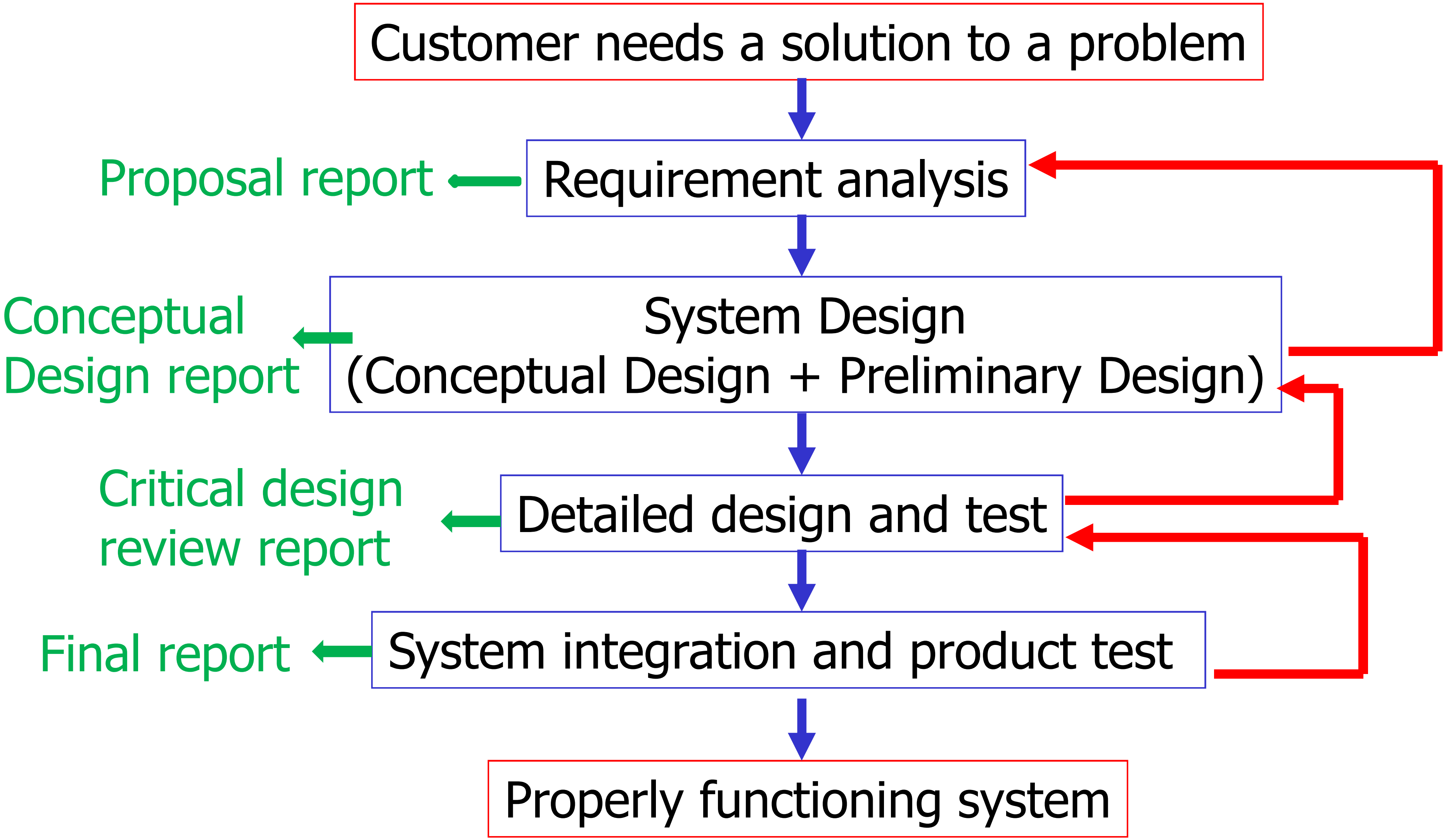
FUNDAMENTALS OF ENGINEERING DESIGN

Best way to learn design is “to design”

Types of designs

- Original design: Employs an innovative concept. A truly original design involves invention, eg. design of microprocessor.
- Adaptive design: A known solution is adapted to a different need. (eg. adapting the ink-jet concept to spray particles and binder for a 3D prototyping machine)
- Redesign: Improving an existing design to reduce cost of manufacturing, improving failure rate etc. Often, there is no change in working principle or concept of the original design.
- Selection design: Consists of selecting components from catalogs with needed performance, quality and cost.

Design Process



Requirement Analysis

- Needs assessment
- Define objectives
- Specify design requirements

Needs Assessment

- The aim is not to solve the problem but to understand what the problem is
  - What does this client want?
  - What is the problem that the design is to solve?

- Identify constraints
  - Constraints: the design must satisfy (takes logical values 0 or 1, helps to decide acceptable or not)

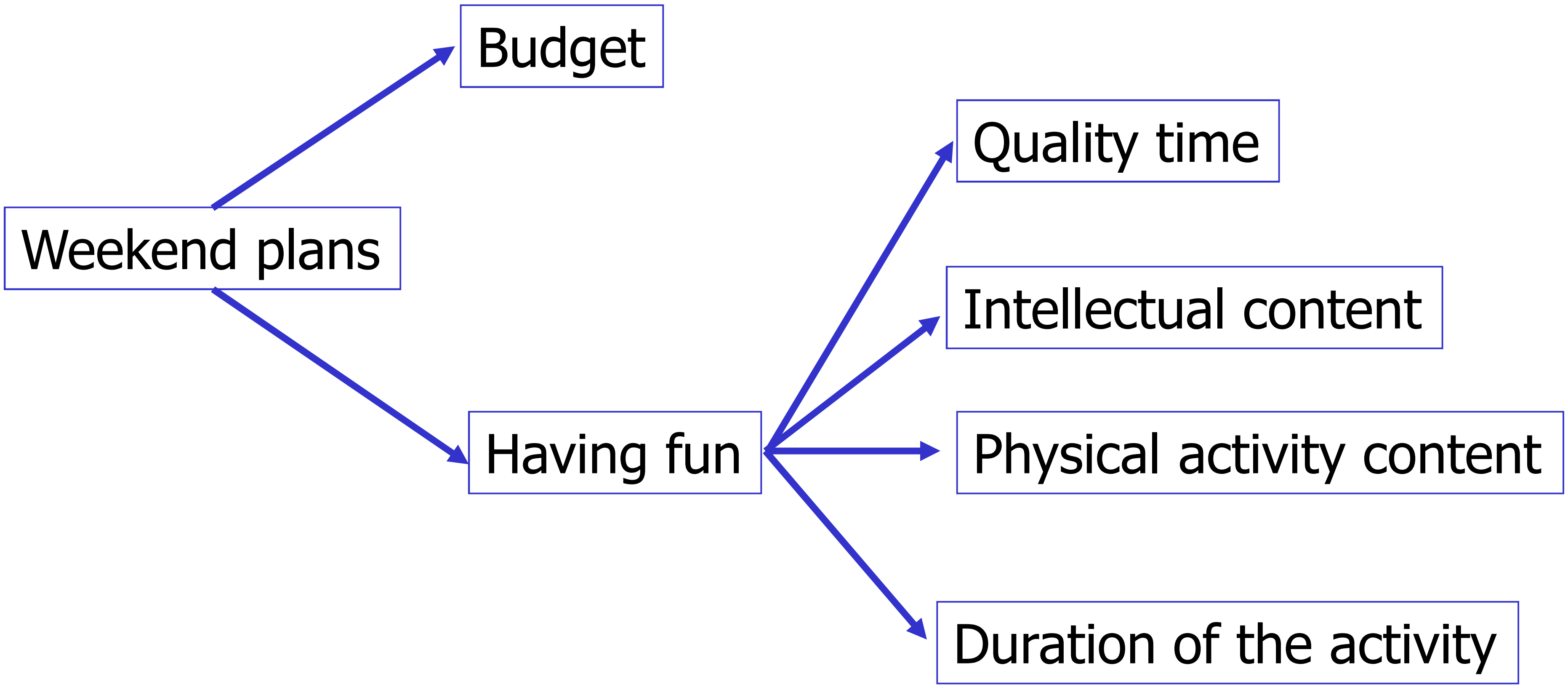
Define objectives

- Objectives: summary of the needs that the design is to satisfy
- Helps us to choose among alternative design configurations
- Make a list of objectives according to the assessed needs and constraints
- Group the relevant objectives
- Form a hierarchical tree structure

Example

- To choose a plan for the weekend
- Alternatives
  - Watching a movie (WM)
  - Visiting Ankara castle and museums around (AC)
  - Cooking a dinner together (CD)
  - Biking at Eymir (BE)
- Objectives
  - Minimize cost
  - Maximize fun

Objective trees



Ranking objectives

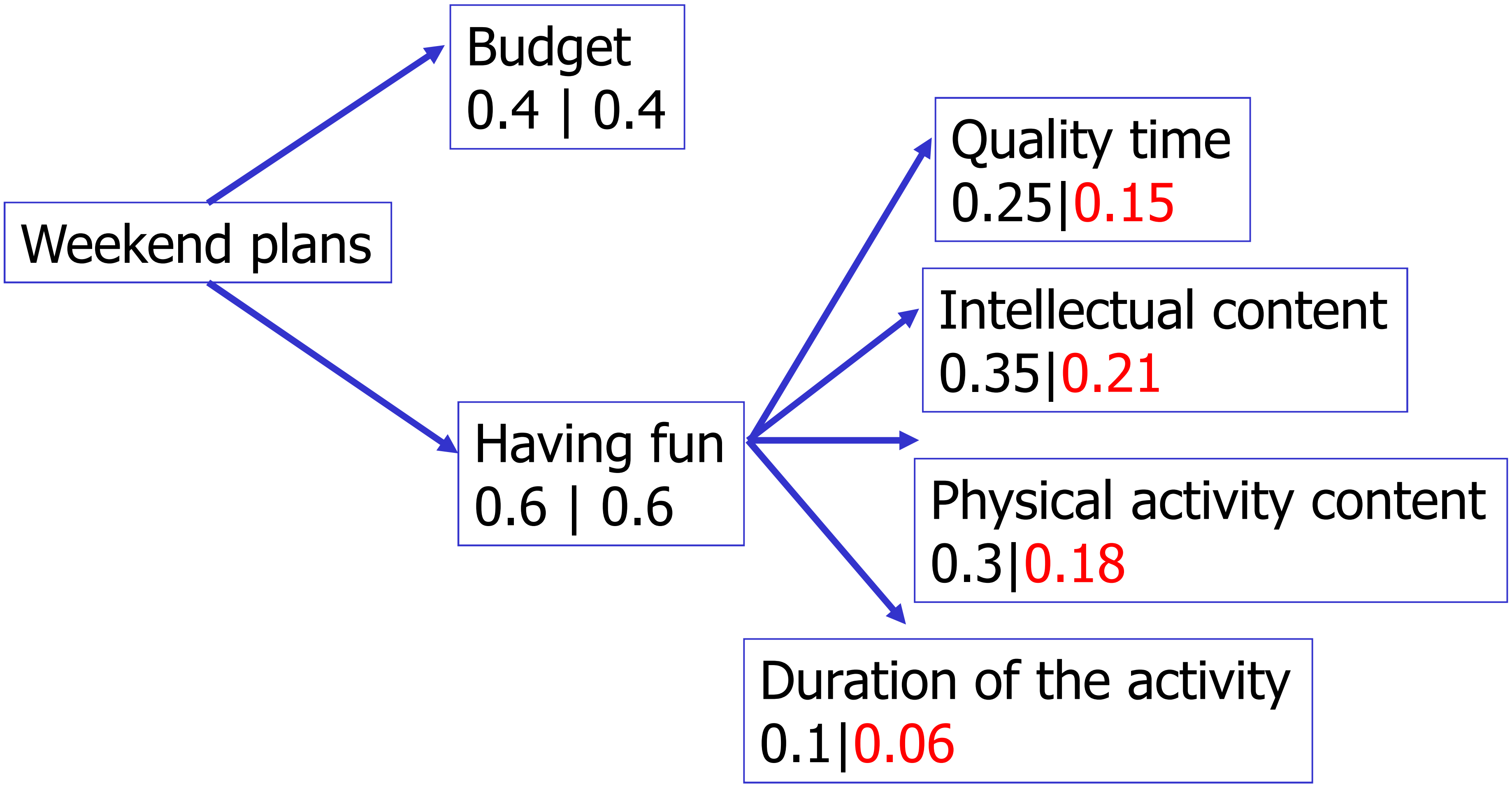
Pairwise comparison charts

	QT Quality Time	IC Intellectual content	PA Physical activity	D Duration	Total
QT	-	1/2	0	1	1.5
IC	1/2	-	1	1	2.5
PA	1	0	-	1	2
D	0	0	0	-	0

Weighted objectives

	Ranking points	Add 1	Weighted objectives
QT	1.5	2.5	2/10=0.25
IC	2.5	3.5	4/10=0.35
PA	2	3	3/10=0.3
D	0	1	1/10=0.1
		Sum=10	Sum=1

Weighted objective trees



Evaluation

	B 0.4	QT 0.15	IC 0.21	PA 0.18	D 0.06	Total
WM	2 0.8	4 0.6	8 1.68	0 0	10 0.6	3.68
AC	4 1.6	8 1.2	10 2.1	8 1.44	2 0.12	6.46
CD	8 3.2	10 1.5	6 1.26	2 0.36	4 0.24	6.56
BE	6 2.4	2 0.30	2 0.42	10 1.8	8 0.32	5.24

10: Excellent,8: Good, 6: Satis., 4: Av., 2: Unacceptable, 0: Failure

Specify design requirements

- A requirement specifies a capability or a condition to be satisfied.
- Translating client and user needs into terminology that helps us find ways to realize those needs and measure how well we met them
  - How will everyone that takes part in the design know that it is done?
  - It turns the problem statement into a technical, quantified specification
- Sets out criteria for verifying that the design meets its intended objectives

Specifications

- How can I express what the client wants in terms that helps me as an engineer
- Expressible as numbers and measures
- Precise description of the properties of the object being designed
- Describes the test for verification

Specification types (1/2)

- Functional : Specifies a behaviour that a system or part of system must perform.
  - What the thing must do?
  - Understanding and decomposing a system starts with its functions

- Performance : Refers to a requirement that quantitatively defines a system's or part's required capability.
  - Tells us how well the design is

Specification types (2/2)

- Physical : Specifies the physical characteristics and/or physical constraints of a system or system part.
- Interface : Specifies the ports for connecting systems to other/external systems and parts within a system.

A good requirement is:

- Achievable
- Verifiable, measurable
- Unambiguous
- Complete
- Consistent
- Traceable (System level-unit level)
- Expressed in terms of need

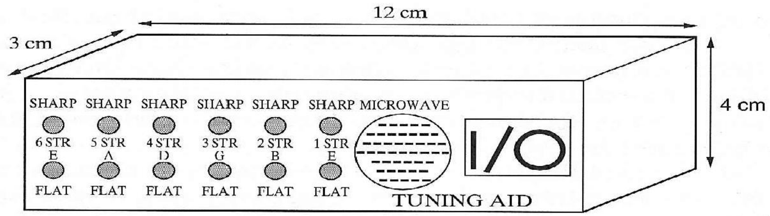
Examples of Poor Requirements

- The computer shall process & display the radar information instantly.
- The ship shall carry enough short range missiles.
- The power supply output shall be 28 volts.
- The power connector shall conform to RS-232.
- The aircraft shall use stainless steel rivets.
- The power supply unit shall provide 12 V DC with a load regulation of 1% while the line voltage variation is 220 +/- 20 V AC under all load current regimes and vibration and shock profiles within the temperature range.

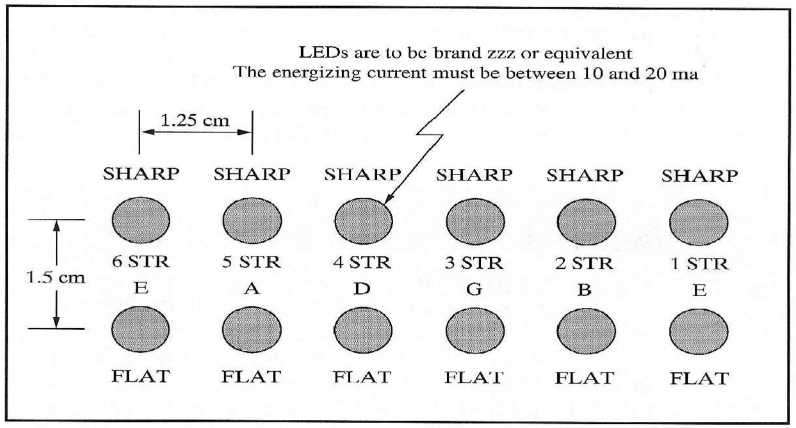
Why requirements analysis is important?

Example

- Customer needs a solution to a problem of designing a guitar tuner



(a)



(b)

Problem Statement

- The accuracy of the device will be measured by the difference between the pitch of a tuned string and the correct pitch. The limits should be well within those of a guitar that has been professionally tuned and then played for one week without further tuning

Objectives

- Performance related
  - Fast
  - Accurate
- Consumer oriented
  - Product safety
  - Ease of maintenance
  - Reliability
  - Convenience in use (user friendly)
  - Economy of operation

Functional specifications

- Determine the frequency of the signal
- Compare with the right frequency
- Turn the corresponding light on

Performance specifications

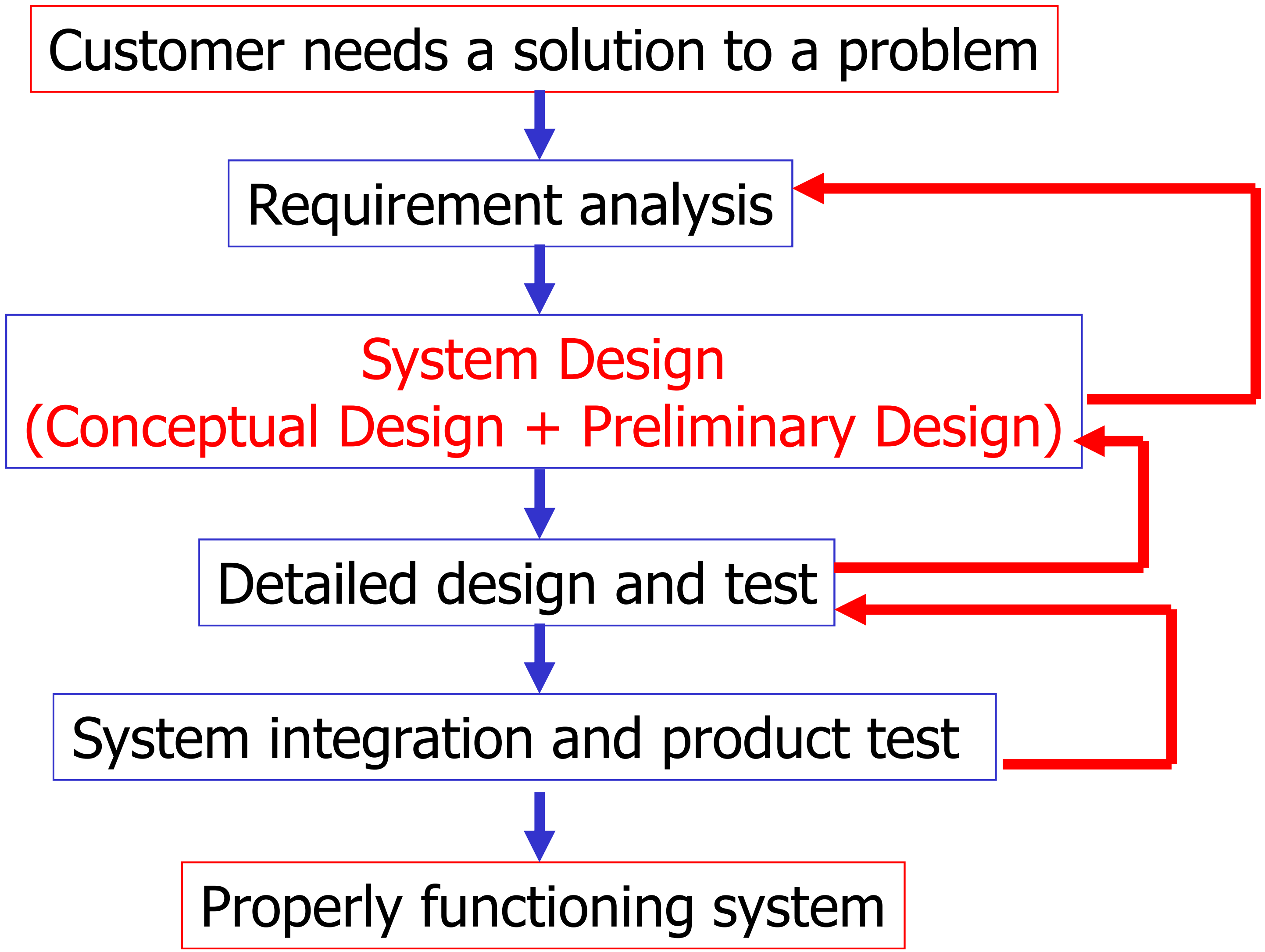
- Determine the frequency of the signal
  - Signal level: Signal to noise ratio
  - Range of frequencies
  - Precision

From objectives to specifications

- Accuracy
  - The guitar can drift up to 20 cents in a week
    - f1 is X cents higher than f2: $f1/f2=2^{X/1200}$
  - Precision tuners have an accuracy of ±2 cents
  - Accuracy requirement is ±6 cents
  - How to test?

Compare with a professional tuner (6+2 = ±8 cents)

Design Process



System Design

- Conceptualization
- Synthesis
- Analysis
- Evaluation

Conceptualization

- Develop a rough, early form of solution
- An idea or notion that can be a solution
- Primitive solutions, no definite form or character
- Lack organization and structure
- Brainstorming for idea generation
  - Seek quantity of concepts not quality
  - No judgement or analysis of concepts

Synthesis

- Create a well-defined structure for the concept
- Sufficient detail that helps analysis
- Preliminary design
- Block diagram of the system, each block will be designed in the detailed design

Analysis

- ➢ Determine if the synthesized system meets the objectives
- ➢ Determine the risks
- Analyze (simulations or experiments)
  - Develop mathematical model for the blocks
  - Build up real hardware to prototype ideas
  - Analyze hidden or explicit systematic error sources & allocate error limits to components of the system, ie. make an error budget
- Go back to synthesis, refine a solution
- Analyze again

Evaluation

- Evaluate the alternative solutions
  - Grade each solution with respect to objectives according to analysis results
- Choose one solution

- Don’t ‘fixated’ on an early solution concept
- Don’t concentrate on exploring single sub-solutions in depth

Preliminary design

- Product architecture is concerned with dividing the overall design system into subsystems or modules. In this step, arrangement of physical components and how to combine them to carry out the functional duties of the design is decided.
- Configuration design of parts and components: Determining how features, functions will be distributed and arranged, eg. in space relative to each other or which function will be addressed in which part of the system.

Conceptual design

- Functions must be allocated to hardware or software
- Configuration defined
- Interfaces defined
- System simulations completed
- Test and integration plans, defining the order the components must be assembled into larger units. (These plans are prepared before detail design)

Back to guitar tuner example

Idea generation to determine the frequency

Concept 1

- Convert analog to digital
- Apply FFT
- Find the frequency component with largest amplitude

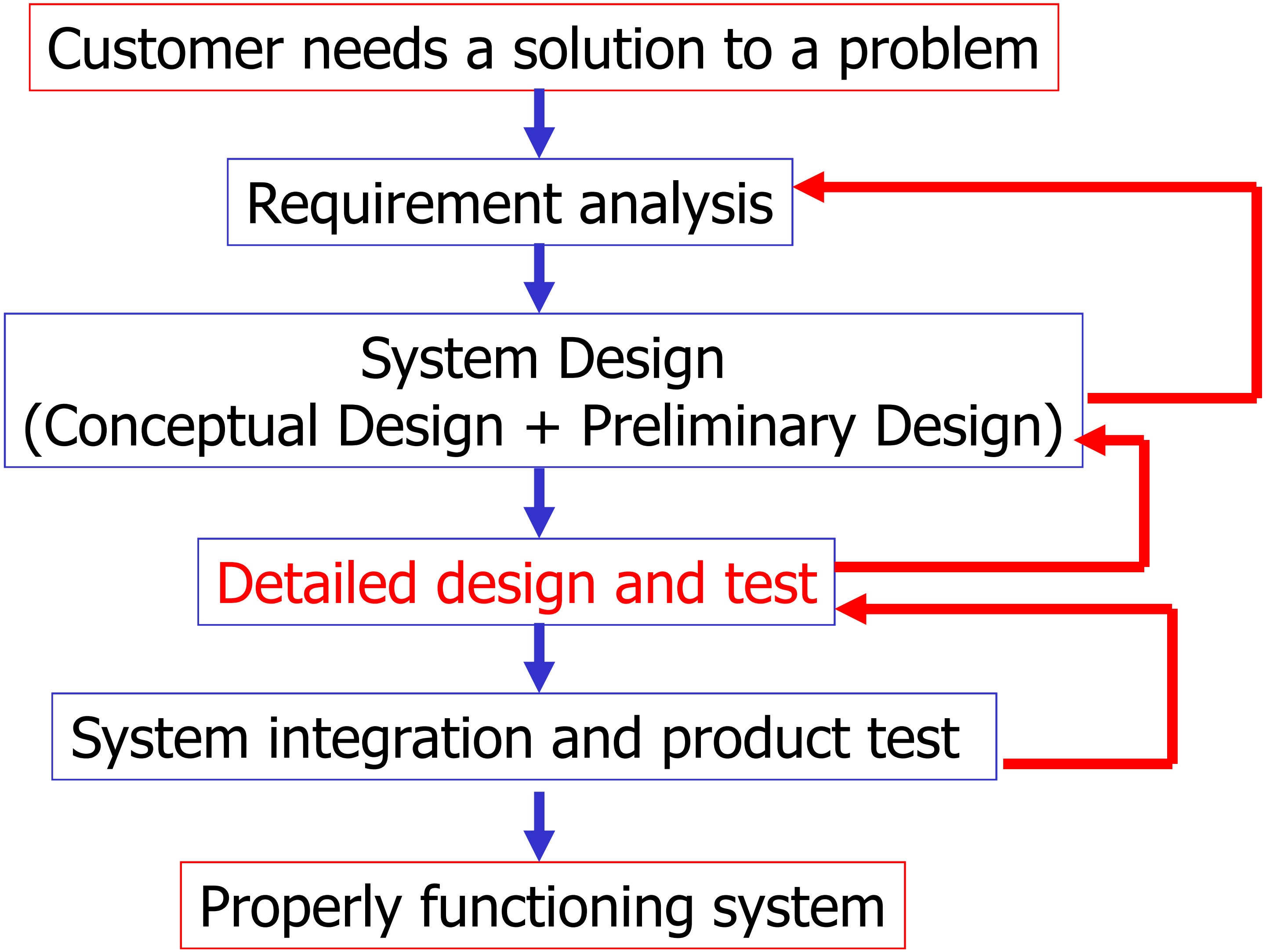
Concept 2

- Switch between several analog filters
- Compare the outputs, decide

Top-down specifications

- System level performance specification
  - Accuracy < ±6 cents
- Concept 1 unit level spec:
  - Sampling rate of ADC
  - Number of samples for FFT
- Concept 2 unit level specs:
  - The bandwidth of the filter
  - The roll-off factor of the filter
  - The number of filters
  - The center frequencies of filters

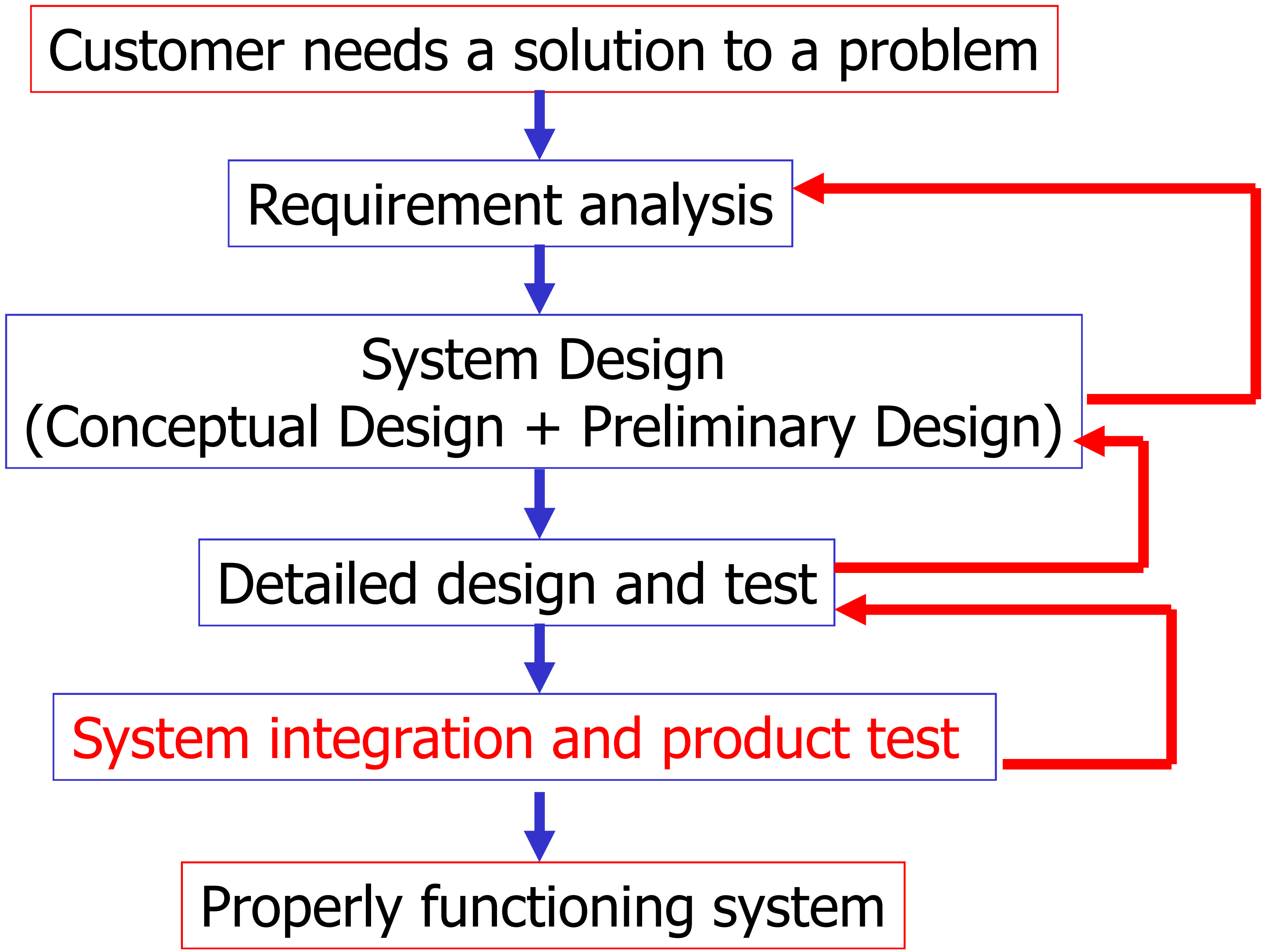
Design Process



Detailed Design and Tests

- Develop detailed design of each block specified in the system design
- Now the engineers begin to design the hardware and software that will implement the top system level specifications.
- Implement, test, and verify each block
- Iterate if necessary
- A detailed product specification, *updated with all the changes made since the conceptual design phase*, prepared.
- Prepare 'Critical Design Review Report'

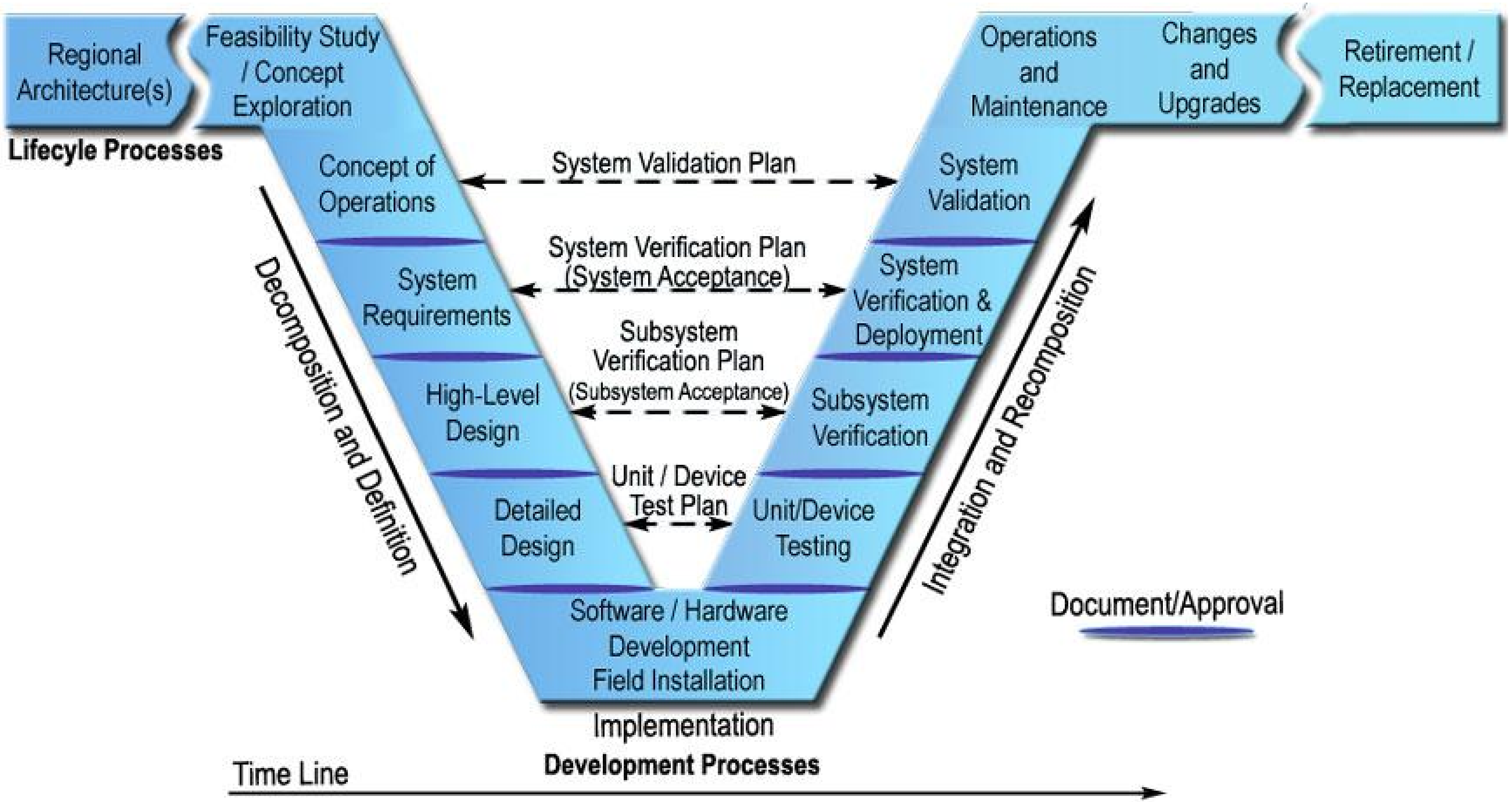
Design Process



System Integration and Product Tests

- Integrate system, produce prototype
- Test system according to the test plan developed in requirements specification document
- Verify design, iterate if necessary
- Prepare ‘Final Report’

V Diagram



http://www.ops.fhwa.dot.gov/publications/seitsguide/section3.htm

Spend <u>equal</u> time on

- Design (synthesis, analysis, debugging)
  - Know when to stop design work, ie. design freeze
- Testing
  - Don't rush but finish well in time to test and correct errors
  - The sooner a flaw is found, cheaper/easier it is to fix
  - Provide some indicators *(LED etc)* at every block for quick troubleshooting to ease your work during integration.
- Documentation (Reports)
  - Keep a good engineering notebook

No Job's Finished Until the Paperwork is Done

Product Life Cycle

- Conceptual design
- Realization of design, detail design
- Tests and acceptance of the final product
- Planning for manufacturing
  - How will the design be manufactured?
- Distribution, servicing, customer relations
  - How will it be marketed?
  - How will it be maintained during use?
- Retirement of product
  - How will it be retired from service and replaced by a new, improved design.

Planning for manufacturing

- A method of manufacturing must be established for each sub-component in the system.
- A process sheet is needed: A sequential list of all manufacturing and test operations to be performed on that component
- Design engineers must know the production flow, facilities and deficiencies of the manufacturing to design producable & testable products.

Planning for distribution

- The shipping package
- Shelf life of the product etc.

Planning for retirement of product

- The disposal of the product when it has reached the end of its useful life
- Green design: a *plan* for its safe disposal or recycling

Advices to be a good engineer

- Think with a systems view, considering the integration and needs of various sides of the problem.
- Explore information and use a variety of resources
- Identify critical technology and approaches and stay abreast of changes in professional practice
- Consider economic, social and environmental aspects of a problem

References

- “Electronic Instrument Design: Architecting for the Life Cycle” 1996, Kim Fowler
- “Engineering Design Methods-Strategies for Product Design” 3rd ed. 2000, Nigel Cross
- “Engineering Design” 4th ed. 2008, G. Dieter & L. Schmidt
- Further reading suggestion: Double Diamond concept: https://medium.com/digital-experience-design/how-to-apply-a-design-thinking-hcd-ux-or-any-creative-process-from-scratch-b8786efbf812#.5am9web1e

Design Process