

Toward a prescriptive semantic basis for change-type ilities

By

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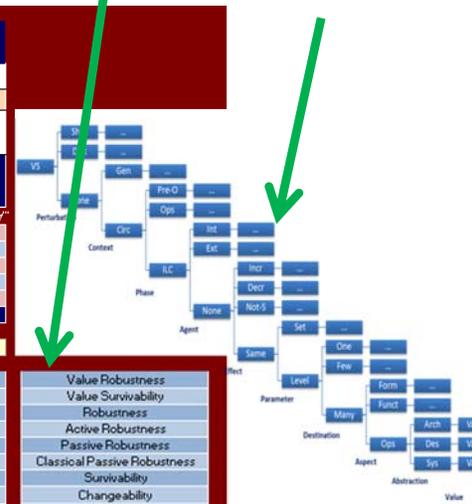
What are the semantic fields that span the general set of ilities?
e.g. "change-type", "architecture-type", "new ability-type"

Prescriptive Semantic Basis for Change-type Ilities

In response to "cause" in "context", desire "agent" to make some "change" in "system" that is "valuable"

| Cause | Context | Phase | Agent | Impetus Change | | | | System | Outcome Change | | | | System | Valuable | | | |
|--------------|---------|-------|-------|----------------|-------------|-------------|--------|--------|----------------|-------------|--------|-------------|-------------|-------------|-------------|-------------|----|
| Perturbation | Context | Phase | Agent | Impetus | | | | System | Outcome | | | | System | Benefit | | | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
| | | | | Nature | Parameter | Destination | Aspect | Effect | Parameter | Destination | Aspect | Abstraction | Reaction | Span | Cost | Benefit | |
| | | | | | "parameter" | "state" | | | "parameter" | "state" | | | "threshold" | "threshold" | "threshold" | "threshold" | |

Generated ility "labels"
Derived ility "hierarchies"



We do not want more definitions, but rather, unambiguous, verifiable, standardized representations of desired system properties

| Perturbation | Context | Phase | Agent | Impetus | | | | System | Outcome | | | | System | Benefit | | | |
|--------------|---------------|----------|----------|----------|-----------|-------------|------------|----------|-----------|-------------|------------|--------------|----------|---------|------|---------|--|
| | | | | Nature | Parameter | Destination | Aspect | Effect | Parameter | Destination | Aspect | Abstraction | Reaction | Span | Cost | Benefit | |
| disturbance | circumstantia | pre-ops | internal | increase | level | one | form | increase | level | one | form | architecture | sooner | shorter | less | more | |
| shift | general | ops | external | decrease | set | few | function | decrease | set | few | function | design | later | longer | more | less | |
| none | any | inter-LC | either | not-same | any | many | operations | not-same | any | many | operations | system | always | same | same | same | |
| any | | any | none | same | any | any | any | same | any | any | any | any | any | any | any | any | |

Ultimate Goal: develop the basis/bases to be a prescriptive instrument(s) for spanning the semantic fields whose union encompass all "ilities"

Design for -ilities Handbook

Now with Metrics!

Table of Contents

Acknowledgements

Foreword

Introduction and Motivation

The need for ilities, history, current use

Defining "ilities"

What it can mean, how it can be represented

Organizing Ilities: Semantic Fields

Change type, architecture type, new ability type

Defining Ilities: Semantic Bases

Change-type, architecture-type, and new ability type

"Design for "ility"

Grouped by some scheme (alphabetical or by semantic field)

- "Definition"/description (also using semantic basis)
- Semantic basis example
- Related ilities
- Enablers/principles
- Examples (with and without the ility; light and detailed)
- Metrics (exist, evaluation, valuation)
- Considerations/concerns/challenges/potential confusion

Open Research Questions

Maps and "Tools"

Hierarchies

Glossary

Index

Wouldn't it be great to have this on your desk?

One of the key objectives for this work is to stimulate a new conversation on a theory of ilities

*Linguistic meaning vs.
speaker meaning*

Literal vs. nonliteral

*"Rep. John Mica called on the agency to "reform" and "become...a thinking, risk-based, **flexible** agency that analyzes risks, sets security standards and audits security performance."*

*"ULA says the network augments 'more **robust** and **flexible** execution of Command and Control, Communications Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR)..."*

*To Axe, there is a "clear" need for the K-MAX because operations in the country are "highly dependent on **flexible, reliable** and secure logistics..."*

*"Defense Secretary Panetta: "The US joint force will be smaller and it will be leaner. But it will be more **agile**, more **flexible**, ready to deploy quickly, innovative and technologically advanced."*

*... "the Defense Department and the Office of the Director of National Intelligence pledged to foster an industrial base that is '**robust**, competitive, **flexible**, healthy, and delivers **reliable** space capabilities on time and on budget.'"*

- Linguistics is the scientific study of human natural language, including semantics
- Semantics is the study of "meaning" and is a promising area for clarifying the "ilities"
- Meaning arises from interplay of "use" (i.e. speech) and "prescription" (i.e. dictionaries)
- Technical and political leaders are using "ilities" so we need to understand them well enough to ensure systems predictably display these properties

Semantic field

"a group of words with related meanings, for example kinship terms or color terms"

Akmajian et al 2001, p. 587

Quotes from AIAA Daily Launch, 20 Jul 2011 – 13 Feb 2012

- Fundamental “ambiguity” in terms
 - Many of these terms are use colloquially and therefore inherit meaning
 - Polysemy – “The property of [a term] having multiple meanings that are semantically related”
 - Flexibility (able to be changed) and flexibility (able to satisfy multiple needs)
 - Synonymy – “The property of multiple terms having similar meaning”
 - Flexibility (able to be changed) and changeability (able to be changed or change itself)
- Problem partly stems from considering one ility at a time
 - e.g. flexibility:
 - Saleh, J. H., Mark, G.T., and Jordan, N.C. (2009). "Flexibility: a multi-disciplinary literature review and a research agenda for designing flexible engineering systems." *Journal of Engineering Design*.
 - Nilchiani, R. (2005). *Measuring Space Systems Flexibility: A Comprehensive Six-element Framework. PhD in Aeronautics and Astronautics*, MIT.
 - De Neufville, R. and Scholtes, S. (2011). *Flexibility in Engineering Design*, MIT Press: Cambridge MA.
- Some work done on sets
 - e.g. changeability:
 - Fricke and Schulz (2005). “Design for Changeability (DfC): Principles to Enable Changes in Systems Throughout their Entire Lifecycle.” *Systems Engineering*
 - Ross, Rhodes and Hastings (2008). “Defining Changeability: Reconciling Flexibility, Adaptability, Scalability, Modifiability, and Robustness for Maintaining System Lifecycle Value.” *Systems Engineering*

If challenge can be addressed by looking at sets of ilities, how do we select members of the set?

Potential Set Sources

Academic Opinion: ESD Symposium Committee (2001)

ESD Symp. Cmtee, "ESD Terms and Definitions (ver 12)" ESD-WP-2002-1, 2001.

| ID Number | Name |
|-----------|-----------------|
| P1 | Flexibility |
| P2 | Agility |
| P3 | Robustness |
| P4 | Fail-safe |
| P5 | Adaptability |
| P6 | Scalability |
| P7 | Modularity |
| P8 | Safety |
| P9 | Durability |
| P10 | Sustainability |
| P11 | Quality |
| P12 | Reliability |
| P13 | Repairability |
| P14 | Maintainability |

"Requirements of systems, such as flexibility or maintainability, often ending in 'ility'; requirements of systems that are not necessarily part of the fundamental set of functions or constraints" p. 4

This list was developed by 11 MIT faculty working as a committee

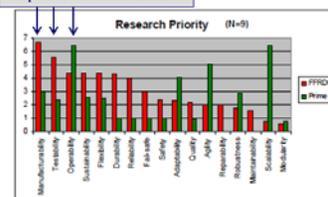
The list is reflective of the interests of the committee members

Asking Practitioners: Interviews for Ilities Knowledge Gap

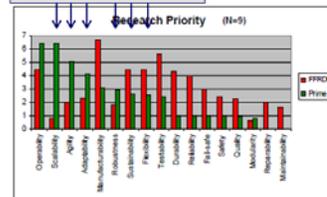
Ross, A.M., "Managing Unarticulated Value: Changeability in Multi-Attribute Tradespace Exploration" *Engineering Systems Division*, Ph.D., 2006.

14 ESD-defined ilities + 3 (manufacturability, testability, operability)

Top 3 are non-ESD



Top 6 ESD



Primes are practitioners; FFRDCs are more like academia

From Prime: The top 6 (ESD) ilities research priorities are

1. Scalability
2. Agility
3. Adaptability
4. Robustness
5. Sustainability
6. Flexibility

"'ilities' are not part of the lexicon of even the most successful project managers"
-Select quote from interviews (p. 37)

From Standards

1. Internal and External Quality
 - a. Functionality: Suitability, Accuracy, Interoperability, Security
 - b. Reliability: Maturity, Fault Tolerance, Recoverability
 - c. Usability: Understandability, Learnability, Operability, Attractiveness
 - d. Efficiency: Time Behavior, Resource Utilization,
 - e. Maintainability: Changeability, Stability, Testability
 - f. Portability: Adaptability, Installability, Co-Existence, Replaceability
 2. Quality in Use
 - a. Effectiveness: Productivity, Safety, Satisfaction
- ISO/IEC, 2007; Boegh, 2008

Nonfunctional Requirements

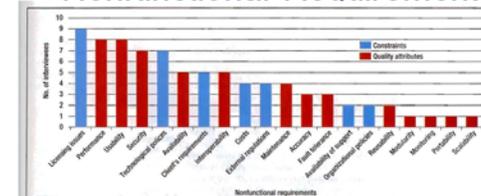


FIGURE 1. Relevance of nonfunctional requirement types from surveyed architects' perspective. This shows the number of interviews that mentioned each type of NFR as relevant.

Buschmann et al., 2012

Crowd Sourced: Wikipedia "ilities" List*

accessibility
accountability
accuracy
adaptability
administrability
affordability
agility
auditability
autonomy
availability
credibility
process capabilities
compatibility
composability
configurability
correctness
customizability
debuggability
degradability
determinability
demonstrability
dependability

deployability
discoverability
distributability
durability
effectiveness
efficiency
evolvability
extensibility
failure transparency
fault-tolerance
fidelity
flexibility
inspectability
inspectability
installability
integrity
interchangeability
interoperability
learnability
maintainability
manageability
mobility
modifiability

modularity
operability
orthogonality
portability
precision
predictability
producibility
provability
recoverability
relevance
reliability
repeatability
reproducibility
resilience
responsiveness
reusability
robustness
safety
scalability
seamlessness
self-sustainability
serviceability (a.k.a.

supportability)
securability
simplicity
stability
standards compliance
survivability
sustainability
tailorability
testability
timeliness
traceability
ubiquity
understandability
upgradability
usability

Within systems engineering, quality attributes are non-functional requirements used to evaluate the performance of a system. These are sometimes named "ilities" after the suffix many of the words share.

Missing from this list: changeability, manufacturability, quality, reconfigurability, versatility

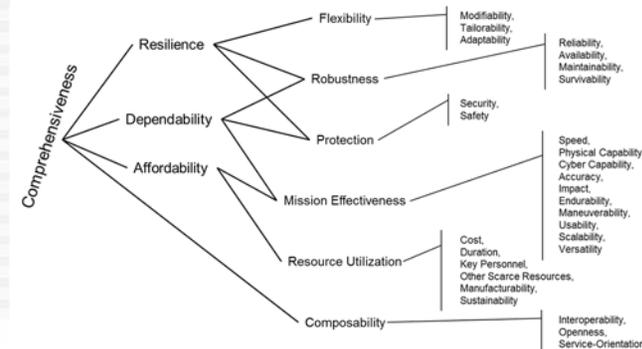
*There were 61 "-ities" on Wikipedia on April 24, 2008, 71 on March 3, 2010, 78 on February 8, 2011, 79 on February 13, 2012

Quality Requirements

| ility | Effect on DoD Operational System |
|----------------------|--|
| Quality of Service | Stakeholder-satisfactory balance of Performance, Accuracy, Usability, Scalability, Versatility |
| Performance | Stakeholder-satisfactory balance of desired performance ilities: speed, range, payload, response time, etc. |
| Accuracy | Closeness to target |
| Usability | Ease of learning, ease of use, difficulty of misuse |
| Scalability | Sustainability of system capability across a range of system or environmental scales |
| Versatility | Range of capabilities provided |
| Resource Utilization | Smallest percent remaining of distance to system constraint |
| Cost | Percent remaining of distance to system cost constraint |
| Duration | Percent remaining of distance to system duration constraint |
| Key Personnel | Percent remaining of distance to system key personnel constraint |
| Other Constraints | Percent remaining of distance to other system constraint (size, weight, energy, bandwidth, data storage, etc.) |
| Protection | Stakeholder loss of value due to natural causes, adversary actions, or compromise of personal information |
| Safety | Stakeholder loss of value due to natural causes. |
| Security | Stakeholder loss of value due to adversary actions |
| Privacy | Stakeholder loss of value due to compromise of personal information |
| Robustness | Ability of the system to continue to deliver stakeholder-desired other-ility levels |
| Reliability | Probability that the system will continue to deliver stakeholder-desired other-ility levels |
| Availability | Fraction of the time that the system will deliver stakeholder-desired other-ility levels |
| Maintainability | Expected amount of time required to restore system capability |
| Survivability | Ability of the system to continue to deliver partial stakeholder-desired other-ility levels |
| Flexibility | Expected ROI in total ownership cost from investments in Modifiability, Tailorability, and Adaptability |
| Modifiability | Expected ROI in total ownership cost from investments in Modifiability |
| Tailorability | Expected ROI in total ownership cost from investments in Tailorability, including Extendability |
| Adaptability | Expected ROI in total ownership cost from investments in Adaptability |
| Composability | Expected ROI in total ownership cost from investments in Interoperability, Openness, and Service-Orientation |
| Interoperability | Expected ROI in total ownership cost from investments in Interoperability, including Portability |
| Openness | Expected ROI in total ownership cost from investments in Openness, including Standards Compliance |
| Service-Orientation | Expected ROI in total ownership cost from investments in Service-Orientation |
| Composile ilities | |
| Comprehensiveness | All of the above |
| Dependability | Quality of Service, Protection, Robustness |
| Resilience | Protection, Robustness, Flexibility |
| Affordability | Quality of Service, Resource Utilization |

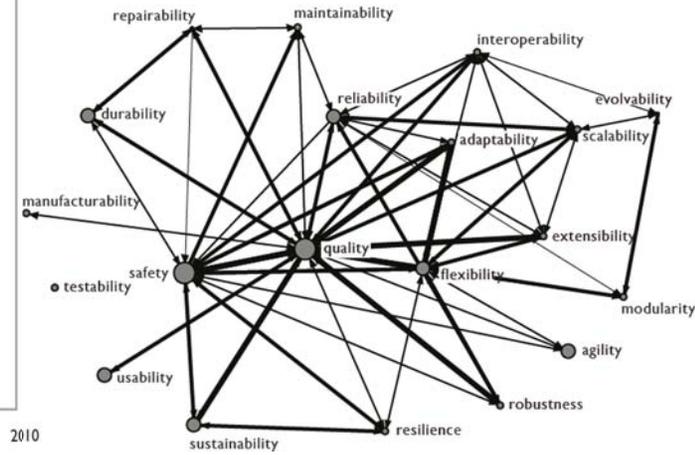
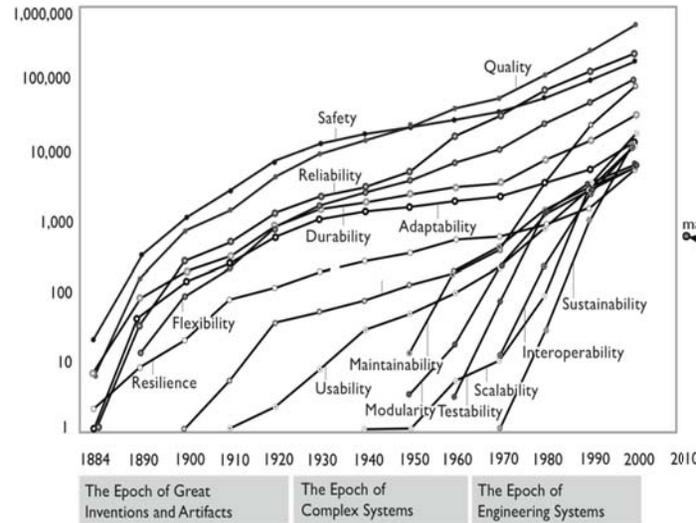
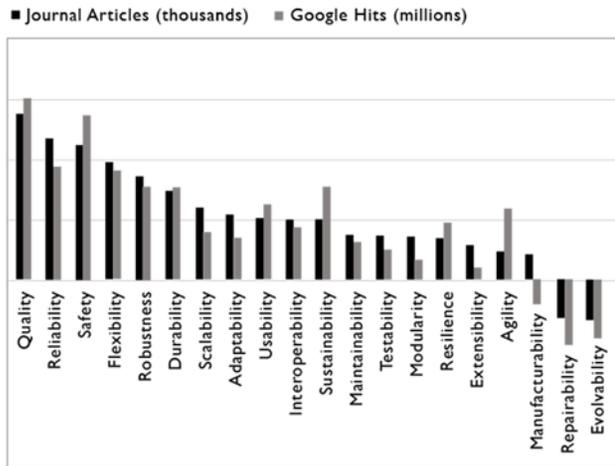
USC technical report, "The Nature of Information System Dependability: A Stakeholder/Value Approach" as USC-CSE-2004-520 at http://csse.usc.edu/cse/TECHRPTS/2004/2004_main.html

SERC ITAP 2013



These are just a handful of sources; What is the basis for their inclusion in each proposed set? How are these ilities related to one another? How can ilities be traded off?

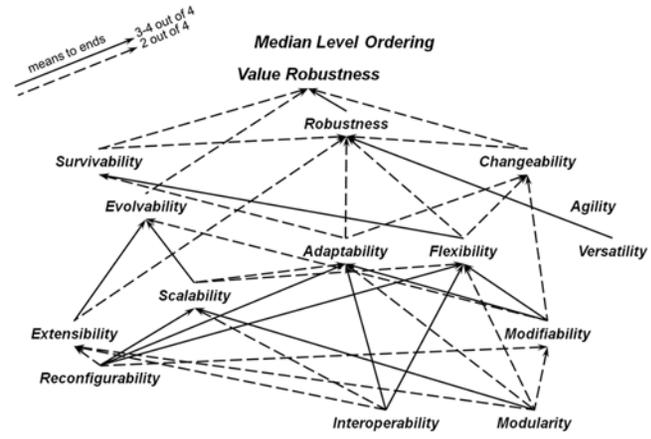
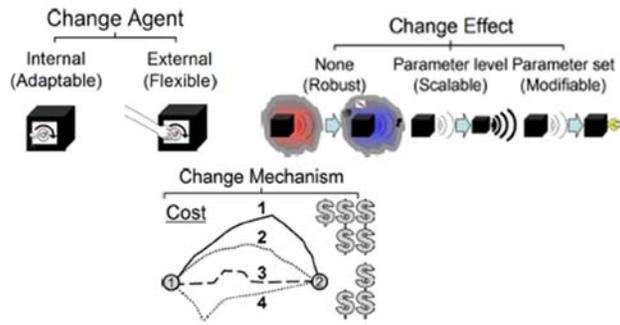
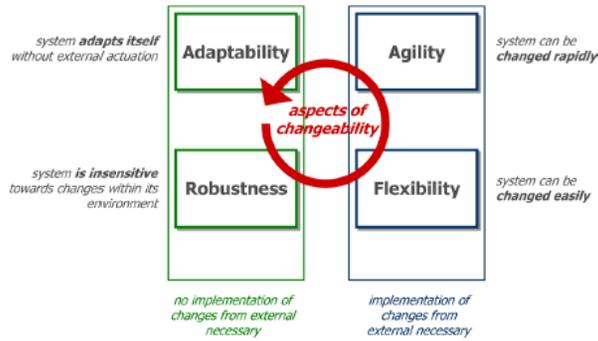
Descriptive and Prescriptive Approaches



Frequency of ilties mentioned in journal articles and Google hits (de Weck, Roos, Magee 2011, p. 67)

Frequency of ilties mentioned in literature across time (de Weck, Roos, Magee 2011, p. 69)

ility term co-occurrence in the literature with implied dependence (de Weck, Roos, Magee 2011, p. 83)

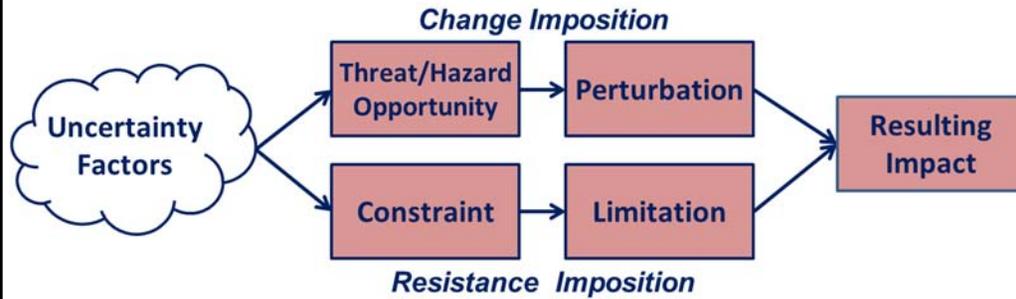


"Design for Changeability (DfC): Principles to Enable Changes in Systems Throughout their Entire Lifecycle" *Syst Eng*, Vol. 8, No. 4, 2005.

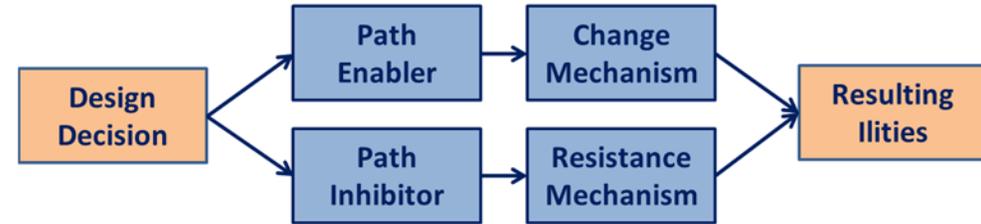
"Defining Changeability: Reconciling Flexibility, Adaptability, Scalability, Modifiability, and Robustness for Maintaining System Lifecycle Value" *Syst Eng*, Vol. 11, No. 3, 2008.

de Weck, O.L., Ross, A.M., and Rhodes, D.H., "Investigating Relationships and Semantic Sets amongst System Lifecycle Properties (Ilties)," 3rd International Conference on Engineering Systems, TU Delft, the Netherlands, June 2012.

Uncertainties



Responses

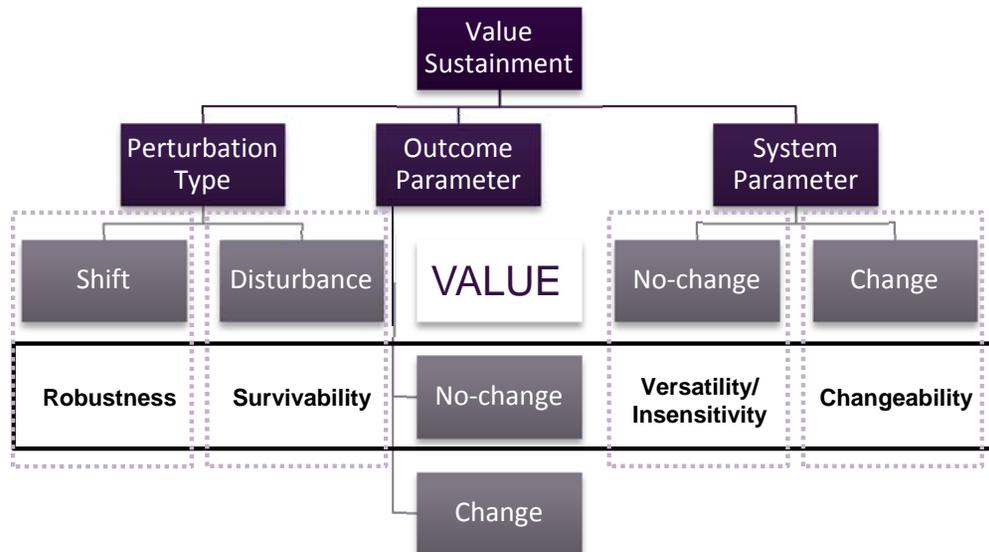


Perturbations and limitations impact value

Changes and resistances maintain value

Suppose we want to maintain value
(i.e. no-change in outcome parameter value)

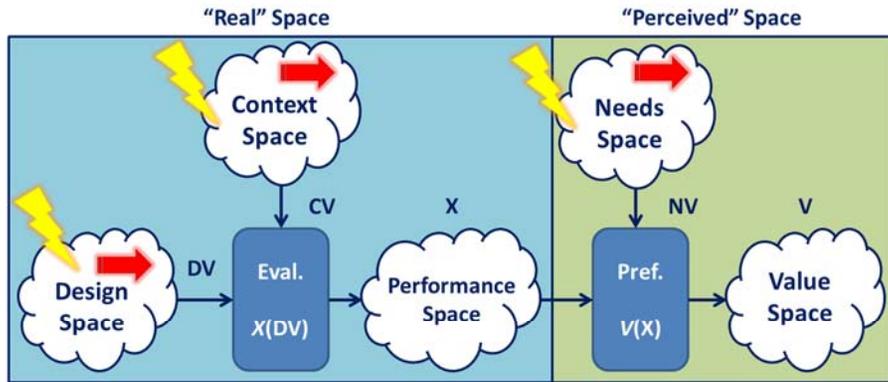
There are four high level ility responses



| | | Perturbation Type | |
|------------------|-----------|--------------------------------------|---|
| | | Shift | Disturbance |
| System Parameter | Change | Robustness (via Change) | Survivability (via Change) |
| | No-Change | Robustness (via No-Change) | Survivability (via No-Change) |

Having a basis allows us to quickly derive responses

Theoretical Framework Motivating a Semantic Basis



- Extracted concepts from wide review of literature and theoretical frameworks
- Avoiding imposed definitions; focused on potential degrees of freedom implied within an array of “change-type” ility definitions
- Results in a “mix and match” set of *bases* from which to propose “definitions” that can be labelled with ility terms

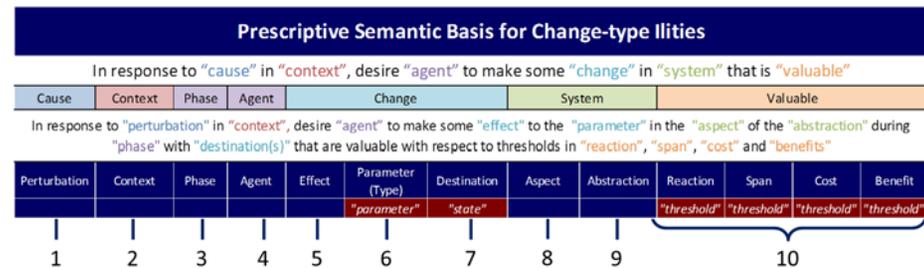
| Real Space |
|-------------|
| Abstraction |
| Aspect |
| Phase |
| Context |

| Perturbation | Change |
|--------------|-------------|
| Disturbance | Parameter |
| Shift | Agent |
| | Effect |
| | Destination |

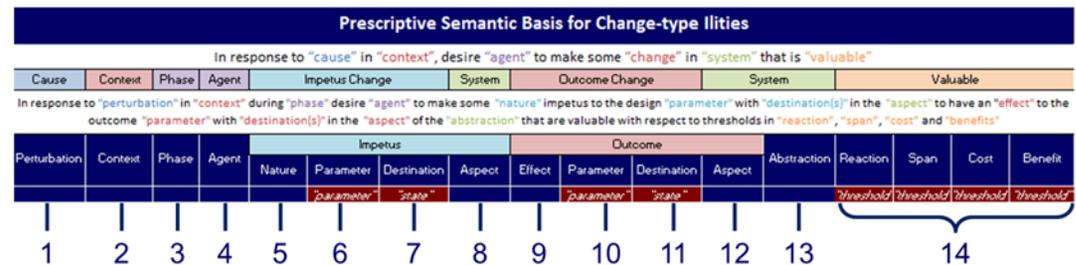
| Perceived Space |
|-----------------|
| Benefit |
| Cost |
| Reaction |
| Span |

| Dimension | Name | Source |
|-----------|-------------------------------|-----------------------------|
| 1 | Perturbation | Chapter 3 |
| 2 | Context | Chapter 3 |
| 3 | Phase (Change Mechanism) | Ross and Rhodes 2011 |
| 4 | Change Agent | Ross, Rhodes, Hastings 2008 |
| 5 | Change Effect | Ross, Rhodes, Hastings 2008 |
| 6 | Parameter (Change Effect) | Ross, Rhodes, Hastings 2008 |
| 7 | End States (Change Mechanism) | Ross and Rhodes 2011 |
| 8 | Aspect | Chapter 3 |
| 9 | Abstraction | Chapter 3 |
| 10 | Valuable | Ross and Rhodes 2011 |

10D Basis



14D Basis



Beesemyer, J.C., *Empirically Characterizing Evolvability and Changeability in Engineering Systems*, Master of Science Thesis, Aeronautics and Astronautics, MIT, June 2012.

Generalizing the Change-related Statement: A Prescriptive Basis

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

(From Ross, Rhodes, and Hastings 2008)

Prescriptive Semantic Basis for Change-related Ilities

In response to “cause” in “context”, desire “agent” to make some “change” in “system” that is “valuable”

| Cause | Context | System | | | Agent | Change | | | | Valuable | | | |
|--------------|----------------|--------------|------------|----------|----------|-------------------|----------------|-----------------|------------------|----------|----------|-----------|----------|
| | | What | What | When | | What | What | What | What | When | When | For What | For What |
| Why | Where | What | What | When | Who | What | What | What | What | When | When | For What | For What |
| Cause | Context | Entity | Aspect | Phase | Agent | Param Change Type | Effect (Scale) | Effect (Amount) | Potential States | Timing | Span | Resources | Benefit |
| perturbation | specificity | abstraction | aspect | LC phase | executes | param type | level | set | target range | reaction | duration | cost | utility |
| disturbance | circumstantial | architecture | form | pre-ops | internal | level | bigger | more | one | sooner | shorter | more | more |
| shift | general | design | function | ops | external | set | smaller | less | few | later | longer | less | less |
| none | any | system | operations | inter-LC | either | any | not-same | not-same | many | always | same | same | same |
| any | | any | any | any | none | | same | same | any | any | any | any | any |
| | | | | | any | | any | any | | | | | |

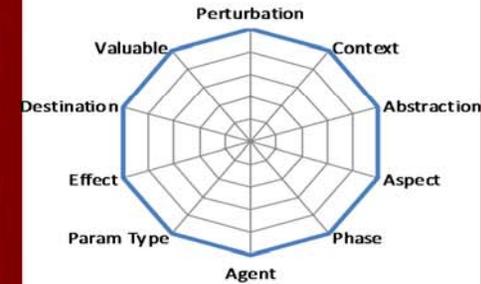
10 category basis for specifying “change-related” ilities

Using the Basis to Map Ility Term Labels An Early Application

Prescriptive Semantic Basis for Change-type Ilities

In response to "cause" in "context", desire "agent" to make some "change" in "system" that is "valuable"

| Cause | Context | Phase | Agent | Change | System | Valuable | | | | | | |
|--|----------------|----------|----------|----------|------------------|-------------|------------|--------------|-------------|-------------|-------------|-------------|
| In response to "perturbation" in "context", desire "agent" to make some "effect" to the "system parameter" in the "aspect" of the "abstraction" during "phase" with "destination(s)" that are valuable with respect to thresholds in "reaction", "span", "cost" and "benefits" | | | | | | | | | | | | |
| Perturbation | Context | Phase | Agent | Effect | Parameter (Type) | Destination | Aspect | Abstraction | Reaction | Span | Cost | Benefit |
| | | | | | "parameter" | "state" | | | "threshold" | "threshold" | "threshold" | "threshold" |
| disturbance | circumstantial | pre-ops | internal | increase | level | one | form | architecture | sooner | shorter | less | more |
| shift | general | ops | external | decrease | set | few | function | design | later | longer | more | less |
| none | any | inter-LC | either | not-same | any | many | operations | system | always | same | same | same |
| any | | any | none | same | | any | any | any | any | any | any | any |
| | | | any | any | | | | | | | | |



| | | | | | | | | | | | | |
|--|--|--|--|--|--|--|--|--|--|--|--|--|
| | | | | | | | | | | | | |
|--|--|--|--|--|--|--|--|--|--|--|--|--|

| | | | | | | | | | | | | |
|-------------|---------|----------|----------|----------|---------------|-----|------------|-----|--------|---------|-----|-----|
| shift | any | any | any | same | "Value" | few | any | any | any | any | any | any |
| disturbance | any | any | any | same | "Value" | few | any | any | any | any | any | any |
| shift | any | ops | any | same | any | few | any | any | any | any | any | any |
| shift | any | ops | none | same | | | | | | | any | any |
| disturbance | any | ops | any | same | | | | | | | any | any |
| any | any | any | either | not-sar | | | | | | | any | any |
| shift | general | inter-LC | any | not-sar | | | | | | | any | any |
| any | any | any | internal | not-sar | | | | | | | any | any |
| any | any | any | external | not-sar | | | | | | | any | any |
| any | any | any | any | not-sar | | | | | | | any | any |
| any | any | any | any | not-same | set | any | any | any | any | any | any | any |
| any | any | ops | either | increase | set | any | any | any | any | any | any | any |
| any | any | any | any | not-same | any | any | any | any | any | shorter | any | any |
| any | any | any | any | not-same | any | any | any | any | sooner | any | any | any |
| any | any | ops | any | same | "Element set" | one | form | any | any | any | any | any |
| any | any | ops | any | not-same | "Link set" | any | form | any | any | any | any | any |
| any | any | ops | any | same | "Element set" | one | operations | any | any | any | any | any |
| any | | | | | "Set" | | | | | | | |
| any | | | | | | | | | | | | |
| any | | | | | | | | | | | | |
| any | any | ops | any | same | any | one | fnct/ops | any | any | any | any | any |
| any | any | ops | any | not-same | set | few | form | any | any | any | any | any |

Interviews should be used to associate ility term labels with particular choices in the bases

Once the ility term mapping "dictionary" is populated, whenever choices are made in the bases, associated ility terms can be assigned

| Ility Name | Publish |
|-------------------------------|---------|
| Value Robustness | |
| Value Survivability | |
| Robustness | |
| Classical Passive Robustness | |
| Survivability | |
| Changeability | |
| Evolvability | |
| Adaptability | |
| Flexibility | |
| Scalability | |
| Modifiability | |
| Extensibility | |
| Agility | |
| Reactivity | |
| Form Reconfigurability | |
| Operational Reconfigurability | |
| Functional Versatility | |
| Operational Versatility | |
| Exchangeability | |

Prescriptive Semantic Basis for Change-type Ilities

In response to "perturbation" in "context", desire "agent" to make some "change" in "system" that is "valuable"

| Perturbation | Context | Phase | Agent | Impetus Change | | | | | Mech | Outcome Change | | | | | System | Valuable* (this category is not complete) | | | |
|--|--|----------|-----------|---------------------|-------------|------------|-------------|--|-----------|----------------|-------------|------------|-------------|------------|--------------|---|----------------------|----------------------|----------------------|
| <p>In response to "perturbation" in "context" during "phase" desire "agent" to make some "nature" impetus to the system "parameter" from "origin(s)" to "destination(s)" in the "aspect" using "mechanism" in order to have an "effect" to the outcome "parameter" from "origin(s)" to "destination(s)" in the "aspect" of the "abstraction" that are valuable with respect to thresholds in "reaction", "span", "cost" and "benefits"</p> | | | | | | | | | | | | | | | | | | | |
| Perturbation | Context | Phase | Agent | Impetus* (optional) | | | | | Mech | Outcome | | | | | Abstraction | Reaction | Span | Cost | Benefit |
| | | | | Nature | Parameter | Origin | Destination | Aspect | Mechanism | Effect | Parameter | Origin | Destination | Aspect | | | | | |
| optional | circumstantial; required; general; optional | null | optional | null | required | optional | optional | null* (this is implied by "parameter") | Optional | null | required | optional | optional | null* | optional | required | required | required | required |
| "name " | "name(s)" | | "name(s)" | | "parameter" | "state(s)" | "state(s)" | | "name " | | "parameter" | "state(s)" | "state(s)" | | "name " | "threshold units" | "threshold units" | "threshold units" | "threshold units" |
| none | circumstantial | pre-ops | none | decrease | level | one | one | form | | decrease | level | one | one | form | architecture | sooner | shorter | less | more |
| disturbance | general | ops | internal | same | set | few | few | function | | same | set | few | few | function | design | later | longer | same | same |
| shift | <empty> | inter-LC | external | increase | <empty> | many | many | operations | | increase | <empty> | many | many | operations | system | always | same | more | less |
| <empty> | <empty> | <empty> | either | not-same | <empty> | <empty> | <empty> | <empty> | | not-same | <empty> | <empty> | <empty> | <empty> | <empty> | <empty> | <empty> | <empty> | <empty> |
| | | | <empty> | <empty> | | | | | | <empty> | | | | | | | | | |

In response to "perturbation" in "context" during "phase" desire "agent" to make some "nature" impetus to the system "parameter" from "origin(s)" to "destination(s)" in the "aspect" using "mechanism" in order to have an "effect" to the outcome "parameter" from "origin(s)" to "destination(s)" in the "aspect" of the "abstraction" that are valuable with respect to thresholds in "reaction", "span", "cost" and "benefits"

The semantic basis would be used differently in different use cases

Full basis:

- When trying to write a very specific requirement statement (should not occur until AFTER analysis to determine what should be done)

Subset of basis:

- Early in the design phase, leave out the "valuable" categories (these are subjective, depend on outside factors)
- If one is trying to avoid fixating on a solution-centric approach, leave out change mechanism (allow engineers to propose own alternatives)

Full basis: 20 columns

| Prescriptive Semantic Basis for Change-type Illities | | | | | | | | | | | | | | | | | | | |
|--|---|----------|-----------|----------------|-----------|----------|-------------|------------------------------------|-----------|----------|-----------|---|-------------|----------|--------------------|--------------------|--------------------|--------------------|--------------------|
| In response to "perturbation" in "context" desire "agent" to make some "change" in "system" that is "valuable" | | | | | | | | | | | | | | | | | | | |
| Perturbation | Context | Phase | Agent | Impetus Change | | | Mech. | Outcome Change | | | System | Valuable (the category is not complete) | | | | | | | |
| | | | | Nature | Parameter | Origin | Destination | Aspect | Mechanism | Effect | Parameter | Origin | Destination | Aspect | Abstraction | Reaction | Span | Cost | Benefits |
| optional | circumstantial required general optional | null | optional | null | required | optional | optional | null (this is implied by "system") | Optional | null | required | optional | optional | null | optional | required | required | required | required |
| Name | Name/ID | Subtype | Parameter | Name/ID | Name/ID | Name/ID | Name/ID | Name | Parameter | Name/ID | Name/ID | Name/ID | Name/ID | Name | Threshold category |
| type | circumstantial | periodic | static | increase | decrease | same | same | same | increase | decrease | same | same | same | same | substructure | structure | structure | time | time |
| distance | general | type | internal | same | set | set | few | few | function | same | set | set | few | function | design | later | longer | same | same |
| prob | category | none/0 | central | increase | category | may | may | operational | increase | category | may | may | operational | system | always | same | more | less | less |
| category | category | other | category | category | category | category | category | category | category | category | category | category | category | category | category | category | category | category | category |

In response to "perturbation" in "context" during "phase" desire "agent" to make some "nature" impetus to the system "parameter" from "origin(s)" to "destination(s)" in the "aspect" using "mechanism" in order to have an "effect" to the outcome "parameter" from "origin(s)" to "destination(s)" in the "aspect" of the "abstraction" that are valuable with respect to thresholds in "reaction", "span", "cost" and "benefits"

In response to "perturbation" in "context" during "phase" desire "agent" using "mechanism" to have an "effect" to the outcome "parameter" from "origin(s)" to "destination(s)" in the "aspect" of the "abstraction"

When to use: if there is a constraint to make use of an existing/inherited mechanism, for example.

Note: This version is OUTCOME oriented, leaving open the "valuable" specification, but leaves in the "mechanism" category to constrain how the change should occur.

(11 columns)

| Prescriptive Semantic Basis for Change-type Illities | | | | | | | | | | |
|---|--|----------|-----------|-----------|----------------|-------------|------------|-------------|------------|--------------|
| In response to "perturbation" in "context", desire "agent" to make some "change" in "system" | | | | | | | | | | |
| Perturbation | Context | Phase | Agent | Mech | Outcome Change | | | | | System |
| In response to "perturbation" in "context" during "phase" desire "agent" using "mechanism" to have an "effect" to the outcome "parameter" from "origin(s)" to "destination(s)" in the "aspect" of the "abstraction" | | | | | | | | | | |
| Perturbation | Context | Phase | Agent | Mech | Outcome | | | | | Abstraction |
| | | | | Mechanism | Effect | Parameter | Origin | Destination | Aspect | |
| optional | circumstantial: required: general: optional | null | optional | optional | null | required | optional | optional | null | optional |
| "name" | "name(s)" | | "name(s)" | "name" | | "parameter" | "state(s)" | "state(s)" | | "name" |
| none | circumstantial | pre-ops | none | | decrease | level | one | one | form | architecture |
| disturbance | general | ops | internal | | same | set | few | few | function | design |
| shift | <empty> | inter-LC | external | | increase | <empty> | many | many | operations | system |
| <empty> | | <empty> | either | | not-same | | <empty> | <empty> | <empty> | <empty> |
| | | | <empty> | | <empty> | | | | | |

In response to "perturbation" in "context" during "phase" desire "agent" to make some "nature" impetus to the system "parameter" from "origin(s)" to "destination(s)" in the "aspect" using "mechanism" in order to have an "effect" to the outcome "parameter" from "origin(s)" to "destination(s)" in the "aspect" of the "abstraction" that are valuable with respect to thresholds in "reaction", "span", "cost" and "benefits"

In response to "perturbation" in "context" during "phase" desire "agent" to have an "effect" to the outcome "parameter" from "origin(s)" to "destination(s)" in the "aspect" of the "abstraction" that are valuable

When to use: early in design in order to not over specify the change mechanism (allow engineers to propose/evaluate alternatives), or impetus (i.e. this is OUTCOME oriented).

Note: Leaving out "valuable" part of statement supports exploration. Later, when implications of ility statement are better understood, one can specify (differently across stakeholders, if desired) subjective thresholds on what makes the change "valuable."

(10 columns)

| Prescriptive Semantic Basis for Change-type Ilities | | | | | | | | | | |
|---|--|----------|-----------|----------------|-------------|------------|-------------|------------|--------------|--------|
| In response to "perturbation" in "context", desire "agent" to make some "change" in "system" | | | | | | | | | | |
| Perturbation | Context | Phase | Agent | Outcome Change | | | | | | System |
| In response to "perturbation" in "context" during "phase" desire "agent" to have an "effect" to the outcome "parameter" from "origin(s)" to "destination(s)" in the "aspect" of the "abstraction" that are valuable | | | | | | | | | | |
| Perturbation | Context | Phase | Agent | Effect | Parameter | Origin | Destination | Aspect | Abstraction | |
| optional | circumstantial; required; general; optional | null | optional | null | required | optional | optional | null | optional | |
| "name" | "name(s)" | | "name(s)" | | "parameter" | "state(s)" | "state(s)" | | "name" | |
| none | circumstantial | pre-ops | none | decrease | level | one | one | form | architecture | |
| disturbance | general | ops | internal | same | set | few | few | function | design | |
| shift | <empty> | inter-LC | external | increase | <empty> | many | many | operations | system | |
| <empty> | <empty> | <empty> | either | not-same | <empty> | <empty> | <empty> | <empty> | <empty> | |
| <empty> | <empty> | <empty> | <empty> | <empty> | <empty> | <empty> | <empty> | <empty> | <empty> | |

Short Example

In response to "perturbation" in "context" during "phase" desire "agent" to make some "nature" impetus to the system "parameter" from "origin(s)" to "destination(s)" in the "aspect" using "mechanism" in order to have an "effect" to the outcome "parameter" from "origin(s)" to "destination(s)" in the "aspect" of the "abstraction" that are valuable with respect to thresholds in "reaction", "span", "cost" and "benefits"

In response to "perturbation" in "context" during "phase" desire "agent" to be able to "effect" the outcome "parameter" of the "abstraction" that is valuable

In response to "loud noises" in "night", during "ops" desire "owner" to be able to "increase" the "level of volume" of the "his stereo" in "less than one second". (10 columns)

Scalable

Flexible

Desire stereo to be *flexibly scalable* in **volume** in *less than one second*

| Prescriptive Semantic Basis for Change-type Ilities | | | | | | | | | |
|---|--|----------|-----------|----------------|------------|------------|-------------|-------------|--------------|
| In response to "perturbation" in "context", desire "agent" to make some "change" in "system" | | | | | | | | | |
| Perturbation | Context | Phase | Agent | Outcome Change | | | | System | |
| In response to "perturbation" in "context" during "phase" desire "agent" to have an "effect" to the outcome "parameter" from "origin(s)" to "destination(s)" in the "aspect" of the "abstraction" that are valuable | | | | | | | | | |
| Perturbation | Context | Phase | Agent | Outcome | | | | Abstraction | |
| | | | | Effect | Parameter | Origin | Destination | Aspect | |
| optional | circumstantial; required; general; optional | null | optional | null | required | optional | optional | null | optional |
| "name" | "name(s)" | | "name(s)" | "parameter" | "state(s)" | "state(s)" | | "name" | |
| none | circumstantial | pre-ops | none | decrease | level | one | one | form | architecture |
| disturbance | general | ops | internal | same | set | few | few | function | design |
| shift | <empty> | inter-LC | external | increase | <empty> | many | many | operations | system |
| <empty> | <empty> | <empty> | either | not-same | <empty> | <empty> | <empty> | <empty> | <empty> |
| <empty> | <empty> | <empty> | <empty> | <empty> | <empty> | <empty> | <empty> | <empty> | <empty> |

In response to "perturbation" in "context" during "phase" desire "agent" to make some "nature" impetus to the system "parameter" from "origin(s)" to "destination(s)" in the "aspect" using "mechanism" in order to have an "effect" to the outcome "parameter" from "origin(s)" to "destination(s)" in the "aspect" of the "abstraction" that are valuable with respect to thresholds in "reaction", "span", "cost" and "benefits"

In response to "perturbation" in "context" during "phase" desire "agent" to be able to "effect" the outcome "parameter" of the "abstraction" that is valuable

In response to "loud noises" in "night", during "ops" desire "owner" to be able to "increase" the "level of volume" of the "his stereo" in "less than one second"

In response to "loud noises" at "night" during "ops", desire "owner" to be able to *impetus* {"increase" the "knob angle level" from "one state" to "many states" in the "system form"} through "turning the knob" that results in the *outcome* {"increasing" the "volume level" from "one state" to "many states" in the "system function"} in the "owner's stereo" that "takes less than one second"

Collecting System Change Examples for Illustrating Basis Use

| System Name | Change Description | Related Property Labels |
|--------------|---|---|
| HMMWV | In response to improved IEDs and ambush tactics in urban warfare, desire AM General to design some increase in protection/armor in the HMMWV for quick valuable long term deployment. | Changeability, Flexibility, Scalability, Value Robustness, Extensibility. |
| B-52 | In response to increased demand in alternative fuel sources in a context of climbing dependence on foreign fossil fuels, desire the Air Force to change fuel mixtures used in B-52s engines (synthetic fuels). | Changeability, Flexibility, Reconfigurability, Modifiability, Extensibility. |
| F-16 | In response to need for longer range, desire ground crew to add external tanks for fuel to aircraft at hard points to increase fuel storage for increased range. | Changeability, Flexibility, Survivability, Scalability, Reconfigurability. |
| F-10 (Swiss) | In response to higher load cycles in a new operating environment (country), desire Swiss engineers to make some improvement to strength by replacing aluminum ribs with titanium ribs, that is always available and valuable. | Changeability, Flexibility, Scalability, Reconfigurability, Value Robustness. |
| S-92 | In response to changing market needs in the civilian helicopter sector and FAA regulations, desire Sikorsky to evolve the S-70 into a new helicopter suitable for military and civilian purposes. Developed from the S-70 or Black Hawk family, the S-92 was planned to utilize as many components and subsystems from the highly reliable Black Hawk. The S-92 ended up with a redesigned a new dynamic component system, rotor, and gearbox. | Changeability, Flexibility, Modifiability, Evolvability, Value Robustness. |
| HMMWV | In response to "improved IEDs and ambush tactics" in "urban warfare", desire "Soldiers in the field" to "make a change to armor" in the "HMMWV" for immediate valuable deployment. This change refers to "hill billy" armor additions made by soldiers in the field to the humvees to help protect against small arms fire. | Changeability, Flexibility, Scalability, Reconfigurability, Value Robustness. |
| HMMWV | In response to "increased weight of the system" in "the new humvees that require more armor for protection", desire "AM General" to "design stronger chassis and better suspension" in the "HMMWV" for immediate valuable deployment. In response to direct hits from armor piercing and high explosive projectiles up to 70mm in the cockpit and close air support, desire the A-10 to withstand attack and protect pilot. | Changeability, Flexibility, Scalability, Value Robustness, Survivability. |

In response to "perturbation" in "context" during "phase" desire "agent" to have an "effect" to the outcome "parameter" from "origin(s)" to "destination(s)" in the "aspect" of the "abstraction" that are valuable

In response to "improved IEDs and ambush tactics" in "urban warfare", during "pre-ops" desire "AM General" to make an "increase" to the "armor" from "baseline" to "above baseline" in the "form" of the "HMMWV design" that is valuable

For existing changeable systems, this is a descriptive capture of a change statement, potentially implemented at various levels of specificity

- Full verbose statement is unwieldy when viewed in “English”
- Construction of “plain English” phrasing is partly customized based on particular statement
- A “translator” would be valuable in converting the basis category choices into English
- We see this translation layer and underlying “little language” as key contributions of this work
- Next phase research will develop the translation layer and seek collaboration with team for feedback and testing

- Spiraling on web service implementation of basis
- Resulted in clarifications on categories
 - Including “naming” and optional fields
- Illustrated need for examples
- Motivated need for translation layer

Case Study Demo

Xi Wang, Ke Dou, Chong Tang, Kevin Sullivan

[Manual](#) | [Coq Specification \(raw\)](#) | [Coq Specification \(formatted\)](#) | [Ross Model](#)

| | |
|--------------------------|---|
| Perturbation_disturbance | loud noise |
| Context_circumstantial | late at night |
| Phase_ops | |
| Agent_external | |
| Nature_increase | |
| Parameter_Level | knob angle |
| | <small>Enter the description of the specific parameter</small> |
| Origin_one | <small>Enter description of origin</small> |
| Destination_many | <small>Enter the target range of the states of the parameter as as result of the change</small> |
| Aspect_form | <small>Enter the aspect of the abstraction being changed</small> |
| Mechanism_some | turning the knob |
| Effect_increase | <small>Enter the effect of the change to the parameter</small> |
| Parameter_Level | volume |
| | <small>Enter the description of the specific parameter</small> |
| Origin_one | <small>Enter description of origin</small> |
| Destination_many | <small>Enter the target range of the states of the parameter as as result of the change</small> |
| Aspect_function | <small>Enter the aspect of the abstraction being changed</small> |
| Abstraction_system | <small>Enter the level of abstraction of the system being affected</small> |
| Valuable_simple | <small>Enter Description</small> |
| Choose Reaction | Enter a number <input type="text"/> Choose Unit <input type="text"/> |
| Choose Span | Enter a number <input type="text"/> Choose Unit <input type="text"/> |
| Choose Cost | Enter a number <input type="text"/> Choose Unit <input type="text"/> |
| Choose Benefit | <small>Enter the utility as a result of the change with respect to the baseline system</small> |

```

undefined "loud noise";undefined "late at night";undefined;undefined;undefined;undefined
"knob angle" "";undefined "";undefined "";undefined "";undefined "turning the
knob";undefined "";undefined "volume" "";undefined "";undefined "";undefined
";undefined "";undefined ""
    
```

Result:

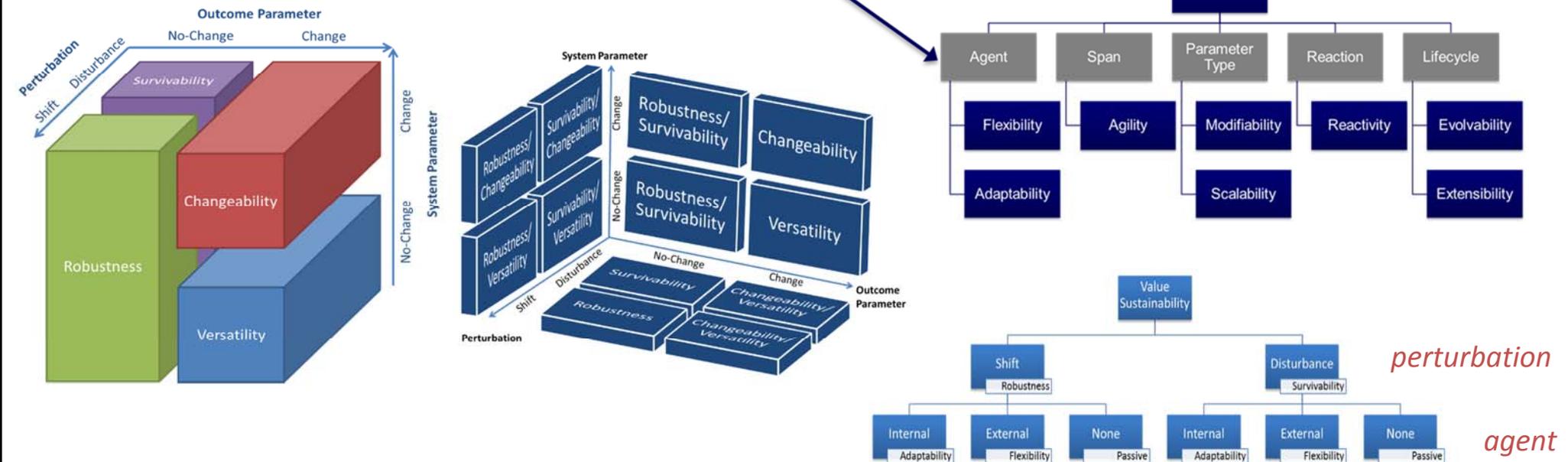
```

[Perturbation_error,Context_error,Phase_error,Agent_error,Nature_error,Parameter1_error,O
rigin1_error,Destination1_error,Aspect1_error,Mechanism_error,Effect_error,Parameter2_err
or,Origin2_error,Destination2_error,Aspect2_error,Abstraction_error,Valuable_error]
    
```

Growing complexity of “full basis” highlights need for (1) different use cases (subsets of basis), and (2) translation layer for practitioner use

- Semantic basis with ility term labels mapped would be able to show relationship between ilities within the spanned semantic field
 - Can you have a flexible AND robust system?
 - Can you have a single adaptably, scalable, extensible, affordable change?
 - What metrics can be used to evaluate and valuate along ilities?
- What are the fundamental tradeoffs between change-type ilities?
 - Categorical choice differences
 - Means to ends differences?

Filter from Semantic Basis



- High level feedback
 - Does this approach make sense?
- Applicability to Semantic Fields
 - Does this basis only apply to “change-type” semantic field?
 - What are the members of this field?
 - What other semantic fields may exist?
 - Can a different basis be used for each semantic field?
- Refinement of basis
 - What are appropriate basis categories?
 - What are appropriate choices within a category?
- Refinement of ility labels
 - Are there consensus patterns in matching SEARi ilities to basis?
 - Are there consensus patterns for given ility terms without provided definitions?
 - How do other definitions for ility labels map to basis?
- Prescriptive use
 - Can someone use the basis to generate change statements, which will automatically label with the appropriate ilities?
 - How useful is the change statement for supporting verifiable requirements?

The intent of this work is to inspire alternative approaches to dealing with, and to promote conversations about, the semantic problem for system ilities

Ultimately we do not want more definitions, but rather, unambiguous, verifiable, standardized representations of desired system properties

Ultimate Goal: develop the basis/bases to be a prescriptive instrument(s) for spanning the semantic fields whose union encompass all “ilities”

Thank you for your attention!

Questions?

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