Introduction to Cybernetics and the Design of Systems

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Cybernetics named

From Greek ‘kubernetes’
— same root as ‘steering’
— becomes ‘governor’ in Latin
Steering

to course set

wind or tide
Steering

course set

wind or tide
Steering

course set

wind or tide
Steering

course set

correction of error

wind or tide
Steering

course set

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wind or tide
Cybernetics named

From Greek ‘kubernetes’
  — same root as ‘steering’
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Cybernetic point-of-view
  - system has goal
  - system acts, aims toward the goal
  - environment affects aim
  - information returns to system — ‘feedback’
  - system measures difference between state and goal
    — detects ‘error’
  - system corrects action to aim toward goal
  - repeat
Steering as a feedback loop

- compares heading with goal of reaching port
- adjusts rudder to correct heading
- ship's heading
Steering as a feedback loop

- Detection of error
  compares heading with goal of reaching port

- Feedback
  adjusts rudder to correct heading

- Ship’s heading
  correction of error
Automation of feedback

thermostat

heater

temperature of room air
Automation of feedback

Thermostat compares to setpoint and, if below, activates heater raises temperature of room air measured by thermostat.
The feedback loop

‘Cybernetics introduces for the first time — and not only by saying it, but methodologically — the notion of circularity, circular causal systems.’

— Heinz von Foerster
Cybernetic terms

- Comparator with a goal
- Sensor
- Effector

System

Feedback

Environment
Cybernetic modeling

system  
feedback  
environment

→ measurement → action

goal  
effect

‘through-looping’
Cybernetics early uses

‘Cybernetics saves the souls, bodies, and material possessions from the gravest dangers.’
— *Socrates according to Plato*

‘The future science of government should be called “la cybernetique.”’
— *André-Marie Ampere, 1843*

‘Until recently, there was no existing word for this complex of ideas, and…I felt constrained to invent one....’
— *Norbert Wiener*
Requisite variety defined

Yes or No—

Does the system possess sufficient variety to regulate its environment and maintain its goal?
Requisite variety—effectors

Sufficient variety?

- What are the parameters in the environment that the system can effect?

- Within what range of those parameters can the system maintain control?
Requisite variety—sensors

Sufficient variety?
- Is there sensing of environment such that deviations from goal can be detected?
- Do the sensors have sufficient resolution & speed so that the system can respond in time?
But who defines ‘system’?

system

environment
(also a system)
But who defines ‘system’?
The introduction of subjectivity

1st-order cybernetics

observed system
The introduction of subjectivity

2nd-order cybernetics

1st-order cybernetics

observing system

observed system
Observing the observer

![Diagram showing the relationship between an observing system and an observed system, with arrows indicating interactions and feedback loops.](image-url)
Observing conversations

observing system  \( e \leftarrow \rightarrow \rightarrow \rightarrow e \) observing system
Conversations about conversations
Defining ‘interaction’

A’s goals

A’s actions

B’s goals

B’s interpretations

B compares B’s goals to A’s actions
Defining ‘relationship’

A’s goals

A’s interpretations

B’s goals

B’s actions

A’s model of B’s goals
Defining ‘conversation’

immaterial aspects

physical world

goals

actions

goals

actions
Domain of cybernetic modeling

Includes goals — the ‘why’ of actions as well as ‘how’
- Systems are defined by boundaries
- Systems have goal(s)
- Information flow from the environment to the system relevant to achieving a goal defines ‘feedback’

Goals bound to actions, actions bound to goals — ‘through-looping’

Systems as abstractions
- Not about what a system is made of
- Not delimited by subject domain or discipline or distinctions such as biological, physical, ecological, psychological, or social
Goals of cybernetic modeling

See causality as a loop
   - Shift from hierarchy of power to participation in shared goals
Place actions in the context of goals
Understand what is possible for a system
   - Possibilities are defined by ‘requisite variety’ (RV)
   - RV enables the design of changes to the system to improve it
Measure the degree of mutual understanding
   - Define ‘conversation’, ‘agreement’
Define and realize ‘intelligent systems’
Discuss participation, choice, ethics
Scope of cybernetics

Explanation of communication = psychology
Modeling of learning = cognitive science
Limits of knowing = epistemology
Hearer makes the meaning = post-modernism
Reality as social construction = constructivism
Reliable methodologies of describing = science

Measuring understanding & agreement
= science of subjectivity
= second-order cybernetics
Cybernetics quoted

‘…communication and control in animal and machine’
  — Norbert Wiener

‘… the science of observing systems’
  — Heinz von Foerster

‘… the art of defensible metaphors’
  — Gordon Pask

‘… the study of the immaterial aspects of systems’
  — W. Ross Ashby

‘… only practiced in Russia and other under-developed countries’
  — Marvin Minsky
de dormir, de travail, la vie quotidienne est plus concrète, immédiate et centaine de stratégies.

Le pouvoir de l'homme et sa complexité, les messages qui mettent en jeu, constitue une

Les découvertes des physiques des vieux Prométhée qu'il appelle science, il trouve sa mythes et celui de Frankenstei et van Ke quelquefois nouvelle se l'on peut de la cyb-

Fig. 2. Cybernétique, science-carrefour.

Electronique

Machine à programmer

Machine à calculer

Régulateurs

Technologie des machines

Productivité

Economie politique

Sociologie

Physiologie nerveuse

Psychologie et Génétique

Linguistique Automates

Théorie de l'Information

Communications

Mécanique

Psychologie

CYBERNÉTIQUE

Qu'est-ce que

La cybernétique est une science de l'information, de la communication, et de la régulation. Son nom platonicien
Cybernetics summarized
Appendix

A brief history of Cybernetics and Systems Design
Early self-regulating systems (non-biological)

~300 BC, Ktesibios, Alexandria credited with inventing a water clock with a self-regulating water supply

~200 BC, Heron, Alexandria invented an inexhaustible goblet, wrote *The Pneumatica*

~1588, Mill-hopper, UK, regulated flow of grain

~1620, Cornelis Drebbel, Holland, invented a float-based thermostat

~1745, E. Lee, fantail pointed windmill into wind
Modern self-regulating systems

1788, James Watt patented the fly-ball governor
1868, James C Maxwell paper: *On Governors*
1883, Warren Johnson, Milwaukee, patented thermostat (company became Johnson Controls)
1885, Albert Butz patented “damper flapper” (company became Honeywell)
1922, Nicholas Minorsky: *Directional Stability of Automatically Steered Bodies*
GE and Sperry Gyroscope built auto-pilots
1934, Harold Hazen: *Theory of Servo-Mechanisms*
Systems design has its origins right before and during WWII

Cybernetics
- Neuro-systems research
- Anti-aircraft fire control

Operations Research (OR)
- Radar and air force fighter system integration
- Submarine air-patrol resource allocation
- Representation of real-world systems by mathematical models with a view to optimizing outcomes

After the war, OR leads to Systems Analysis
- Later, management science; also management cybernetics
Post-war development

1946, RAND founded in Santa Monica
1951, MIT founds Lincoln Lab to develop SAGE air defense system; MITRE founded to run project
1952, Herbert Simon spends summer at RAND
1955, Ramo-Woolridge (later TRW) awarded contract as overall systems manager for Atlas and Titan missile projects
1969, Ramo: *Cure of Chaos: Fresh Solutions to Social Problems through the Systems Approach*
McCulloch, Pitts, Shannon, and Wiener on faculty
Vannevar Bush, Dean of Engineering, was also President Roosevelt’s Science Advisor
Servo Lab
Radiation Lab
George Valley, Air Defense System Engineering Committee, Project SAGE
Lincoln Lab
Negroponte, Architecture Machine Group
MITRE Corporation (MIT Research & Engineering)
Trans-disciplinary conversation
Macy meetings 1946-1953

Wiener & von Neumann . . . mathematics
Bateson & Mead . . . anthropology
Warren McCulloch . . . neurophysiology
Conrad Lorenz . . . psychology
Heinz von Foerster . . . physics
. . .

Conference Subtitle —
‘Circular Causal and Feedback Mechanisms in Biological and Social Systems’
Related publications (selected)

1943, Bigelow, Rosenbleuth, & Wiener: *Behavior, Purpose, and Teleology*
1943, McCulloch & Pitts: *A Logical Calculus of the Ideas in Nervous Activity*
1948, Wiener: *Cybernetics*
1949, Shannon & Weaver: *Mathematical Model of Communications*
1952, Ashby: *Design for the Brain*
1956, Ashby: *An Introduction to Cybernetics*
1961, Pask: *An Approach to Cybernetics*
Cybernetics construed — Norbert Wiener’s 1948 subtitle
communication and control
in
animal and machine

1st-order cybernetics
Cybernetics intended

to study communication and control in animal and machine communication and regulation in goal-directed systems, whether organic or constructed

1st-order cybernetics
Cybernetics evolved —
Heinz von Foerster, Gordon Pask, c.1960s

communication and regulation → language and agreement
in
goal-directed systems, whether organic or constructed
in
linguistic, goal-directed systems, whether organic or constructed

science of observed systems → 2nd-order cybernetics → science of observing systems
HfG Ulm

1953 to 1968, Hochschule für Gestaltung
Wiener, Heidegger, visit and lecture
Fuller, Eames, Bayer, et al. visit
Archer, Rittel on faculty
1962, American design school leaders visit
1966, British design school leaders visit
Classes offered in operations research, cybernetics, and semiotics
Design Methods Movement

1962, conference in London
1962, Rittel leaves Ulm for UC Berkeley
1965, conference in Birmingham
1966, Design Methods group formed at Waterloo
1968, conference in Cambridge, Mass
1971, conference at CalTech
1974, conference at Columbia
Related publications (selected)

1962, Alexander: *Notes on the Synthesis of Form*
1962, Englebart: *Augmenting Human Intellect*
1964, Rittel: *Universe of Design*
1964, Archer: *Systematic Methods for Designers*
1967, Papanek: *Design for the Real World*
1968, Brand: *Whole Earth Catalog*
1970, Jones: *Design Methods*
1972, Negroponte: *Soft Architecture Machine*
1973, Koberg & Bagnal: *Universal Traveler*
Reactions (selected)

1968, City government forces HfG Ulm to close
1972, Churchman and Hoos: *Critiques*
1972, Rittel: *Dilemmas*
1973, Venturi et al.: *Learning from Las Vegas*
Alexander and Jones express concerns
Analogs to cybernetics

Disciplines relying on feedback processes:
Refining and clarifying goals = design

Understanding customer needs = consultative selling
Organizing evidence to support conclusions = law
Directing and measuring work = management
Diagnosing treatments based on symptoms = medicine
Specifying appropriate physical systems = engineering
When a cybernetic framework is appropriate for design

context of use
meaning/structure
form/grammar
When a cybernetic framework is appropriate for design

context of use
meaning/structure
form/grammar

object | system
When a cybernetic framework is appropriate for design

context of use
meaning/structure
form/grammar

object | system
static    dynamic
When a cybernetic framework is appropriate for design

context of use
meaning/structure
form/grammar

object system

static dynamic

1st order 2nd order
When a cybernetic framework is appropriate for design

- Context of use
  - Individual
  - Intuitive
  - Idiosyncratic

- Meaning/structure
  - Team
  - Explicit
  - Shared

- Form/grammar
  - Object
  - System
  - Static
  - Dynamic
  - 1st order
  - 2nd order
The design of goals: ‘how’ problems and ‘what’ problems

In maximization problems . . .

one is attempting to optimize a clearly definable objective function; the solution is embodied in the available data, if they are used correctly.

In choice-of-objectives problems . . .

the fundamental question is the selection of the appropriate mix of goals. The data suggest no solution in themselves.

– James Schlesinger