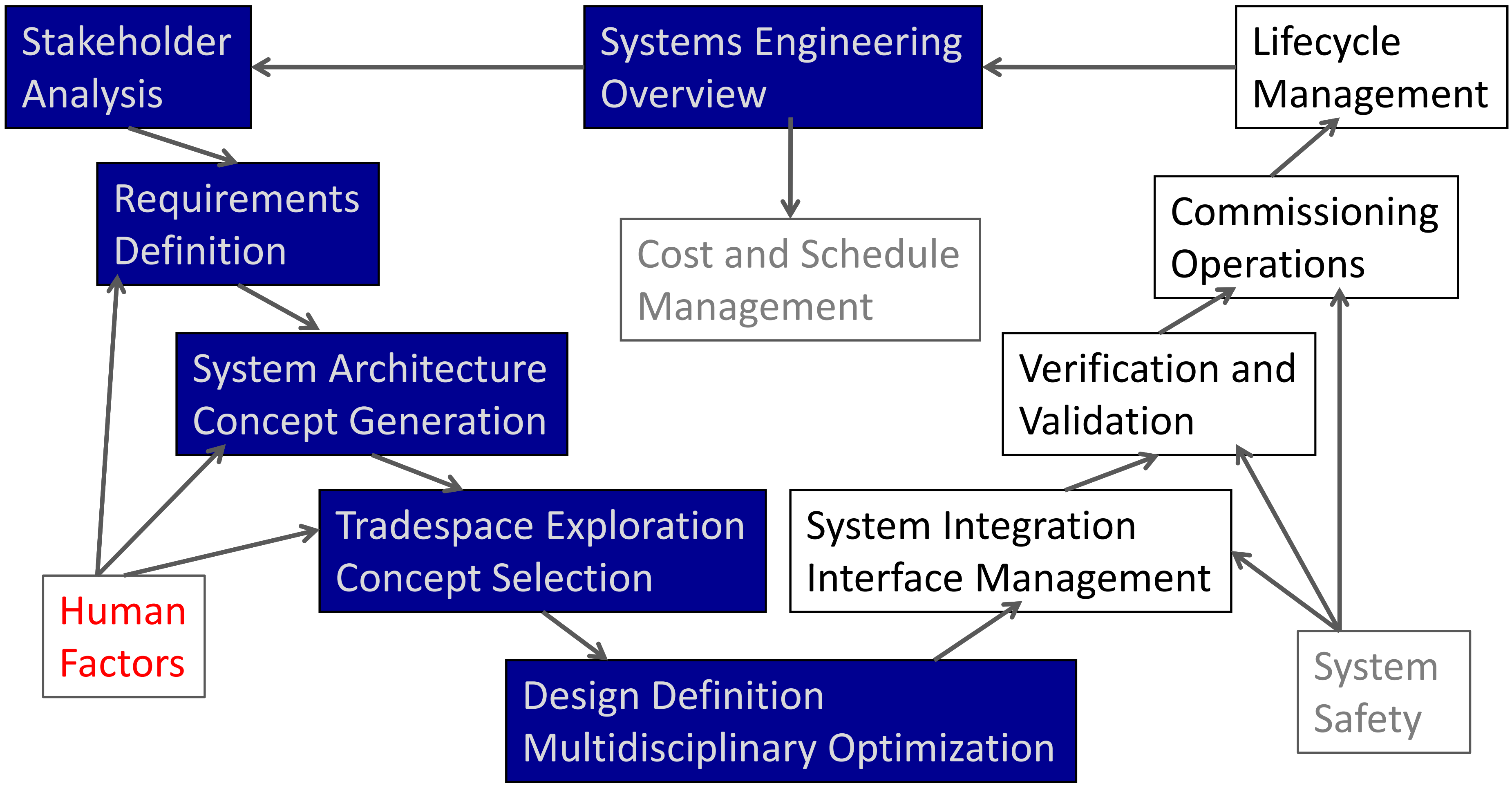
16.842

Fundamentals of Systems Engineering

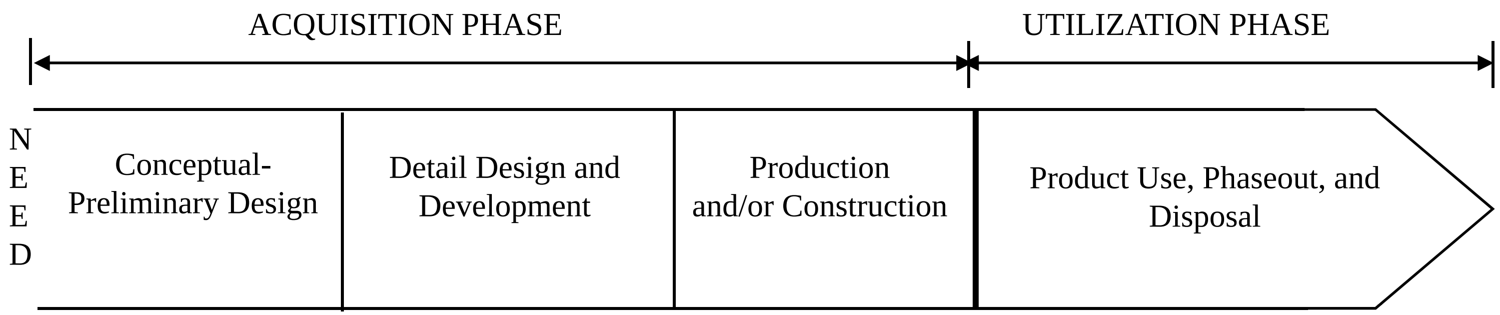
Human-Systems Engineering

Massachusetts Institute of Technology

V-Model – Oct 23, 2009



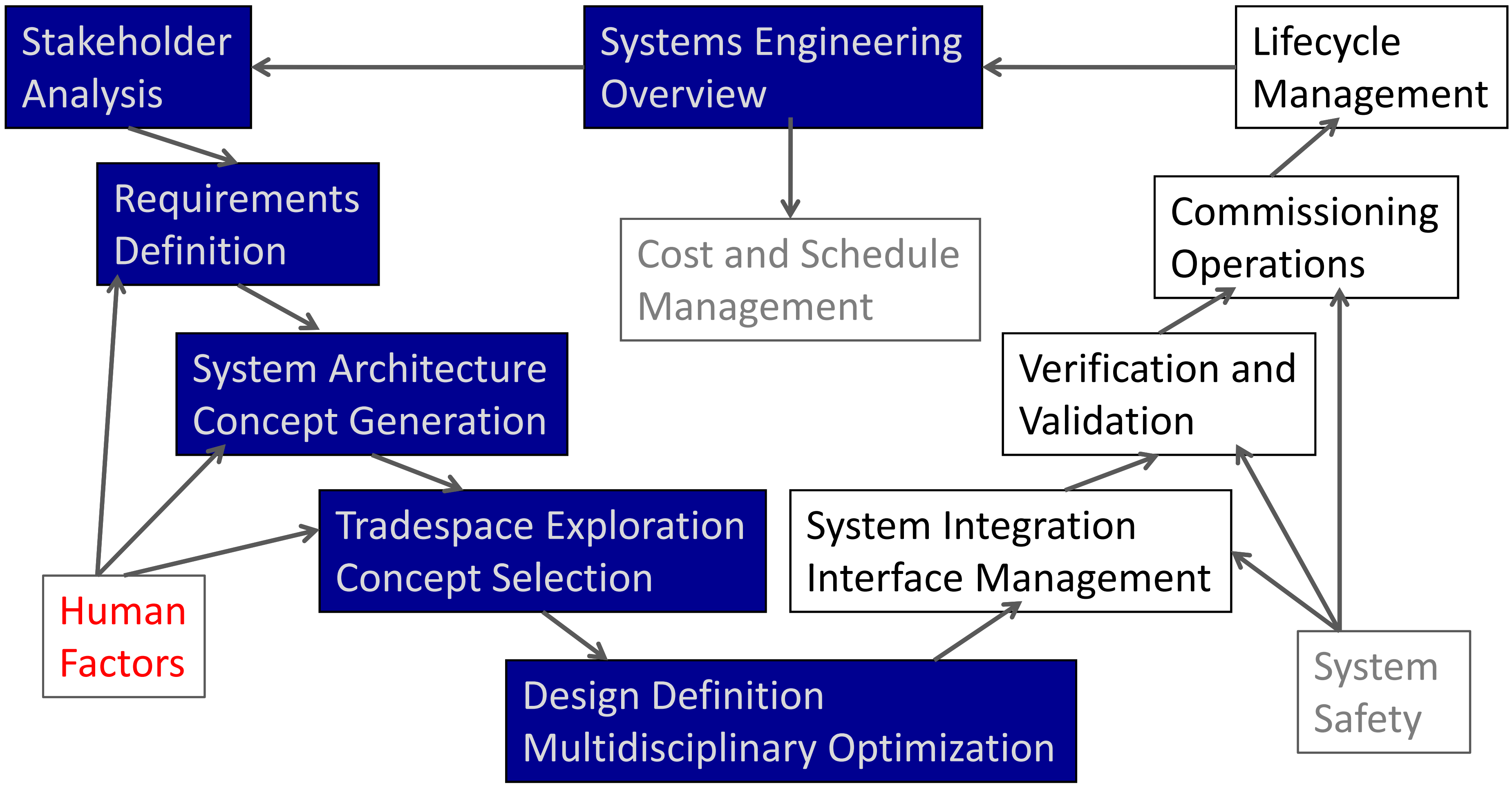
Traditional Systems Engineering Process Model*



- Operational requirements drive technical performance measures which drive human factors requirements…..
  - Human considerations often are low priority

*Blanchard, B. S., & Fabrycky, W. J. (1998). Systems Engineering and Analysis (3rd ed.). Upper Saddle River, NJ: Prentice Hall.

Or stuck out on the periphery…



Results of "Classic" SE Methods

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Three Mile Island

- March 28th, 1979
- Main feedwater pump failure, caused reactor to shut down
- Relief valve opened to reduce pressure but became stuck in the open position
  - No indication to controllers
  - Valve failure led to a loss of reactant coolant water
- No instrument showed the coolant level in the reactor
- Operators thought relief valve closed & water level too high
  - High stress
  - Overrode emergency relief pump

Three Mile Island, cont.

- System worked as designed, automation worked correctly
  - Confirmation bias: people seek out information to confirm a prior belief and discount information that does not support this belief
  - Operators selectively filtered out data from other gauges to support their hypothesis that coolant level was too high

The Spiral Systems Engineering Process Model*

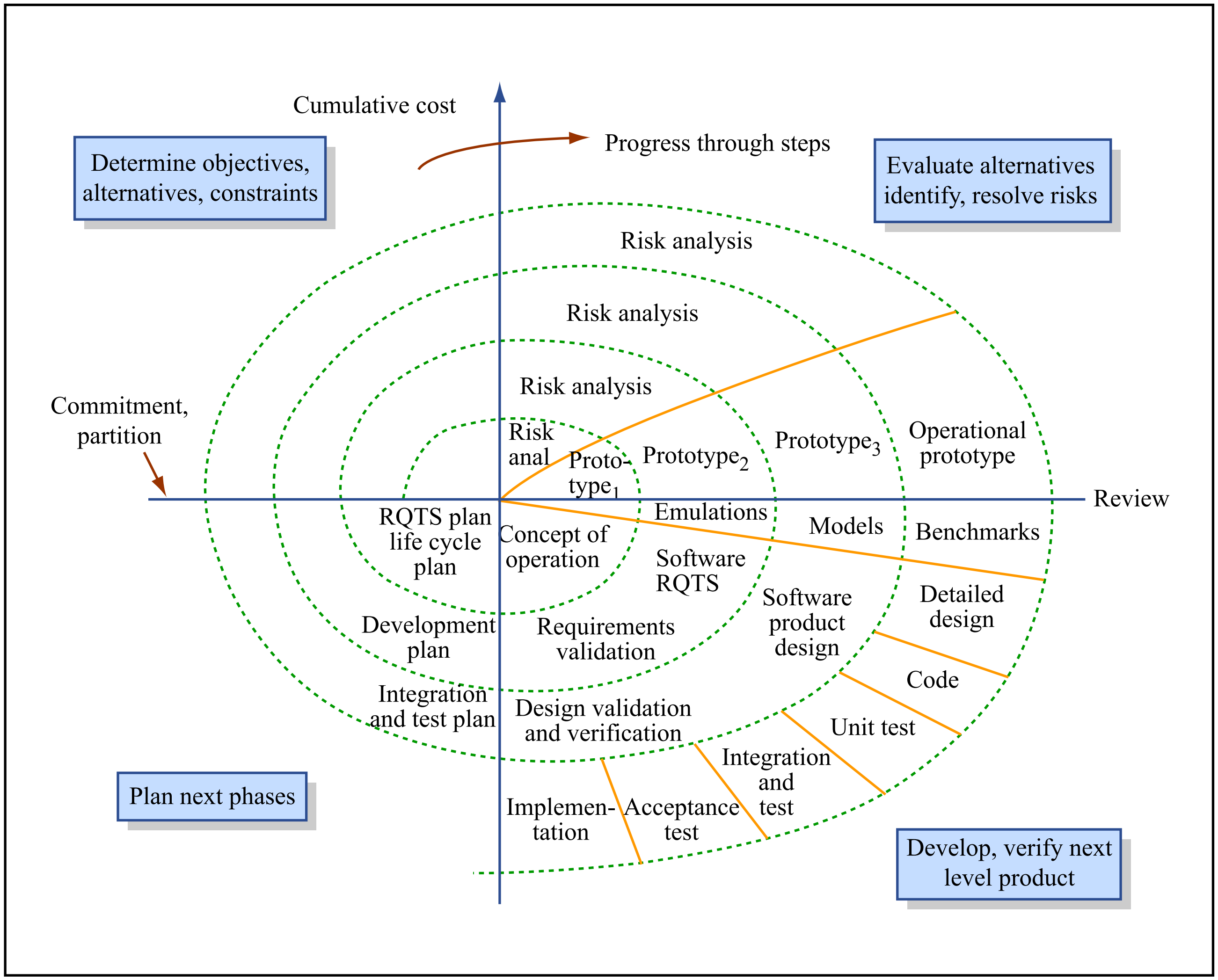
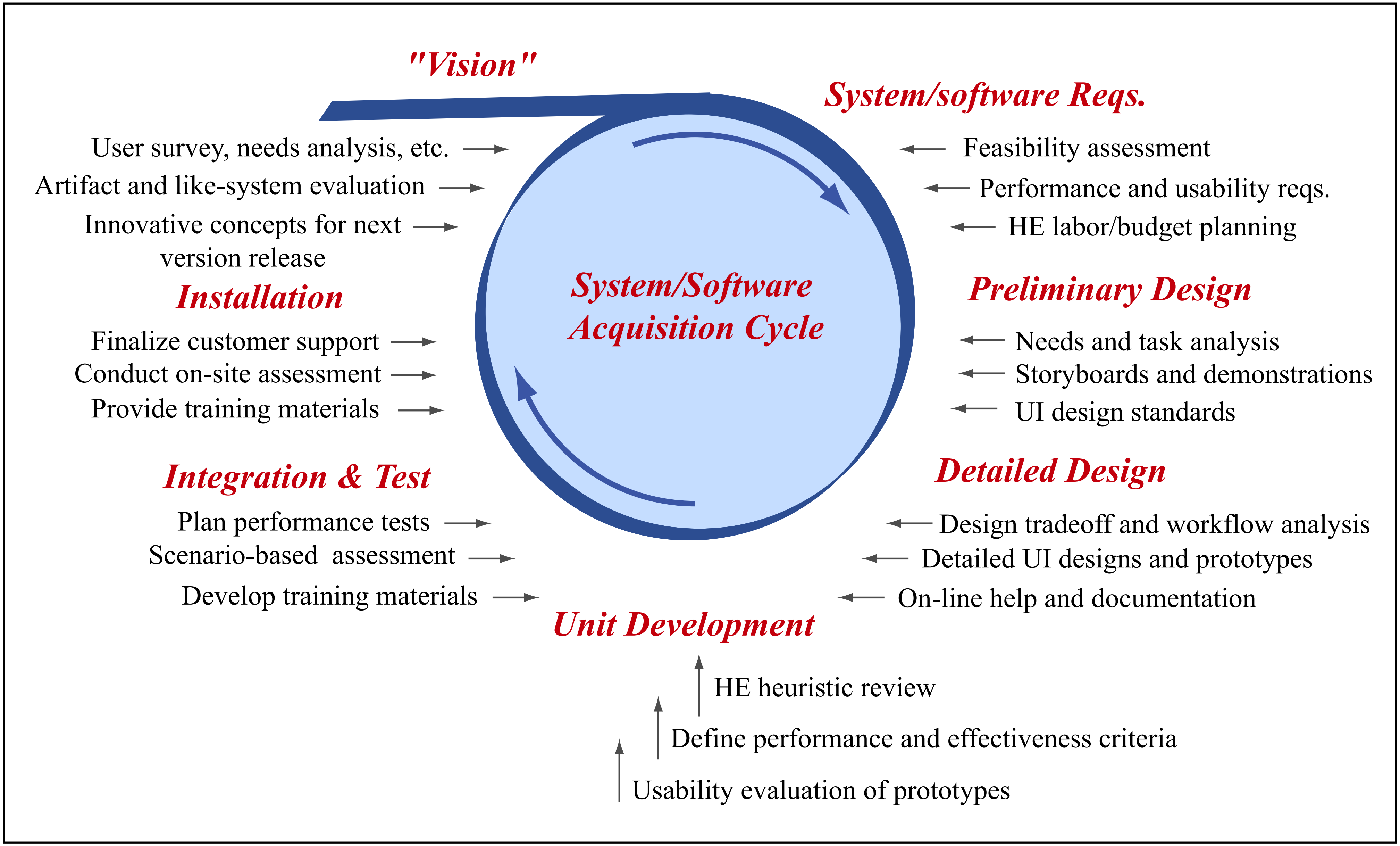


Image by MIT OpenCourseWare.

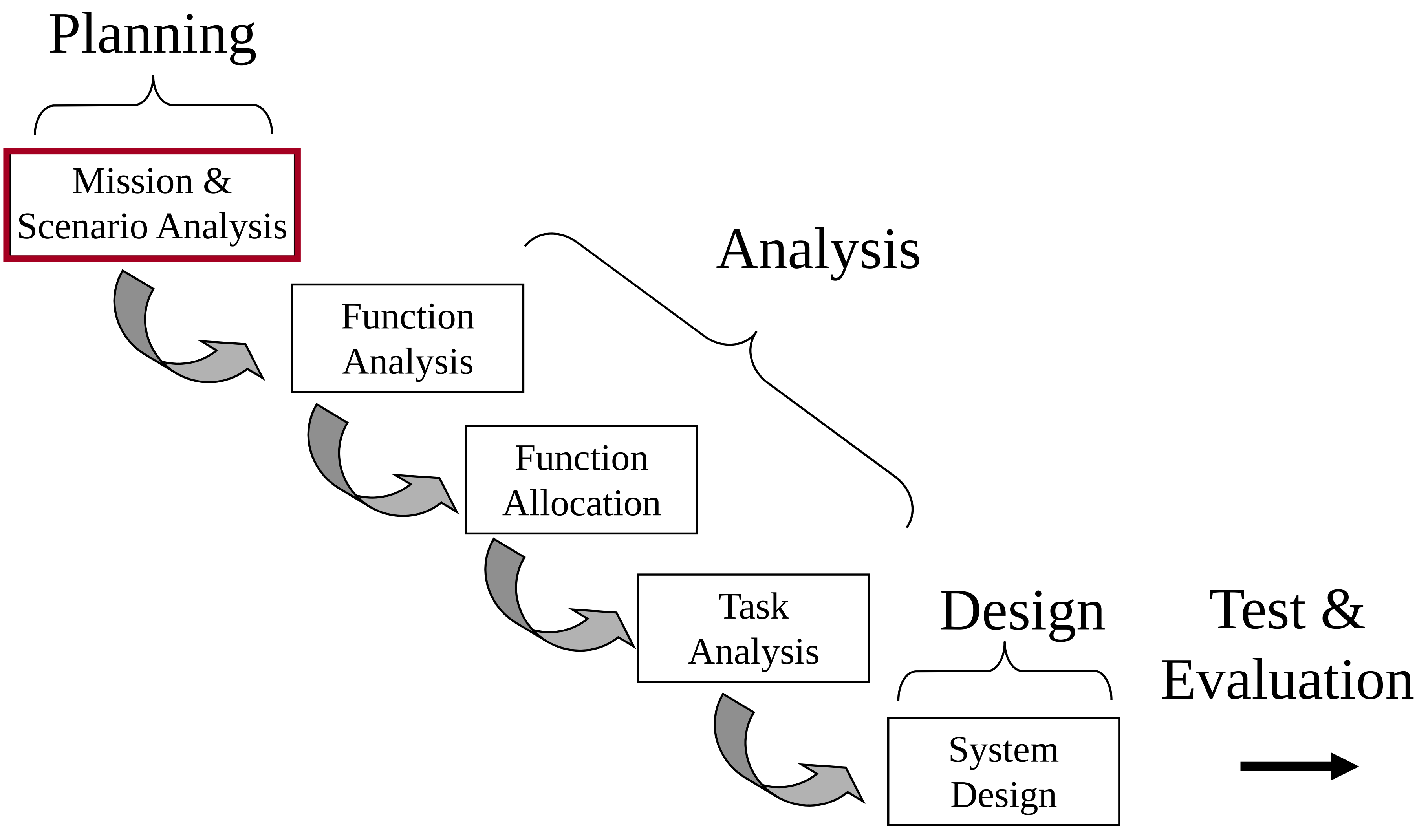
*Boehm, B. (1988). A Spiral Model of Software Development and Enhancement. Computer, 61-72.

Human Systems Engineering*



* Aptima, Inc. rendition

A Simplified HSE approach

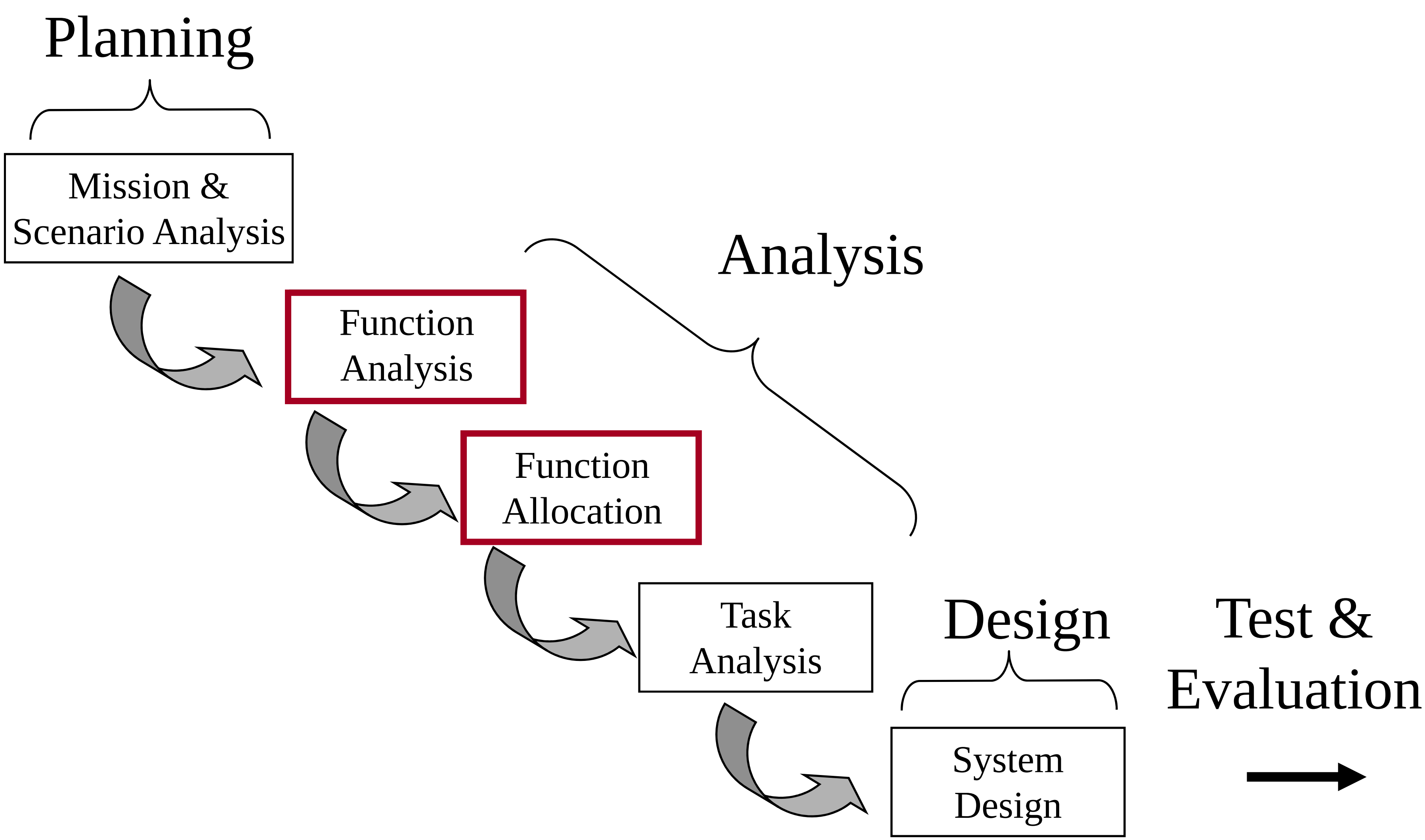


Mission & Scenario Analysis

- Stakeholder analysis
- Do users always know what they want/need?
  - Revolutionary vs. evolutionary systems
- Interviews & observations
- Work process flows
- This is a critical step and should be agreed upon before moving forward

The most ill-defined but the most important step

A Simplified HSE approach



Determining function allocation

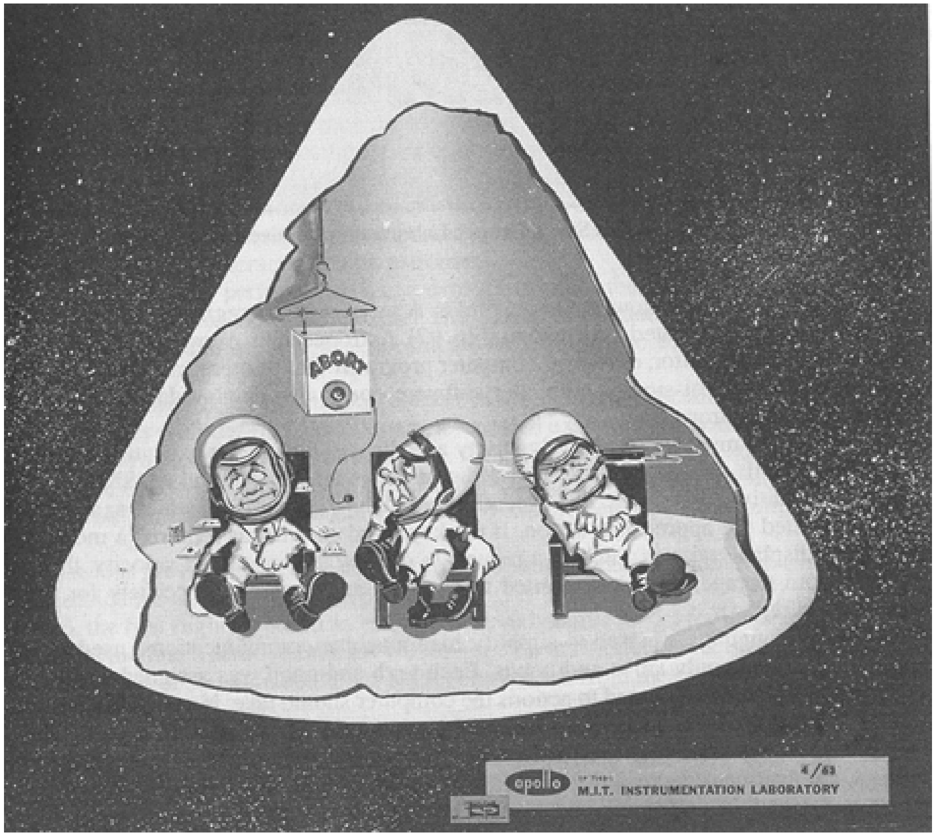
- More art than science
- Steps:
  - Identify functions
    - Use Cases
    - Interviews
    - Customer requirements
  - Identify who is best suited for each function
    - Human or automation or shared?
    - Static vs. dynamic/adaptive
- Sounds easy!

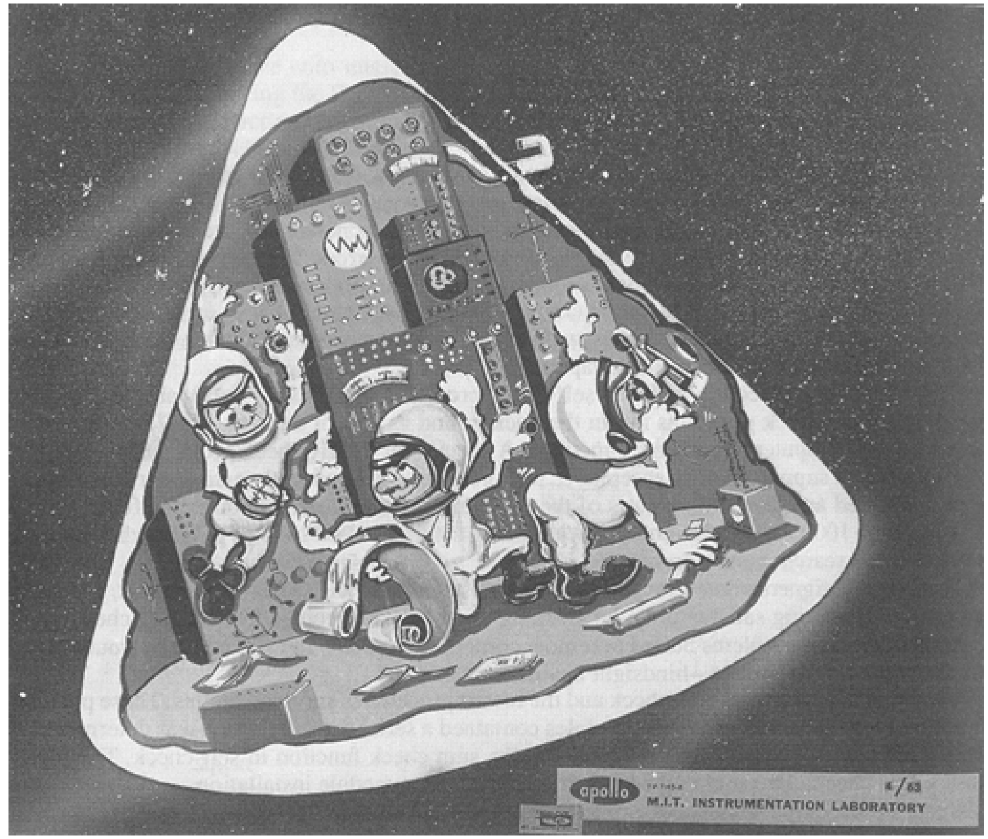
Function Allocation via Fitts' List?

Attribute	Machine	Human
Speed	Superior	Comparatively slow
Power Output	Superior in level in consistency	Comparatively weak
Consistency	Ideal for consistent, repetitive action	Unreliable, learning & fatigue a factor
Information Capacity	Multi-channel	Primarily single channel
Memory	Ideal for literal reproduction, access restricted and formal	Better for principles & strategies, access versatile & innovative
Reasoning Computation	Deductive, tedious to program, fast & accurate, poor error correction	Inductive, easier to program, slow, accurate, good error correction
Sensing	Good at quantitative assessment, poor at pattern recognition	Wide ranges, multi-function, judgment
Perceiving	Copes with variation poorly, susceptible to noise	Copes with variation better, susceptible to noise

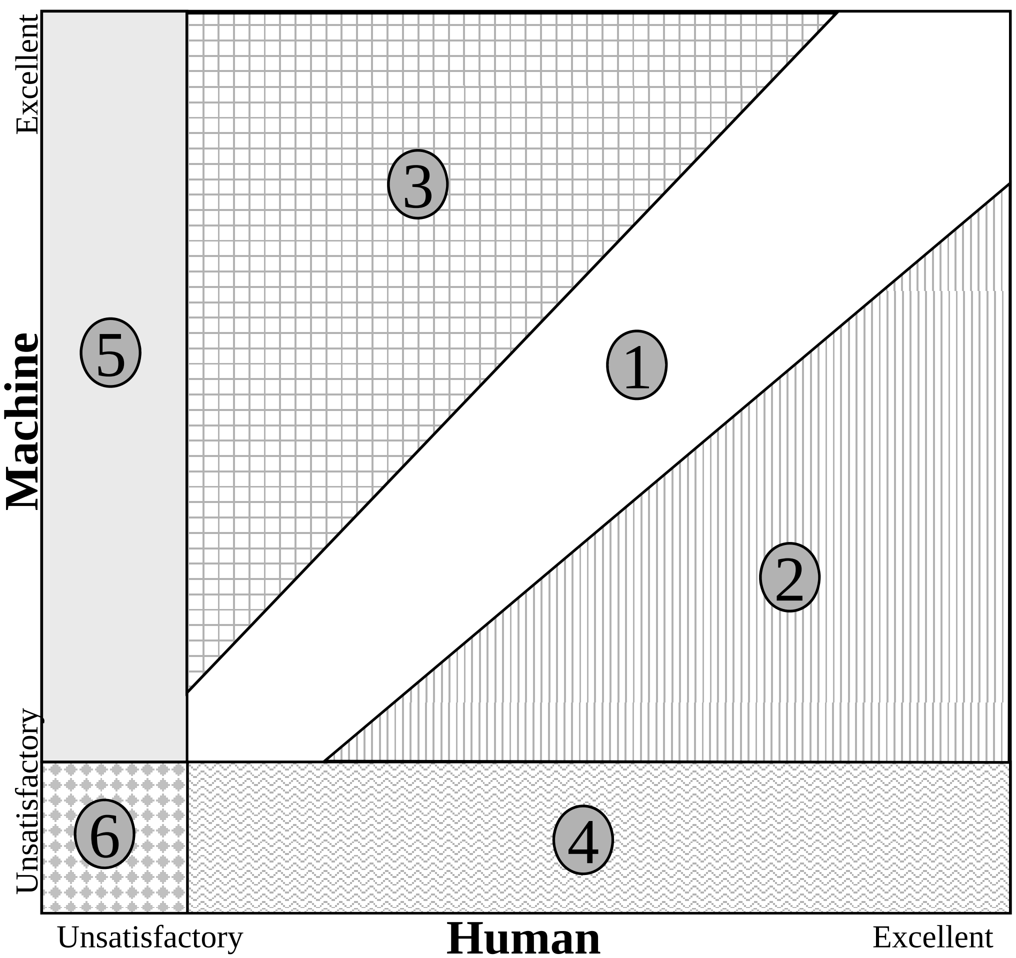
Hollnagel, 2000

To automate or not to automate?





Function Allocation Criteria



Price, 1985

1: No difference in the relative capabilities of human & machine.

2: Human performance > machine performance.

3: Machine performance > human.

4: Machine performance is so poor that the functions should be allocated to humans.

5: Human performance is so poor that the functions should be allocated to machine.

6: Unacceptable performance by both human and machine.

Three function allocation criteria:

- Balance of value
- Utilitarian & cost-based allocation
- Allocation for affective or iti t

Sheridan and Verplank's 10 Levels of Automation of Decision and Action Selection

Automation Level	Automation Description
1	The computer offers no assistance: human must take all decision and actions.
2	The computer offers a complete set of decision/action alternatives, or
3	narrows the selection down to a few, or
4	suggests one alternative, and
5	executes that suggestion if the human approves, or
6	allows the human a restricted time to veto before automatic execution, or
7	executes automatically, then necessarily informs humans, and
8	informs the human only if asked, or
9	informs the human only if it, the computer, decides to.
10	The computer decides everything and acts autonomously, ignoring the human.

The Human-Automation Paradox

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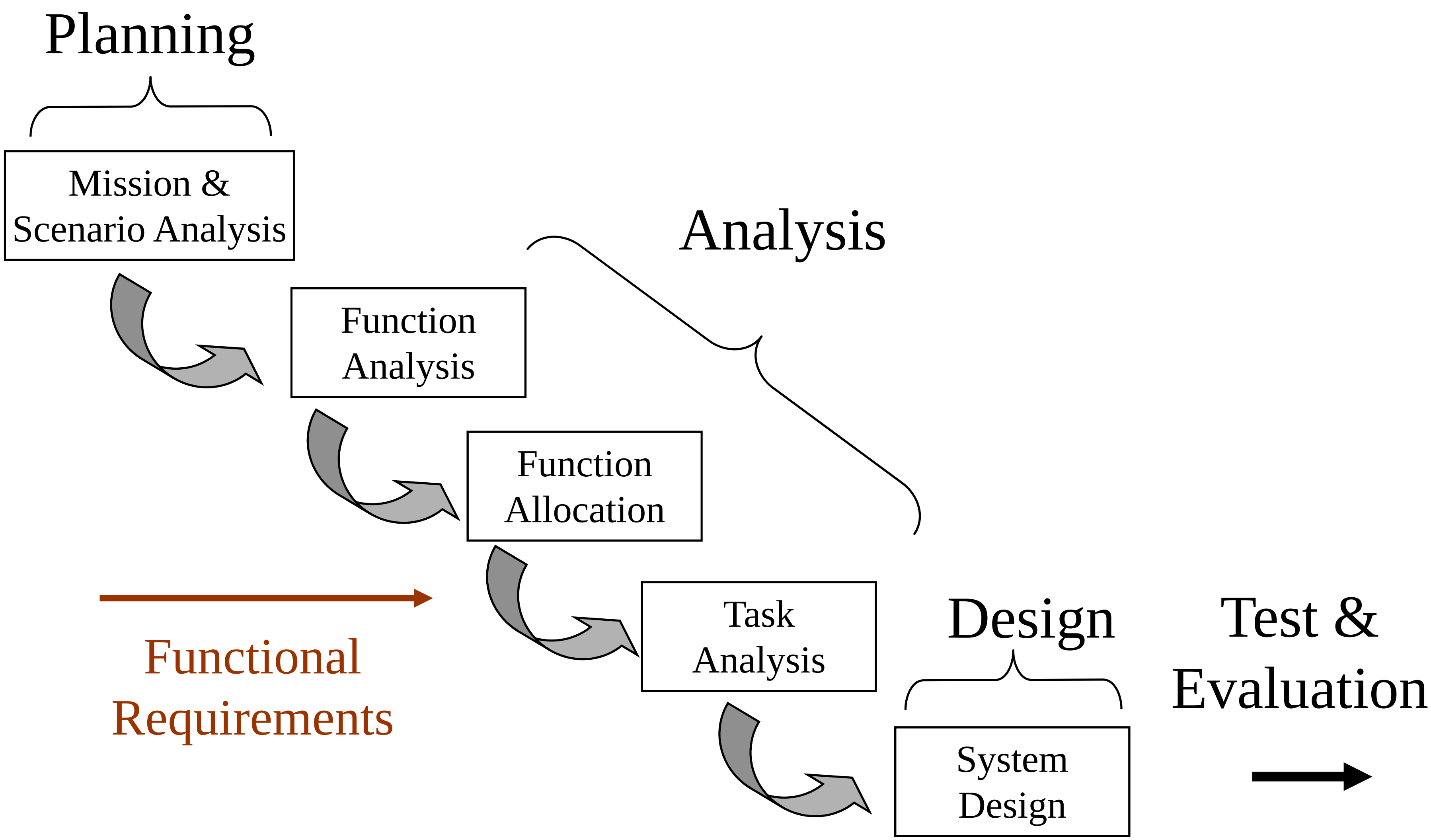
Adaptive Automation

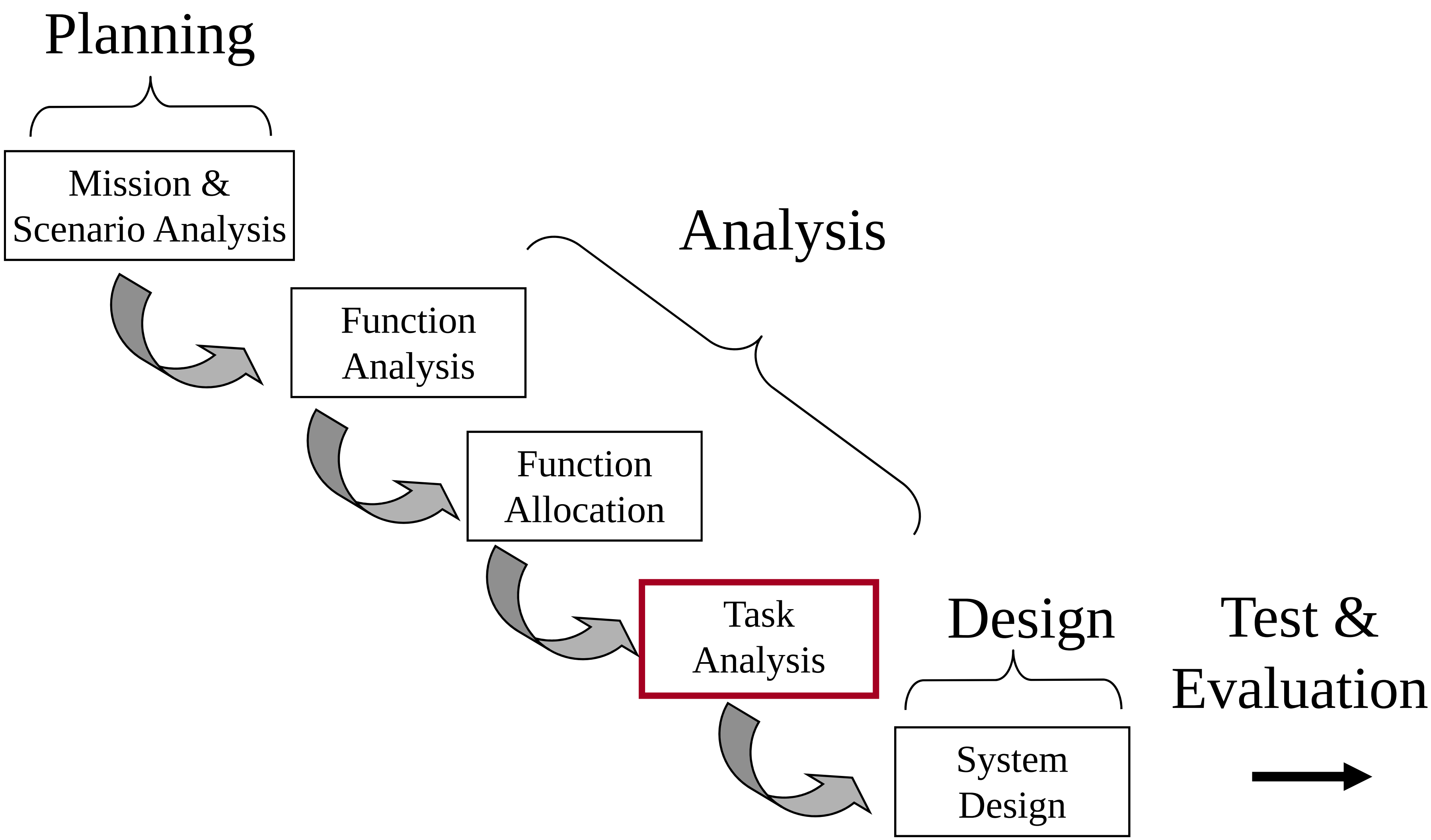
- Dynamic function allocation
- Mode Confusion
  - A problem of intent
- Mixed initiative
- Flexible automation

This image of a crashed jet has been removed due to copyright restrictions.

Functional Requirements



Task Analysis



Task Analysis

- Taylor
- Determining what an operator must accomplish to meet a mission goal
  - Interactions both on a local & system level are critical
  - Will contain actions and/or cognitive processes
- Flow process charts, operational sequence diagrams, critical task analysis

  Attempt to understand how a particular task could exceed human limitations, both physical and cognitive
- Cognitive task analysis
  - Shift from system control to systems management.

Cognitive Task Analysis (CTA)

- Goal: To analyze and represent the knowledge and cognitive activities needed in complex work domains
- CTA is generally a descriptive modeling technique of workers' knowledge and cognition
  - As opposed to Computational Cognitive Models (CCM)
  - Knowledge Elicitation is a central feature
    - Experts vs. Novices
- Evolutionary systems vs. revolutionary systems
- Background Research
  - Standards, procedures, manuals, organizational charts
- Field Studies
  - In both real environments and high fidelity simulations
- Questionnaires/Surveys

CTA, Cont.

- Interviews
  - Individuals vs. focus groups
  - Critical Incident Technique/Critical Decision Method
- Observations
  - Verbal protocols
- Design Reviews
  - Usability, Expert, Heuristic
- Problems with CTA
  - Labor intensive
  - Generate much data that is difficult to analyze
  - Gap between CTA and design
  - Opportunistic

SRK* Taxonomy of Cognitive Control

- Skill-Based Behavior (SBB)
  – Motor control/automaticity in perception-action cycle
- Rule-Based Behavior (RBB)
  – Procedural, stored if-then-else rules that dictate action
- Knowledge-Based Behavior (KBB)
  – Serial, analytical reasoning based on a mental model (internal, symbolic representation of environmental constraints and relationships in the environment.)
- Which of these should be automated?
- Analyst's best guess for SRK assignment?

(*Rasmussen, 1976)

The Need for Iteration

Planning

Mission & Scenario Analysis

Function Analysis

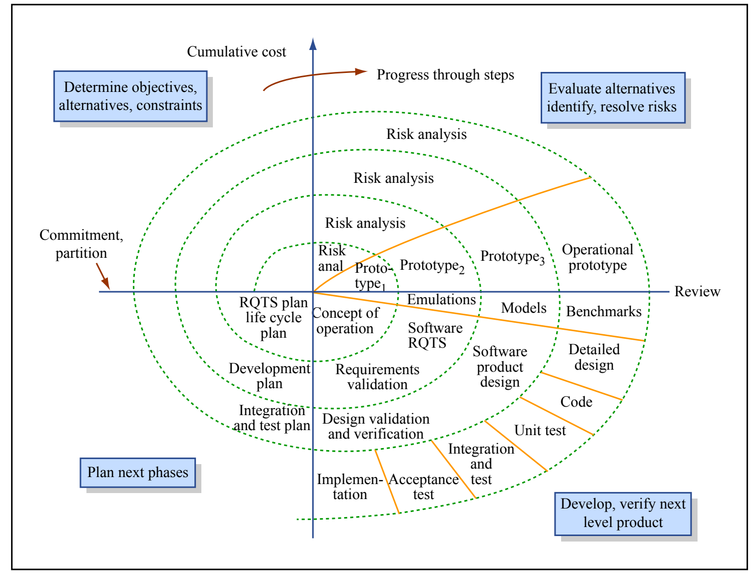
Function Allocation

Task Analysis

System Design

Functional Requirements?

Test & Evaluation



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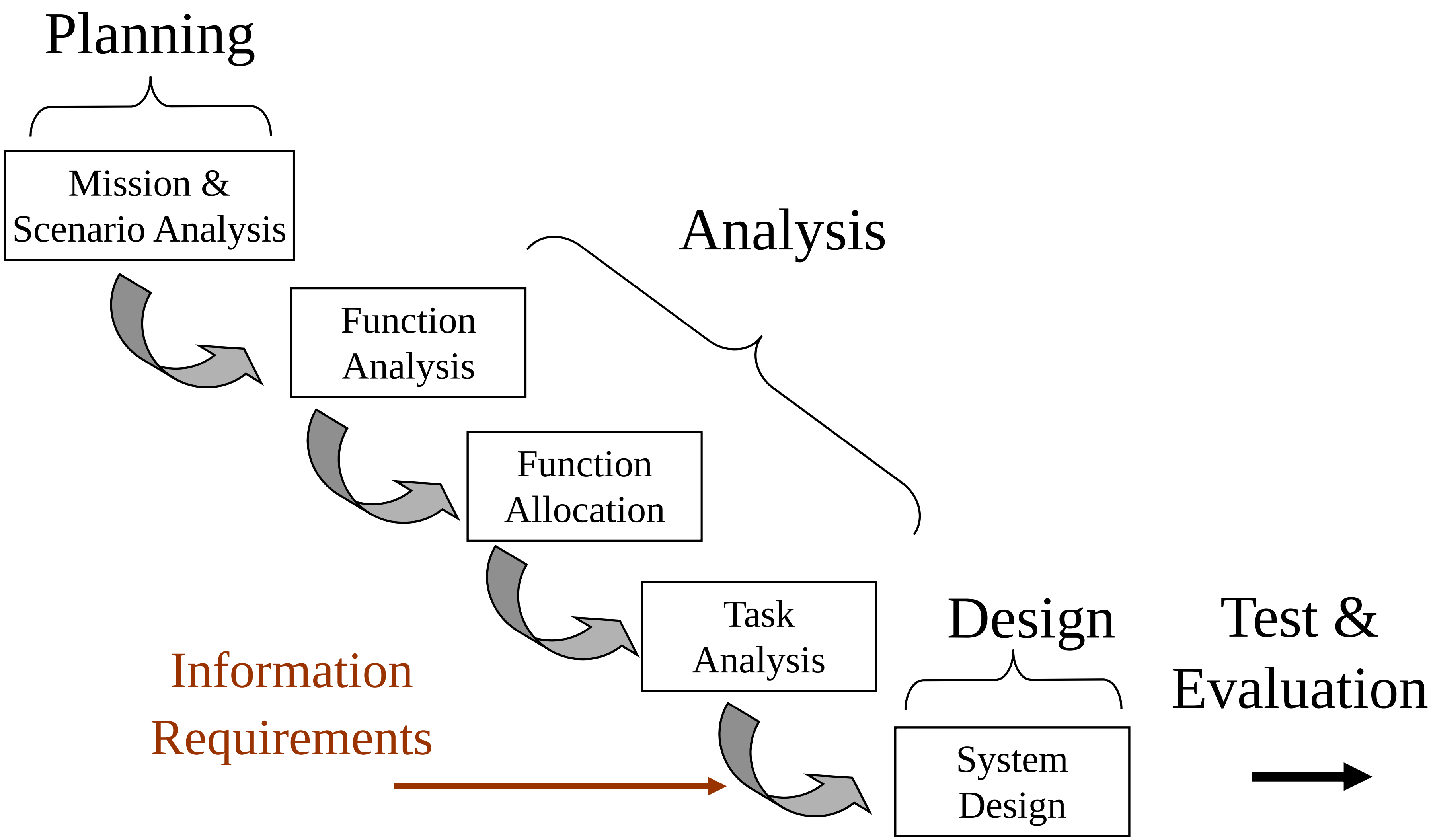
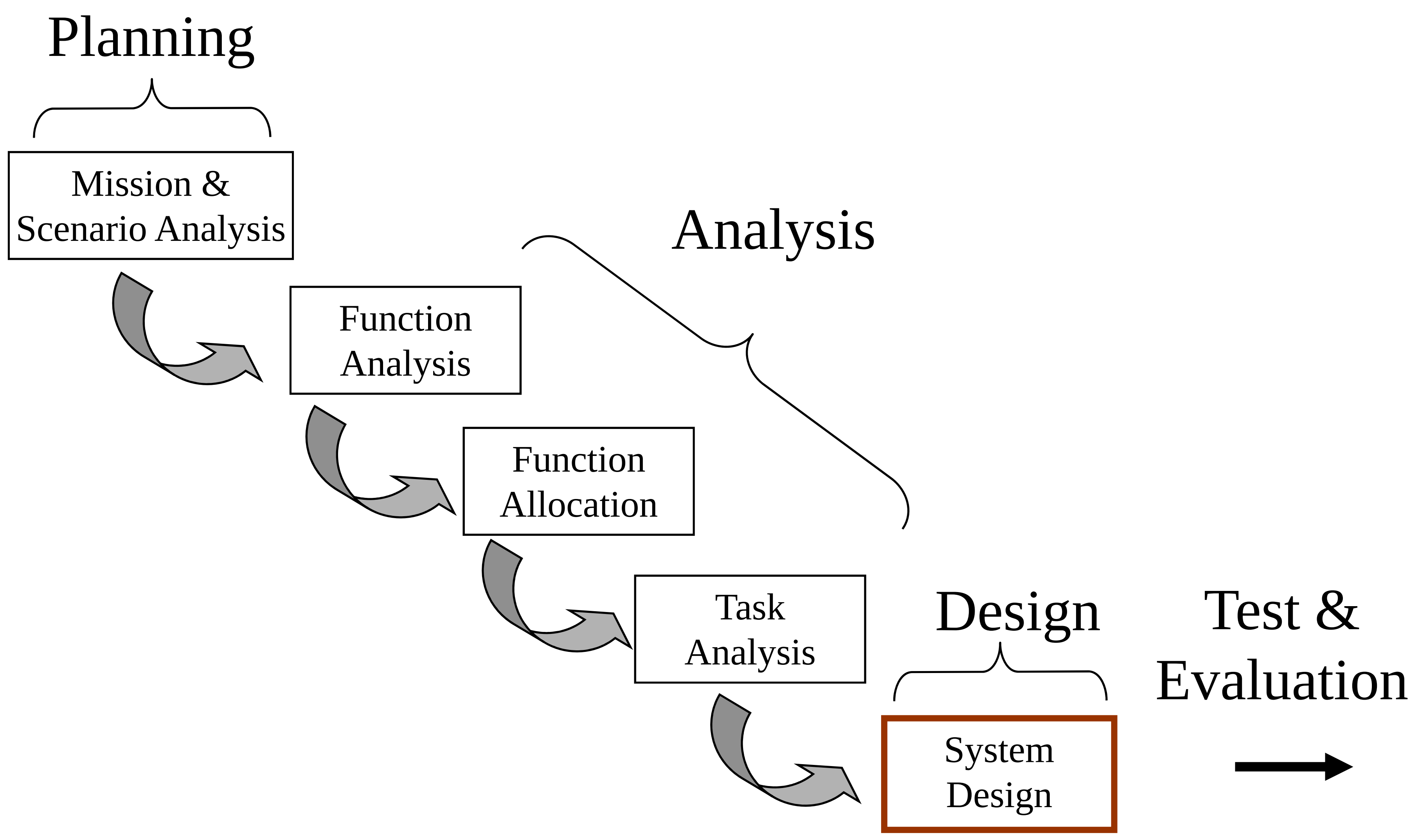
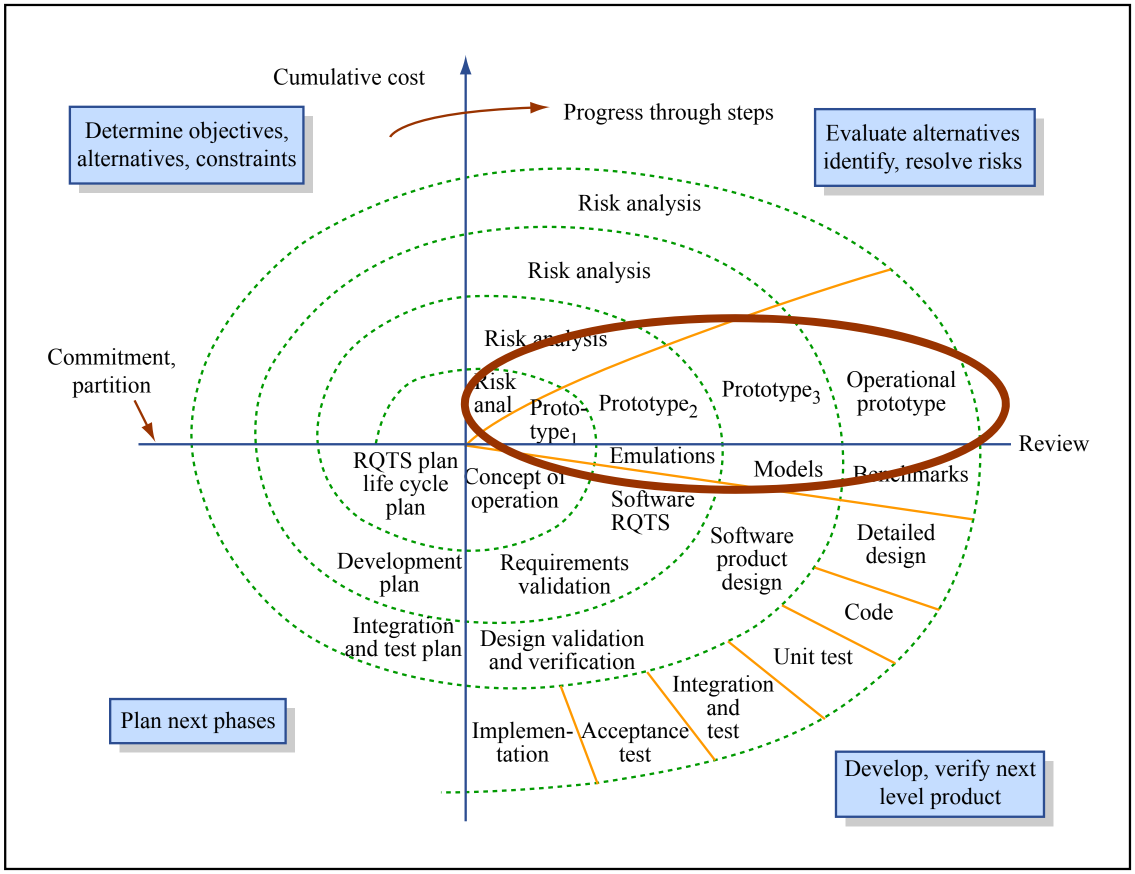
Information Requirements



Prototyping



The Spiral Systems Engineering Process Model*



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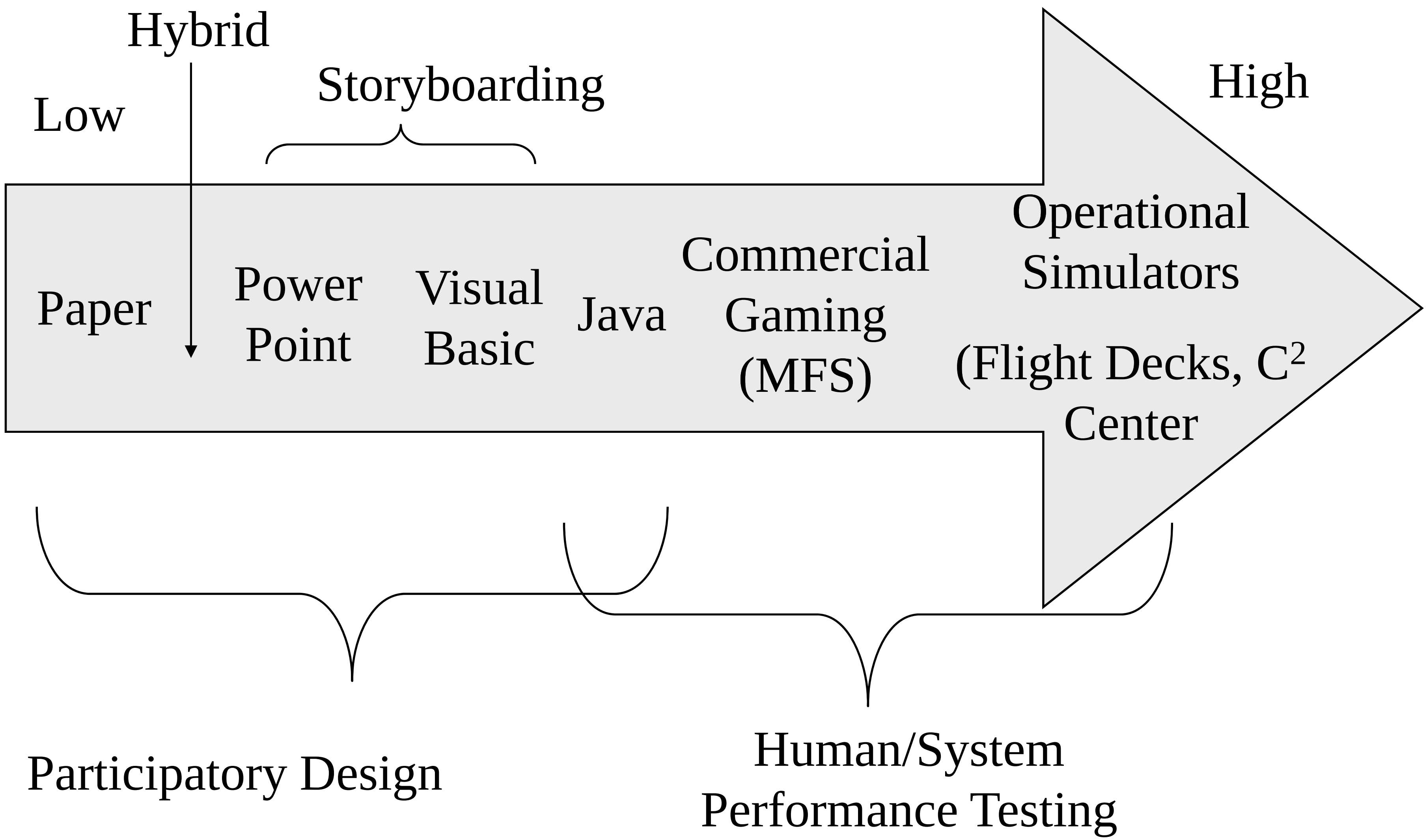
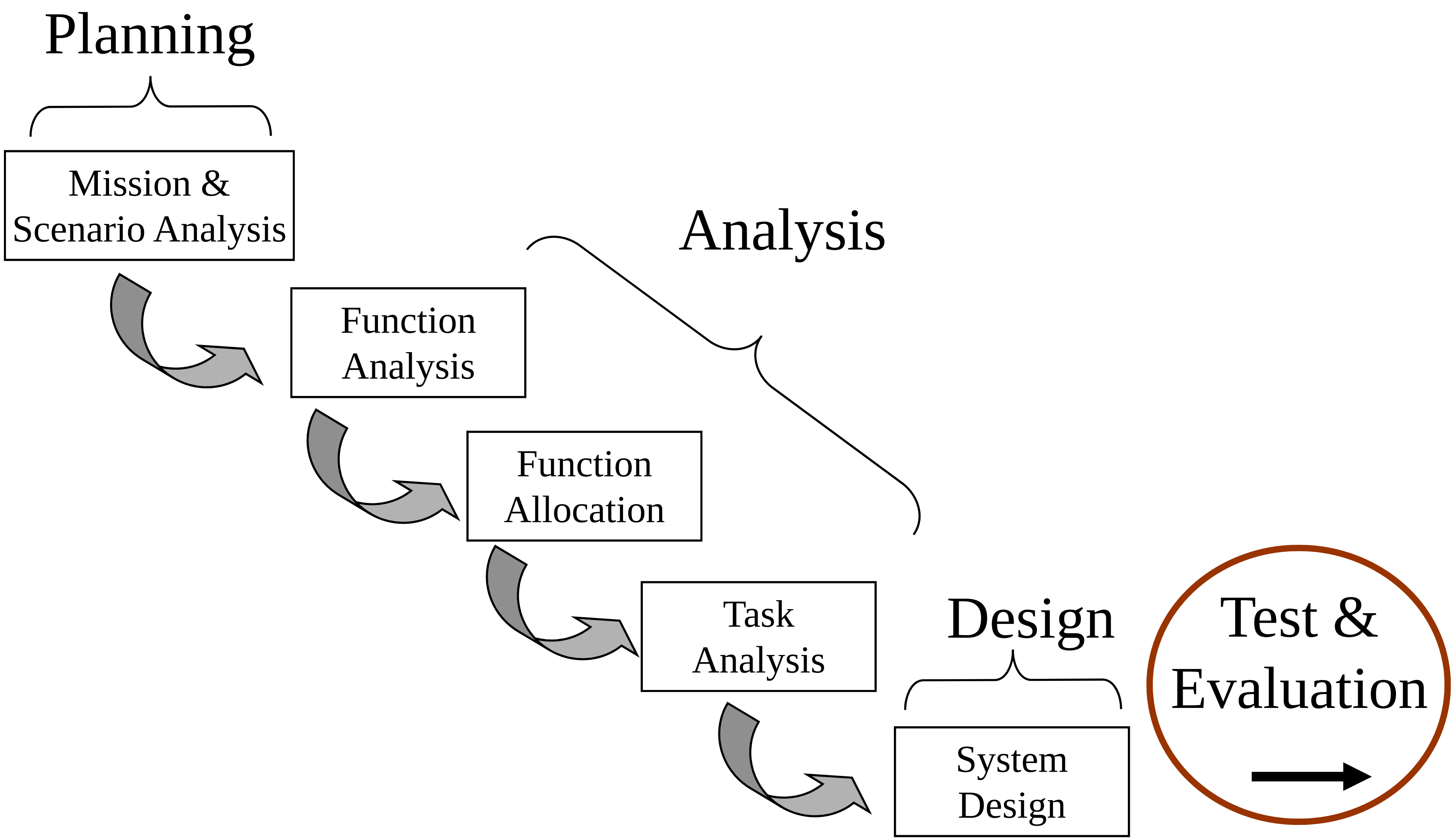
Prototyping & HSE

- Does design meet functional requirements?
  Will lead to design requirements
  - Elegant usability is not the primary focus
- Low fidelity vs. medium/high fidelity
- Feedback & interactivity
  - Participatory design
  - Wizard of Oz
- Breadth vs. depth
  - Front end vs. back end / Horizontal vs. vertical
- DANGER
  - Research vs. product
  - Decision support design – not cool interface design

Prototyping Fidelity



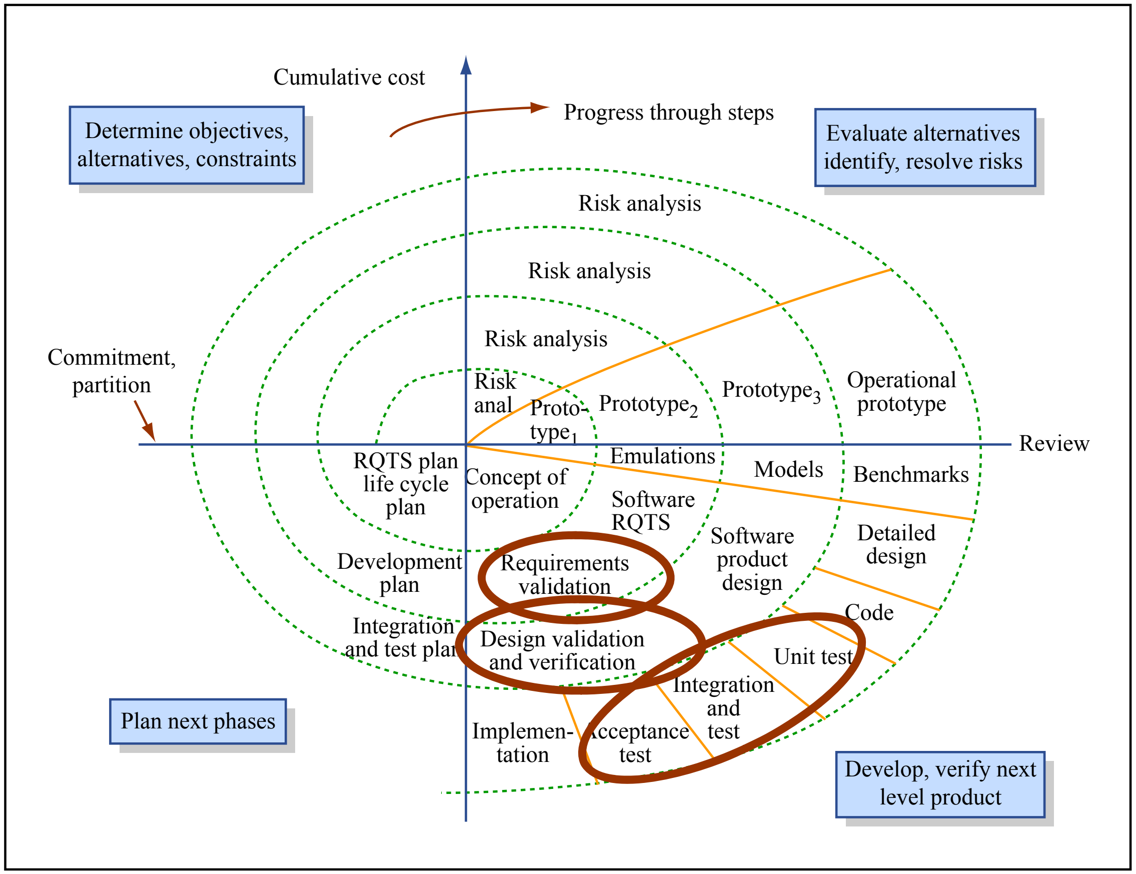
T & E


Planning
Mission & Scenario Analysis
Function Analysis
Analysis
Function Allocation
Task Analysis
Design
System Design
Test & Evaluation

Test & Evaluation

- Concurrent testing
- Human vs. system performance testing
  - Simulation
  - Demonstrations
- Usability evaluations
  - Subjective vs. objective
- Lab testing vs. field testing
- Cost-benefit analysis
  - Human trials are expensive!
  - Testing in the spiral stages
- Formal experimental design (16.470)
- COUHES

The Spiral Systems Engineering Process Model*



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*Boehm, B. (1988). A Spiral Model of Software Development and Enhancement. Computer, 61-72.

Resources

- Schraagen, J.M., Chipman, S.F., & Shalin, V.L. (Eds) (2000). *Cognitive task analysis*. Mahwah, New Jersey: Lawrence Erlbaum Associates.
- ONR/Aptima Cognitive Task Analysis website
- A Survey of Cognitive Engineering Methods and Uses