** Venezuela: small and N .Korea: small **Op plan 19:** Venezuela: medium and Russia: small **Op plan 44:** Iran: small and Russia: large **Op plan 45:** Iran: small and N. Korea: small **Op plan 49:** Iran: small and China: medium **Op plan 60:** Iran: medium and China: large **Op plan 84**: Russia: medium and China: large **Op plan 94:** N. Korea: small and China: medium **Op plan 103:** China: small and China: medium
	Environment	Communications jamming	Yes / No
Nat Sec Strat/Policy	***Utility SAR v. GMTI***	Relative importance of the two stakeholder types of multi-attribute utility	**Level 1** – SAR < GMTI **Level 2** – SAR = GMTI **Level 3** – SAR > GMTI
Resources	***NA***	Vary budget constraints	Era-level Attributes

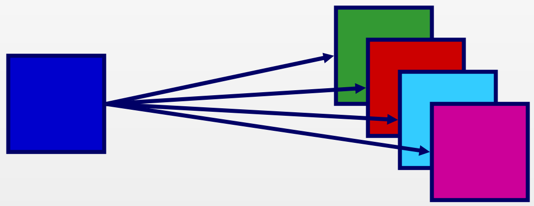
928 Future Contexts

Epoch variables allow for parameterization of some "context" drivers for system value

Generating Metrics

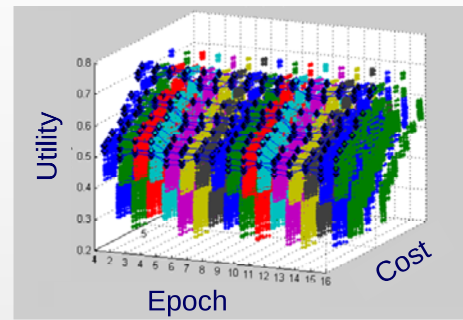
Future context must be known in order to evaluate goal end state and value of end state

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



Today

Possible futures (epochs)



Alternatives can be evaluated over many possible epochs

This topic will be revisited in Lecture 7

Example Constructs and Considerations

STRUCTURAL	• heterogeneous components and constituent systems • elaborate networks, loose and tight couplings • layers, vertical/horizontal structures, multiplicity of scales
BEHAVIORAL	• complex variance in response to stimuli • unpredictable behavior of technological connections • emergent social network behavior
CONTEXTUAL	• many complexities and uncertainties in system context • political, economic, environmental, threat, market factors • stakeholder needs profile and overall worldview
TEMPORAL	• decoupled acquisition phases and context shifts • systems with long lifespan and changing characteristics • time-based system properties (flexibility, survivability, etc.)
PERCEPTUAL	• many stakeholder preferences to consider • perception of value shifts changes with context shifts • cognitive constraints and biases

Unique Focus of Epoch-Based Thinking Approach

Classical Approaches:

- Anticipated possible futures by “spinning scenarios” (typically 3-4)
- Typically used to make ongoing strategic business decisions based on positioning and adaptation strategies should any one of these futures be realized

Epoch-Based Approach:

- Epoch variables are enumerated for key uncertainties and used to generate possible futures
- Used to make architectural design decisions for systems and enterprises

Summary

- An "epoch" represents a discrete and natural way of thinking about context, needs, and time
- The discretization of possible future contexts and needs into ***epochs*** is the basis of Epoch-Based Thinking