SYSTEMS ENGINEERING
Research Center

Interactive Model-Centric Systems Engineering (IMCSE)

Progress and Updates

By
Dr. Adam M. Ross, MIT

6th Annual SERC Sponsor Research Review
December 4, 2014
Georgetown University
School of Continuing Studies
640 Massachusetts Ave NW,
Washington, DC

www.sercuarc.org

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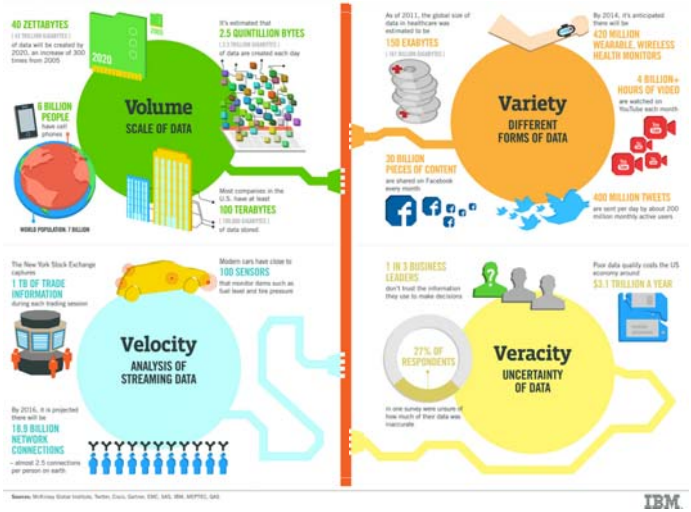
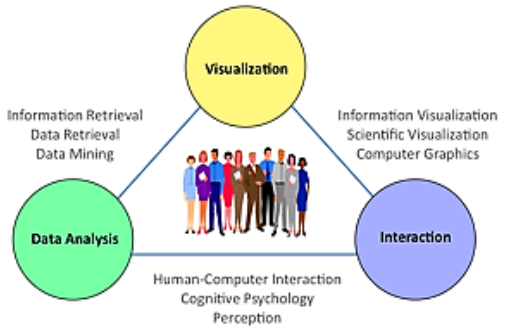
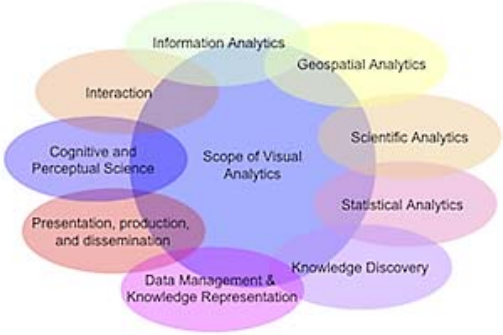
Nexus of Transformational Ideas



Big Data

http://www.ibmbigdatahub.com/sites/default/files/infographic_file/4-Vs-of-big-data.jpg

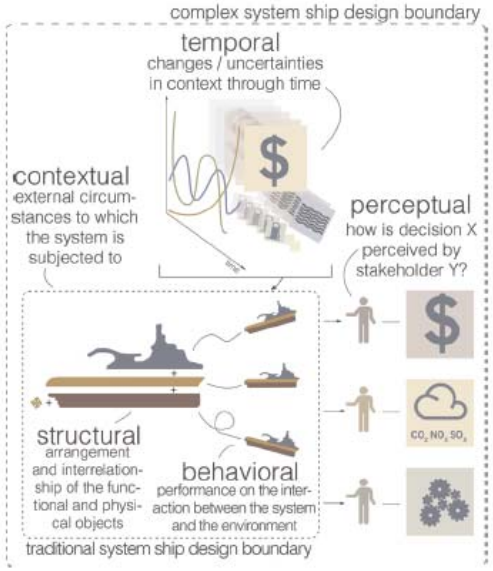




www.visual-analytics.eu/faq/

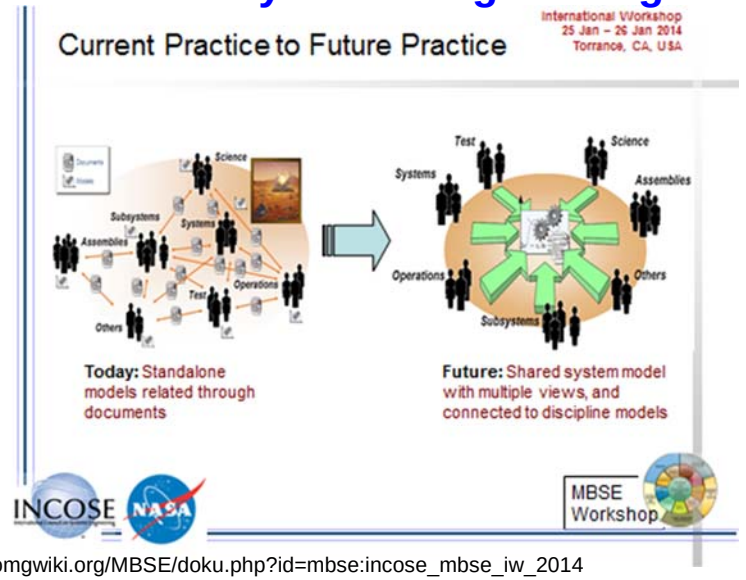
Visual Analytics

Complex Systems



Gaspar, H., Rhodes, D.H., Ross, A.M., and Erikstad, E.O., "Addressing Complexity Aspects in Conceptual Ship Design: A Systems Engineering Approach" *Journal of Ship Production and Design*, Vol. 28, No. 4, Nov 2012, pp. 145-159.

Model-based Systems Engineering



http://www.omgwiki.org/MBSE/doku.php?id=mbse:incose_mbse_iw_2014

Merging the Four:
Interactive Model-Centric Systems Engineering

- Big Data + Visual Analytics…
  + Complex Systems + MBSE = IMCSE
  - Volume, variety, velocity, and veracity of data
  - Collect data, visualize, interact, model, find patterns, generate insights, repeat
  - Structural, behavioral, contextual, temporal, and perceptual complexities
  - Integrated models including requirements, structure, behavior, parametrics

- Potential use for this merged capability for decision support within and across systems engineering throughout lifecycle

On the power of humans with computers:

"statistics (computing) + humans is much more powerful than statistics alone or humans alone"

– Professor Remco Chang, Tufts University
Visual Analytics Lab, Aug 2013

Interactive Model-Centric Systems Engineering	MBSE			
		STRUCTURAL	form of system components and their interrelationships	**Existing "state of practice"** systems architecting and model-based systems engineering
		BEHAVIORAL	function/performance, operations, and reactions to stimuli	
		CONTEXTUAL	circumstances in which the system or enterprise exists	**Emerging "state of art"** *Epoch Modeling* *Multi-Epoch Analysis* *Epoch-Era Analysis* *Dynamic Tradespace Exploration* *Multi-Stakeholder Negotiations* *Comprehension of Complex Datasets* *Studies of Decision Making* *and more….*
		TEMPORAL	dimensions and properties of systems over time	
		PERCEPTUAL	stakeholder preferences, perceptions and cognitive biases	

Developing complex systems necessitates an approach to generate, manage, and analyze artificial data across these five aspects, which result in improved SE decision making

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Interaction between Humans and Models Enables Anticipatory Capacity

SEAri System Engineering Advancement Research Initiative

Systems scientists have long recognized that humans possess unique abilities for anticipation rather than simple reactive response

- Anticipation (ability to look forward in order to take a future decision or action)
- Pattern recognition skills
- Subject to cognitive limits, preferences, and biases…

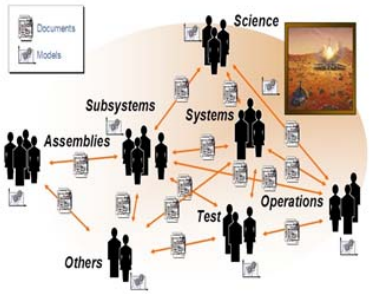
Interactive Model-Centric Systems Engineering
Decision Science – Visual Analytics – MBSE

Anticipatory Capacity Key Enablers

Mindset – systems thinking

Methods – model-based

Environment – hw/sw enhanced



- Complex, integrated models
- Varied levels of fidelity
- Large artificial data sets

Anticipatory Capacity is the capacity to continuously develop and apply knowledge acquired through a structured approach to anticipate: (1) changing scenarios as stakeholder needs and systems context change over time; (2) to consider their consequences; and (3) to formulate design decisions in response.

Rhodes, D.H. and Ross, A.M., "Anticipatory Capacity: Leveraging Model-Based Approaches to Design Systems for Dynamic Futures," 2nd Annual Conference on Model-based Systems, Haifa, Israel, March 2009.

Vision for IMCSE Research Program

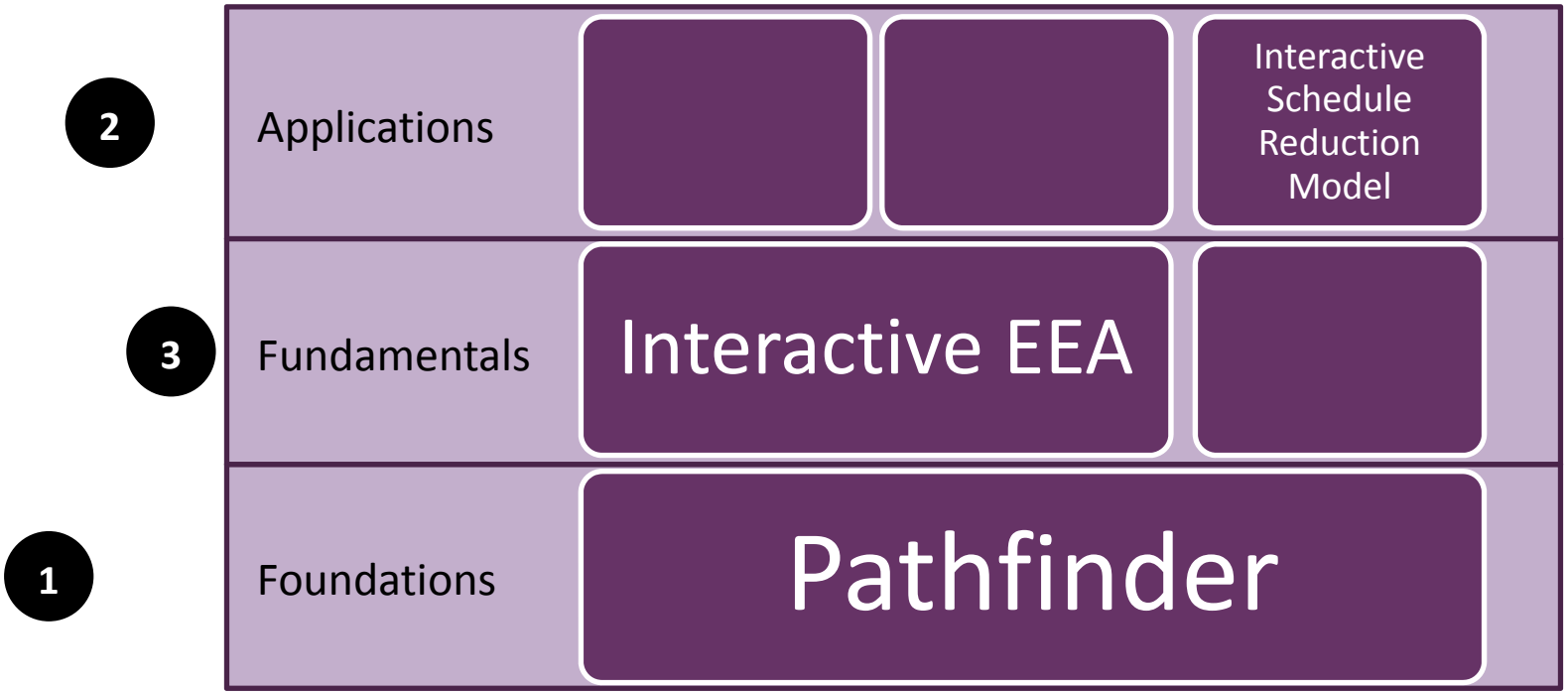
- IMCSE will pursue a balanced basic and applied research approach
  - leveraging strengths of academic environment (e.g. fundamentals, rigor, neutral party view of problem), and
  - keeping the research relevant to the sponsor community, and
  - enabling opportunities for knowledge and MPT transfer to sponsors
- As the program matures, collaborations inside and outside of SERC

Knowledge Transfer Opportunities

Workshops, teleconferences and meetings, reports, papers, collaboration with other SERC activities, prototypes, MPTs, government partner applications, potential student internships

The IMCSE research program aims to develop transformative results through enabling intense human-model interaction, to rapidly conceive of systems and interact with models in order to make rapid trades to decide on what is most effective given present knowledge and future uncertainties, as well as what is practical given resources and constraints.

Approach in Three Thrusts



- To have most impact, IMCSE uses three complimentary thrusts with different timescales for impact
  1. Foundations: 1 year, set the stage for IMCSE
  2. Applications: 1 year, short timescale impact, deployment opportunities
  3. Fundamentals: multi-year, medium timescale impact, potentially broad applicability
- Following year one, we anticipate additional projects within applications and fundamentals, plus updates to foundations

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Updates this Year (June – Dec 2014)

- Progress on Three Thrusts
  - —Foundations: Pathfinder
  - —Applications: ISRM
  - —Fundamentals: IEEA
- Supporting MPTs
  - —Software: IVTea Suite
  - —Methods: Value Model Trading
- Emerging Challenges
  - —Interactive tradeoffs of models
  - —Visual analytics of artificial (model-generated) data
  - —Perceptual and cognitive considerations in human-model interaction

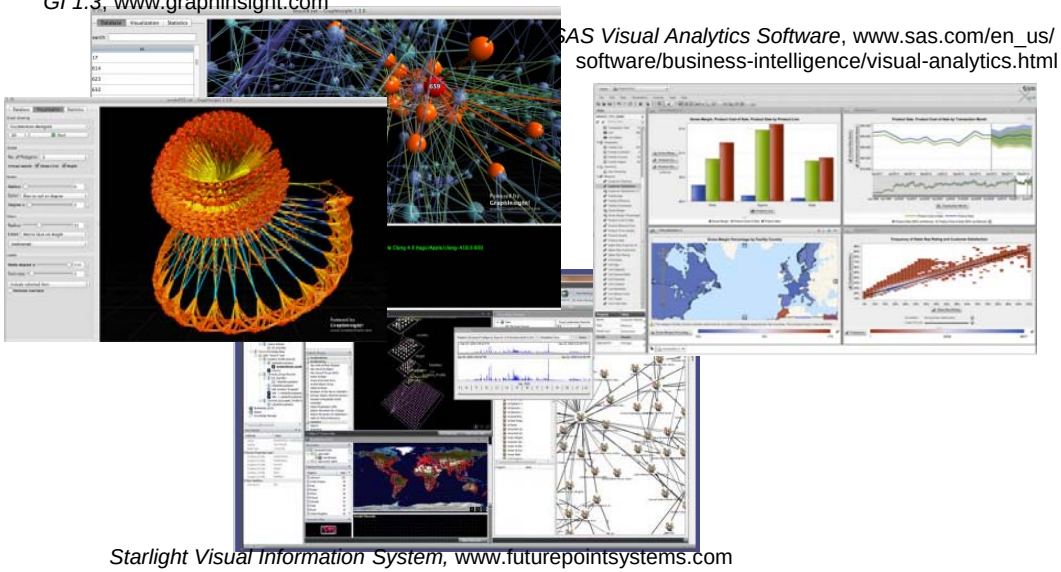
Ultimately, the goal of IMCSE is *to* ***leverage visual analytics*** *applied to* ***model-generated "big data,"*** *in order to* ***develop a rigorous framework****, with associated methods, processes, and tools (****MPTS****), which will result in* ***transformative new capabilities for complex systems engineering decision making****.*

Thrust 1: Foundations

IMCSE Research Pathfinder

Enabling Software Tools

GI 1.3, www.graphinsight.com



SAS Visual Analytics Software, www.sas.com/en_us/software/business-intelligence/visual-analytics.html

Starlight Visual Information System, www.futurepointsystems.com

The Pathfinder project will focus on identification of past and present related state of art and practice, and will begin to build a community of interest around IMCSE

- **Lead**: Dr. Donna H. Rhodes, Dr. Adam M. Ross
- **Summary**: Investigation of state of art and practice, conduct of an invited workshop including SERC and selected outside entities
- **Example Anticipated Outcomes**: Workshop summary report, literature review, research agenda report

Georgia Tech MBSE Model-Based Systems Engineering Center
http://www.mbse.gatech.edu/

http://www.lboro.ac.uk/research/avrrc/

[v]alt Visual Analytics Laboratory @ Tufts
http://valt.cs.tufts.edu/

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

Visual Analytics Community
NVAC National Visualization and Analytics Center
http://vacommunity.org/tiki-index.php

Pathfinder Project

- IMCSE Pathfinder project brings together the relevant stakeholders to develop a research vision and research priorities, and a roadmap to achieve them

Big Data + Visual Analytics…
+ Complex Systems + MBSE = IMCSE

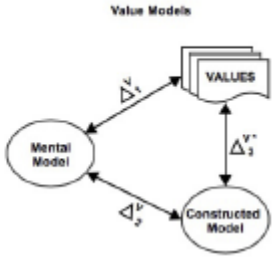
- Activities include:
  - —Investigation of the current state practice and emerging state of the art through literature review and discussions with subject matter experts
  - — Face-to-face gatherings of stakeholders to define a research agenda
    - o Initial small invited workshop at MIT on 20 Jan 2015
  - —Tap into the broader research community to develop a collaboratively-derived research agenda
  - —Building a community of interest and collaboration partners
  - —Elucidation of challenge problems within IMCSE scope

The ultimate goal is to build a community of interest around the IMCSE research agenda, establish partnerships for research, and to foster collaboration in addressing the emerging challenges at the intersection of the four pillars.

Challenge 1: Tradeoff of Models

- Since every model is an abstraction from reality, it is important for any model user to understand the implications of embedded assumptions
- Sensitivity analyses should be performed whenever time and resources allow, yet in practice, many studies are resource constrained and therefore only cursory (if any) sensitivity analysis is conducted
- Since the assumptions in the models impact the results of those models, not only are choices of model parameters important from a "within" model sensitivity perspective, but also choice of the model itself can have large ramifications on results

		Mental Model v. Values	
		Low Δ_1 (truthful)	High Δ_1
Constructed Model v. Mental Model	Low Δ_2 (trust)	**Correct Trust:** Trust present. Correct representation of values.	**Type I error:** Trust present. Incorrect representation of values.
	High Δ_2	**Type II error:** Trust not present. Correct representation of values.	**Justified Mistrust:** Trust not present. Incorrect representation of values.



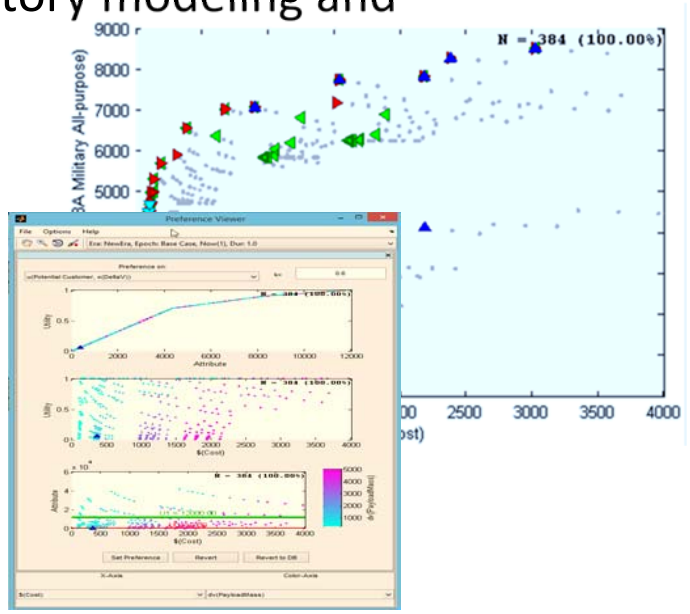
Preliminary research was done to trade "within model" sensitivities in value models, investigating the potential for interaction in refining value model parameter choices (Ricci et al. 2014)

IMCSE will seek to address the challenge of performing broad sensitivity analysis, in terms of model choice, as part of a given study, so that it is not relegated to a later activity that is subject to omission when resources are short

Challenge 2: Visual Analytics of Artificial (Model-generated) Data

- Since the goal of visual analytics is to generate insights into relationships and patterns in the data, the existence of potentially confounding artifacts in the data makes it especially challenging when ground truth is no longer available

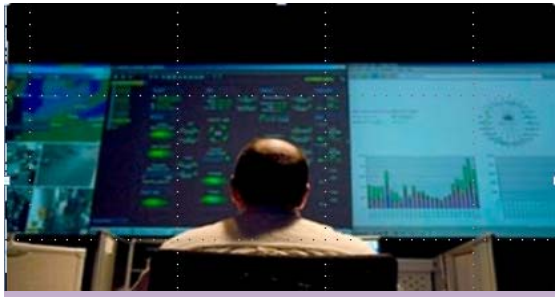
- This is essentially the difference between exploratory modeling and consolidative modeling:
  - ***consolidative modeling*** includes "techniques in which known facts are consolidated into a single model" in order to generate explanatory relationships of existing data
  - the intent of ***exploratory modeling*** is to "generate artificial data" that "can inform modelers and decision makers of the ramifications of various sets of assumptions, as well as provide consistent communication"



In IMCSE, models will tend to be of exploratory nature and therefore additional considerations must be taken into account when generating and visualizing the data in order to properly interpret the results

Challenge 3: Perceptual and Cognitive Considerations in Human-Model Interaction

- *Human-Systems Integration* research has advanced the theory and methods concerning integration of humans and operational systems
- IMCSE is concerned specifically with interaction of humans with engineering models, and environments for human-model interaction
- Research from HSI and other fields informs IMCSE, but additional research is needed, for example: *investigating human cognitive and perceptual limitations as they impact interactions between users and predictive models*:
  - *behavioral over-reliance on cognitive biases in choice behavior*
  - *tendency towards ambiguity aversion;*
  - *limitations of affective forecasting when making projections*



In considering the form of visual analytics to represent big data, and the structure of model-based approaches to forecasting the evolving complexities of large-scale system, it is crucial to also consider the perceptual and cognitive capabilities of human beings at the center of these exploratory efforts

Just as basic human factors has evolved to a science of *human systems integration*, there is a need to evolve a science of *human-model interaction*

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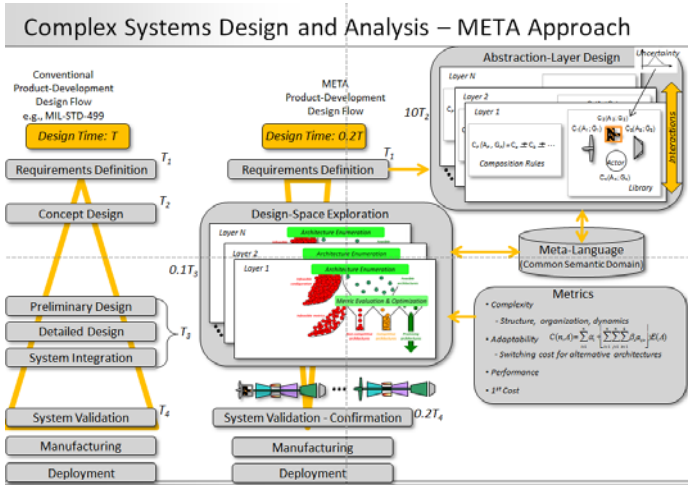
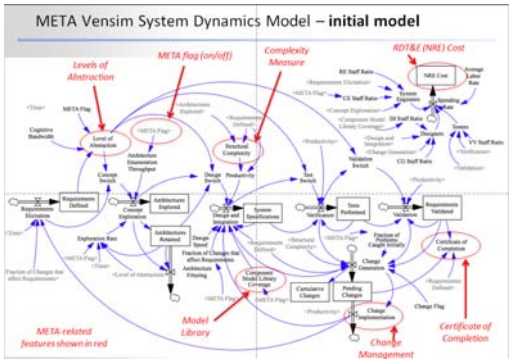
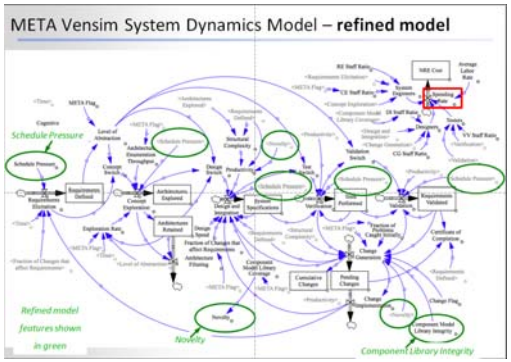
Thrust 2: Applications

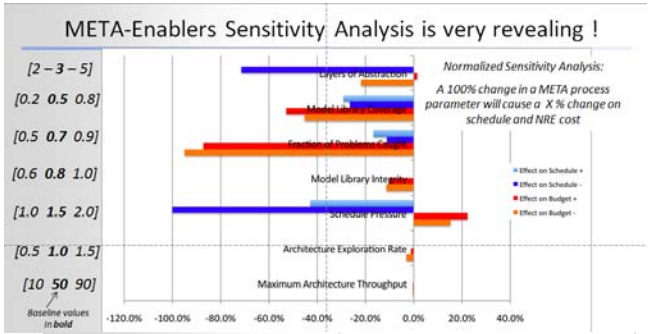
Interactive Schedule Reduction Model



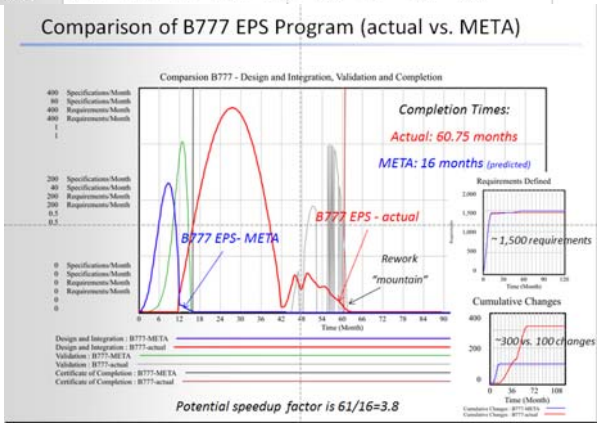




de Weck, O., "Feasibility of a 5x speedup in system development due to META design", ASME 2012 IDETC, Chicago, IL, Aug 12-15, 2012, paper DETC2012-70791.



Leveraging prior work from DARPA META, the Schedule Reduction Model will be extended with interactivity as a central aspect, promoting sensitivity analyses and benchmarking to be the central use case



- **Lead**: Professor Olivier de Weck
- **Summary**: Exploratory extension of system dynamics-based Schedule Reduction Model, w/prototype model for pilot application
- **Example Anticipated Outcomes**: Report, Demo, Prototype, Potential Deployment Partner

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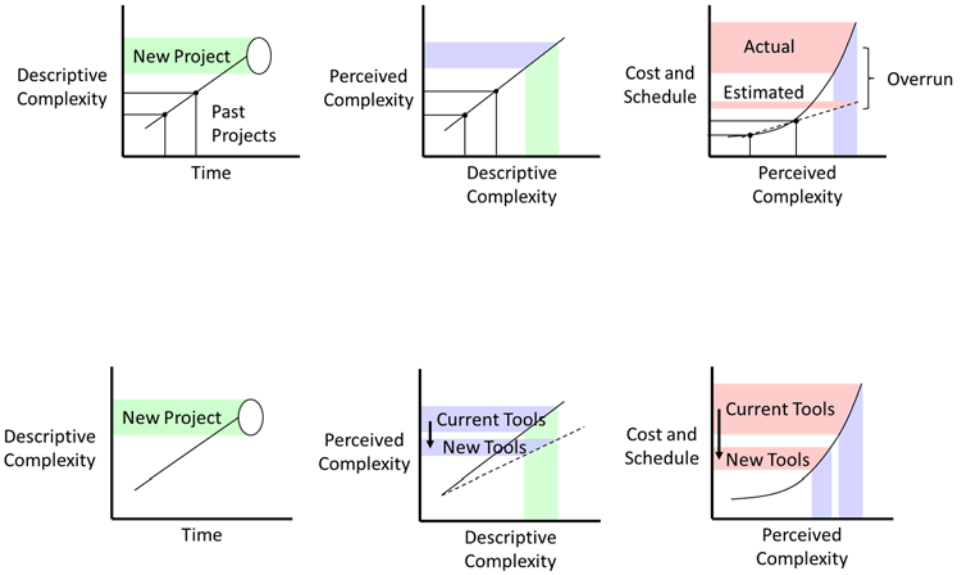
Interactive Schedule Reduction Model (ISRM)

SEAri System Engineering Advancement Research Initiative

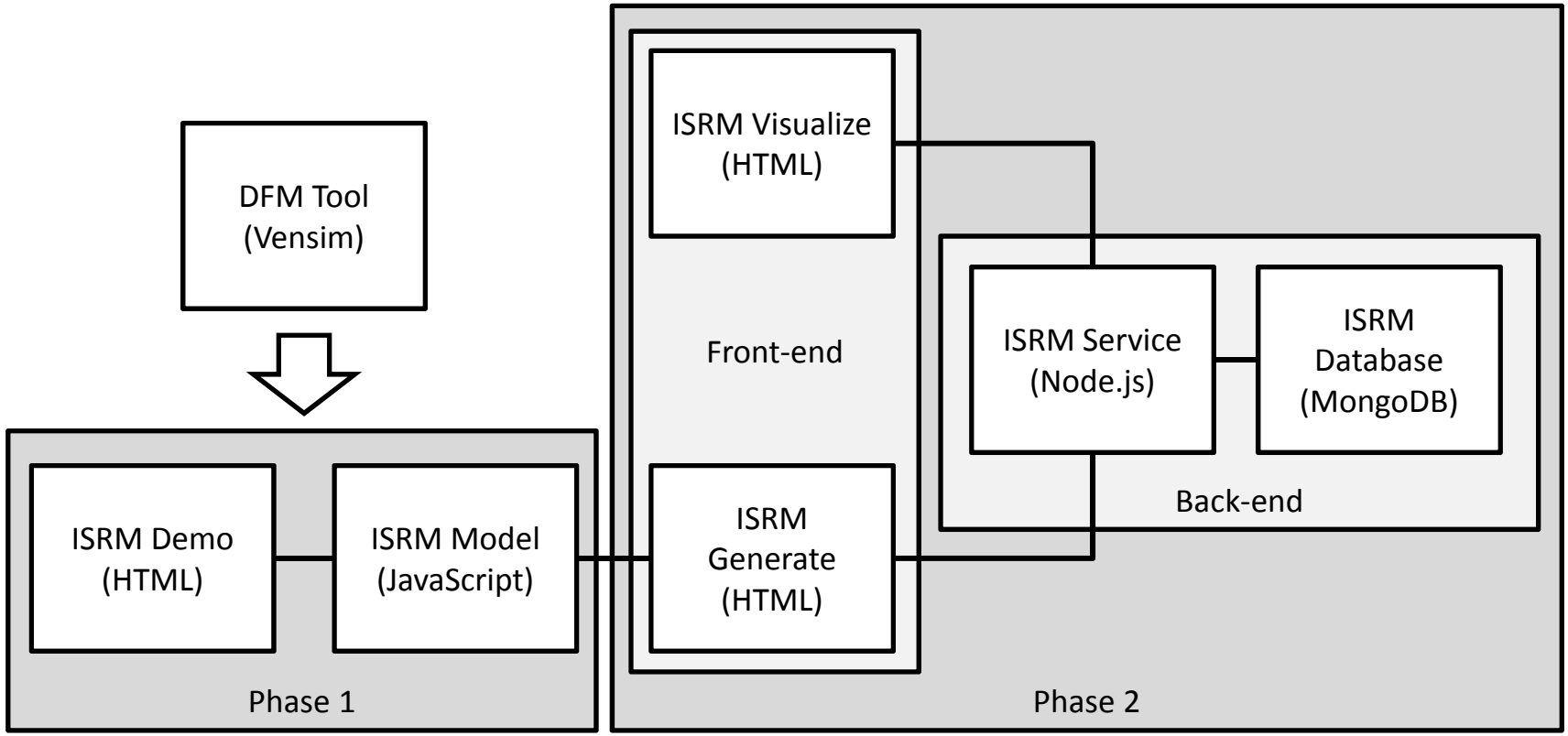
- DARPA META II program background
  - Study to avoid effort overruns on complex projects
  - Methods evaluated in Design Flow Model (de Weck, 2012)
    - System dynamics model of META-enabled project flow
    - Reqs → Exploration → Specs → Verification → Validation
    - Illustrates 5X speed-up for META-enabled projects
- ISRM extends DFM to add rapid sensitivity analysis
  - New tool to generate, collect, and visualize large data sets
  - DFM is a use case for new model-based methods
  - Generate new insights for DFM results
  - No additional model refinement or validation
- Approach: loosely-coupled browser-based modules



ISRM develops browser-based methods to rapidly analyze output datasets from a model of product development

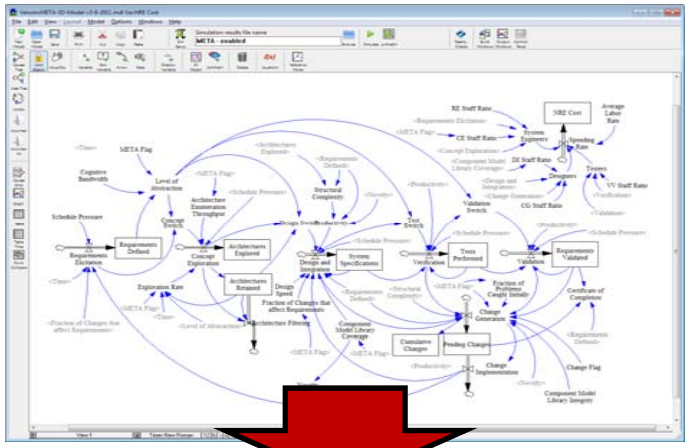
ISRM Structure and Workflow

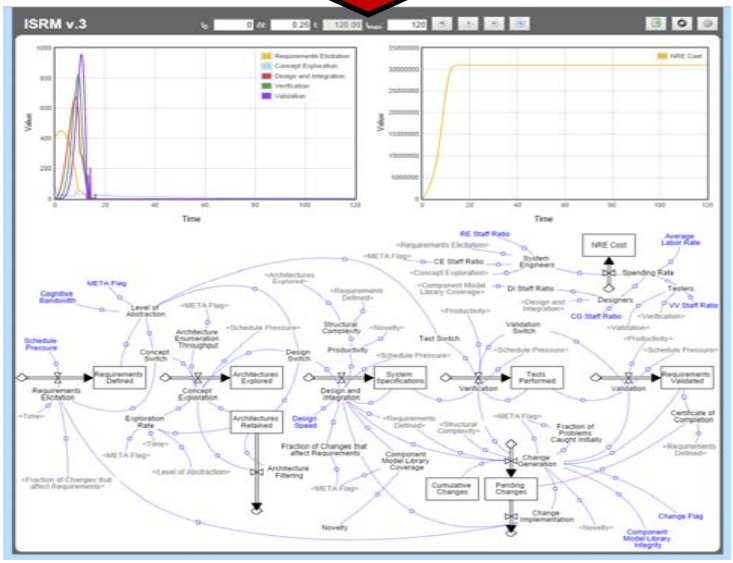
- Phase 1: demonstrate browser-based tool
- Phase 2: develop services for sensitivity analysis



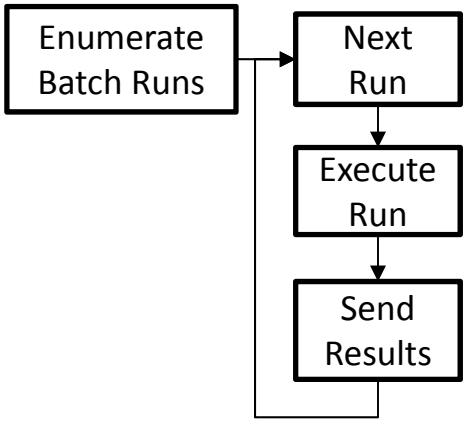
Phase 1 replicates the model in a browser environment, and
Phase 2 creates services to generate, collect, and visualize data

ISRM Phases 1 and 2



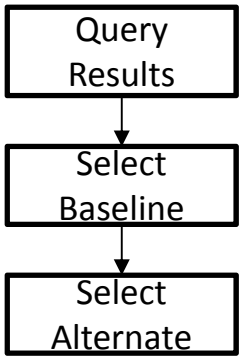


Process to generate/store data in batches




```
POST /results
→ OK
```

Process to query data sets (visualization input)




```
GET /results?param1=0
→ [{_id: 47},{_id: 48},
   {_id: 49}, ...]
GET /data/47/outputs
→ {time:[0,1,2,...], ...}
GET /data/48/outputs
→ {time:[0,1,2,...], ...}
```

The existing model is ported to JavaScript and used in an interactive web page to control and view single executions

Back-end services collect, store, and query data across executions and front-end interfaces control batch executions and visualize aggregated data

ISRM Findings and Limitations

Key Findings

- Vensim results replicated
  - Non-optimized execution time: ~1 second
  - Output data ~100 kB
- Loose coupling effective
  - JavaScript + JSON as common language
  - Simple interfaces (GET/POST services)
- Sacrifice efficiency for accessibility and extensibility

Limitations

- Design Flow Model limited by assumptions
  - e.g. no staff constraint
  - Serves as example use case for development
- ISRM prototypes assume fixed model structure
  - Can vary parameter levels
  - Must manually edit source code to change structure

Note: this is currently a proof of concept demonstration capability

Web technologies provide a simple interface on a common platform but are slower than optimized tools
Future work aimed at schedule reduction may change the model structure to address known limitations

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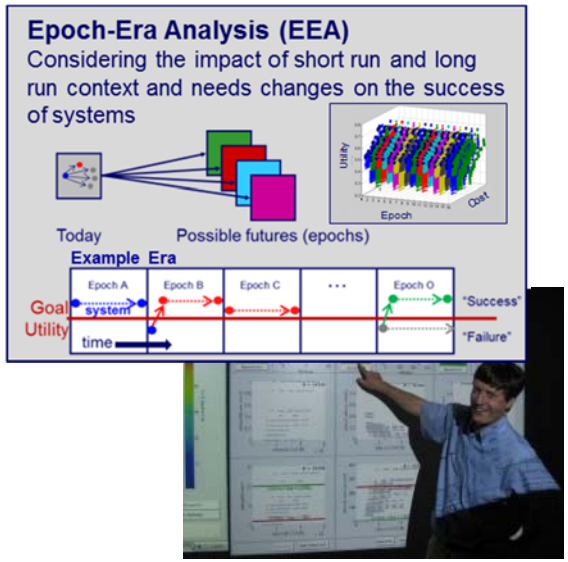
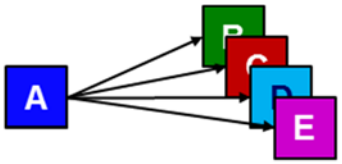
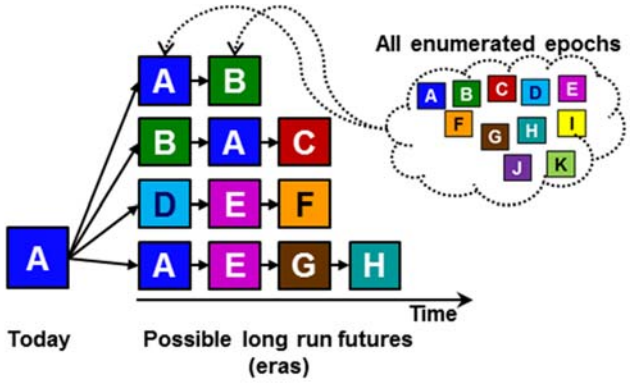
Thrust 3: Fundamentals

Interactive Epoch-Era Analysis



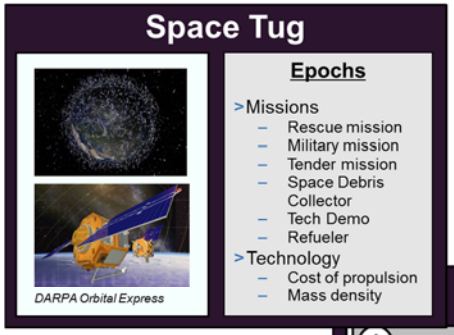


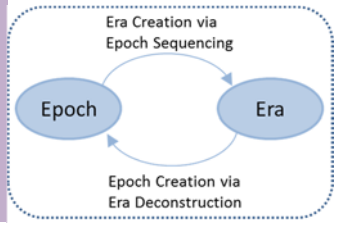


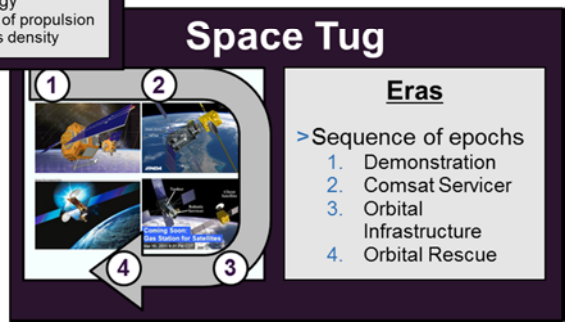
IED attacks in Iraq: (*Wired*)

EEA is a framework that supports narrative and computational scenario planning and analysis for both short run and long run futures

- **Lead**: Dr. Adam M. Ross, Dr. Donna H. Rhodes
- **Summary**: Exploratory development of interactive Epoch-Era Analysis, including human interface and reasoning considerations for epoch and era characterizations, as well as single and multi- epoch/era analyses
- **Example Anticipated Outcomes**: Report, Papers, Proof of concept demo via mission planning support







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

Roberts, C.J., Richards, M.G., Ross, A.M., Rhodes, D.H., and Hastings, D.E., "Scenario Planning in Dynamic Multi-Attribute Tradespace Exploration," *3rd IEEE Systems Conf*, Vancouver, Canada, March 2009.

Schaffner, M.A., Wu, M.S., Ross, A.M., and Rhodes, D.H., "Enabling Design for Affordability: An Epoch-Era Analysis Approach," *Proceedings of the 10th Acquisition Research Symposium- Acquisition Management*, April 2013.

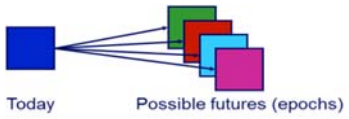
…

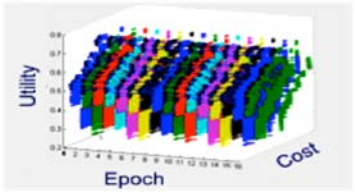
Preliminary Hypotheses

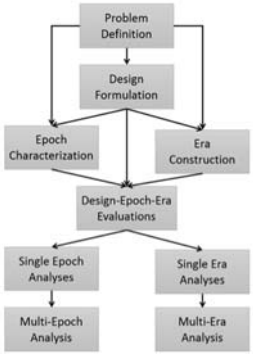
- IEEA will enable the elicitation of more broad/complete set of possible epochs.
  - Infrastructure that enables IEEA could include databases of epoch variables, which could be leveraged in future IEEA studies.
  - Explicit implementations in an interface will provide repeatable and more understandable elicitation experiences, resulting in more epoch variables.
- IEEA, through a human-in-the-loop implementation, will help to intelligently limit the potentially unbounded growth in the epoch/era space.
  - Using visual analytic techniques such as filtering, binning, pattern matching, search algorithms and human-in-the-loop interaction, IEEA can be used to effectively manage multi-epoch and multi-era analysis scale growth.
- IEEA will enable the development of superior intuition, buy-in, and insight generation for decision-making.
  - By allowing decision makers to “experience” (i.e. “see” and “interact with”) epochs and eras, they will better understand and accept the impact of context and needs changes on systems and therefore how resilience can be better achieved.

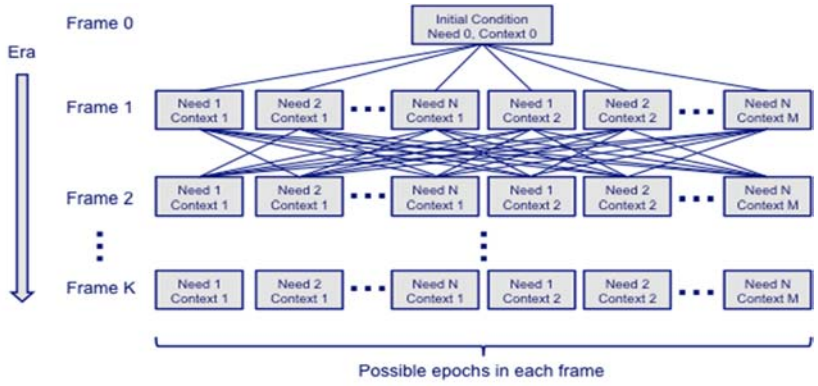
Interactivity and data persistence between studies will enable deeper data exploration, and facilitate the development of user skills for anticipatory thinking

Challenges and Enablers









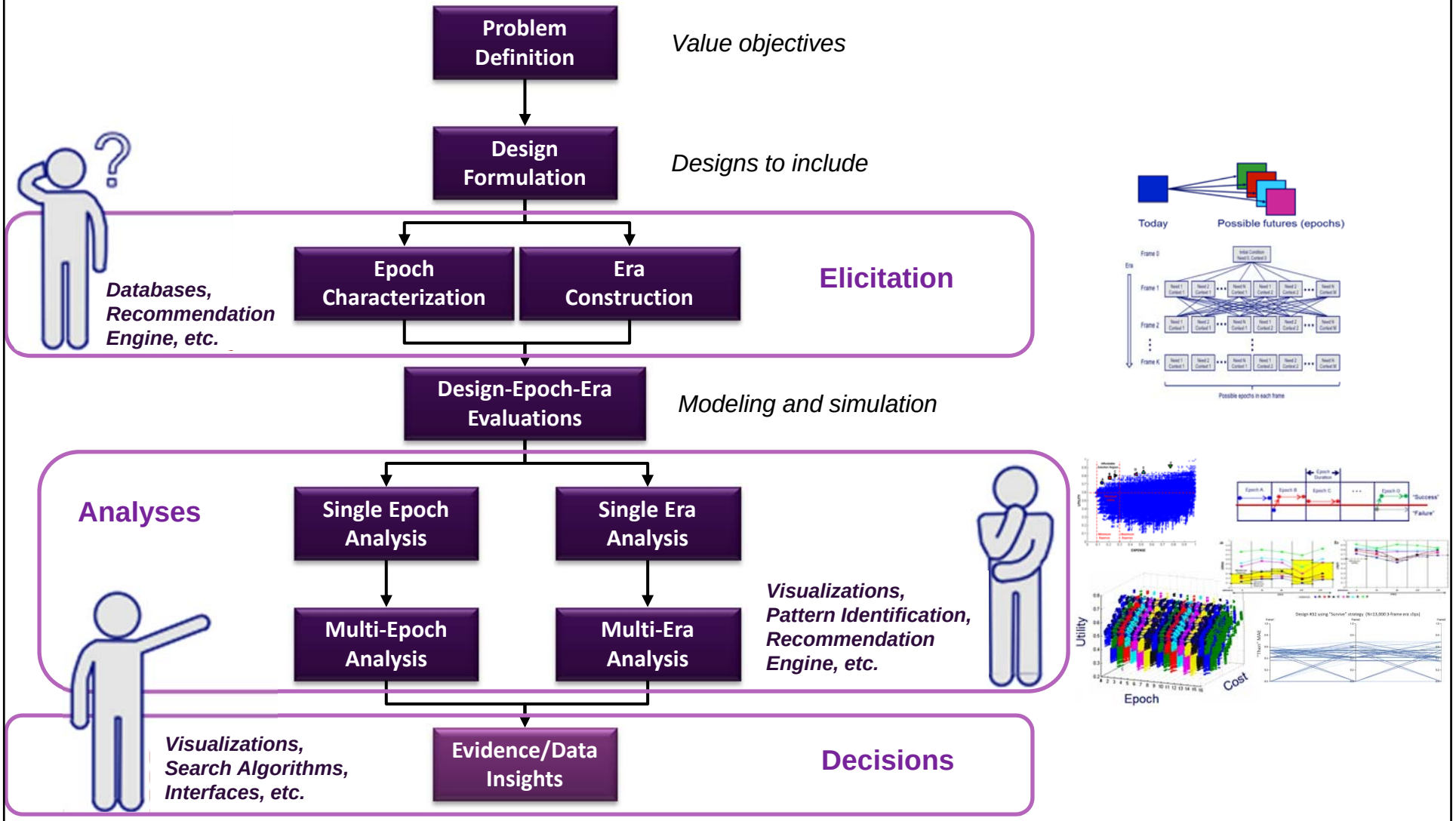
Challenges

- Data size increases which creates a storage and data transmission problem.
- Data size increase also creates a separate problem related to cross-filtering across large numbers of data dimensions. Human cognitive limitations make comprehension of high-dimensional data difficult so datasets must be “sliced” or cross-tabulated across dimensions before rendering them as 1D, 2D or 3D visualizations.
- Larger data sets require increased amounts of processing time to manipulate.
- Rendering problems arise when large amounts of data must be visualized simultaneously.

Enabling Research

- Data Reduction Methods
- Online Analytical Processing
- Human Interaction Methods
- Search Algorithms

A Framework for Interactive Epoch-Era Analysis



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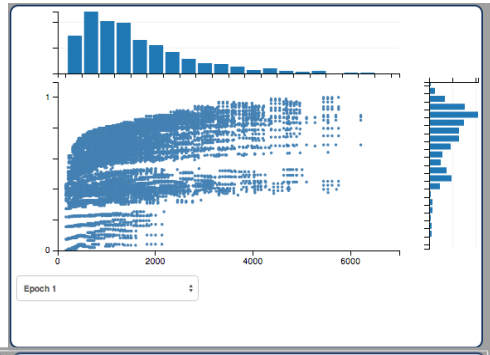
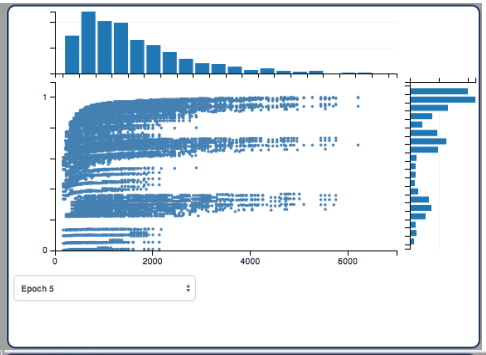
Example Enabled Prototypes

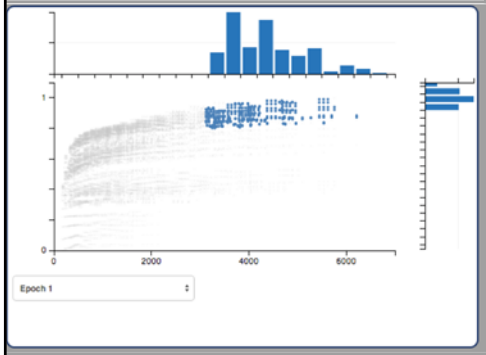
SEA RI
System Engineering Advancement
Research Initiative

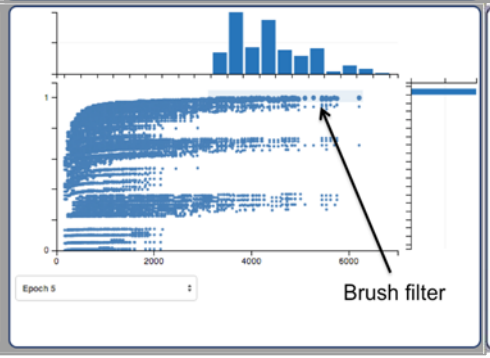
Subset selection

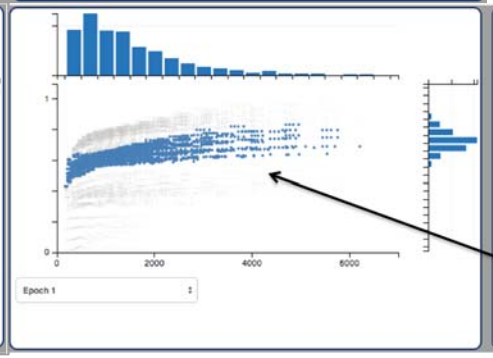


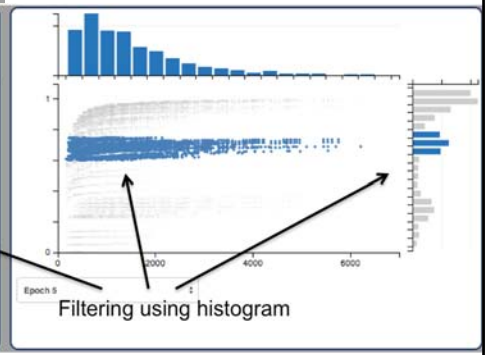


Brushing

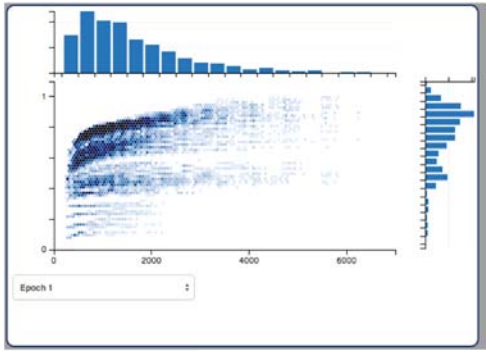


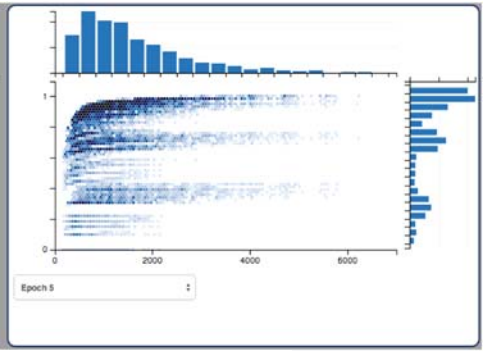






Hexagonal binning



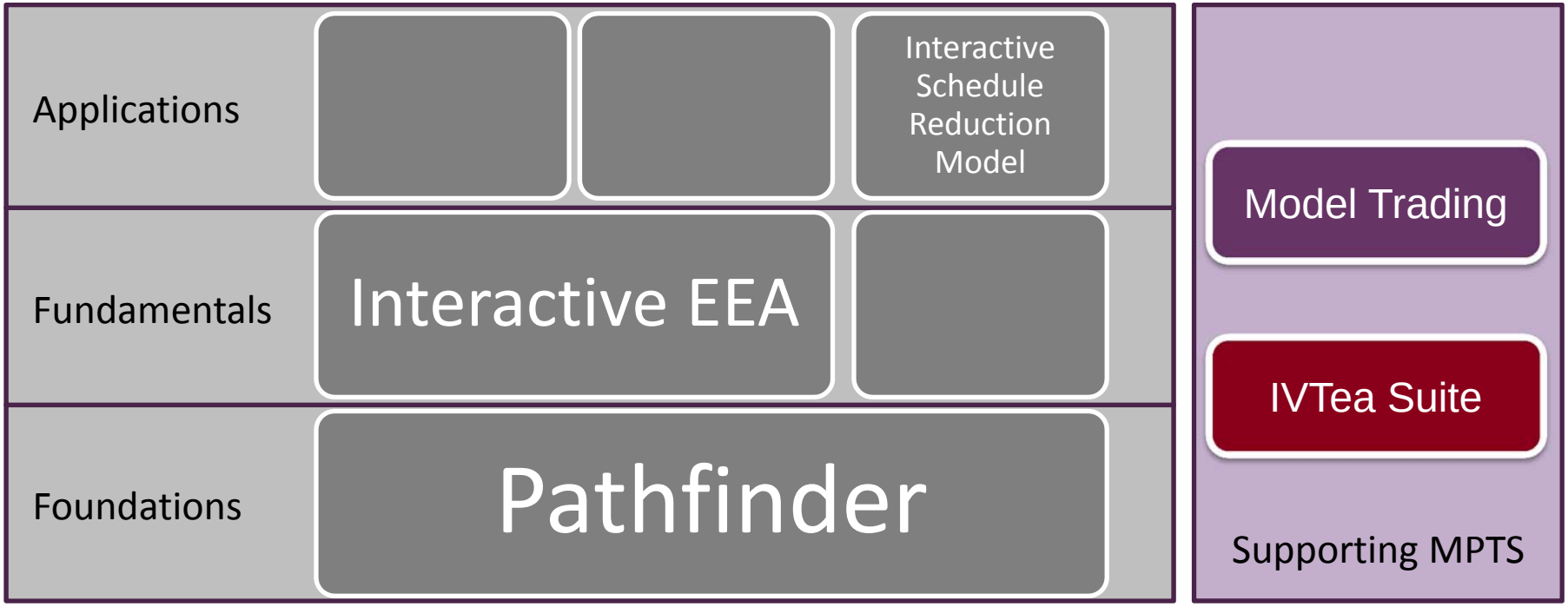


Real time filtering

Data density visualization

Supporting MPTs: IVTea Suite

Thrusts with Supporting MPTs



Supporting infrastructure to collate and synthesize demonstration software capabilities

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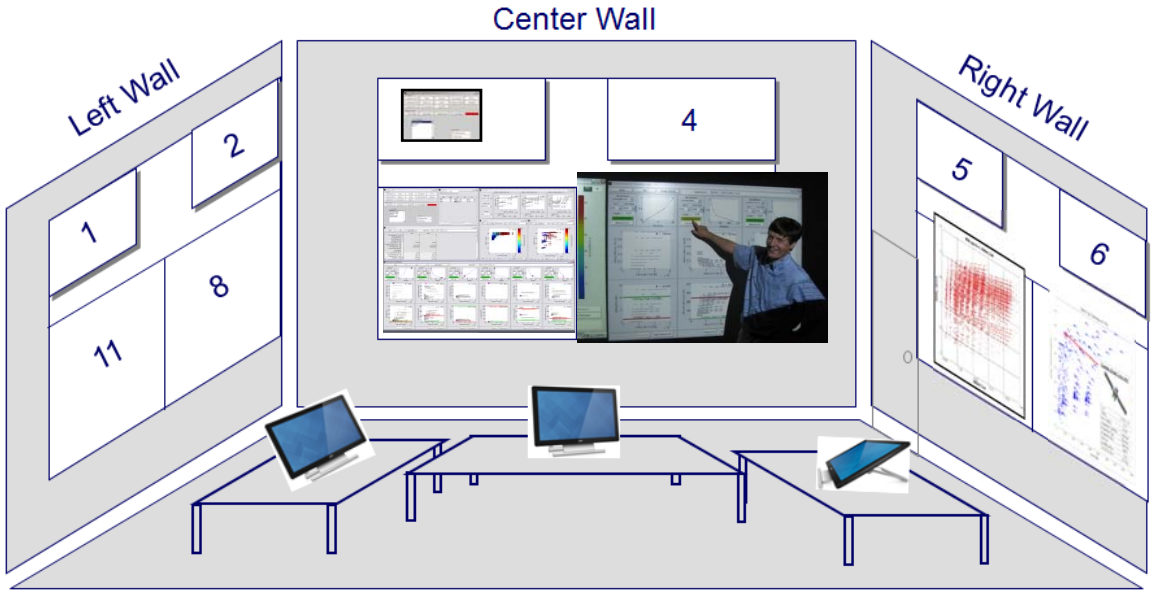
Tradespace Exploration Lab

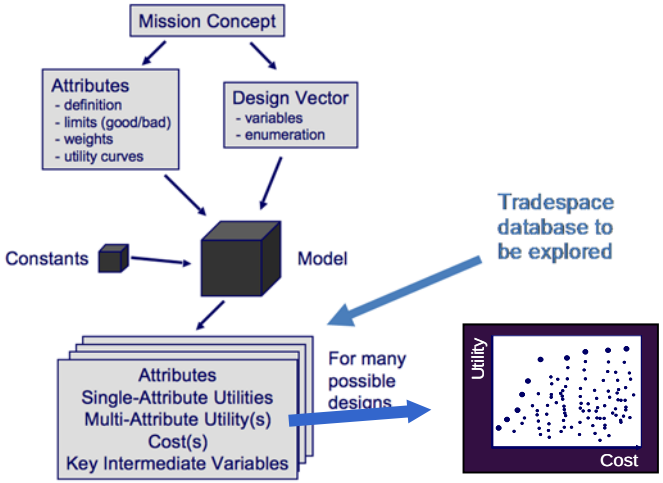
SEAri System Engineering Advancement Research Initiative

Moving beyond a technique used only by expert tradespace analysts…

A concept of operations for creating, using and sharing tradespace data with multiple, diverse decision makers

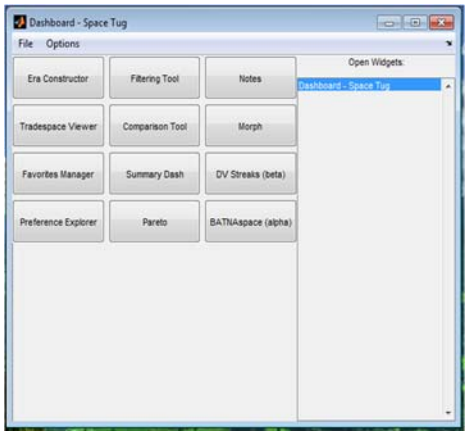
Development of a multi-sensory tradespace exploration lab *(research laboratory)*
To address the shortcomings in sense-making of large dynamic tradespace data sets (IVTea Suite)

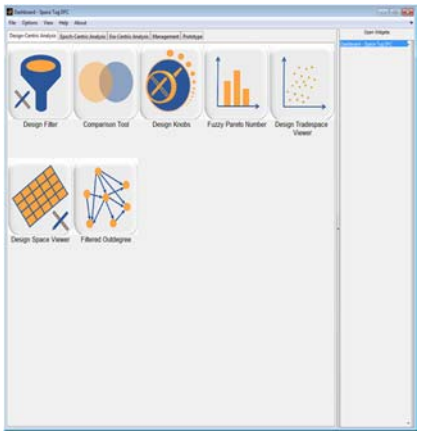




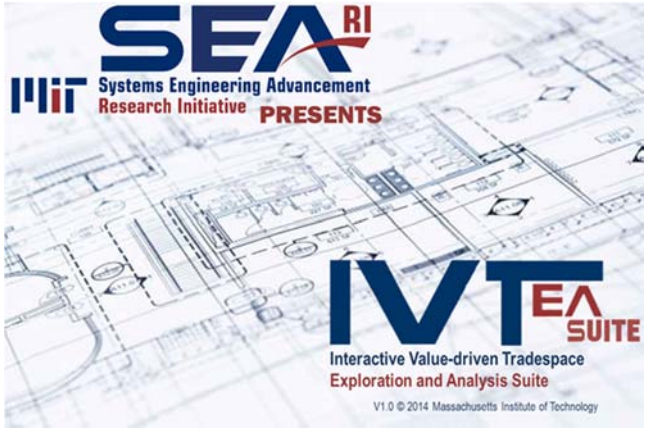
Rich data sets can be explored to reveal complex relationships between design-space and value-space for generating intuition into problem—a multi-dimensional analogy to graphing y=f(x)

Enabling Tools for Interactive Artificial Data Exploration & Analysis





Interactive **V**alue-driven **T**radespace **E**xploration and **A**nalysis **Suite**



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IV Tea Suite v0.1

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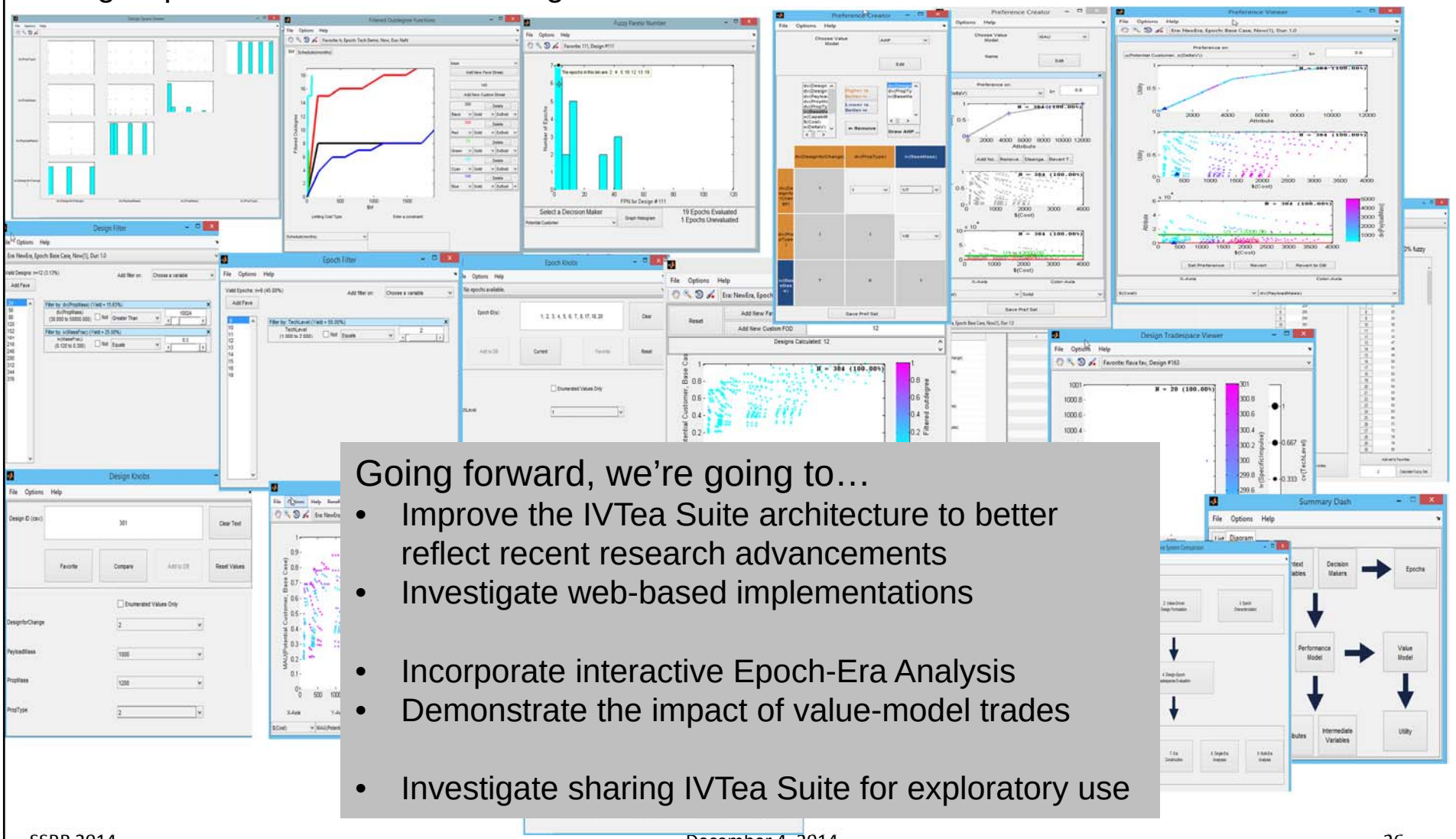
Design Space Viewer Filtered Outdegree Functions Fuzzy Pareto Number



Going forward, we're going to…

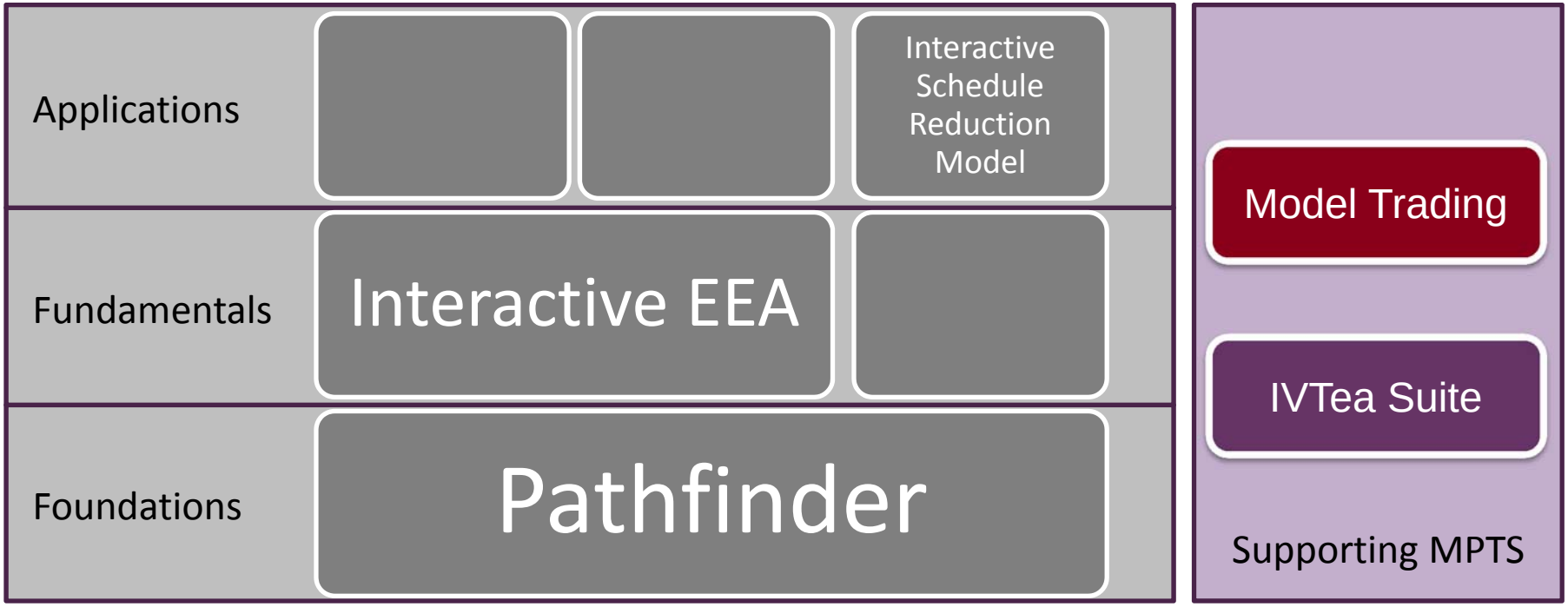
- Improve the IVTea Suite architecture to better reflect recent research advancements
- Investigate web-based implementations

- Incorporate interactive Epoch-Era Analysis
- Demonstrate the impact of value-model trades

- Investigate sharing IVTea Suite for exploratory use

Supporting MPTs: Model Trading

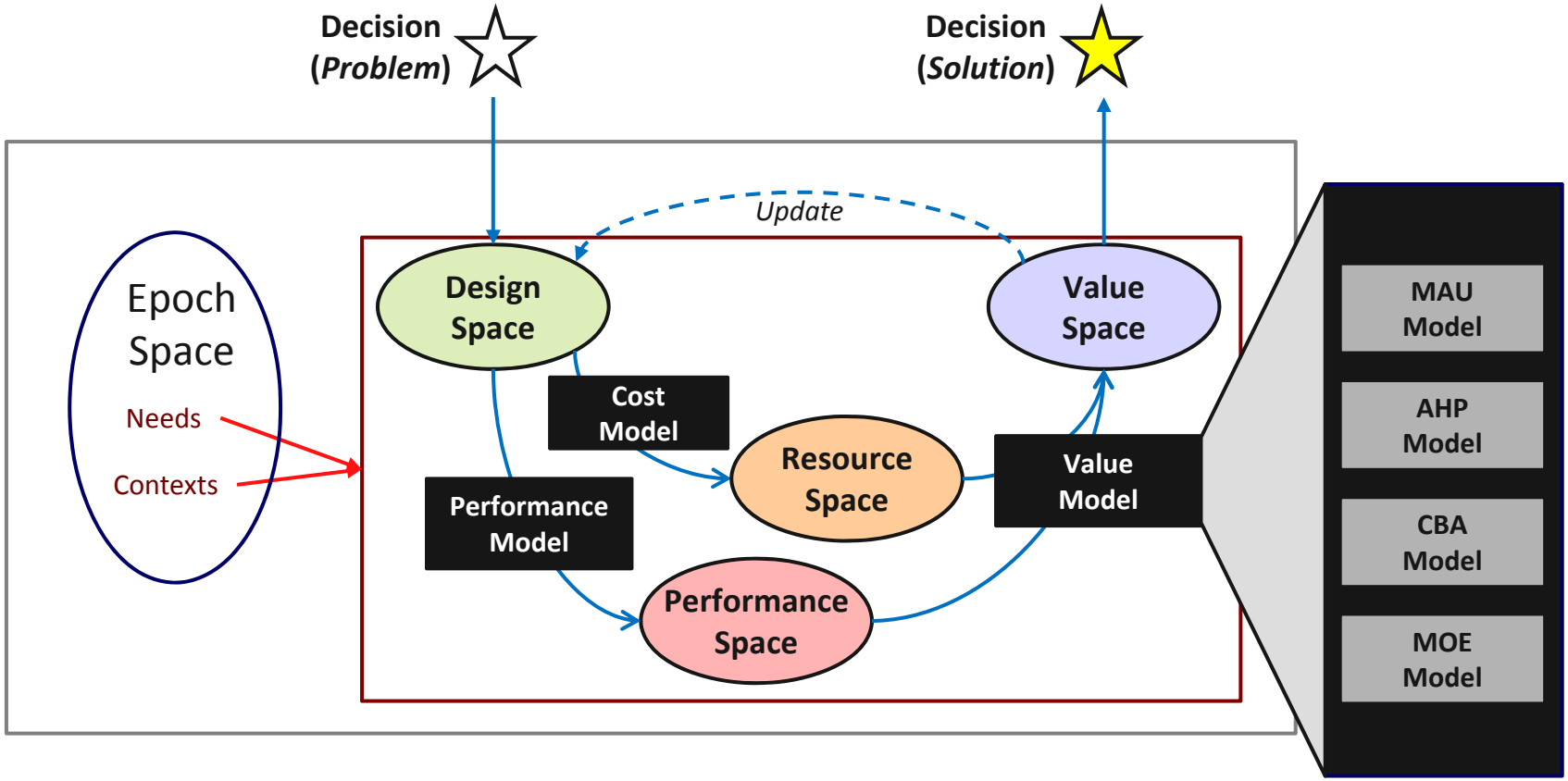
Thrusts with Supporting MPTs



Enabling meta-thinking about the impact of model choice on decision support

Design-Value Loop

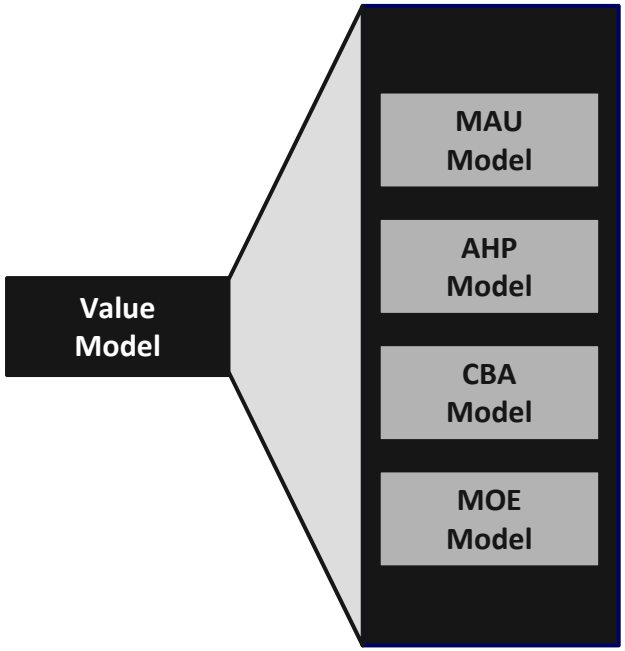
Selection of Value Model is just as important as Performance Model and Cost Model



Ricci, N., Schaffner, M.A., Ross, A.M., Rhodes, D.H., and Fitzgerald, M.E., "Exploring Stakeholder Value Models Via Interactive Visualization," 12th Conference on Systems Engineering Research, Redondo Beach, CA, March 2014.

What if we had better understanding and trust in the implications of model choice?

Aggregating Information for Decisions: Value Models



$$U(\hat{X}) = \frac{[\prod_{i=1}^{n}(K \cdot k_i \cdot U_i(X_i) + 1)] - 1}{K}$$

$$K = -1 + \prod_{i=1}^{n}(K \cdot k_i + 1)$$

$$AHP(\hat{X}) = \sum_{i=1}^{n} k_i \cdot AHP_i(X_i)$$

$$AHP_i(X_i) = \frac{(X_i - X_{i,min})}{X_{i,max} - X_{i,min}}$$

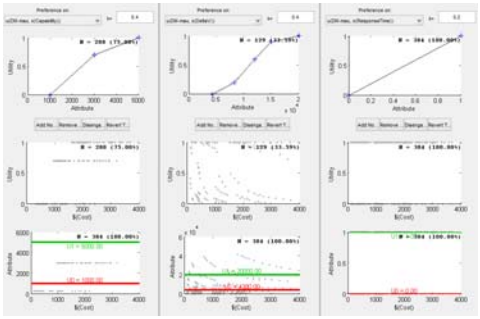
$$k_i = \frac{\sum_{q=1}^{n} \frac{a_{i,q}}{\sum_{p=1}^{n} a_{p,q}}}{n}$$

$$CBA(\hat{X}) = \sum_{i=1}^{n} CBA_i(X_i)$$

$$CBA_i(X_i) = \frac{m_i}{r_i}(1 - e^{-r_i \cdot X_i})$$

$CBA_i(X_i) = 0$

$MOE(X_i) = X_i$



	x(Capability)	x(DeltaV)	x(ResponseTime)
x(Capability)	1	1	2
x(DeltaV)	1	1	2
x(Response Time)	1/2	1/2	1

$X_i >= X_{i,min}$;

$X_i < X_{i,min}$

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Value Model Tradeoffs

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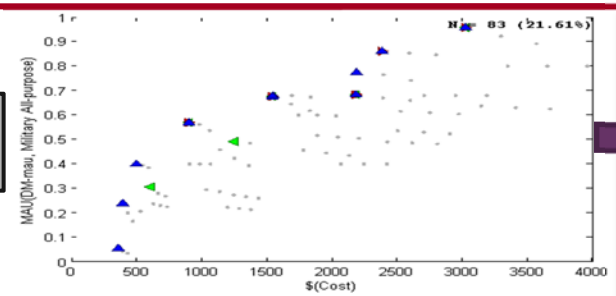
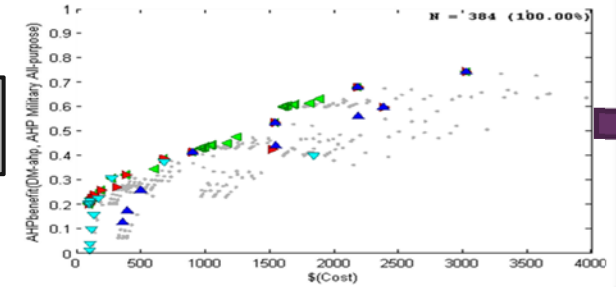
MAU Model

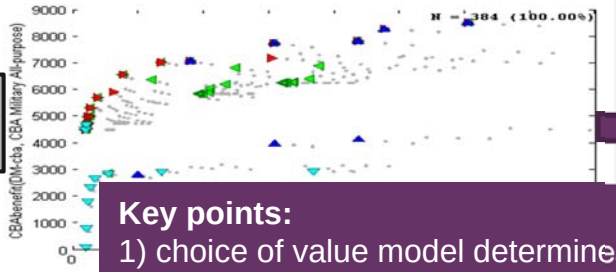
AHP Model

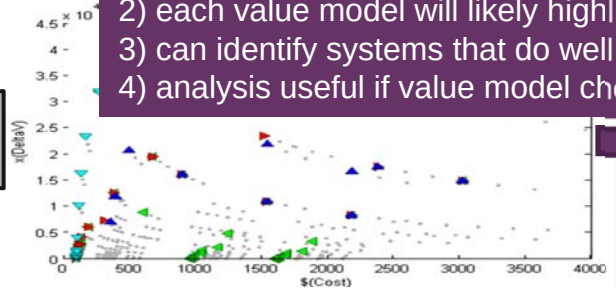
CBA Model

MOE Model

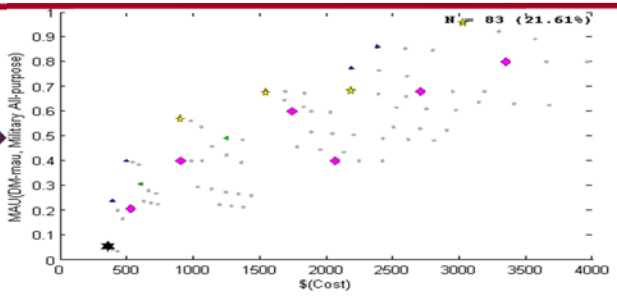


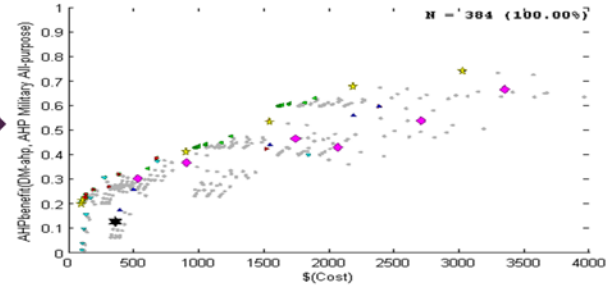


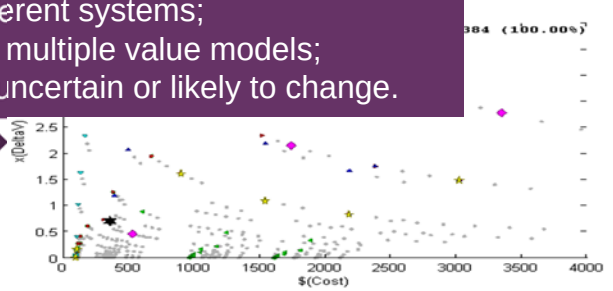




Model comparisons and tradeoffs







Key points:
1) choice of value model determines the attractiveness of each solution;
2) each value model will likely highlight different systems;
3) can identify systems that do well across multiple value models;
4) analysis useful if value model choice is uncertain or likely to change.

"Best" design(s)

Design selection

MAU-Cost Pareto Set ▲ AHP-Cost Pareto Set ◀ CBA-Cost Pareto Set ▶ MOE-Cost Pareto Set ▼

Compromise ◆ Promising ★ 7% Fuzzy Joint ✱

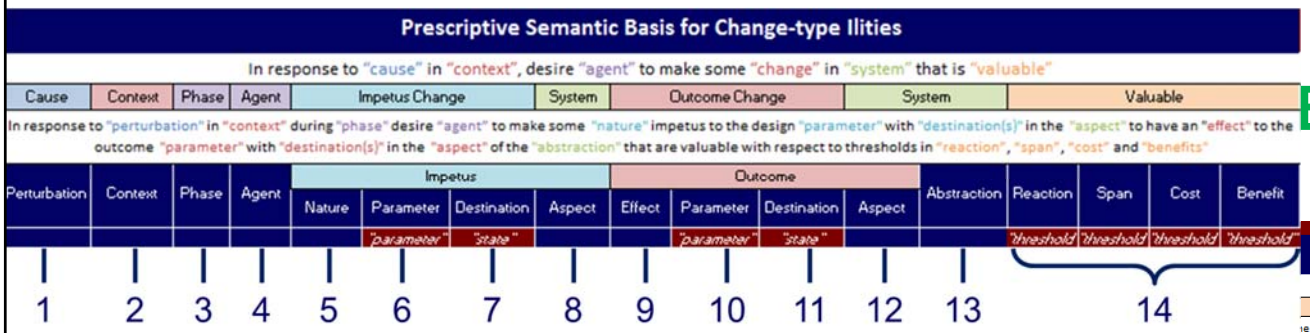
IMCSE Outcomes so Far

- Task 1: Pathfinder
  - Literature investigation into the four pillars
  - Three important challenges emerged and further investigation is ongoing
  - January workshop planned as first step in evolving the research agenda
- Task 2: Interactive Schedule Reduction Model (ISRM)
  - Demonstration web-based interactive model implementation
  - CSER15 paper: Grogan, P.T., de Weck, O.L., Ross, A.M., and Rhodes, D.H., "Interactive Models as a System Design Tool: Applications to System Project Management," 13th Conference on Systems Engineering Research, Hoboken, NJ, Mar 2015.
- Task 3: Interactive Epoch-Era Analysis (IEEA)
  - Enabling technology prototypes
  - Storyboarding prototypes
  - CSER15 paper: Curry, M. and Ross, A.M., "Considerations for an Extended Framework for Interactive Epoch-Era Analysis," 13th Conference on Systems Engineering Research, Hoboken, NJ, Mar. 2015.
- MPTs: Model Tradeoffs
  - Demonstration case study (value model tradeoff)
  - CSER15 paper: Ross, A.M., Rhodes, D.H., and Fitzgerald, M.E, "Interactive Value Model Trading for Resilient Systems Decisions," 13th Conference on Systems Engineering Research, Hoboken, NJ, Mar. 2015.
- MPTs: IVTea Suite
  - Early v0.1 implemented in MATLAB
  - Preliminary rearchitecting effort

IMCSE Phase 1 Technical Report (September 30, 2014)
http://www.sercuarc.org/wp-content/uploads/2014/05/SERC-RT-122-Phase-I-Technical-Report-2014-TR-048-1-20140930.pdf

Toward a Theory of Ilities

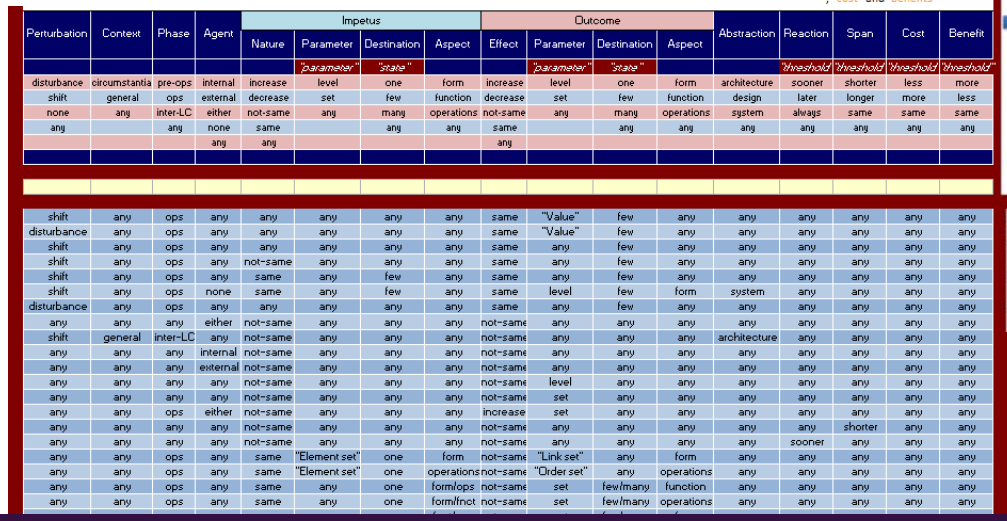
What are the semantic fields that span the general set of ilities?
e.g. “change-type”, “architecture-type”, “new ability-type”



Generated ility “labels”

Basis

Derived ility “hierarchies”



Perturbation	Context	Phase	Agent	Impetus: Nature	Impetus: Parameter	Impetus: Destination	Impetus: Aspect	Outcome: Effect	Outcome: Parameter	Outcome: Destination	Outcome: Aspect	Abstraction	Reaction	Span	Cost	Benefit
					"parameter"	"state"			"parameter"	"state"			"threshold"	"threshold"	"threshold"	"threshold"
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	same		any	any	any	any	any	any	any
			any	any				any								
shift	any	ops	any	any	any	any	any	same	"Value"	few	any	any	any	any	any	any
disturbance	any	ops	any	any	any	any	any	same	"Value"	few	any	any	any	any	any	any
shift	any	ops	any	any	any	any	any	same	any	few	any	any	any	any	any	any
shift	any	ops	any	not-same	any	any	any	same	any	few	any	any	any	any	any	any
shift	any	ops	any	same	any	few	any	same	any	few	any	any	any	any	any	any
shift	any	ops	none	same	any	few	any	same	level	few	form	system	any	any	any	any
disturbance	any	ops	any	any	any	any	any	same	any	few	any	any	any	any	any	any
any	any	any	either	not-same	any	any	any	not-same	any	any	any	any	any	any	any	any
shift	general	inter-LC	any	not-same	any	any	any	not-same	any	any	any	architecture	any	any	any	any
any	any	any	internal	not-same	any	any	any	not-same	any	any	any	any	any	any	any	any
any	any	any	external	not-same	any	any	any	not-same	any	any	any	any	any	any	any	any
any	any	any	any	not-same	any	any	any	not-same	level	any	any	any	any	any	any	any
any	any	any	any	not-same	any	any	any	not-same	set	any	any	any	any	any	any	any
any	any	ops	either	not-same	any	any	any	increase	set	any	any	any	any	any	any	any
any	any	any	any	not-same	any	any	any	not-same	any	any	any	any	any	shorter	any	any
any	any	any	any	not-same	any	any	any	not-same	any	any	any	any	sooner	any	any	any
any	any	ops	any	same	"Element set"	one	form	not-same	"Link set"	any	form	any	any	any	any	any
any	any	ops	any	same	"Element set"	one	operations	not-same	"Order set"	any	operations	any	any	any	any	any
any	any	ops	any	same	any	one	form/ops	not-same	set	few/many	function	any	any	any	any	any
any	any	ops	any	same	any	one	form/fnct	not-same	set	few/many	operations	any	any	any	any	any

Value Robustness
Value Survivability
Robustness
Active Robustness
Passive Robustness
Classical Passive Robustness
Survivability
Changeability
Evolvability
Adaptability
Flexibility
Scalability
Modifiability
Extensibility
Agility
Reactivity
Form Reconfigurability
Operational Reconfigurability
Functional Versatility
Operational Versatility

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”

RT-113 Ilities Tradespace and Affordability Progress

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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)

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"

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 w/units"	"threshold w/units"	"threshold w/units"	"threshold w/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>	either	not-same		<empty>	<empty>	<empty>		not-same		<empty>	<empty>	<empty>	<empty>	<empty>	<empty>	<empty>	<empty>
			<empty>	<empty>						<empty>									

Perturbation	Context	Phase	Agent	Impetus* (optional)					Mech	Outcome					Abstraction	Reaction	Span	Cost	Benefit
				Nature	Parameter	Origin	Destination	Aspect	Mechanism	Effect	Parameter	Origin	Destination	Aspect					
shift		ops								same	"Value"		few						
disturbance		ops								same	"Value"		few						
shift		ops								same			few						
shift		ops		not-same						same			few						
shift		ops		same		few	few			same			few						
shift		ops	none	same		few	few			same	level		few	form	system				
disturbance		ops								same			few						
			either	not-same						not-same									
shift	general	inter-LC		not-same						not-same					architecture				
			internal	not-same						not-same									
			external	not-same						not-same									
				not-same						not-same	level								
				not-same						not-same	set								
		ops	either	not-same						increase	set								
				not-same						not-same							shorter		
				not-same						not-same						sooner			
		ops		same	"Element set"	one	one	form		not-same	"Link set"			form					
		ops		same	"Element set"	one	one	operations		not-same	"Order set"			operations					
		ops		same		one	one	form/ops		not-same	set		few/many	function					
		ops		same		one	one	form/!not		not-same	set		few/many	operations					
		ops		same		one	one	!not/ops		not-same	set		few/many	form					

Ility Label
Value Robustness
Value Survivability
Robustness
Active Robustness
Passive Robustness
Classical Passive Robustness
Survivability
Changeability
Evolvability
Adaptability
Flexibility
Scalability
Modifiability
Extensibility
Agility
Reactivity
Form Reconfigurability
Operational Reconfigurability
Functional Versatility
Operational Versatility
Substitutability

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 "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".

Scalable

Flexible

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

For more info, please see:

Ross, A.M., and Rhodes, D.H., "Towards a Prescriptive Semantic Basis for Change-type Ilities," 13th Conference on Systems Engineering Research, Hoboken, NJ, Mar. 2015.

Dou, K., Wang, X., Tang, C., Ross, A.M., and Sullivan, K., "An Evolutionary Theory-Systems Approach to a Science of the Ilities," 13th Conference on Systems Engineering Research, Hoboken, NJ, Mar. 2015.