Science & Software Engineering

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The Scientific Method

"History of science is a story of a continuous attempt to use the scientific method to arrive at a rational comprehension of the world we live in and to construct a logically consistent picture of that world."

The Scientific Method

- More a philosophical outlook that a single fixed procedure
- Not one thing but many things
- Explanatory, predictive, descriptive
- Arsenal of methods:
  - Logical
  - Mathematical
  - Instrumentive

Some Characteristics of Science

- Relies on methods of empirical enquiry
  - Not armchair theorizing
  - Not political/religious persuasion
  - Not personal positioning

- Characterized by
  - Domain specific rhetoric, technical terms
  - Various kinds of analyses
  - Hypotheses and theories
  - Methodological standards based on logic and experience

- Goal for the course is to determine what is appropriate for empirical SWE

Some Characteristics of Science

- A number of hidden assumptions or regulative principles
  - Strict determinism
    - Carry over from classical physics
    - A causal law for every behavior/action
  - Heisenberg: uncertainty, probabilistic
  - Behavioral sciences:
    - Not strictly deterministic, but variable
      - ✓ Conscious events
      - ✓ Voluntary decisions vary from person to person
- Explanations are based on observations
  - A way of thinking
  - Relationships are perceptible in a way that has to make sense given accepted truths
- Creativity is as important as in art
  - Hypotheses, experimental designs
  - Search for elegance, simplicity

Some Characteristics of Science

- There are limits, boundaries – eg,
  - Cognitive capacity to visualize/express our experiences fully
  - Natural limits – bending elbow backwards
  - Logical and temporal boundaries of certain empirical methods
  - Some aspects of reality are always beyond the bounds of particular methods
- All scientific enquiry is subject to error
  - Be aware of it
  - Study its sources in order to reduce it
  - Eliminate/reduce the magnitude of such errors in our findings
- Sometimes success occurs only all the rules are broken and new rules created

Philosophy of Science

- Logical Positivism:
  - ★Separates discovery from validation
  - ★Logical deduction, to link theoretical concepts to observable phenomena
  - ★Scientific truth is absolute, cumulative, and unifiable
- Popper:
  - ★Theories can be refuted, not proved;
  - ★Only falsifiable theories are scientific
- Campbell:
  - ★Theories are underdetermined;
  - ★All observation is theory-laden & biased
- Quine:
  - ★Terms used in scientific theories have contingent meanings
  - ★Cannot separate theoretical terms from empirical findings
- Kuhn:
  - ★Science characterized by dominant paradigms, punctuated by revolution

Philosophy of Science

- Lakatos:
  - Not one paradigm, but many competing research programs
  - Each has a hard core of assumptions immune to refutation
- Feyerabend:
  - Cannot separate scientific discovery from its historical context
  - All scientific methods are limited;
  - Any method offering new insight is okay
- Toulmin:
  - Evolving Weltanschauung determines what is counted as fact;
  - Scientific theories describe ideals, and explain deviations
- Laudan:
  - Negative evidence is not so significant in evaluating theories.
  - All theories have empirical difficulties
  - New theories seldom explain everything the previous theory did

Postmodernism and Science

- Modernism
  - ★ Rationality is the highest form of mental functioning
  - ★ Modern science produces universal truths
    - ➢ …independent from the context and status of the scientist who produced them
  - ★ Rationality will always lead to progress and perfection
    - ➢ All human institutions can be scientifically analyzed and improved
  - ★ Reason is the ultimate judge of what is right (true, legal, ethical,…)
  - ★ Language must be rational
    - ➢ It only exists to represent the real world;
    - ➢ There must be a firm, objective connection between the "signifier" and the "signified"
    - ➢ The meaning cannot depend on the audience

Postmodernism and Science

- Postmodernism
  - Questioning the grand narrative
    - A grand narrative is a story that a culture/society tells itself about it's practices and beliefs
    - E.g. in the US: "democracy is the most enlightened/rational form of government"
    - E.g. in science: "scientific truths are universal and eternal"
    - Postmodernism identifies and critiques such narratives
  - Instead, look for mini-narratives
    - Stories that explain small practices, local events, situated, contingent behavior
    - …and don't make any claims about universality, truth, or stability
  - E.g. Literary Deconstruction
    - Examine what a text does not say, what it represses
    - Reveal internal arbitrary hierarchies and dichotomies
  - E.g. Semiotics
    - The study of the relationship between signs and the things they signify

Philosophy of Behavioral Science

- 19th Century view of man as machine
  - Study how it works, not why
  - Detached curiosity akin to physics
  - Value judgments, good/bad, personal feelings have no place
  - Humans subject to mechanical laws
- Period of uncertainty
  - Loss of great hope: certainty
- Change in outlook
  - Experimental work of *artifact* researchers helped to change the face of much of behavioral science
  - View of laws of human behavior as socio-culturally and temporally pluralistic
  - Change is a given, a reflection of the inherent complexity and open-ended nature of ongoing active events and their contexts

Philosophy of Behavioral Science

- Current new position and ideas
  - Active, intentional nature of much of human behavior
  - People are continuously engaged in the reconstruction of knowledge
  - Researchers are active participants, not detached
  - Multiple methods to uncover process-like, intentional nature of cognition and behavior
  - Human phenomena acquire meaning as part of a wider socio-historical context

Contextualism

- SC Pepper, *World Hypotheses: A Study of Evidence, Berkeley: UC Press, 1942*
  - Named Contextualism
  - Human events are active, dynamic, developmental moments of a continuously changing reality
  - Knowledge is embedded in an evolving context of time, space, culture and the local tacit rules of conduct
  - The context of explanation is an integral part of both what is explained and how it is explained
  - The scientific enterprise is a part of an evolving socio-historic context
  - Analogy: a boat being reconstructed at sea, one board at a time
- Contextualism: Attractive to behavioral scientists
  - Interpreted as advocating methodological and theoretical pluralism
  - Every method or theory is limited – fallible - in some way
  - No single proper or complete or unlimited perspective on reality
  - Obliged to search for multiple routes, each at a different level of analysis

Behavioral Sciences

- Umbrella concepts for fields traditionally grouped together
  - ★ Behavior of people in various contexts
  - ★ Differences in these various contexts
- Traditional areas
  - ★ Cultural anthropology: most macro, societal systems
  - ★ Sociology: macro, relationships among groups
  - ★ Social psychology: micro, interpersonal behavior
  - ★ Personal psychology: most micro, traits, dispositions
- Traditional differences in tactics
  - ★ Sociologists use questionnaires and survey sampling procedures
  - ★ Social psychologists prefer controlled experiments
  - ★ Borrowed from each other

Behavioral Sciences

- Current trend – more multiplistic
  - Multiple methods of observation, explanation
  - Interdisciplinary, more ecumenical
  - New fields from combining methods/theories
- Not *methodological behaviorism*
  - Not pure empiricism confined only to fully observable
  - Allows cognitive functioning as legitimate
  - Liberalizes what is analyzable
- Methods differ but goals are the same
  - To describe and explain
    - How and why people think the way the do
    - How and why they feel and think about things

What is Engineering?

- **Traditional View:**

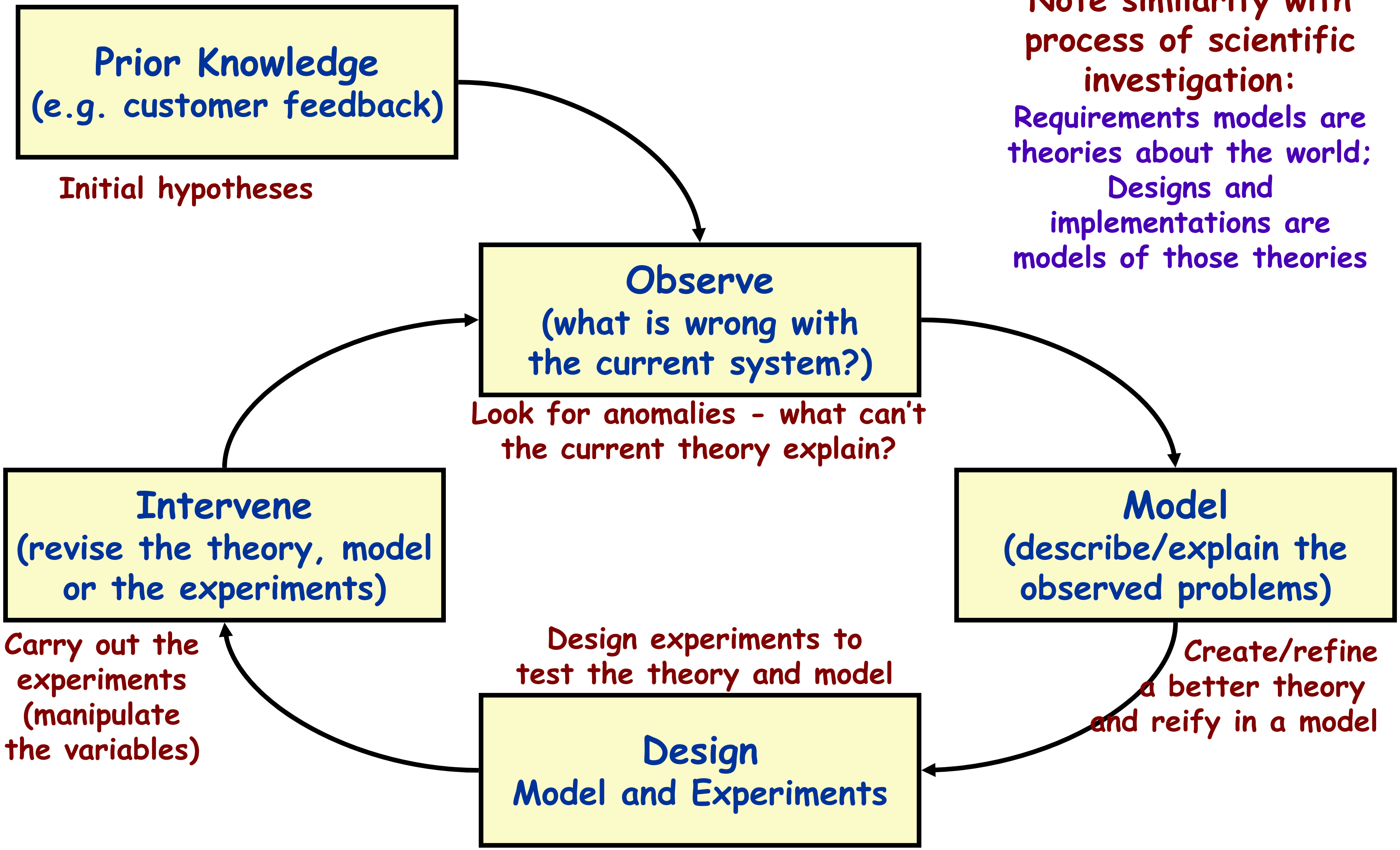
Scientists…	Engineers…
create knowledge	apply that knowledge
study the world as it is	seek to change the world
are trained in scientific method	are trained in engineering design
use explicit knowledge	use tacit knowledge
are thinkers	are doers

- **More realistic View**

Scientists…	Engineers…
create knowledge	create knowledge
are problem-driven	are problem-driven
seek to understand and explain	seek to understand and explain
design experiments to test theories	design devices to test theories
prefer abstract knowledge	prefer contingent knowledge
but rely on tacit knowledge	but rely on tacit knowledge

Both involve a mix of design and discovery

Inquiry Cycle

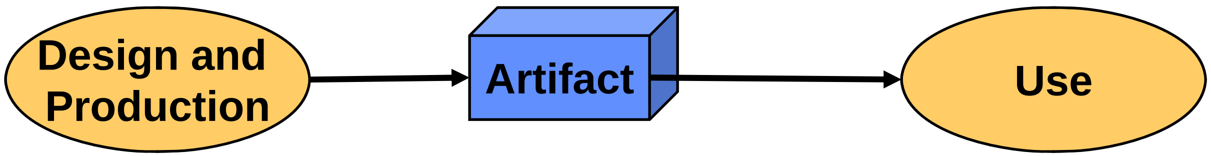


Note similarity with process of scientific investigation:

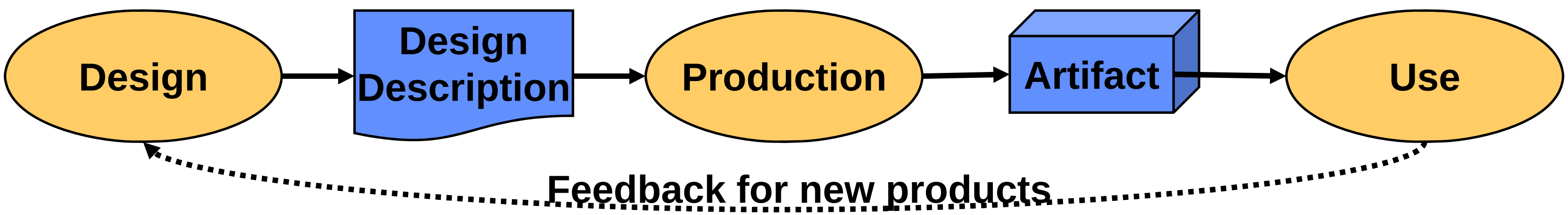
Requirements models are theories about the world; Designs and implementations are models of those theories

What is (Software) Design?

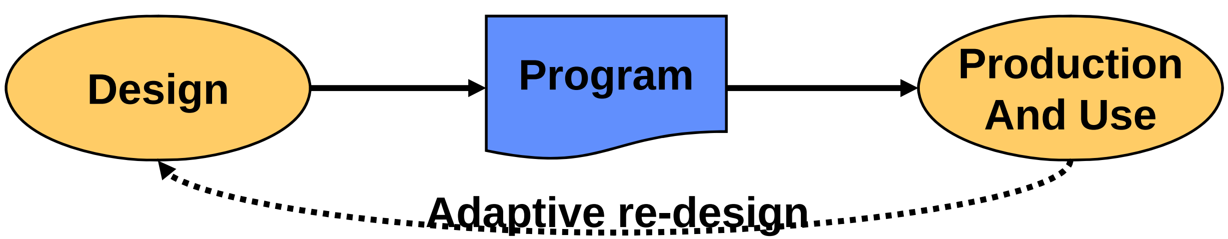
Pre-industrial design:



Industrial design:



Software Design:



Normal vs Radical design

- Normal design:
  - Old problems, whose solutions are well known
    - Engineering codifies standard solutions
    - Engineer selects appropriate methods and technologies
  - Design focuses on well understood devices
    - Devices can be studies independent of context
    - Differences between the mathematical model and the reality are minimal
- Radical design:
  - Never been done, or past solutions have failed
    - Often the challenge is to deal with a very complex problem
  - Bring together complex assemblies of devices into new systems
    - Such systems are not amenable to reductionist theories
    - Such systems are often soft: no objective criteria for describing the system
- Examples:
  - Most of Electrical Engineering involves normal design
  - All of Systems Engineering involves radical design (by definition!)
  - The part of S/W Eng concerned with human activities is radical design – what else?

SE Weltanschauung

- Software-intensive systems
  - software + hardware + human activity
    - the human activity gives a system its purpose
  - RE is about discovering that purpose
  - SE is about satisfying that purpose
- Continuous Change
  - Introduction of new system changes the human activity
  - People find new ways of using it
- Human Centered Development
  - Goal is to change human activities…
    - …to make them more effective, efficient, safe, enjoyable, etc.
  - …rather than to design a new computer system
- A Systems Perspective
  - Treat relevant parts of the world as systems with emergent properties
- Multi-disciplinary approach
  - Use whatever techniques seem useful
    - Social, cognitive, mathematical,…
- Design as Reflection
  - New designs arise in response to observed problems with existing ones
  - There is always an existing system!
- Form does not follow function
  - Because we only understand the function properly in hindsight
- Multiple Viewpoints
  - Many stakeholders
  - Each model presupposes a viewpoint
  - All models are imperfect
- Negotiation is central
  - Resolve conflicts between different stakeholders' goals
  - Manage customer's expectations

Analogs in SWE

- CS/SWE as empirical enquiry
  - CS: study of phenomena surrounding computers
  - SWE: study/practice of building software systems
- Both experimental, but have unique forms of observation, experience
  - CS/SWE: Building a new *machine* can be an experiment
    - Poses a question to nature
    - We observe and experience by
      - Watching machine in operation
      - Analyzing and measuring it
    - Design artifacts that can be opened up and observed
    - Relate structure to behavior and draw lessons
  - SWE: Various forms of testing are experiments to test the theory (requirements) and its model (implementation)
    - Independent and dependent variables
    - Manipulations
    - Data collection and analysis

Analogs in SWE

- SWE doubly rich
  - Machines/systems execute programs/processes
  - People designing machines
  - People using machines
  - Processes are analogous to machines
    - People use processes
    - People execute processes
- Technology
  - Anthropology: families of systems, collections of systems
  - Sociology: systems in context
    - Relationships among systems
    - Centralized, distributed, networked
  - Social psychology: individual systems
    - component interaction
  - Personal psychology: individual systems
    - Characteristics

Analogs in SWE

- People and processes
  - Anthropology: projects and organizations
  - Sociology: interactions among teams, projects, etc
  - Social psychology: interactions
    - People in teams
    - People and technology
  - Personal psychology: traits, dispositions
    - Of developers and managers etc