Steps toward a Science of Design

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NSF PI Conference on the Science of Design
March 1, 2007
Alexandria, VA

A journey of a thousand miles begins with a single step…

Confucius, c. 500 BC

How a science is structured—1

- The Vannevar Bush theory

Basic Research — Applied Research

NSF funded — Corporate funded

Motivation: Let scientists do what they want

Method of transfer: Trickle down

Donald Stokes’ critique

- Trickle down doesn’t work—who will integrate dispersed basic results?
- What about feedbacks? Real world problems can motivate excellent basic science

Basic Research

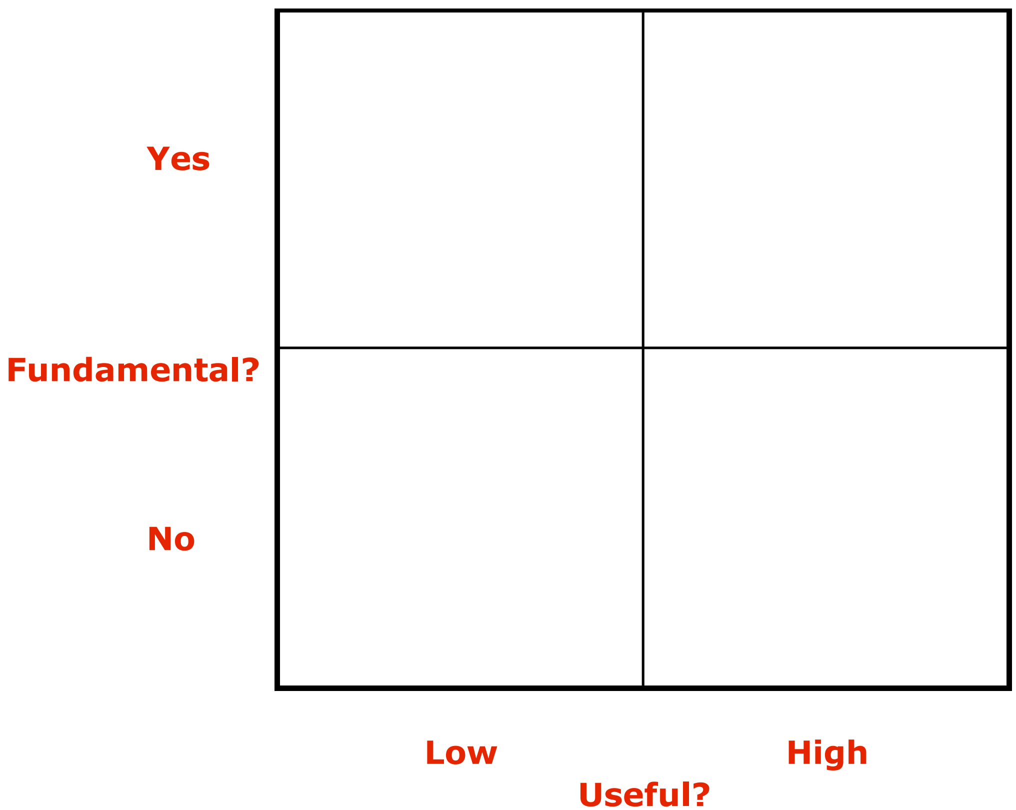
Applied Research

NSF funded

Corporate funded

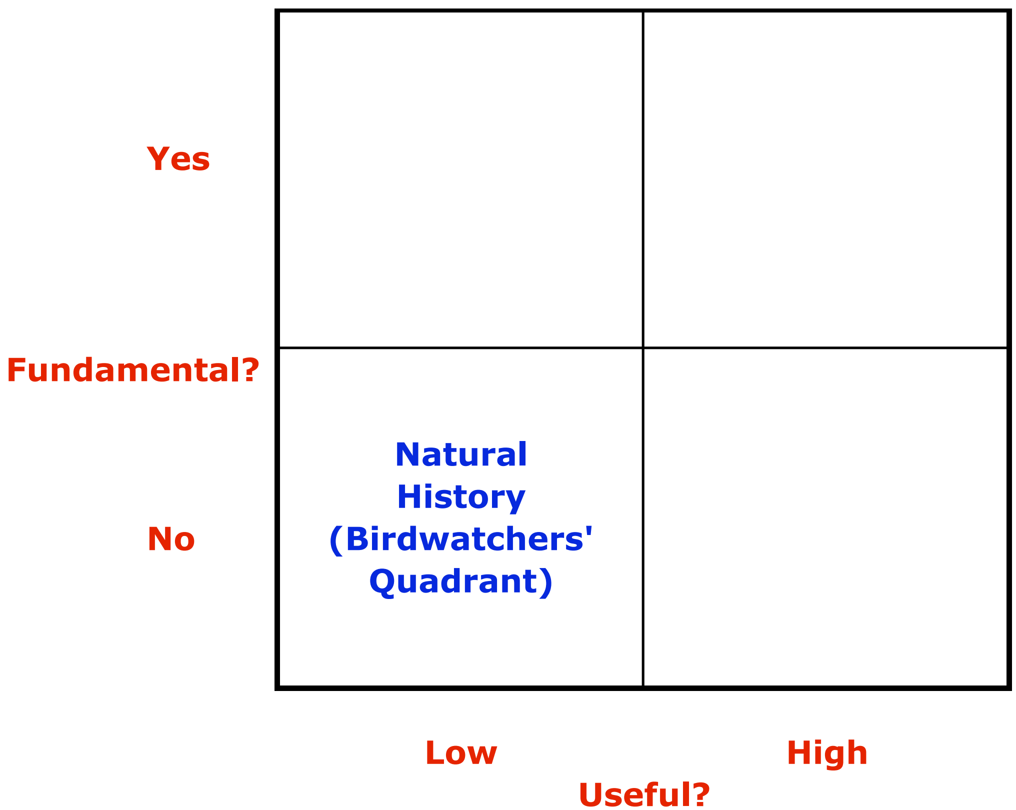
How a science is structured—2

- Stokes' Matrix



How a science is structured—2

- Stokes' Matrix



How a science is structured—2

- Stokes’ Matrix

Fundamental?	Low	High
Yes		
No	**Natural History (Birdwatchers' Quadrant)**	**Pure applied Research (Edison's Quadrant)**

Useful?

How a science is structured—2

- Stokes' Matrix

Fundamental?	Useful? Low	Useful? High
Yes	Pure Basic Research (Bohr's Quadrant)	
No	Natural History (Birdwatchers' Quadrant)	Pure applied Research (Edison's Quadrant)

How a science is structured—2

- Stokes' Matrix

Fundamental?	Low	High
Yes	Pure Basic Research (Bohr's Quadrant)	Use-inspired Basic Research (Pasteur's Quadrant)
No	Natural History (Birdwatchers' Quadrant)	Pure applied Research (Edison's Quadrant)

Useful?

Golden quadrant!

Comroe-Dripps study

- Identified 10 most important clinical advances in cardiovascular and pulmonary diseases
- 500 “key articles” (going back 200 years)
- Classified the articles
  - Basic unrelated to clinical problem (Bohr)
  - Basic related to a clinical problem (Pasteur)
  - Not concerned with basic mechanisms (Edison)

Comroe-Dripps study—results

Fundamental?	Useful? Low	Useful? High
Yes	Pure Basic Research 37%	Use-inspired Basic Research 25%
No	Natural History 15%	Pure Applied Research 21%

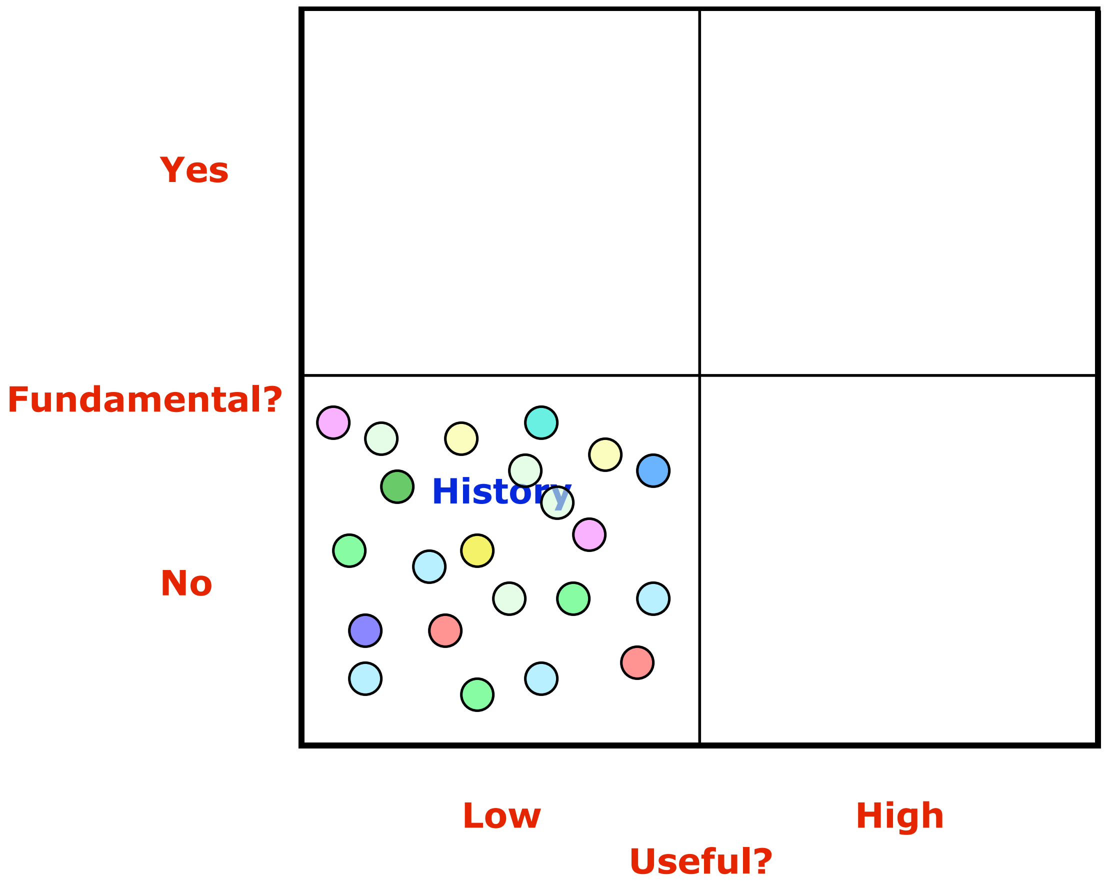
Fundamental?

Useful?

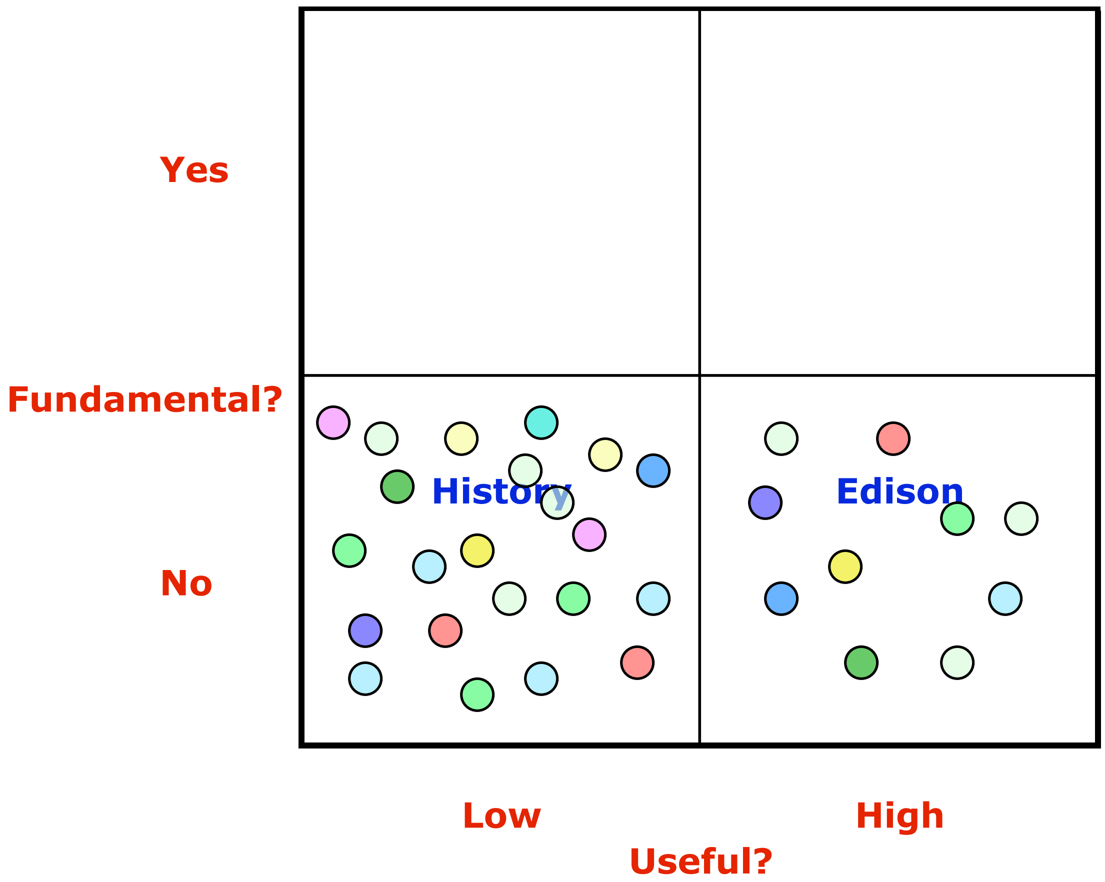
Review and Synthesis 2%

It takes all kinds!

Where is the science of design?



Where is the science of design?



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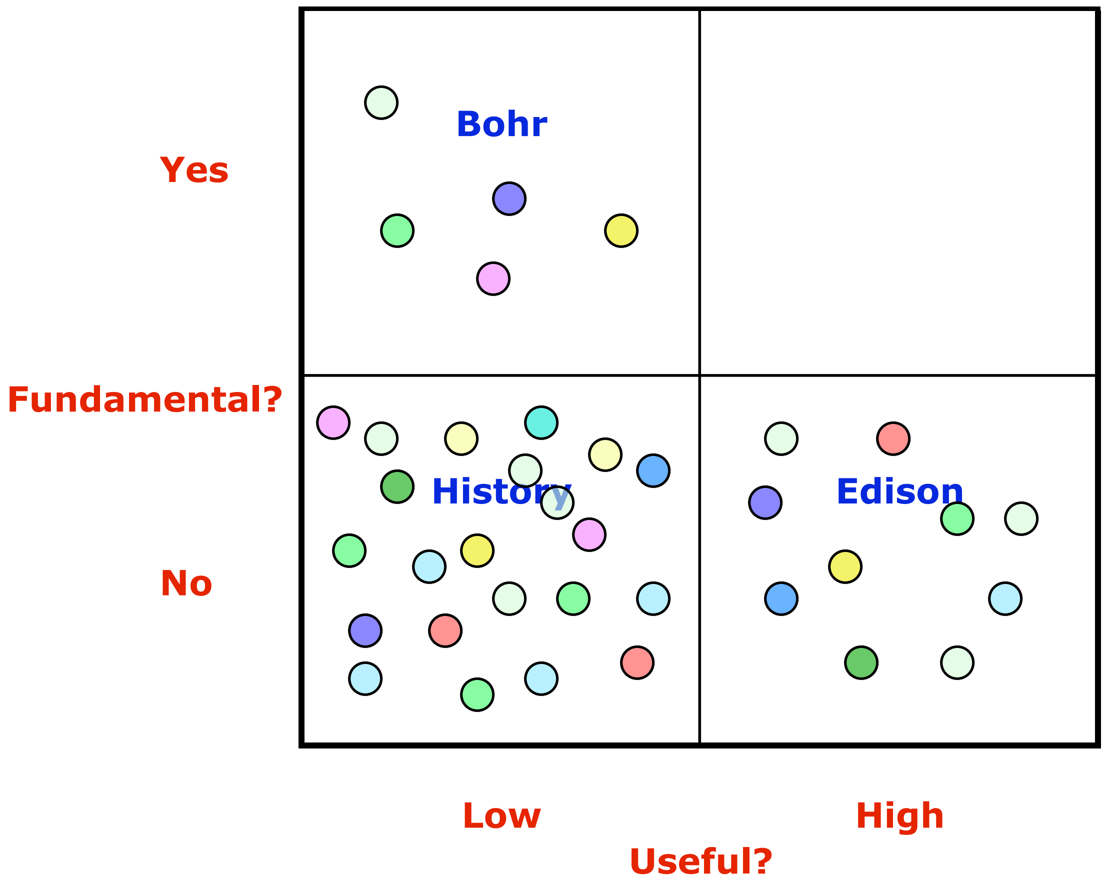

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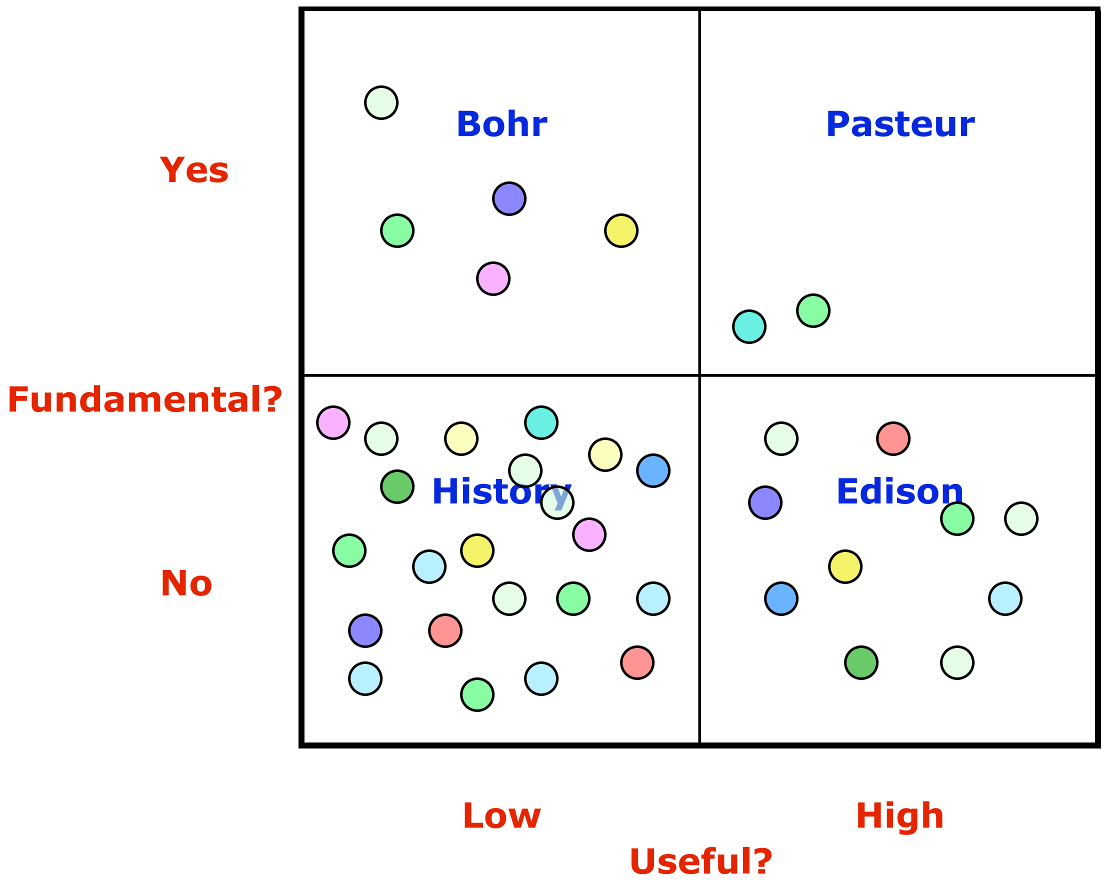
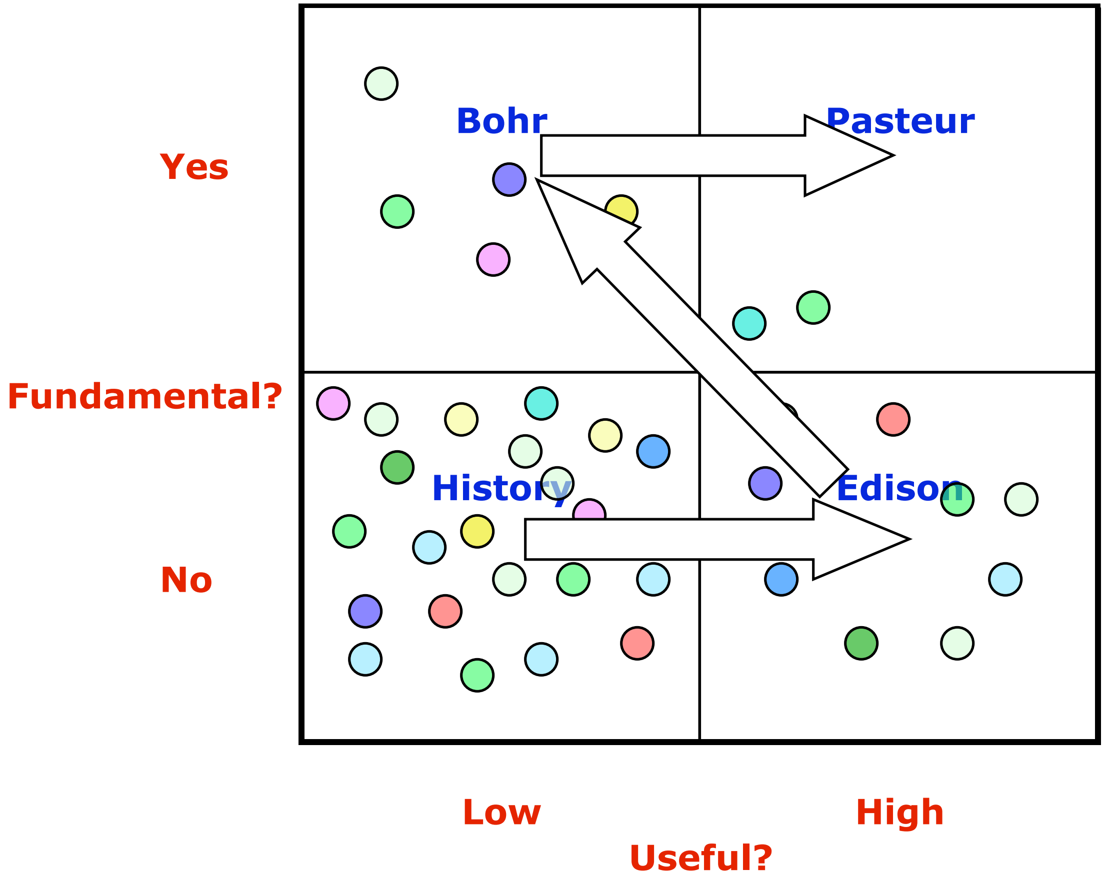
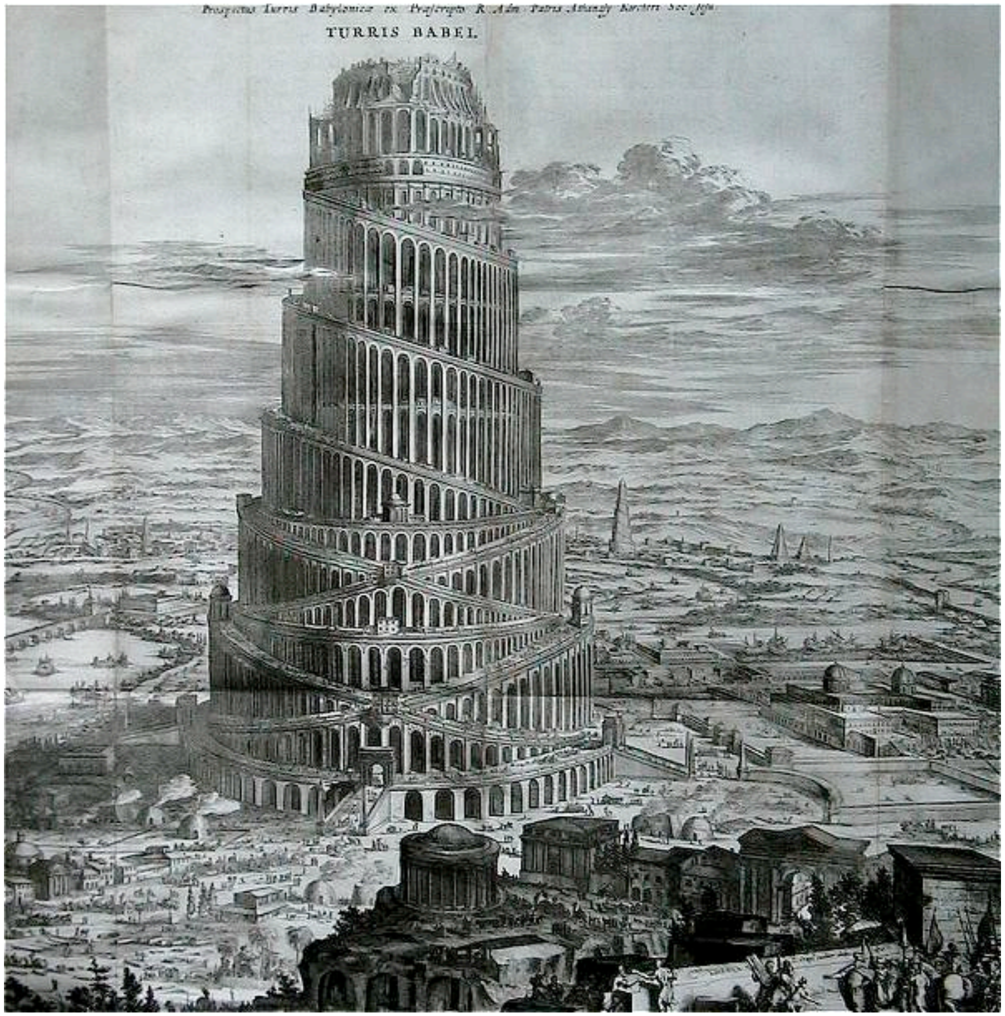


How a science develops



Where we are now—



Turris Babel

The Tower of Babel

So in the rest of this talk…

Let us find our common ground!

Tribute to the Domain Specialists

- Bell and Newell: *Computer Structures*
- Hennessy and Patterson: *Computer Architecture*
- Mead and Conway: *Intro to VLSI*
- Nevins and Whitney: *Concurrent Engineering*
- Nam Suh and German design theorists in mechanical engineering

Who occupies Bohr's quadrant in the science of design?

- Herbert Simon
- Christopher Alexander
- Fred Brooks
- David Parnas
- John Holland
- Baldwin and Clark (inadvertant and accidental)

Herbert Simon

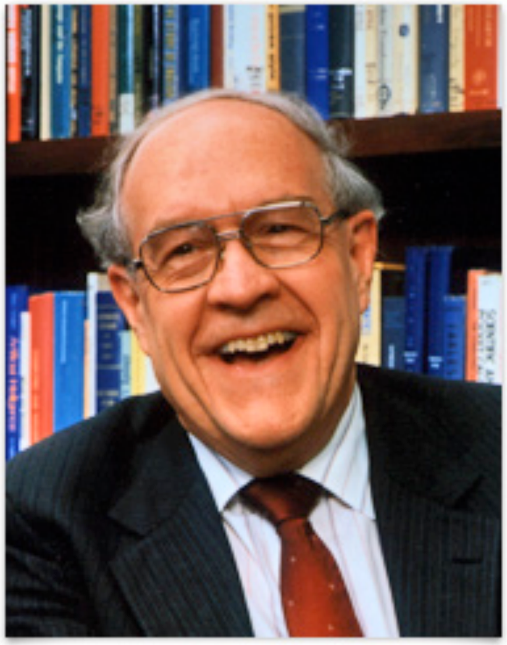
- *Sciences of the Artificial*
- NOT his most important work
- Most fundamental insight: Design is a decision-making process (under constraints of physics, logic and cognition)
- Rational and reductionist

Christopher Alexander

- *Notes on the Synthesis of Form; A Pattern Language; A City is not a Tree; The Nature of Order*
- Most fundamental insights: user-centered adaptive design; non-hierarchical complexity; unfolding designs; patterns
- Mystic and visionary (frustrating to scientists)

Frederick Brooks

- *The Mythical Man Month; No Silver Bullet; Computer Architecture*
- Most fundamental insights: the complexity catastrophe lurking in large designs; limits on the division of knowledge and labor; group inter-communication formula
- Waiting for the field to catch up to him; May belong in Pasteur's quadrant



David Parnas

- *On the Criteria to be Used in Decomposing Systems into Modules*; *Software Fundamentals*
- Most important ideas: Information-hiding modularity; Abstraction; Interface; Modules are task assignments
- Almost an Edisonian, but keeps breaking out

John Holland

- *Hidden Order; Adaptation in Natural and Artificial Systems; Emergence*
- Most important ideas: Formal dynamics of complex adaptive systems; unified theory of natural and artificial evolution; operators; tags
- Our best link to complexity sciences (better than Kauffman)

Baldwin and Clark

- *Design Rules: The Power of Modularity*
- Most important ideas: designs are lodged in the larger economy; financial value is a force driving design evolution; designs are options; uncertainty is valuable
- We read everyone else!

We must hang together, gentlemen…

Else we shall most assuredly hang separately.

Information Hierarchy Decisions View of Designs

Definition of Designs:

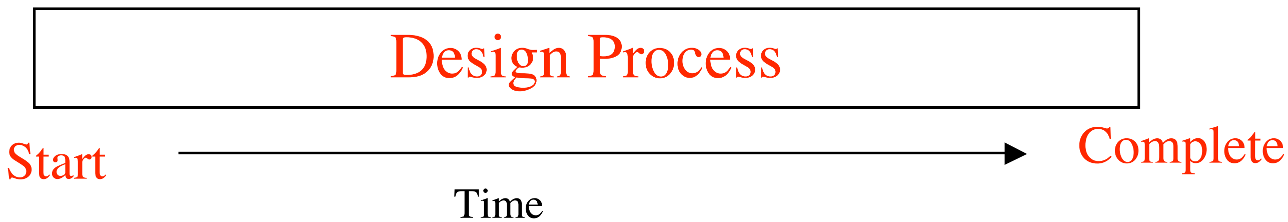
Designs are the *instructions*, based on knowledge, that *turn resources into things* people *use and value*.

Implications of the definition

- Designs are not “the thing itself”, they are the instructions for making it
  - In software: source code = design
  - Compiled, running code = the thing itself
- Designs are information
- Designs are part of human knowledge
  - But not all knowledge is design
  - Designs are what make knowledge useful

The Process of Designing

- Is the process of filling in the set of instructions
- Designing occurs in time



- When design is complete, the design process is over, “production” can begin
- Along the way, you have partial designs
  – A source of huge amounts of confusion!

Think of the Many Different Names for Partial Designs

Design Process

Start → Complete

Time

First idea

Sketch

Drawing

Architecture

Standards

Platform

Interfaces

Dominant Design

Alpha version

Beta version

Ready to Ship

The Many Different Names for Partial Designs

Design Process

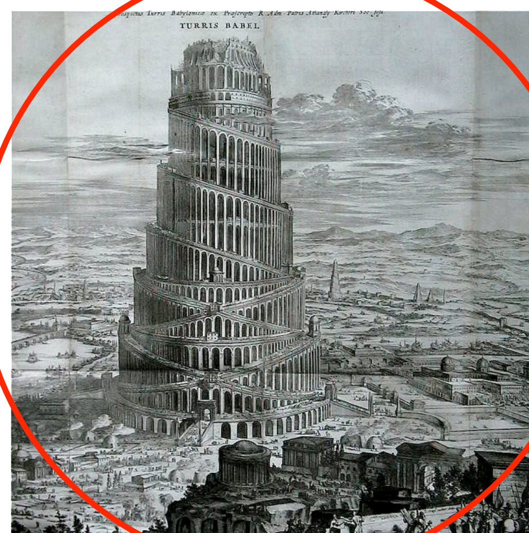
Start → Complete

Time

First idea

Sketch

Drawing



Alpha version

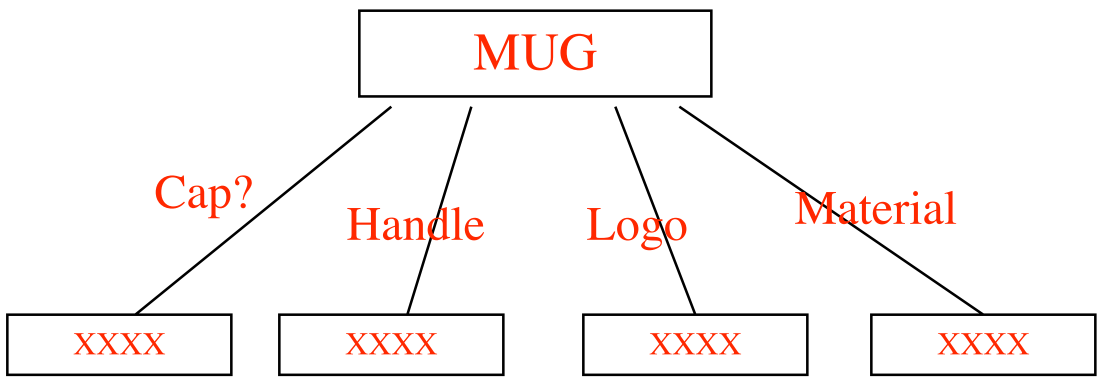
Beta version

Ready to Ship

The modern Tower of Babel is right here!

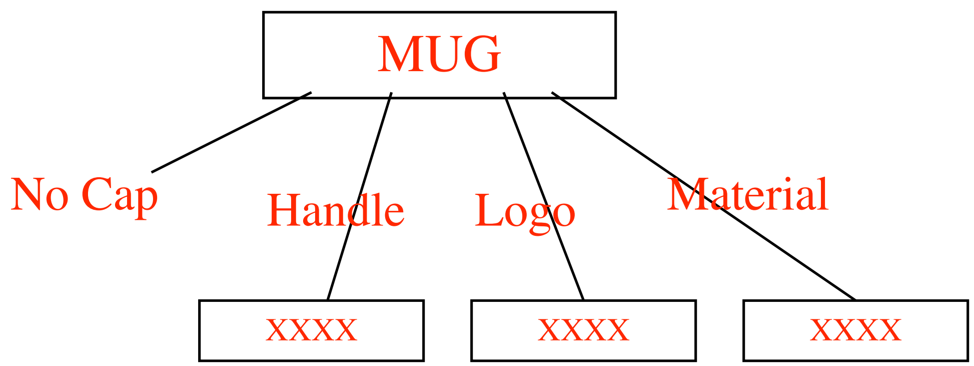
Decision-Information Hierarchies

- Process of design is a decision-making process (remember Simon!)
- Some design decisions create the need for subsequent decisions



Decision-Information Hierarchies

- If no cap—Decisions contingent on "cap" disappear
- List of instructions becomes shorter



Problem solving design hierarchy

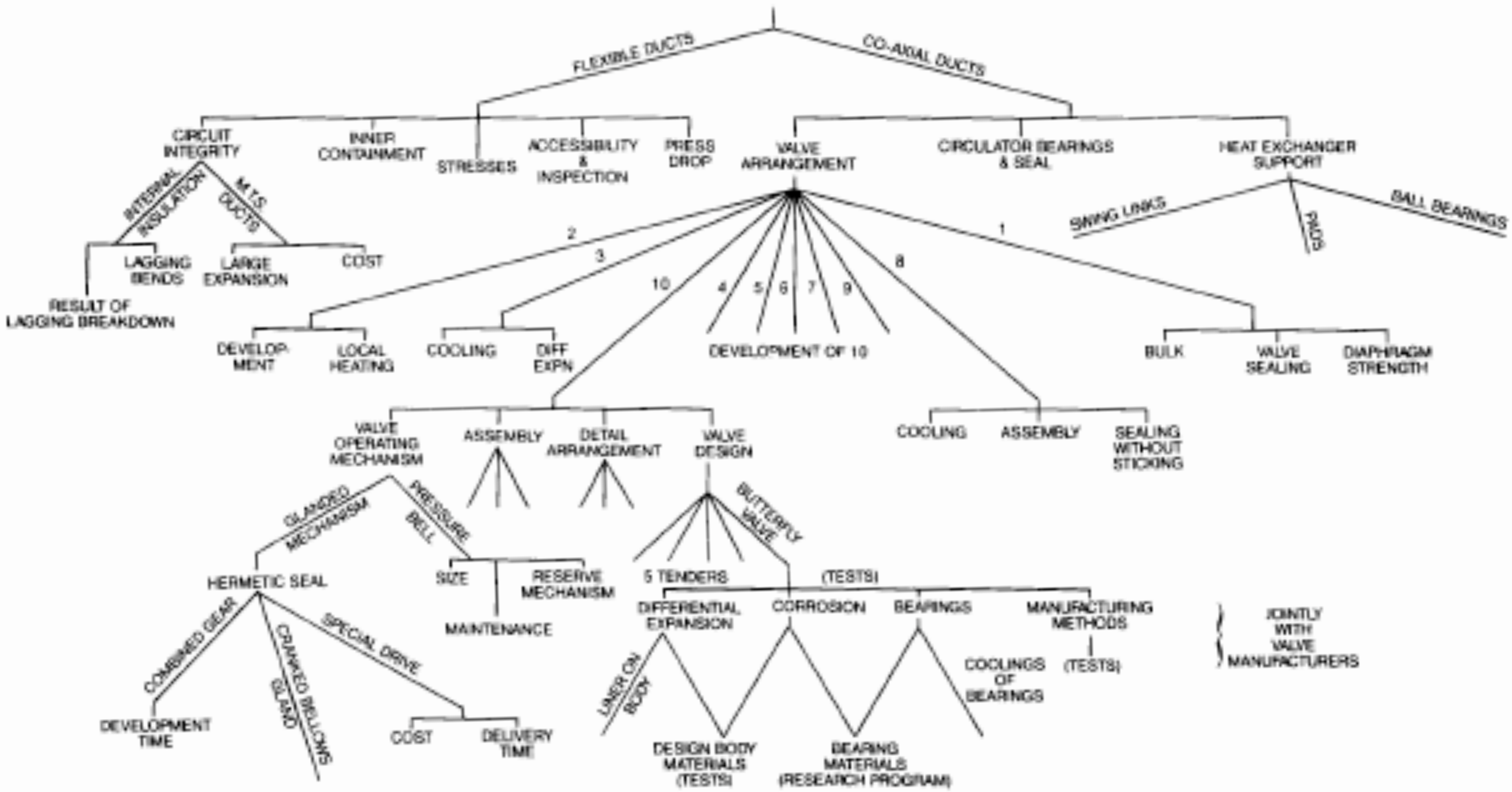


Fig. 1. Marple's ducts and valves problem. Sloping lines are alternatives; vertical lines are subproblems.
Source: Marple's [17,p.60]. "The Decisions of Engineering Design" IEEE Transactions on Engineering Management (June, 1961), p. 60.

Design Search Spaces

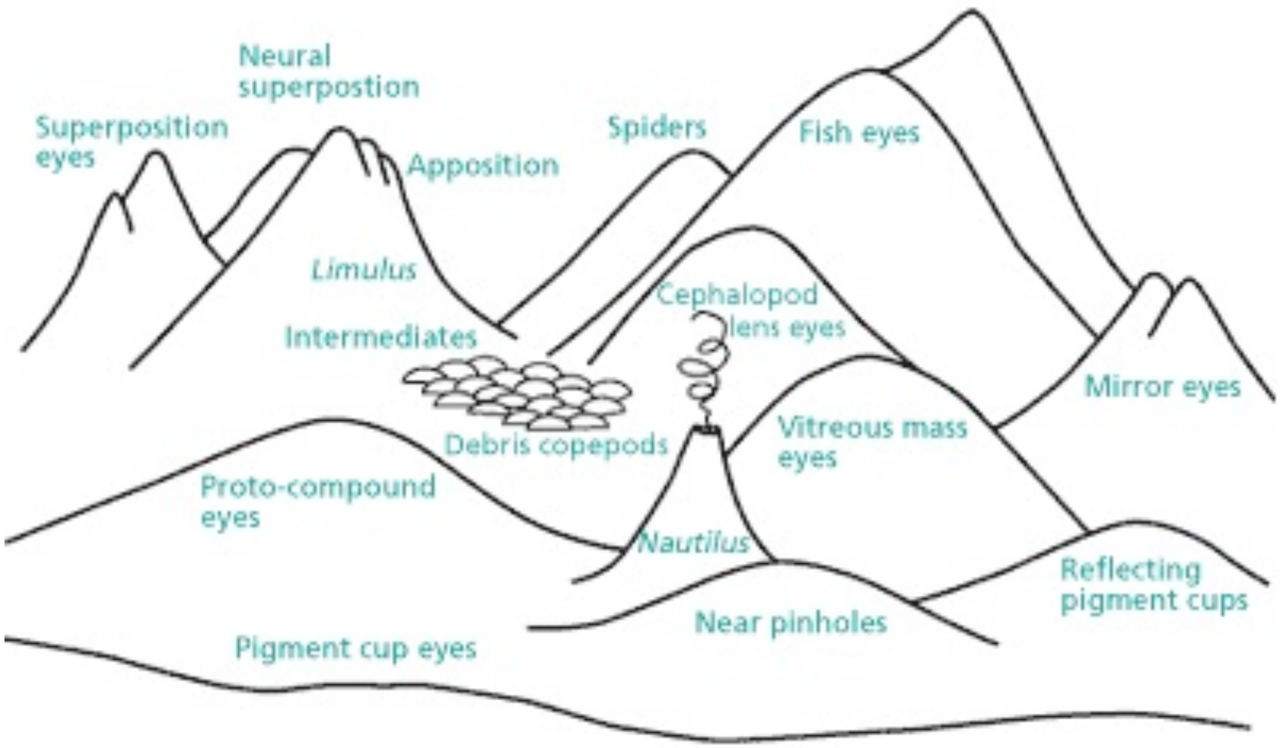
- A design space comprises the set of all possible variants of a set of designs
- Design spaces are bounded by prior design decisions
  - Mug … w/ cap
  - Pentium chip … w/ out-of-order, superscalar microarchitecture
- Can be mapped, unmapped, partially mapped

The newer the artifact, the less we know, the more exploration

All these—and many more— are in the design space of “bicycles”

Mapping Value to Design Spaces

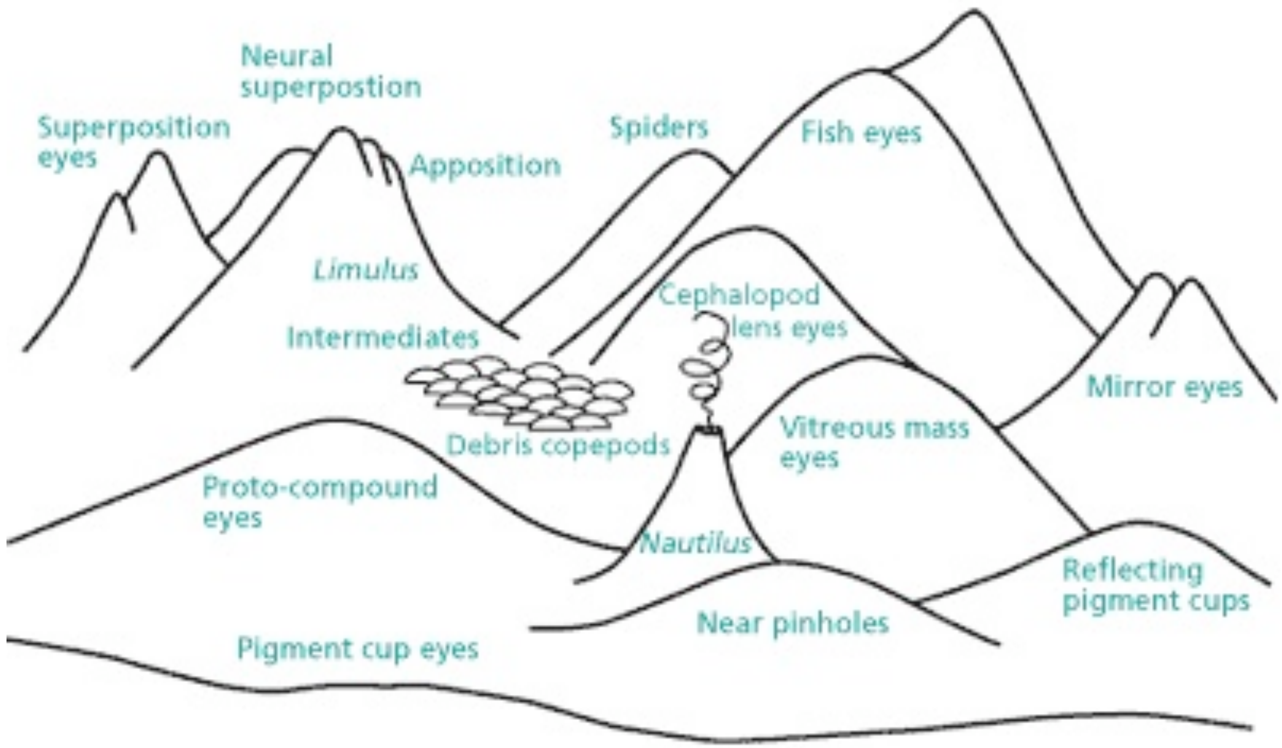
- "Fitness landscape" for eyes



Created by Mike Land. Height represents optical quality and the ground plane evolutionary distance.
From Dawkins R: Climbing Mount Improbable. New York, Norton, 1996.

Can we do this for designs?

- "Fitness landscape" for eyes



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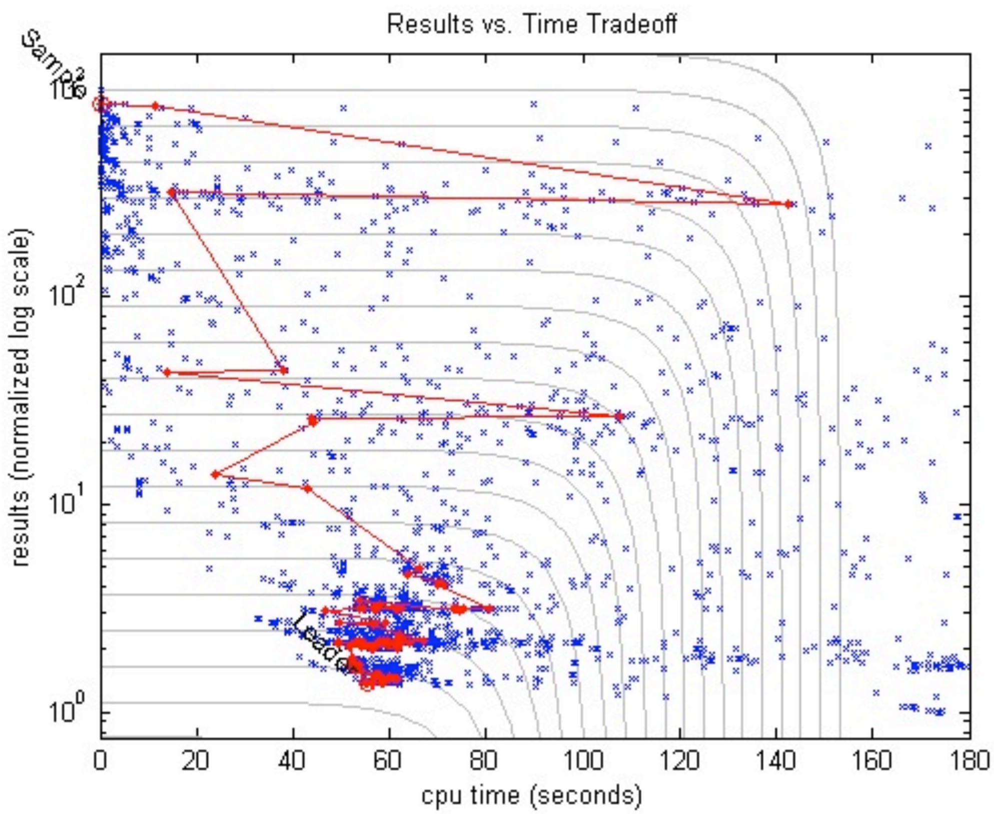
Can we do this for designs?

- “Fitness landscape” for a computer program



Scored results of submissions to the Mathworks “Sudoku” programming contest. Red path shows trajectory of best design over time.

http://www.mathworks.com/contest/sudoku/evolution.html

Properties of Designs

- Costly
- Cannot be consumed directly
- Non-rival
- Uncertain outcomes ex ante
- "Options" ex post
- Sometimes rankable
- *Composable in our imaginations*

A chimera

- Is a mythical beast with
  - The head and body of a lion
  - The head of a goat
  - A tail that is the head and body of a snake

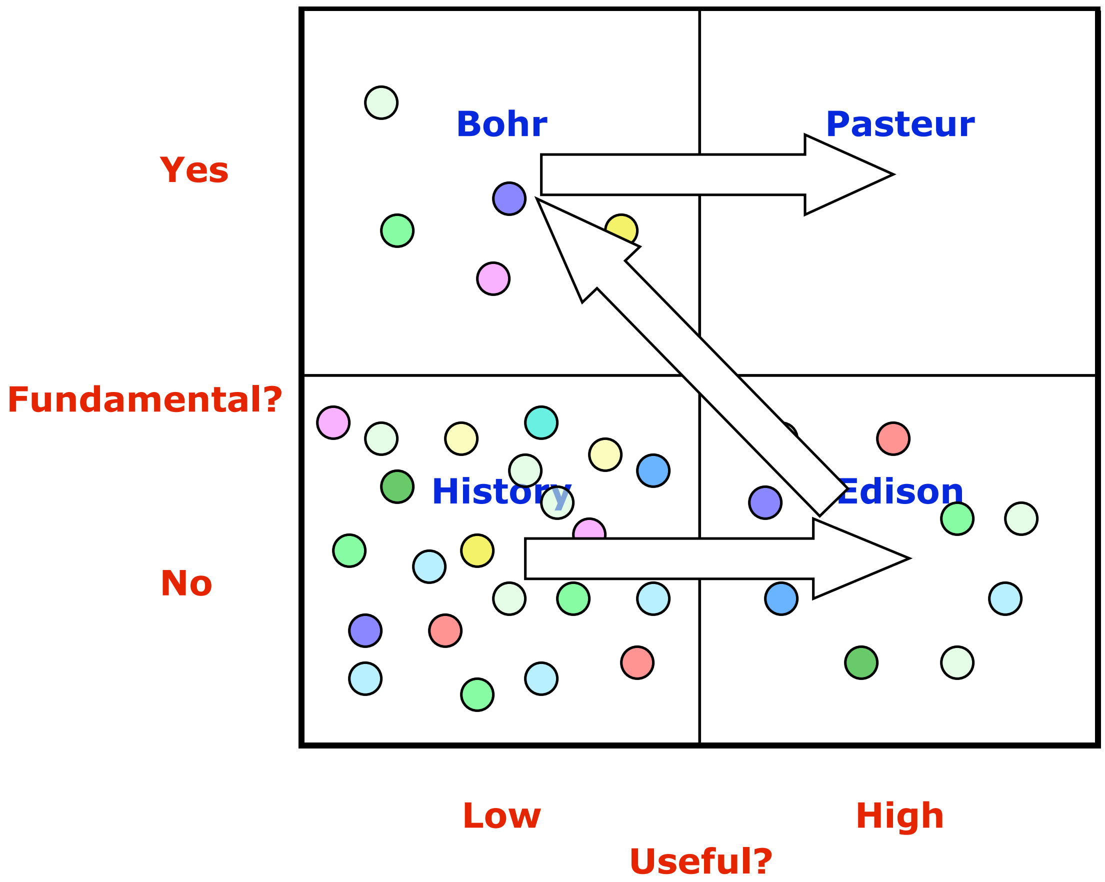
- Imagine a chimera
- Would you recognize one if you saw it?

The chimera of Arrezzo

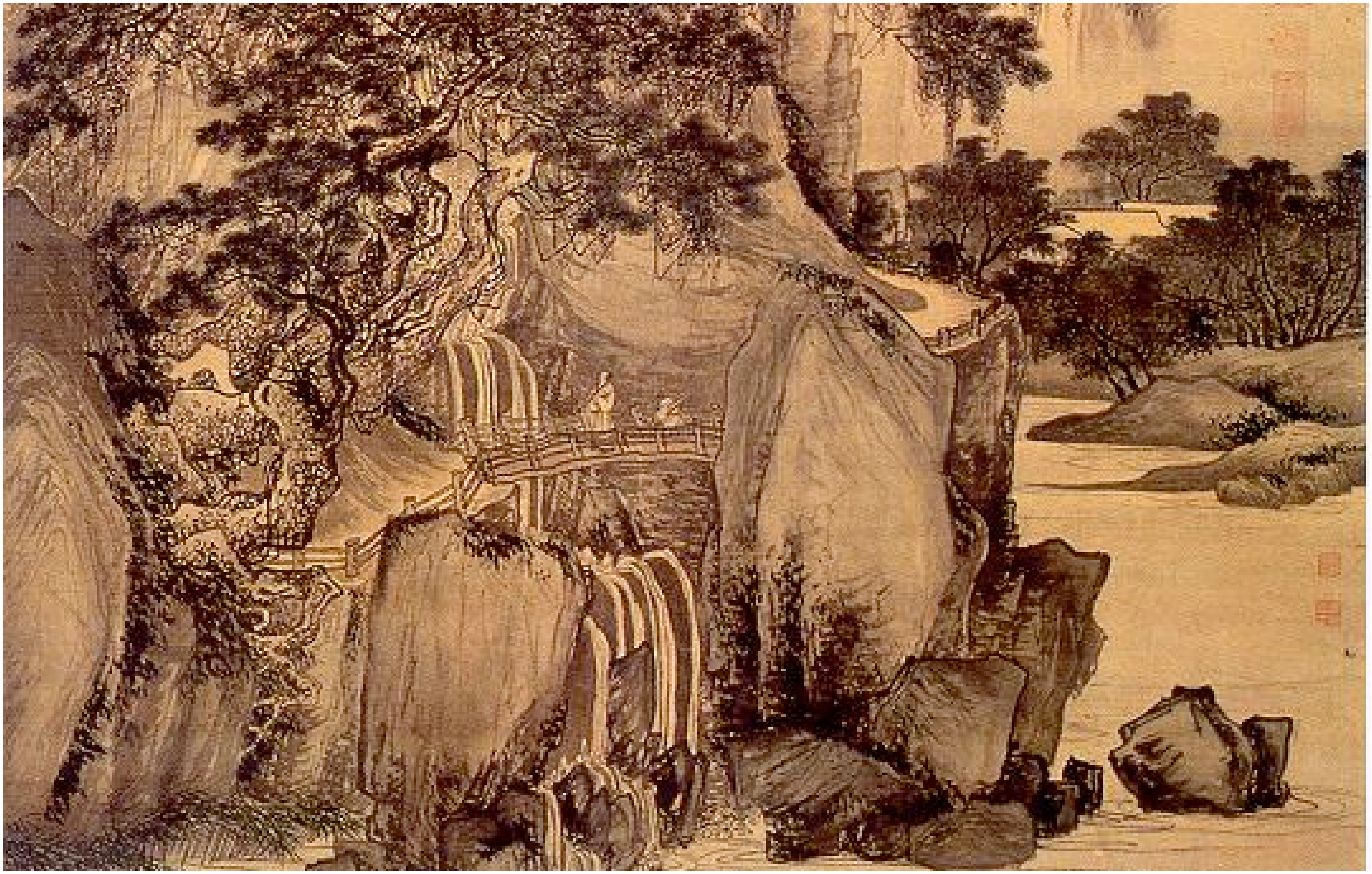
Headlines for a Science of Design

- Tools and methods that span different design domains
- Studies of design value and values
- Studies of large, complex, multi-domain systems

Heading for Pasteur's Quadrant



Step by step on the 1000 mile journey …



Thank you!