Control Engineering the Hidden Technology

K. J. Åström
Lund Institute of Technology
Lund University

The Hidden Technology

- ☺ Widely used
- ☺ Very successful
- ☹ Seldom talked about
- 😐 Except when disaster strikes
- 😐 Why?

Easier to talk about devices than ideas
Not enough attention to popularization

Engineering Education

Followed the pattern of emerging industries in the 19th and 20th century:

Civil Engineering, Mining, Mechanical, Chemical, Electrical.

New fields such as

Control and Systems

which are not tied to particular industries appeared in the middle of the 20th century.

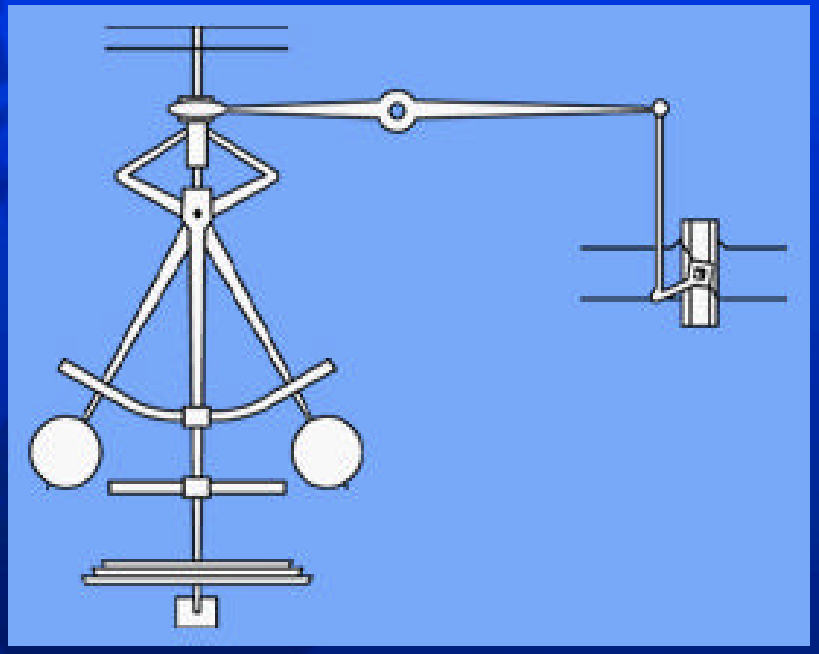
1. Introduction
2. A Brief History
3. State of the Art
4. The Future
5. Conclusions

A Brief History

- Early use in many fields
  - Process control
  - Vehicle control
  - Communication
- Servomechanism Theory
- Consequences
- The Second Wave

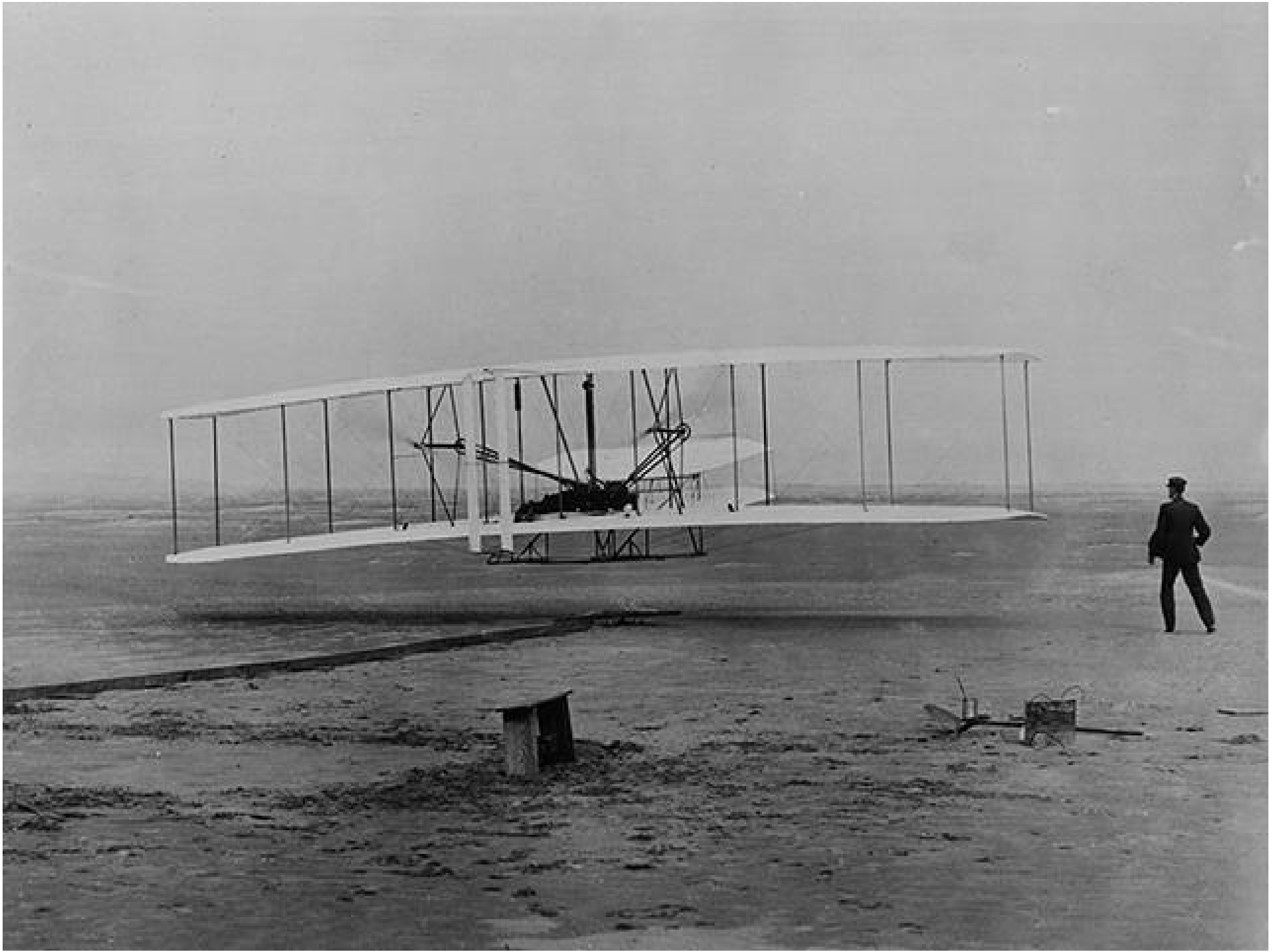
Industrial Process Control

- Windmills Mead 1787
- Steam Engines 1788
- Governors 1890
- Water Turbines 1893
- Tolle's Book 1905
- The PID Controller 1930



Wilbur Wright 1901

We know how to construct airplanes. Men also know how to build engines. Inability to balance and steer still confronts students of the flying problem. When this one feature has been worked out, the age of flying will have arrived, for all other difficulties are of minor importance



Sperry's Autopilot 1912

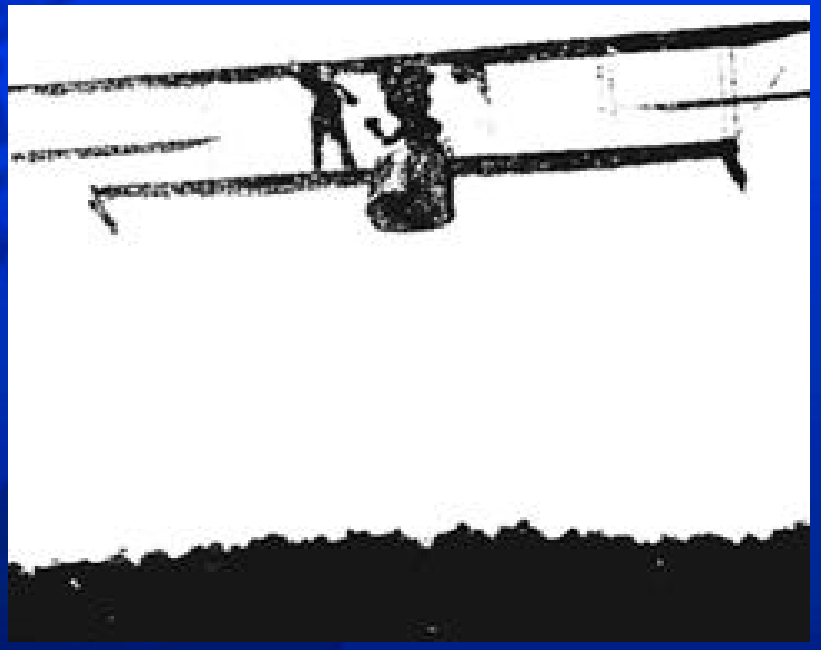
A Quiz!

Robot Piloted Plane makes
Safe Crossing of the Atlantic
No hands on controls from
Newfoundland to Oxforshire
Take-Off, Flight and Landing are
fully Automatic.

New York Times 19XX

Flight Control

The Wright Brothers	1903
Sperry's Autopilot	1912
Robert E. Lee	1947
V1 and V2 (A4)	1942
Sputnik	1957
Apollo	1969
Mars Pathfinder	1997



The Feedback Amplifier

Telephone Calls Over Long Distances

The Problem: How to Increase Signal Strength?

The Solution: The Feedback Amplifier

Patented by Black 1928

Patent Granted 1937

Strong Development of Theory and Design Methods

Telecommunications

The Repeater Problem

Black's Invention **1928**

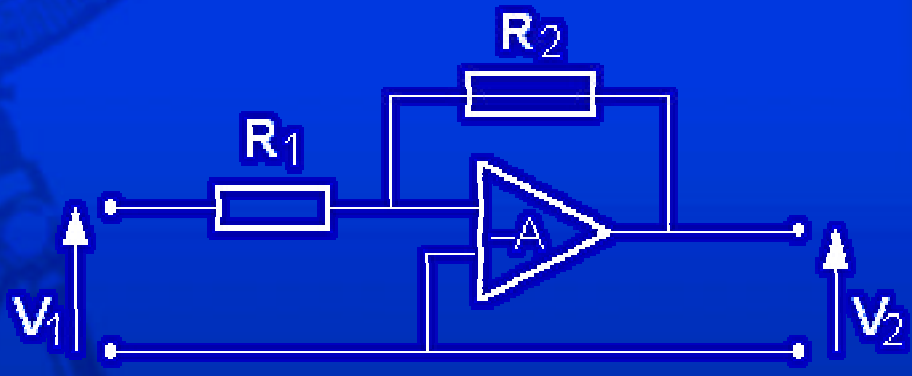
"Singing" = Instability

Nyquist's Theorem **1932**

Bode's Paper **1940**

Bode:

Network Analysis
and
Feedback Amplifier Design



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

Mervin Kelley on Black 1957

It is no exageration to say that without Black's invention of the feedback amplifier, the present long-distance telephone and television networks, which covers our entire country and the transoceanic telephone cables would not exist.

The Magic of Feedback

- Make precise systems from imprecise components
- Keep variables constant
- Stabilize unstable system
- Reduce effects of disturbances and component variations
- New degrees of freedom for designers
- Main drawback - danger of instability

The Scene of 1940

Widespread use of control in many fields

- **Power generation and distribution**
- **Process control**
- **Autopilots for ships and aircrafts**
- **Telecommunications**

The similarities were not recognized

A Discipline Emerges

Industrial Process Control

Telecommunications

Flight Control

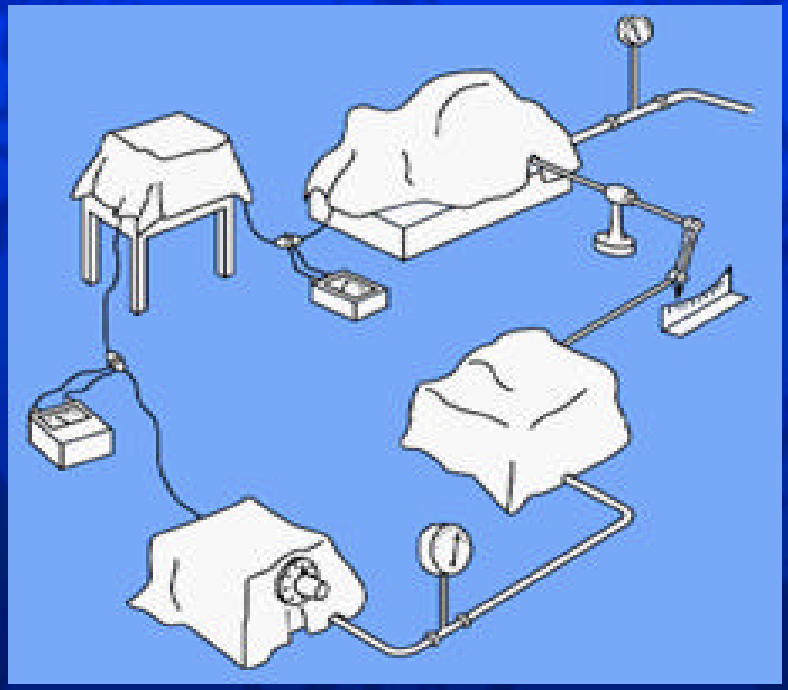
Mathematics

Principles Theory

Design Methodology

Applications

The Black Box Concept



Abstraction

Information hiding

Transfer functions

Servomechanism Theory

- Foundations
  - Complex variables
  - Laplace Transforms
- System Concepts
  - Feedback
  - Feedforward
- Methodology Design
  - Frequency Response
  - Graphical Methods
- Analog Simulation
- Implementation

Theory of Servomechanisms

Hubert M. James

Professor of Physics Purdue University

Nathaniel B. Nichols

Director of Research Taylor Instrument Companies

Ralph S. Phillips

Associate Professor of Mathematics University of Southern California

Office of Scientific Research and Development

National Defence Research Committee

Cybernetics

Norbert Wiener 1948

- Cybernetics - Control and Communication in Human and Machine

Interaction with neurophysiology

McCulloch and Pitts 1943

Consequences

Education

Application

Industrialization

Organisation

Journals

Conferences

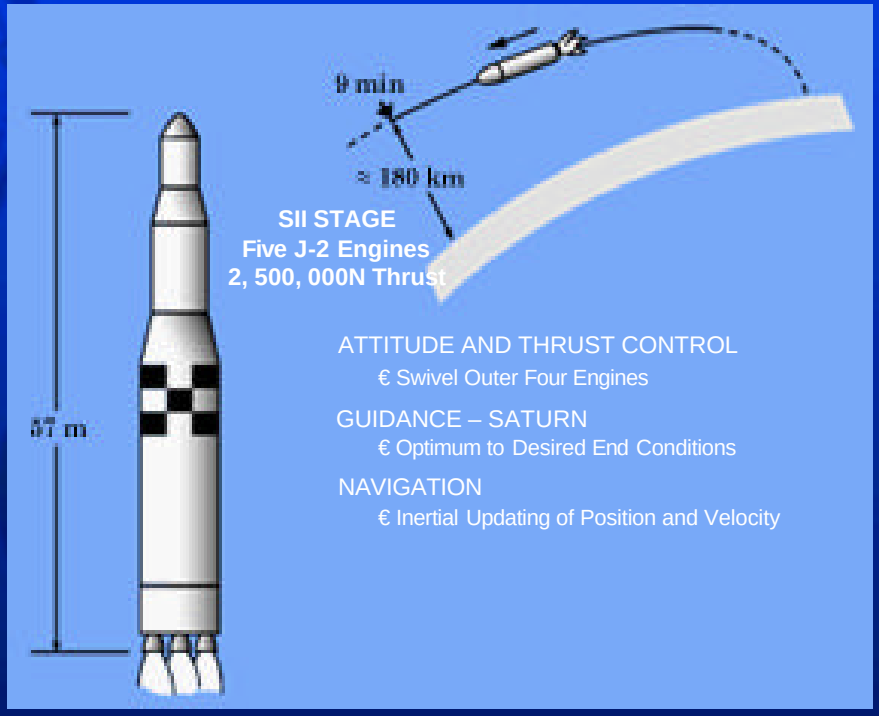
The Second Wave

- Driving Forces
  - Space race
  - Mathematics
  - Computers
- A New Paradigm
  - State Space
- Rapid Expansion
  - Subspecialities

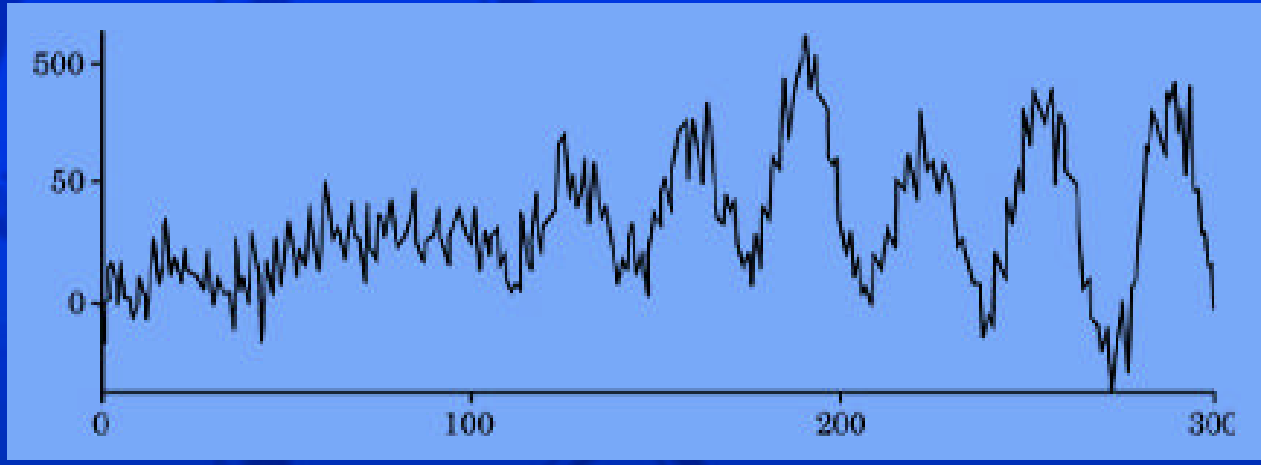
- Optimal Control
- Nonlinear Control
- Computer Control
- Stochastic Control
- Robust Control
- System Identification
- Adaptive Control
- CACE

Optimal Control

Euler	**1707–1783**
Lagrange	**1736–1813**
Pontryagin	**1908-1988**
Hamilton	**1805–1865**
Jacobi	**1804–1851**
Bellman	**1925-1984**



Kalman Filtering



Gauss	1810 least squares
Wold	1935 innovations
Kolmogorov	1941 discrete time
Wiener	1941 spectral factorization
Kalman	1961 recursive equations

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Current Status

A well established body of ideas, concepts, theory and design methods.

Wide and growing application areas

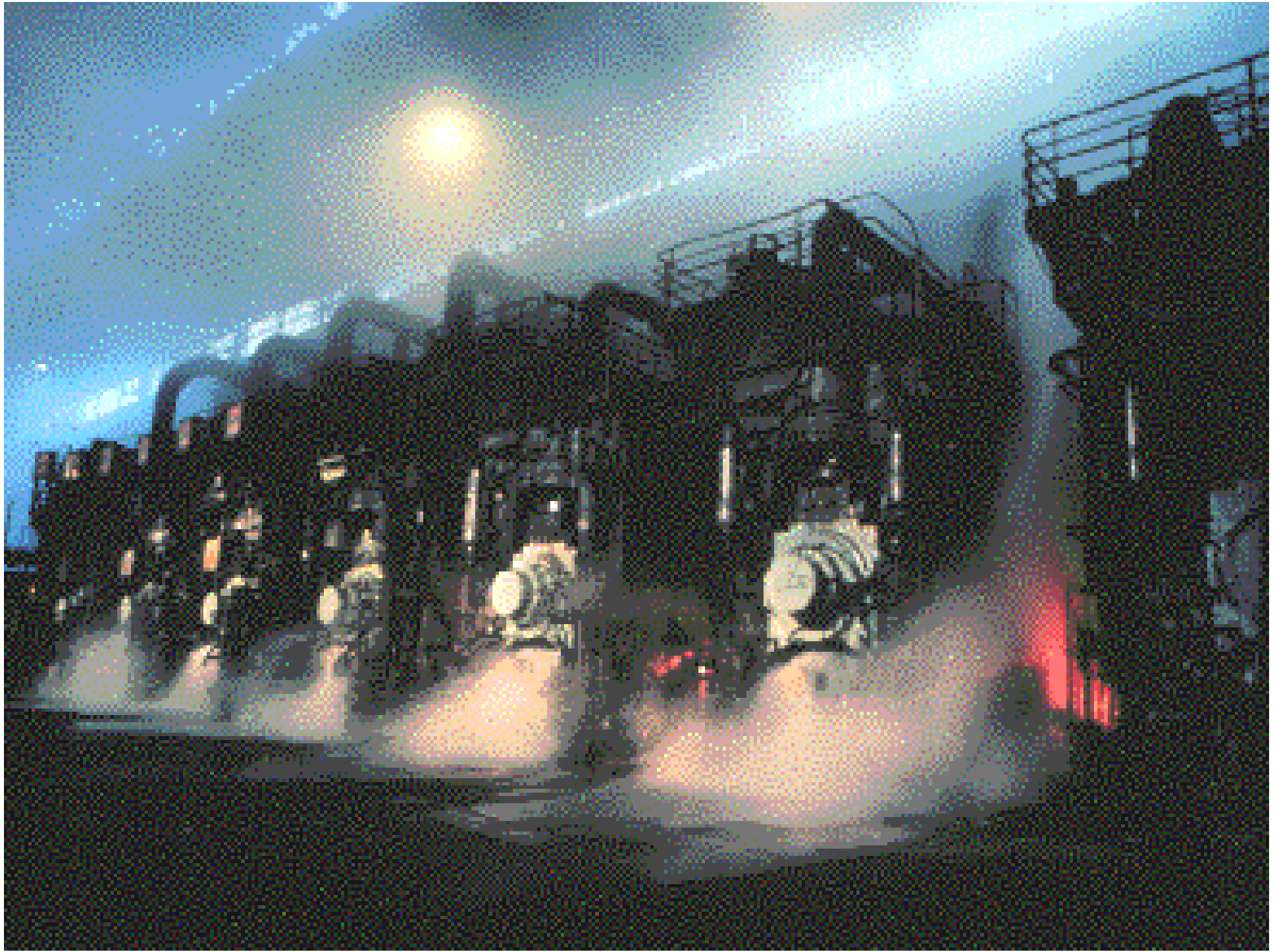
Still developing rapidly

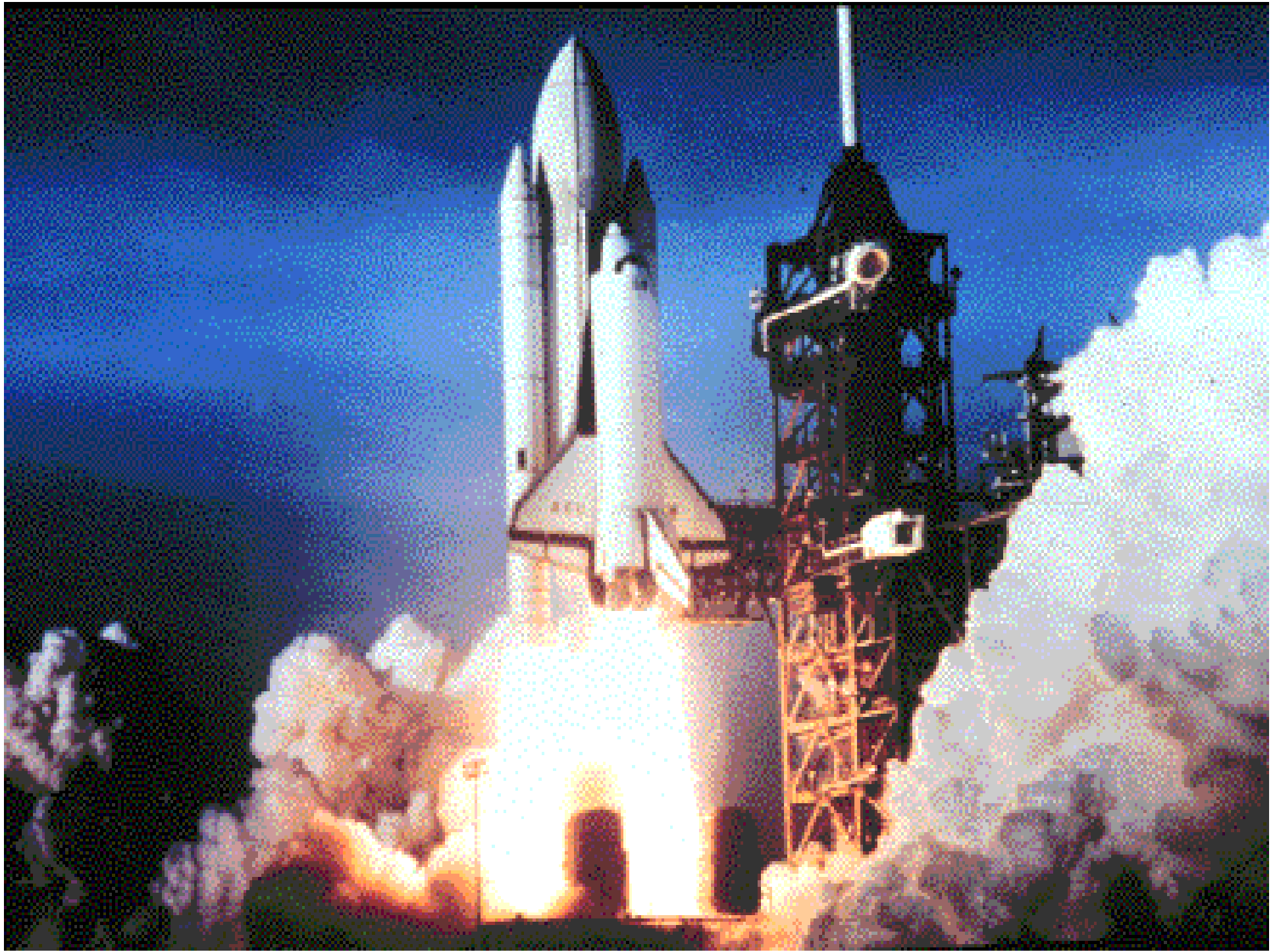
Perhaps Most Important

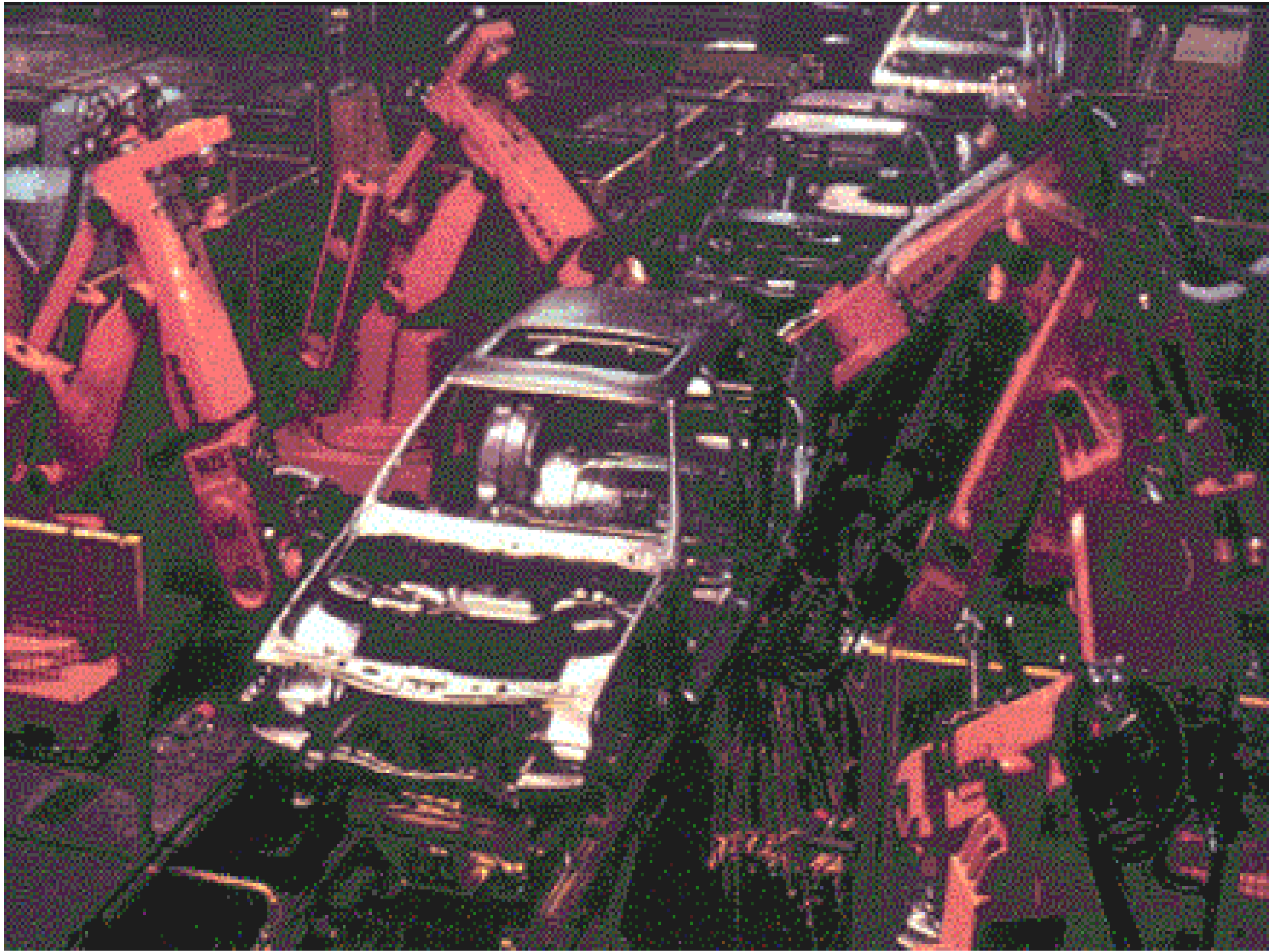
A good group of very talented and creative young researchers.

Applications

- Energy generation
- Energy transmission
- Process control
- Discrete manufacturing
- Communication
- Transportation
- Buildings
- Entertainment
- Instrumentation
- Mechatronics
- Materials
- Physics
- Biology
- Economics





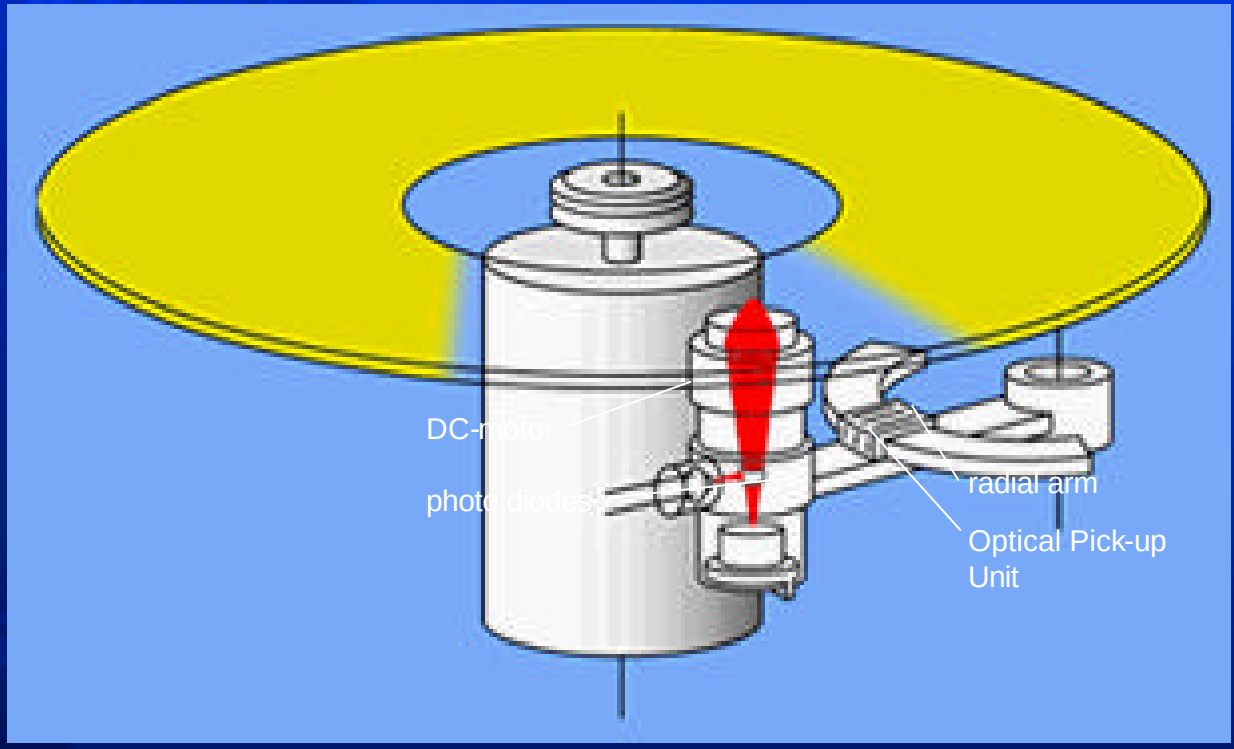


CD Player

Tracking

Searching

Focusing



A Dilemma

Automatic control is a collection of ideas, concepts and theories with very wide applications areas. How to cope with:

- Coupling to hardware
- Coupling to industries
- Specific domain knowledge
- Academic positioning

A Soul but No Body

- ☺ Technology transfer
- ☺ Student attraction
- ☹ Searching for a home court
- ☹ Many base industries
- ☺ Generality
- ☹ Academic positioning

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Natural and Engineering Sciences

Understand Nature vs Man-made Systems

Equally Challenging

Extensive use of Mathematics

Design and Operation of Systems

Physical Laws vs System Principles

Isolation vs Interaction

Reductionism vs Systems

Theoretical Physics vs System Theory

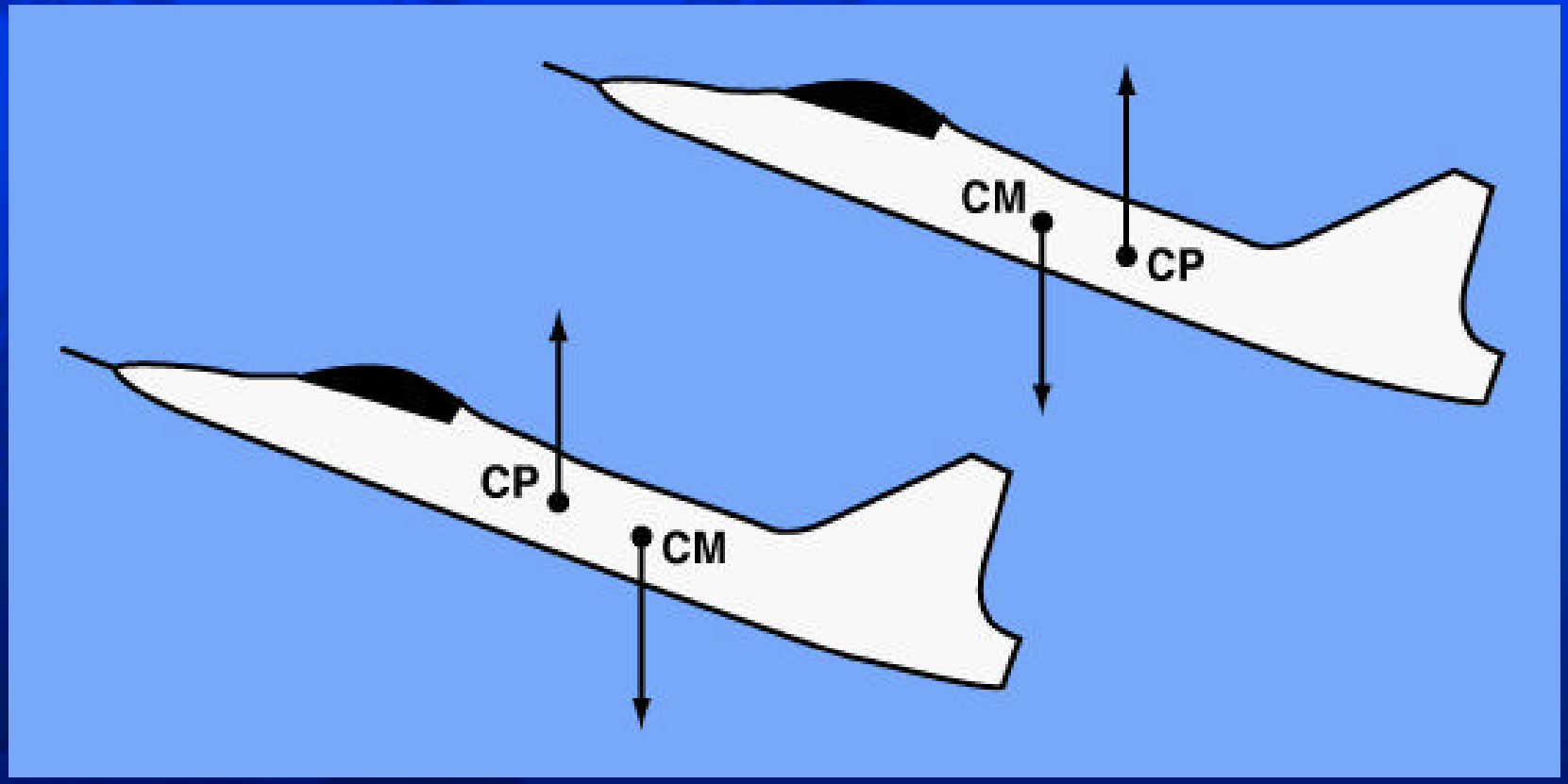
The Future of Control

- **Increased use in engineering**
  - Control over/of communication networks
  - Autonomous systems
- **Biology and Medicine**
  - Many previous attempts, Will it work this time?
- **Physics**
  - Devices and Ideas, Quantum systems

Process and Control Design

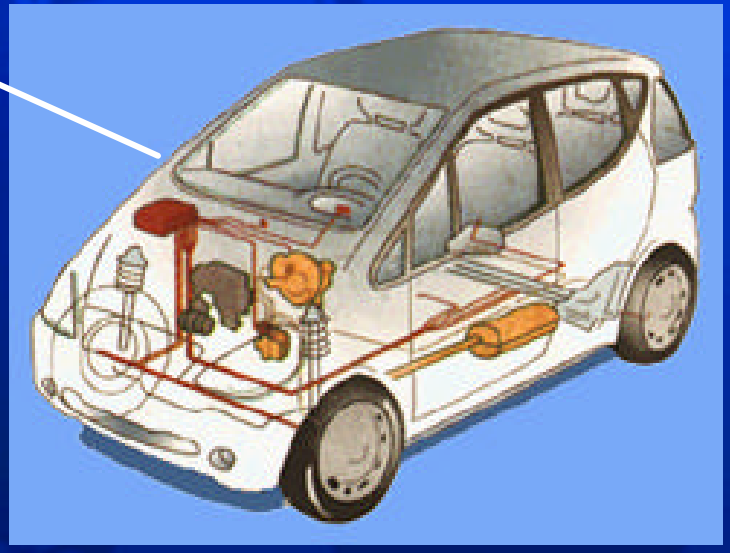
- Wright Brothers rejected the dogma that aircraft should be inherently stable
- Minorsky 1922: It is an old adage that a stable ship is difficult to steer
- Integrated process and control design
- Control gives designers extra freedom
- The cardinal sin of control

Co-Design of Process and Control



The Mercedes A-class

Control comes to the rescue!



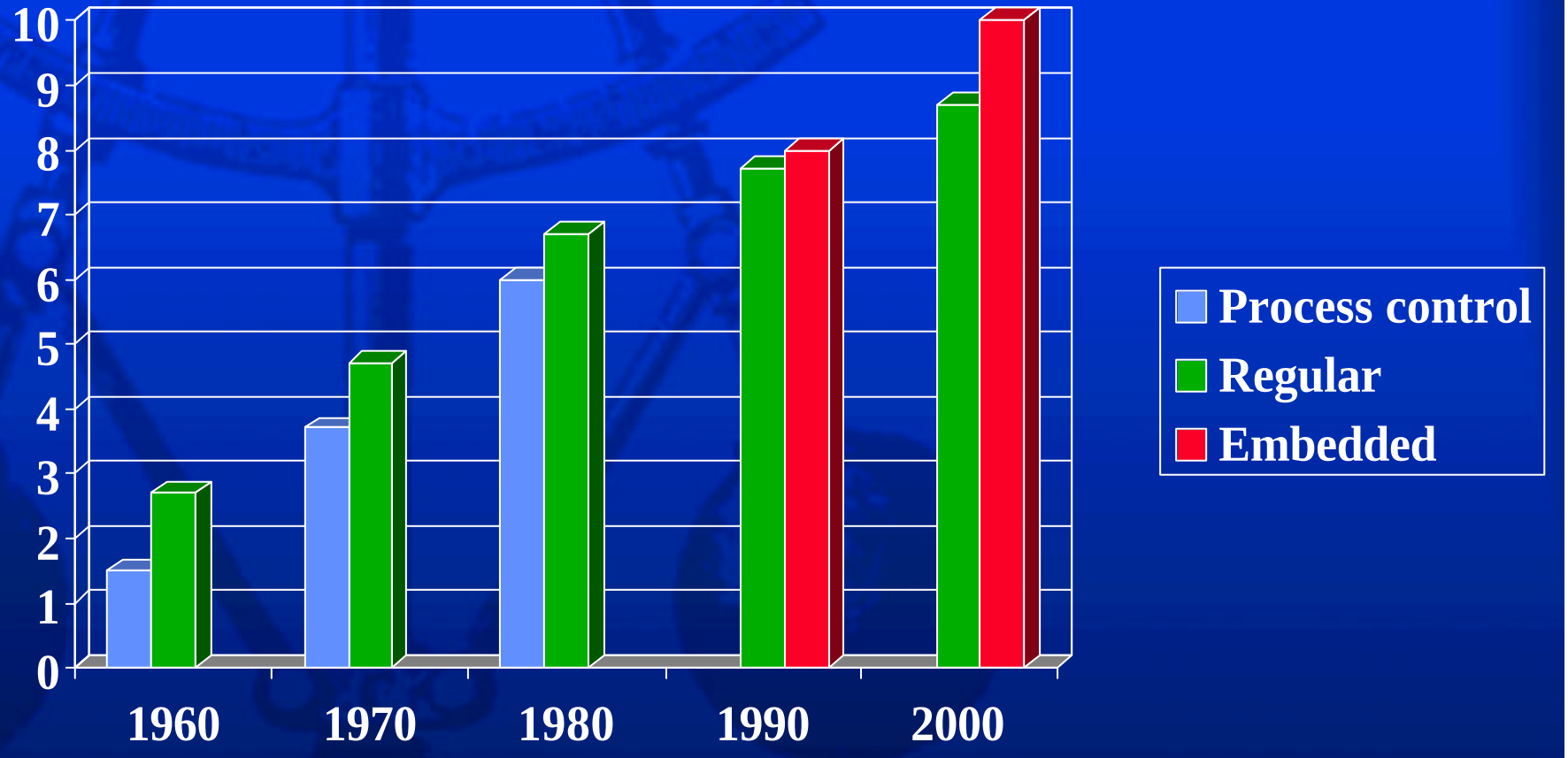
Unstable behavior improved by

Electronic Stabilization Program (ESP)

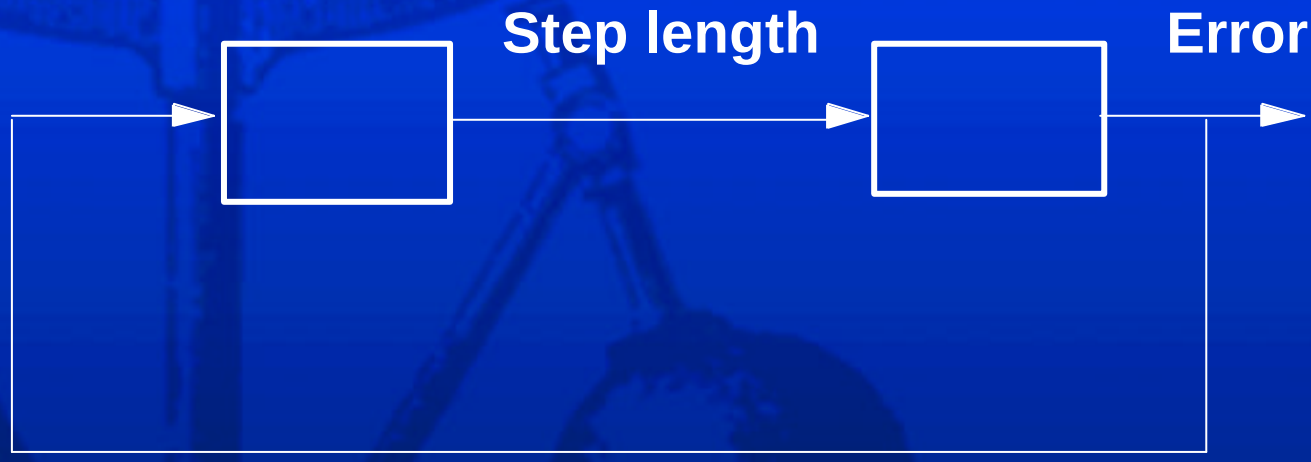
Computing and Control

- Software issues increasingly important
- Object oriented modeling
- Feedback scheduling
- Control of servers and nets
- Vision Feedback and haptics
- High level control principles
- Learning systems

Computers and Control



Step Length Control in ODE Solvers



- Dead-beat control was standard
- PI control gives much better behavior
- Control view gives better code

Physics

- Devices and ideas
- Particle Accelerators
  - The 1984 Nobel Prize Van Der Meer
- Adaptive Optics
- Atomic Force Microscope
- Quantum and Molecular Systems
- Turbulence

Adaptive Optics

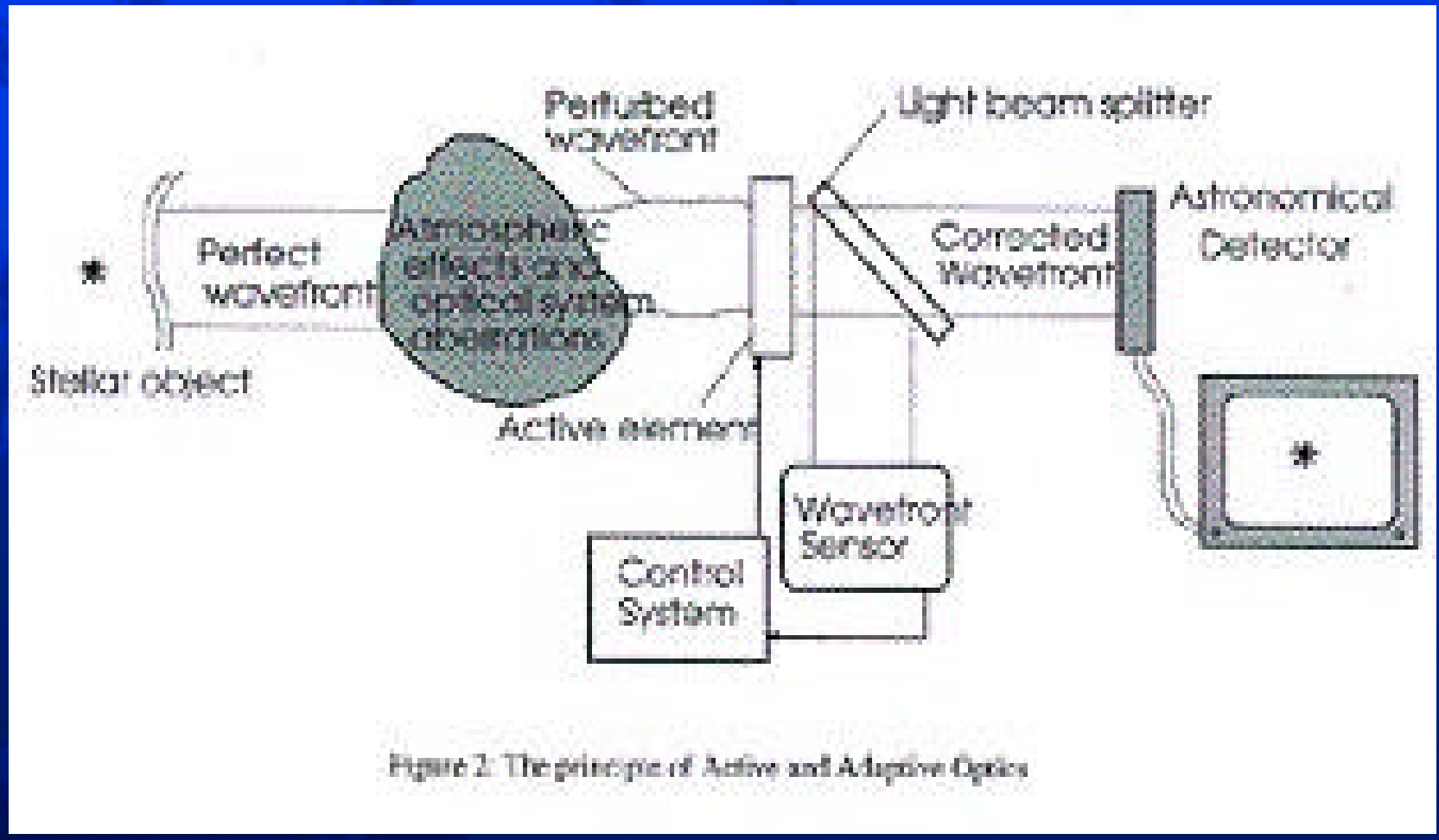


Figure 2: The principle of Active and Adaptive Optics

Biology

Feedback is a central feature of life. The process of feedback governs how we grow, respond to stress and challenge, and regulate factors such as body temperature, blood pressure, and cholesterol level. The mechanisms operate at every level, from the interaction of proteins in cells to the interaction of organisms in complex ecologies.

Mahlon B Hoagland and B Dodson The Way Life Works Times Books 1995

Charles Darwin

It is not the strongest of the species that survive, nor the most intelligent, it is the one that is most adaptable to change.

Educational Challenges

- Theory and applications expanding
- How to compactify the knowledge?
- The engineering aspect
- The field had changed a lot, the courses have not
- Relations to computing

Interesting Areas

- **C^3 - Control Computing Communication**
  - Control over/of communication networks
- **Biology and Medicine**
  - Many previous attempts, Will it work this time?
- **Complex systems**
  - Autonomous and learning systems
  - Supply chains, quantum systems

Examples of New Problems

- Sensor-rich control
- Actuation-rich control
- High level control principles

Recipe for Success

- Good ideas and demanding problems
- Solid theory
- Good engineering
- Examples

  Servomechanisms, Optimal control

  Robust control, Nonlinear control

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Conclusions

- An exciting field
- Use of feedback often revolutionary
- Rapid growth of applications
- Streamline available knowledge
- Education is a key issue
- Many new challenging problems

Take Care of Both Body and Soul

- Intellectual challenges (the soul)
  - Basics that generalizes easily
  - Give the general picture
  - Particular attention to introductory courses
- The engineering aspect (the body)
  - Educate students broadly so that they can take full systems responsibility
- Learn theory and a particular domain

The End