Black Boxes & White Noise

The Evolution of Automatic Control

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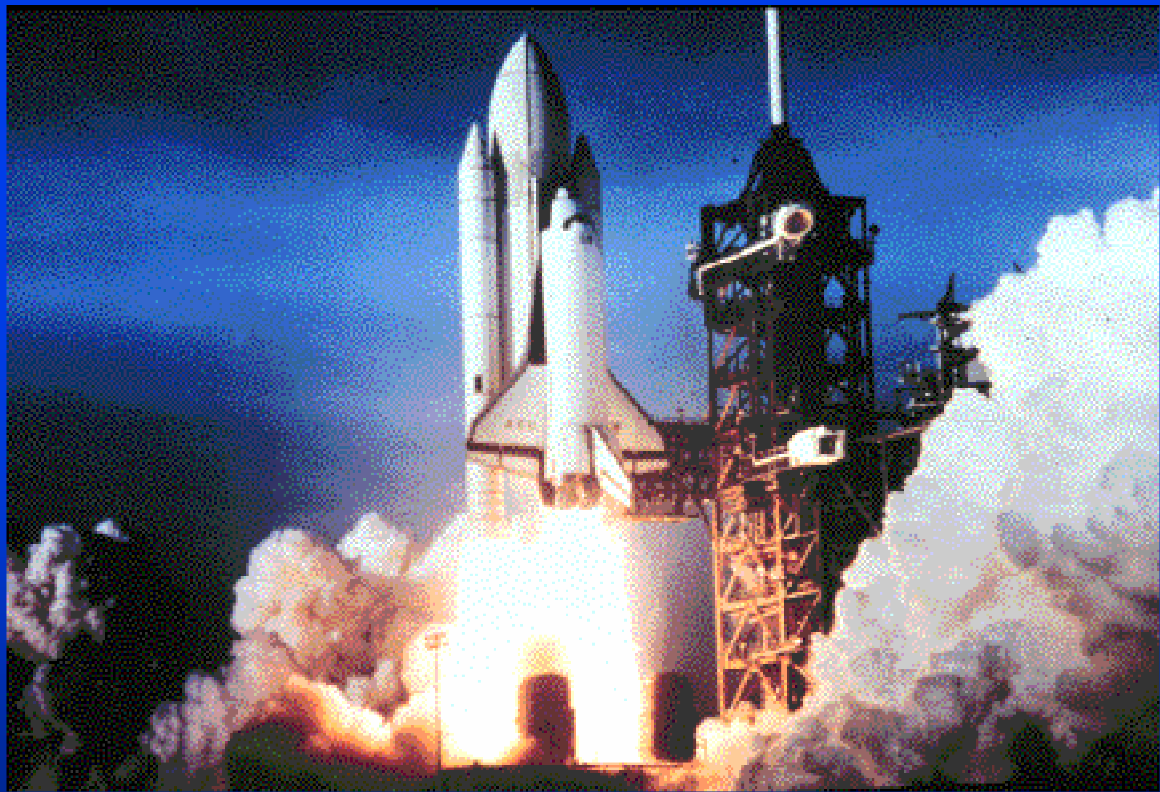
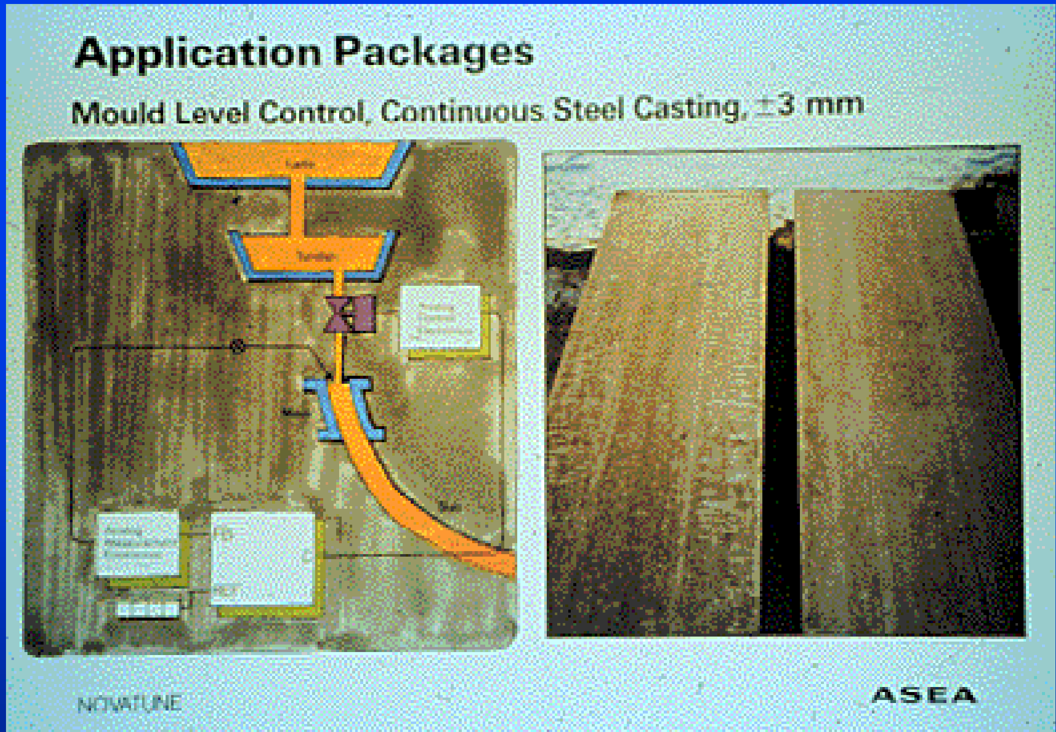
1. Introduction
2. Early Ideas
3. A Discipline Emerges
4. The Second Wave
5. Conclusions

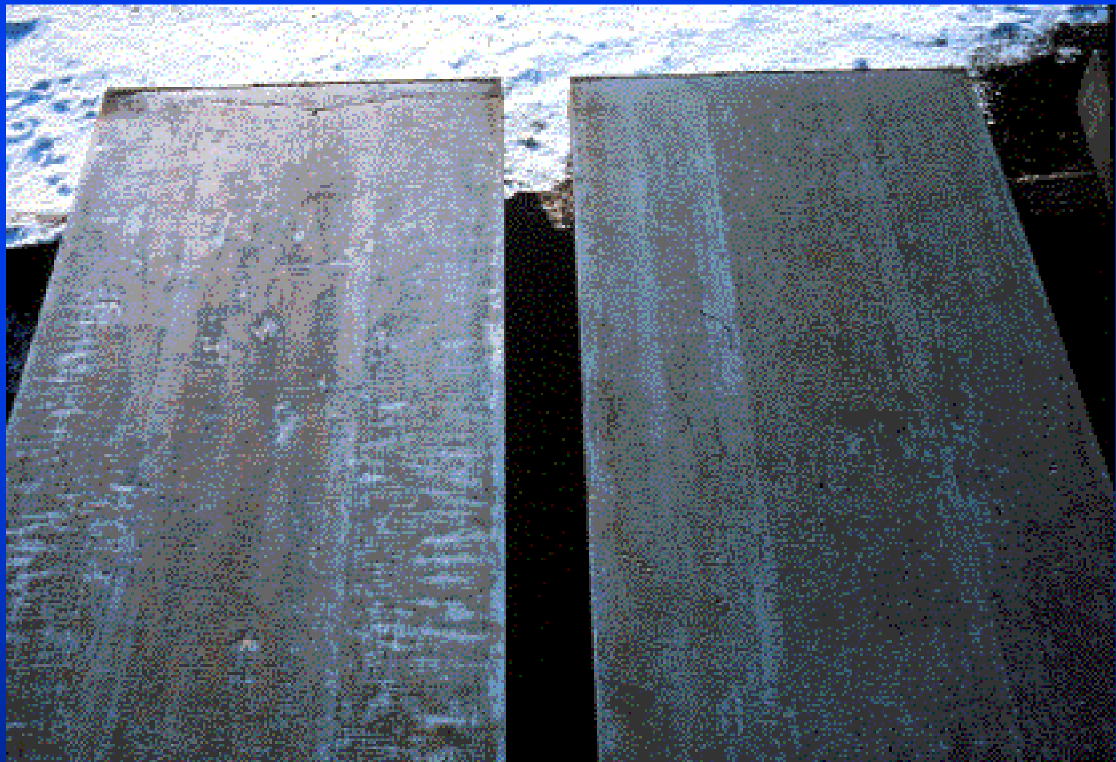


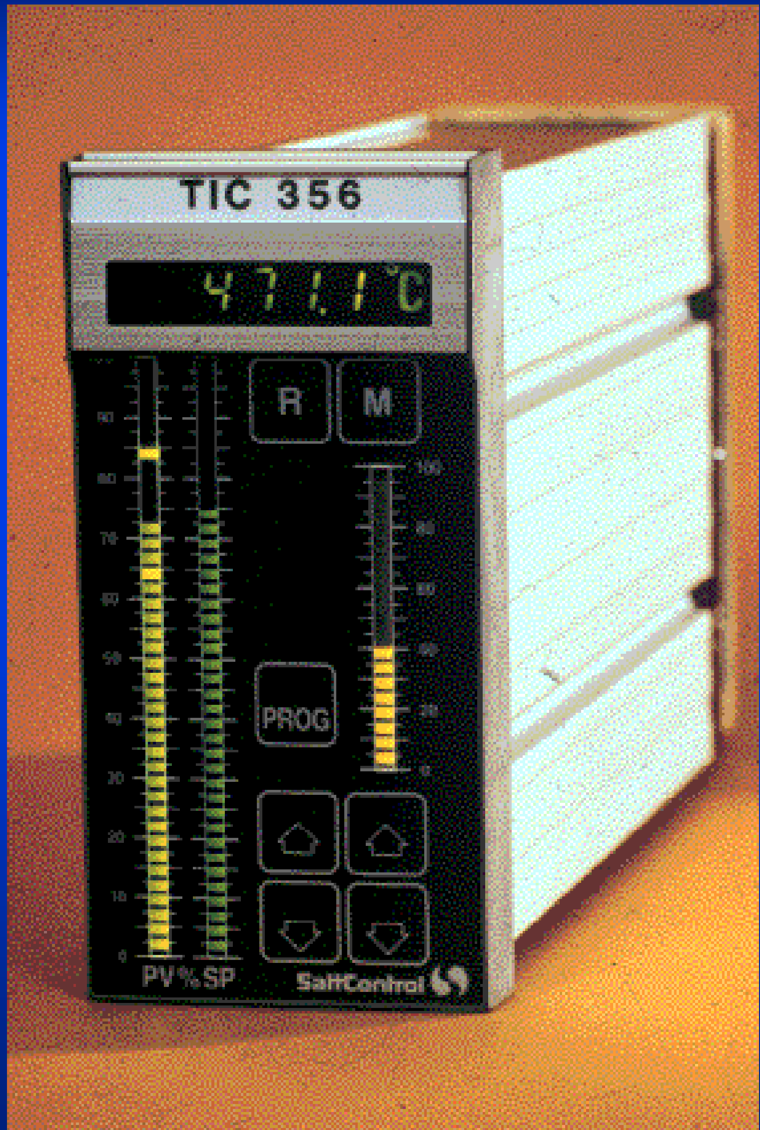

34
39
3ZJ

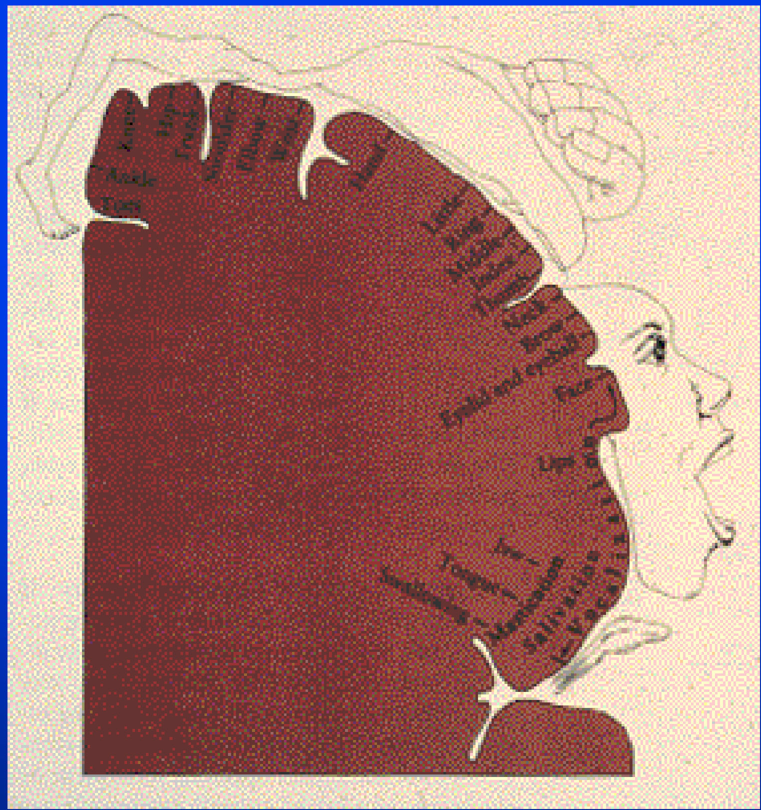

SONY
48x
DIGITAL ZOOM
SteadyShot
Handycam
Video 8

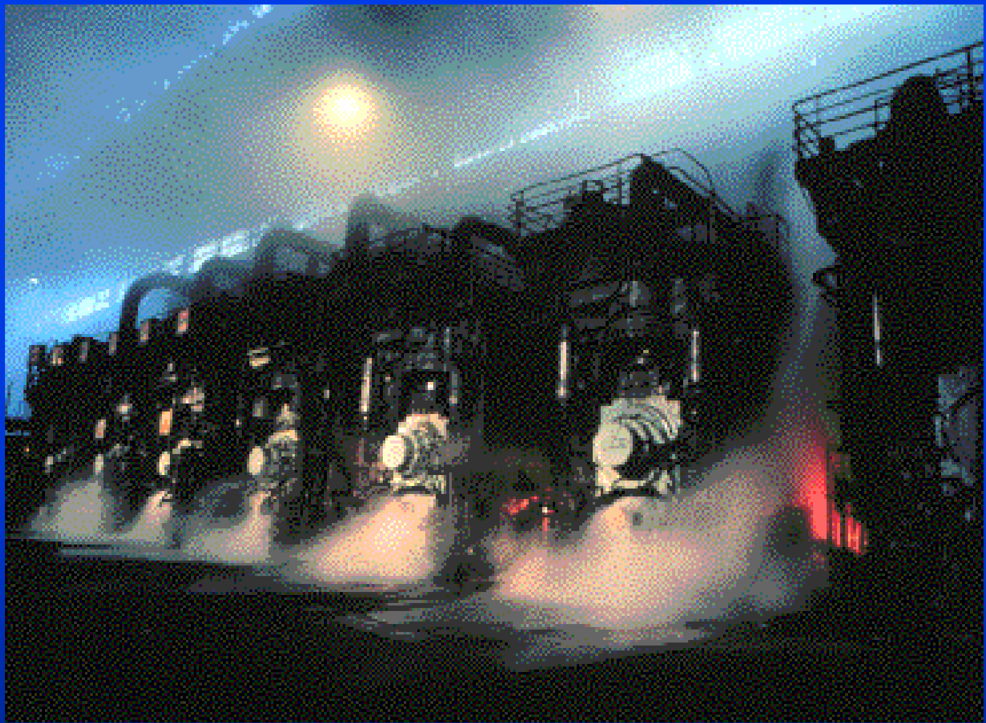

SEA STRATUS

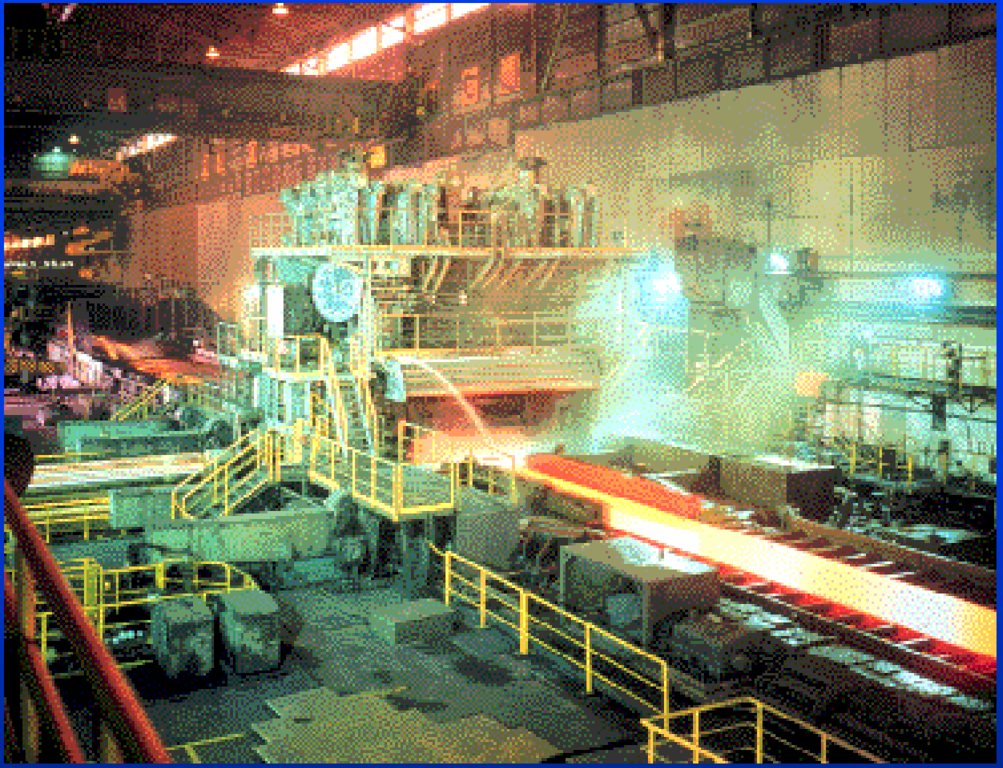

Application Packages
Mould Level Control, Continuous Steel Casting, ±3 mm
NOVATUNE
ASEA

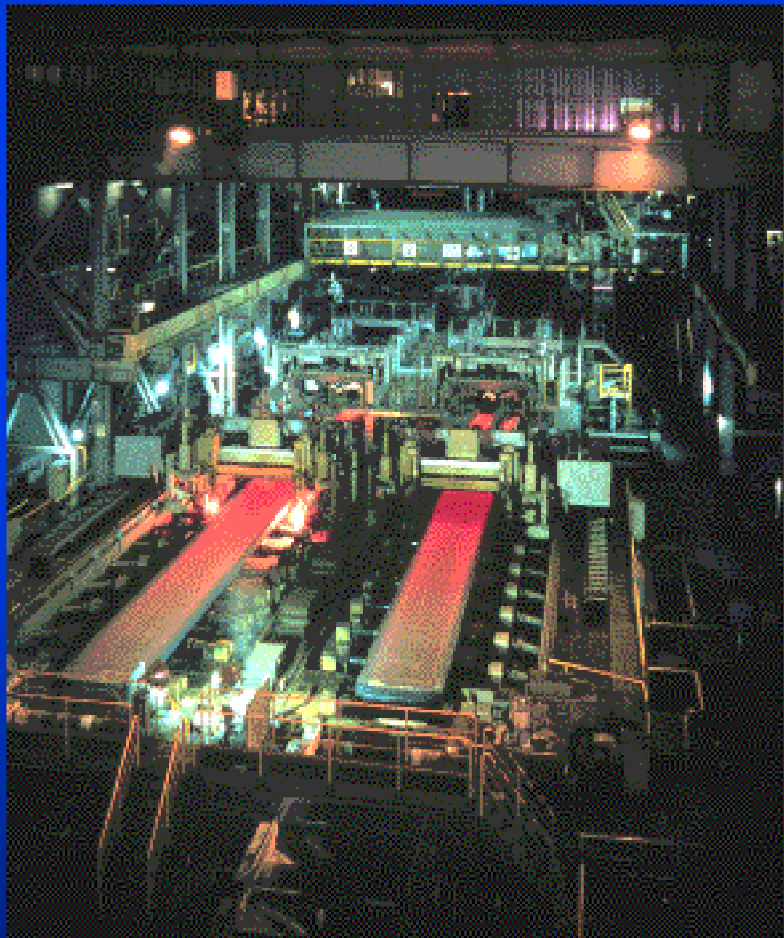



TIC 356
471.1 °C
R
M
PROG
PV % SP
SattControl


Ankle
Toes
Face
Lips







Natural Science and Engineering Science

Many similarities but also differencies

Natural Phenomena

Analysis

Isolate phenomena

Simplicity

Basic laws

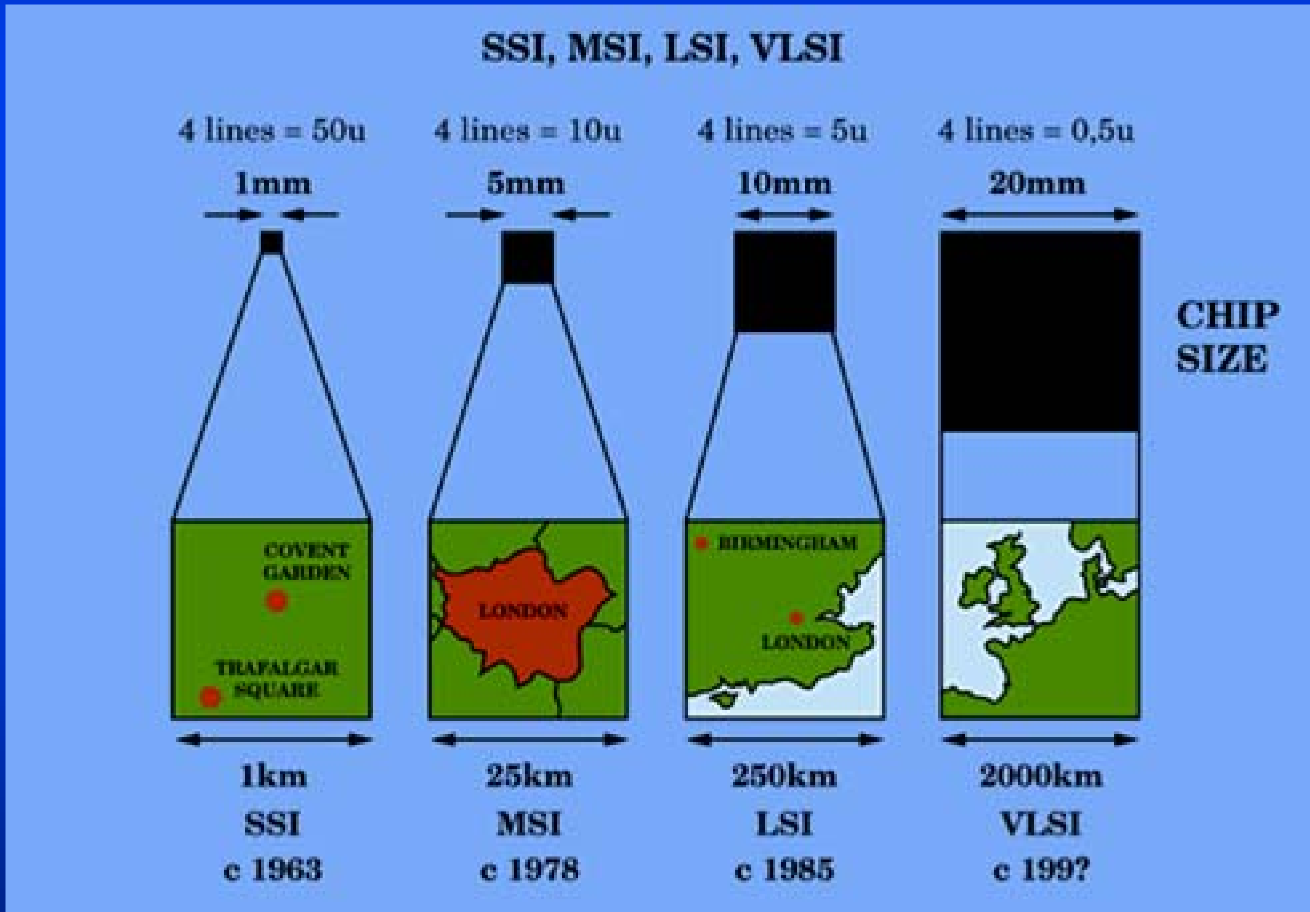
Technical Systems

Synthesis

Interaction

Complexity

System principles


SSI, MSI, LSI, VLSI
4 lines = 50u
1mm
4 lines = 10u
5mm
4 lines = 5u
10mm
4 lines = 0,5u
20mm
CHIP SIZE
COVENT GARDEN
TRAFALGAR SQUARE
LONDON
BIRMINGHAM
LONDON
1km
SSI
c 1963
25km
MSI
c 1978
250km
LSI
c 1985
2000km
VLSI
c 199?

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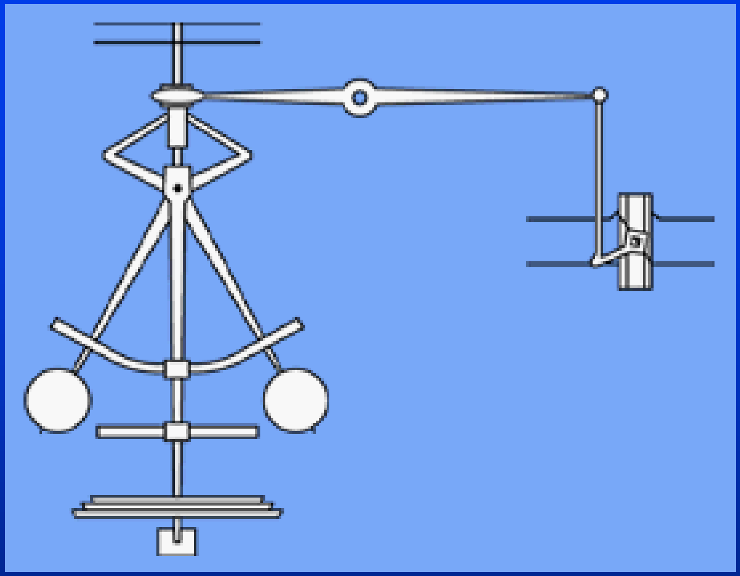
Industrial Process Control

Windmills Mead	1787
Steam engines	
Watt, Boulton	1788
Maxwell	1868
Routh	1875
Water turbines	
Stodola	1893
Hurwitz	1895



Accuracy & Stability

PID Control

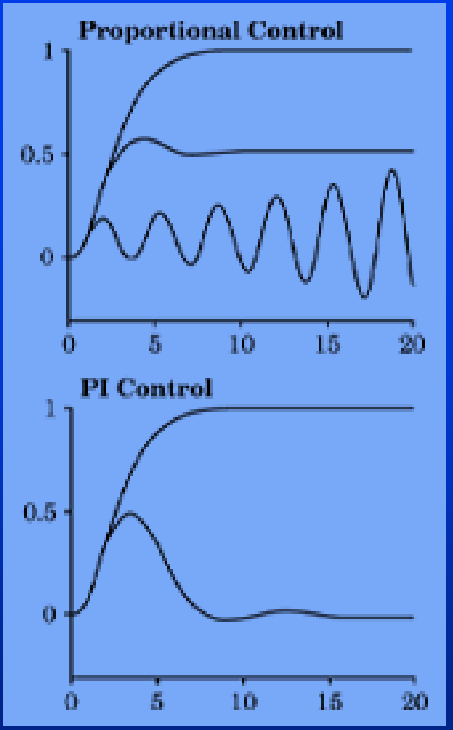
$$u(t) = k\left(e(t) + \frac{I}{T_i}\int_0^t e(s)\,ds + T_d\frac{de}{dt}\right)$$

Honeywell

Taylor Instrument

Leeds & Northrup

Foxboro



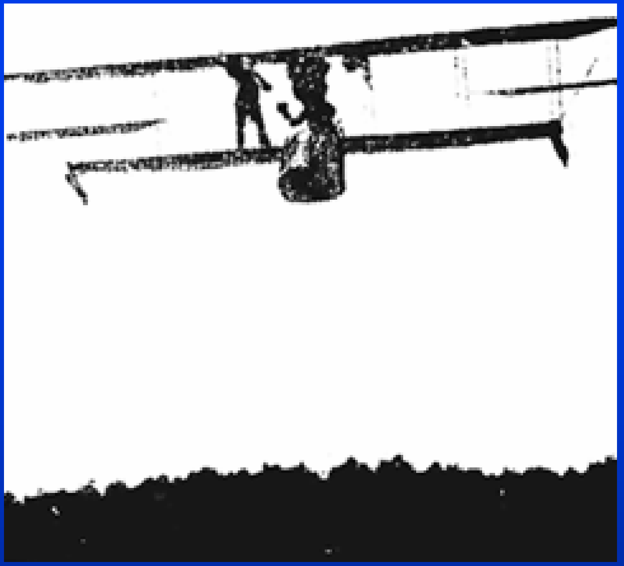
Flight Control

The Wright Brothers 1903

Sperry 1912

Fully Automatic
transatlantic flight 1947

Apollo 1969



Minorsky 1922

It is an old adage that a stable ship is difficult to steer.

Telecommunication

SYSTEM	DATE	CHANNELS PER PAIR	LOSS IN DB (3000 MI)	REPEATERS (3000 MI)
1st Transcontinental	1914	1	60	3–6
2nd Transcontinental	1923	1–4	150–400	6–20
Open Wire Carrier	1938	16	1000	40
Cable Carrier	1936	12	12000	200
First Coaxial	1941	480	30000	600

The Feedback Amplifier

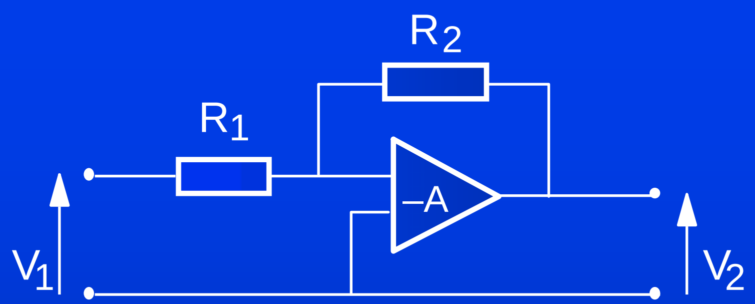
Black's patent 1928

Granted 1937

“Singing” = Instability

Nyquist 1932

Bode 1945
Network Analysis and
Feedback Amplifier Design



$$\frac{V_2}{V_1} = -\frac{R_2}{R_1} \cdot \frac{1}{1 + \frac{1}{A}\left(1 + \frac{R_2}{R_1}\right)}$$

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A Discipline Emerges

Industrial Process Control
Telecommunications
Flight Control
Mathematics

→

Principles
Theory
Design Methodology
Applications

War Pressures

National Defense Research Committee

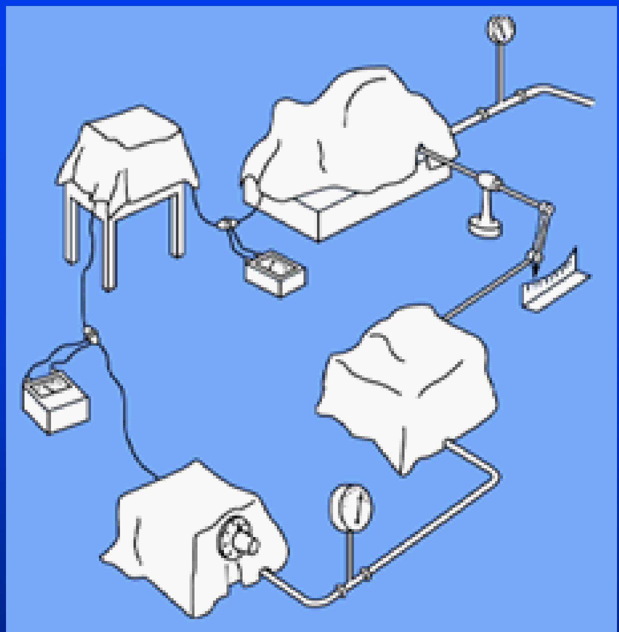
MIT Radiation Laboratory

MIT Servomechanism Laboratory

MIT Instrumentation Laboratory

MIT Lincoln Laboratory

The Black Box Concept

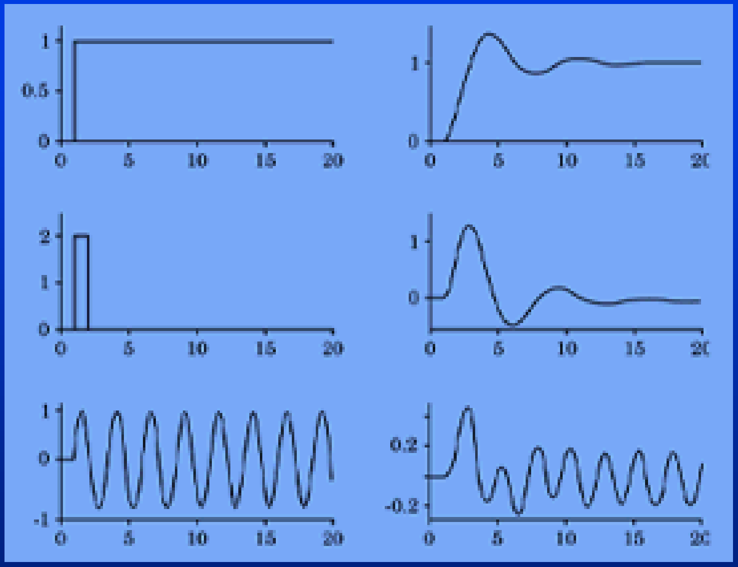


Abstraction

Information hiding

The Black Box View of Dynamical System

Input Output



Linearity

Superposition

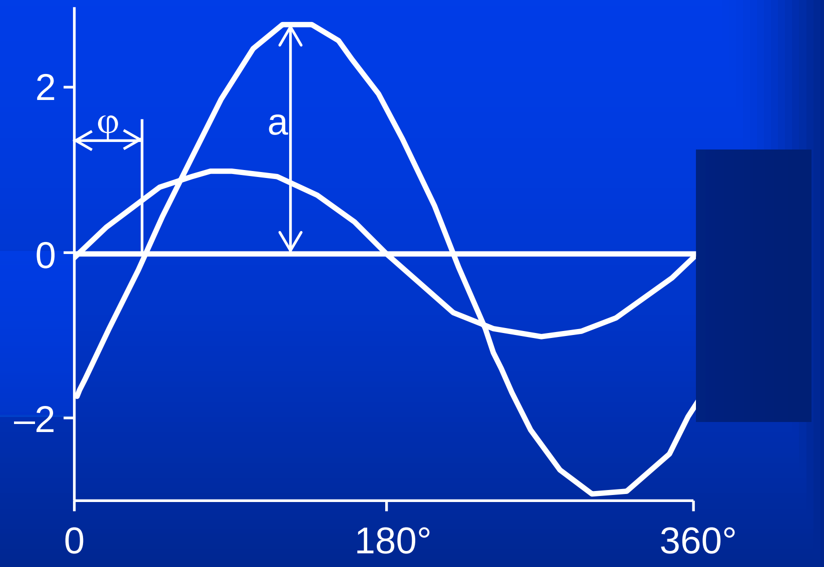
Sinusoids

One pair sufficies

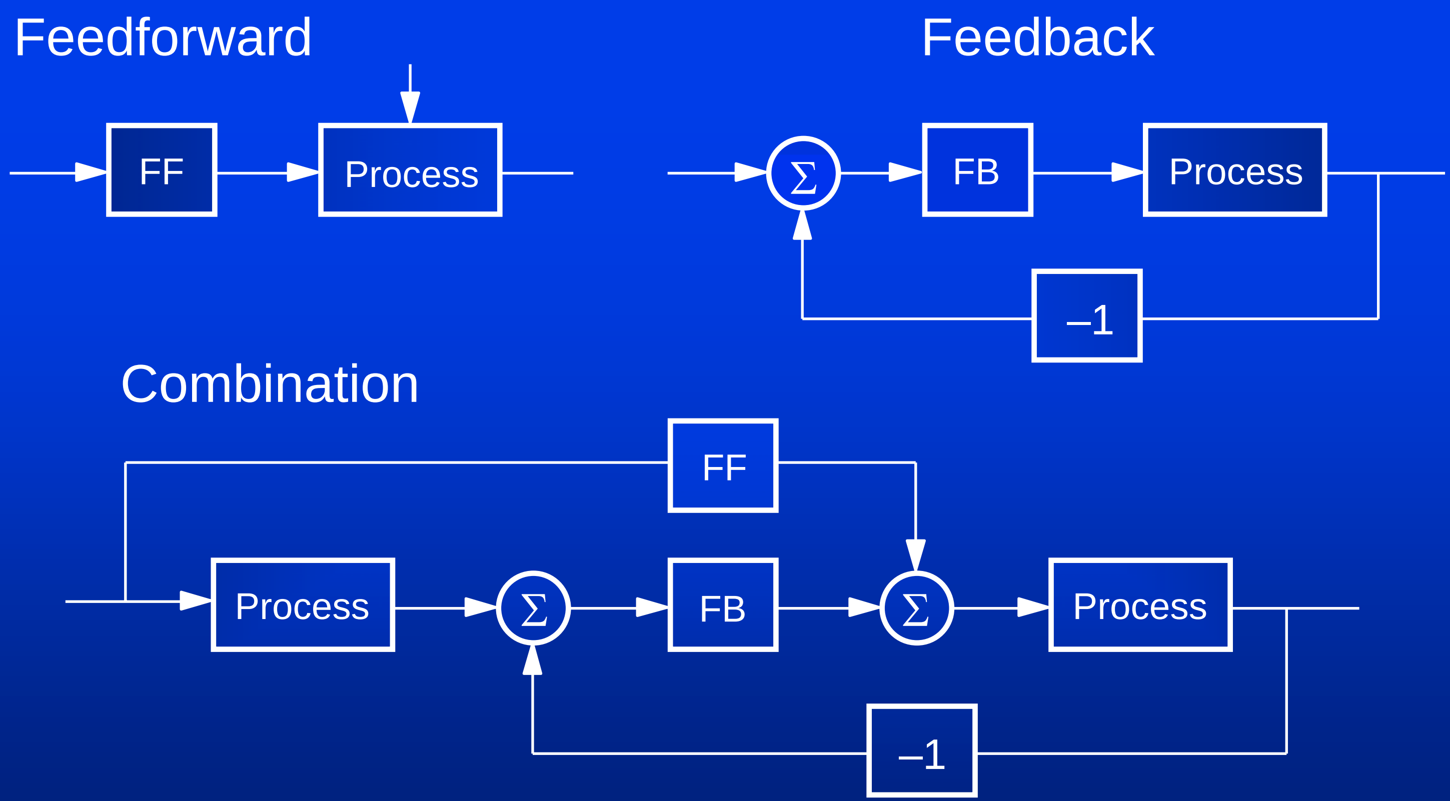
The Notion of Transfer Function

$$G(s) = \int_0^\infty e^{-st} g(t)\,dt = \mathcal{L}(g)$$

$$G(s) = \frac{\mathcal{L}\{y\}}{\mathcal{L}\{u\}}$$



System Principles



Two Paradigms

Feedback	Feedforward
Open loop	Closed loop
Acts only on deviations	Act before deviations occur
Market driven	Planning
Unmeasurable disturbance	Measurable disturbance
Less accurate model	Accurate model

Servomechanism Theory

Foundations
- Complex variables
- Laplace transforms

System Concepts
- Feedback
- Feedforward

Design methodology
- Frequency response
- Graphical methods

Analog simulation

Implementation

Consequences

Education

Application

Industrialization

Organisation

Journals

Conferences

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The Second Wave

Feedback from applications

Challenging problems

New technology

New ideas

Key Elements

Reexamination of fundamentals

Vital interaction with other disciplines

Theory to match new technology

Two views of Dynamical Systems

External Description

Electrical engineering

Input/Output

Black Box

Internal descriptions

Mechanical Engineering

The notion of state

$$\frac{dx}{dt} = f(x,u)$$

$$y = g(x,u)$$

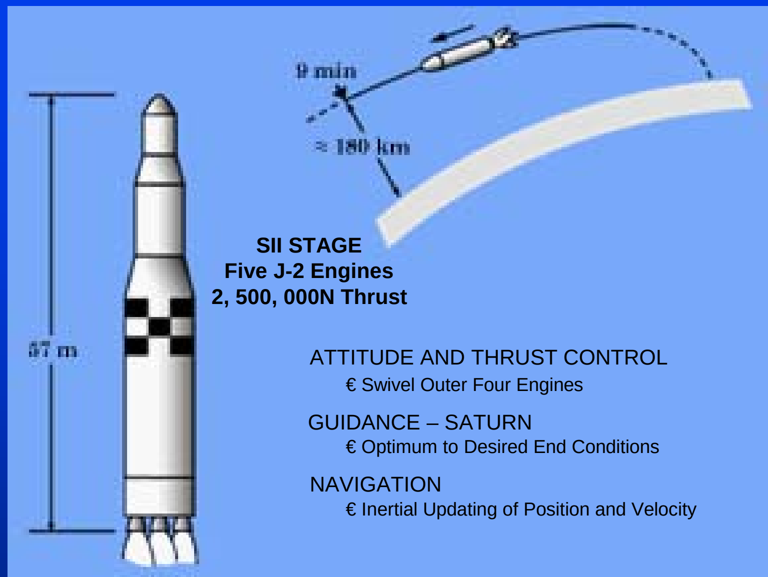
“Modern” Control Theory

Optimal control
Computer control
Stochastic control
Robust control

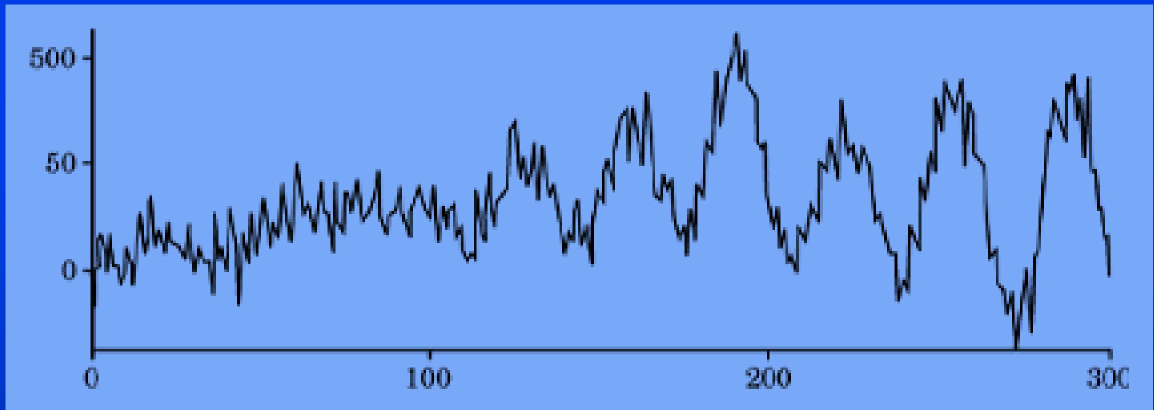
CACE
System identification
Adaptive control
Intelligent control

Optimal Control

Euler	1707–1783
Lagrange	1736–1813
Pontryagin	1962
Hamilton	1805–1865
Jacobi	1804–1851
Bellman	1957



Modeling Disturbances



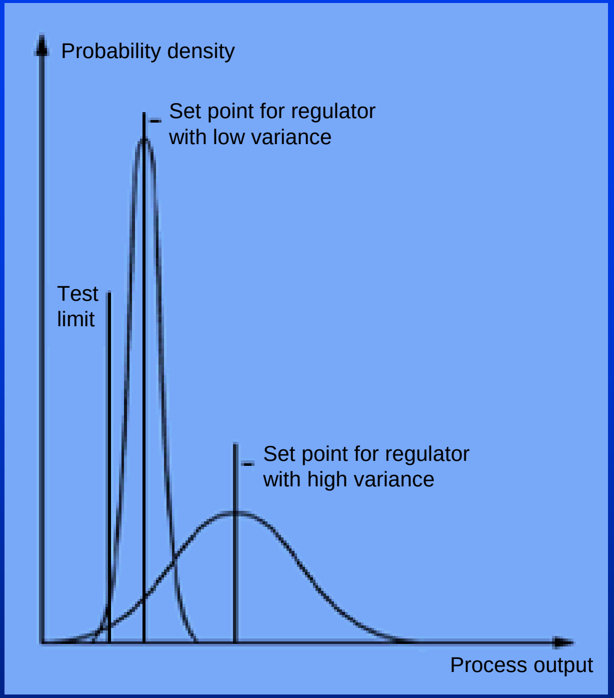
Power spectra

White noise

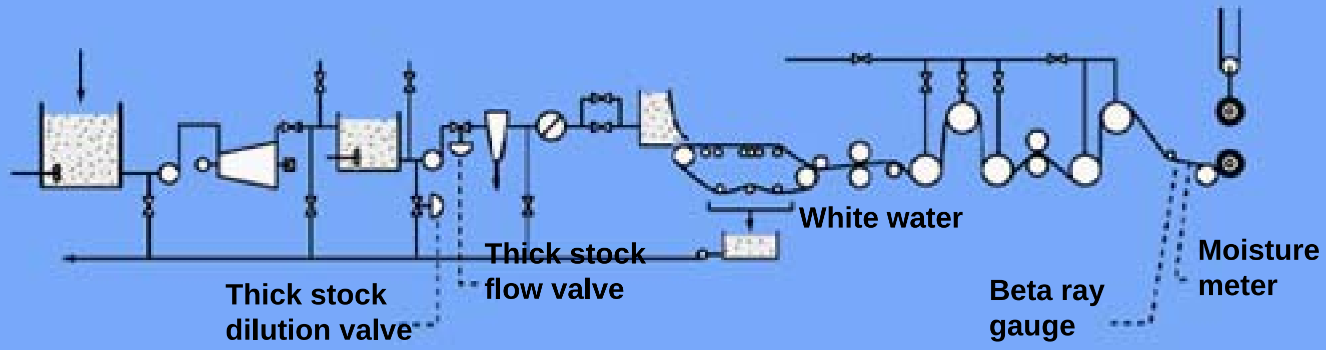
Innovations

Stochastic Control Theory

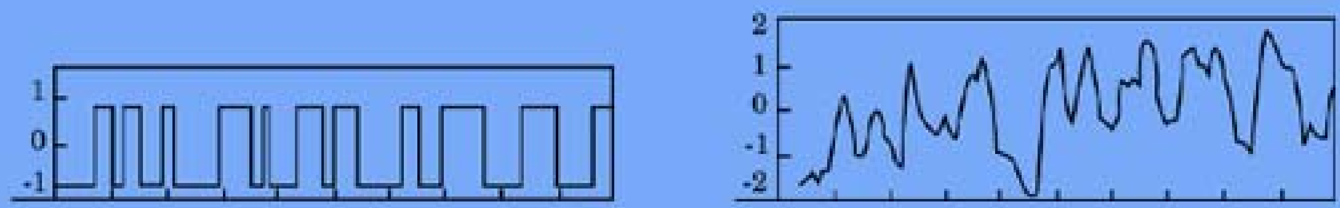
- Filtering and prediction
- Merger of calculus of variations and theory of random processes
- Decision making under uncertainty
- Industrial process control



System Identification

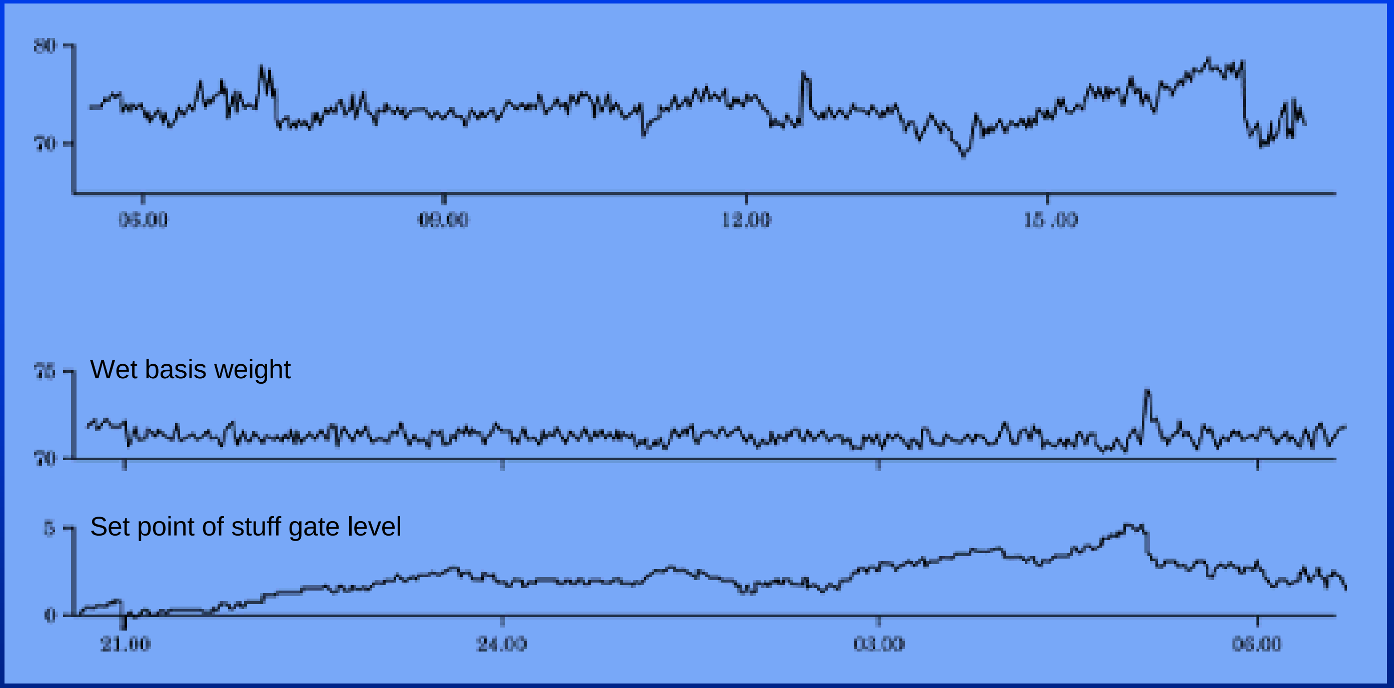


Simplified diagram of a kraft paper machine

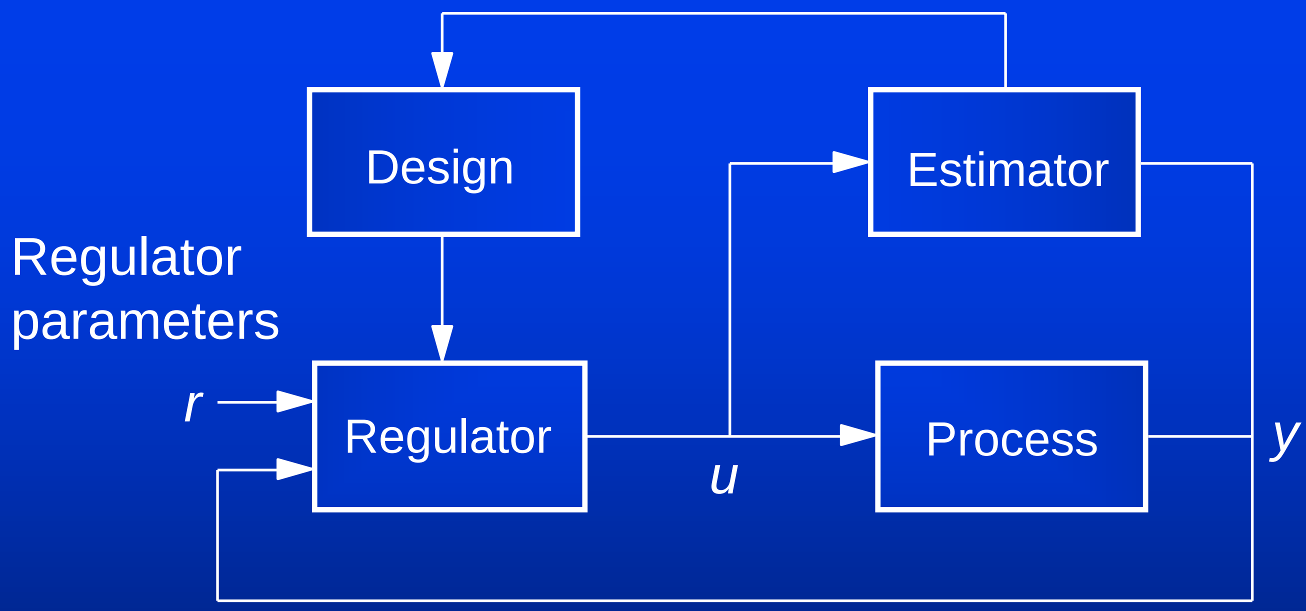


MODEL OF PROCESS DYNAMICS AND DISTURBANCES

Control of Basis Weight



Adaptive Control



Dual Control

- Control actions should be both directing and investigating
- Consequences for decision making decisions under uncertainty

Two Principles

Certainty Equivalence (H. Simon 1956)

Make the best estimate act as if it was true.

Dual Control

Control should be investigating as well as directing.

Computer Aided Control Engineering

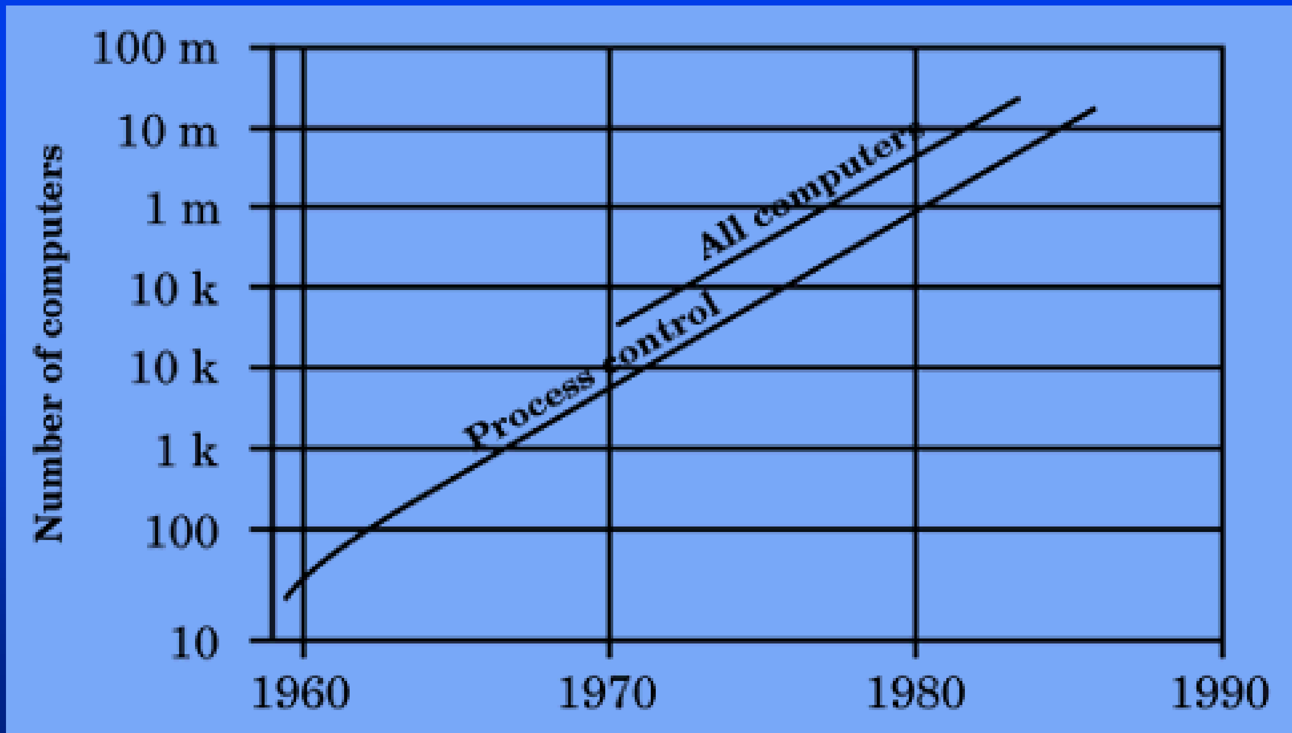
How to disseminate complicated technology?

Conceptual simplicity computational sophistication

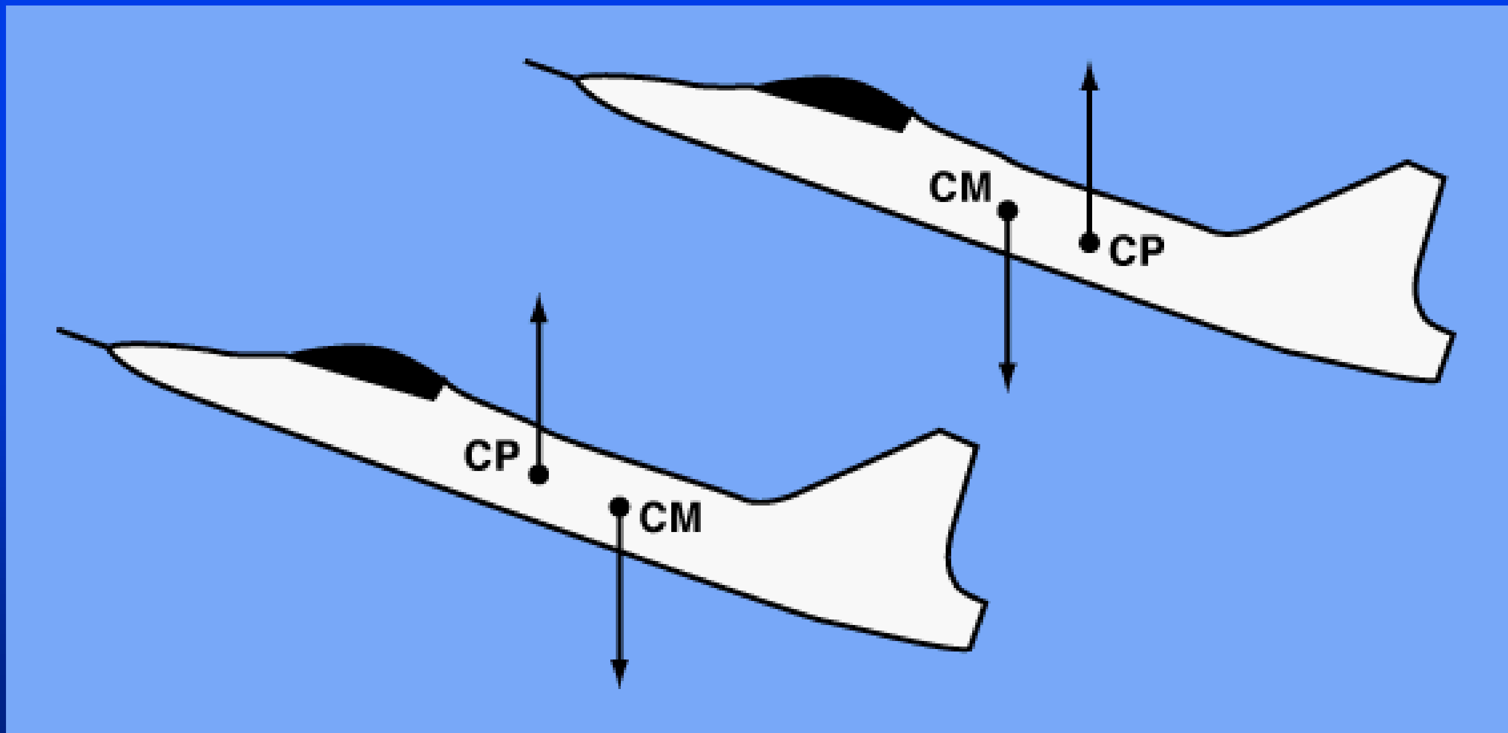
Combine human intuition with computational power

Nice way to package theory

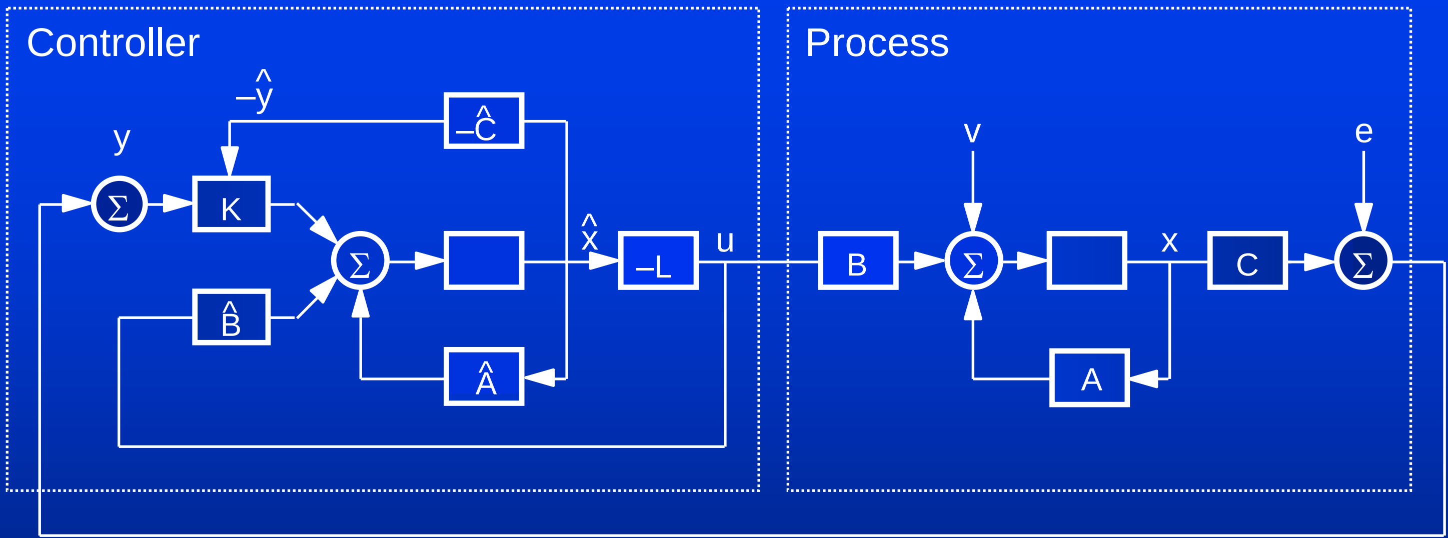
Computer Control



Control Design & Process Design



The Internal Model Principle



Applications

Energy generation	Transportation
Energy transmission	Heating, ventilation, aircondition
Process control	Entertainment
Discrete manufacturing	Physics
Instrumentation	Biology
Telecommunication	Economics

Mission Critical

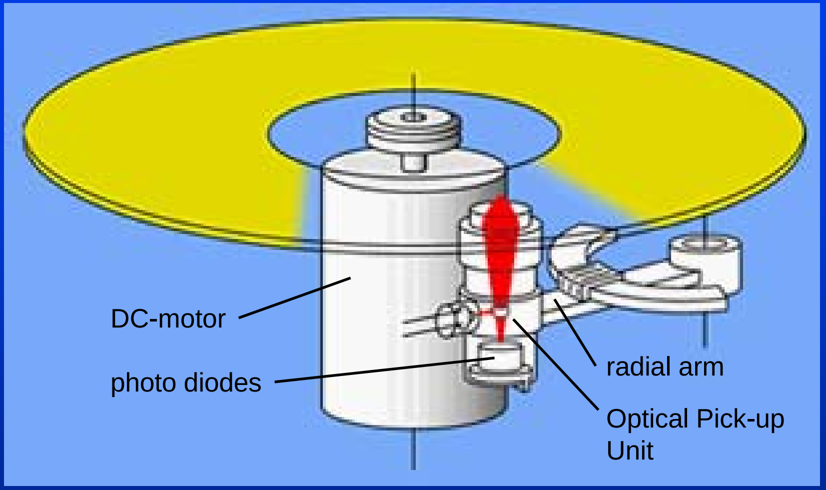
Flight Control

Space flight

Automotive

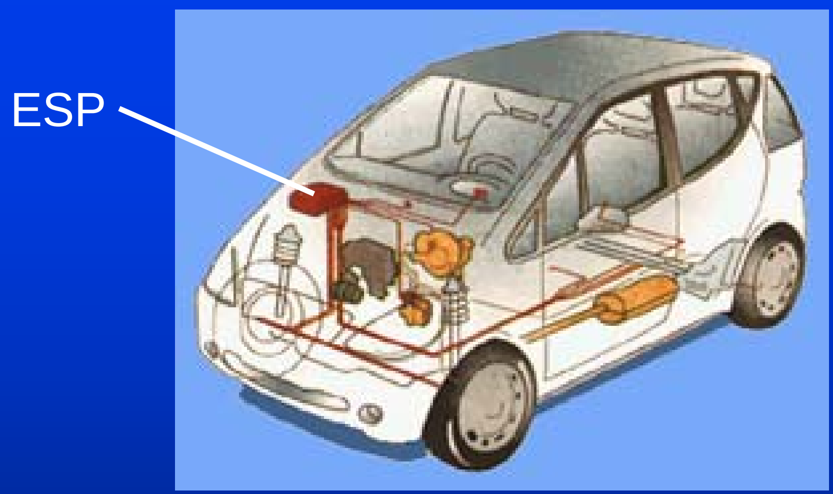
CD player

Camcorder manufacturing



The Mercedes A-class

Automatic control gives extra freedom to the designer



Unstable behavior improved by

Electronic Stabilization Program (ESP)

Control and Economics

Committee on Policy Optimisation HSO 1978

To consider the present state of development of optimal control techniques as applied to macro-economic policy. To make recommendations concerning the feasibility and value of applying thes techniques within Her Majesty's Treasury.

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Some Challenges

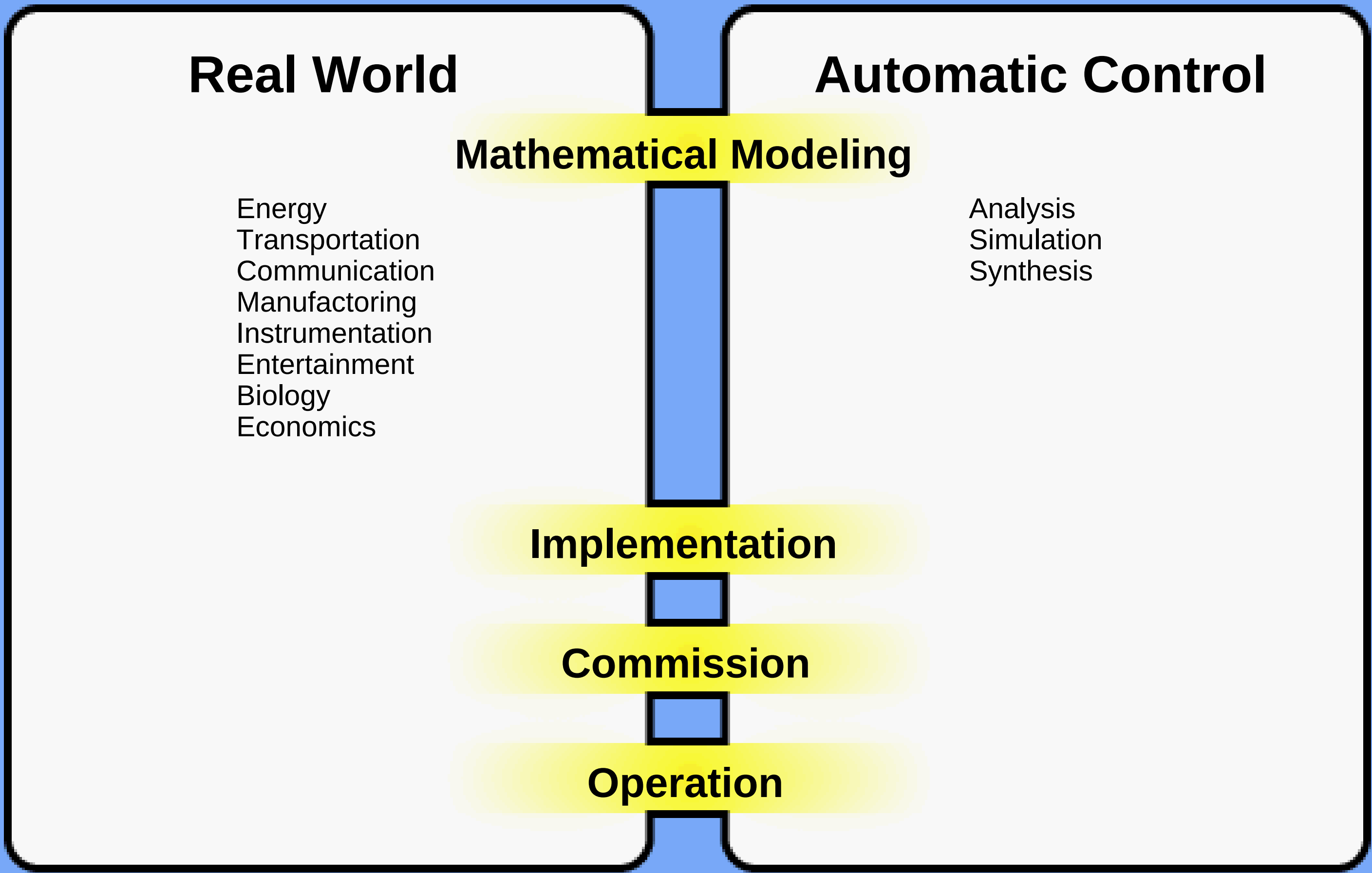
The gap between theory and practice

"Intelligent" systems

Man–machine interfaces

Technology / society interfaces

Academic positioning


Real World
Automatic Control
Mathematical Modeling
Energy
Transportation
Communication
Manufactoring
Instrumentation
Entertainment
Biology
Economics
Analysis
Simulation
Synthesis
Implementation
Commission
Operation

Conclusions

A glimpse of an emerging field

Automatic control is pervasive

Some system principles

Many challenges ahead