

ESD.33 -- Systems Engineering

Session #4

**Axiomatic Design**

**Decision-Based Design**

**Summary of Frameworks Phase**

Dan Frey



# Follow-up on Session #3

- Mike Fedor - Your lectures and readings about Lean Thinking have motivated me to re-read "The Goal" by Eliyahu M. Goldratt
- Don Clausing – Remember that although set-based design seems to explain part of Toyota's system, it also includes a suite of other powerful tools (QFD, Robust Design)
- Denny Mahoney – What assumptions are you making about Ops Mgmt?

# Plan for the Session

 Why are we doing this session?

- Axiomatic Design (Suh)
- Decision-Based Design (Hazelrigg)
- What is rationality?
- Overview of frameworks
- Discussion of Exam #1 / Next steps

# Claims Made by Nam Suh

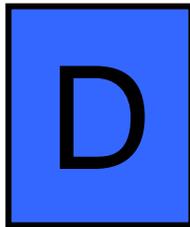
- “A general theory for system design is presented”
- “The theory is applicable to ... large systems, software systems, organizations...”
- “The flow diagram ... can be used for many different tasks: design, construction, operation, modification, ... maintenance ... diagnosis ..., and for archival documentation.”
- “Design axioms were found to improve all designs without exceptions or counter-examples... When counter-examples or exceptions are proposed, the author always found flaws in the arguments.”

# Claims Made by Hazelrigg

- “We present here ... axioms and ... theorems that underlie the mathematics of design”
- “substantially different from ... conventional ... eng design”
- “imposes severe conditions on upon design methodologies”
- “all other measures are wrong”
- “apply to ... all fields of engineering ... all products, processes, and services, and also for the management of engineering design, ...and the integration of engineering design with ... the entire product life cycle ...
- “without the axiomatic framework ... there will be an attendant loss .. typically a factor of two or more in the bottom line”

# Pop Quiz

- Cards have letters on one side and numbers on the other
- Hypothesis-*if* a card has a D on one side it *must* have a 3 on the other side
- You are a scientist testing this hypothesis
- You are allowed to turn over any two cards
- Which of the four cards below should be turned over?

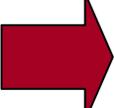


# Falsifiability

- The criterion of demarcation of empirical science from pseudo science and metaphysics is falsifiability.
- The strength of a theory can be measured by the breadth of experimental results that it precludes
  - Sir Karl Popper (1902-1994), *Logik der Forschung*

# Plan For the Session

- Why are we doing this session?

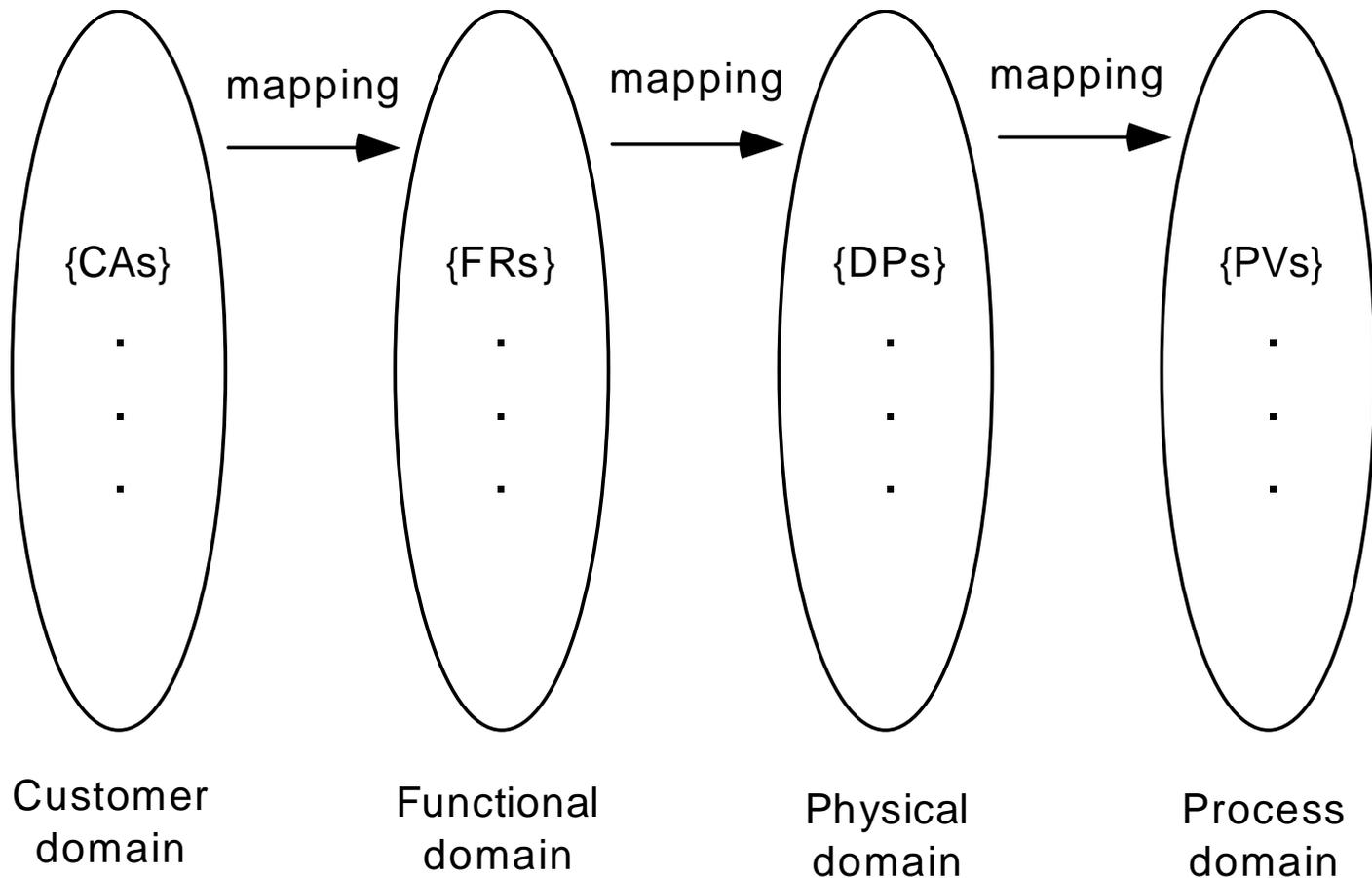
 Axiomatic Design (Suh)

- Decision-Based Design (Hazelrigg)
- What is rationality?
- Overview of frameworks
- Discussion of Exam #1 / Next steps

# What are Axioms?

- “Primitive propositions whose truth is known immediately without the use of deduction”
  - *Cambridge Dictionary of Philosophy*
- “A statement that is stipulated to be true for the purpose of constructing a theory”
  - *Harper Collins Dictionary of Mathematics*
- “Fundamental truths that are always observed to be valid and for which there are no counterexamples or exceptions”
  - Suh, *The Principles of Design*
- “Axioms are posited as accepted truths, and a system of logic is built around them”
  - Hazelrigg, “An Axiomatic Framework for Engineering Design”

# Domains and Mapping



# Benefit of Separate Domains

- Customer Needs are stated in the customer's language
- Functional Requirements and Constraints are determined to satisfy Customer Needs
- “The FRs must be determined in a solution neutral environment” (or, in other words, say “what” not “how”)
  - BAD = the adhesive should not peel
  - BETTER = the attachment should hold under the following loading conditions
- Keeping FRs in solution neutral terms prevents inadvertent “lock in” to specific modes of solution

# Suh's Design Axioms

- The Independence Axiom
  - Maintain the independence of the functional requirements.
- The Information Axiom
  - Minimize the information content.

# The Design Matrix

$$\{\mathbf{FR}\} = [\mathbf{A}]\{\mathbf{DP}\}$$

$$\mathbf{A}_{i,j} = \frac{\partial \mathbf{FR}_i}{\partial \mathbf{DP}_j}$$

# Types of Design Matrices

$$\begin{bmatrix} X & 0 & 0 \\ 0 & X & 0 \\ 0 & 0 & X \end{bmatrix}$$

uncoupled  
design

$$\begin{bmatrix} X & X & X \\ 0 & X & X \\ 0 & 0 & X \end{bmatrix}$$

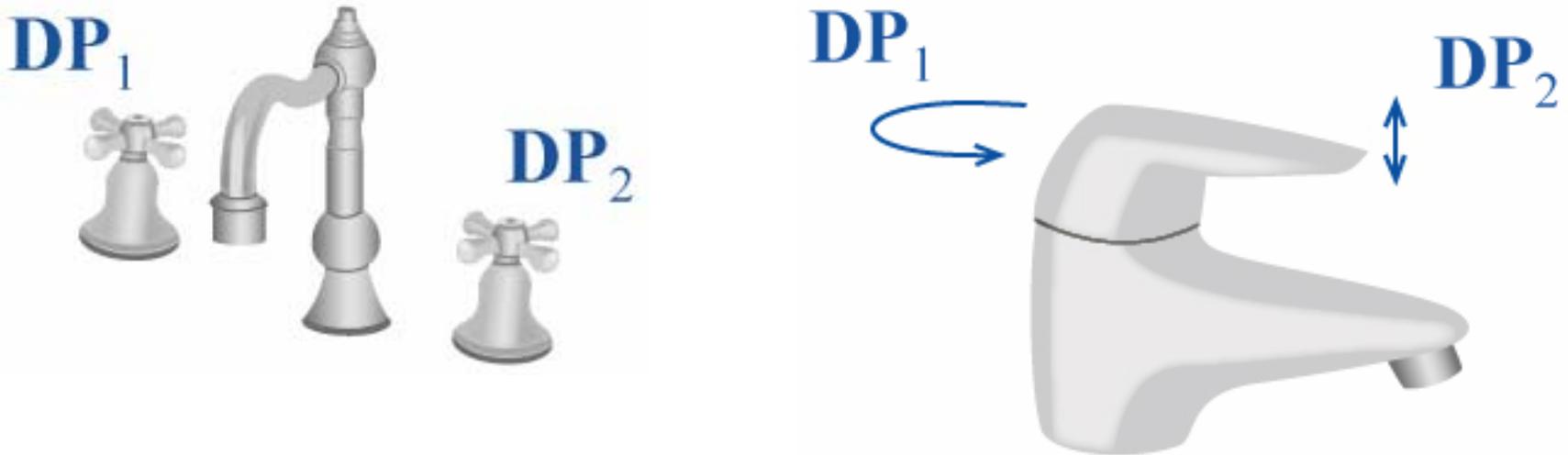
decoupled  
design

$$\begin{bmatrix} X & X & X \\ X & X & X \\ X & X & X \end{bmatrix}$$

coupled  
design

# Independence Axiom Applied to Water Faucets

$$\{\mathbf{FR}\} = \left\{ \begin{array}{l} \text{Water Temperature} \\ \text{Water Flow Rate} \end{array} \right\}$$

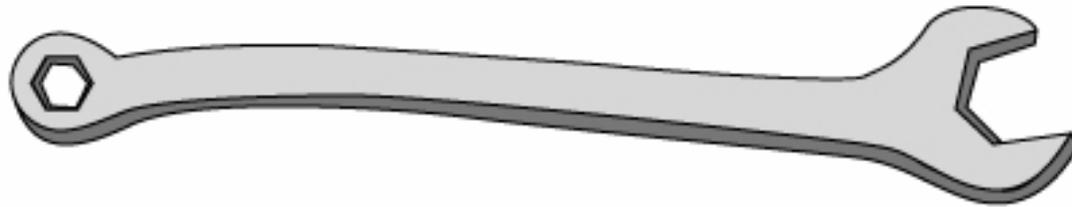


# Chris Lutz

- During an NPR program last year, they were discussing that there exists a strong cultural bias in favor of separate hot and cold water faucets in Britain even though a good single Moen design (and now others) exists.
- Even though a design is superior (based on the axioms), it may fail in the marketplace. How do you address this?

# Functional Coupling vs Physical Coupling

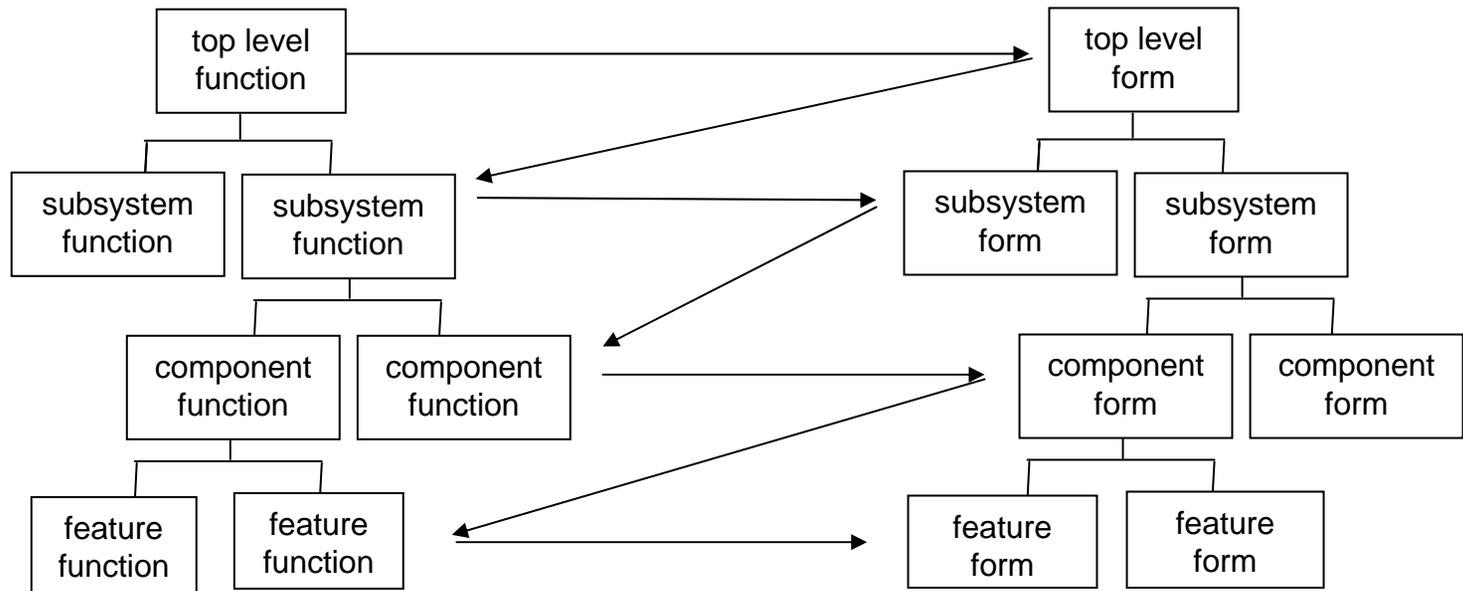
- Just because a single physical entity carries out multiple functions it does not imply functional coupling!



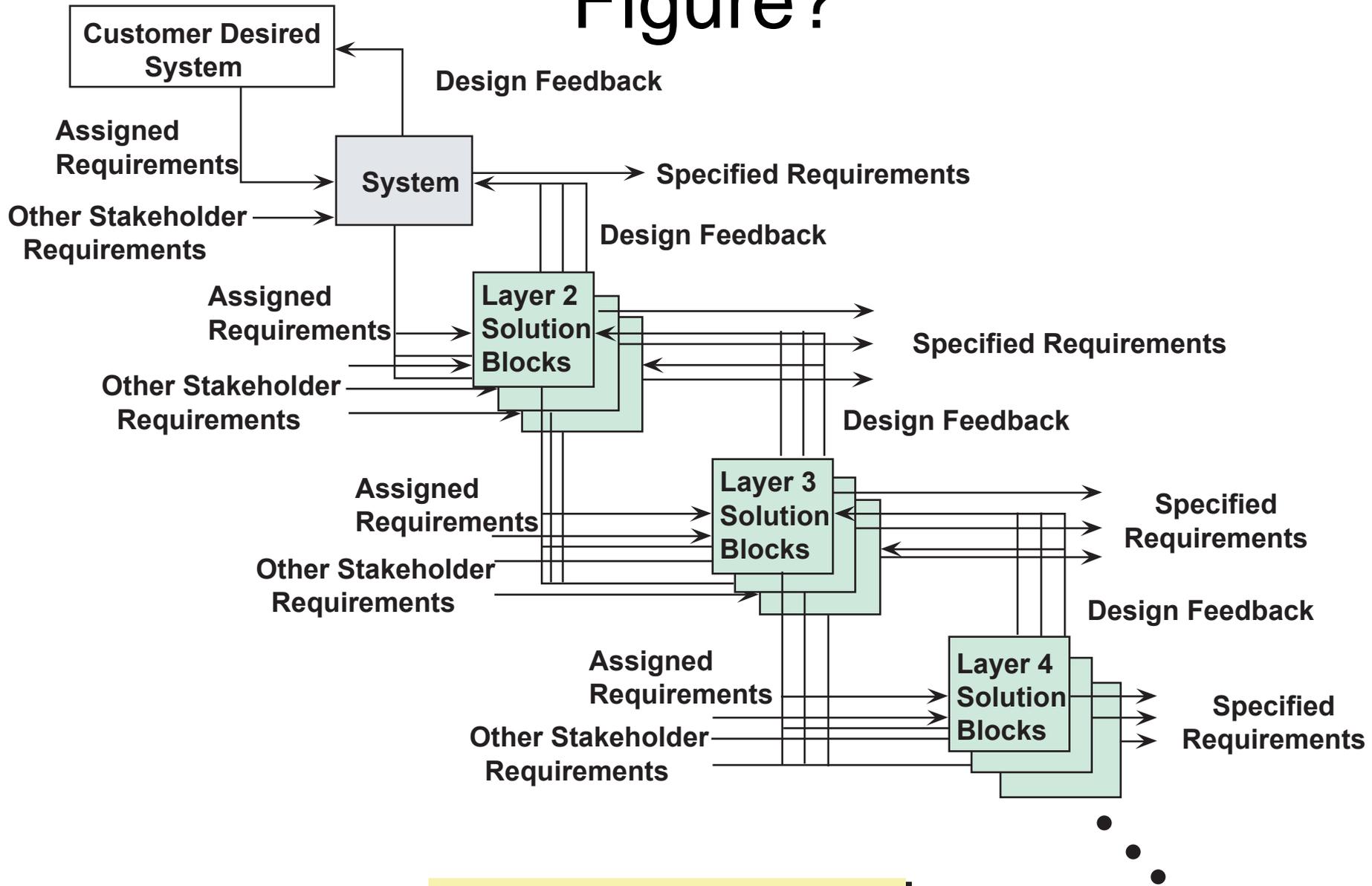
# Benefits of Uncoupling

- Simpler operation
- More transparent design
- Simpler to change the design
- More parallelism in the design process

# Zig-zagging



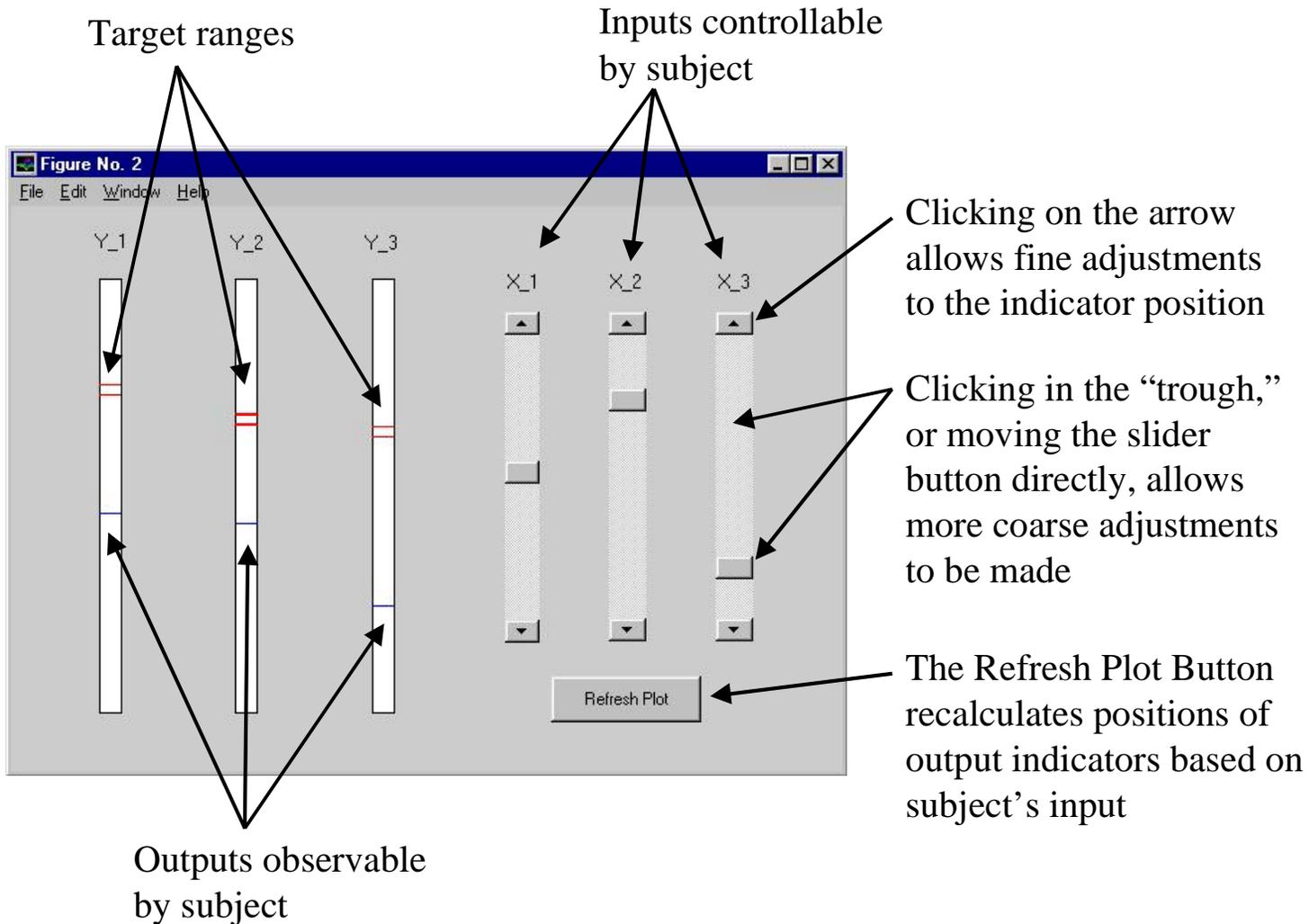
# How Would Uncoupling Affect this Figure?



**System Design Hierarchy**

# The Supposedly Dire Consequences of Coupling

- “.. when several functional requirements must be satisfied, designers **must** develop designs that have a diagonal or triangular matrix”
- “For a product to be manufacturable, the design matrix of a product,  $[A]$  ... times the design matrix for the manufacturing process,  $[B]$  ... must yield either a diagonal or triangular matrix. Consequently, when ... either  $[A]$  or  $[B]$  represents **a coupled design**, the product **cannot be manufactured.**” Theorem 9 (Design for Manufacturability)



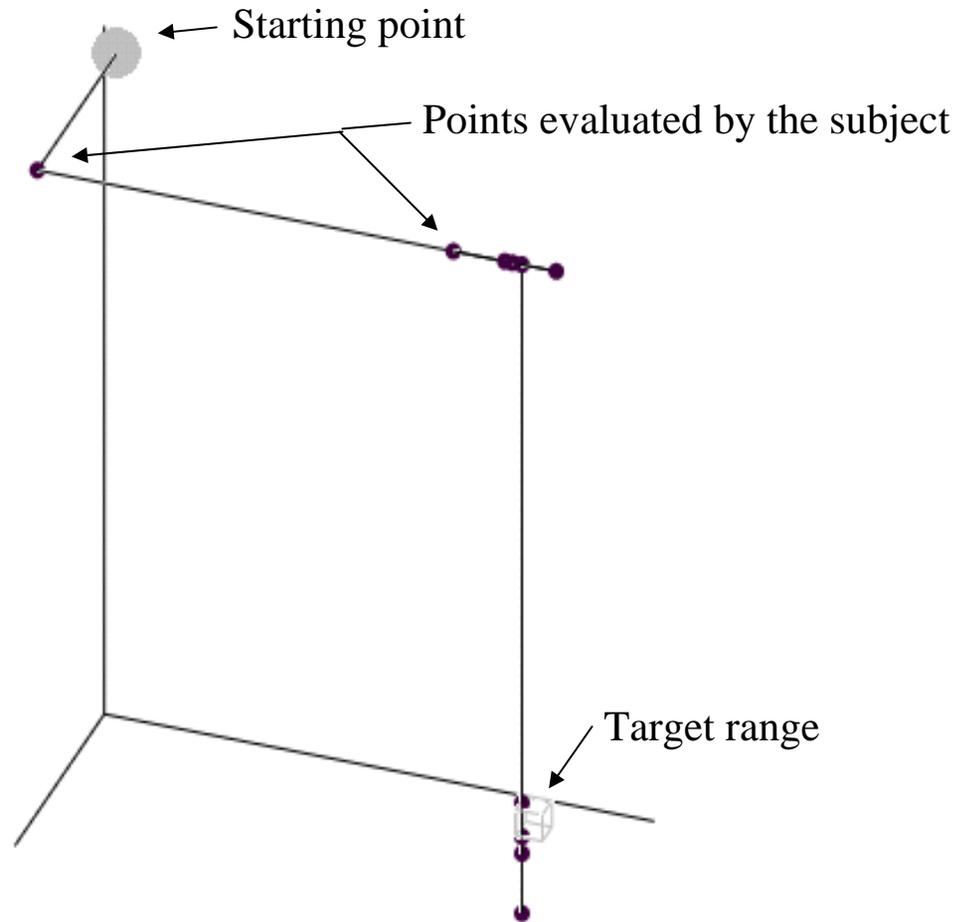
Hirschi, N. W., and D. D. Frey, 2002, "Cognition and Complexity: An Experiment on the Effect of Coupling in Parameter Design," *Research in Engineering Design* 13(3): 123-131.

# Properties of the Systems

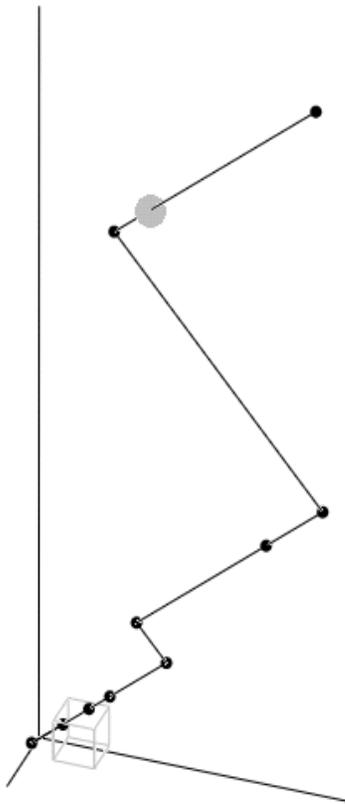
- Two types
  - Entirely uncoupled
  - Strongly coupled
- If strongly coupled, then orthonormal

	Input #1	Input #2	Input #3
Output #1	0.683	-0.658	0.317
Output #2	0.658	0.366	-0.658
Output #3	0.317	0.658	0.683

# Typical Uncoupled 3X3 Solution

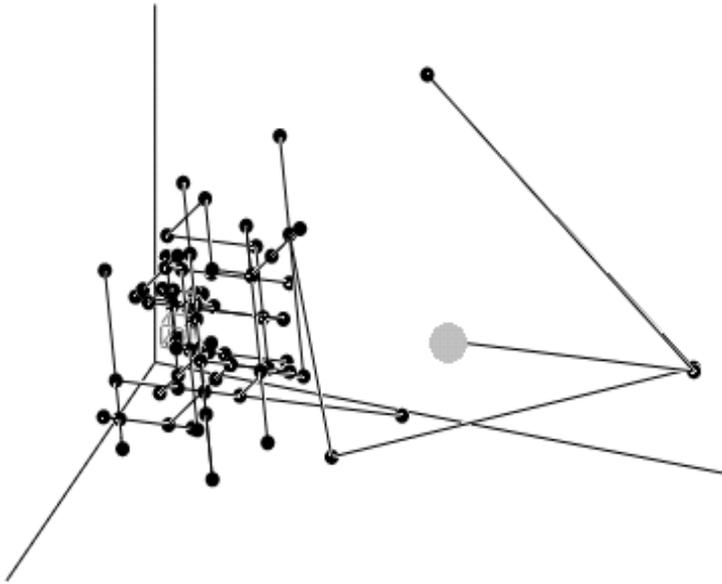


# Typical Coupled 2X2 Solution



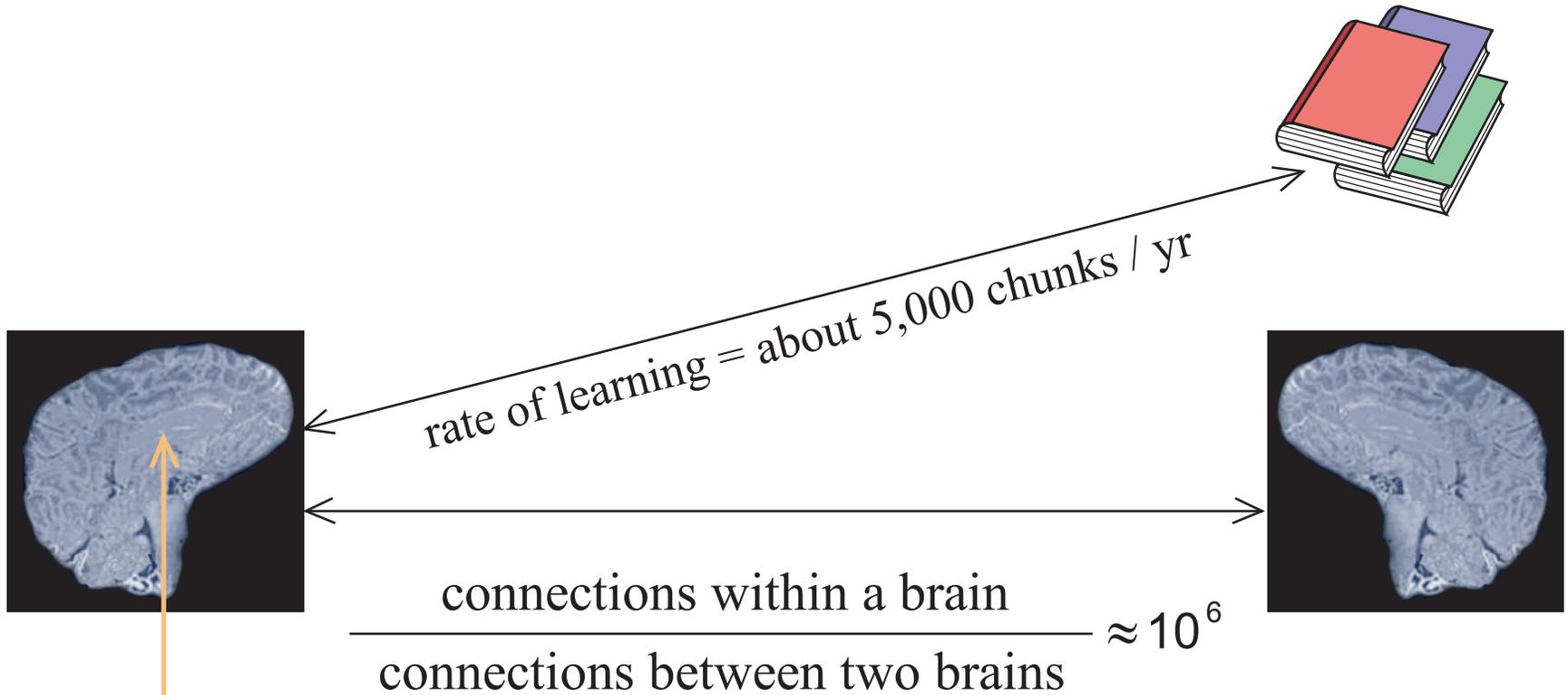
- Initial moves used to identify the design matrix
- Subsequent moves almost **directly to the solution**
- Solution **nearly as fast** as uncoupled 2X2

# Coupled 3X3 Solution



- Qualitatively different from coupled 2X2
- A lot of apparently random moves
- Decreasing step sizes as solution converges

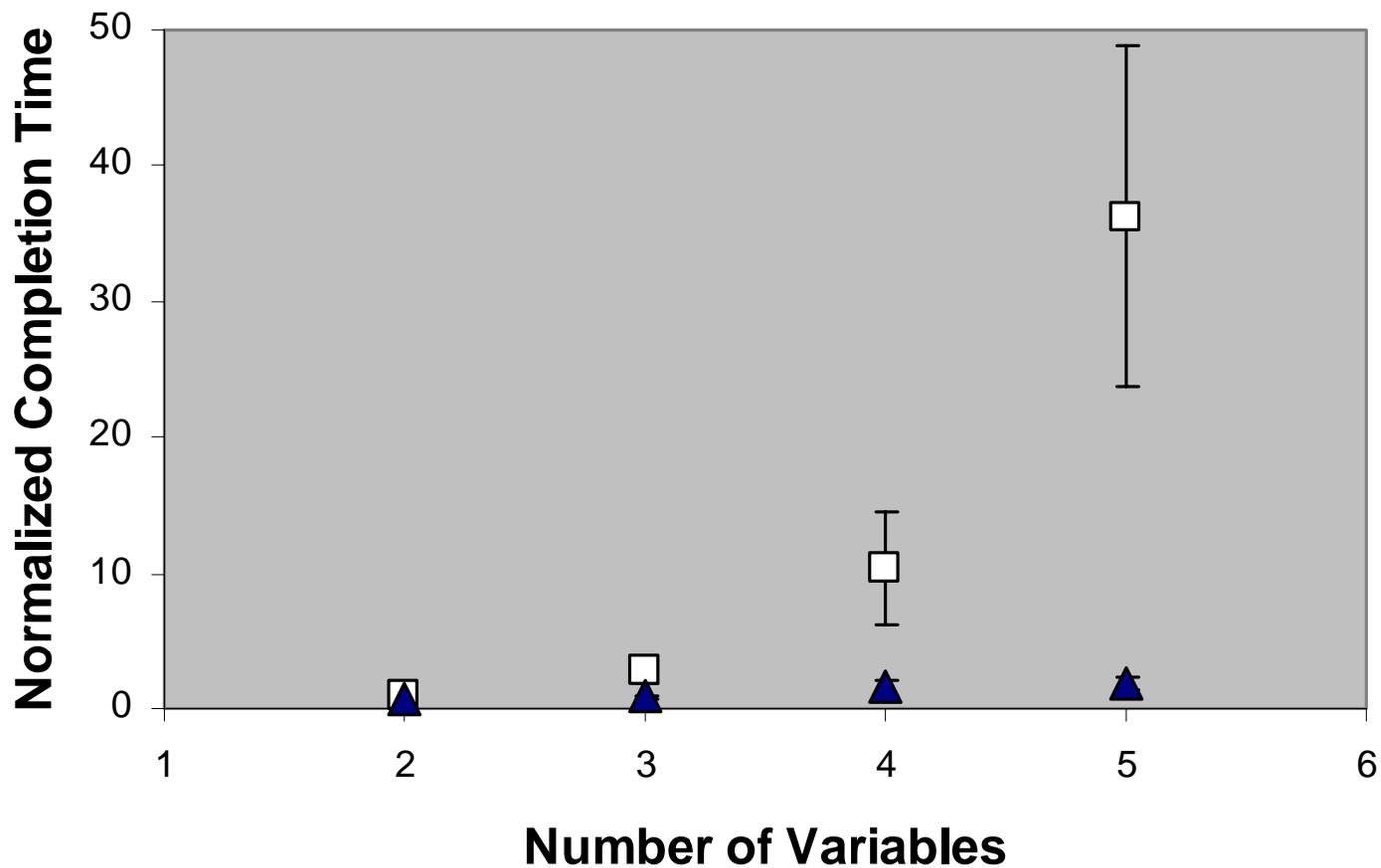
# Cognitive Parameters



working memory =  $7 \pm 2$  chunks

expert knowledge  $\approx 50,000$  chunks

## The Effect of Coupling and Scale on Completion Time



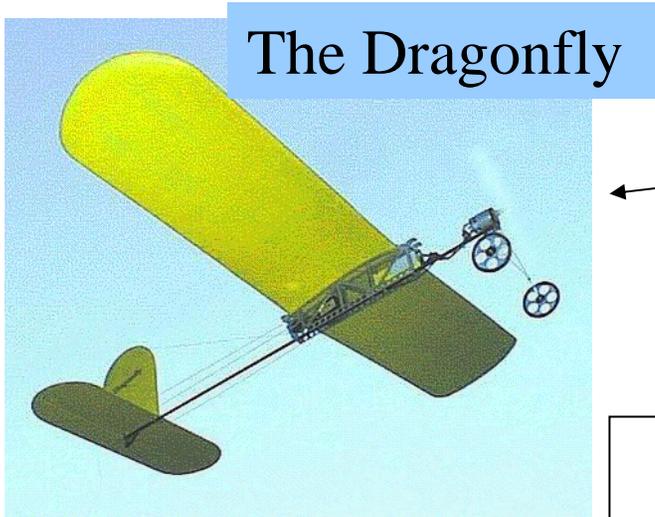
□ Full Matrix ▲ Uncoupled Matrix

# Cognition and Complexity

## Conclusions

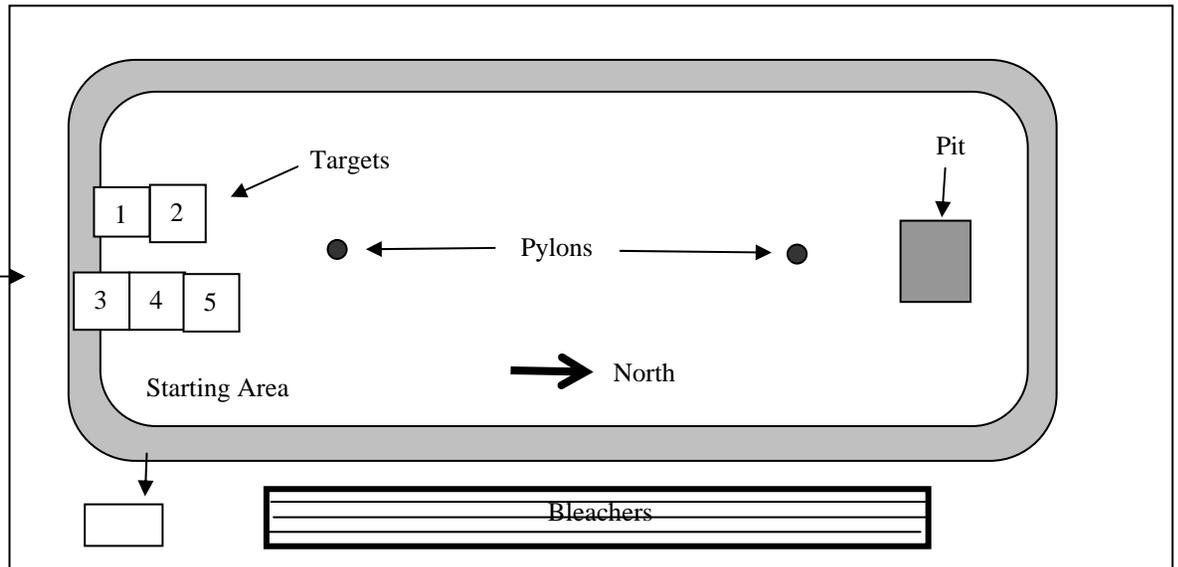
- Coupled designs can be executed successfully
- BUT the scaling laws for coupled systems are very unfavorable:
  - $O(n^3)$  for computers
  - $O(3^n)$  for humans

# The UAV Design Contest



Given a “starting point” design

Adapt it to improve performance on a task



# UAV Design Matrix

## Design Parameters

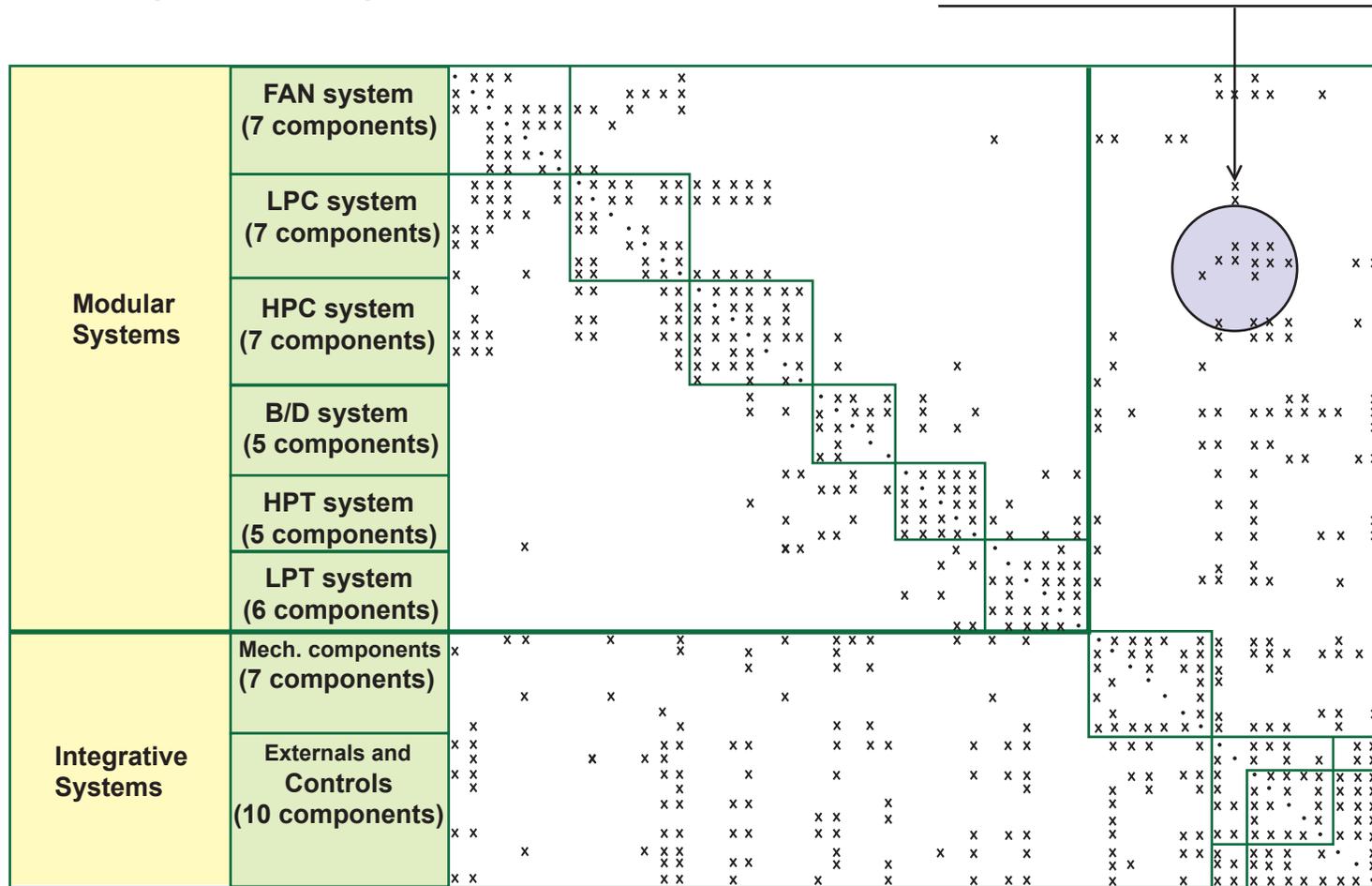
## Functional Requirements

*Gear ratio*  
*Prop diameter*  
*Number of cells*  
*Wing area*

- Rate of climb
- Full throttle speed
- Endurance
- Stall speed

$$\begin{bmatrix} X & X & X & X \\ X & X & X & x \\ x & x & X & X \\ o & o & x & X \end{bmatrix}$$

# Secondary flow systems and controls cause a risk of rework



**Design Interface Matrix**

Adapted from Sosa, Manuel E., S. D. Eppinger, and C. M. Rowles, 2000, "Designing Modular and Integrative Systems", *Proceedings of the DETC*, ASME.

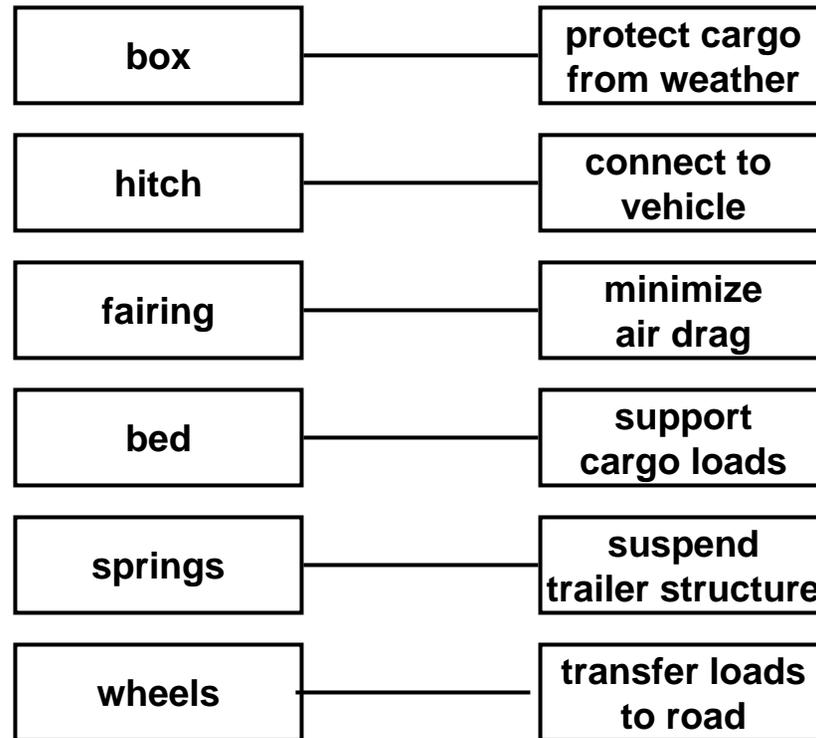
# My Conclusions

- Uncoupled or decoupled alternatives are not always available
- Coupled designs can be executed successfully
- Simulation is helps us execute coupled designs

## Suh's Conclusions

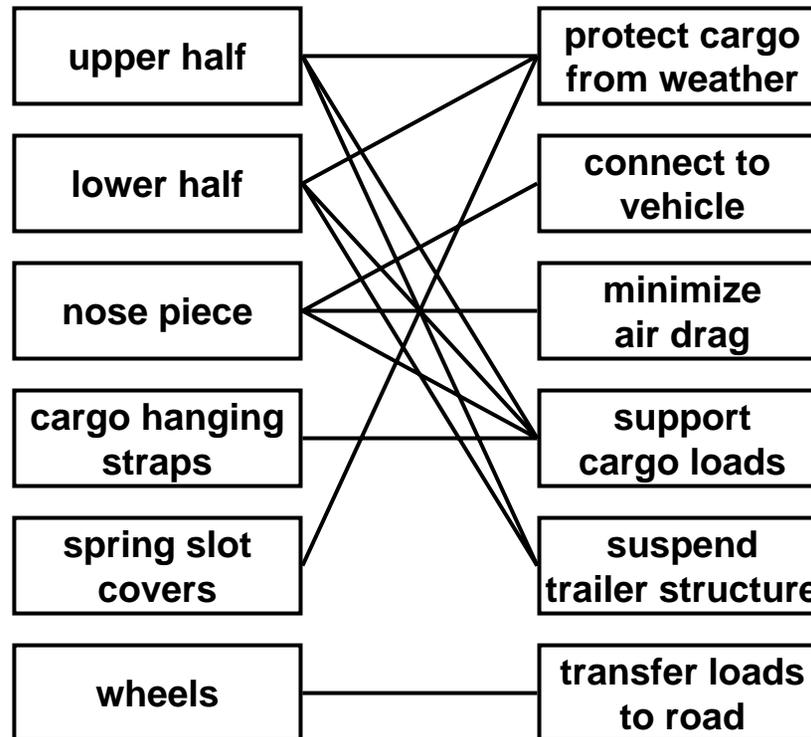
- If a design is coupled, FRs can only be satisfied when there is a unique solution
- If a fully coupled design is acceptable, it is equivalent to having only one independent FR
- FRs are defined as the minimum set of independent requirements

# Trailer Example: Modular Architecture



Architecture -- The arrangement of functional elements into physical chunks which become the building blocks for the product or family of products.

# Trailer Example: Integral Architecture



# Modules Redefined

$$\begin{Bmatrix} FR1 \\ FR2 \end{Bmatrix} = \begin{bmatrix} a & 0 \\ b & c \end{bmatrix} \begin{Bmatrix} DP1 \\ DP2 \end{Bmatrix}$$

$$FR2 = b \cdot DP1 + c \cdot DP2 = M2 \cdot DP2$$

$$M2 = b \cdot (DP1/DP2) + c$$


So, in new Suh's definition a module is this thing

Can we translate this math into some meaningful interpretation?

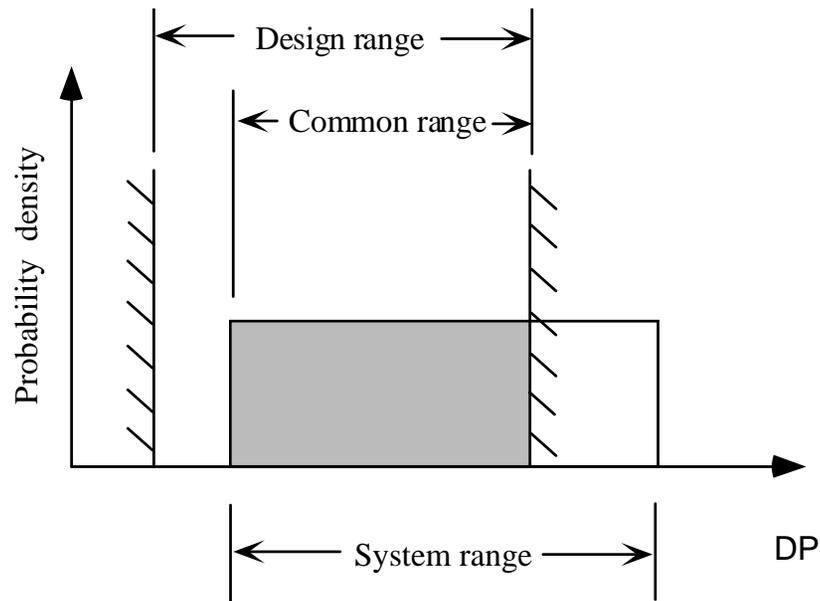
# Information in Axiomatic Design

- The probability that a product can satisfy *all* of its FRs is called the probability of success ( $p_s$ )

$$I = \log(1/p_s)$$

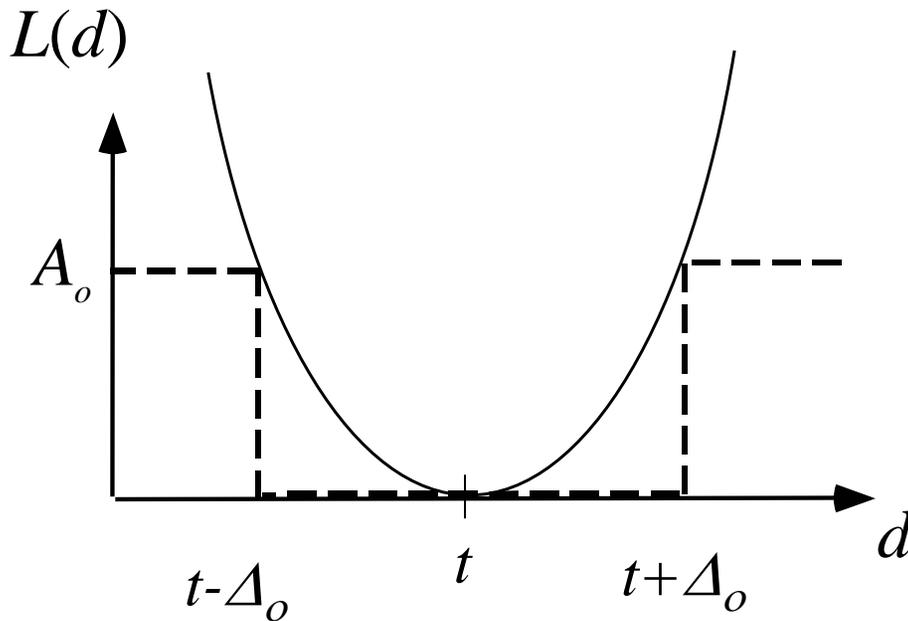
- The Information Axiom
  - Minimize information content  $I$
  - (thereby maximizing  $p_s$ )
- “The Information Axiom provides a theoretical foundation for robust design”

# Uniformly Distributed FRs



$$I = \log \left( \frac{\text{system range}}{\text{common range}} \right)$$

# Quadratic Loss Function

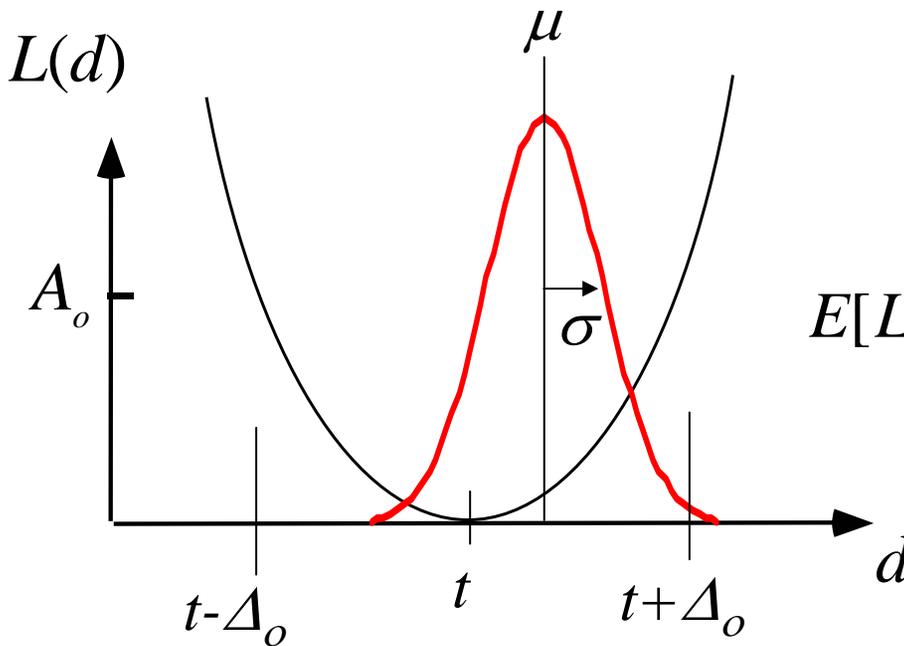


$$L(d) = \frac{A_o}{\Delta_o^2} (d - t)^2$$

— quadratic quality loss function

--- "goal post" loss function

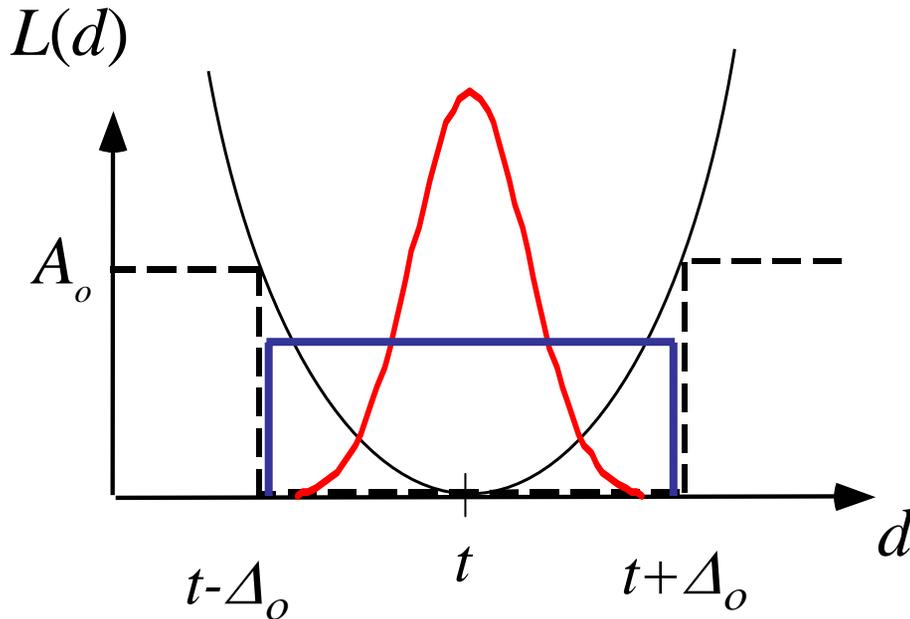
# Average Quality Loss



$$E[L(d)] = \frac{A_o}{\Delta_o^2} [\sigma^2 + (\mu - t)^2]$$

- quadratic quality loss function
- probability density function

# Information content vs Quality Loss Function



— quadratic quality loss function

- - - "goal post" loss function

— A  $3\sigma$  process

$$p_s = 99.7\% \quad I = 0.004 \text{ bits}$$

$$E[L(d)] = \frac{A_o}{9}$$

— A uniformly distributed process just within spec

$$p_s = 100\% \quad I = 0 \text{ bits}$$

$$E[L(d)] = \frac{A_o}{3}$$

**RD and AD lead to different decisions**

# Summing Information

## **Theorem 13 (Information Content of the Total System)**

– If each FR is probabilistically independent of other FRs, the information content of the total system is the sum of information of all individual events associated with the set of FRs that must be satisfied.

**Suh [1990]**

$$I = \sum_i I_{FR_i} \quad \text{or} \quad p_s = \prod_i P(\text{satisfying } FR_i)$$

iff FRs are probabilistically independent

# Information Cannot be Summed for Decoupled Designs

**Proposition** – If the design matrix  $\mathbf{A}$  is decoupled and the DPs are probabilistically independent with non-zero variance and the on-diagonal elements of  $\mathbf{A}$  are non-zero, then the FRs CANNOT be probabilistically independent and the information content cannot be summed.

# A Simple Example

$$\mathbf{A} = \begin{bmatrix} 1 & 1 \\ 0 & 1 \end{bmatrix} \quad \text{Triangular, therefore a decoupled design.}$$

$$\mathbf{K}_{\text{DP}} = \begin{bmatrix} 1 & 0 \\ 0 & 4 \end{bmatrix} \quad \text{The zero off-diagonal elements of } \mathbf{K}_{\text{DP}} \text{ indicate that the DPs are probabilistically independent.}$$

$$\mathbf{K}_{\text{FR}} = \mathbf{A}\mathbf{K}_{\text{DP}}\mathbf{A}^T \quad \begin{pmatrix} 1 & 1 \\ 0 & 1 \end{pmatrix} \cdot \begin{pmatrix} 1 & 0 \\ 0 & 4 \end{pmatrix} \cdot \begin{pmatrix} 1 & 0 \\ 1 & 1 \end{pmatrix} = \begin{pmatrix} 5 & 4 \\ 4 & 4 \end{pmatrix}$$

The non-zero off-diagonal elements of  $\mathbf{K}_{\text{FR}}$  indicate that the FRs are NOT probabilistically independent.

# Computing Probability of Success With Correlated FRs

- We found a closed form equation for the limits of integration
- The limits of every integral are either known or given by outer nested integrals

$$p_s = \frac{\int_{\frac{-\tau\mathbf{FR}_1 + \delta\mathbf{FR}_1}{\mathbf{A}_{1,1}}}^{\frac{\tau\mathbf{FR}_1 + \delta\mathbf{FR}_1}{\mathbf{A}_{1,1}}} \int_{\frac{-\tau\mathbf{FR}_2 + \delta\mathbf{FR}_2 + \mathbf{A}_{2,1}\mathbf{DP}_1}{\mathbf{A}_{2,2}}}^{\frac{\tau\mathbf{FR}_2 + \delta\mathbf{FR}_2 - \mathbf{A}_{2,1}\mathbf{DP}_1}{\mathbf{A}_{2,2}}} \dots \int_{\frac{-\tau\mathbf{FR}_n + \delta\mathbf{FR}_n + \sum_{i=1}^{n-1} \mathbf{A}_{n,i}\mathbf{DP}_i}{\mathbf{A}_{n,n}}}^{\frac{\tau\mathbf{FR}_n + \delta\mathbf{FR}_n - \sum_{i=1}^{n-1} \mathbf{A}_{n,i}\mathbf{DP}_i}{\mathbf{A}_{n,n}}} f(\mathbf{DP}_1, \mathbf{DP}_2, \dots, \mathbf{DP}_n) d\mathbf{DP}_n \dots d\mathbf{DP}_2 d\mathbf{DP}_1$$

# For Uniformly Distributed DPs

- In one dimension

$$I = \log \left( \frac{\text{system range}}{\text{common range}} \right)$$

- In  $n$  dimensions

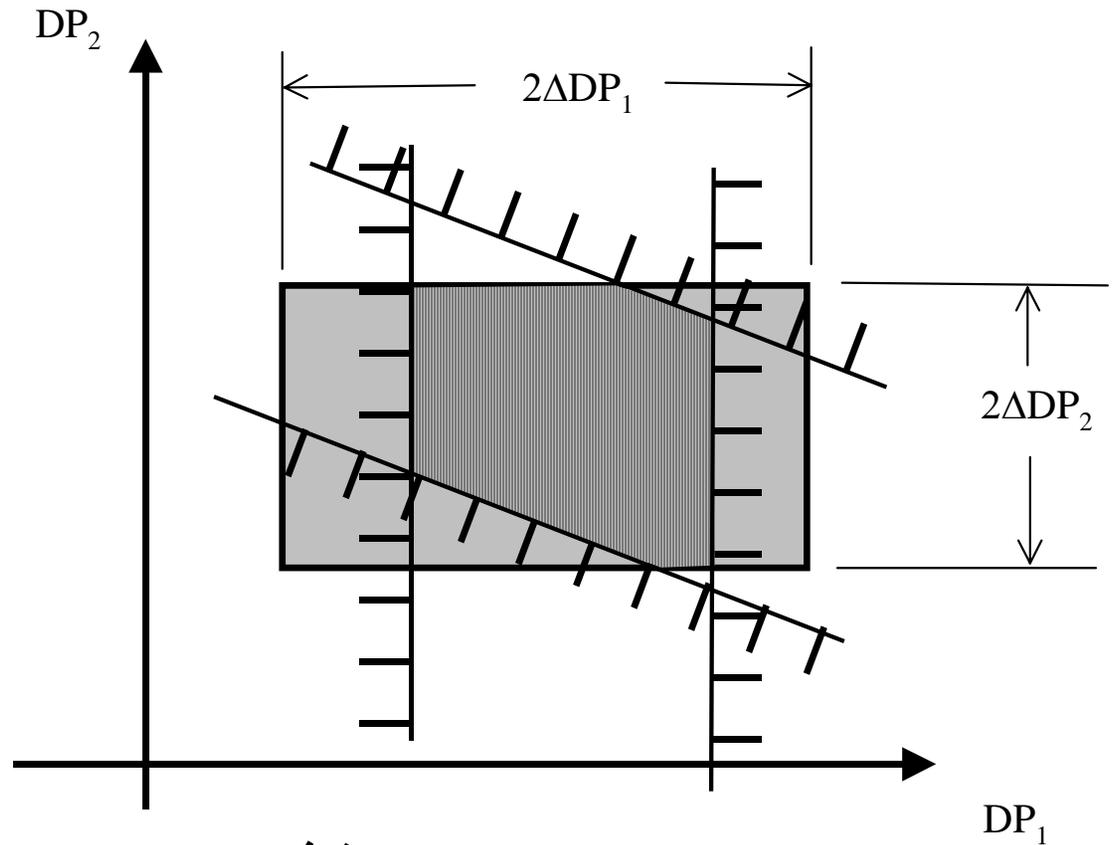
$$I = \log \left( \frac{V(\text{system range})}{V(\text{common range})} \right)$$

- where  $V(\bullet)$  denotes the hyper-volume of a set in  $n$  space.

$$V(\text{system range}) = \prod_{i=1}^n 2\Delta\mathbf{DP}_i$$

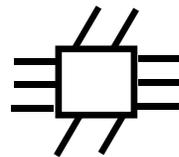
$$V(n, \mathbf{A}, \mathbf{b}) = \frac{1}{n} \sum_{p=1}^m \frac{\mathbf{b}_p}{|\mathbf{A}_{p,q}|} \cdot V(n-1, \tilde{\mathbf{A}}, \tilde{\mathbf{b}})$$

In 2D,  $V(\bullet)$  denotes the *area* of the regions



$$V(\text{system range}) = \prod_{i=1}^n 2\Delta DP_i$$

$$V(n, \mathbf{A}, \mathbf{b}) = \frac{1}{n} \sum_{p=1}^m \frac{\mathbf{b}_p}{|\mathbf{A}_{p,q}|} \cdot V(n-1, \tilde{\mathbf{A}}, \tilde{\mathbf{b}})$$



Design Range



System Range



Common Range

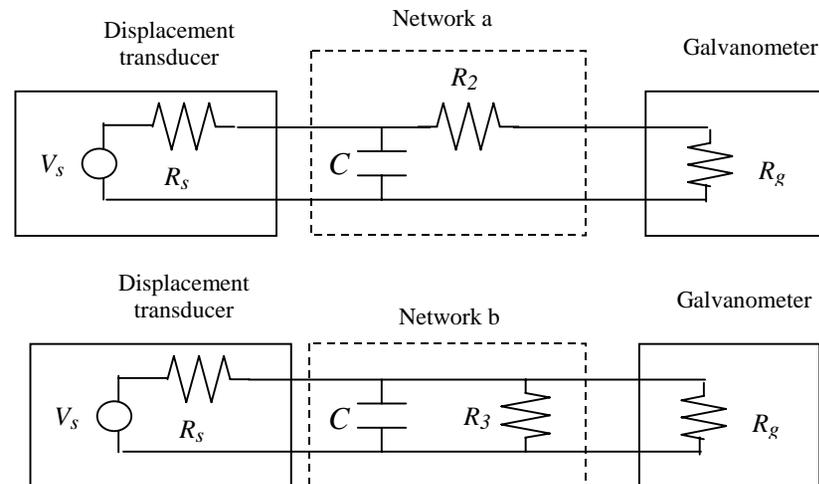
# Passive Filter

FR1: Design a low-pass filter with a filter pole at 6.84 Hz or 42.98 rad/sec.

FR2: Obtain D.C. gain such that the full-scale deflection results in  $\pm 3$  in. light beam deflection.

DP1: capacitance.

DP2: resistance.



# Design Matrices

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**Network A**

**Network B**

$$-1.86 \times 10^5 \left( \frac{\text{rad}}{\text{sec} \cdot \text{F}} \right) \quad -1.10 \times 10^{-2} \left( \frac{\text{rad}}{\text{sec} \cdot \Omega} \right)$$

$$-3.00 \times 10^4 \left( \frac{\text{rad}}{\text{sec} \cdot \text{F}} \right) \quad -1.38 \left( \frac{\text{rad}}{\text{sec} \cdot \Omega} \right)$$

$$0 \left( \frac{\text{in}}{\text{F}} \right) \quad -4.03 \times 10^{-3} \left( \frac{\text{in}}{\Omega} \right)$$

$$0 \left( \frac{\text{in}}{\text{F}} \right) \quad 9.50 \times 10^{-2} \left( \frac{\text{in}}{\Omega} \right)$$

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Reangularity = 0.982

Reangularity = 0.707

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Network A is almost uncoupled.

Network B is decoupled.

# Results

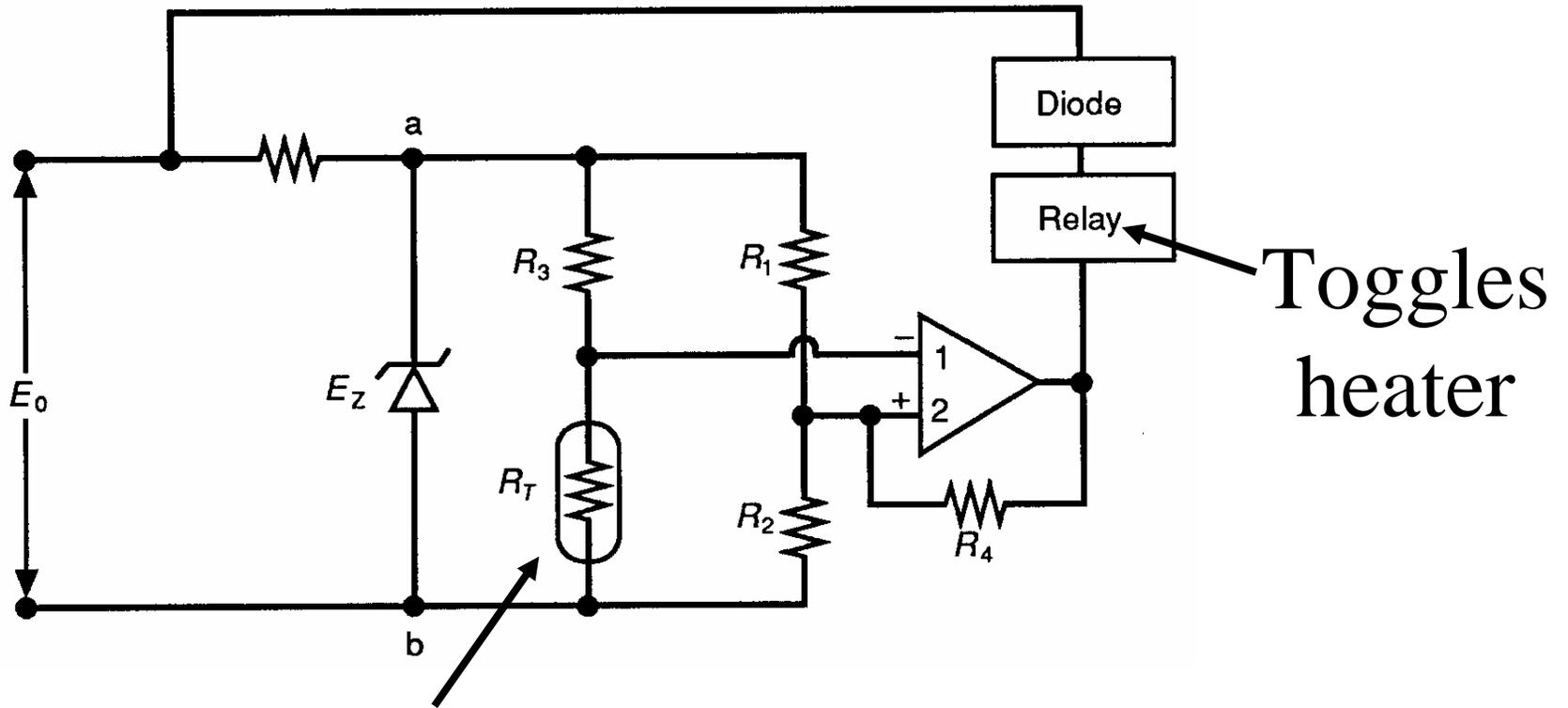
		Network A		Network B	
		$I$ (bits)	$p_s$	$I$ (bits)	$p_s$
Information content for normally distributed DPs	Integration of pdf (Equation 15)	0.084	94.4%	0.059	96.0%
	Monte Carlo	0.095	93.6%	0.063	95.7%
	Summing information of each FR	0.084	94.4%	0.107	92.9%
Information content for uniformly distributed DPs	Ratio of volumes (Equation 17-20)	0.880	54.4%	0.576	67.1%
	Monte Carlo	0.844	55.7%	0.593	66.3%
	Summing information of each FR	0.887	54.1%	1.038	48.7%

Summing  $I$  is much too conservative for decoupled designs

# Assigning Tolerances to DPs

	Network A		Network B	
	Mean	Tolerance	Mean	Specification
Capacitor	$C=231\mu\text{F}$	$\pm 15\mu\text{F}$	$C=1474\mu\text{F}$	$\pm 15\mu\text{F}$
Resistor	$R_2=527\Omega$	$\pm 10\% \cdot R_2$	$R_3=22.3\Omega$	$\pm 10\% \cdot R_3$

# Temperature Control Circuit



Thermistor senses temperature

Toggles  
heater

# Design Scenario

$FR_1$  = Resistance at which heater turns ON

$FR_2$  = Resistance at which heater turns OFF

$DP_1$  = Zener diode voltage,  $E_z$

$DP_2$  = Resistance  $R_1$  for design A

$R_4$  for design B

All tolerances 5% bilateral about target

Normal distributions with  $C_p=1$

# Governing Equations

$$FR_1 = \frac{R_3 \cdot R_2 \cdot (E_z \cdot R_4 + E_o \cdot R_1)}{R_1 \cdot (E_z \cdot R_2 + E_z \cdot R_4 - E_o \cdot R_2)}$$

$$FR_2 = \frac{R_3 \cdot R_2 \cdot R_4}{R_1 \cdot (R_2 + R_4)}$$

# Results for Temperature Controller

## Design A

- $R = S = 0.585$
- $p_s = 97.0\%$
- $I = 0.044$
- Sum of  $I = 0.046$

## Design B

- $R = S = 0.328$
- $p_s = 99.1\%$
- $I = 0.013$
- Sum of  $I = 0.013$

$$\begin{bmatrix} -237 \Omega/V & -0.577 \Omega/\Omega \\ 0 \Omega/V & -0.417 \Omega/\Omega \end{bmatrix}$$

$$\begin{bmatrix} -237 \Omega/V & -0.020 \Omega/\Omega \\ 0 \Omega/V & -0.007 \Omega/\Omega \end{bmatrix}$$

The more strongly coupled design has lower  $I$

# Coupling and Information

## Conclusions

- The information content of decoupled designs can sometimes be significantly different from the sum of information of the FRs
- These differences can sometimes critically affect engineering decision making
- In some cases, the Information Axiom requires that decoupled designs are to be preferred to uncoupled designs

# Plan for the Session

- Why are we doing this session?

- Axiomatic Design (Suh)

## Decision-Based Design (Hazelrigg)

- What is rationality?

- Overview of frameworks

- Discussion of Exam #1 / Next steps

# Decision Based Design

- Engineering design is a decision making process in which the designer must, in the presence of uncertainty, make choices among alternatives
- Decision making has an axiomatic basis in vN-M utility theory etc.
- Designers should try to maximize  $E(u)$

# Definitions

- Decision – a choice among alternatives, an irrevocable allocation of resources
- Outcome – the result of a decision
- Expectation – One's knowledge about the outcome prior to making a decision
- Uncertainty – a lack of precise knowledge
- Risk – The result of uncertainty on the outcome of a decision
- Information – The basis on which good decisions are made

# The Axioms of DBD

- Axioms 1-7 are von Neumann and Morgenstern's
- Axiom 8 – All engineering designs are selected from among the set of designs that are explicitly considered.
- Basically, Axiom 8 says that Axioms 1-7 apply to engineering design decisions

# Arrow's Impossibility Theorem

There is no way of consistently aggregating the preferences of more than two individuals if

- Collective ordering scheme is applied uniformly
- A preference shared by all must be reflected in the collective preference
- Independence from irrelevant alternatives
- No individual has dictatorial power

Kenneth Arrow, Nobel Prize in Economics, 1972

# Preferences and Pie

- You are presented with two pies
  - Banana Cream and Cherry
  - You select **Banana Cream**
- You are presented with two pies
  - Apple and Banana Cream
  - You select **Apple**
- You are presented with two pies
  - Cherry and Apple
  - You select **Cherry**

Is there anything problematic RE: this situation?

# Intransitivity of Preferences

The preference ordering

$$A > B > C > A$$

Implies an ordering of utilities

$$U(A) > U(B) > U(C) > U(A)$$

Intransitive preferences

- Allow a Dutch bet to be formed
- Are considered by many to be “irrational”

# Arrow's Theorem and Engineering

Engineer	Preference	Votes		
		A vs B	B vs C	A vs C
I	A>B>C	A	B	A
II	B>C>A	B	B	C
III	C>A>B	A	C	C
Group preference		A>B	B>C	C>A

# Hazelrigg's Claims

- Arrow's theorem implies that
  - “irrationality is practically assured”
  - “a customer-centered view of design is not possible”
- The majority of methods in common use in engineering design provide results that are “egregiously in error”
- Adopting his approach leads to a factor of two improvement in the bottom line

# Utility and Choice

- “Some common misperceptions about utility are:
- ... *The test of utilities is to see if they result in reasonable choices.* It is common for engineers to test utility functions by examination of the reasonableness of choices. The reality is that utilities need to be tested against preferences, not choices.”

# Hazelrigg's Example

- Estimate the number of M&Ms in a jar
- Whoever is closest without going over wins
- “Conventional” approach
  - Create a model
  - Submit your best estimate
- “Rational” approach
  - Create a model
  - Propagate uncertainty
  - Model the competitive scenario
  - Select guess for  $\max E(u)$

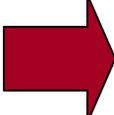
$$n = \frac{V_j}{V_c} \mu$$

# Benefits of Decision Theory

- Emphasizes the role of **uncertainty** in engineering design
- Shows that **resolution among alternatives** is an important criteria for handling uncertainty
- Brings in the **influence of competitors** on our designs
- Aligns decisions with “**the goal**” of engineering design (profit?)
- Preferences are of the **decision maker**

# Plan for the Session

- Why are we doing this session?
- Axiomatic Design (Suh)
- Decision-Based Design (Hazelrigg)

 What is rationality?

- Overview of frameworks
- Discussion of Exam #1 / Next steps

# Suh, Hazelrigg and Rationality

- “Some people use dimensional analysis, decision theory (etc).... They do not provide tools for coming up with a **rational** system design”
  - Suh, *Axiomatic Design Theory for Systems*
- “Axiomatic design can lead to a **rational** design ...”
  - Suh, “Axiomatic Design Theory for Systems”
- “In order to ensure that engineering design is conducted as a **rational** process ...”
  - Hazelrigg, “An Axiomatic Framework for Engineering Design”
- “...one logically can either accept these results or disagree with the axioms. There is no other **rational** choice.”
  - Hazelrigg, “An Axiomatic Framework for Engineering Design”

# What is Rationality?

- “No ... positive characterization has achieved anything close to universal assent ... Irrationality seems to be the more fundamental normative category...”

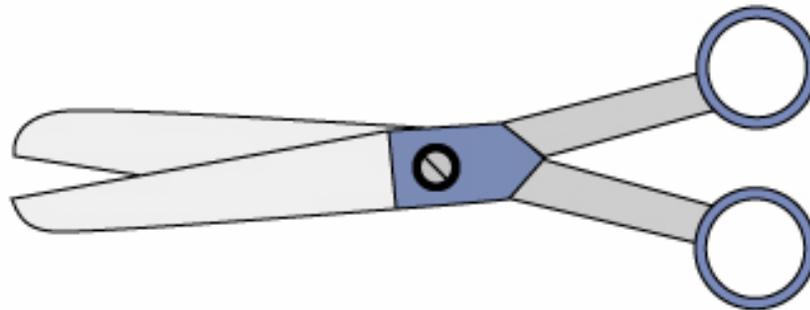
- *Cambridge Dictionary of Philosophy*

# What is Rationality?

- “Theoretical rationality applies to beliefs ... e.g. beliefs that are self evident or derived from self evident beliefs by a reliable procedure...”
- “Another account of rational action is ... to act rationally is to act on universalizable principles, so that what is a reason for one person must be a reason for everyone...”
- “Practical rationality applies to actions...acting rationally simply means acting in a way that is maximally efficient in achieving one’s goals”
  - *Cambridge Dictionary of Philosophy*

Human rational behavior is shaped by a scissors whose two blades are the **structure of task environments** and the **computational capabilities** of the actor.

- Herbert Simon



Simon, H. A., 1990, "Invariants of human behavior,"  
*Annual Review of Psychology*, 41, 1-19.

"Bounded rationality is a genuinely interdisciplinary topic. Its subject matter is the mechanisms that humans, institutions, and artificial agents use to achieve their goals. The common denominator is that decisions need to be made with **limited time, knowledge, and other resources, and in a world that is uncertain and changing.**"

Gigerenzer, G. and R. Selten, 2001, "Rethinking Rationality," in *Bounded Rationality*, MIT Press, Cambridge, MA.

“Heuristics that are matched to particular environments allow agents to be ecologically rational, making adaptive decisions that combine accuracy with speed and frugality. We call the heuristics “**fast and frugal**” because they process information in a relatively simple way, and they search for little information.”

Todd, P. M., and G. Gigerenzer, 2003, “Bounding Rationality to the World,” *Journal of Economic Psychology*, v. 24, pp. 143-165.

# Plan for the Session

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# Frameworks Phase

- INCOSE model
- RCI model
- Lean thinking
- Set-based design
- Axiomatic design
- Decision based design
- “No Silver Bullet”

# No Silver Bullet:

## Essence and Accidents of Software Engineering

- The essence of a software entity is a construct of interlocking concepts
- I believe the hard part of building software to be the specification, design, and testing of this conceptual construct
- If this is true, building software will always be hard

# Promising Attacks on the Essence

- Buy versus build
- Incremental development
- Requirements refinement
- Rapid prototyping
- **Great designers**

Brooks, Fred, “No Silver Bullet”

# Plan For the Session

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# Why an Exam?

- I just hate exams...  Why?
- How about we do without the exam and instead have a team project assignment...?

Projects = Practice

Exam = Reflection!

- ...put less pressure on people to cram and emphasize learning. 

OK. Let me suggest how to study.

# Exam Logistics

- OPEN BOOK / OPEN EVERYTHING
- Individual effort, you may not discuss with classmates or any other human being
- Download the exam from “Exam” folder on sloanspace (avail 7:30AM Tues 22 June)
- Do the exam in a single 2 hour sitting
- Do the exam wherever you want
- Upload your file to sloanspace folder HOMEWORK/Exam #1

File naming convention -- LastFirst\_EX1.doc

# Richard Felder's Guide to Exams

- Test on what you teach
- Consider providing a study guide
- Minimize speed as a factor in performance
- Revise to eliminate flaws
- Design 10-15% of the exam to discriminate between A and B level performance

# Exam Content

There will be three questions

- Question #1 will be a set of “short answer” questions probing basic facts (Bloom 1,2,3) about the reading assignments
- Question #2 will ask you to demonstrate working knowledge of a major framework (Lean Thinking or Set Based Design) to a scenario
- Question #3 will be related to Fred Brooks’ paper “No Silver Bullet” – not details but the essence and form of his argument as related to everything we’ve done so far

# Study Guide

- Form a study group (2-8 class mates)
- List every major concept/term used in the assigned readings (divide & conquer! use team to assemble list)
- Study that list of key concepts
- Develop a few scenarios to which Lean Thinking or Set-Based design might be applied and talk them through with your group
- Read Fred Brooks' article "No Silver Bullet"
- Imagine different questions I might pose about Brooks' article and outline different essay responses

# Next Steps

- Do the reading assignment
  - Brooks\_No Silver Bullet.pdf
- Study for the exam
- Do the exam
  - 8:30AM Tues 22 June
  - Or another time
- Upload the exam to HW folder