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TERMINOLOGY AND CONCEPTS OF CONTROL AND FUZZY LOGIC

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PURPOSES OF THIS TALK

- Briefly review control history - how do ideas "fit together"
- Establish terminology of control theory and fuzzy logic to promote useful discussions
- Establish basic concepts and issues in both areas for the same purpose

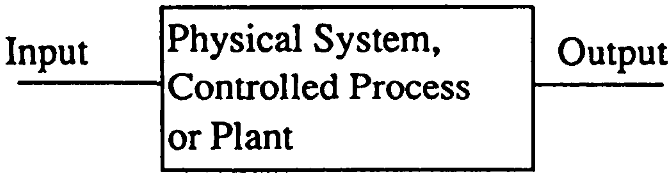
CONTROL SYSTEMS

- A means by which a variable quantity or a set of variable quantities is made to conform to a prescribed norm or to vary in a prescribed way

- May be operated by electrical means, mechanical means, hydraulic means, pneumatic means, or a combination

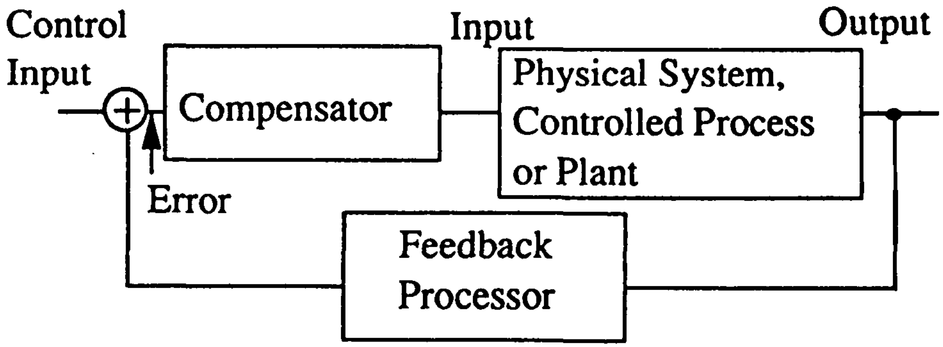
FEEDFORWARD CONTROL

- Open Loop Control

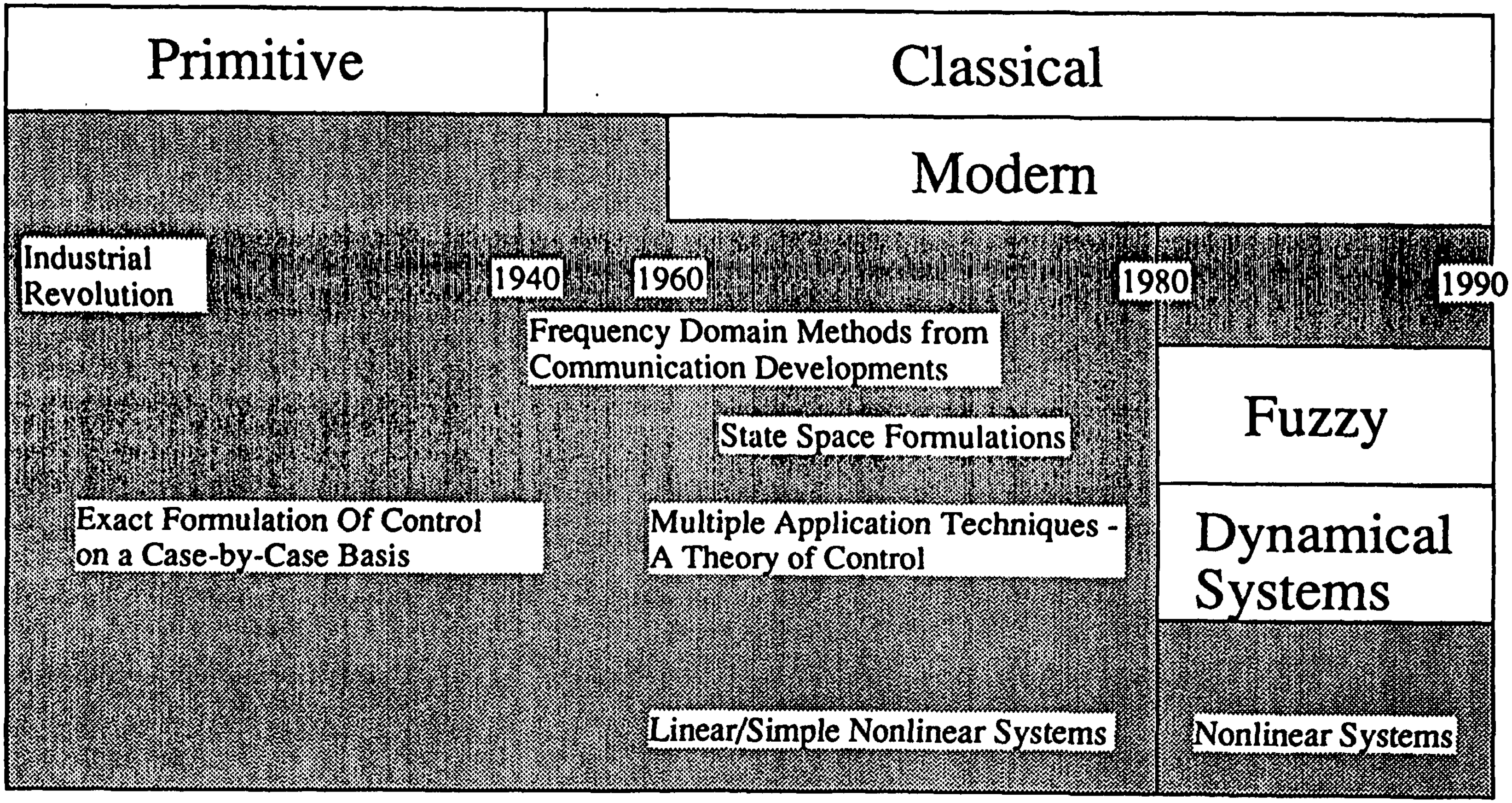


FEEDBACK CONTROL

- Closed Loop Control
- Servomechanism



CONTROL THEORY WAS FORMULATED IN THREE PHASES



Primitive

Classical

Modern

Industrial Revolution

1940

1960

1980

1990

Frequency Domain Methods from Communication Developments

State Space Formulations

Fuzzy

Exact Formulation Of Control on a Case-by-Case Basis

Multiple Application Techniques - A Theory of Control

Dynamical Systems

Linear/Simple Nonlinear Systems

Nonlinear Systems

ISSUES IN THE DESIGN OF A CONTROL SYSTEM

Stability and Transient Response

Response Time or Bandwidth

Observability

Controllability

Continuous or Sampled Data

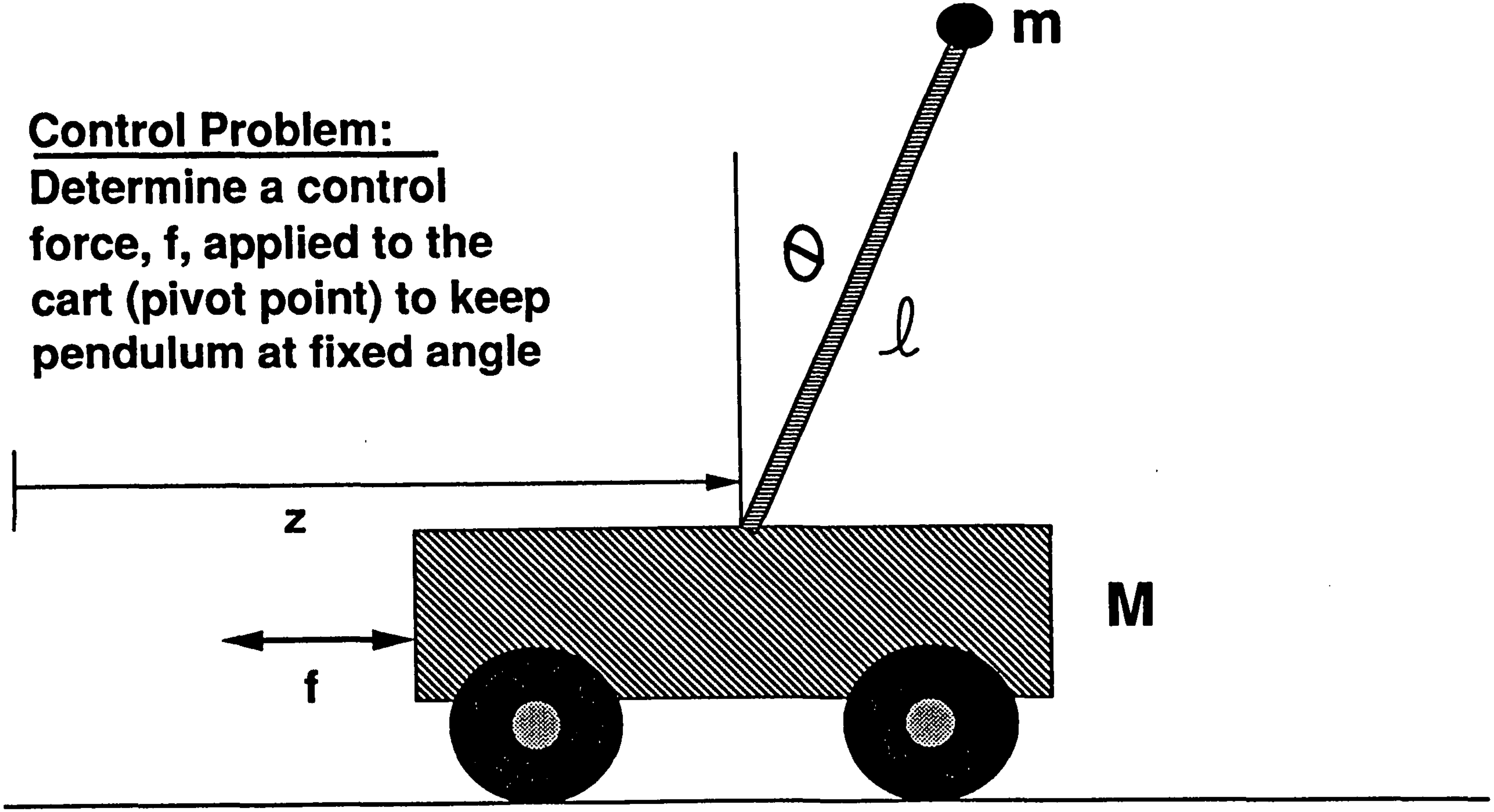
Single or Multiple Control Loops

Optimizing or "Near-Optimal" Control

Fixed, Adaptive, or Learning Control

EXAMPLES: INVERTED PENDULUM

Control Problem:
Determine a control force, f, applied to the cart (pivot point) to keep pendulum at fixed angle



STATE SPACE CONTROL FOR INVERTED PENDULUM

Equations of Motion

$$(M+m)\,\ddot{z} + m\ell\cos\theta\,\ddot{\theta} - m\ell\dot{\theta}^{2}\sin\theta = f$$

$$m\ell\cos\theta\,\ddot{z} + m\ell^{2}\ddot{\theta} - mg\ell\sin\theta = 0$$

State

$$\begin{bmatrix} z \\ v \\ \theta \\ \omega \end{bmatrix}$$

State Space Description of Dynamical System

$$\dot{z} = v$$

$$\dot{v} = \frac{m\ell\omega^{2}\sin\theta}{M + m\sin^{2}\theta} - \frac{mg\cos\theta\sin\theta}{M + m\sin^{2}\theta} + \frac{f}{M + m\sin^{2}\theta}$$

$$\dot{\theta} = \omega$$

$$\dot{\omega} = \frac{g\sin\theta(M+m)}{\ell(M + m\sin^{2}\theta)} - \frac{m\omega^{2}\sin\theta}{M + m\sin^{2}\theta} - \frac{f\cos\theta}{M + m\sin^{2}\theta}$$

LINEARIZED STATE SPACE

$$\dot{z} = v$$

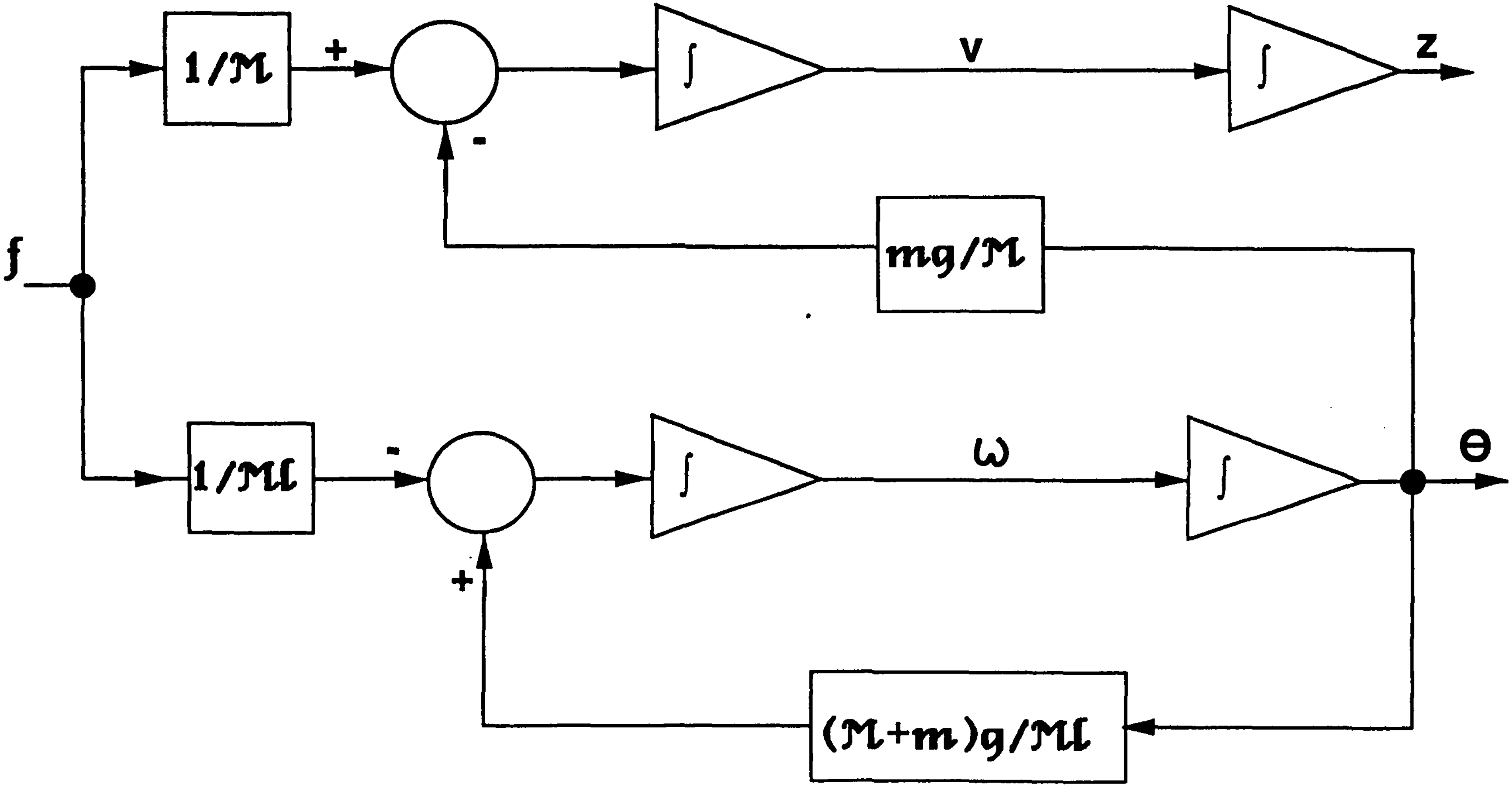
$$\dot{v} = \frac{f}{M} - \frac{mg\Theta}{M}$$

$$\dot{\theta} = \omega$$

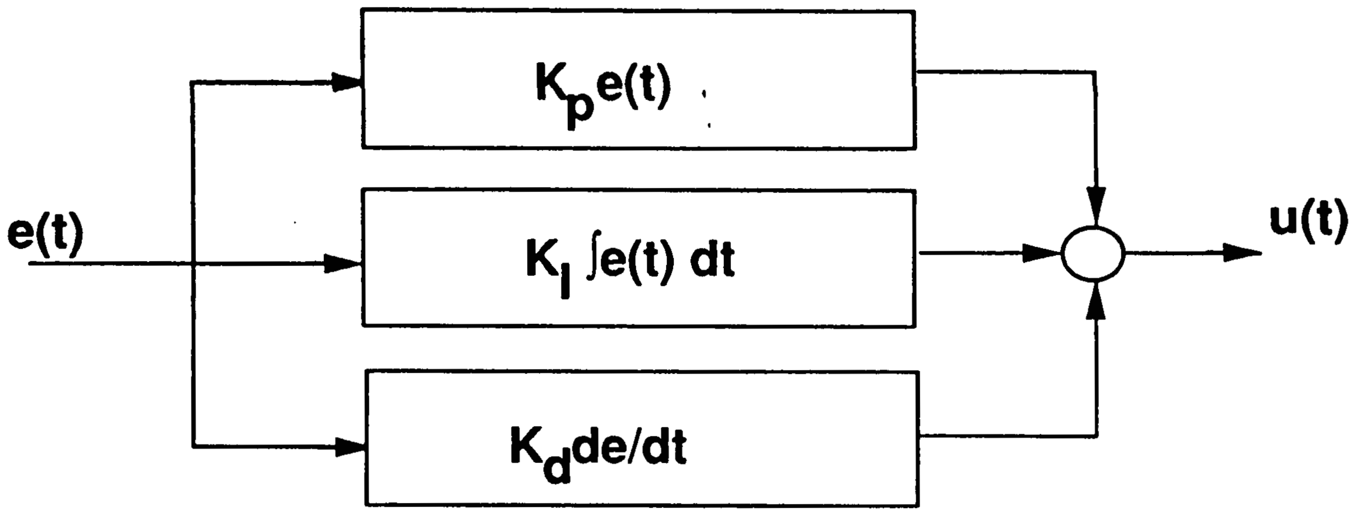
$$\dot{\omega} = \frac{(M+m)g\Theta}{M\ell} - \frac{f}{M\ell}$$

DYNAMICAL SYSTEM MODEL FOR INVERTED PENDULUM ON A CART

MCDONNELL DOUGLAS



PROPORTIONAL-INTEGRAL-DERIVATIVE (PID) CONTROLLER



$K_p e(t)$

$e(t)$

$K_I \int e(t)\,dt$

$u(t)$

$K_d de/dt$

Proportional component reduces error
Integral component reduces steady state offset
Derivative component anticipates and reduces overshoots

ADVANTAGES OF USING CONVENTIONAL CONTROL

- Technology is well established

- Many control problems are well approximated by linear plants or can be handled with adaptive systems that perturb controller parameters

- Technology is mathematically based allowing general properties of controllers to be explored by a theoretical approach

PROBLEMS WITH STATE SPACE CONTROL?

- Model building stage is elaborate, iterative, error-prone, and time consuming

- A performance index that can be used for optimization must be formulated

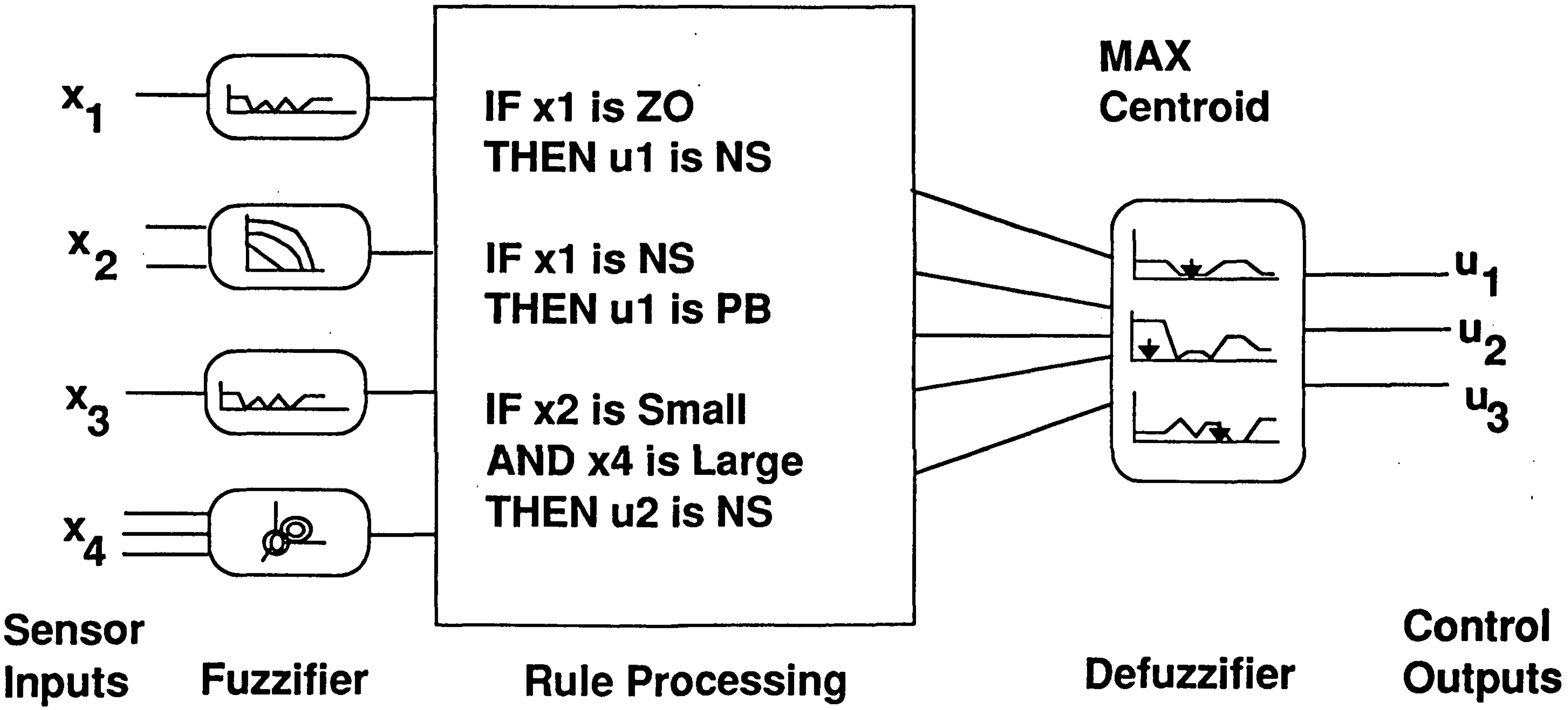
- Actuators may be nonlinear

- Complex equipment may be poorly described by systems of differential equations but may be best described from experimental data or heuristics (rules of thumb or experience).

- Heuristics may be part of the operating procedure and may be based on mental models other than the physical models

FUZZY CONTROLLER OVERVIEW

DESIGNER-SUPPLIED
INFORMATION IS UNDERLINED



Fuzzy
Set
Membership
Functions

IF...THEN... Rules

Defuzzifier
Techniques

MAX
Centroid

x_1

x_2

x_3

x_4

IF x1 is ZO
THEN u1 is NS

IF x1 is NS
THEN u1 is PB

IF x2 is Small
AND x4 is Large
THEN u2 is NS

u_1

u_2

u_3

Sensor
Inputs

Fuzzifier

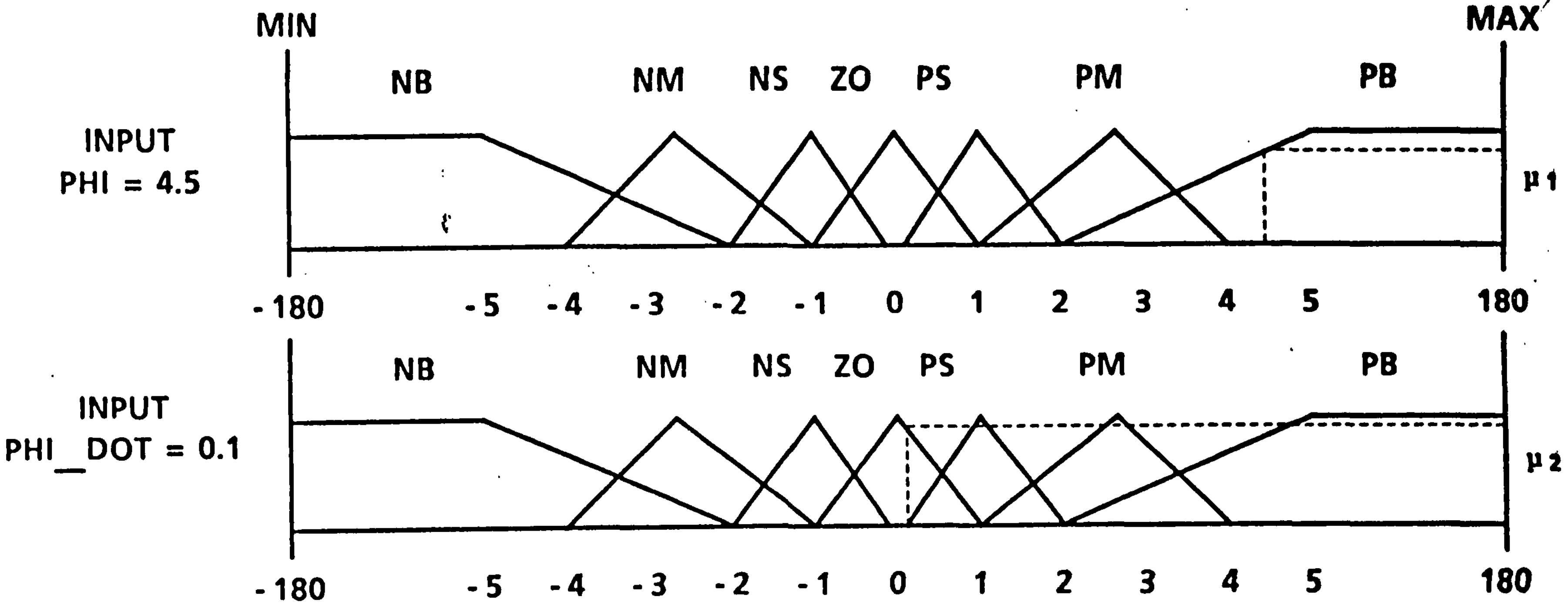
Rule Processing

Defuzzifier

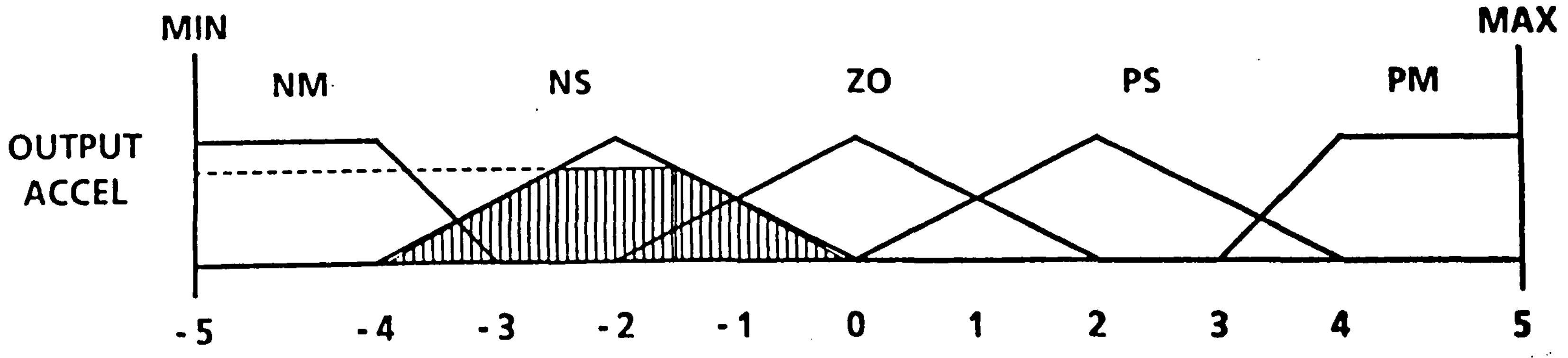
Control
Outputs

APPROACH (CONT.)

FUZZY PROCESSING



RULE: IF (PHI EQ PB AND PHI_DOT EQ Z0) THEN ACCELERATION IS NS
MIN (μ_1, μ_2) IS APPLIED TO NS FUNCTION IN ACCELERATION



RULE BASE FOR FORCE ON INVERTED PENDULUM CART

Fuzzy Table Inv Pend

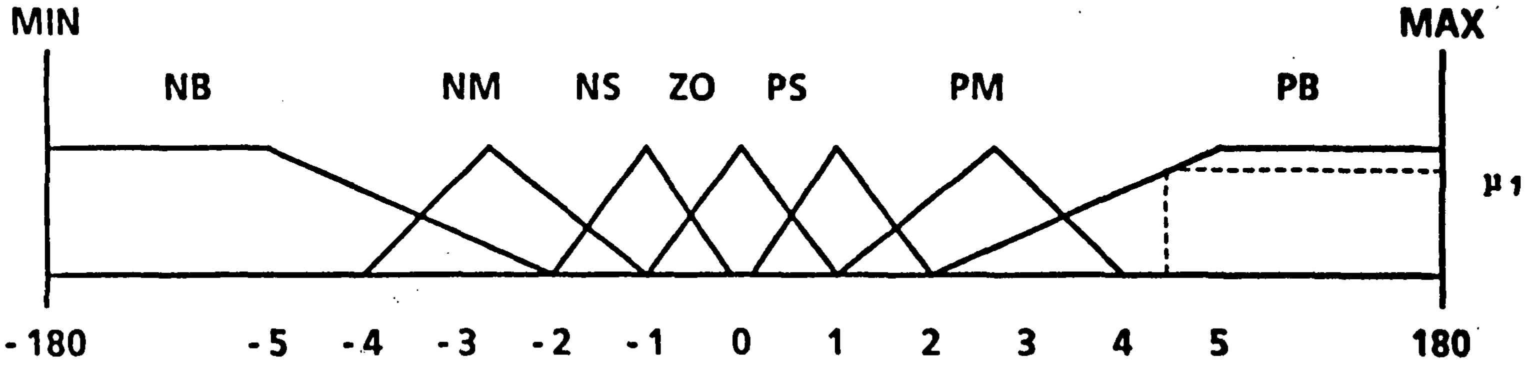
		Angle			
Angle Rate	NB	NS	ZO	PS	PB
PB	ZO	PB	PB	PB	PB
PS	NB	ZO	PS	PB	PB
ZO	NB	NS	ZO	PS	PB
NS	NB	NB	NS	ZO	PB
NB	NB	NB	NB	NB	ZO

Example Rule: IF Angle is PS AND Angle Rate is NS THEN Force is ZO

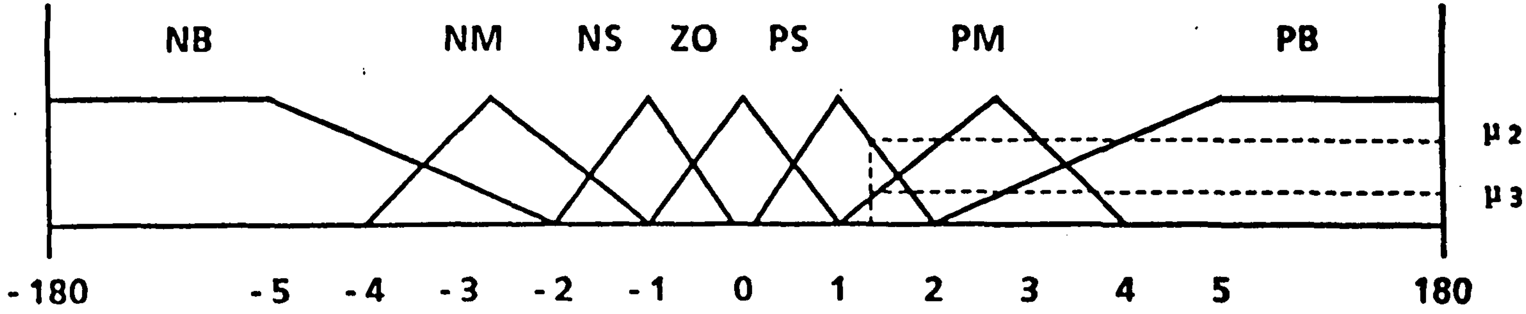
APPROACH (CONT.)

FUZZY PROCESSING

INPUT
PHI



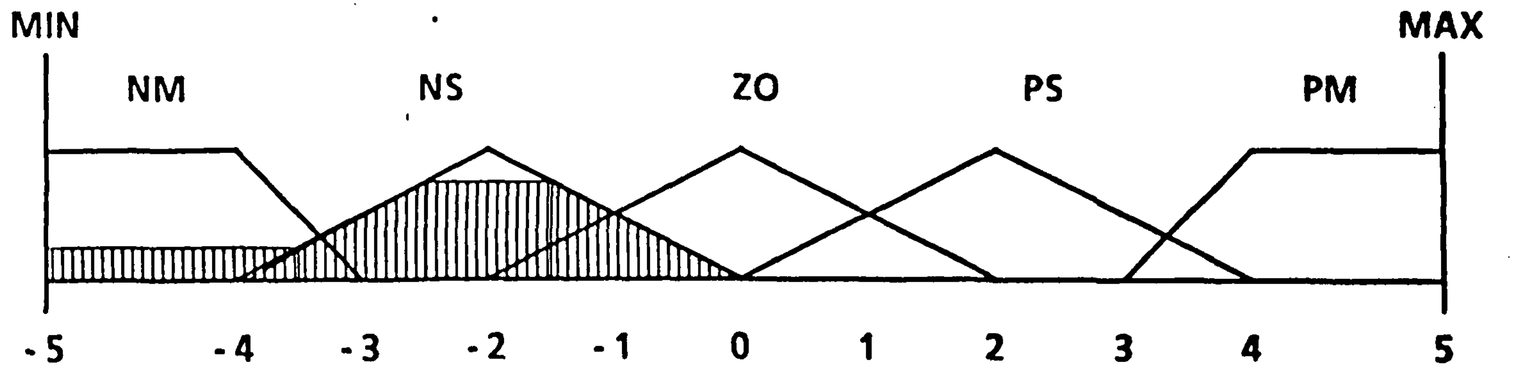
INPUT
PHI_DOT



TWO RULES FIRE:

1. IF PHI IS PB AND PHI_DOT IS PS THEN ACCEL IS NS
2. IF PHI IS PB AND PHI_DOT IS PM THEN ACCEL IS NM

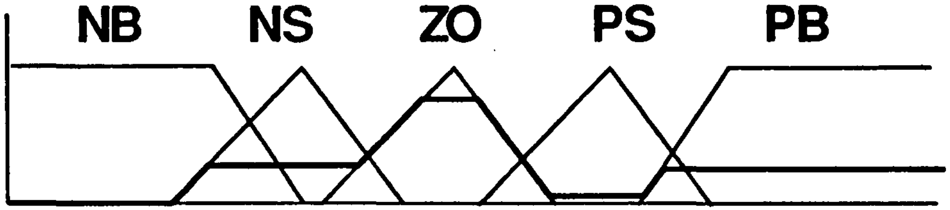
ACCEL IS OUTPUT
VIA CENTROID
METHOD



FUZZY RULE PROCESSING

USE MAXIMUM FOR LOGICAL OR

IF ... THEN u is NS .3
IF ... THEN u is ZO .8
IF ... THEN u is PS .1
IF ... THEN u is PB .3



USE MINIMUM FOR LOGICAL AND

Rule: IF x1 is NS AND x2 is ZO
THEN u is PS

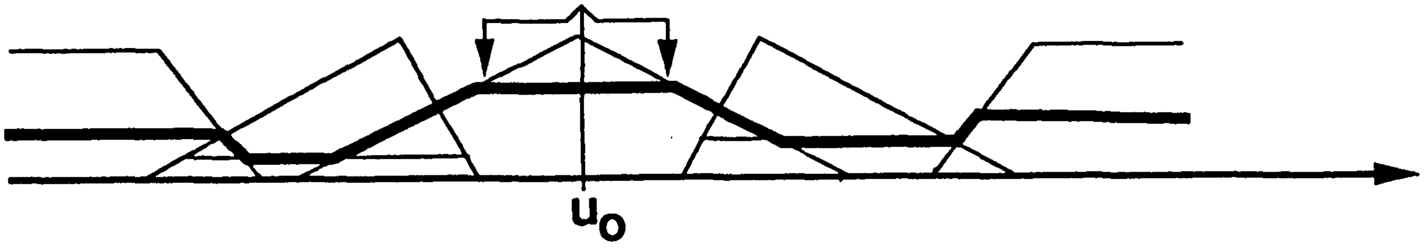
Facts:
x1 is NS 0.2
x2 is ZO 0.8 => u is PS 0.2

Other options exist for combining logical connectives but these preserve all results from normal set theory except exclusion law:
A AND NOT A = ø

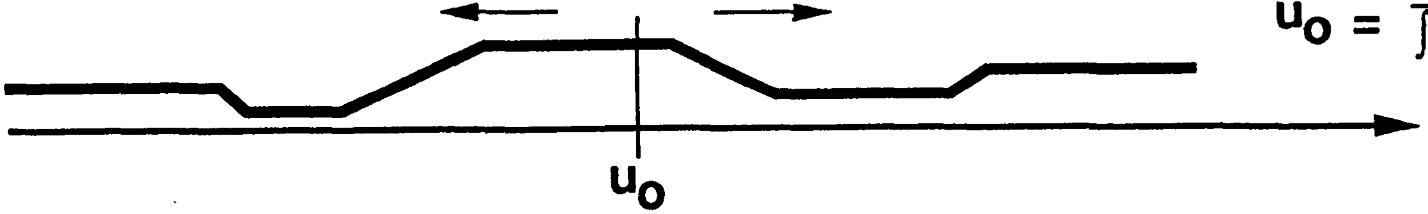
DEFUZZIFICATION

MCDONNELL DOUGLAS

MAX Procedure



Centroid Procedure



$$\overset{\mu'}{u_o} = \frac{\int \overset{\mu ?}{u}\, U\, du}{\int U\, du}$$

Indexed MAX or Centroid Procedure

Same as above except use only points > threshold value

FUZZY CONTROLLER ADVANTAGES

- Can exploit heuristic knowledge of operation of controlled systems. This includes physical intuition.

- Can accomodate small changes in system or controller parameters. This are the aging effect and nonlinear effects such as flexibility of beams

- Experience has been that these techniques seem to handle nonlinearity well

- Tools have been developed to assist in studying and building fuzzy controllers in short times

- The development of fuzzy chips has provided computationally capable platforms on which to build the controller, independent of general purpose computers used for spacecraft control

REMAINING ISSUES FOR FUZZY CONTROL

- Issues such as stability, observability, and controllability raised in servomechanism and state space control are not yet in comparable state of development. This may limit initial applicability to noncritical applications

- Definition of membership functions is arbitrary and controller designer dependent.

- Procedures for selecting membership functions and defuzzifier options are not firmly established in the control community

- There are limited sources for fuzzy control chips