Getting Design Right: Systems Engineering for the Non-Engineer

Peter L. Jackson
Professor, Systems Engineering Program
Cornell University
Ithaca, NY

Motivation

- Why doesn't everyone learn systems engineering?
- What are the impediments to dissemination?
  - Emphasis on complexity
  - Engineering vs. design
  - Document-centric
- What is the joy of systems engineering?
- What are the lessons from the Six Sigma movement?

DoD Systems Engineering

PHASE O	I	II	III
CONCEPT EXPLORATION	PROG. DEFINITION & RISK REDUCTION	ENGINEERING & MANUFACTURING DEVELOPMENT	PRODUCTION, FIELD-ING/DEPLOY, & OPNL. SUPPORT
1. SYSTEM ANALYSIS 2. REQTS. DEFINITION 3. CONCEPTUAL DESIGNS 4. TECHNOLOGY & RISK ASSESSMENT 5. PRELIM. COST, SCHED. & PERF. OF RECOMMENDED CONCEPT	6. CONCEPT DESIGN UPDATE 7. SUBSYS. TRADEOFFS 8. PRELIMINARY DESIGN 9. PROTOTYPING, TEST, & EVALUATION 10. INTEGRATION OF MANUFACTURING & SUPPORTABILITY CONSIDERATIONS INTO DESIGN EFFORT	11. DETAIL DESIGN 12. DEVELOPMENT 13. RISK MANAGEMENT 14. DEVELOPMENT TEST & EVALUATION 15. SYSTEM INTEGRATION, TEST, & EVALUATION 16. MANUFACTURING PROCESS VERIFICATION	17. PRODUCTION RATE VERIFICATION 18. OPERATIONAL TEST & EVALUATION 19. DEPLOYMENT 20. OPERATIONAL SUPPORT & UPGRADE 21. RETIREMENT 22. REPLACEMENT PLANNING

NEED

DISPOSAL

Nouns

EVOLUTIONARY REQUIREMENTS DEFINITION

US DOD Mil499B as reproduced in INCOSE Handbook v2

DMAIC Process (Six Sigma)

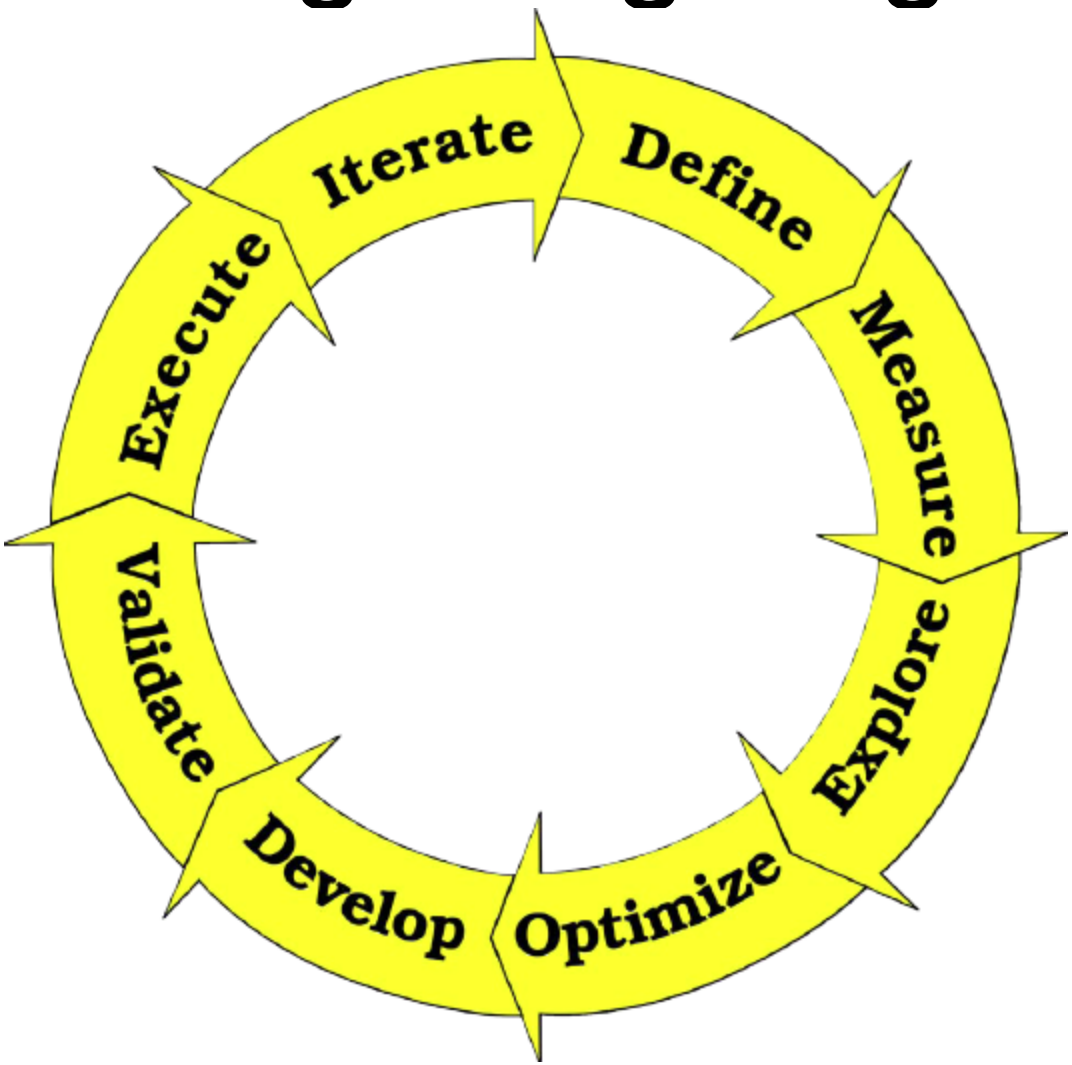
Define	Measure	Analyze	Improve	Control
Identify objectives	Identify input, output, and process	Stratify process	Design of experiments	Verify reduction in root cause
Identify customers	Develop operational definition and measurement plan	Stratify data	Response surface methods	Are additional solutions necessary?
Identify customer needs and requirements	Plot and analyze data	Develop problem statement	Generate solution ideas	Identify and develop replication and standardization procedures
Identify quality characteristics	Cause and effect analysis	Identify root causes	Determine solution impacts	Integrate and manage solutions in daily work
Prioritize characteristics (Critical to customer)	Failure modes and effects analysis	Design root cause verification analysis	Evaluate and select solutions	Integrate lessons learned
Create a process map	Identify key inputs	Validate root causes	Communicate solutions	
	Identify key process steps	Sources of variation studies	Develop pilot plans	
	Business process charting to track project metrics	Regression analysis	Verify critical inputs	
	Collect baseline performance data	Design of experiments	Op[illegible] inputs	
		Process control		
		Process capability		

Verbs

Curriculum Requirements

- Emphasize discovery, design, problem-solving, and validation
- Defer discussions of complexity until after a basic design methodology has been taught
- Describe the methodology as a design cycle of simple steps
- Blend the systems engineering approach with other customer-focused and product-development focused approaches
- Use action-oriented verbs to describe the steps
- Motivate each major design step with “What Went Wrong” case studies
- Restrict techniques to those requiring only secondary-school level mathematics and science
- Illustrate each step using a running example
- Reinforce systems thinking with repeated opportunities for abstraction (‘dive and surface’)
- Provide design challenges in both business and engineering applications

Design Cycle: ‘Eight Steps to Getting Design Right’

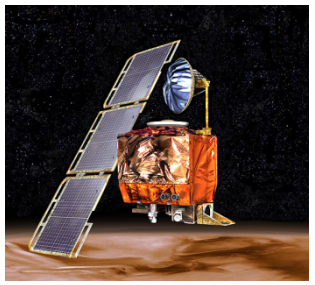


‘What Went Wrong’ Case Studies

The Vasa Warship

The ‘Titanic’

The Hubble Telescope

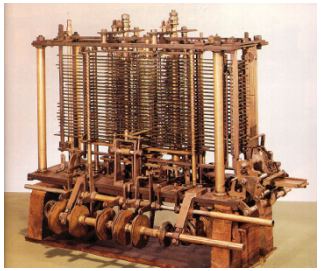


The Mars Orbiter

Boeing 787 Dreamliner

The International Space Station

The Relaxacisor

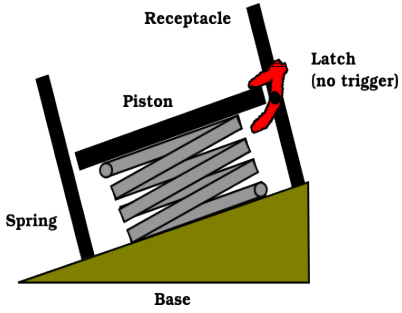


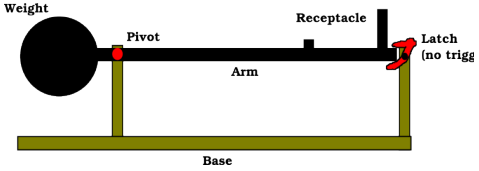
Babbage Difference Engine

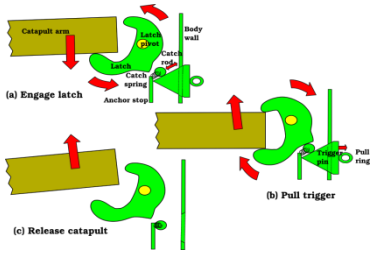
The Patriot Missile

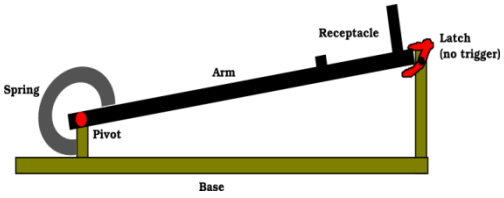
http://www.traveljournals.net/pictures/l/18/188954-vasa-warship-at-the-vasa-muset-stockholm-sweden.jpg
http://www.museumofquackery.com/devices/images/relaxwoman.jpg
http://www.plyojump.com/classes/images/computer_history/analytical_engine_fragment.JPG
http://www.tcappsbct.com/BCT/img/Patriot_missile_launch.jpg
http://nssdc.gsfc.nasa.gov/image/spacecraft/mars98orb.jpg
http://www.dailyhotnews.org/wp-content/uploads/2010/04/hubble-telescope-752865.jpg
http://schsscience.files.wordpress.com/2009/06/international-space-station2.jpg
http://www.juvandesign.com/wp-content/uploads/2009/05/boeing1.jpg
http://lostcruiseliners.webs.com/0_paintings_titanic%5B1%5D.jpg

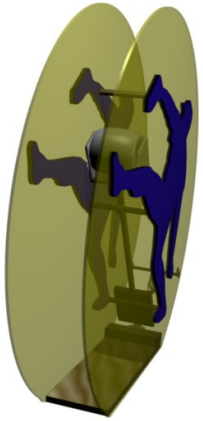
Running Example: Designing a Toy Catapult

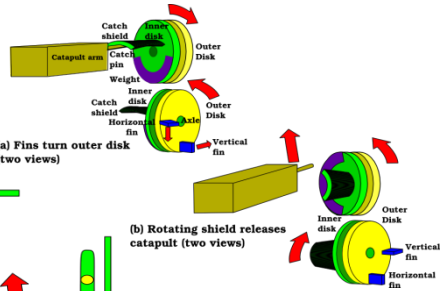


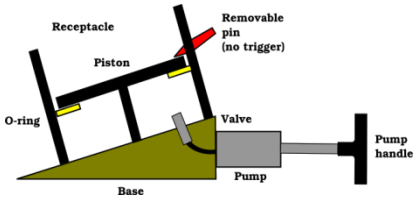


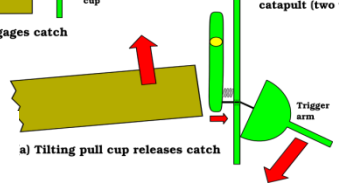


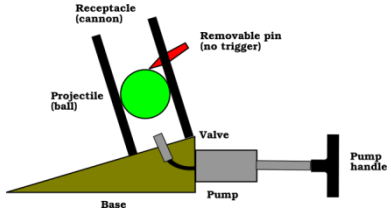


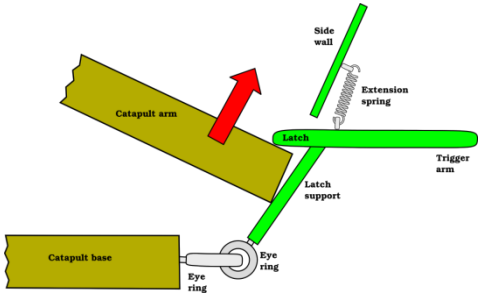




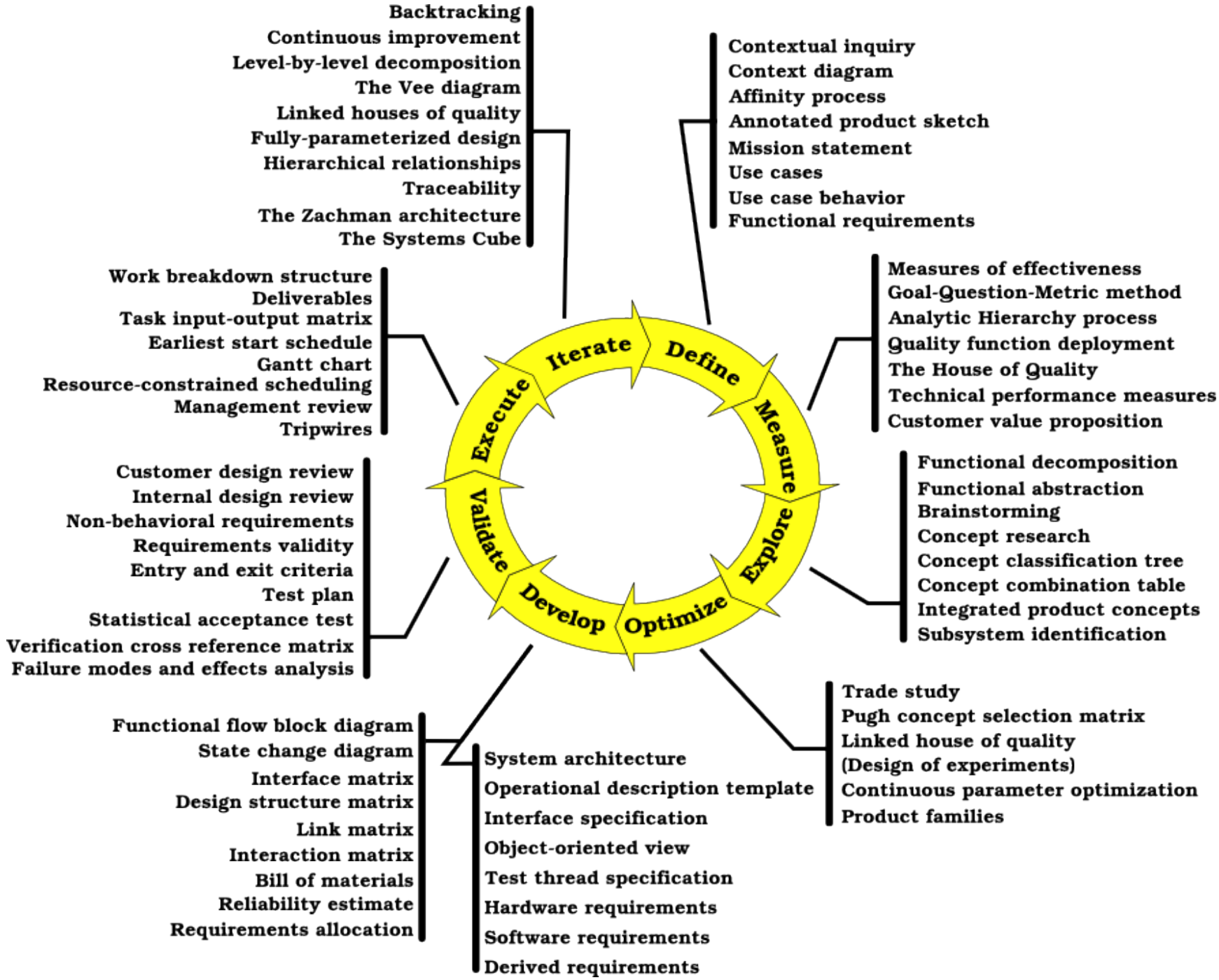




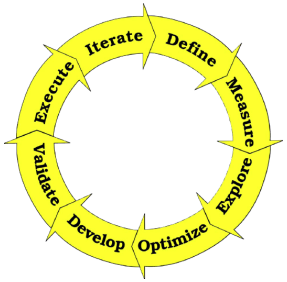




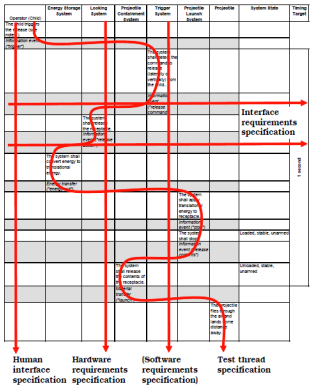
http://static.letsbuyit.com/filer/images/uk/products/original/128/40/schleich-catapult-12840960.jpeg


Backtracking
Continuous improvement
Level-by-level decomposition
The Vee diagram
Linked houses of quality
Fully-parameterized design
Hierarchical relationships
Traceability
The Zachman architecture
The Systems Cube
Contextual inquiry
Context diagram
Affinity process
Annotated product sketch
Mission statement
Use cases
Use case behavior
Functional requirements
Work breakdown structure
Deliverables
Task input-output matrix
Earliest start schedule
Gantt chart
Resource-constrained scheduling
Management review
Tripwires
Measures of effectiveness
Goal-Question-Metric method
Analytic Hierarchy process
Quality function deployment
The House of Quality
Technical performance measures
Customer value proposition
Iterate
Define
Measure
Explore
Optimize
Develop
Validate
Execute
Customer design review
Internal design review
Non-behavioral requirements
Requirements validity
Entry and exit criteria
Test plan
Statistical acceptance test
Verification cross reference matrix
Failure modes and effects analysis
Functional decomposition
Functional abstraction
Brainstorming
Concept research
Concept classification tree
Concept combination table
Integrated product concepts
Subsystem identification
Functional flow block diagram
State change diagram
Interface matrix
Design structure matrix
Link matrix
Interaction matrix
Bill of materials
Reliability estimate
Requirements allocation
System architecture
Operational description template
Interface specification
Object-oriented view
Test thread specification
Hardware requirements
Software requirements
Derived requirements
Trade study
Pugh concept selection matrix
Linked house of quality
(Design of experiments)
Continuous parameter optimization
Product families

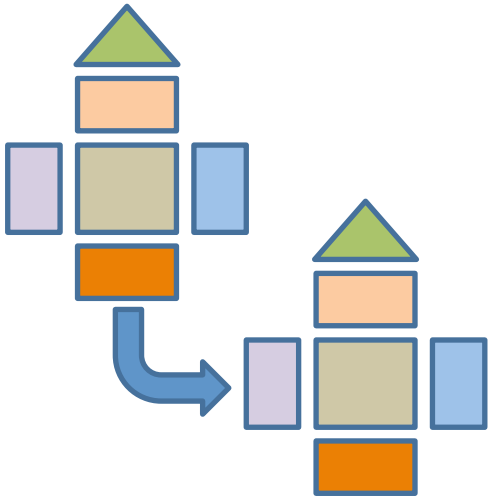
Fundamental Views



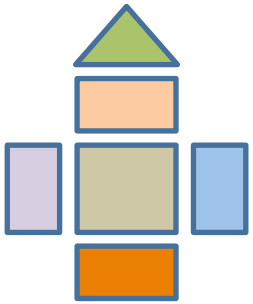
Eight Steps



The Operations Description Template

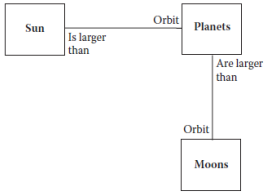


The Linked House of Quality

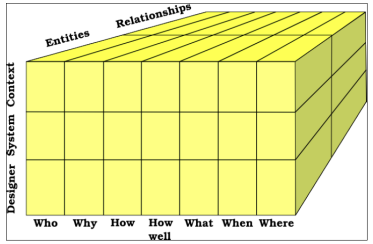


The House of Quality

The Vee Diagram

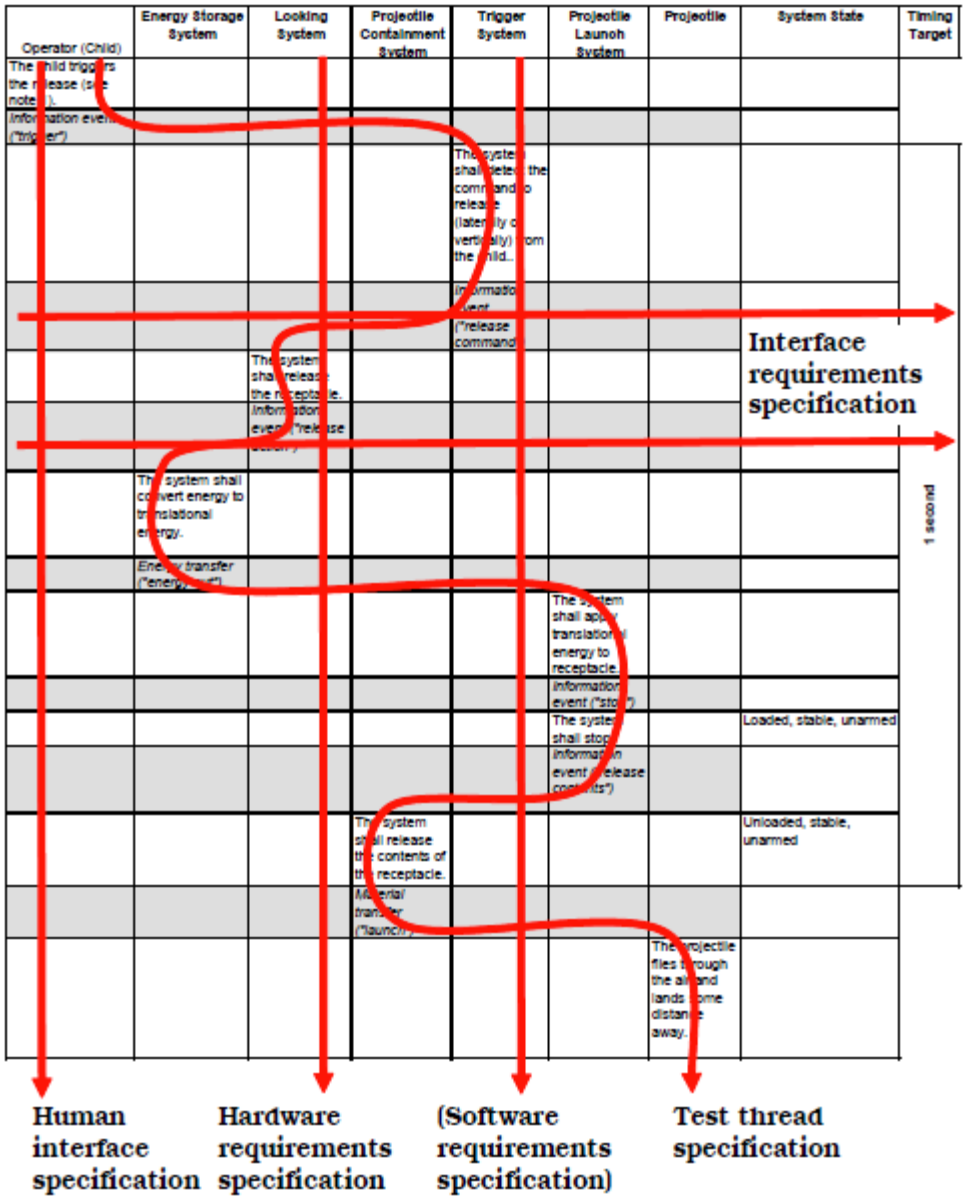


The Context Diagram



The Systems Cube

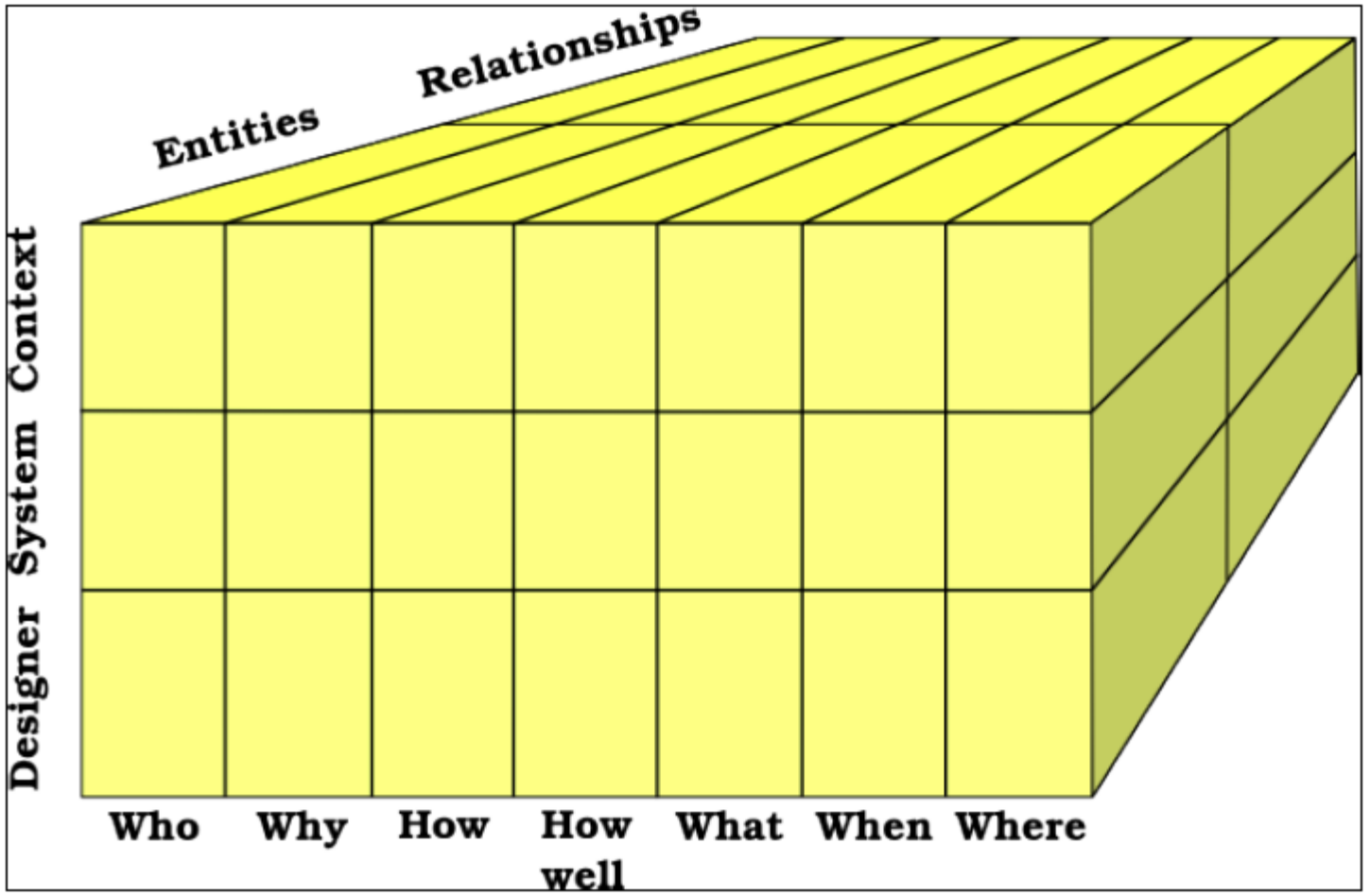
The Operations Description Template Integrates Views



Dive and Surface

- Applications of abstraction
  - Functional requirements
  - Voice of the customer
  - Concept classification
  - Subsystem identification
  - Behavior threads to functional flow and state change
  - Zachman architecture

The Systems Cube



Design Challenges

- A Bathroom-Cleaning Robot
- A Home Health-Care Monitoring Station
- A Night-Vision System for Automobiles
- An Internet-Based Meal Delivery System

Implementations

- 'A Systems Approach to Product and Service Design'
  - eCornell certificate program
- SYSEN 1100 Getting Design Right: A Systems Approach
  - Distance learning summer course
- ECE Design Course
  - Juniors in ECE
- CRC Press: Textbook