Premier atelier canadien sur la logique floue et ses applications dans l'industrie

Le jeudi 17 mars 1994

First Canadian Workshop on Fuzzy Logic and its Industrial Applications

Thursday, March 17, 1994

ATELIER / WORKSHOP

Organisé par/*Organized by*

Centre de recherche informatique de Montréal

CRIM

Avec la collaboration de/*In collaboration with*

CITI
Centre d'innovation en technologies de l'information
Centre for Information Technologies Innovation

Industrie Canada Industry Canada

Conseil de recherches en sciences naturelles et en génie du Canada
Natural Sciences and Engineering Research Council of Canada

Programme

Commanditaires et comité organisateur

Logique floue : historique et concepts de base
Dr Benoît Julien, CRIM

10 h 30 Fuzzy Control and Applications
13 h 45 Software Tools for Fuzzy Control
Prof. M. Stephen L. Chiu, Rockwell International Science Center

11 h 15 Impact of Fuzzy Theory on Science and Technology
13 h 00 Applications of Fuzzy Theory
Dr. I. Burhan Türksen, Université de Toronto

Fuzzy Logic: A New World Technology
MM. Stéphane Côté et George Keirys, Omron Canada Inc.

14 h 45 AutoFuzz: A System For Automatic Fuzzy Controller Application Development -
Dr Talib Janabi, Mentalogic Systems Inc.

15 h 00 Overview of MSI Fuzzy Logic Technology Developments
Dr Labib Sultan, Mentalogic Systems Inc.

Exemple d'applications de la logique floue pour le choix des conditions de coupe en tournage
M. Marek Balazinski, École Polytechnique de Montréal

Systèmes de contrôle - logique floue
MM. Mario Deschênes et Jean-François Ouellet, AutoSoft

CRIM

Centre de recherche
informatique de Montréal
1801, avenue McGill College
Bureau 800
Montréal (Québec)
H3A 2N4
Tél.: (514) 398-1234
Téléc.: (514) 398-1244

Premier atelier canadien sur la logique floue et ses applications dans l'industrie

Liste des participants

Centre de recherche informatique de Montréal
17 mars 1994

M. Roger Adm
Conseiller en développement technologique
Soutien à la recherche et au développement
Min. Industrie, Commerce, Science et Technologie
770, rue Sherbrooke ouest, 6e étage
Montréal, Québec
H3A 1G1

Téléphone : (514) 982-3001
Télécopieur: (514) 873-1353

M. Aissa Aomari
Chargé de secteur
Technologies avancées de production
Industrie Canada
800, Place Victoria, bureau 3800
C.P. 247
Montréal, Québec
H4Z 1E8

Téléphone : (514) 283-7814
Télécopieur: (514) 283-3302

M. Luc Audette
Chercheur

IREQ
1800, Montée Ste-Julie
Varennes, Québec
J3X 1S1

Téléphone : (514) 652-8230
Télécopieur: (514) 652-8005

M. Daniel Authier
Chef de projets

S.M.I.S. Inc.
3330, rue King Ouest, bureau 212
Sherbrooke, Québec
J1L 1C9

Téléphone : (819) 829-5120
Télécopieur: (819) 829-1133

Dr. Marek Balazinski

École Polytechnique de Montréal
C.P. 6079, succ. centre-ville
Montréal, Québec
H3C 3A7

Téléphone : (514) 340-4015
Télécopieur: (514) 340-5867

M. Fred Bassal
Professeur agrégé
Génie industriel
École Polytechnique de Montréal
C.P. 6079, succ. centre-ville
Montréal, Québec
H3C 3A7

Téléphone : (514) 340-4868
Télécopieur: (514) 340-4173

M. Jean Bernier
Professeur

Cégep de Limoilon
445, Jean XXIII
Charlesbourg, Québec
G2N 1V4

Téléphone : (418) 647-6720
Télécopieur: (418) 647-6798

M. Claude Blais
Chargé projet-Transf. Partenariats tech.
Compétitivité et analyse économique {CAE}
Industrie Canada
800, Place Victoria, bureau 3800
Montréal, Québec
H4Z 1E8

Téléphone : (514) 283-7856
Télécopieur: (514) 283-3302

M. Marc Bourgault
Journaliste
"Aujourd'hui la science" - Information radio
Société Radio-Canada
1400, boul. René-Lévesque est
Montréal, Québec
H2L 2M2

Téléphone : (514) 597-5739
Télécopieur: (514) 597-5728

M. Jean-Marc Bourgeois
Chercheur

IREQ
1800, Montée Ste-Julie
Varennes, Québec
J3X 1S1

Téléphone : (514) 652-8477
Télécopieur: (514) 652-8435

M. Serge Bédard
Agent de développement industriel

Min. Industrie, Commerce, Science et Technologie
710, Place d'Youville, 5e étage
Québec, Québec
G1R 4Y4

Téléphone : (418) 691-5898
Télécopieur: (418) 643-6669

M. Bob Chafetz

Centre innovation technologies information (CITI)
1575, boul. Chomedey
Laval, Québec
H7V 2X2

Téléphone : (514) 270-7798
Télécopieur: (514) 973-5757

M. Jeannot Chapdelaine
Directeur associé

Informission Ltée
7811, Louis H. Lafontaine, bureau 200
Anjou, Québec
H1K 4E4

Téléphone : (514) 351-7755
Télécopieur: (514) 351-5845

M. Raynald Chassé
Écotoxicologue

Ministère de l'Environnement du Québec
360, rue Franquet
Bureau 40
Ste-Foy, Québec
G1P 4N3

Téléphone : (418) 528-0416
Télécopieur: (418) 528-1091

M. Stephen Chiu
Professor
Control and Signal Processing Dept.
Rockwell International Science Center
1049 Camino Dos Rios
P.O. Box 1085
Thousands Oaks, California
USA
91360
Téléphone : (805) 373-4408
Télécopieur: (805) 373-4383

M. Denis Choquette
Quebec Regional Manager

Mentalogic Systems Inc.
145 Renfrew Drive - Unit #210
Markham, Ontario
L3R 9R6

Téléphone : (905) 940-6756
Télécopieur: (905) 940-0321

M. Pierre Chouinard
Enseignant

Cégep de Limoilon
445, Jean XXIII
Charlesbourg, Québec
G2N 1V4

Téléphone : (418) 647-6758
Télécopieur: (418) 647-6798

M. Stéphane Côté

OMRON Electronics Inc.
1825, 32e Avenue
Lachine, Québec
H8T 3G1

Téléphone : (514) 636-6676
Télécopieur: (514) 636-2959

Mme Kim Dalkir
Responsable
Systèmes de soutien à la performance
Centre innovation technologies information (CITI)
1575, boul. Chomedey
Laval, Québec
H7V 2X2

Téléphone : (514) 973-5840
Télécopieur: (514) 973-5757

Dr. Renato De Mori
Director
School of Computer Science
Université McGill
3480, rue University
Bureau 318
Montréal, Québec
H3A 2A7

Téléphone : (514) 398-7072
Télécopieur: ( ) -3883

M. Mario Deschênes

AutoSoft
5655, avenue Élie, bureau 404
St-Hubert, Québec
J3Y 6P3

Téléphone : (514) 656-2323
Télécopieur: (514) 656-1009

M. Camille Dubé
Staff Engineer

IBM Canada Ltée
23, boul. de l'Aéroport
Bromont, Québec
J0E 1L0

Téléphone : (514) 534-6187
Télécopieur: (514) 534-7100

M. François Desjardins
Conseiller

Informission Ltée
7811, Louis H. Lafontaine
Bureau 200
Anjou, Québec
H1K 4E4

Téléphone : (514) 351-7755
Télécopieur: (514) 351-5845

M. Carl Duhamel
Ingénieu concepteur électrique

Bombardier Inc.
1110, rue Parent
St-Bruno, Québec
J3V 6E6

Téléphone : (514) 441-2020   Poste: 6771
Télécopieur: (514) 441-6417

M. Pierre Desjardins

Centre innovation technologies information (CITI)
1575, boul. Chomedey
Laval, Québec
H7V 2X2

Téléphone : (514) 973-5700
Télécopieur: (514) 973-5757

Dr. Jennifer Farkas
Chercheure
Architecture de l'information
Centre innovation technologies information (CITI)
1575, boul. Chomedey
Laval, Québec
H7V 2X2

Téléphone : (514) 973-5825
Télécopieur: (514) 973-5757

M. Richard Desjardins
Président

CSTEMS-EXPERT
872, montée Ste-Thérèse
Bellefeuille, Québec
J0R 1A0

Téléphone : (514) 431-2174
Télécopieur: (514) 431-1662

M. Abel Ferreira
Directeur, Ingénierie et production

Alex Informatique Inc.
8055, route Transcanadienne
Saint-Laurent, Québec
H4S 1S4

Téléphone : (514) 956-5500
Télécopieur: (514) 956-5505

M. Alain Dionne
Programmeur

CSTEMS-EXPERT
872, montée Ste-Thérèse
Bellefeuille, Québec
J0R 1A0

Téléphone : (514) 431-2174
Télécopieur: (514) 431-1662

M. Marc Fortin
Ingénieur de projet

Digico
950, rue Bergar
Laval, Québec
H7L 5A1

Téléphone : (514) 967-7100
Télécopieur: (514) 967-7444

M. Paul Freedman

CRIM
1801, avenue McGill College
Bureau 800
Montréal, Québec
H3A 2N4

Téléphone : (514) 398-1234
Télécopieur: ( ) -1244

M. Réal Frenette

CRIM
1801, avenue McGill College
Bureau 800
Montréal, Québec
H3A 2N4

Téléphone : (514) 398-1234
Télécopieur: ( ) -1244

M. Gilles Gagnon
Chargé de secteur
Produits électroniques et informatiques
Industrie Canada
800, Place Victoria, bureau 3800
C.P. 247
Montréal, Québec
H4Z 1E8

Téléphone : (514) 283-7861
Télécopieur: (514) 283-3302

M. Pierre Gauthier
Technicien de recherche

IREQ
1800, Montée Ste-Julie
Varennes, Québec
J3X 1S1

Téléphone : (514) 652-8438
Télécopieur: (514) 652-8435

M. Pierre Gautreau
Expert- conseil en gestion de la technologie
Direction des technologies de l'information
Industrie Canada
235, Queen Street
Ottawa, Ontario
K1A 0H5

Téléphone : (613) 954-3467
Télécopieur: (613) 952-8419

M. Daniel Gauvin
Directeur, R-D

Groupe LGS Inc.
1253, avenue McGill College
7e étage
Montréal, Québec
H3B 2Y5

Téléphone : (514) 861-2673
Télécopieur: (514) 861-3832

M. Denis Gingras
Chercheur
Traitement de l'information
Institut national d'optique
369, rue franquet
Sainte-Foy, Québec
G1P 4N8

Téléphone : (418) 657-7006
Télécopieur: (418) 657-7009

M. Yves Gonthier
Graduate Student
CIM
Université McGill
3480, University, Room 410
McConnell Building
Montréal, Québec
H3A 2A7

Téléphone : (514) 398-7472
Télécopieur: ( ) -7348

M. Bertrand Grenier
Directeur Systèmes Procédés
Plastiques et Chimiques
Pétromont Inc.
10555, boul. Métropolitain est
Montréal-Est, Québec
H1B 1A1

Téléphone : (514) 640-6400 Poste: 1202
Télécopieur: (514) 645-4705

M. Dominik Hartman
Graduate Student
CIM
Université McGill
3480, University, Room 410
McConnell Building
Montréal, Québec
H3A 2A7

Téléphone : (514) 398-6319
Télécopieur: ( ) -7348

Dr. Talib Janabi
Director of Technology

Mentalogic Systems Inc.
145 Renfrew Drive - Unit #210
Markham, Ontario
L3R 9R6

Téléphone : (905) 940-6756
Télécopieur: (905) 940-0321

M. George Keirys

OMRON Electronics Inc.
885 Milneraue
Scarborough, Ontario
M1B 5V8

Téléphone : (416) 286-6465

M. Normand Janelle
Ingénieur, R-D

FRIGIDAIRE CANADA
802, boulevard l'Ange Gardien
L'Assomption, Québec
J0K 1G0

Téléphone : (514) 589-5701
Télécopieur: (514) 589-0601

M. Réal L'Archevêque
Premier conseiller à la Haute direction

Agence spatiale canadienne
6767, route de l'Aéroport
St-Hubert, Québec
J3Y 8Y9

Téléphone : (514) 926-4329
Télécopieur: (514) 926-4315

M. Antoni Jedrzejowski
étudiant
Département de génie mécanique
École Polytechnique de Montréal
C.P. 6079, succ. centre-ville
Montréal, Québec
H3C 3A7

Téléphone : (514) 340-4015
Télécopieur: (514) 340-5867

M. Gérard Lachiver
Professeur
Département de génie électrique et informatique
Université de Sherbrooke
2500, boul. de l'Université
Sherbrooke, Québec
J1K 2R1

Téléphone : (819) 821-7141
Télécopieur: (819) 821-7937

Dr. Benoît Julien
Chercheur

CRIM
1801, avenue McGill College
Bureau 800
Montréal, Québec
H3A 2N4

Téléphone : (514) 398-1234
Télécopieur: ( ) -1244

M. Marc Lacroix
Ingénieur
Division Automatismes
Hydro-Québec
Complexe Desjardins, 11e étage
C.P. 10000
Montréal, Québec
H5B 1H7

Téléphone : (514) 289-3913
Télécopieur: (514) 289-4695

M. Aldo Kampodonico

Equifax Canada Inc.
7171, rue Jean-Talon Est
Anjou, Québec
H1M 3N2

Téléphone : (514) 493-2472
Télécopieur: (514) 355-0731

M. René Lacroix
Attaché de recherche
Département de génie agricole
Université McGill
21111 Lakeshore Road
Campus Macdonald
Ste-Anne-de-Bellevue, Québec
H9X 3V9

Téléphone : (514) 398-7530
Télécopieur: ( ) -8387

M. Daniel Lanoix
Ingénieur concepteur électrique

Bombardier Inc.
1110, rue Parent
St-Bruno, Québec
J3V 6E6

Téléphone : (514) 441-2020 Poste: 6505
Télécopieur: (514) 441-6417

M. Marc Legault
Chef de division

Hydro-Québec
Complexe Desjardins, 11e étage
C.P. 10000
Montréal, Québec
H5B 1H7

Téléphone : (514) 289-4482
Télécopieur: (514) 289-4695

M. Yves Lapierre
Spécialiste, transfert de technologie

Téléport de Montréal
1205, Papineau, bureau 351
Montréal, Québec
H2K 4R2

Téléphone : (514) 599-5723
Télécopieur: (514) 599-5724

M. Marc C. Lemieux
Directeur exécutif

Industrie Canada
800, Place Victoria, bureau 3800, C.P. 247
Montréal, Québec
H4Z 1E8

Téléphone : (514) 283-1885
Télécopieur: (514) 283-3302

M. Jean-Pierre LeBoeuf
Consultant

Kéops Informatique Inc.
266, rue Notre-Dame Ouest
Bureau 201
Montréal, Québec
H2Y 1T6

Téléphone : (514) 845-6158
Télécopieur: (514) 845-7274

M. Robert Lessard
Designer

Autolog Inc.
1287, rue Bergar
Laval, Québec
H7L 4Z7

Téléphone : (514) 967-0766
Télécopieur: (514) 967-0769

M. Sinh LeQuoc
Directeur
Direction de l'enseignement et de la recherche
Ecole de technologie supérieure
4750, avenue Henri-Julien
Montréal, Québec
H2T 2C8

Téléphone : (514) 289-8806
Télécopieur: (514) 289-8539

M. Yves Lusignan
Président

Groupe conseil Sygertech Inc.
600, boul René-Lévesque ouest
11e étage
Montréal, Québec
H3B 1N4

Téléphone : (514) 861-7360
Télécopieur: (514) 861-8934

Mme Monique Lefebvre
Présidente-directrice générale

CRIM
1801, avenue McGill College
Bureau 800
Montréal, Québec
H3A 2N4

Téléphone : (514) 398-1234
Télécopieur: ( ) -1244

M. Félix Maltais
Journaliste

Agence Science-Presse
3995, rue Ste-Catherine Est
Montréal, Québec
H1W 2G7

Téléphone : (514) 522-1304
Télécopieur: (514) 522-1761

M. Mircea Manolescu
Senior System Engineer

Mentalogic Systems Inc.
145 Renfrew Drive - Unit #210
Markham, Ontario
L3R 9R6

Téléphone : (905) 940-6756
Télécopieur: (905) 940-0321

M. Joseph Merheb-Herb

CRIM
1801, avenue McGill College
Bureau 800
Montréal, Québec
H3A 2N4

Téléphone : (514) 398-1234
Télécopieur: ( ) -1244

M. Jean Millo
Président

Systèmes Intégrés A.B.D.M.F.
233, rue Dunbar, bureau 302
Montréal, Québec
H3P 2H4

Téléphone : (514) 737-4763
Télécopieur: (514) 737-9353

M. Bernard Morneau
Président

COGEXEL
8150, boul. Métropolitain Est
Bureau 200
Anjou, Québec
H1K 1A1

Téléphone : (514) 493-0663
Télécopieur: (514) 493-0980

M. Jean-François Ouellet

AutoSoft
5655, avenue Élie, bureau 404
St-Hubert, Québec
J3Y 6P3

Téléphone : (514) 656-2323
Télécopieur: (514) 656-1009

M. Louis Paquette
Professeur
Département Mathématiques et Informatique
Université du Québec à Trois-Rivières
C.P. 500
Trois-Rivières, Québec
G9A 5H7

Téléphone : (819) 376-5125
Télécopieur: (819) 376-5012

Mme Valérie Paquette
étudiante
Département d'animation culturelle
Université du Québec à Montréal
C.P. 8888, succ. A
Montréal, Québec
H3C 3P8

Téléphone : (514) 383-0404
Télécopieur: (514) 383-4971

Mme. Annick Paraud
Conseillère en communications

Industrie Canada
800, Place Victoria, bureau 3800
C.P. 247
Montréal, Québec
H4Z 1E8

Téléphone : (514) 283-5142
Télécopieur: (514) 283-2269

M. David E. Paterson

Dir. gén. de l'ind. des technologies d'information
Industrie Canada
235, rue Queen, bureau 978 A
Ottawa, Ontario
K1A 0H5

Téléphone : (613) 954-3294
Télécopieur: (613) 952-8419

M. Michel Payment

FRIGIDAIRE CANADA
802, boulevard l'Ange Gardien
L'Assomption, Québec
J0K 1G0

Téléphone : (514) 589-5701
Télécopieur: (514) 589-0601

M. Jean Perron
Scientifique

Alcan Aluminium Ltée
1955, boul. Mellon
C.P. 1250
Jonquière, Québec
G7S 4K8

Téléphone : (418) 699-2339
Télécopieur: (418) 699-6378

M. Richard Pinsonneault

S.M.I.S. Inc.
3330, rue King Ouest, bureau 212
Sherbrooke, Québec
J1L 1C9

Téléphone : (819) 829-5120
Télécopieur: (819) 829-1133

M. Michel Rheault
Chargé de projet

Raymond, Chabot, Martin, Paré & Associés
600, rue de la Gauchetière ouest
Bureau 1900
Montréal, Québec
H3B 4L8

Téléphone : (514) 878-2691
Télécopieur: (514) 878-2127

M. Alain Ross
Agent de recherche

Centre de recherche industrielle du Québec (CRIQ)
8475, Christophe-Colomb
Montréal, Québec
H2M 2N9

Téléphone : (514) 383-1550 Poste: 553
Télécopieur: (514) 383-3229

M. Michel Ruel
Enseignant

Cégep Lévis-Lauzon
205, Mrg Bourget
Lévis, Québec
G6V 6Z9

Téléphone : (418) 833-5110
Télécopieur: (418) 833-7323

M. Carlos Saldanha
Chercheur principal

CRIM
1801, avenue McGill College
Bureau 800
Montréal, Québec
H3A 2N4

Téléphone : (514) 398-1234
Télécopieur: ( ) -1244

M. Lofti Sansa

Département de génie mécanique
Université Concordia
1455, boul. de Maisonneuve ouest
Montréal, Québec
H3G 1M8

Téléphone : (514) 848-7930

M. Marc Alain Simard

Systèmes Paramax Canada Inc.
6111, avenue Royalmount
Montréal, Québec
H4P 1K6

Téléphone : (514) 340-8310
Télécopieur: (514) 340-8318

Dr. Labib Sultan
Director of R&D

Mentalogic Systems Inc.
145 Renfrew Drive - Unit #210
Markham, Ontario
L3R 9R6

Téléphone : (905) 940-6756
Télécopieur: (905) 940-0321

M. Gabriel Taraboulsi
Assistant gradué en recherche
CONCAVE {génie mécanique}
Université Concordia
1455, boul. de Maisonneuve ouest
Montréal, Québec
H3G 1M8

Téléphone : (514) 848-7939
Télécopieur: (514) 848-8635

M. Michel Teasdale
Chargé de secteur
Logiciel
Industrie Canada
800, Place Victoria, bureau 3800
C.P. 247
Montréal, Québec
H4Z 1E8

Téléphone : (514) 496-1388
Télécopieur: (514) 283-3302

M. E. Turcott
Research Associate

Université McGill
817, rue Sherbrooke Ouest
Montréal, Québec
H3A 2K6

Téléphone : (514) 398-4237
Télécopieur: ( ) -7361

M. Michel Thibault
Vice-président

Automation R.P. Inc.
593, Principale
St-Étienne-de-Lauzon, Québec
G6J 1E7

Téléphone : (418) 831-3344
Télécopieur: (418) 831-8200

Dr. I. Burhan Turksen

Department of Industrial Engineering
University of Toronto
10, Kings College Road
Toronto, Ontario
M5S 1A4

Téléphone : (416) 978-1278
Télécopieur: (416) 978-1280

M. Jean-Raymond Touchette
Professeur
Pavillon Ordinique
Collège Lionel-Groulx
150, rue Duquet
Ste-Thérèse, Québec
J7E 5B3

Téléphone : (514) 437-8088
Télécopieur: (514) 437-1102

M. Laurent Villeneuve
Professeur titulaire

École Polytechnique de Montréal
C.P. 6079, succ. centre-ville
Montréal, Québec
H3C 3A7

Téléphone : (514) 340-4911
Télécopieur: (514) 340-4173

M. Claude Tremblay
Conseiller en technologie industrielle (CTI)
CNRC
ACRGTQ
435, Grande Allée Est
Québec, Québec
G1W 2A9

Téléphone : (418) 529-2949
Télécopieur: (418) 522-4105

M. Alexander Trica
Senior System Engineer

Mentalogic Systems Inc.
145 Renfrew Drive - Unit #210
Markham, Ontario
L3R 9R6

Téléphone : (905) 940-6756
Télécopieur: (905) 940-0321

Total de la liste: 88.

PROGRAMME

8 h 00	**Inscription tardive et petit déjeuner continental**
9 h 00	Mots de bienvenue
	Mme Monique Lefebvre, Présidente et directrice générale du CRIM
	M. Marc C. Lemieux, directeur exécutif, Industrie Canada
9 h 15	**Allocution d'ouverture**
	Dr Renato De Mori, directeur du Département d'informatique de l'Université McGill
9 h 25	**Logique floue : historique et concepts de base**
	Dr Benoît Julien, chercheur, groupe des systèmes à base de connaissances, CRIM
10 h 20	**Pause**
10 h 30	**Fuzzy Control and Applications**
	M. Stephen L. Chiu, chercheur, Rockwell International Science Center
11 h 15	**Impact of Fuzzy Theory on Science and Technology**
	Dr I. Burhan Türksen, professeur, Génie industriel, Université de Toronto
12 h 00	**Déjeuner**
13 h 00	**Applications of Fuzzy Theory**
	Dr I. Burhan Türksen, professeur, Génie industriel, Université de Toronto
13 h 45	**Software Tools for Fuzzy Control**
	M. Stephen L. Chiu, chercheur, Rockwell International Science Center
	Présentation de logiciels à logique floue
14 h 30	**Fuzzy Logic: A New World Technology**
	Stéphane Côté et George Keirys, OMRON Canada Inc.
14 h 45	**AutoFuzz: A System For Automatic Fuzzy Controller Applications Development**
	Dr Talib Janabi, Mentalogic Systems Inc.
15 h 00	**Overview of MSI Fuzzy Logic Technology Developments**
	Dr Labib Sultan, Mentalogic Systems Inc.
15 h 15	**Logique floue en fabrication**
	M. Marek Balazinski, École Polytechnique de Montréal
15 h 30	**Systèmes de contrôle - logique floue**
	M. Mario Deschênes et M. Jean-François Ouellet, AutoSoft
15 h 45	**Pause-café et démonstration de logiciels à logique floue**
16 h 30	**Table ronde**
	Conférenciers et sociétés participantes
16 h 45	**Cocktail**

PROGRAM

8:00	**Late registration et continental breakfast**
9:00	**Welcoming speeches**
	Mrs. Monique Lefebvre, P & CEO, CRIM
	Mr. Marc Lemieux, Executive Regional Director, Industry Canada
9:15	**Opening speech**
	Dr. Renato De Mori, Director of the Computer Science Department at McGill University
9:25	**Logique floue : historique et concepts de base**
	Dr. Benoît Julien, Research Scientist, Knowledged-based systems, CRIM
10:20	**Coffee break**
10:30	**Fuzzy Control and Applications**
	Mr. Stephen L. Chiu, Research Scientist, Rockwell International Science Center
11: 15	**Impact of Fuzzy Theory on Science and Technology**
	Dr. I. Burhan Türksen, Professor, Industrial Engineering, University of Toronto
12:00	**Lunch**
13: 00	**Applications of Fuzzy Theory**
	Dr. I. Burhan Türksen, Professor, Industrial Engineering, University of Toronto
13:45	**Software Tools for Fuzzy Control**
	Mr. Stephen L. Chiu, Research Scientist, Rockwell International Science Center
	Presentations of fuzzy logic software
14:30	**Fuzzy Logic: A New World Technology**
	Mr. Stéphane Côté and Mr. George Keirys, OMRON Canada Inc.
14:45	**AutoFuzz: A System For Automatic Fuzzy Controller Applications Development**
	Dr. Talib Janabi, Mentalogic Systems Inc.
15:00	**Overview of MSI Fuzzy Logic Technology Developments**
	Dr. Labib Sultan, Mentalogic Systems Inc.
15:15	**Logique floue en fabrication**
	Mr. Marek Balazinski, École Polytechnique de Montréal
15:30	**Systèmes de contrôle - logique floue**
	Mr. Mario Deschênes and Mr. Jean-François Ouellet, AutoSoft
15:45	**Coffee break and demonstrations of fuzzy logic software**
16:30	**Panel**
	Guest speakers and participating companies
16:45	**Cocktail**

LISTE DES COMMANDITAIRES

Centre de recherche informatique de Montréal
Centre d'innovation en technologies de l'information
Industrie Canada
Conseil de recherches en sciences naturelles et en génie du Canada

COMITÉ ORGANISATEUR

Président de l'Atelier
Dr Benoît Julien, CRIM

Gilles Gagnon, Industrie Canada
Francine Robillard, Industrie Canada
Érica Huber, CRIM
Anne Lévesque, CRIM

Centre de recherche
informatique de Montréal

Premier atelier canadien sur la logique floue et ses applications dans l'industrie

Logique floue :
historique et concepts de base

Présenté par

Benoît Julien, Ph.D., ing.

Chercheur

Groupe des systèmes à base de connaissances

Mars 1994

Introduction

Chapitres:

☞ *Introduction*
- *Contexte*
- *Théorie des ensembles flous*
- *Théorie des possibilités*
- *Logique floue*
- *Conclusion*

Points abordés:

- *Motivations*
- *Applications*
- *Bref historique*
- *Définitions générales*

Introduction
Motivations

Plus un système devient complexe, plus la formulation d'énoncés précis et pertinents sur son comportement est difficile.

Le précision et la pertinence peuvent même devenir mutuellement exclusives.

Plutôt que de chercher à éliminer l'imprécision associée aux comportements de systèmes complexes, les approches "floues" visent à représenter et manipuler cette imprécision.

Introduction
Applications

- **Systèmes de contrôle**

En 1991, le Japon possède approximativement 80 % des parts du marché de la logique floue avec des revenus d'environ 200 millions de dollars canadiens.

Il existe plus de 2 000 brevets reliés à la logique floue au Japon.

Produits développés

- Métro de Sendai (accélération plus graduelle et arrêt avec trois fois la précision du contrôle manuel),
- Machines à laver (contôle flou implanté sur 70% des machines de Matsushita Electric),
- Caméras-vidéos (optimise le focus de certaines caméras-vidéos de Sanyo avec moins de mémoire),
- Climatiseurs (économie de 20% en électricité pour le produit de Mitsubishi),
- Ordinateurs et microprocesseurs,
- Transmissions d'automobile, etc.

- **Systèmes d'aide à la décision**

  - Ingénierie (ex : gestion de réservoirs),
  - Environnement,
  - Gestion et sélection de projets (ex : gestion de portefeuilles)

Introduction
Bref historique

1965 Le Professeur Lotfi A. Zadeh introduit la notion d'ensemble flou.

1970 Première application par Bellman et Zadeh de la théorie des ensembles flous à des problèmes de décision.

1974 Premier développement d'un système à contrôle flou par Mamdani.

1975 Premier développement de la logique floue et du raisonnement approximatif par Zadeh.

1977 Introduction du concept de mesure floue par Sugeno.

1978 Développement de la théorie des possibilités.

1985 Première implantation sur microprocesseur (Togai et Watanabe).

Introduction
Définitions générales

Théorie des ensembles flous

Cadre mathématique pour le traitement de problèmes dans lesquels l'incertitude provient de l'imprécision plutôt que de l'aléatoire.

- **Énoncé précis**

La température est à 27°C.

- **Énoncé imprécis**

La température est <u>élevée</u>.

Introduction
Définitions générales

Logique floue

Logique à valeurs multiples permettant le raisonnement approximatif à partir d'informations imprécises.

- **Règle précise**

Si température > 17°C
alors fermer la valve de 2 unités.

- **Règle imprécise**

Si température <u>élevée</u>
alors fermer la valve <u>légèrement</u>.

Contexte

Chapitres:

- *Introduction*
- ☞ *Contexte*
- *Théorie des ensembles flous*
- *Théorie des possibilités*
- *Logique floue*
- *Conclusion*

Points abordés:

- *Caractéristiques de l'information*

Contexte

Caractéristiques de l'information

- **Information inexacte**

  Exprime la différence entre une croyance et la réalité.

  Exemple : Jean a 25 ans. (En fait Jean a 22 ans).

- **Information incomplète**

  Impossibilité de formuler certaines affirmations à partir d'énoncés connus.

- **Information incertaine**

  Degré de croyance dans un énoncé.

<u>**Expressions possibles de l'incertitude**</u>

- **Probabiliste**

  Exemple : Jean a 22 ans (probabilité de 80 %).

- **Imprécision**

  Exemple : Jean a <u>environ 22 ans</u>.

- **Possibiliste**

  Exemple : Jean a 22 ans (possibilité de 100 %).

Contexte

Caractéristiques de l'information

- **L'imprécis et l'aléatoire**

  1) Le coût du projet est environ 70 millions de dollars.
  2) Le coût du projet est 70 millions de dollars avec une probabilité de 80 %.

- **L'imprécis et le précis**

  1) Le niveau de nitrate est bas.
  2) Le niveau de nitrate est inférieur à 10 mg/l.

Théorie des ensembles floues

Chapitres:

- Introduction
- Contexte
- ☞ Théorie des ensembles flous
- Théorie des possibilités
- Logique floue
- Conclusion

Points abordés:

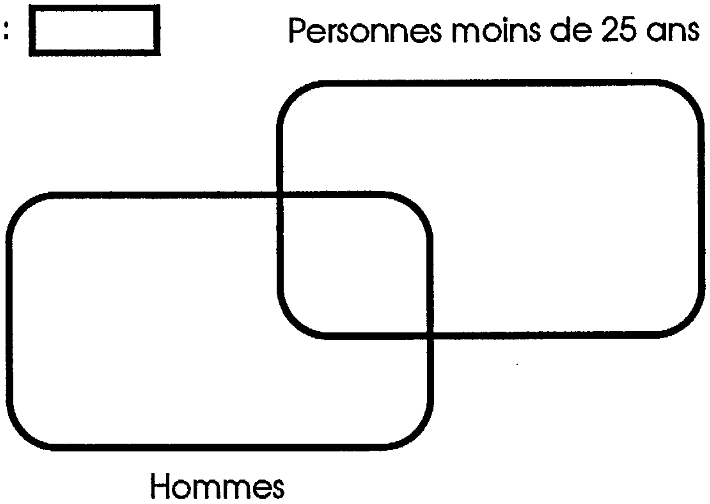
- Ensembles classiques
- Objectif
- Définition d'un ensemble flou
- Ensembles flous et classiques
- Nombre flou
- Représentation discrète
- Acquisition
- Opérateurs de base
- Principe d'extension

Théorie des ensembles flous

Ensembles classiques

$A \cap B$:

$A \cup B$:



Jean est un homme de moins de 25 ans.

Jean $\in (A \cap B)$

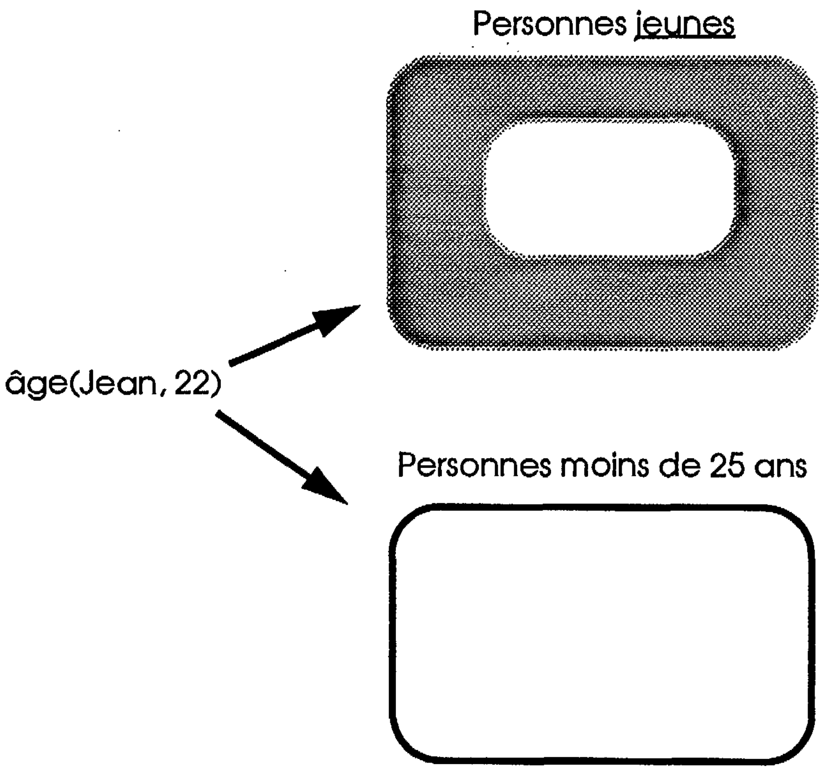
Théorie des ensembles flous

Objectif

Fournir un cadre mathématique pour la représentation et le traitement de l'incertitude attribuable à l'imprécision.

L'imprécision est définie par l'absence d'une démarcation nette entre l'appartenance et la non-appartenance à une classe.

La théorie des ensembles flous représente le degré d'appartenance d'éléments à des ensembles possédant des frontières imprécises.

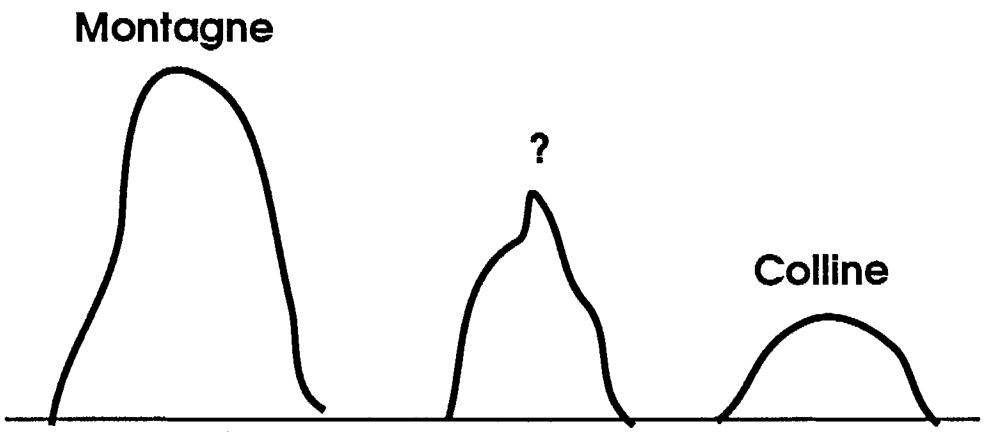


Théorie des ensembles flous

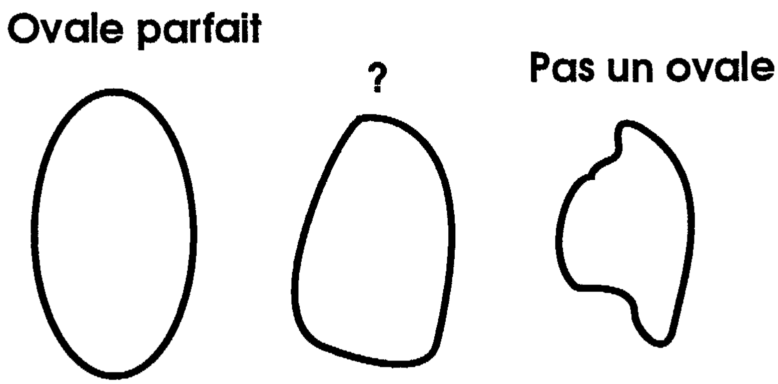
Ensembles flous et classiques

Exemples

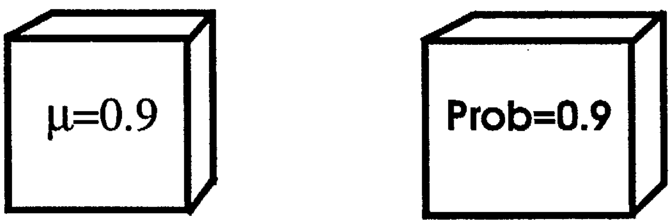
- À partir de quelle hauteur un relief est-il une colline ou une montagne?



- Ovale flou ou parfait?



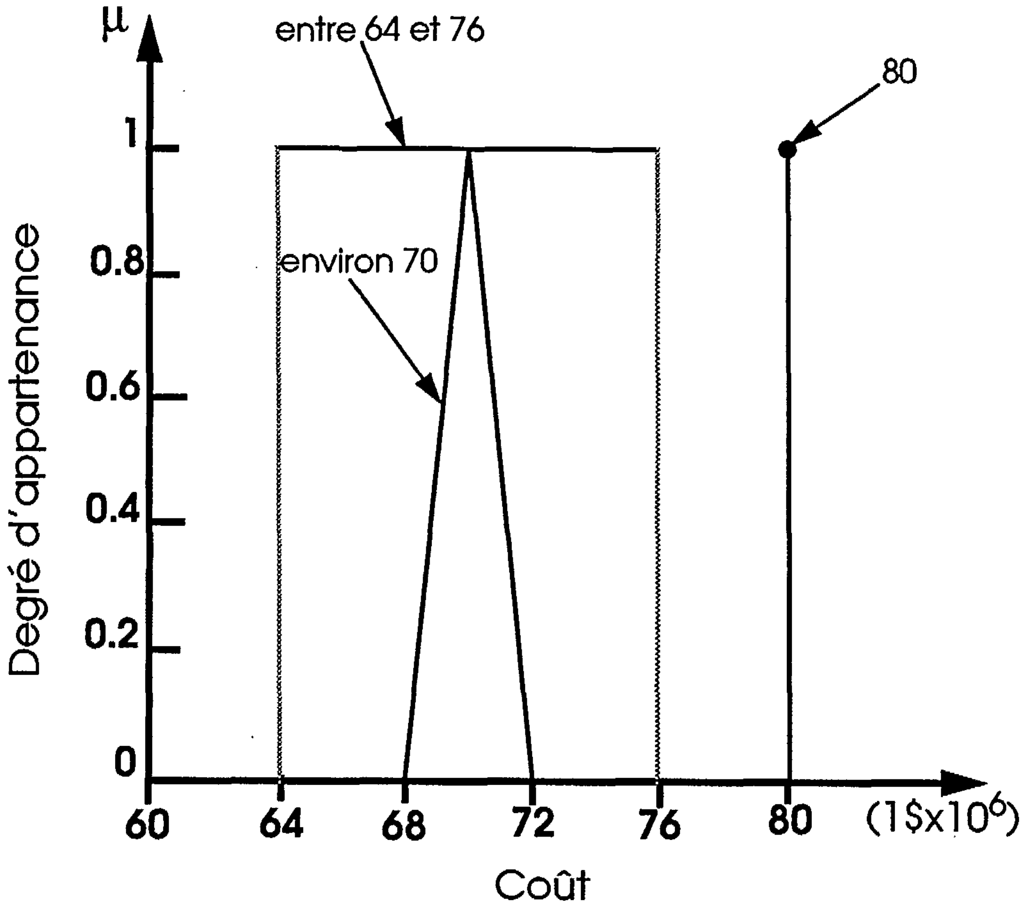
- Liquide potable ou non potable?



Théorie des ensembles flous

Définition d'un ensemble flou

Une collection d'éléments pour lesquels il n'existe pas de brusque transition entre l'appartenance ($\mu = 1$) et la non-appartenance ($\mu = 0$).

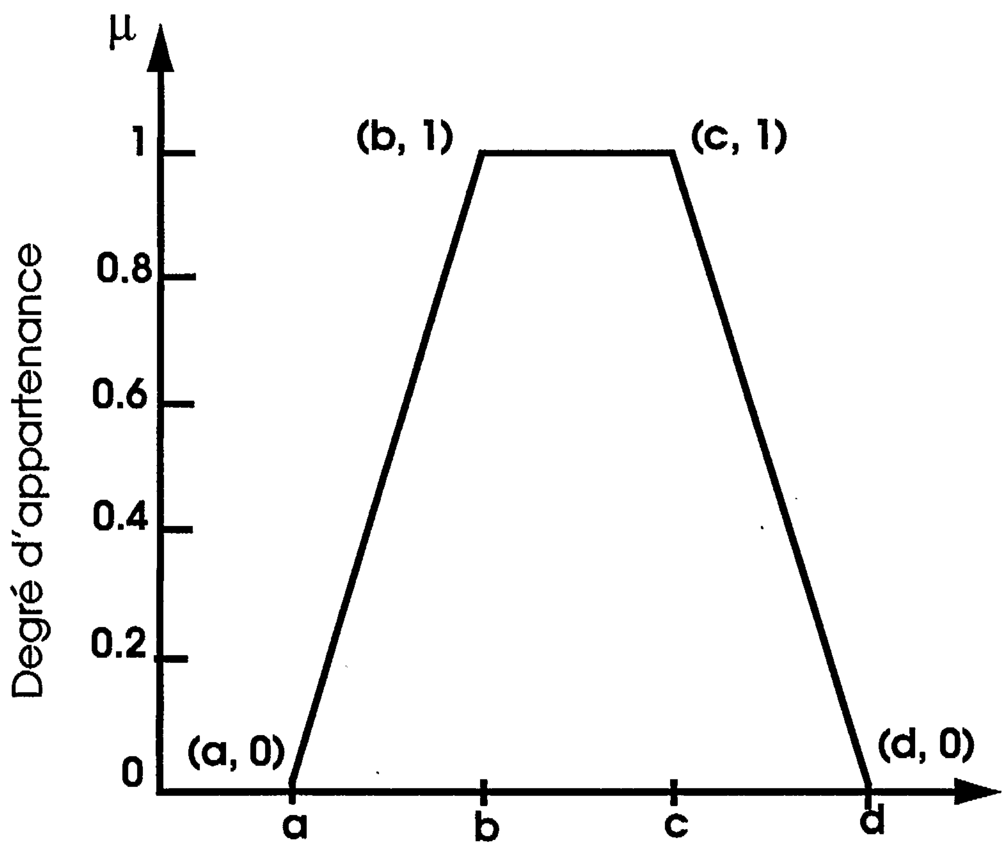


Évaluation des coûts de projet

Théorie des ensembles flous
Nombre flou

Représentation simplifiée : (a, b, c, d)

Si b = c, fonction d'appartenance triangulaire.
Si a=b=c=d, nombre précis.
Si a=b, c=d, ensemble (intervalle).

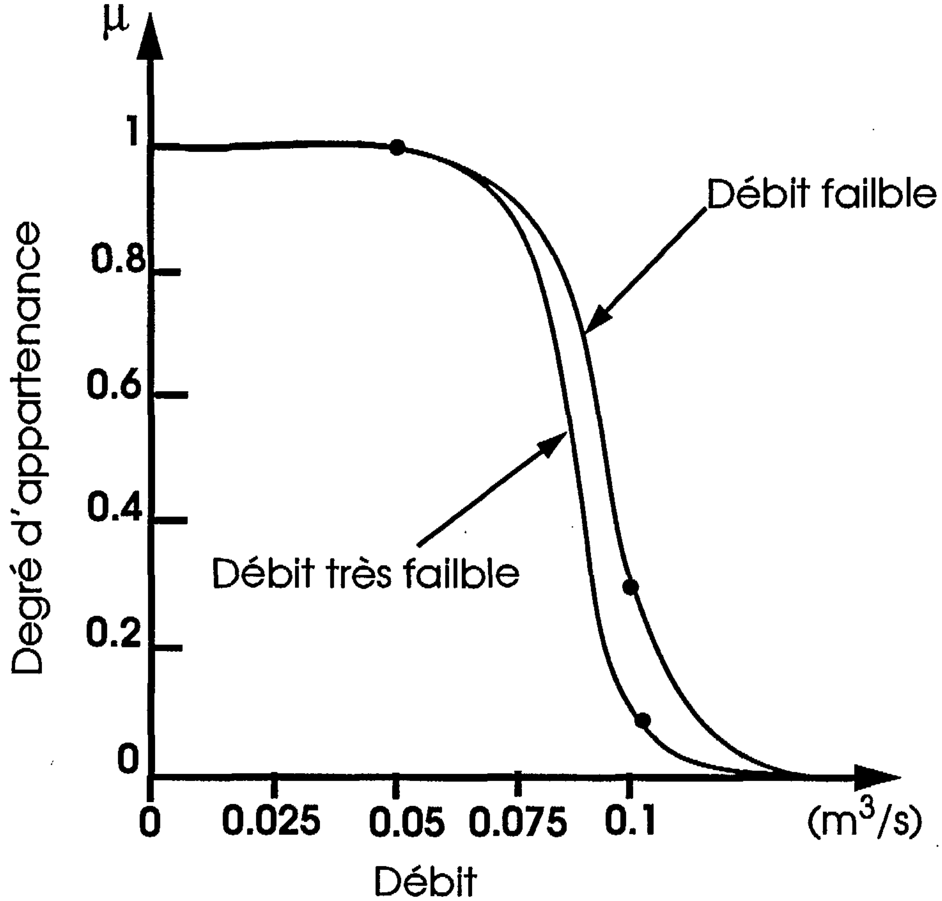


Théorie des ensembles flous

Représentation discrète

Débit faible (m^3/s) = $\mu_{DF}(x)$
$\mu_{DF}(x) = \{1/0.05, 0.3/0.1\}$

Débit très faible (m^3/s) = $\mu_{DTF}(x) = (\mu_{DF}(x))^2$
$\mu_{DTF}(x) = \{1/0.05, 0.09/0.1\}$

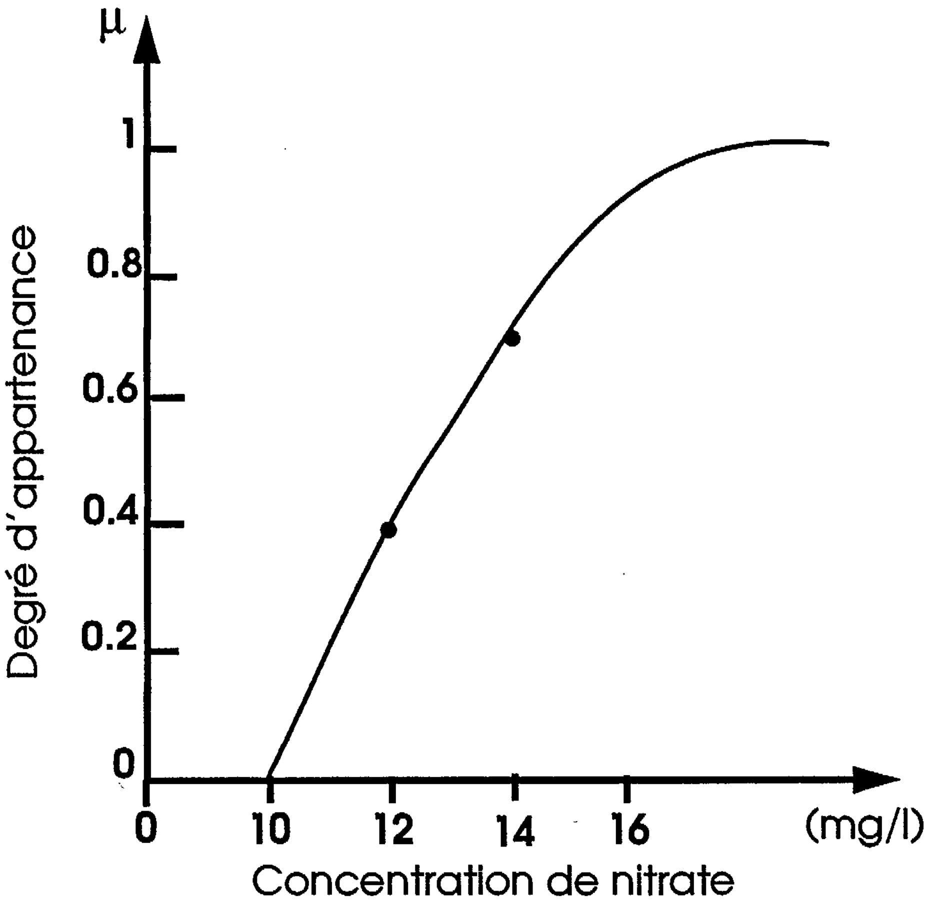


Théorie des ensembles flous

Représentation discrète

Concentration élevée de nitrate (mg/l) = $\mu_{CE}(y)$
$\mu_{CE}(y) = \{0.4/12, 0.7/14\}$

Valeur linguistique : concentration élevée



Concentration élevée

Théorie des ensembles flous

Acquisition

Les degrés d'appartenance sont généralement subjectifs et dépendent du contexte de l'évaluation.

Des études (Turksen 1991, Norwich et Turksen 1984) ont démontré que les degrés d'appartenance peuvent au mieux être mesurés sur une échelle ordinale ou intervalle.

Des méthodes empiriques ont été proposées pour la détermination des fonctions d'appartenance. Ces méthodes requièrent la définition d'expériences sur des populations tests afin de mesurer les perceptions subjectives des degrés d'appartenance.

Méthodes par apprentissage.

Théorie des ensembles flous
Opérateurs de base

Exemple

Débit faible = $\mu_{DF}(x) = \{1/0.05, 0.3/0.1\}$

Concentration élevée = $\mu_{CE}(y) = \{0.4/12, 0.7/14\}$

(Débit faible) et (Concentration élevée de nitrate) = ?

Union

$$\forall\ (x, y) \in X \times Y : \mu_{A \cup B}(x,y) = \max\ (\mu_A(x), \mu_B(y))$$

Intersection

$$\forall\ (x, y) \in X \times Y : \mu_{A \cap B}(x,y) = \min\ (\mu_A(x), \mu_B(y))$$

Complément

$$\forall\ x \in X : \mu_{\neg A}(x) = 1 - \mu_A(x)$$

Avantages

- Les opérateurs max et min respectent la plupart des propriétés de l'union et l'intersection classiques.
- Ces deux opérateurs sont non interactifs et limitent donc la propagation des erreurs de mesure.

Théorie des ensembles flous
Opérateurs de base

Exemple

(Débit faible) et (Concentration élevée) = $\mu_{DF \cap CE}(x, y)$

	min	y	12	14
x	$\mu_{DF}(x)$	$\mu_{CE}(y)$	0.4	0.7
0.05	1		0.4	0.7
0.1	0.3		0.3	0.3

$\mu_{DF \cap CE}(x, y) = \{0.4/(0.05, 12), 0.7/(0.05, 14),$
$0.3/(0.1, 12), \ 0.3/(0.1, 14)\}$

Théorie des ensembles flous

Opérateurs de base

Les lois classiques de contradiction et d'exclusion des ensembles ne sont plus valides dans la théorie des ensembles flous. Elles sont remplacées par :

$$A \cap (\neg A) \neq \emptyset$$
$$A \cup (\neg A) \neq X$$

Exemple

$\mu_A(x) = \{1/x_1, 0.3/x_2\}$

$\mu_{\neg A}(x) = 1 - \mu_A(x) = \{0/x_1, 0.7/x_2\}$

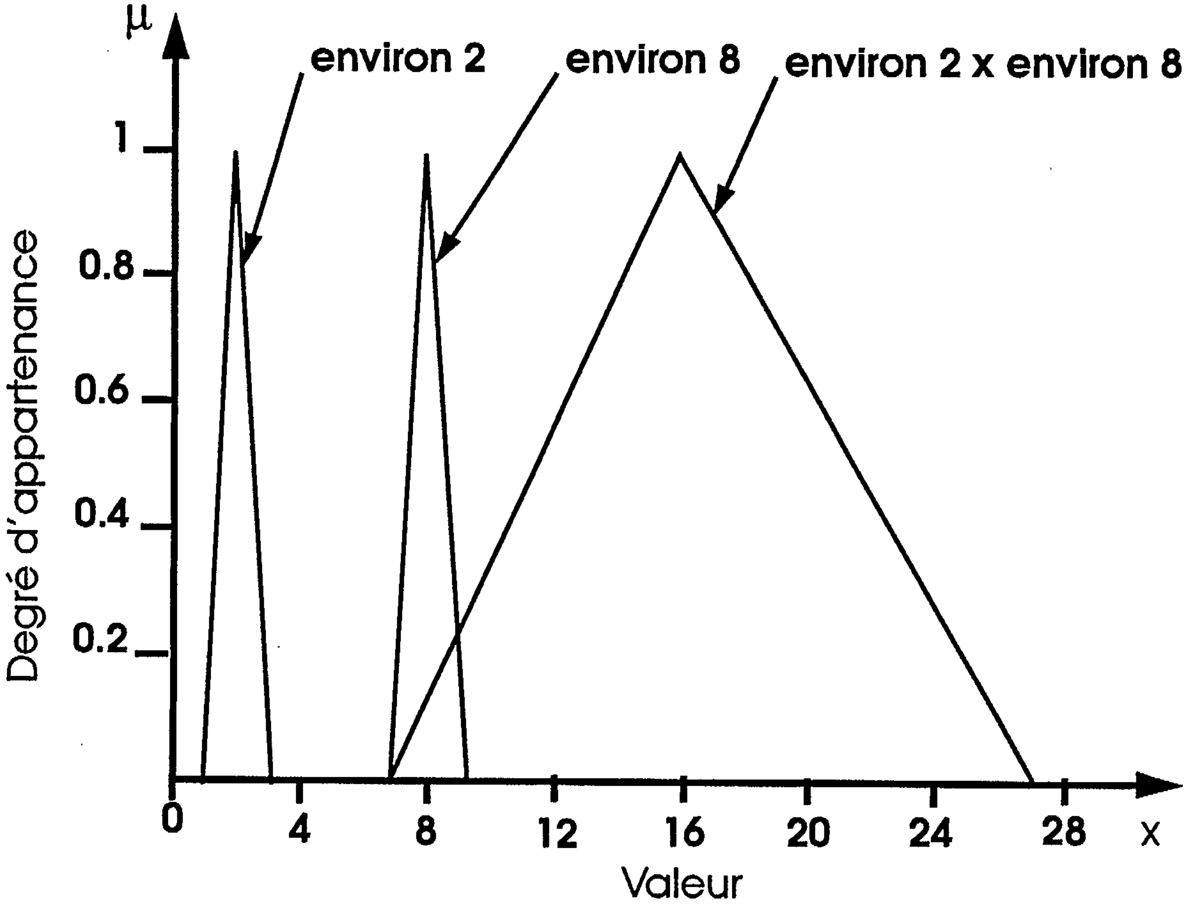
$\mu_{\neg A \cap A}(x) = \min(\mu_A(x), \mu_{\neg A}(x)) = \{0/x_1, 0.3/x_2\} \neq \{0/x_1, 0/x_2\}$

$\mu_{\neg A \cup A}(x) = \max(\mu_A(x), \mu_{\neg A}(x)) = \{1/x_1, 0.7/x_2\} \neq \{1/x_1, 1/x_2\}$

Théorie des ensembles flous
. Principe d'extension

Exemple

$\alpha = 0$: (1, 3) x (7, 9) = (7, 27)
$\alpha = 0.5$: (1.5, 2.5) x (7.5, 8.5) = (11.25, 21.25)
$\alpha = 1$: (2, 2) x (8, 8) = (16, 16)



environ 2 multiplié par environ 8

Théorie des ensembles flous
Principe d'extension

Le principe d'extension permet d'étendre l'applicabilité d'un opérateur mathématique conventionnel afin de traiter des quantités floues.

$$\mu_B(z) = \vee_{x \in A,\, y \in B,\, y = f(x,y)} \{ \wedge (\mu_A(x), \mu_B(y)) \}$$

$$\mu_B(z) = \max_{x \in A,\, y \in B,\, y = f(x,y)} \{ \min (\mu_A(x), \mu_B(y)) \}$$

Solution approximative

- **Ensemble niveau α**

$$A_\alpha = \{x \in X \mid \mu_A(x) \geq \alpha\}$$

- **Calcul par intervalle**

$$(a, b) + (c, d) = ((a+c), (b+d))$$

$$(a, b) - (c, d) = ((a-d), (b-c))$$

$$(a, b) \times (c, d) = (\min(ac, ad, bc, bd), \max(ac, ad, bc, bd))$$

$$(a, b) \div (c, d) = (a, b) \times (1/c, 1/d) \text{ si } c \neq 0 \text{ et } d \neq 0$$

- **Mise en garde**

$$(a, b) \div (a, b) \neq 1$$

Théorie des possibilités

Chapitres:

- *Introduction*
- *Contexte*
- *Théorie des ensembles floues*
- ☞ *Théorie des possibilités*
- *Logique floue*
- *Conclusion*

Points abordés:

- *Interprétation*
- *Principe de cohérence*

Théorie des possibilités
Interprétation

Grâce aux opérateurs max et min d'union et d'intersection, la théorie des ensembles flous peut être reliée à celle des possibilités.

La théorie des possibilités interprète la fonction d'appartenance comme une distribution de possibilités exprimant une restriction floue sur les valeurs qui peuvent être assignées à une variable.

Exemple

- **Théorie des ensembles flous**

  âge 22, $\mu_{jeune}(0.7)$

  Degré de compatibilité de 0,7 de l'âge 22 ans avec le concept imprécis de jeune.

- **Théorie des possibilités**

  Jean est jeune.

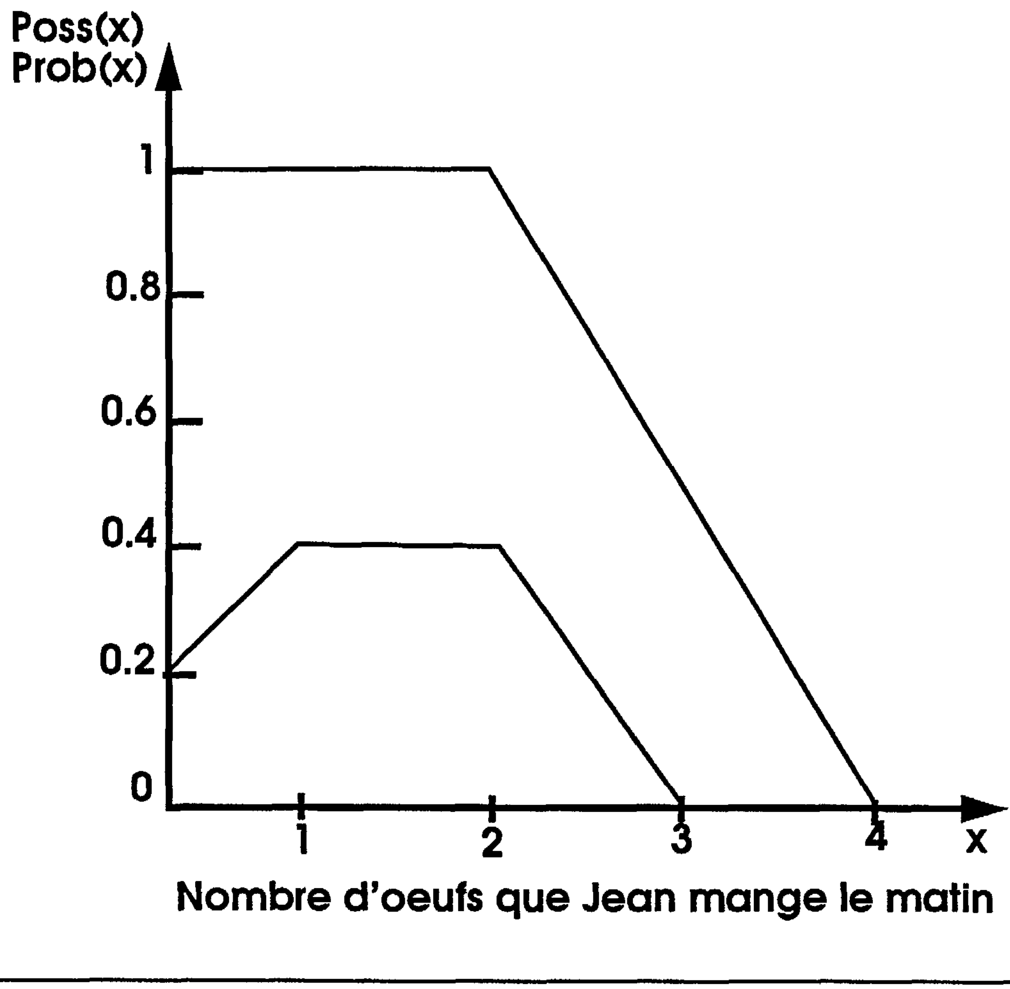
  Si Jean est jeune le degré de possibilité qu'il ait 22 ans est de 0,7.

Théorie des possibilités

Principe de cohérence

Une distribution de possibilités peut être interprétée comme une enveloppe sous laquelle doit se retrouver la fonction de probabilité.

Exemple



Théorie des possibilités

Principe de cohérence

Plutôt que d'être possibles (1) ou impossibles (0), des événements sont possibles à différents degrés entre 0 et 1.

Le principe de cohérence stipule qu'un événement x doit d'abord être possible avant d'être probable.

$$Poss(x) \geq Prob(x)$$

$$(Poss(x) = 0) \rightarrow (Prob(x) = 0)$$

Logique floue

Chapitres:

- *Introduction*
- *Contexte*
- *Théorie des ensembles flous*
- *Théorie des possibilités*

☞ *Logique floue*

- *Conclusion*

Points abordés:

- *Objectif*
- *Implication floue*

Logique floue
Objectif

Afin de raisonner avec des informations imprécises, il nous faut assouplir les structures logiques classiques.

Il faut éviter l'exactitude de la logique classique en permettant à la vérité d'être imprécise.

Grâce à la théorie des ensembles flous, la distinction nette entre le vrai et le faux peut être éliminée.

Les degrés d'appartenance deviennent des degrés de vérité associés à des énoncés.

Exemples

1. L'eau est polluée de nitrates.
2. Le niveau de pollution en nitrate est élevé.

Logique floue
Implication floue

Exemple

Si température > 17°C (a)
alors fermer la valve de 2 unités (b).

La logique floue est une logique à valeurs multiples entre 0 et 1.

La logique du premier ordre utilise l'opérateur d'implication booléen suivant :

$a \rightarrow b$ CNF: $(\neg a \cup b)$		b = 0	b = 1
a	0	1	1
	1	0	1

Logique floue

Implication floue

Différents opérateurs d'implication à valeurs multiples ont été suggérés :

Opérateur	Nom	Définition de a → b
$\rightarrow_1$	standard sharp	1 si a≠ 1 ou b = 1 0 autrement
$\rightarrow_2$	standard strict	1 si a ≤ b 0 autrement
$\rightarrow_3$	standard star	1 si a ≤ b b autrement
$\rightarrow_4$	Gaines	1 si a = 0 min(1, b/a) autrement
$\rightarrow_5$	Gaines modifié	1 si a = 0 ou b = 1 min(1, b/a, (1-a)/(1-b)) autrement
$\rightarrow_6$	Lukasiewicz	min(1, 1 - a + b)
$\rightarrow_7$	Kleene-Dienes Lukasiewicz	1 - a + ab
$\rightarrow_8$	Kleene-Dienes	max((1-a), b)
$\rightarrow_9$	early Zadeh	max(a $\rightarrow_8$ b, a, (1-a))
$\rightarrow_{10}$	Willmott	min(a $\rightarrow_9$ b, max(b, (1-b)))

Logique floue

Implication floue

L'opérateur d'implication à valeurs multiples établit une relation entre la prémisse et la conclusion d'une règle lorsque ces deux composantes sont imprécises.

L'implication floue permet donc de générer un ensemble flou représentant une règle.

Exemple

Si température élevée (A)
et pression forte (B)
alors fermer la valve légèrement (C).

Si (A et B) → C

$\mu_{A \cap B}(x,y)$

$\mu_{((A \cap B) \rightarrow C)}(x,y,z)$

Conclusion

Chapitres:

- Introduction
- Contexte
- Théorie des ensembles flous
- Théorie des possibilités
- Logique floue
- ☞ Conclusion

Points abordés:

- Avantages
- Limites
- Controverse
- Mot de la fin

Conclusion

Avantages

Théorie des ensembles flous

- La théorie des ensembles flous offre une représentation mathématique rigoureuse de l'incertitude attribuée à l'imprécision.
- L'interprétation possibiliste permet de relier la théorie des ensembles flous à celle des probabilités.
- La théorie classique des ensembles devient un cas spécial de la théorie des ensembles flous.

Conclusion
Avantages

Logique floue

- La logique floue permet le raisonnement approximatif à partir d'informations imprécises.
- La disponibilité de divers opérateurs d'implication et de mesure de similarité permet d'adapter le mode de raisonnement pour chaque application.
- La logique du premier ordre devient un cas spécial de la logique floue.

Conclusion
Limites

- Définition et signification des fonctions d'appartenance
- Sélection et validité des opérations affectant les fonctions d'appartenance
- Validation et vérification des systèmes flous

Conclusion
La controverse

- **Opposants**

''... we should keep the vagueness of the scale localised into it, rather than letting it infect the whole inferential system''
Patrick J. Hayes, 1974

''It is so difficult to quantify a belief or preference as a single noumber, why is it easier to quantify it as a complete set membership function?''
Simon French, 1984

- **Partisans**

''In fact, it is the ability to reason in qualitative, imprecise terms that distinguishes human intelligence from machine intelligence.''
Lotfi A. Zadeh, 1979

''... in the decision process certain forms of imprecision occur that are intrinsic to the problem and for which the probability calculus is inadequate.''
Gaines et al., 1984

Conclusion

Mot de la fin

Si nous acceptons l'imprécision dans le seul but d'excuser notre propre ignorance, alors il est possible que nous ne fassions jamais l'effort de discerner certains phénomènes précis.

Si, par contre, nous refusons de reconnaître que certains concepts sont fondamentalement imprécis alors il se peut que nous produisions une multitude d'alternatives plus précises mais moins utiles.

La théorie des ensembles flous est en elle-même neutre, car elle permet la représentation de concepts précis aussi bien qu'imprécis. Les seuls avantages et dangers résident dans la façon de l'utiliser.

Traduit de Gaines, 1976

Bibliographie

Livres

- [DUBO80] Dubois, Didier et Prade, Henri. *Fuzzy Sets and Systems: Theory and Applications*, Academic Press, New York, 1980.
- [DUBO88] Dubois, Didier et Prade, Henri. *Possibility Theory, An Approach to Computerized Processing of Uncertainty*, Plenum Press, New York, 1988.
- [DUBO92] Dubois, Didier, Prade, Henri et Yager Ronald R., éditeurs. *Readings in Fuzzy Systems*. Morgan Kaufmann Publishers, 1992.
- [GUPTA82] Gupta, M. M. et Sanchez, E., éditeurs. *Approximate Reasoning in Decision Analysis*. Elsevier North-Holland, 1982.
- [GUPTA85] Gupta, M. M., Kandel, A., Bandler, W. et Kiszka, J. B., éditeurs. Approximate Reasoning in Expert Systems. North Holland, 1985.
- [KANA86] Kanal, L. N. et Lemmer J. F., éditeurs. *Uncertainty in AI*. Elsevier Science Publishers, 1986.
- [KAND86] Kandel, A. *Fuzzy Mathematical Techniques with Applications*. Addison-Wesley Publishing Company, 1986.
- [KLIR88] Klir, G. J. et Folger, T. A. *Fuzzy Sets Uncertainty and Information*. Prentice Hall, 1988.
- [KOSK92] Kosko, B. *Neural Networks and Fuzzy Systems*. Prentice Hall, Englewood Cliffs, New Jersey, 1992.
- [SUGE90] Sugeno, M. *Industrial Applications of Fuzzy Control*. North Holland, 1990.
- [WANG91] Wang, Z. et Klir G. J. *Fuzzy Measure Theory*. Plenum Press, New York, 1991.
- [YAGE87] Yager, R. R. et al. *Fuzzy Sets and Applications: Selected Papers by L.A. Zadeh*. John Wiley & Sons, New York, 1987.
- [YAGE91] Yager, R. R. et Zadeh, L.A. *An Introduction to Fuzzy Logic Applications in Intelligent Systems*. Kluwer Academic Publishers, 1991.
- [ZIMM85] Zimmermann, H.-J. *Fuzzy Set Theory and its Applications*. Kluwer-Nijhoff Publishers, 1985.
- [ZIMM87] Zimmermann, H.-J. *Fuzzy Sets, Decision Making, and Expert Systems*. Kluwer Academic Publisher, 1987.

Bibliographie

Articles généraux

- [CONN93] Conner, D. «Special report: designing a fuzzy logic control systems requires a new way of thinking». *EDN*, 1993 (Mars).
- [COX93} Cox, E. «Adaptative fuzzy systems». *IEEE Spectrum*, 1993 (Février).
- [KOS93} Kosko, B et Isaka, S. «La logique floue». *Pour la Science*, 1993 (Septembre).
- [ROGE90} Rogers, M. et Hoshiai, Y. «The future looks fuzzy». *Newsweek*, 1990 (Mai).
- [SCHW92} Schwartz, D. G. «Fuzzy logic flowers in Japan». *IEEE Spectrum*, 1992 (Juillet).
- [SELF90] Self, K. «Designing with fuzzy logic». *IEEE Spectrum*, 1990 (Novembre).
- [SIBI92] Sibigtroth, J. M. «Implementing fuzzy expert rules in hardware». *AI Expert*, 1992 (Avril).

Fuzzy Control and Applications

First Canadian Workshop on Fuzzy Logic & Industrial Applications
March 17, 1994

Stephen L. Chiu

Rockwell International Science Center
1049 Camino Dos Rios
Thousand Oaks, CA 91360
Email: slc@risc.rockwell.com

Outline

1. What is fuzzy control?

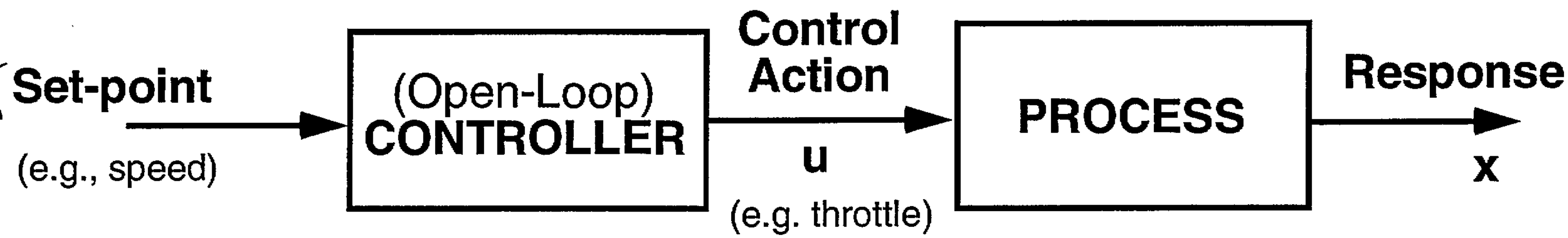
2. What are its advantages & disadvantages?

3. How can I use fuzzy control?

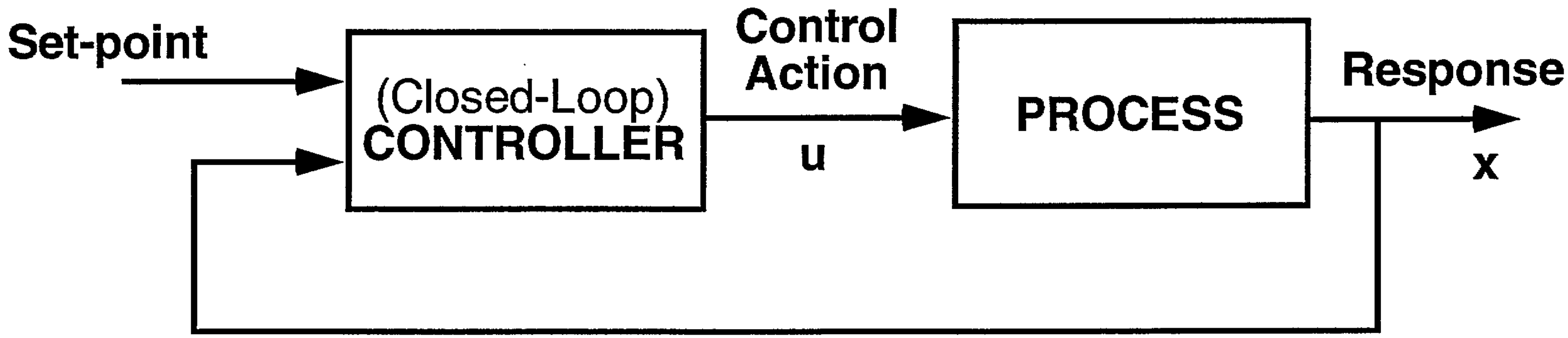
   Examples
   - Temperature control
   - PID supervisory control
   - Automatic transmission
   - Subway train operation
   - Consumer products

Set-Point Control: Make Response Follow Command

Where knowledge of process is good



Weak/poor process model



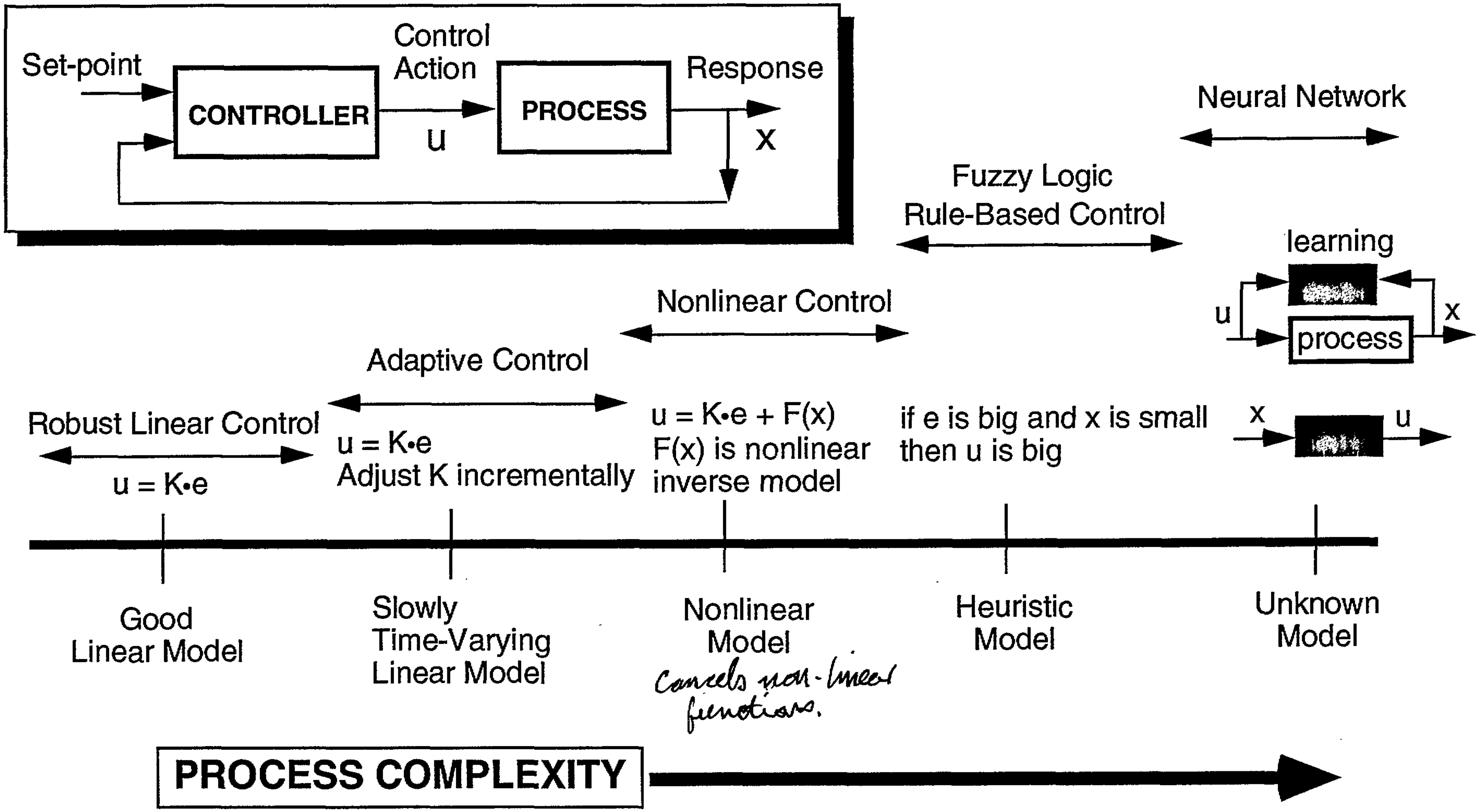
Controller is based on Inverse Model

Process Model: If u is applied, what will x be?

Inverse Model: If we want x, what should u be?

S. Chiu
Rockwell Science Center

Applicability of Control Methods

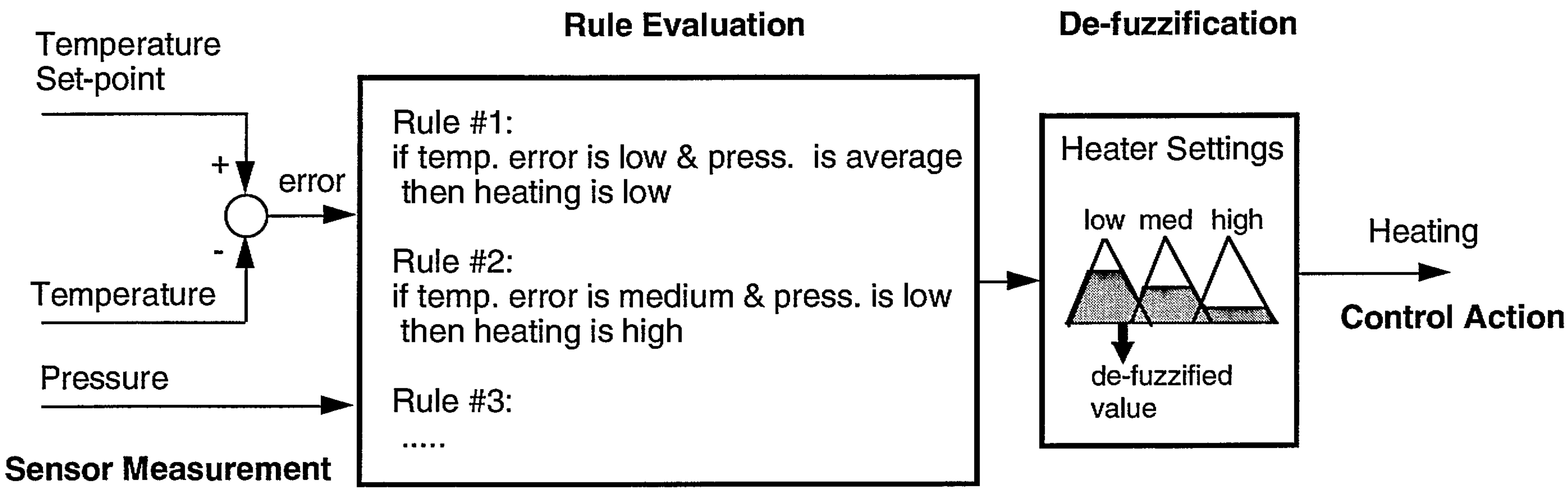


S. Chiu
Rockwell Science Center

Fuzzy Controller

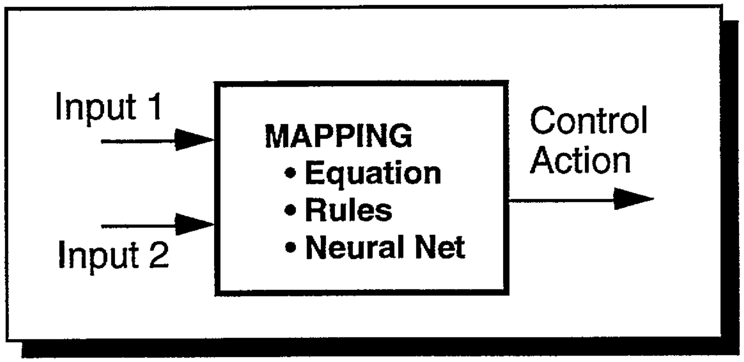
A controller that uses fuzzy rules to determine control action

- **"If" part of rule is a process state**
- **"Then" part of rule is a control action**

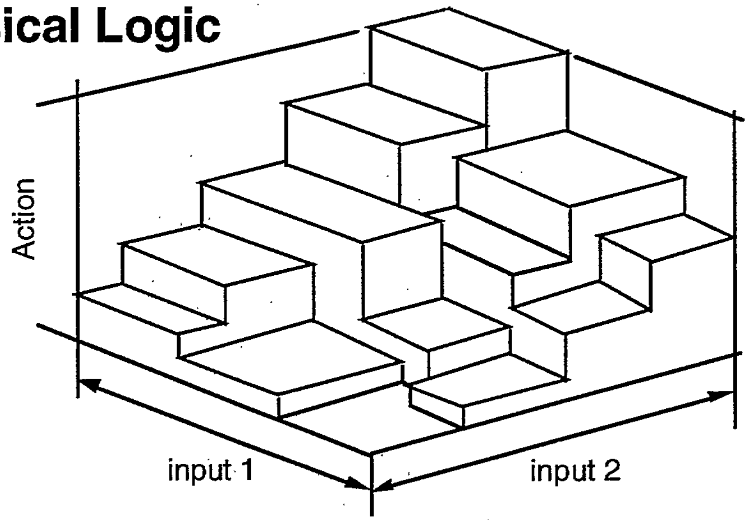


S. Chiu
Rockwell Science Center

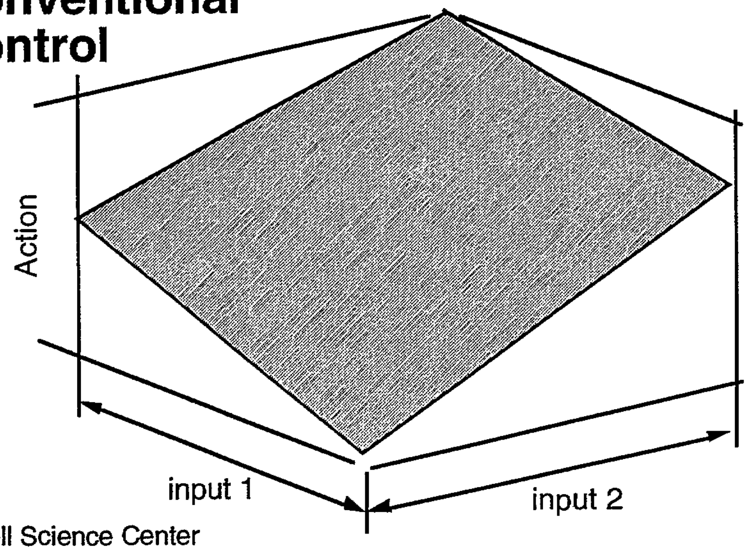
Fuzzy Control = Interpolative Rule-Based Control



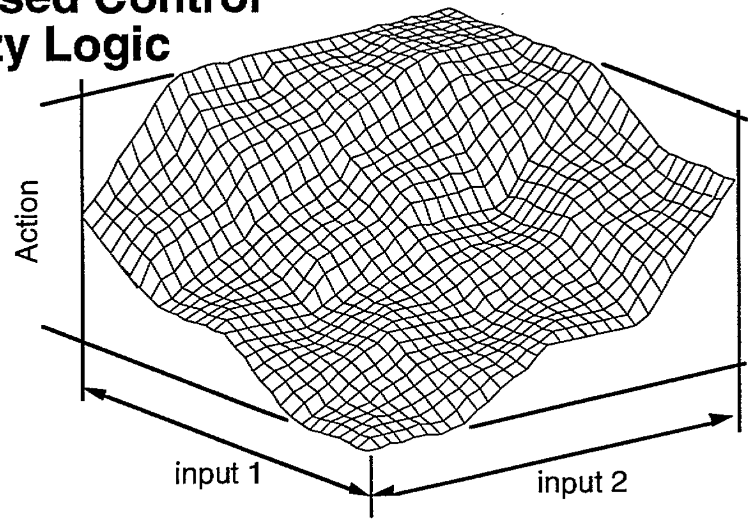
Rule-Based Control via Classical Logic



Conventional Control



Rule-Based Control via Fuzzy Logic



S. Chiu
Rockwell Science Center

Why Fuzzy Control?

Difficulties in applying conventional control

- **Requires accurate mathematical model of process**
  - expensive to obtain
- **Process is often highly nonlinear**
  - requires many diffferent linear controller designs
- **Control objective limited to a linear quadratic form**
- **Loss of physical insight in large problems**
- **Not applicable to high-level, task-oriented control**

Advantages of fuzzy control

- **Does not require mathematical model of process**
  - A qualitative inverse plant model is implicitly provided by the human expert
- **Control law can be highly nonlinear to exploit process nonlinearity**
- **Complex objective is easily incorporated in control rules**
- **Easy to understand & apply (fast time-to-market)**
- **Easy to maintain & extend**
- **High speed hardware available (> 200,000 rules/sec)**

S. Chiu
Rockwell Science Center

Why NOT Fuzzy Control?

Disadvantages of Fuzzy Control

1. **Ad-hoc design methodology**
   - automated design methods exist only for very simple systems
2. **Lacks well-developed stability & robustness analysis techniques**
   - validate by extensive simulation & prototype testing
3. **Increased computation**

#1 and #2 apply only to set-point oriented fuzzy control

Essence of Fuzzy Control:

IT LETS YOU EXPRESS WHAT'S IN YOUR MIND

S. Chiu
Rockwell Science Center

Commercial-Refrigeration/Incubation Module (C-RIM)
(Space Industries, Texas)

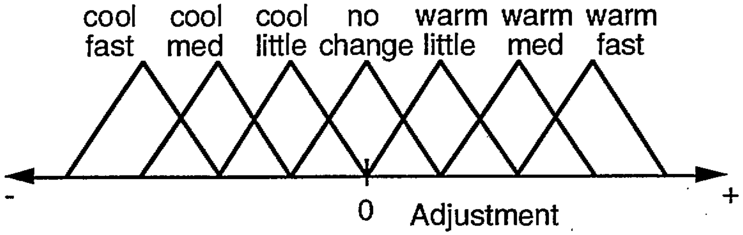
- **Controls temperature in chamber for crystal growth experiments**
- **Flown on Space Shuttle in April 1992**

Why fuzzy control?

1. **Traditional control techniques did not achieve desired accuracy** (need to control temp. to ±0.5°C; previous unit can only maintain ±2°C)
2. **Widely variable thermal load** (no accurate process model)
3. **Had only 10 months development time**

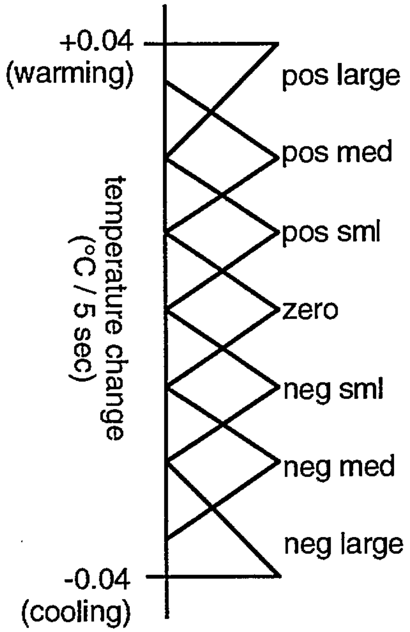
S. Chiu
Rockwell Science Center

C-RIM Temperature Control Rules

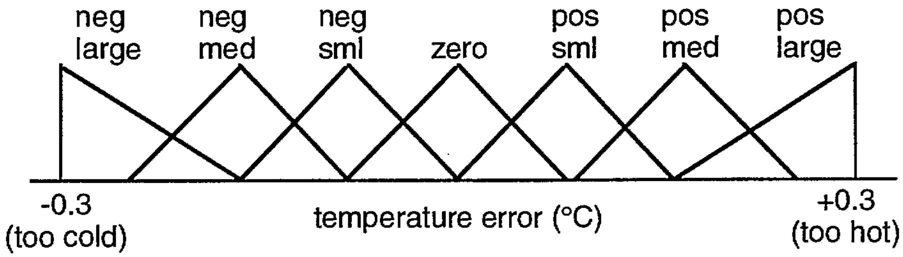


heat pump current = previous current + adjustment
(polarity of current determines heating or cooling)

if error is "neg sml" & temp change is "pos large"
then adjustment is "cool little"



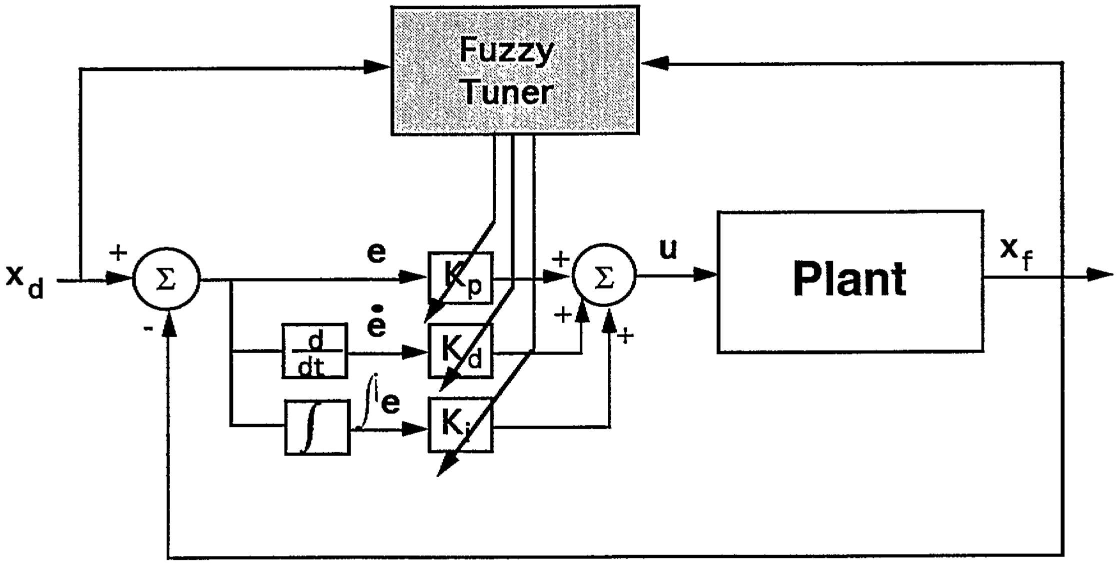
temperature change \ temperature error	neg large	neg med	neg sml	zero	pos sml	pos med	pos large
pos large	cool little	cool little	cool little	cool med	cool med	cool fast	cool fast
pos med	warm little	no change	cool little	cool little	cool med	cool med	cool fast
pos sml	warm little	warm little	warm little	no change	cool little	cool little	cool fast
zero	warm little	warm little	no change	warm little	no change	no change	cool med
neg sml	warm med	warm med	warm med	warm med	warm little	no change	cool little
neg med	warm fast	warm med	warm med	warm med	warm med	no change	cool little
neg large	warm fast	warm fast	warm med	warm med	warm little	warm little	warm little

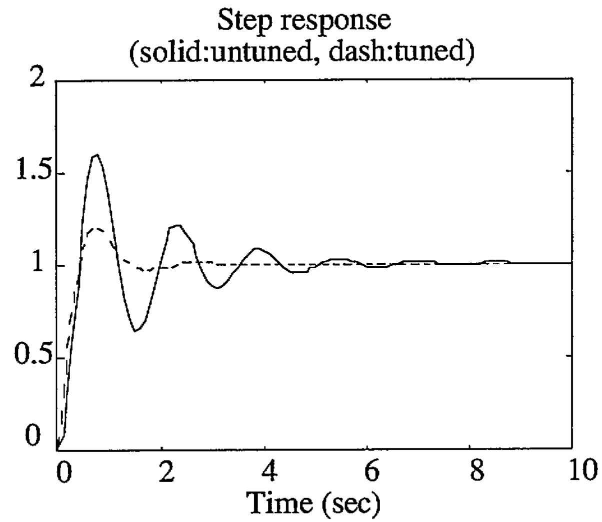


S. Chiu
Rockwell Science Center

Supervisory Control: Self-Tuning PID Controller (Rockwell International)

On-line continuous adjustment of PID gains to compensate for changes in plant dynamics





- **23 rules encapsulate PID tuning expertise**

  e.g., If damping is low then reduce Kp & increase Kd
- **Self-monitoring algorithm safeguards tuning**

S. Chiu
Rockwell Science Center

PID Tuning Rules

Basic Tuning Rules

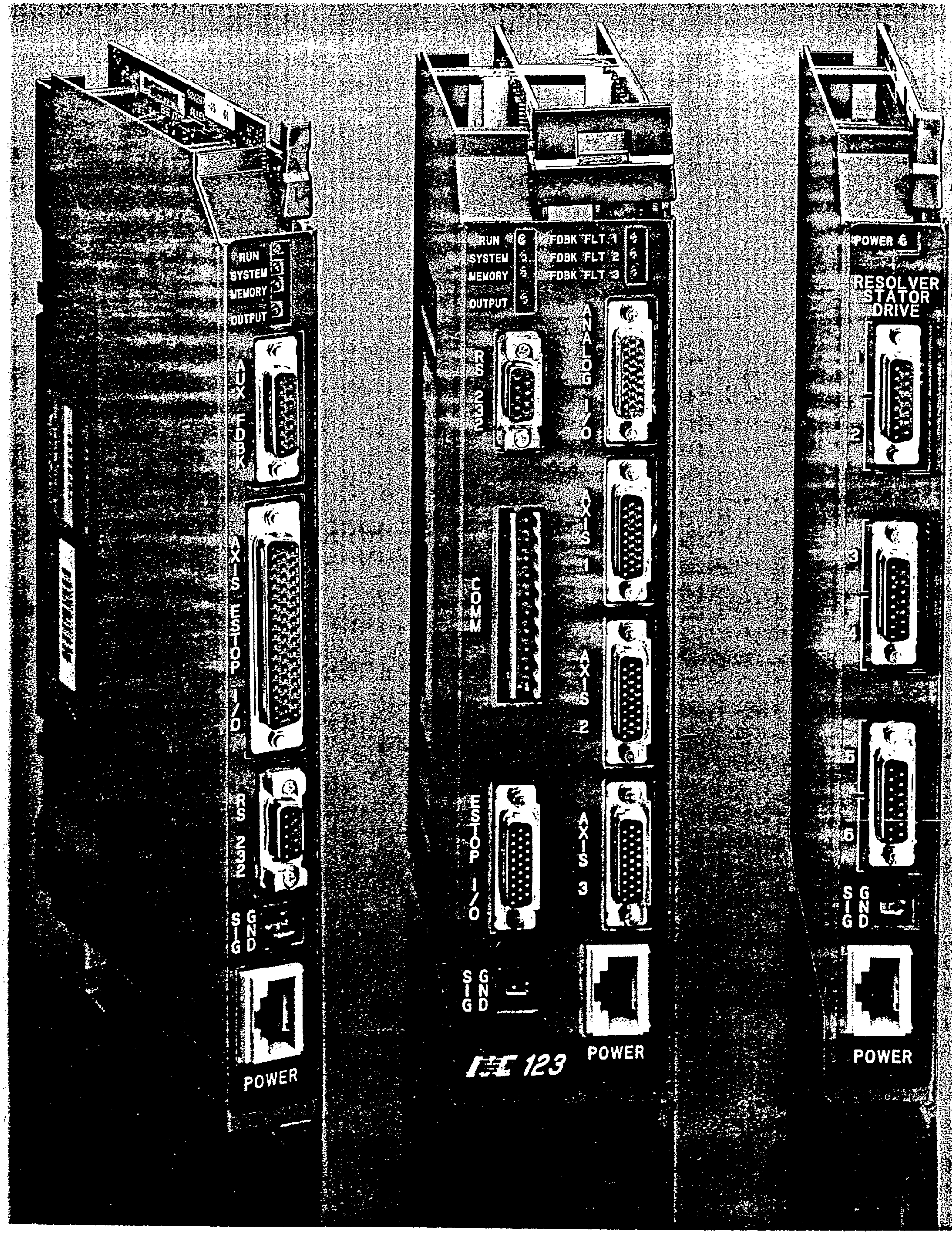
if damping is very low then ΔKp is neg. big & ΔKd is pos. big
if damping is very high then ΔKp is pos. big & ΔKd is neg. big
:
if s.s. error is big then ΔKi is pos. big
if freq is high then ΔKp is neg. big & ΔKi is neg. big

Self-Monitoring Rules

if consistency is high & effectiveness is high then reward factor is high
if consistency is med & effectivenss is medium then reward factor is med
if consistency is low or effectivenss is low then reward factor is low

$$\Delta K_{actual} = \Delta K * RF$$

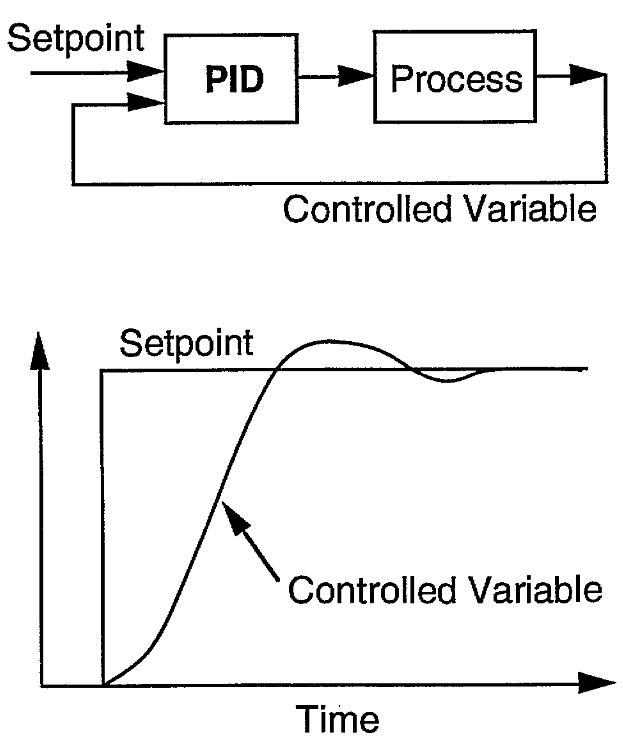
S. Chiu
Rockwell Science Center

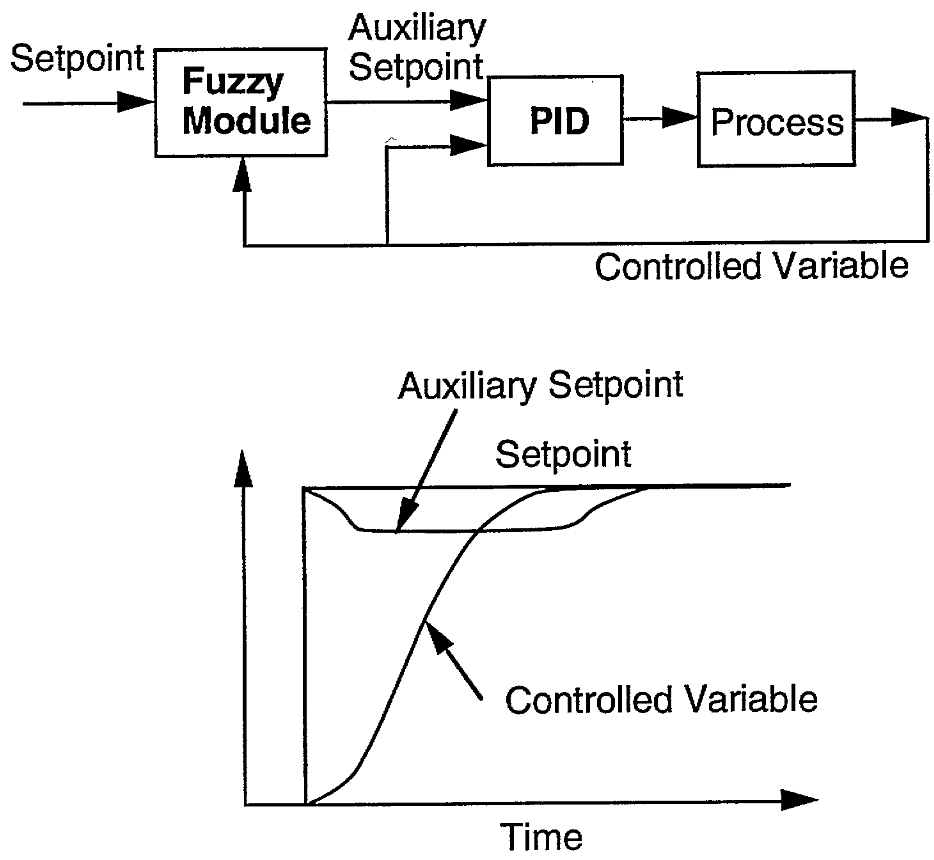

RUN
SYSTEM
MEMORY
OUTPUT
AUX FDBK
AXIS ESTOP I/O
RS 232
SIG GND
POWER
RUN
SYSTEM
MEMORY
OUTPUT
FDBK FLT 1
FDBK FLT 2
FDBK FLT 3
RS 232
ANALOG I/O
AXIS 1
COMM
AXIS 2
ESTOP I/O
AXIS 3
SIG GND
POWER
123
POWER
RESOLVER STATOR DRIVE
1
2
3
4
5
6
SIG GND
POWER

Fuzzy-Assisted PID Control (Yokogawa Electric)

Emulate human operator strategy for supressing overshoot

1. Sense impending overshoot
2. Change setpoint to "slightly lower" value
3. Monitor deviation & return setpoint "little by little" to desired value

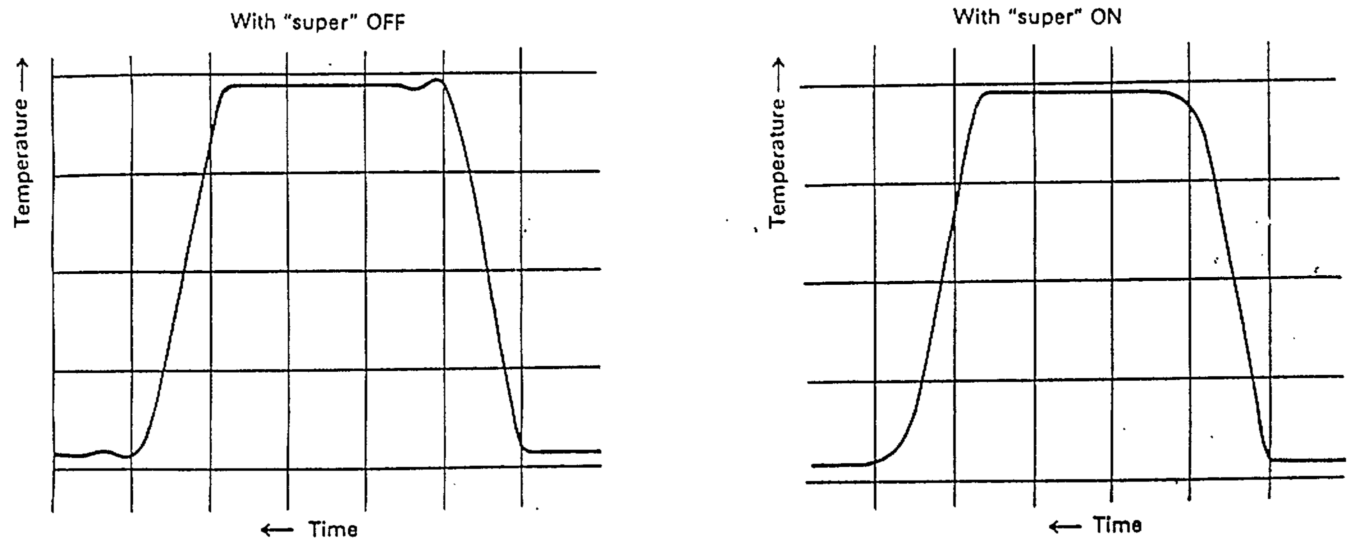




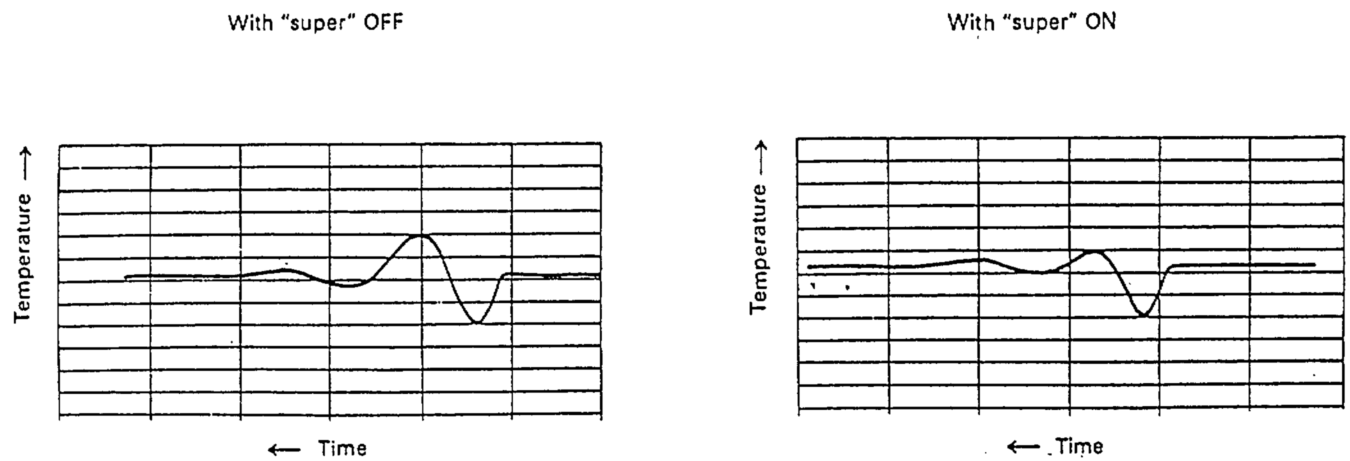
S. Chiu
Rockwell Science Center

From: Yokogawa UT15/UT14 Controllers Technical Info. Oct 1990

Response to an abrupt change in the setpoint



Response to a disturbance

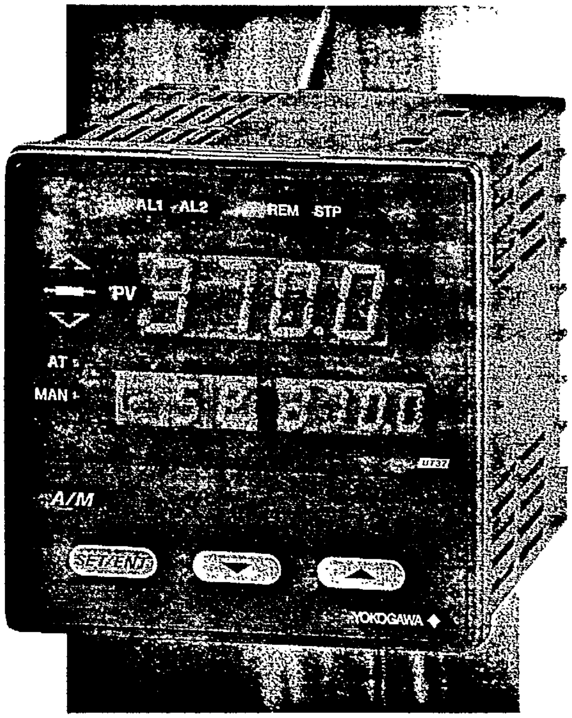


YOKOGAWA

NEW

UT37/UT38

Digital Indicating Controllers



UT37 and UT38 are advanced digital indicating controllers that are simple to use and feature universal input and output types. They utilize the exclusive fuzzy logic SUPER function to suppress overshoot and improve performance.

Bulletin 5B4B7-E

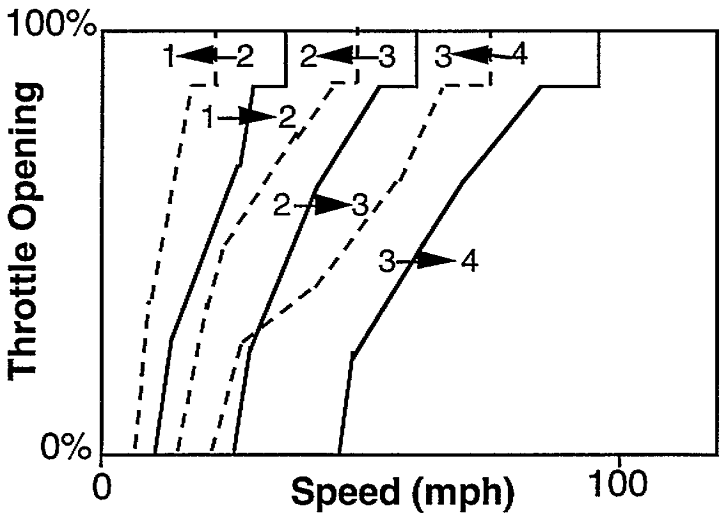
Selecting Discrete Control Option: Automatic Transmission (Nissan Motor)

Conventional shift controllers

- **Only considers speed and throttle opening**
- **Do not always match driver's intention**
- **Do not consider driving condition**

  e.g., steep incline, passenger load

Typical Shift Pattern for Automatic Transmission



Examples of Bad Shifting:

- Driver lets up on accelerator to enter a corner ->shifts to higher gear
- Driver lets up on accelerator to coast down steep incline -> shifts to higher gear

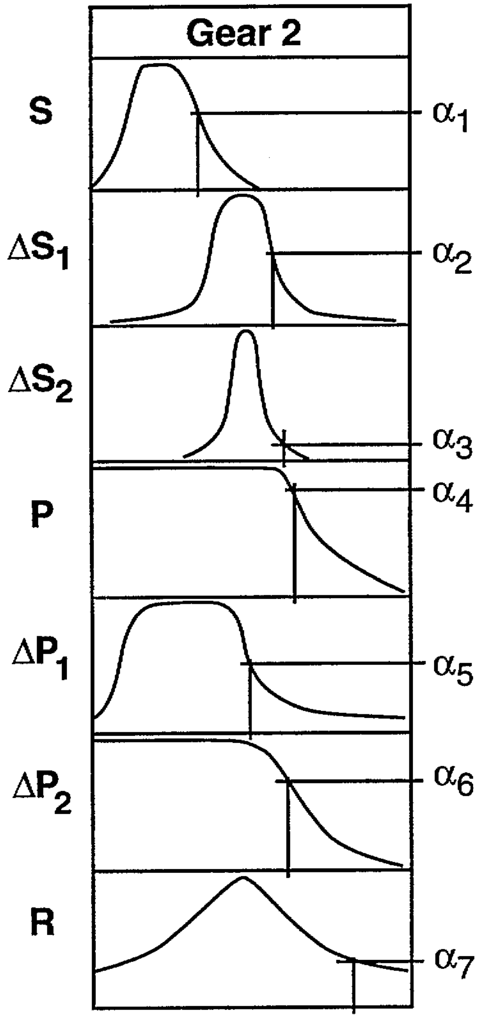
S. Chiu
Rockwell Science Center

Determining Suitability of A Gear

Inputs to the fuzzy controller

- S = current speed
- P = current throttle opening
- ΔS_1 = change in speed during last 2 seconds
- ΔS_2 = change in speed during last 5 seconds
- ΔP_1 = change in throttle during last clock period
- ΔP_2 = change in throttle during last 2 clock periods
- R = running resistance
  - R = 1 corresponds to single driver on flat road
  - higher R means steep incline or increase in passengers
  - R is estimated from speed, throttle opening, and gear position

Suitability of choosing gear 2



For each gear, a set of membership functions describe the condition under which the gear should be chosen

$$G_k = \text{suitability of gear } k = \frac{\sum_{i=1}^{7} \alpha_i}{7}$$

S. Chiu
Rockwell Science Center

Fuzzy Shift Controller

Evaluate the function:

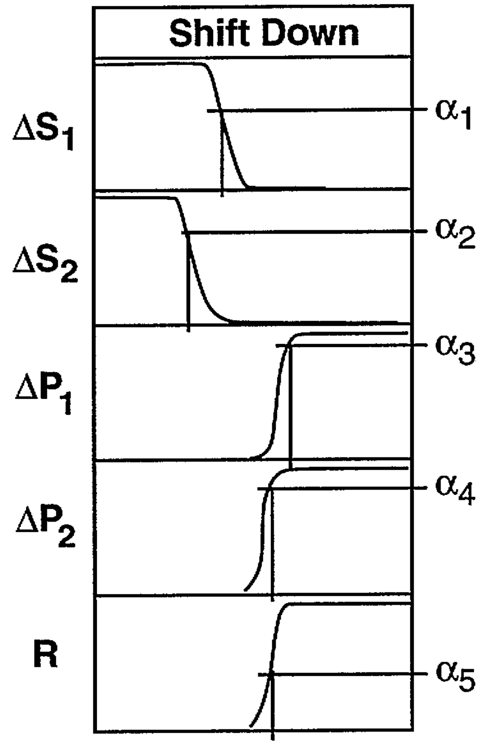
$$S = \frac{G_i * i + G_{up} * G_{i+1} - G_{down} * G_{i-1}}{G_i * i}$$

where

i = current gear number
G_k = suitability of using gear k for the present condition
G_{up} = desirability of shifting up
G_{down} = desirability of shifting down

Command upshift if S is greater than 1 by some threshold
Command downshift if S is less than 1 by some threshold

Desirability of shifting down



$$G_{down} = \frac{\sum_{i=1}^{5} \alpha_i}{5}$$

S. Chiu
Rockwell Science Center

Notable Points in Shift Controller Design

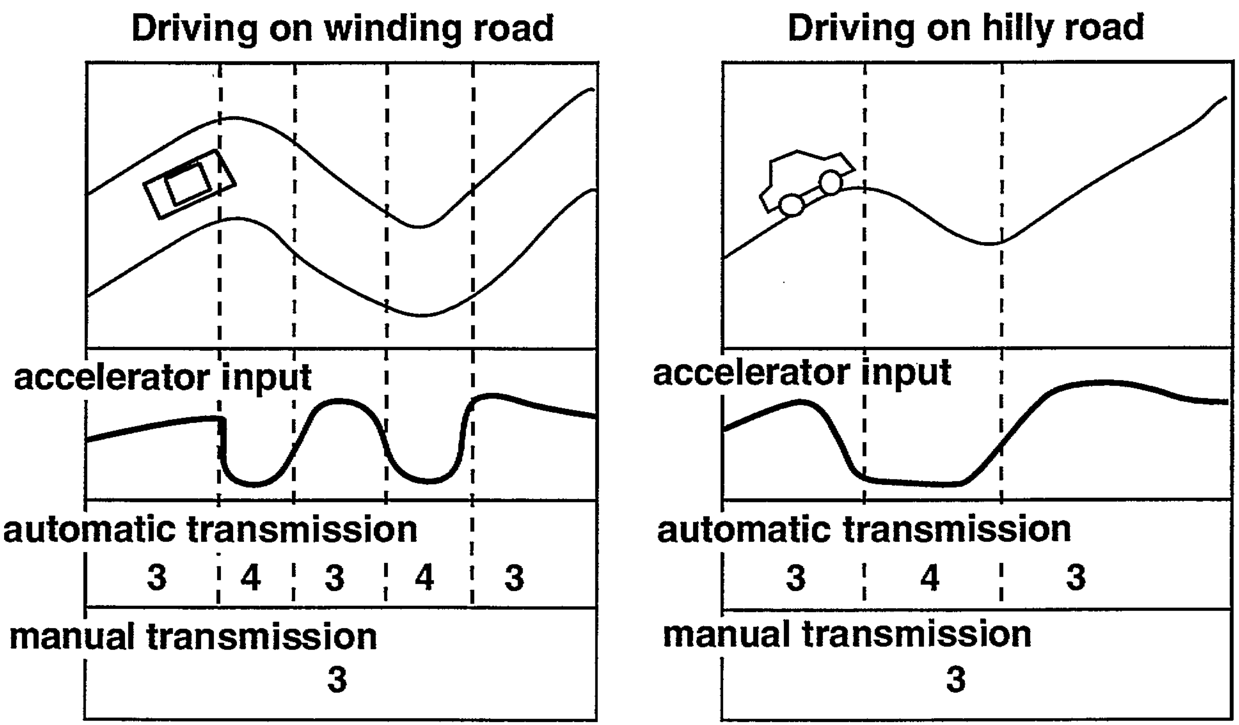
- A task-oriented fuzzy controller
- Fuzzy sets used only to determine degree of similarity between conditions
  - degrees of similarity are parameters in an analytical criterion function
- Fuzzy Control ≠ Fuzzy Rule-Based Control

S. Chiu
Rockwell Science Center

Classification of Operating Environment (Nissan Motor)

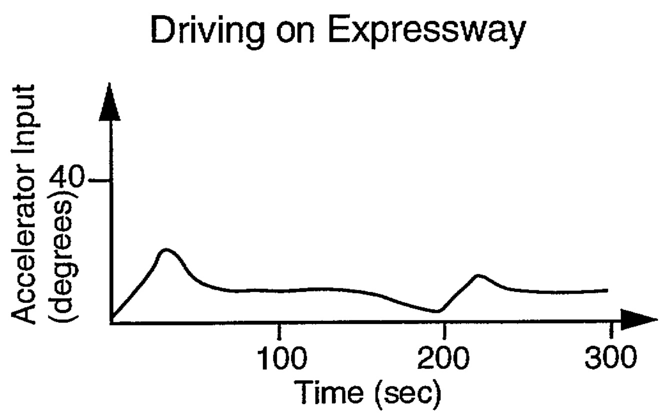
- Automatic transmission should have different shift pattern for driving in different environment, e.g., expressway vs. winding road
- Correct identification of driving environment allows selection of appropriate shift pattern

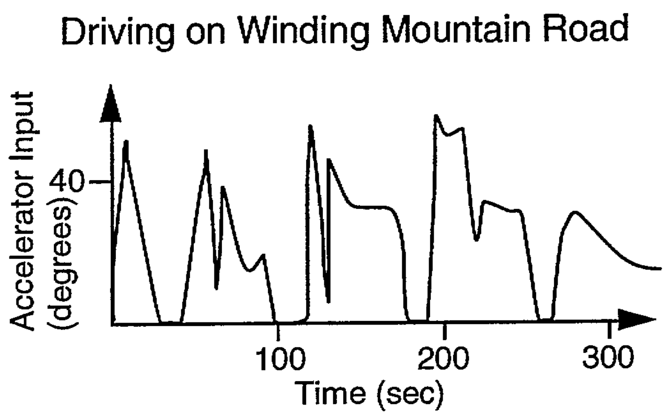
Gear Shift Behavior

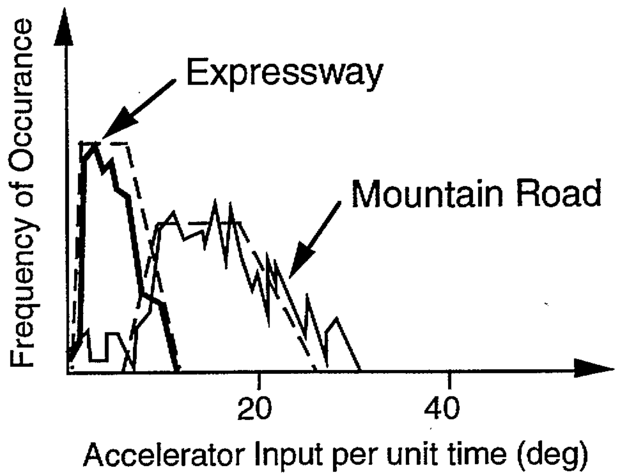


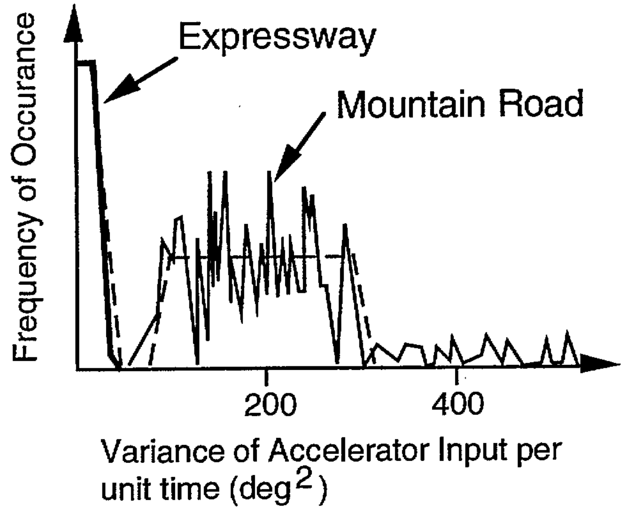
S. Chiu
Rockwell Science Center

Determining Fuzzy Boundaries for Classification



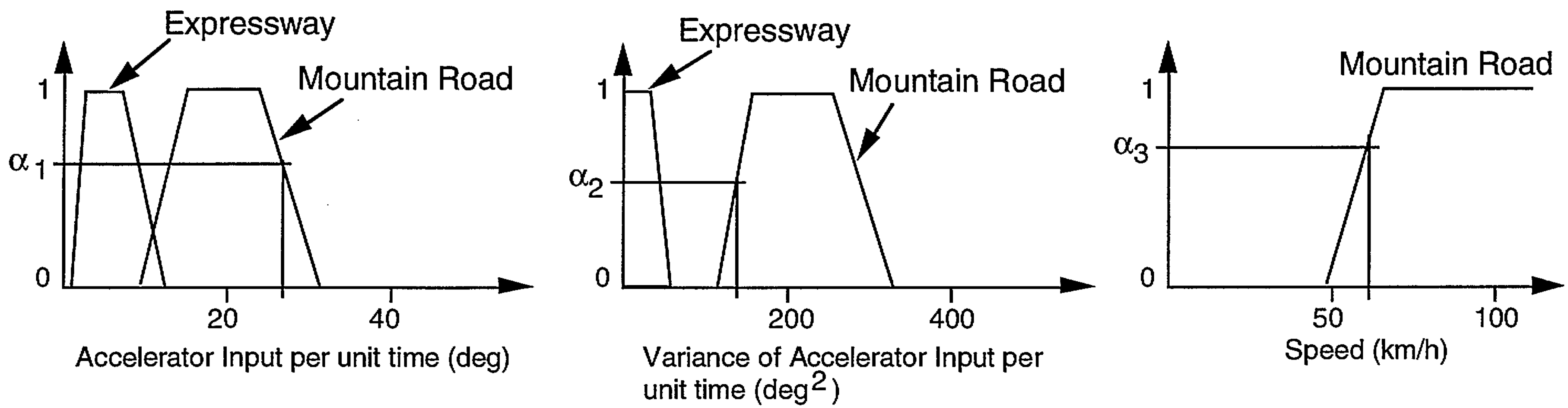






S. Chiu
Rockwell Science Center

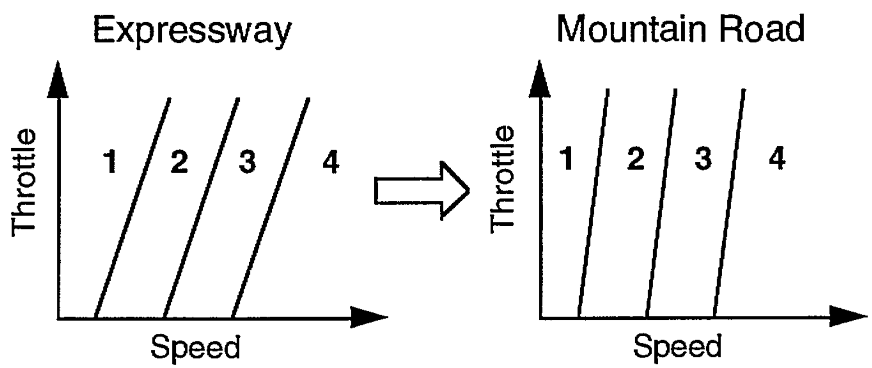
Determining the Class



Degree of match = min(α_1, α_2, α_3)

- **Environment is classified as mountain road if degree of match exceeds some threshold**
- **Change shift pattern according to classification**

Change in Shift Pattern



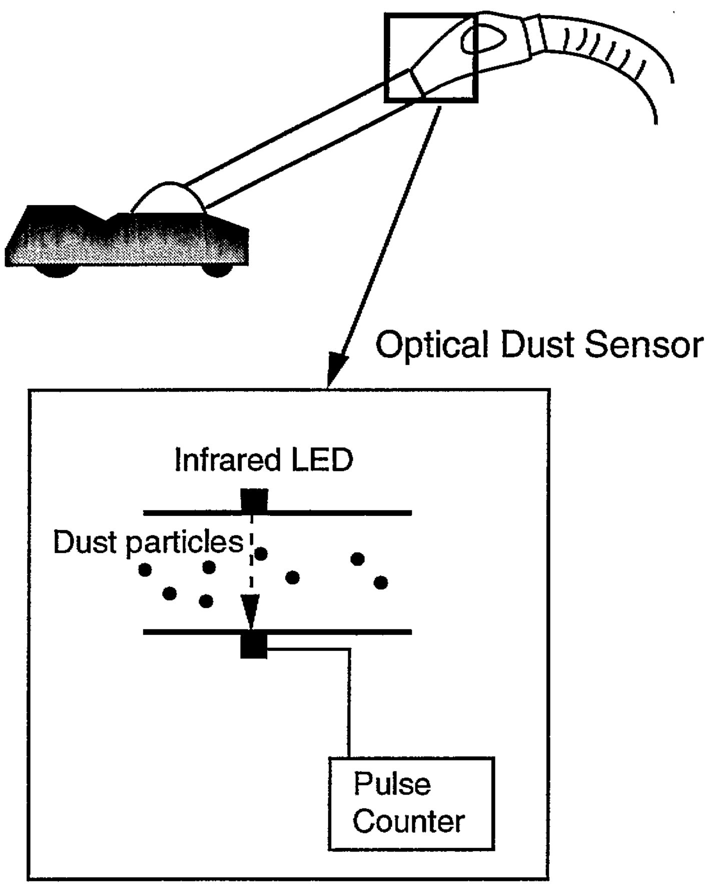
S. Chiu
Rockwell Science Center

Notable Points in Environment Classification

- Membership functions determined from experimental data, not human description
- Used fuzzy logic to classify operating environment - determine which conventional control law to use
- No rules
- Extension: Classification of driver/user e.g., preference for sporty or comfortable drive
- Used human driver as the sensor and infer the environment from driver behavior
- If we can't measure a parameter directly, can we infer it from measurement of some other variables?

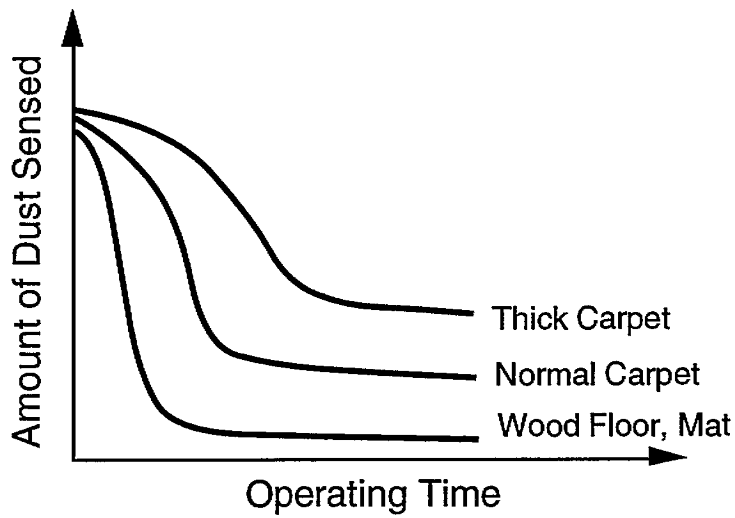
S. Chiu
Rockwell Science Center

Fuzzy Vacuum Cleaner
(Matsushita Electric)



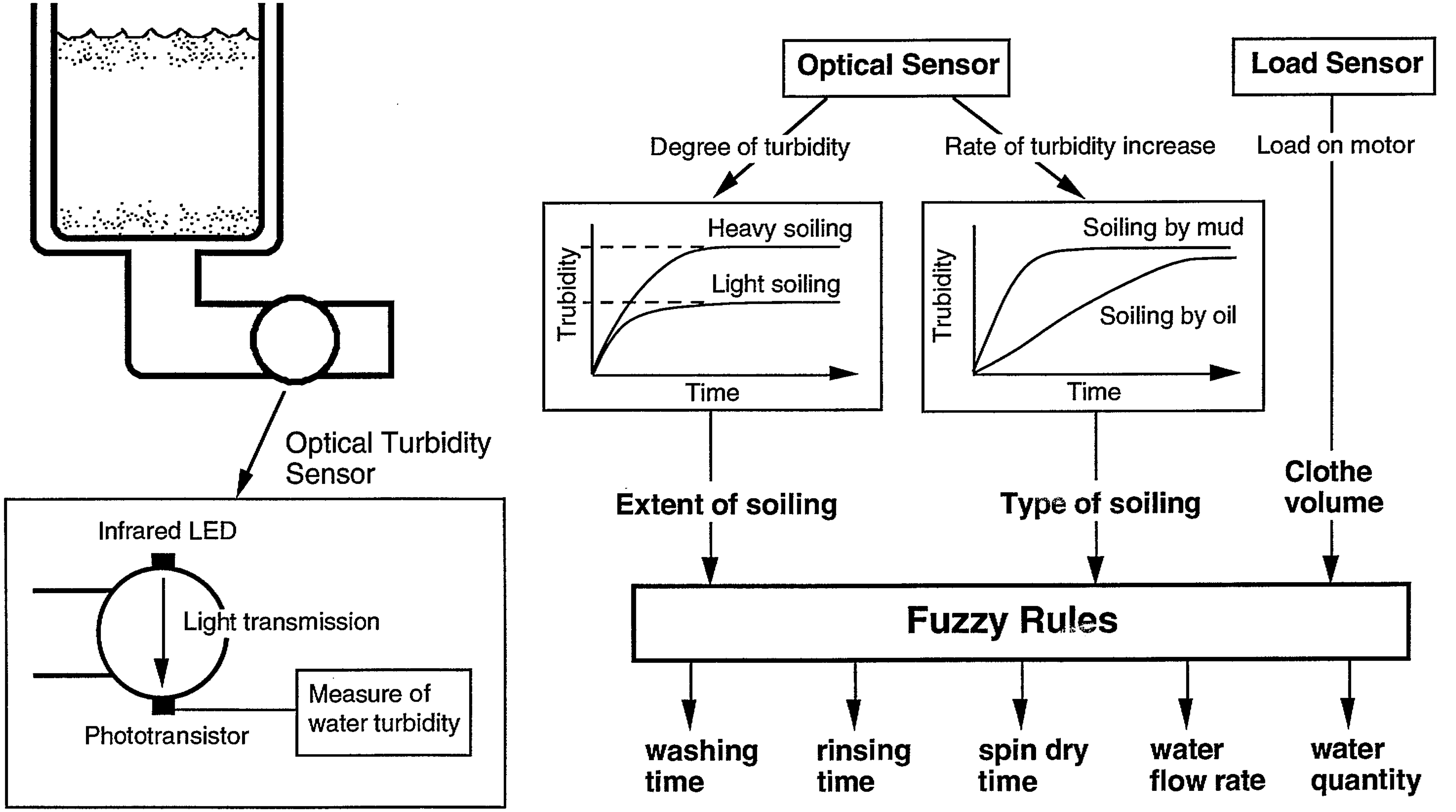
Vacuum power too high => difficult to operate
Vacuum power too low => poor dust pickup

- **Optimum vacuum power depends on amount of dust and floor type**



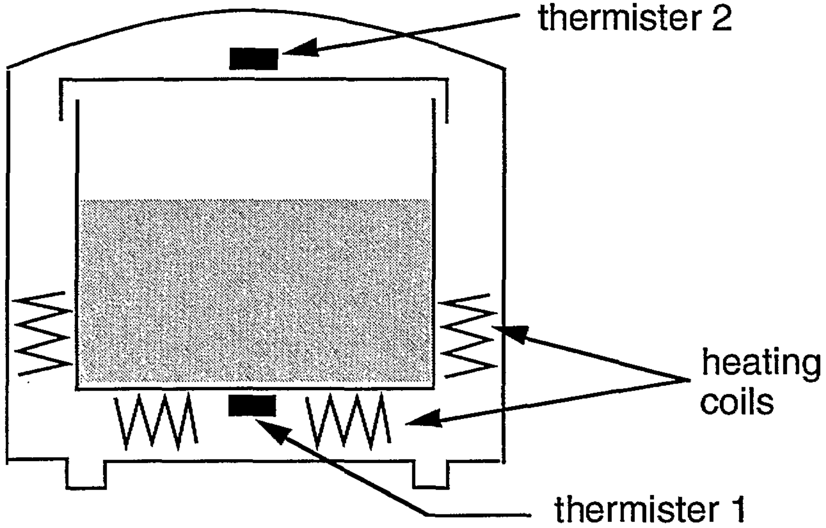
S. Chiu
Rockwell Science Center

Fuzzy Washing Machine (Matsushita Electric)

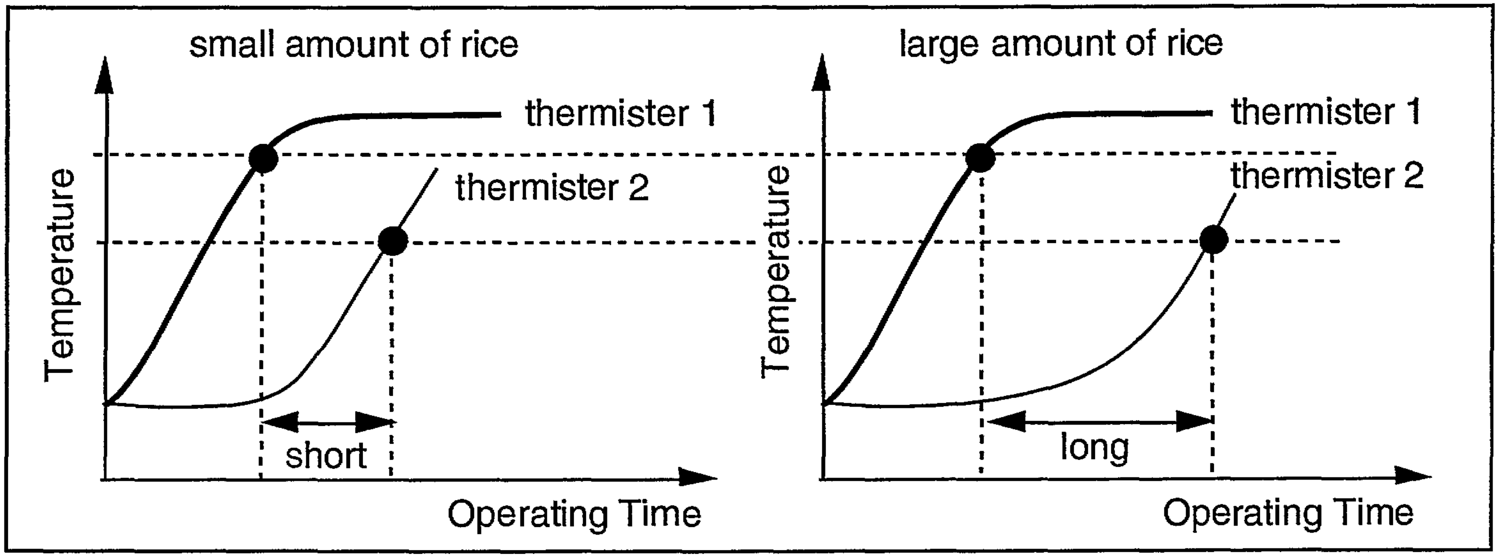


S. Chiu
Rockwell Science Center

Fuzzy Rice Cooker
(Matsushita Electric)



- **Optimum heating power depends on amount of rice & desired hardness**



S. Chiu
Rockwell Science Center

こんなこともカンタン

か簡単にできます。

押せば、パネル表示が次々
な表示だけが呼び出せ、操
行の現金自動支払い機と

キーを押せば、好きなかたさに炊き分けられます。

白米炊き分けキー

水加減しなくても、キーを押すだけで、好きなかたさに炊き分けます。すしめしも水位線を合わせて、キーを押せば上手に炊けます。

洗ってすぐでも少量でもおいしく炊けます。

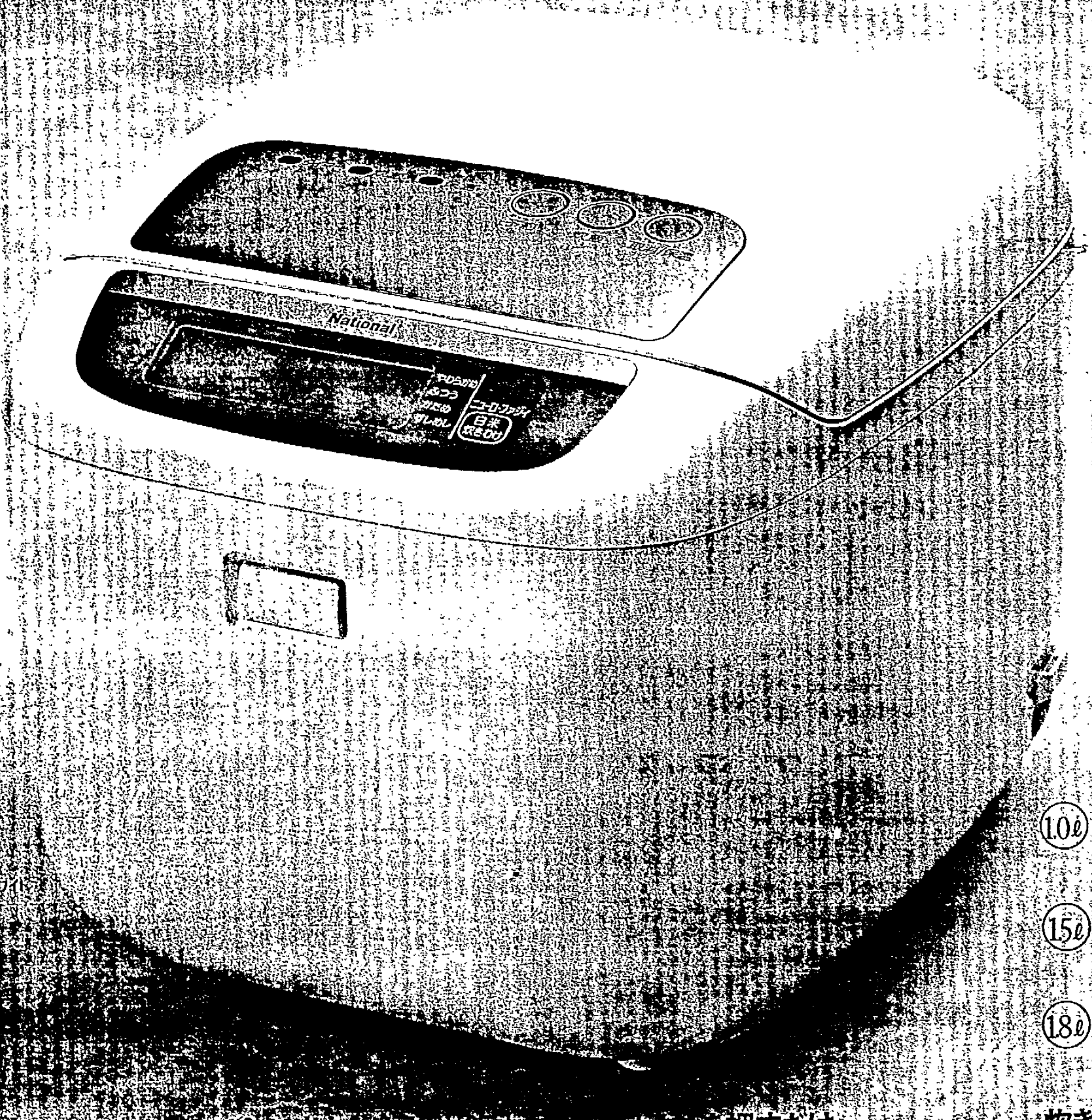
マイコンコントロール

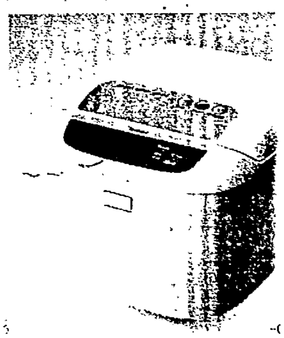
米をつけおきしなくても、マイコンが火力をコントロールして米に水を吸わせながら炊き上げます。少量でも、おいしい火加減が選べます。

食べたい時刻をセットすれ その時刻に食べられます。

食べ時刻タイマー

例えば、朝の7時30分にごはんが食べ
ば、タイマーを7時30分に合わせるだ
タン。食べたい時刻に炊き上がります。





IH ジャー炊

SR-IH10X1 1.0ℓ
標準価格54,000円(税別)
消費電力(約):1,060W 大きさ(約):幅25
高さ24cm 色:-Wホワイト、-Cベージュ

SR-IH15X1 1.5ℓ
標準価格56,000円(税別)
消費電力(約):1,270W 大きさ(約):幅27
高さ25cm 色:-Wホワイト、-Cベージュ

SR-IH18X1 1.8ℓ
標準価格58,000円(税別)
消費電力(約):1,270W 大きさ(約):幅27
高さ27cm 色:-Wホワイト、-Cベージュ

速く炊けます。

機能

にほしくなった…そんなときは
「白米高速」を選んでくださ
く炊き上がります。

つゆが出ないよう炊飯中に余分なつゆをとばせます。

露しらず

ふた部分につけたふたヒーターが、余分なつゆをとばしながら炊き上げます。つゆうけがないので、お手入れもカンタンに。

ボタンを押すだけ、指1本でふたが開けられます。

ワンプッシュ自動オープンのふた

ボタンを軽く押すだけ。ふたが自動的に開きます。何かを持っているときや手がぬれているときなどはとくに便利です。

炊きこみごはんのほかにも いろいろつくれます。

5メニュー選択キー

メニューキーを選べば、白米・炊き
んのほか、白米高速、おかゆ、玄米、
(おこわなど)もじょうずにつくれます。

掲載しております商品の価格には消費税は含まれておりませんので、ご購入の際、別途消費税額をお支払いください。

Notable Points in Many Fuzzy Consumer Products

- **Fuzzy approach PLUS additional sensor info provided new capability**
- **Fuzzy logic is a powerful paradigm, but it's not magic**
- **The solution to a problem often lies in finding creative ways to infer additional information**

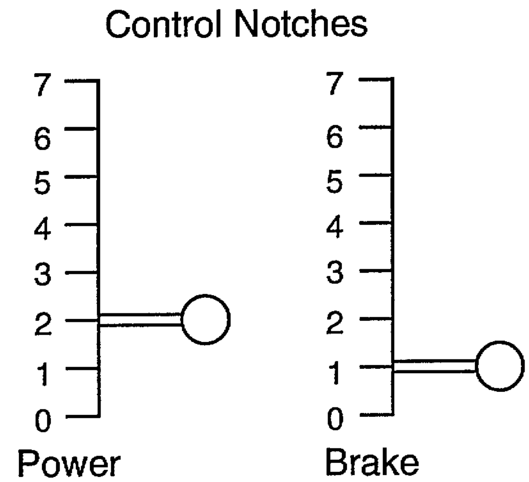
  "If I were to perform this task (or perform it better), what additional info would I need?"

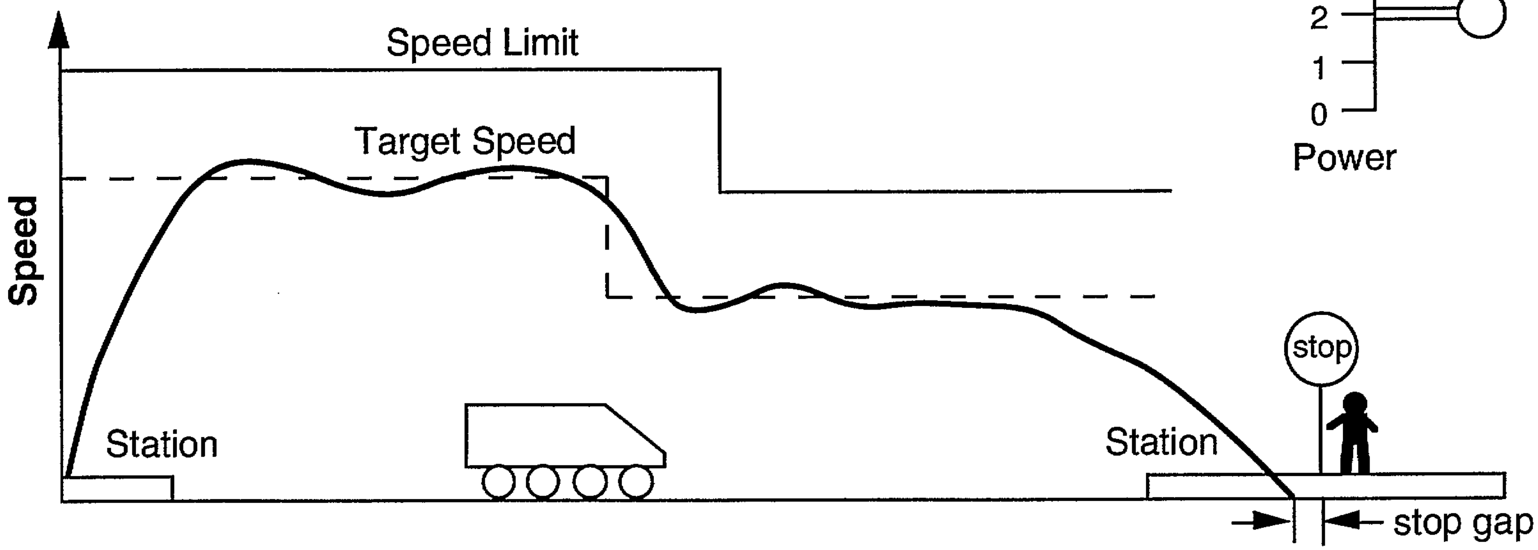
  "If I can't measure it directly, how can I infer it?"
- **Fuzzy logic fosters a new mindset in product development; opens up possibilities**

Predictive Fuzzy Control: Subway Train Operation (Hitachi)

Train Operation Criteria: Sendai Subway System - 1987 - key application - reliable results - raised credibility of F/L

- Safety = F(time to danger zone, speed)
- Comfort = F(amount of notch change, time since last notch change)
- Traceability = F(deviation from target speed)
- Stop gap distance
- Energy consumption





S. Chiu
Rockwell Science Center

Notable Points in Subway Train Controller

- Control based on prediction & ranking of possible control actions
- Fuzzy rules used to rank the results of candidate actions
- Balance of multiple performance criteria
- Qualitative factors, i.e., "comfort" and "safety", can be extracted from measurable parameters

Summary

- **Fuzzy control = using fuzzy logic in control application**
  - -Implement nonlinear control function
  - -Perform supervisory control
  - -Classify operating environment/select conventional control law
  - -Rank results of candidate control actions
- **Fuzzy logic allows you to express what's in your mind**
- **Two levels of fuzzy control**
  - -Low level, set-point oriented — can use conventional techniques
  - High payoff — -High level, task oriented ($$$!) cannot " " "
- **Fuzzy systems are usually based on simple, qualitative strategies, are easy to develop (fast time-to-market) and easy to understand (ease of maintenace)**
- **Commercial applications aimed at "human-friendly" machines**
  - -Increased convenience
  - -Increased match with human intentions/objectives

S. Chiu
Rockwell Science Center

Software Tools for Fuzzy Control

First Canadian Workshop on Fuzzy Logic & Industrial Applications
March 17, 1994

Stephen L. Chiu

Rockwell International Science Center
1049 Camino Dos Rios
Thousand Oaks, CA 91360
Email: slc@risc.rockwell.com

** Many viewgraphs used in the presentation of development tools are provided by courtesy of the following companies: Aptronix, Fuzzy Systems Engineering, HyperLogic, INFORM, Integrated Systems Inc., and Togai InfraLogic.

Outline

- **What tools are available for fuzzy control product development?**

  - **-CubiCalc** (HyperLogic)
  - **-TIL Shell** (Togai InfraLogic)
  - **-fuzzyTech** (INFORM)
  - **-FIDE** (Aptronix)
  - **-RT/Fuzzy** (Integrated Systems Inc.)
  - **-A-B FLEX** (Allen-Bradley)
  - **-Manifold Graphics Editor** (Fuzzy Systems Engineering)
  - **-Fuzz-C** (Byte Craft Ltd.)

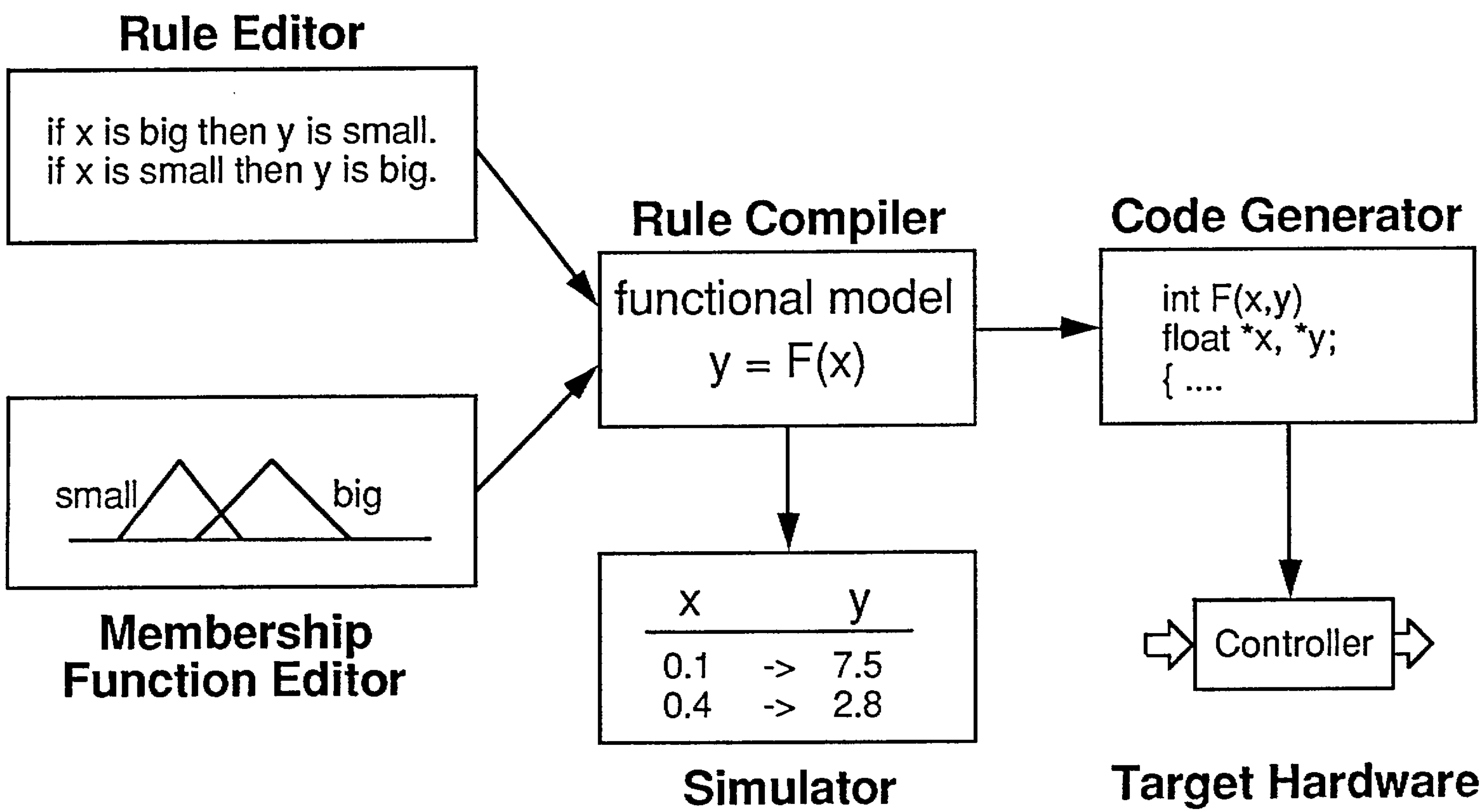
  ...

- **Which one is best suited for my needs?**

Price range $100 to $25k

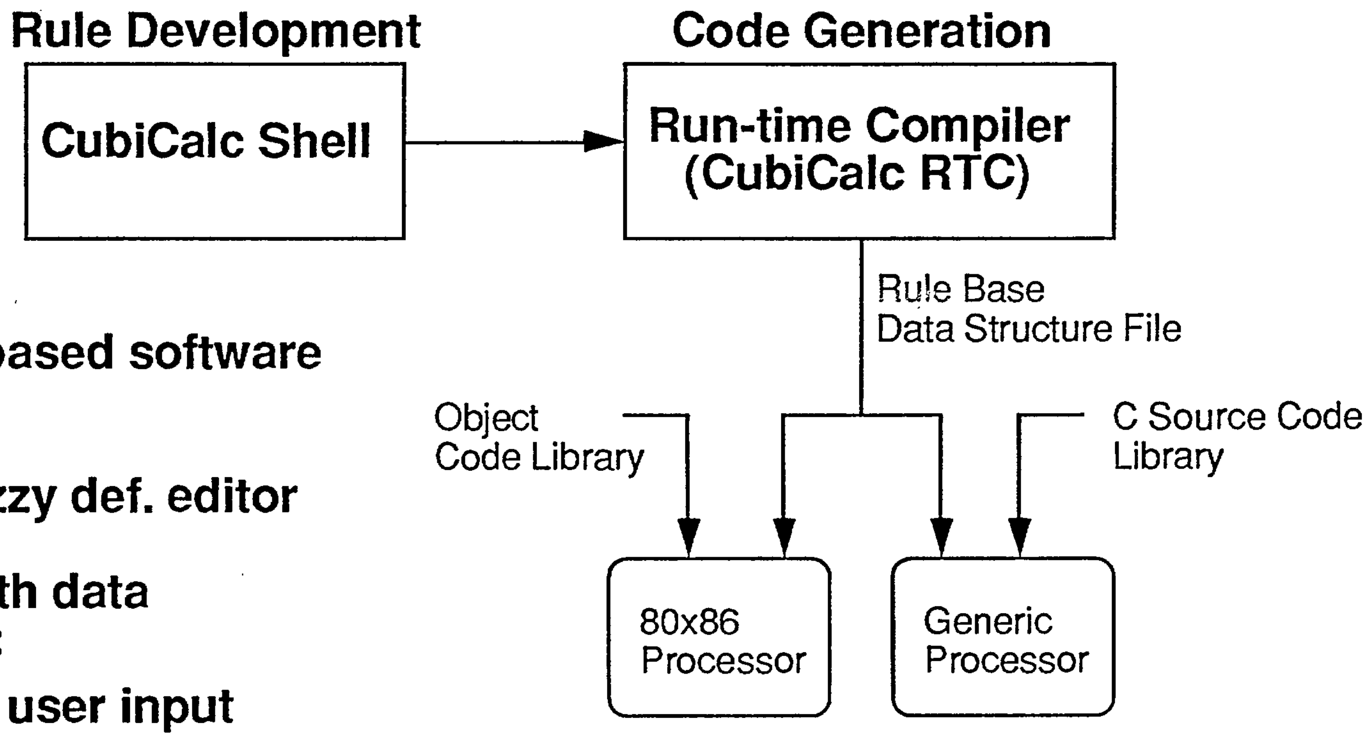
S. Chiu
Rockwell Science Center

Common Features of Fuzzy Software Tools



S. Chiu
Rockwell Science Center

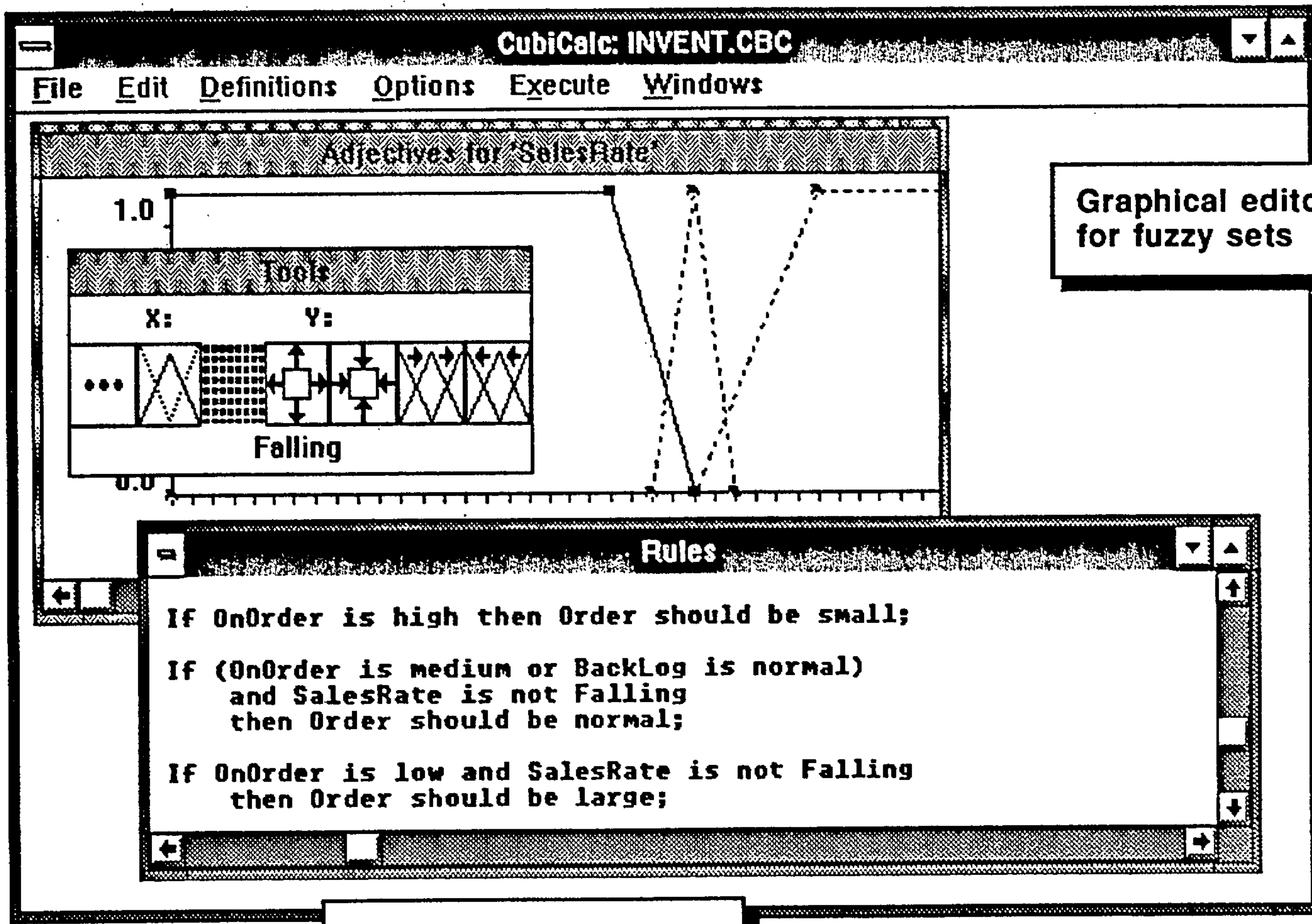
CubiCalc



- A Windows-based software for IBM PC
- Graphical fuzzy def. editor
- Test rules with data received from:
  - Interactive user input
  - File input
  - Other Windows Application (via DDE)
  - Built-in process simulator
- Designed for non-programmers

S. Chiu
Rockwell Science Center

CubiCalc Displays
(Fuzzy Definitions)



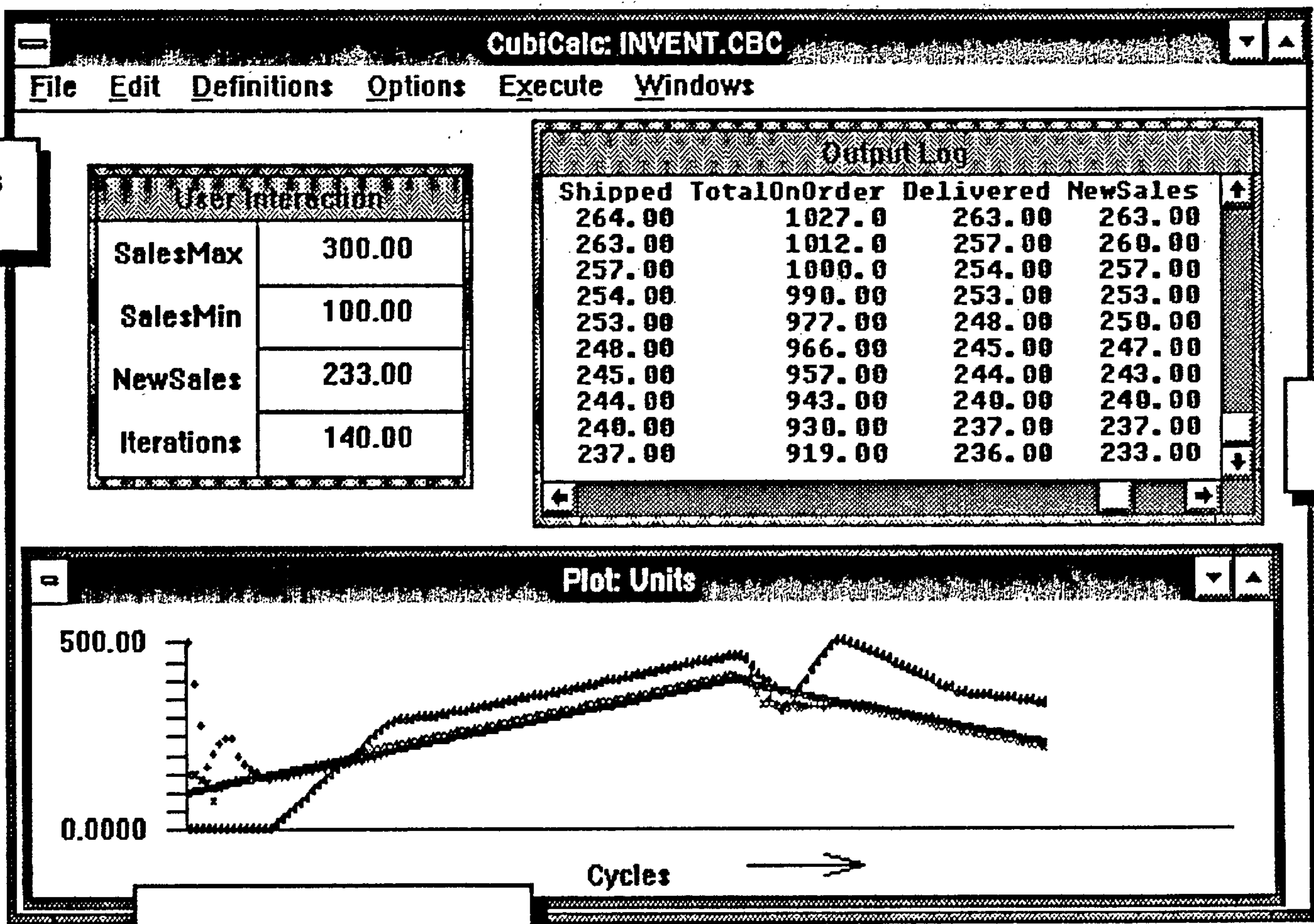
Graphical editor for fuzzy sets

Define English-like rules with builtin text editor

HyperLogic

CubiCalc Displays
(Rule Execution and Simulation)

Enter values interactively



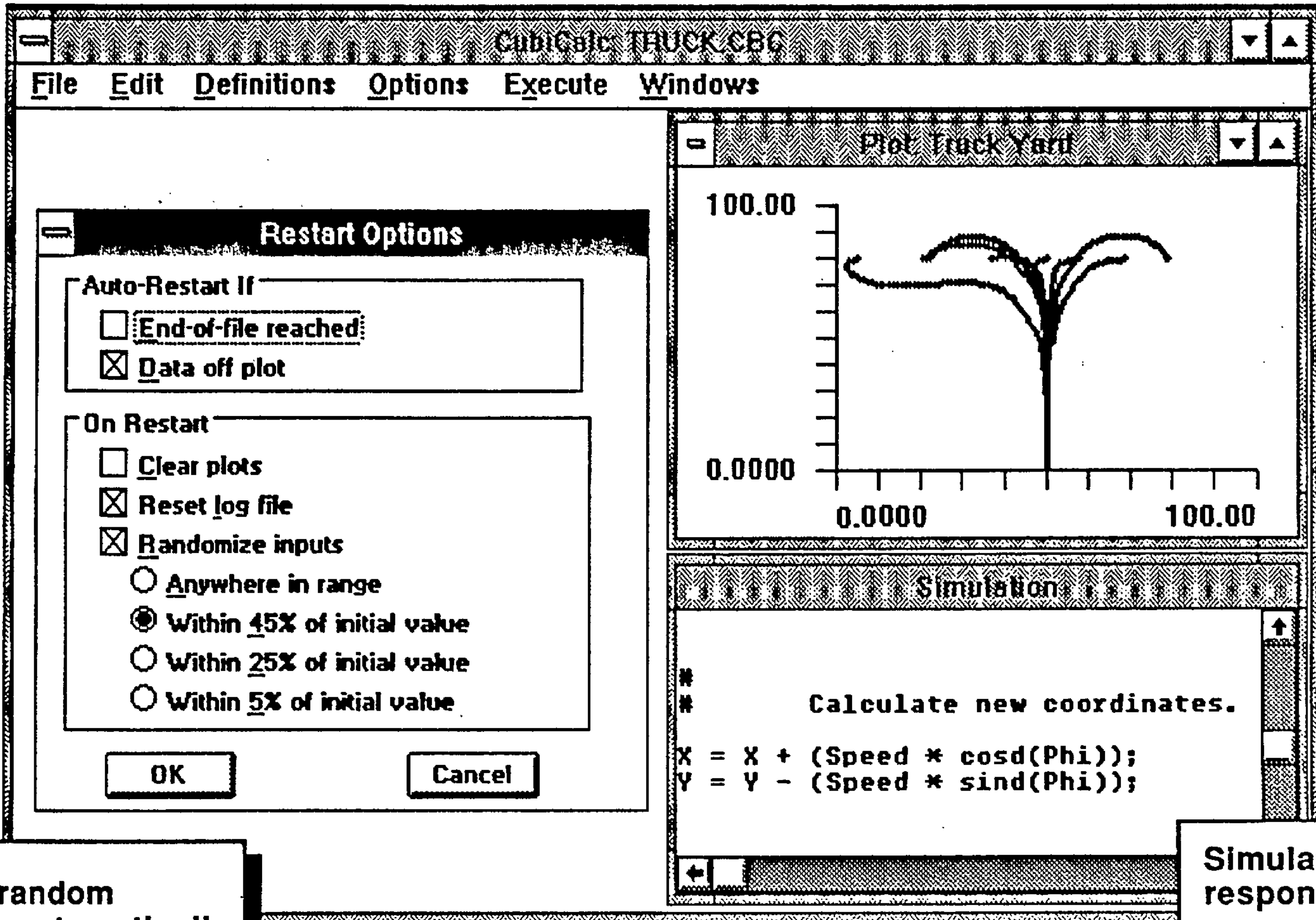
Shipped	TotalOnOrder	Delivered	NewSales
264.00	1027.0	263.00	263.00
263.00	1012.0	257.00	260.00
257.00	1000.0	254.00	257.00
254.00	990.00	253.00	253.00
253.00	977.00	248.00	250.00
248.00	966.00	245.00	247.00
245.00	957.00	244.00	243.00
244.00	943.00	240.00	240.00
240.00	930.00	237.00	237.00
237.00	919.00	236.00	233.00

Log to file or window

Plot to scatter chart or scrolling strip chart

HyperLogic

CubiCalc Displays
(Control System Simulation)

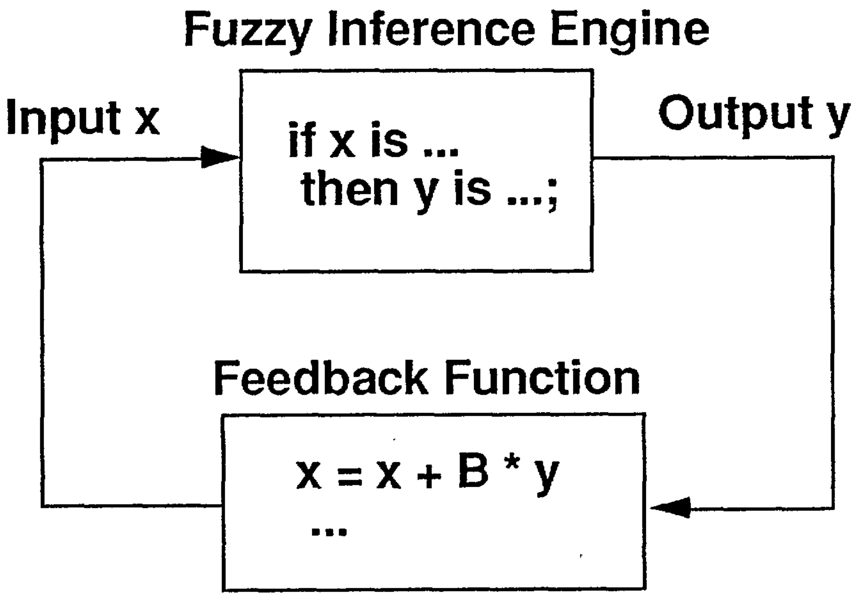


Generate random
test cases automatically

Simulate system
response

HyperLogic

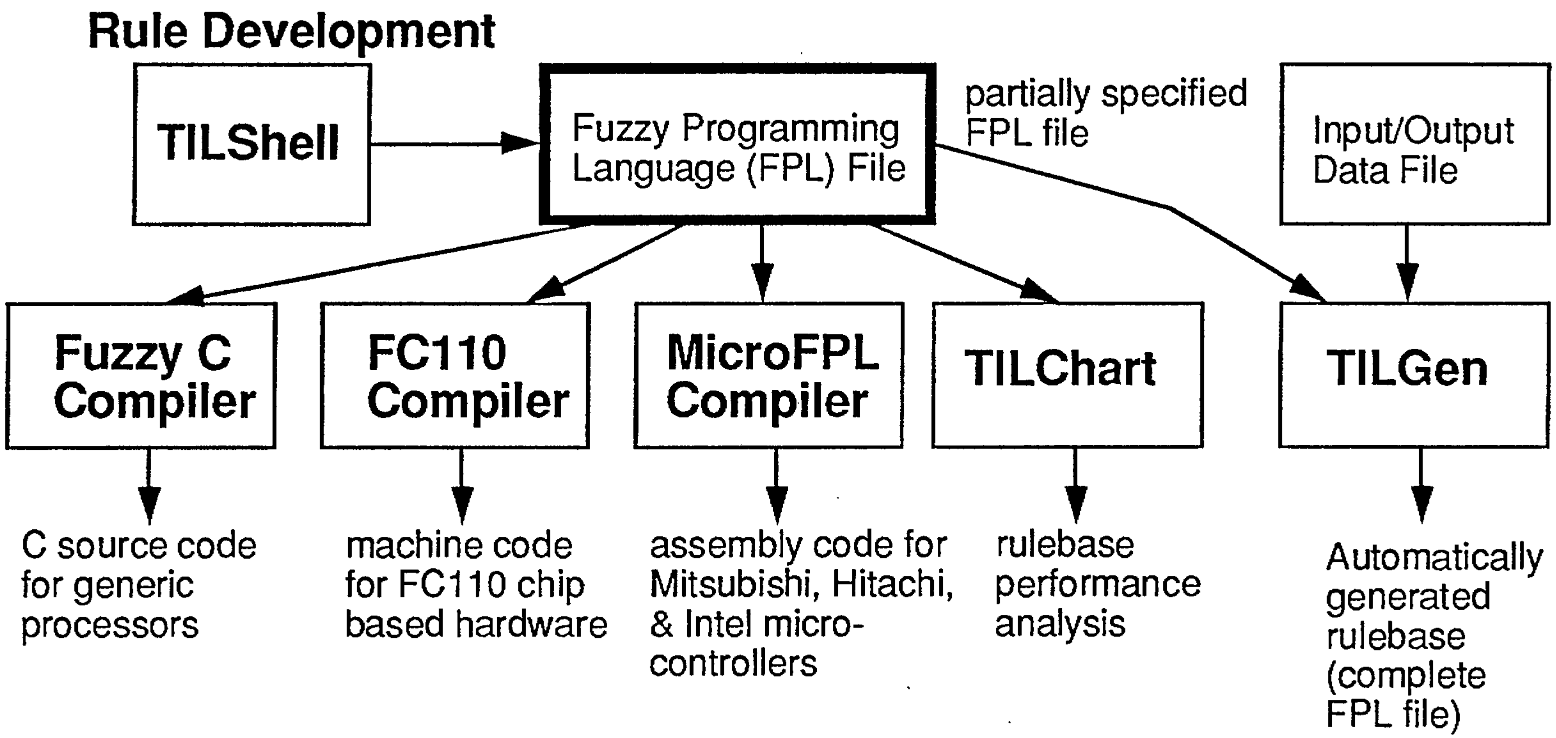
CubiCalc's Process Simulator



- Feedback function specifies next input value
- Suitable for simulating simple processes

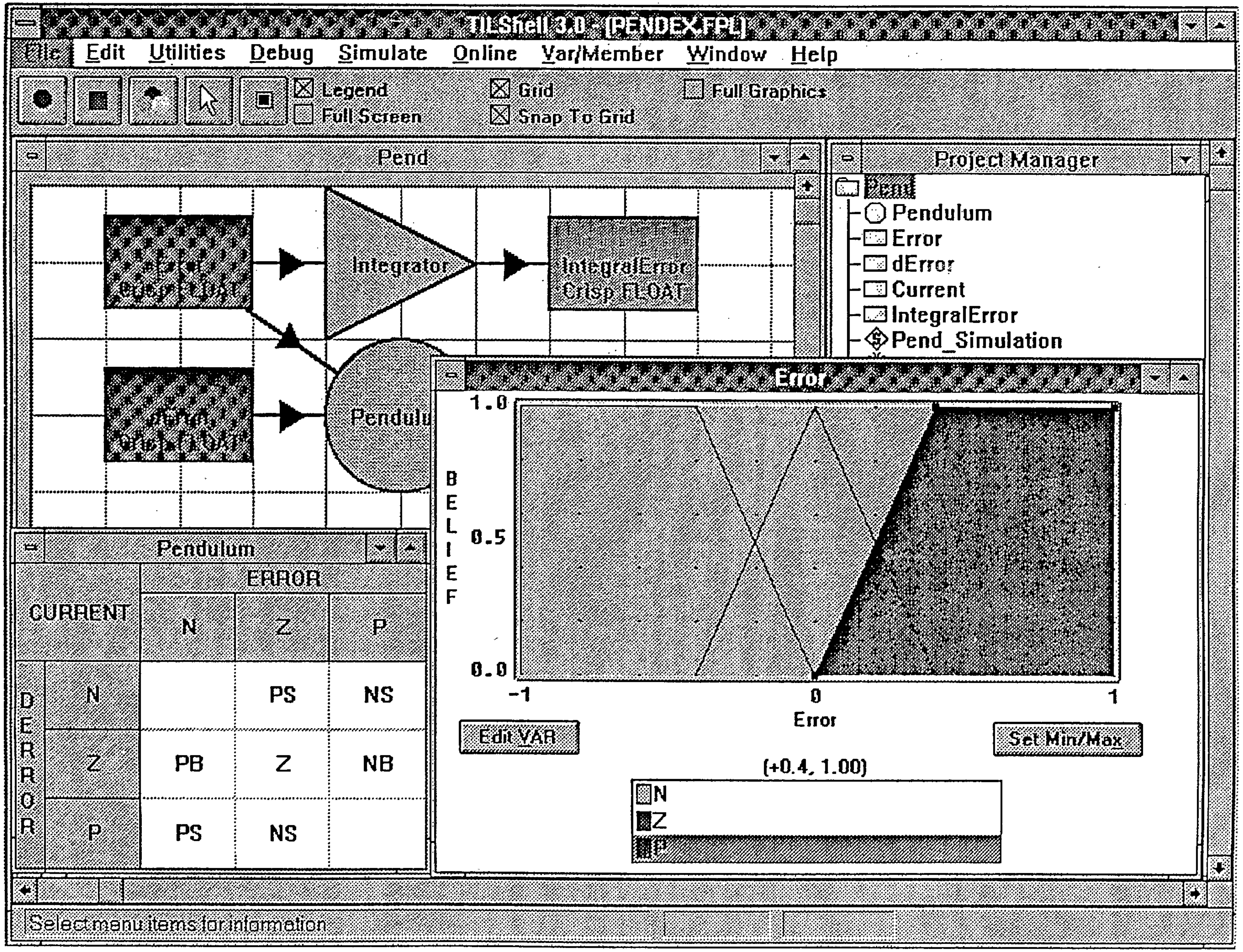
S. Chiu
Rockwell Science Center

TILShell

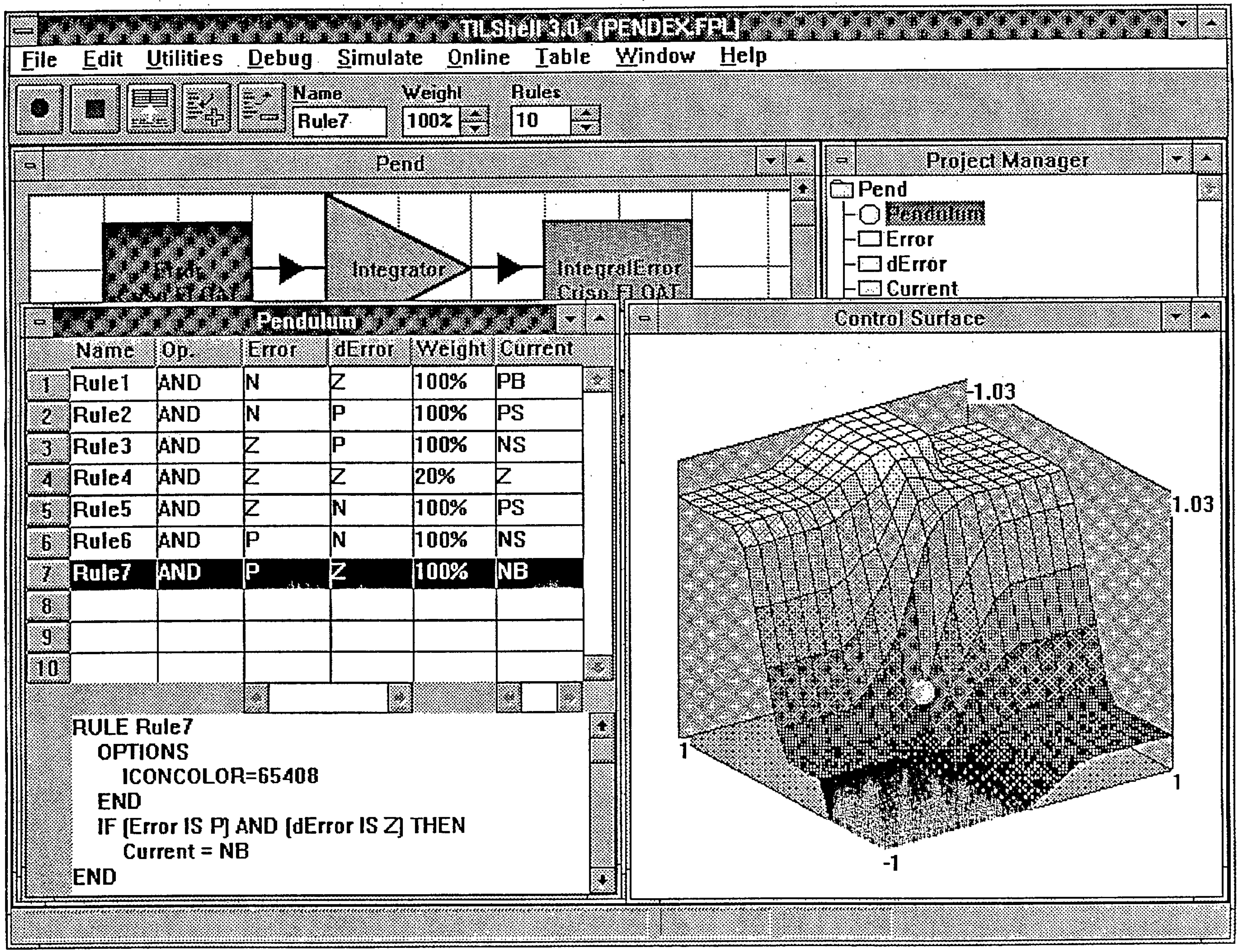


- **Sophisticated CASE-like tool for PC & SUN**
- **Graphical front-end for creating FPL files used by other TIL tools**
- **High-speed hardware support**
- **Designed for programmers & development engineers**

S. Chiu
Rockwell Science Center

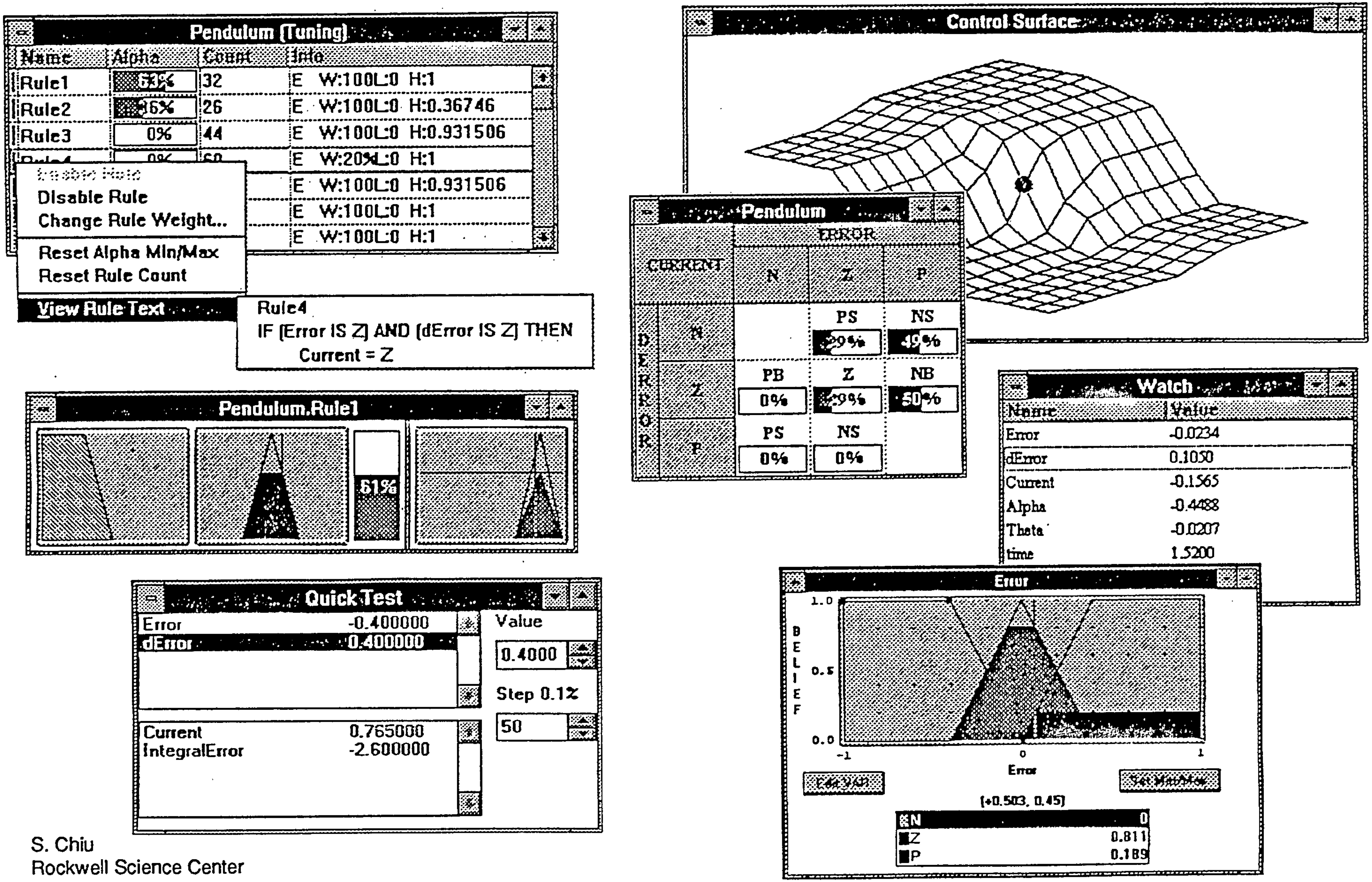


TILShell 3.0 - [PENDEX.FPL]
File Edit Utilities Debug Simulate Online Var/Member Window Help
Legend
Full Screen
Grid
Snap To Grid
Full Graphics
Pend
Integrator
IntegralError Crisp FLOAT
Pendulu
Project Manager
Pend
Pendulum
Error
dError
Current
IntegralError
Pend_Simulation
Error
1.0
0.5
0.0
BELIEF
-1
0
1
Error
Edit VAR
Set Min/Max
(+0.4, 1.00)
N
Z
P
Pendulum
CURRENT
ERROR
N
Z
P
DERROR
N
PS
NS
Z
PB
Z
NB
P
PS
NS
Select menu items for information



TILShell 3.0 - [PENDEX.FPL]
File Edit Utilities Debug Simulate Online Table Window Help
Name Rule7
Weight 100%
Rules 10
Pend
Integrator
IntegralError
Project Manager
Pend
Pendulum
Error
dError
Current
Pendulum
Name Op. Error dError Weight Current
1 Rule1 AND N Z 100% PB
2 Rule2 AND N P 100% PS
3 Rule3 AND Z P 100% NS
4 Rule4 AND Z Z 20% Z
5 Rule5 AND Z N 100% PS
6 Rule6 AND P N 100% NS
7 Rule7 AND P Z 100% NB
8
9
10
RULE Rule7
OPTIONS
ICONCOLOR=65408
END
IF (Error IS P) AND (dError IS Z) THEN
Current = NB
END
Control Surface
-1.03
1.03
1
1
-1

TILShell's Debugging Tools



S. Chiu
Rockwell Science Center

Debug/Tune Rulebase During Simulation or On-Line

Debug/Tune during Running Simulation

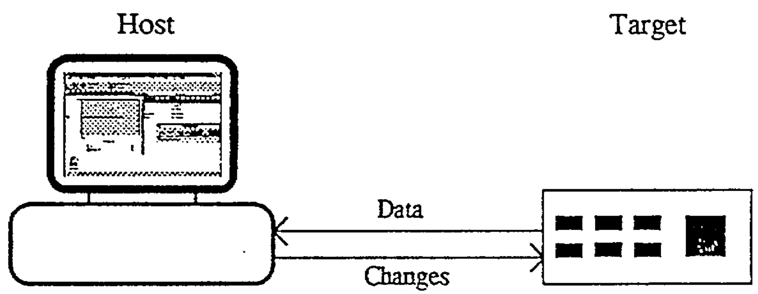
- Define process model via C-like script language
- TILShell debugging windows updated during simulation
- Knowledge base can be modified interactively during simulation

```
Torque = motorK * Current;
Accel = Torque/Inertia;
Vel = Vel + Accel*dT;
Pos = Pos + Vel*dT + Accel*dT*dT;

if Pos > LimitRight then
   Pos = LimitRight;
end
if Pos < LimitLeft then
   Pos = LimitLeft;
end
graphic
dError = Vel;
Error = Pos - Setpoint;
```

Process Model

Debug/Tune a Running External Controller

- Compile a debugging version of control code for target processor
- Target proc. communicates w/ TILShell on host computer
- TILShell debugging windows updated to reflect real-time data
- Changes to knowledge base in TILShell enacted in target processor



S. Chiu
Rockwell Science Center

TOGAI INFRALOGIC INC

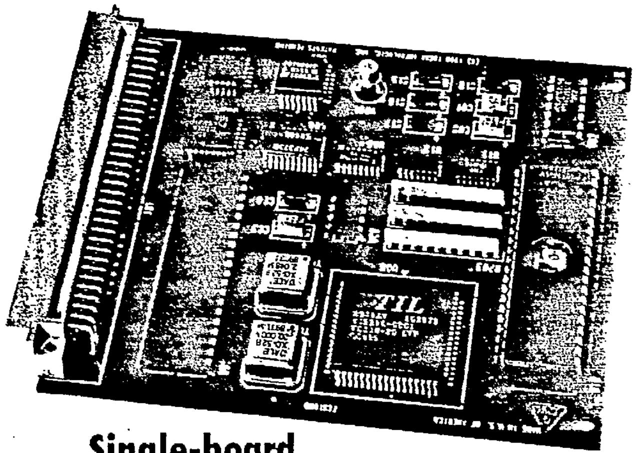
Board-Level Solutions

Togai InfraLogic (TIL) offers more ways to integrate fuzzy logic into your applications than anyone else. TIL's line of board-level products ranges from fuzzy logic accelerator boards to embedded control subsystems.

$40-70 US

The FC110 Foundation

A unique device, the FC110 Digital Fuzzy Processor (DFP™), is at the heart of all Togai InfraLogic hardware solutions. Designed from the ground up for real-time, embedded fuzzy logic control applications, the CMOS FC110 can perform more than 200,000 fuzzy rule evaluations per second.

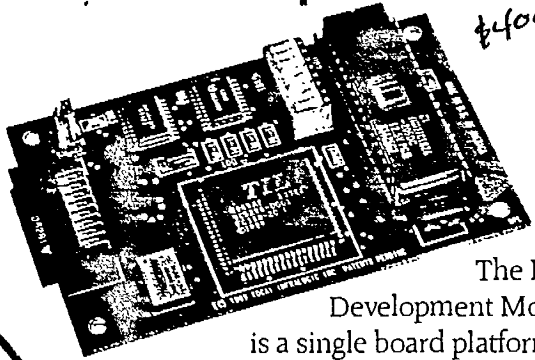


Single-board Fuzzy Controller

TIL's Single-board Fuzzy Controller is a powerful stand alone unit designed for fuzzy logic control applications. In addition to the FC110, the 5″ × 4″ board provides the resources necessary to form a complete fuzzy control module.

FC110 Development Module

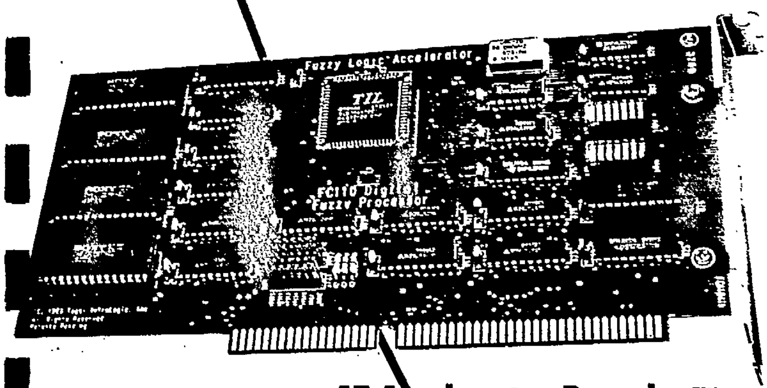
$400



The FC110 Development Module is a single board platform for developing FC110-based embedded expert systems. The board is designed to be connected to a host system requiring acceleration of fuzzy logic inferencing.

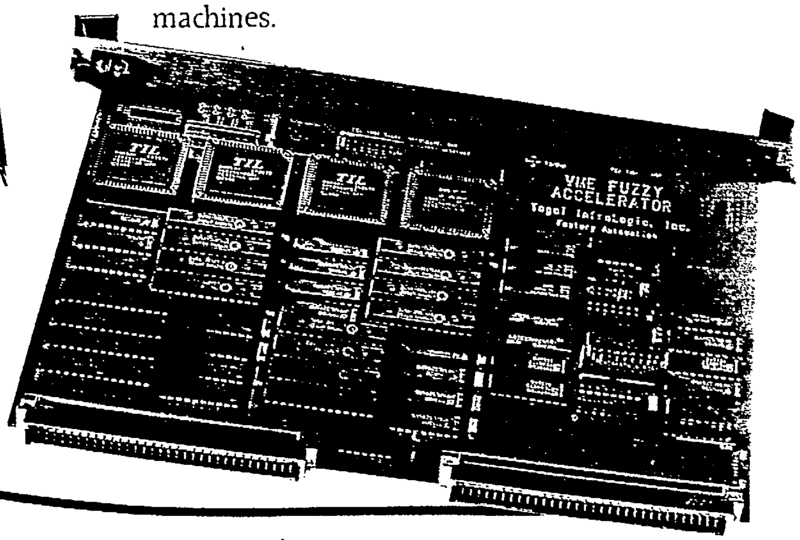
VME Accelerator Board

A high performance single board fuzzy logic accelerator, the VME Accelerator Board is designed for the development and evaluation of complex real-time fuzzy logic applications on VME-based machines.



AT Accelerator Board

Designed for the IBM PC/AT® bus, the AT Accelerator Board allows the development and evaluation of complex fuzzy logic applications on a personal computer.



Benchmarking Fuzzy Hardware

Togai InfraLogic FC110 Chip*

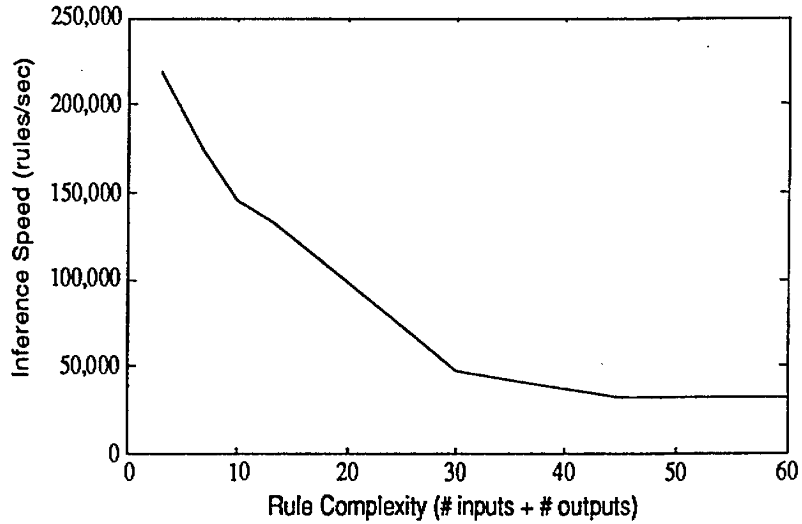
Rule Base Size	Rule Base Evaluation Time	# Rules Per Second
2-inputs, 1-output, 7 rules	32 µsec	218,750
5-inputs, 2-outputs, 20 rules	114 µsec	175,000
7-inputs, 3-outputs, 25 rules	172 µsec	145,350
10-inputs, 3-outputs, 35 rules	266 µsec	131,580
20-inputs, 10-outputs, 100 rules	2,110 µsec	47,393
30-inputs, 15-outputs, 125 rules	3,810 µsec	32,808
50-inputs, 10-outputs, 150 rules	4,682 µsec	32,038
50-inputs, 10-outputs, 175 rules	5,449 µsec	32,116

* Data provided by Togai InfraLogic, based on FC110 operating at 20MHz

Rule Format:

"If input-1 is A & input-2 is B,
then output-1 is C and output-2 is D"

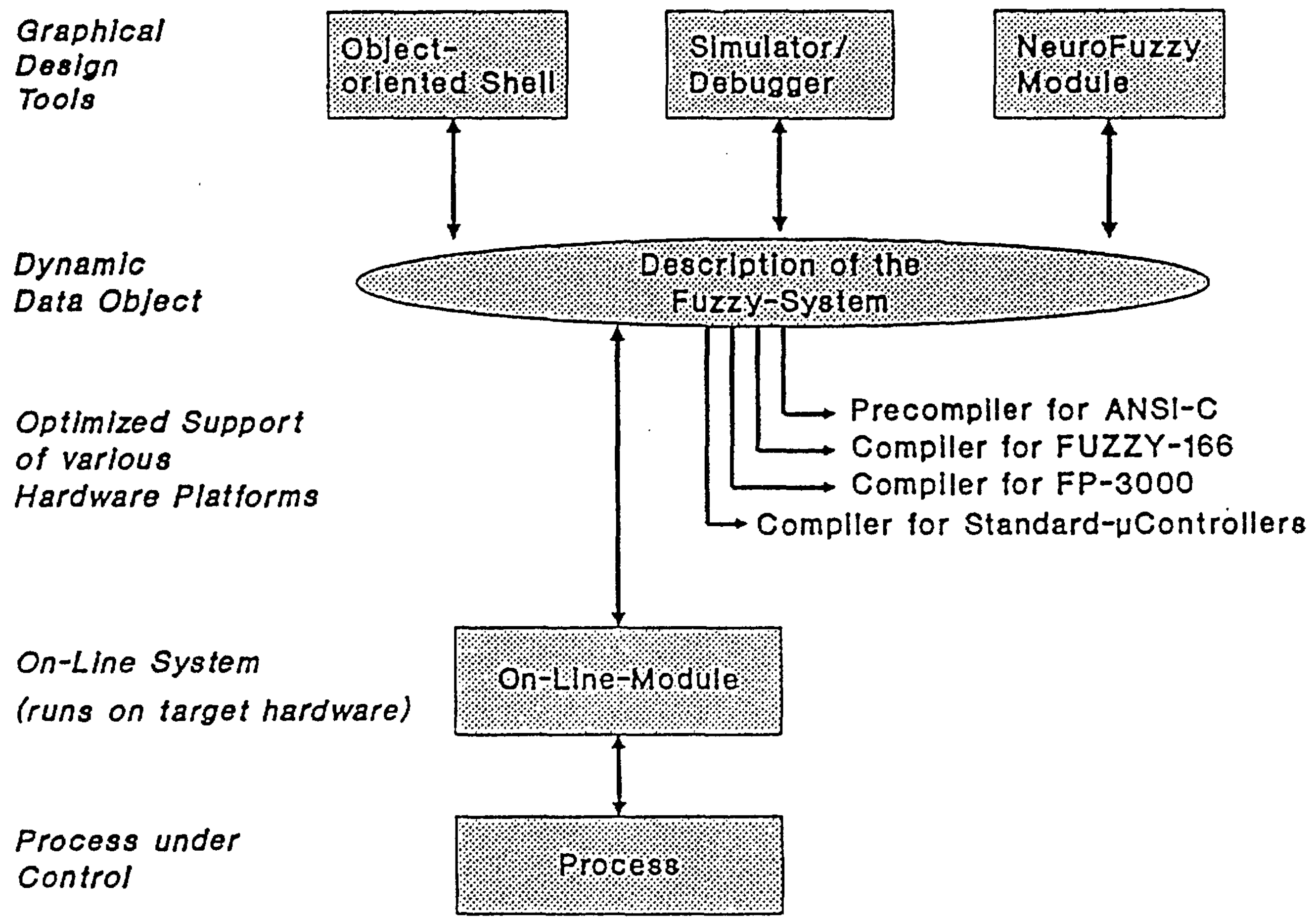
Membership functions discretized into 256 levels horizontally & vertically



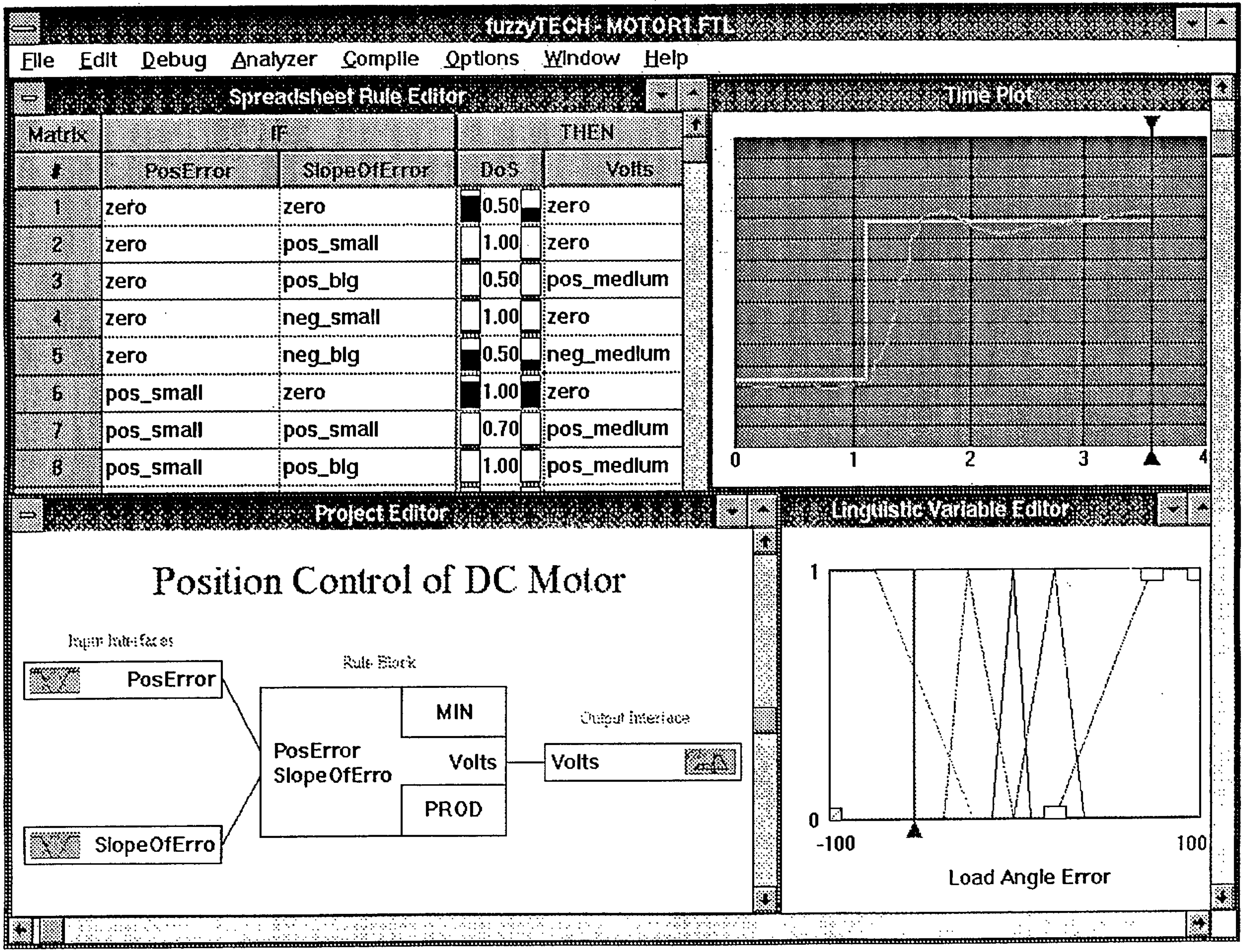
- **Inference speed highly dependent on number of inputs & outputs, mildly dependent on number of rules**
- **No standardized benchmark for fuzzy inference**
- **Inference speed only meaningful w.r.t. rule complexity & memb. fn. resolution**

S. Chiu
Rockwell Science Center

The *fuzzy*TECH Workbench

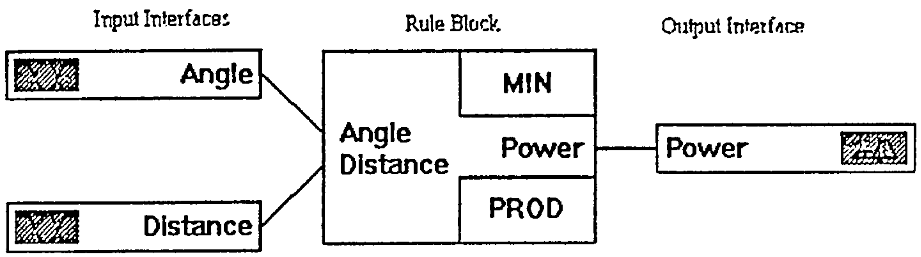


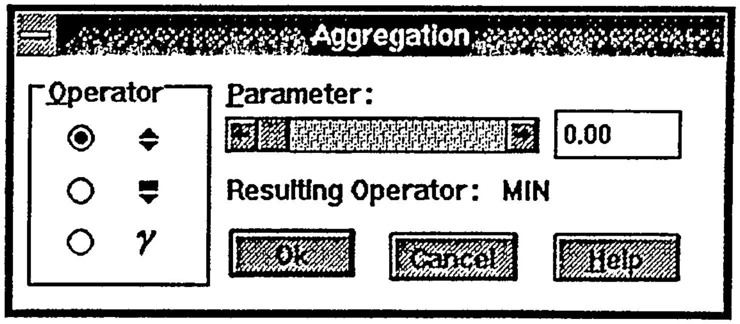
*fuzzy*TECH™ Enables Full Graphical Development

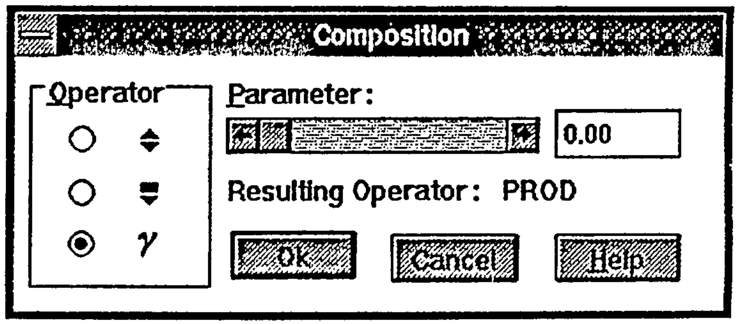


fuzzyTech's Parameterized Operators

- Assume all rule conjunctions are "and"s
- Meaning of "and" depends on aggregation operator & its parameter value
  - MIN-MAX(val), MIN-AVG(val), GAMMA(val)
- One operator at a given parameter value applies to entire rule block
  - cannot mix "and" and "or"





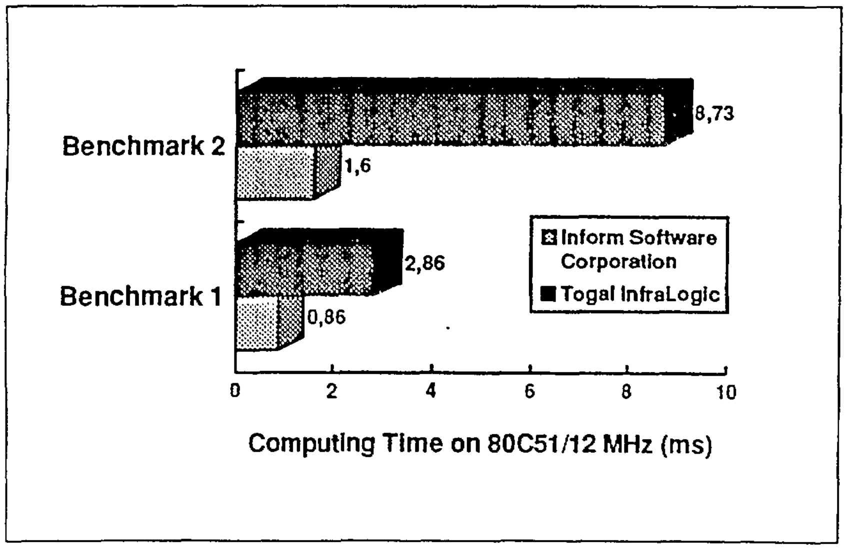


S. Chiu
Rockwell Science Center

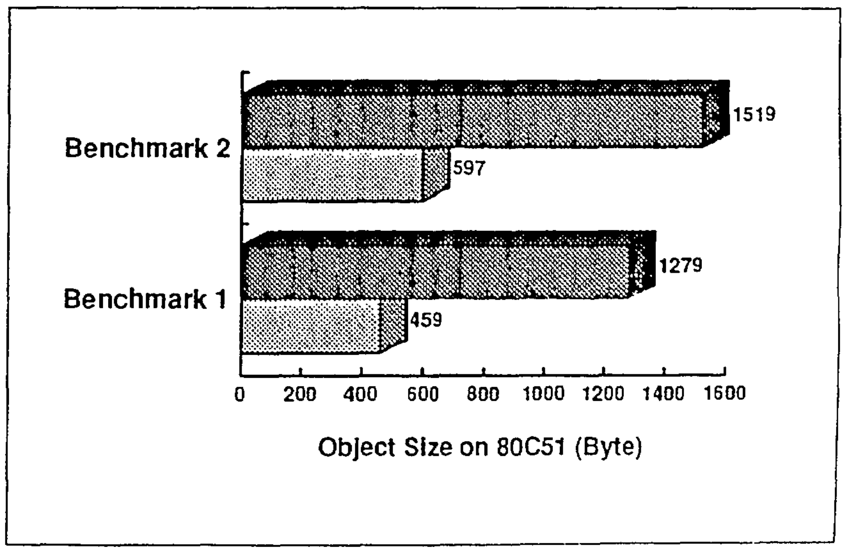
*fuzzy*TECH™ is Europe's Leading Fuzzy Logic Software Tool

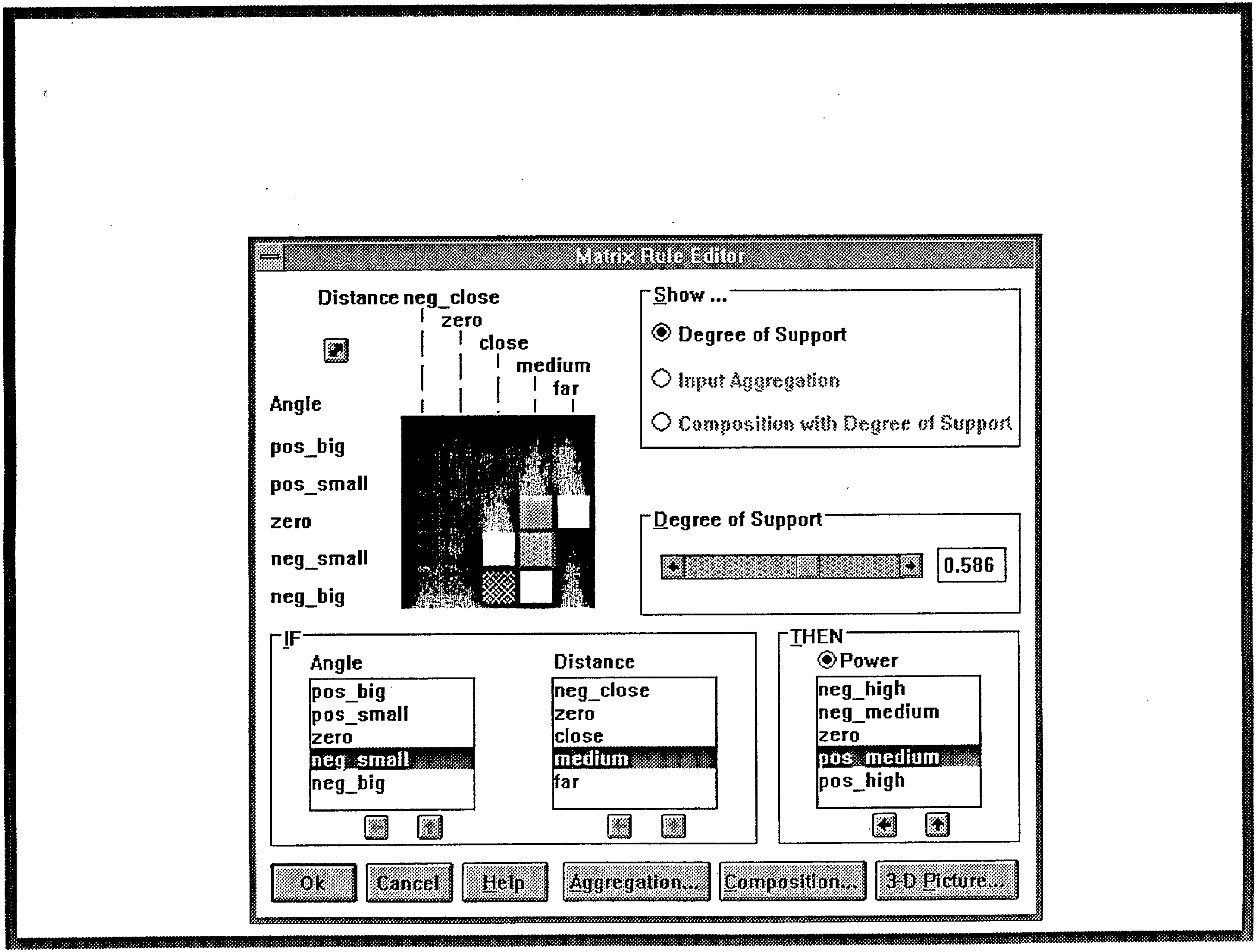
- Only Tool to Support Full Graphical Design, Optimization and Systems Verification
- Only Tool to Implement Online Development on a Running System ("on-the-fly" modifications)
- Supports Fuzzy Associative Maps (FAM-Inference) for more efficient fine-tuning
- Integrates Neural Network Technologies for NeuroFuzzy System Design
- Open Standards: all *fuzzy*TECH Interfaces and Data Formats are Public, allowing Integration, Customizations and User Extensions
- Integrates Simulations Written in Any Language Under MS-Windows™
- Allows Full Interactive Simulation of System Design to Speed Up Time-To-Market
- Supports Almost Every Target Hardware
- Only Quality ISO9000 Approved Fuzzy Logic Design Tool

☑ Fastest Code Generation

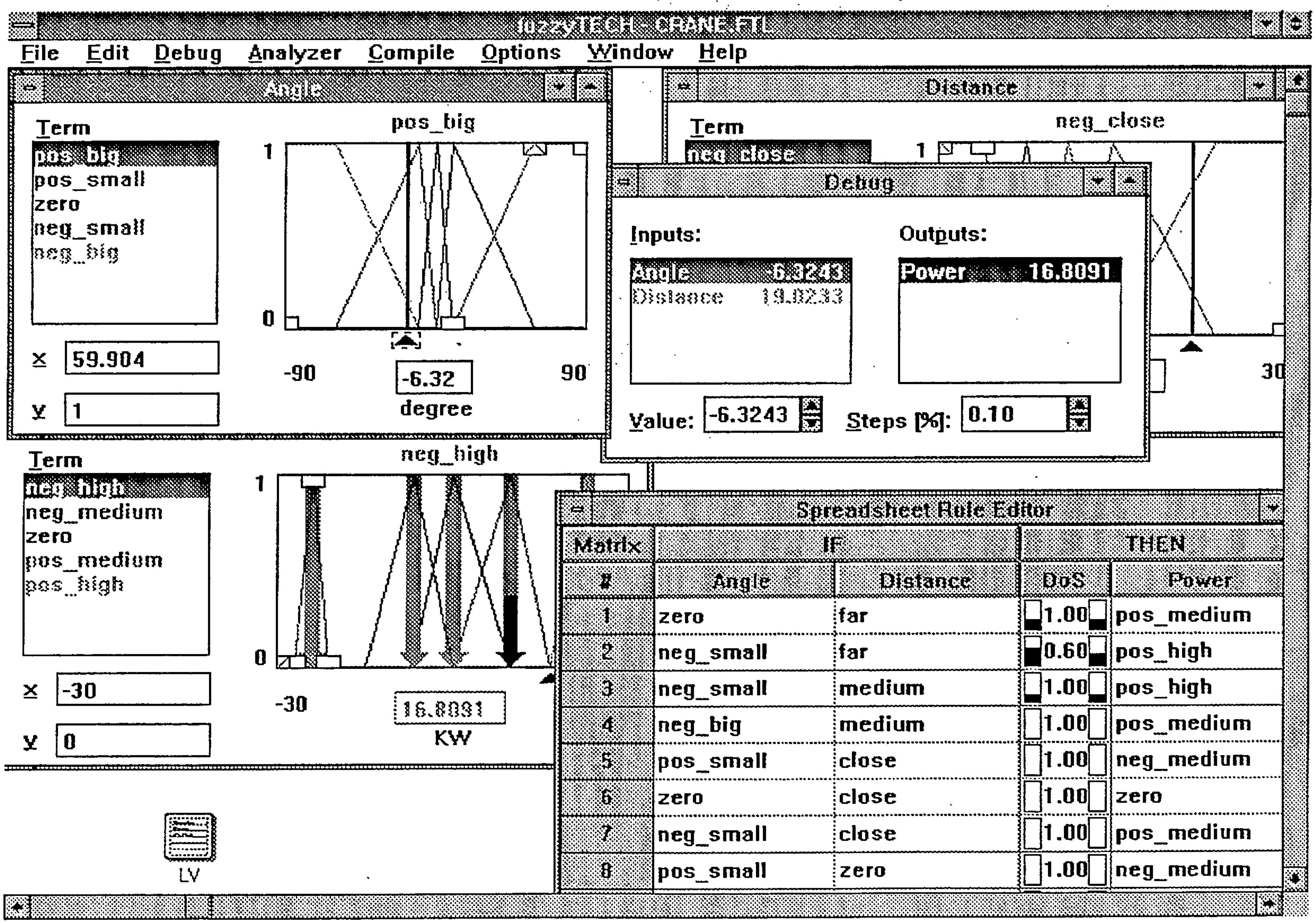


☑ Most Compact Code




Matrix Rule Editor
Distance neg_close
zero
close
medium
far
Angle
pos_big
pos_small
zero
neg_small
neg_big
Show ...
Degree of Support
Input Aggregation
Composition with Degree of Support
Degree of Support
0.586
IF
Angle
pos_big
pos_small
zero
neg_small
neg_big
Distance
neg_close
zero
close
medium
far
THEN
Power
neg_high
neg_medium
zero
pos_medium
pos_high
Ok
Cancel
Help
Aggregation...
Composition...
3-D Picture...

INTERACTIVE DEBUGGING



Debug/Tune Rulebase During Simulation or On-Line

Debug/Tune during Running Simulation

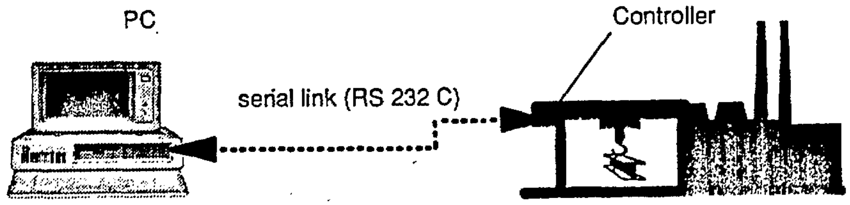
- Define process model via external program that communicates w/ fuzzyTech via DDE-like routines
- fuzzyTech debugging windows updated during simulation
- Knowledge base can be modified interactively during simulation

External Program

```
/* all data are passed through a
data structure called FTLINK */

/* allocate memory for an FTLINK */
myFtlink = FtlAllocMem(...);

while (...) {
    :
    FtlSetInput(myFtlink,inputNames);
    FtlCallFuzzy(mySimWindow,myFtlink);
    FtlGetOutput(myFtlink,outputNames);
}
```

Debug/Tune a Running External Controller

- Compile a debugging version of control code for target processor
- Target proc. communicates w/ fuzzyTech on host computer
- fuzzyTech debugging windows updated to reflect real-time data
- Changes to knowledge base in fuzzyTech enacted in target processor



S. Chiu
Rockwell Science Center

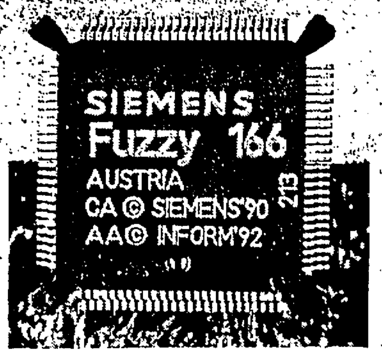
INFORM

Fuzzy Technologies Division
Pascalstr. 23 · D-5100 Aachen · Tel. (0 24 08) 94 56-180 · Fax 60 90

FUZZY-166

Quick Reference Guide

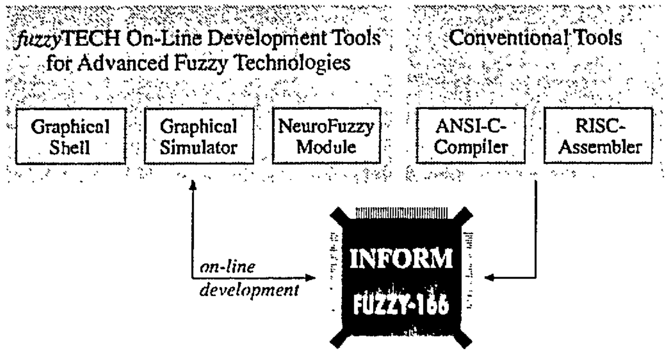
The FUZZY-166 is a 16-bit fuzzy logic processor designed for high speed fuzzy logic based systems. It is the first fuzzy processor to contain both a full conventional instruction set and a fuzzy logic functionality. With plenty of on-chip periphery, it is best suited for the integrated implementation of fuzzy and nonfuzzy functionality on a single chip.



The FUZZY-166 uses the most advanced technologies in fuzzy logic, like On-Line-Optimization and Fuzzy Associative Maps. On-Line-Optimization allows to debug and optimize a fuzzy system at runtime. Fuzzy Associative Maps (FAM) form the link to neutral network technology and also render even complex non-linear systems easy to comprehend. In a special development mode, the FUZZY-166 itself establishes communication with the *fuzzy*TECH workbench on power-up for download of On-Line-Optimization.

Complete Tool Set for the FUZZY-166

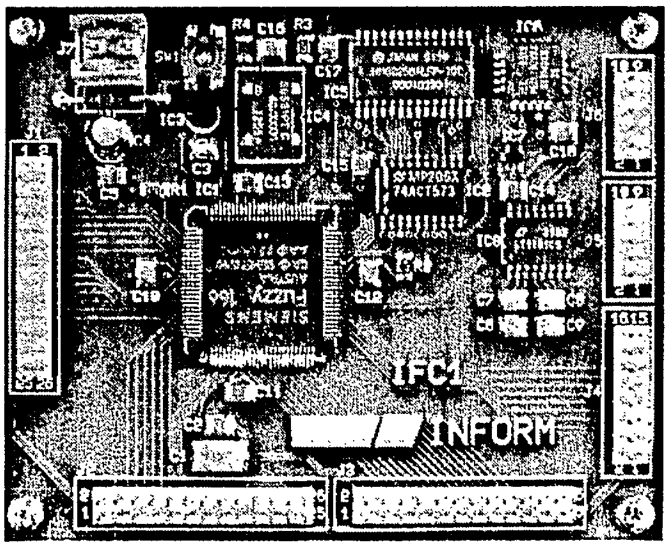
For the FUZZY-166, a complete set of development tools exists. A C-Compiler and a RISC-Assembler can be used for programming the conventional part of the system. To implement a fuzzy logic system on the FUZZY-166, all design tools of the *fuzzy*TECH family may be used.



The FUZZY-166 is fully pin-compatible with the SAB80C166/83C166 standard microcontroller series from SIEMENS. Any application based on this microcontroller can be converted to a fuzzy logic application by exchanging the chip. All Software development tools for the SAB80C166/83C166 can be used with the FUZZY-166.

Evaluation Board for FUZZY-166

To get started with fuzzy logic applications, the FUZZY-166 Evaluation Board can easily be connected to existing hardware. In addition to digital and analog periphery, the FUZZY-166 Evaluation Board has two RS 232 serial ports, which are usable for on-line development with all *fuzzy*TECH development tools.



Fuzzy Logic Function Set

The entire Fuzzy Logic Function Set is implemented in the internal FUZZY-166 firmware and contains three function groups:

1. *fuzzy*TECH Kernel (Fuzzy Function Set)

✗ Fuzzification for linear and S-shaped membership functions with up to 9 defining points
✗ Fuzzy-Operators: MIN-MAX, GAMMA, MIN-AVG (parameter interval partial supported)
✗ Defuzzification Methods: Center-of-Area, Center-of-Maximum and Fuzzy-Output. All functions are fully supported by the *fuzzy*TECH-Precompiler for the FUZZY-166. However, they may be used from C-code level and assembly code level just as well. The full function set is documented in the FUZZY-166 reference manual.

2. *fuzzy*TECH On-Line-Module

✗ Communication functions for serial interfaces S0 and S1
✗ On-Line development functions:
- Change of membership functions definition at runtime
- Change of rule strategy at runtime
- Polling of any fuzzy inference data in the system at runtime
- Tracing of control variables at runtime

The integrated On-Line-Module is fully supported by all *fuzzy*TECH design tools. However, they may be used by other software as well. The full feature set is documented in the FUZZY-166 reference manual.

3. Communications Manager

✗ Program download via serial interface S1
✗ Utility functions to control program execution

Fuzzy Logic Performance

✗ Fuzzification of 4 linear terms: 39 µs
✗ FAM-inference of 51 rules: 204 µs
✗ COM-defuzzification of 3 linear terms: 25 µs
✗ COA-defuzzification of 3 linear terms with 64-step numerical integration: 2220 µs

All times average performance with 8-bit external data bus, all data located in external RAM and zero waitstates. Locating data in the FUZZY-166 internal RAM will increase the speed for 20% and using an 16-bit external data bus will increase the speed for 10%.

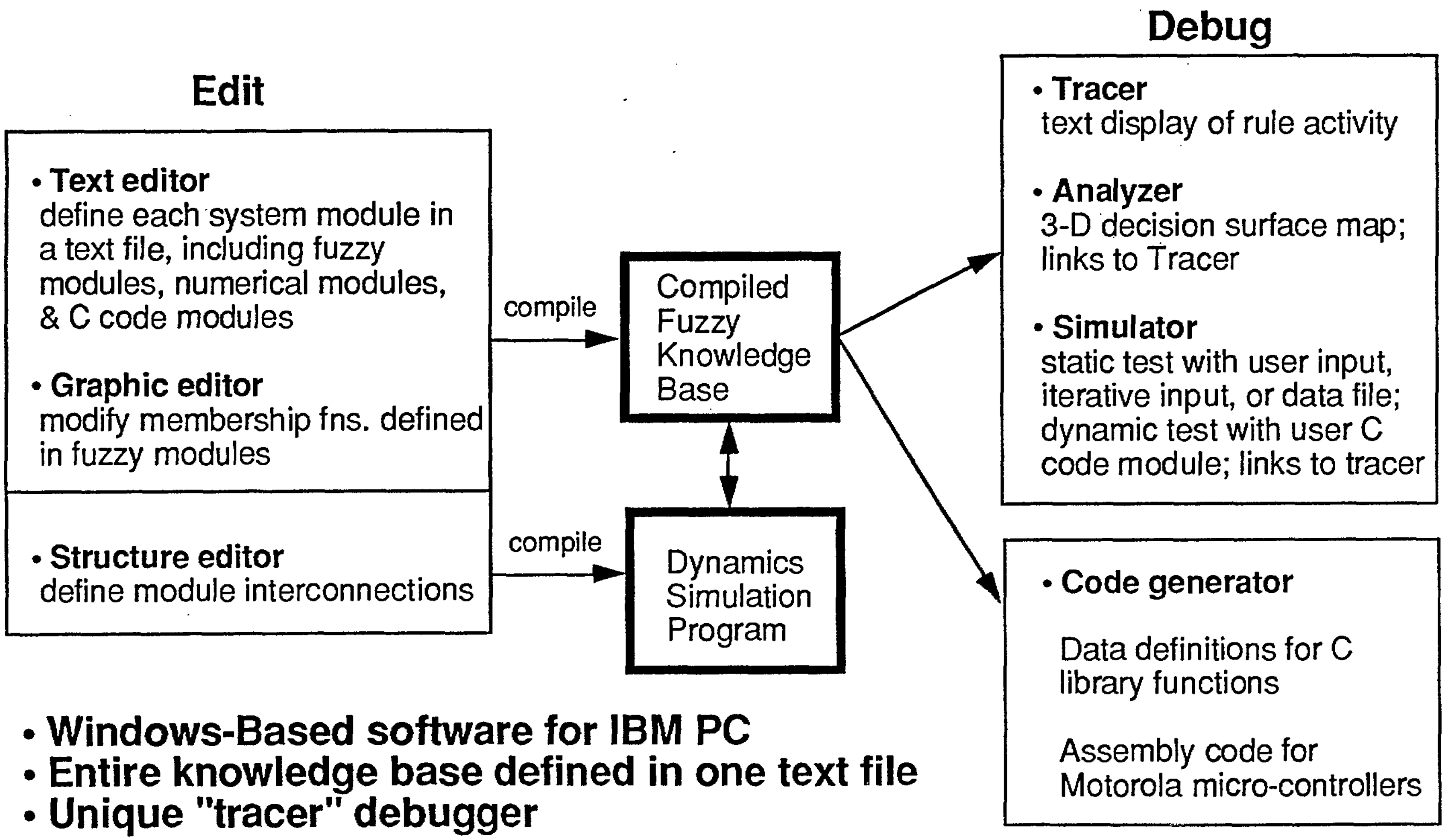
Periphery and Specifications

✗ Packaging: 100-pin plastic quad flat package (PQFP 100)
✗ High-Performance 16-bit RISC-CPU with four stage pipeline, 100% compatible to SAB 80C166/83C166
✗ 100 ns minimum instruction cycle time
✗ 500 ns 16-bit multiplication
✗ Direct adressability of 4 Kbits for peripherials and user defined flags
✗ 1 KB internal RAM
✗ 4 different bus configuration modes
✗ 8-channel peripherial event controller
✗ 10-channel 10-bit A/D converter, 9.75 µs conversion time
✗ 16-channel capture/compare unit
✗ 5 16-bit timers 200 ns and 400 ns resolution
✗ 2 serial channels
✗ watchdog timer with programmable time intervals
✗ 76 I/O lines with individual bit adressability

For further specifications, see the SAB 80C166/83C166 user's manual

Simpler/cheaper than TilShell & FuzzyTech fuzzytech

FIDE
(Fuzzy Inference Development Environment)

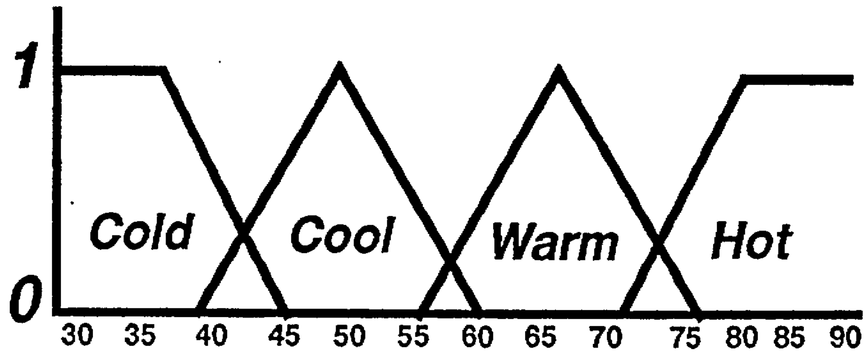


- **Windows-Based software for IBM PC**
- **Entire knowledge base defined in one text file**
- **Unique "tracer" debugger**

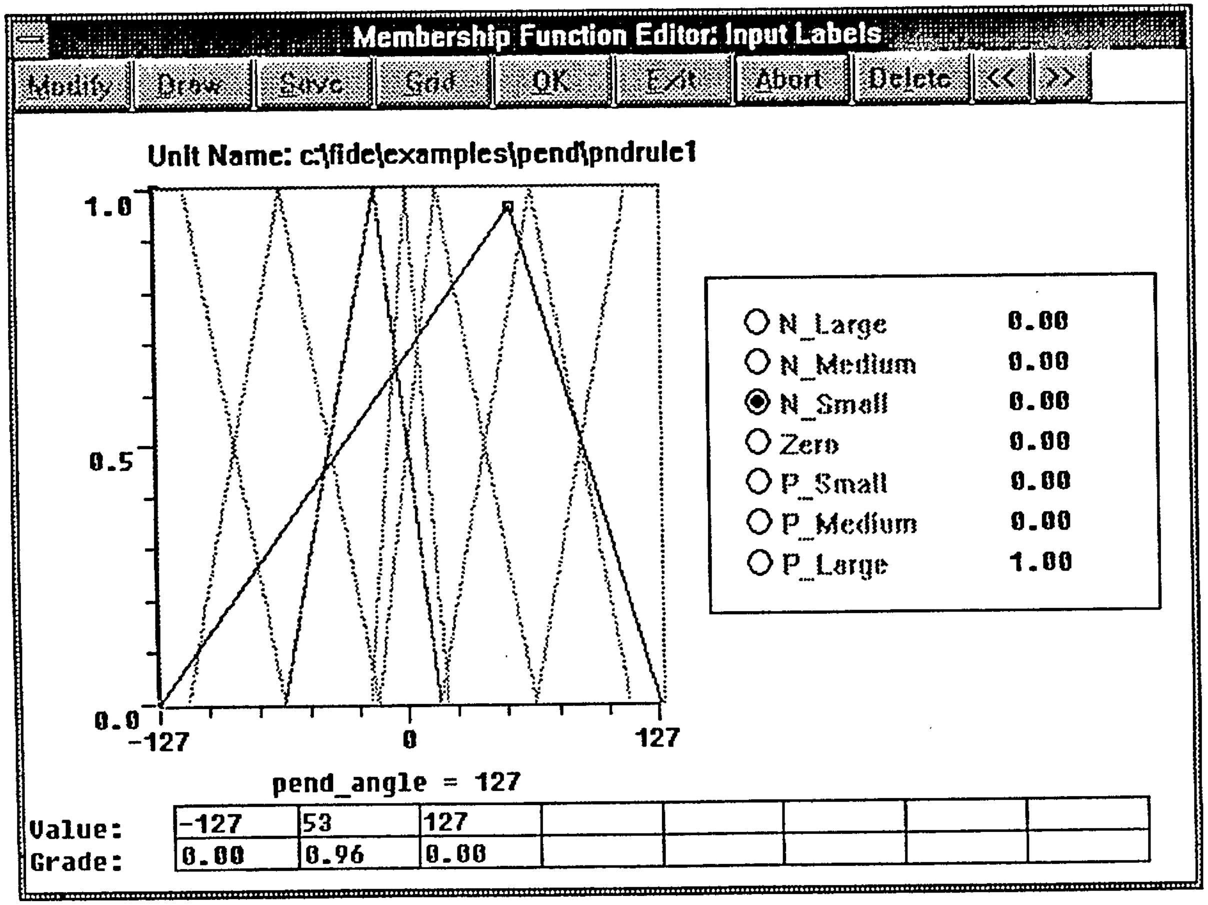
S. Chiu
Rockwell Science Center

Module Definition

```
fiu tvfi (Min Max) *8;

invar temperarure "degree": -110(1)110 [
   cold (@30,1,@38,1,@45,0),
   cool (@40,0,@50,1,@60,0),
  warm "file_wm",
   hot (@70,0,@80,1,@90,1) ];

outvar fan_speed."rpm": 0 (5) 1000 * (
   low = 200,
   medium = 500,
   high = 800) ;

if temperature is warm then fan_speed is low ;
if temperature is hot   then fan_speed is high ; ...
```

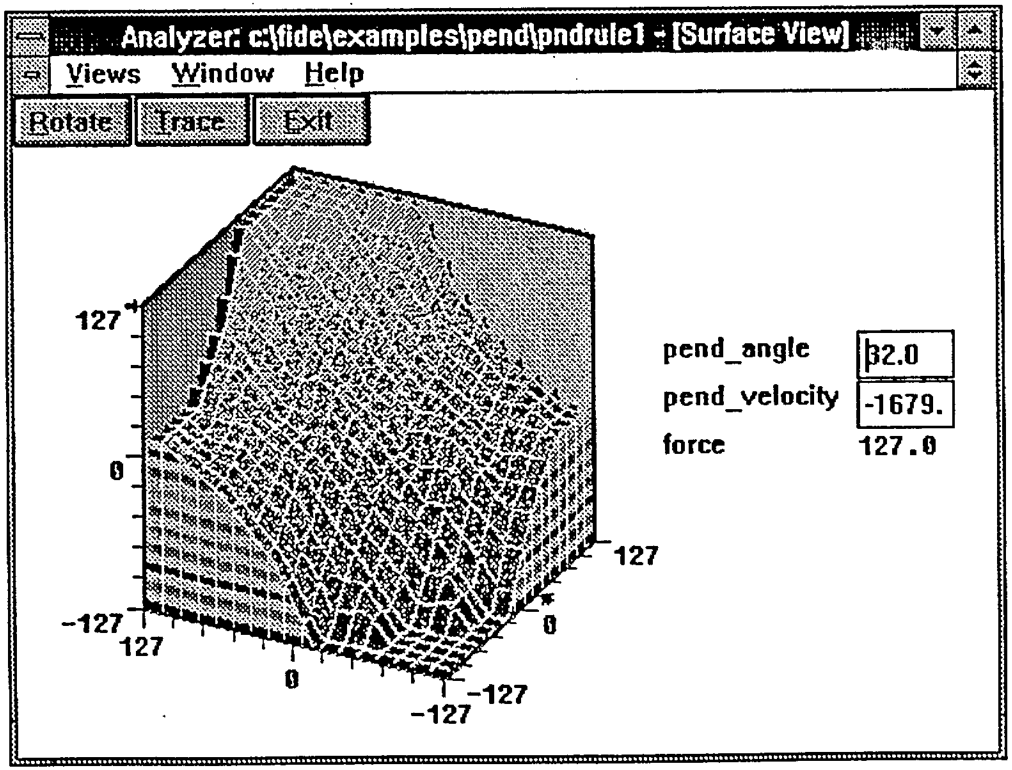


Graphics editing



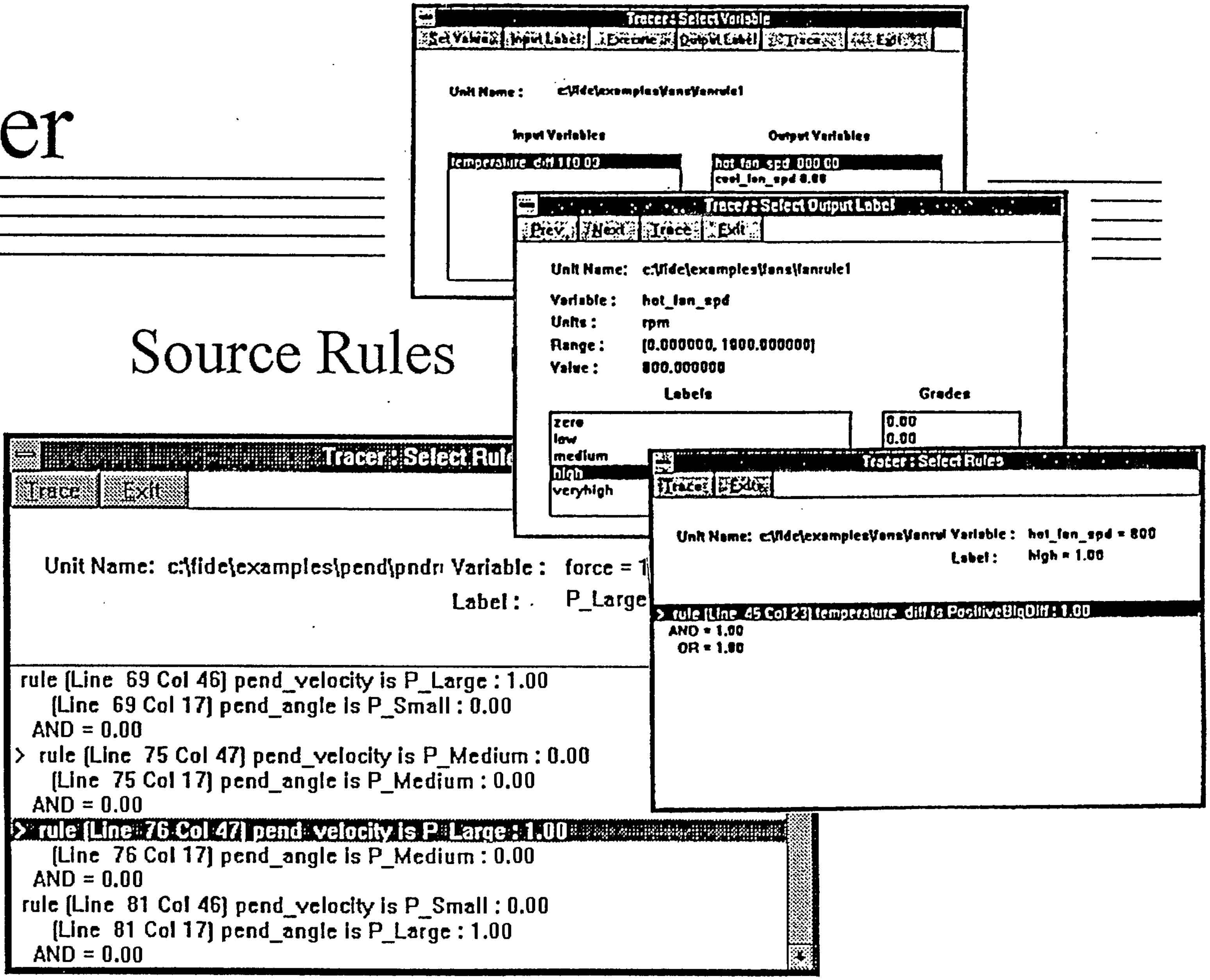
Analyzer

Surface View



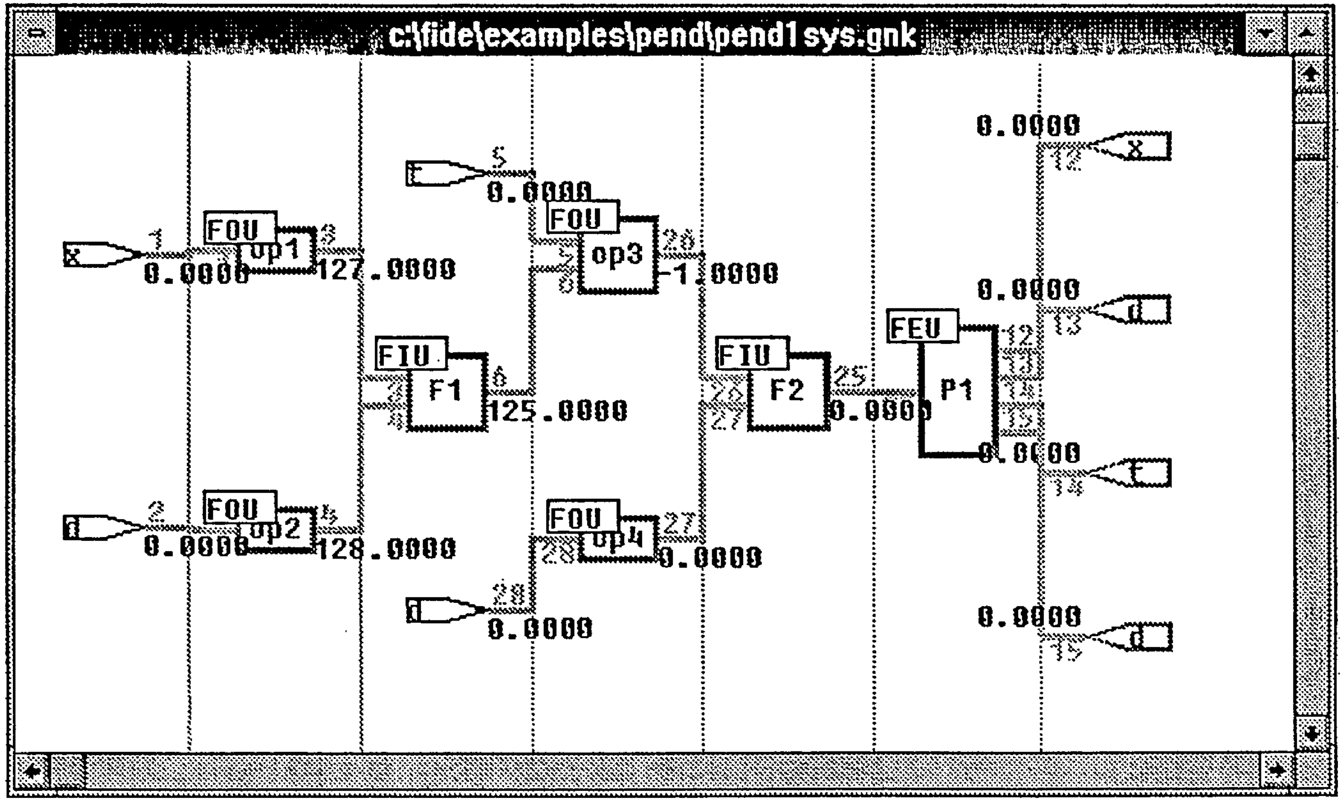
Tracer

Source Rules

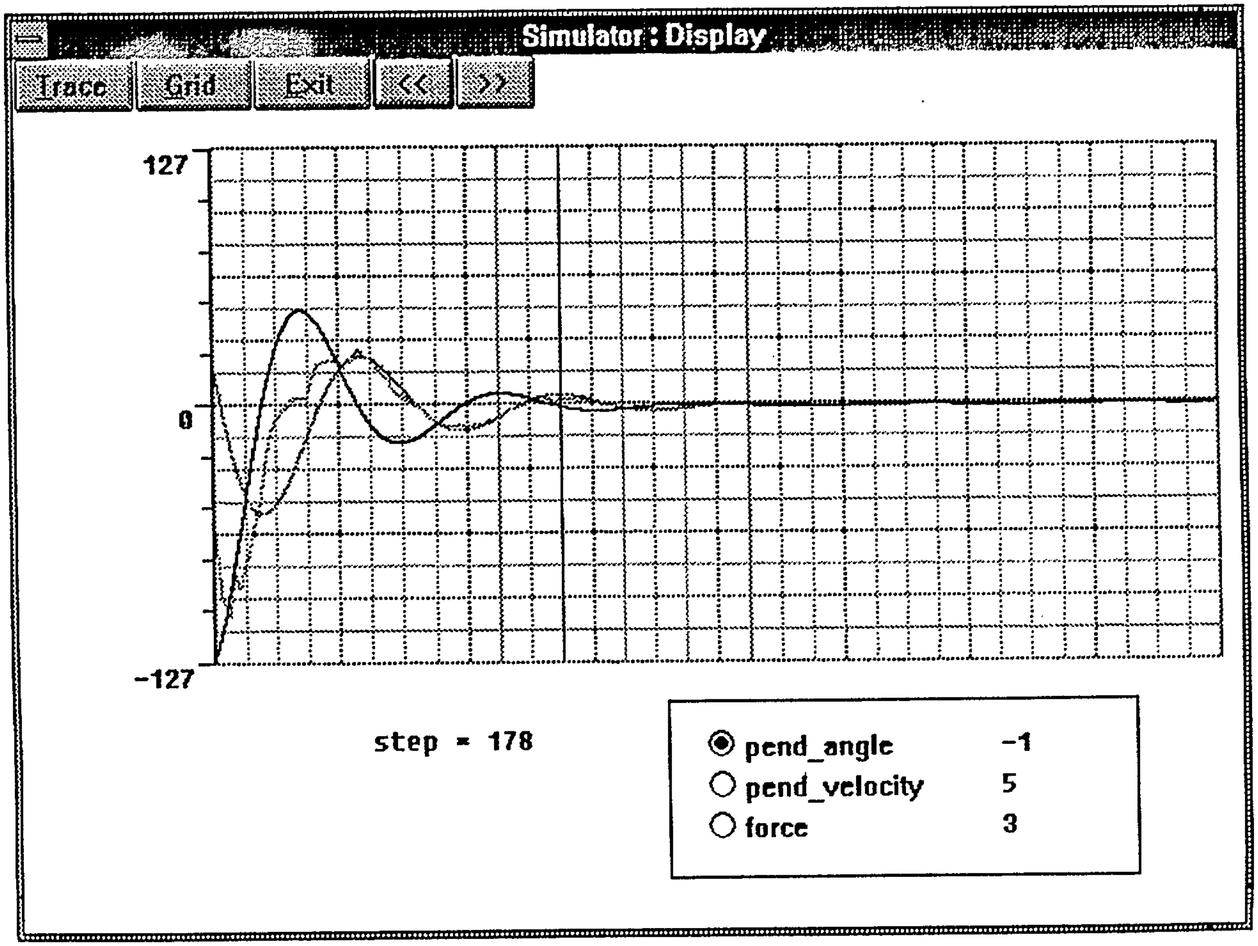


Aptronix

Data Flow Display

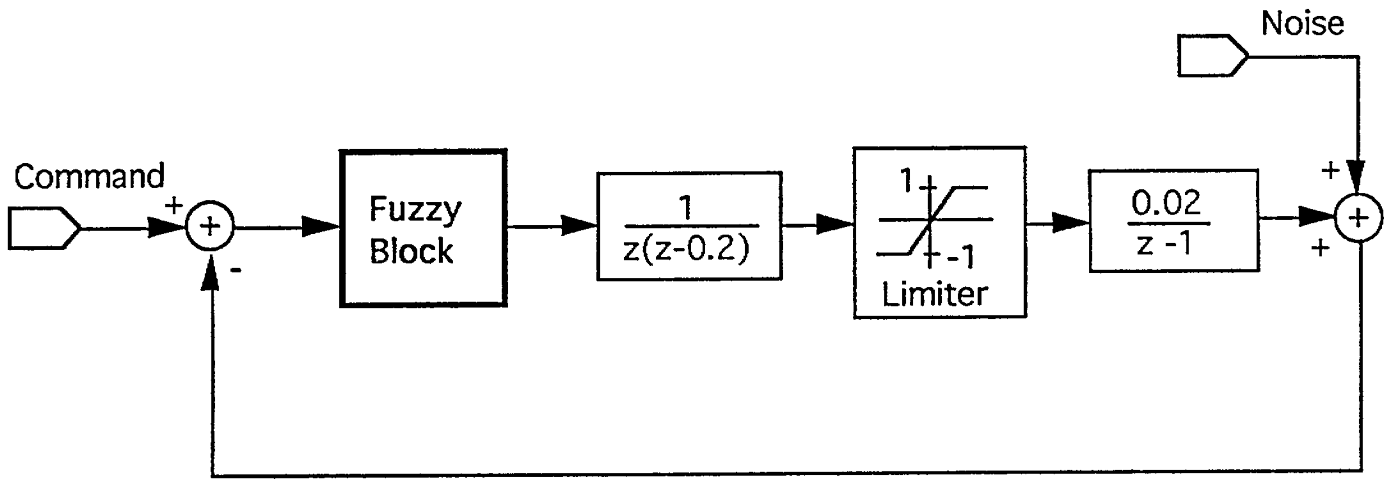


Simulator


Simulator : Display
Trace
Grid
Exit
<<
>>
127
0
-127
step = 178
pend_angle -1
pend_velocity 5
force 3

RT/Fuzzy (Run Time/Fuzzy) for MATRIXx

- Fuzzy Logic option added to one of the best conventional control system development environment (MATRIXx)
- RT/Fuzzy creates fuzzy block for MATRIXx SystemBuild
- Available for most workstations (not PC)

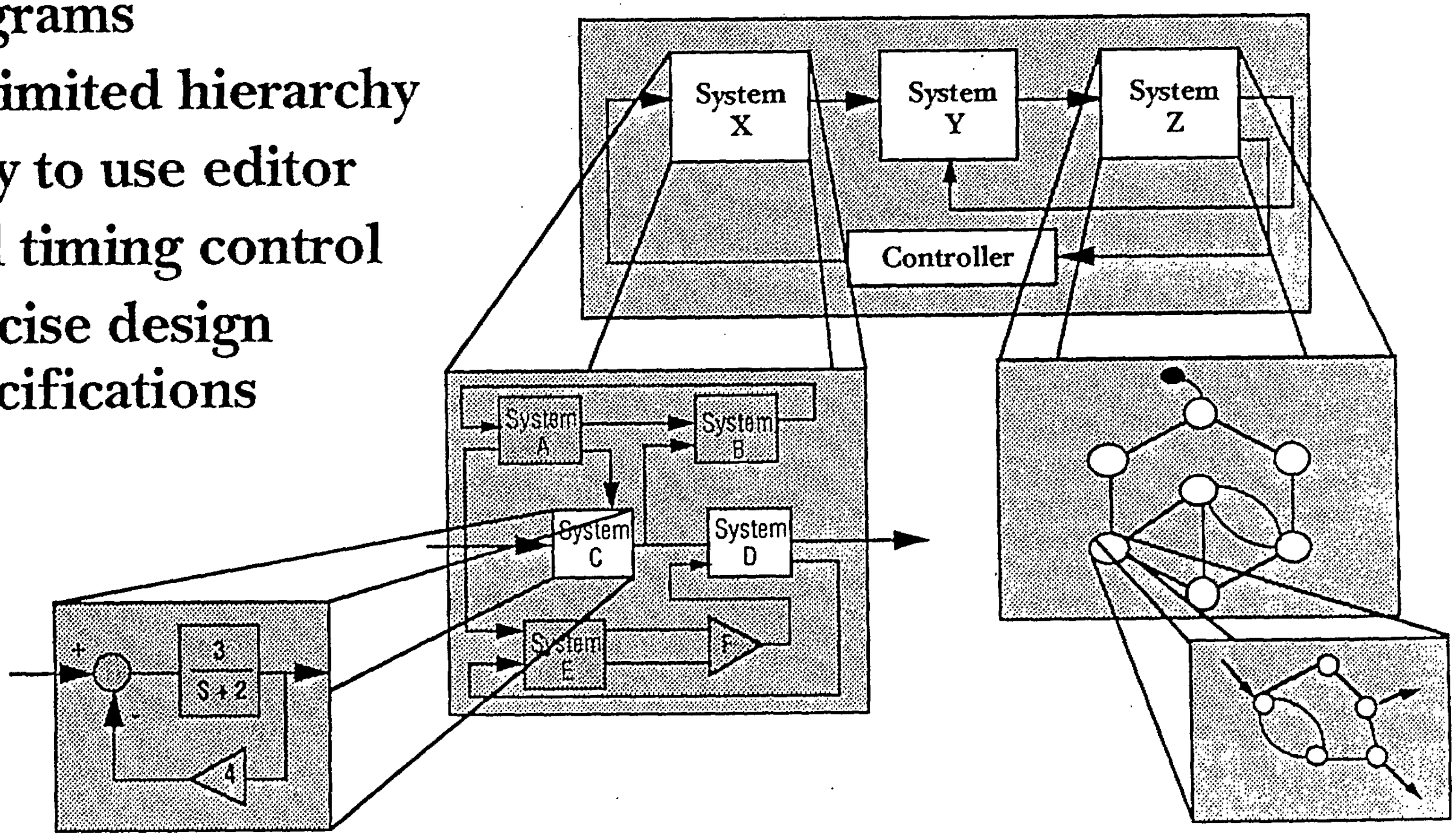


SystemBuild: MATRIXx's Block Diagram Simulation Environment

S. Chiu
Rockwell Science Center

Modeling with the SystemBuild Block Editor

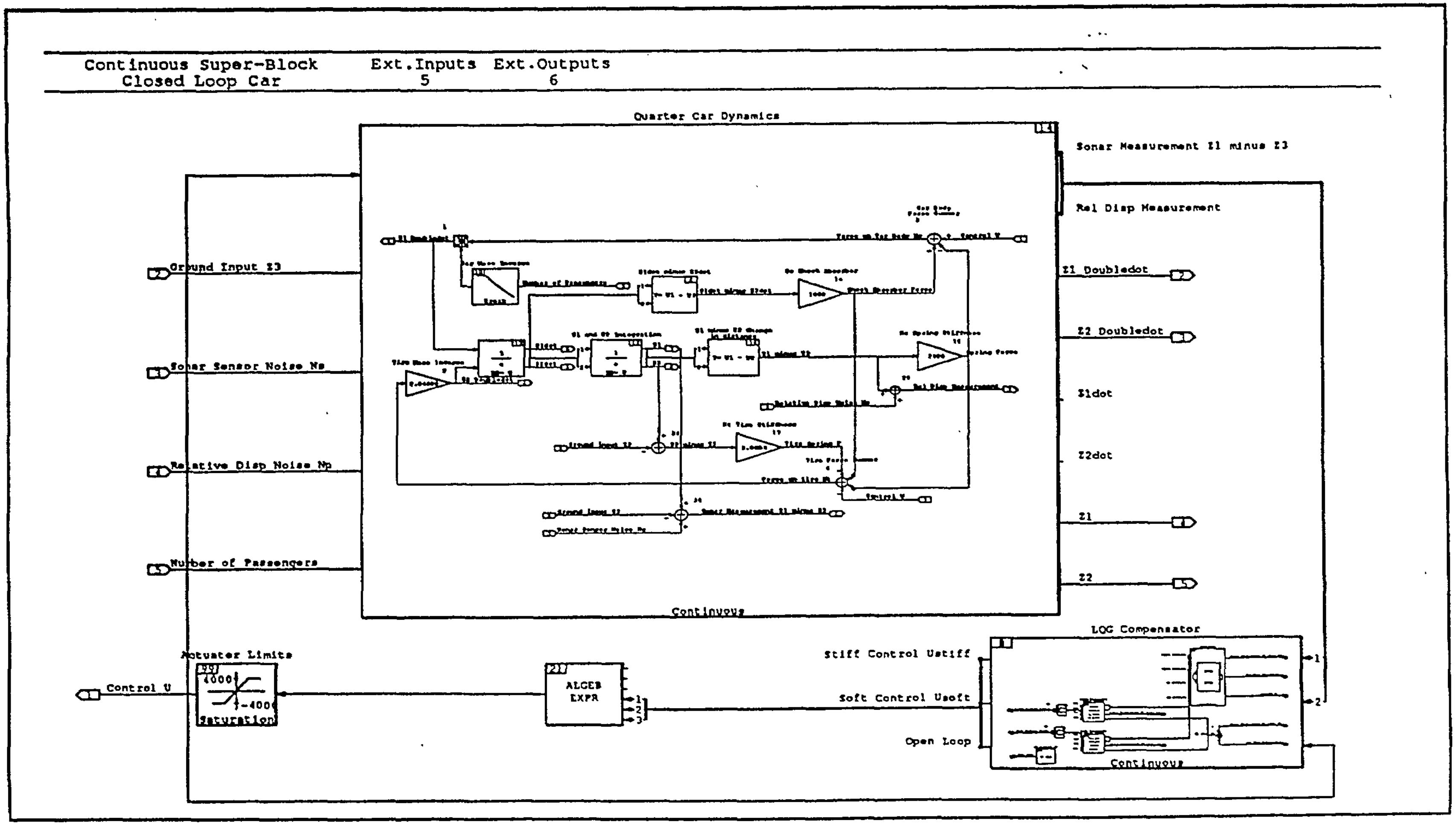
- Familiar block diagrams
- Unlimited hierarchy
- Easy to use editor
- Full timing control
- Precise design specifications



integrated systems inc.

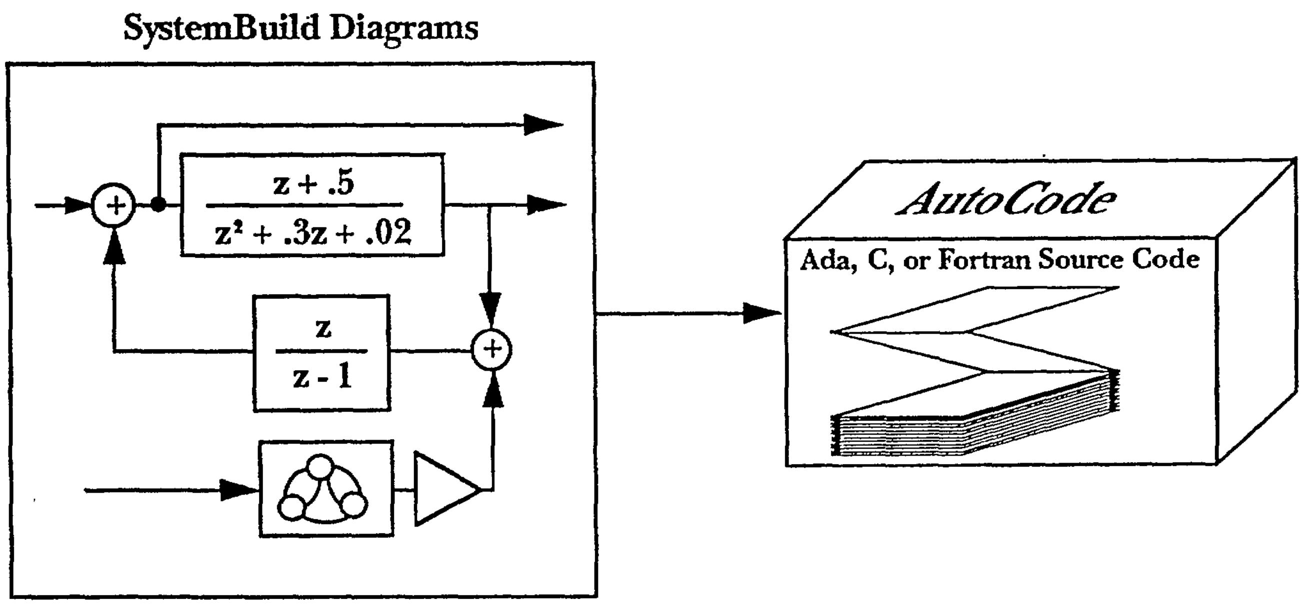
SystemBuild Simulator

What You See is What You Simulate



integrated systems inc.

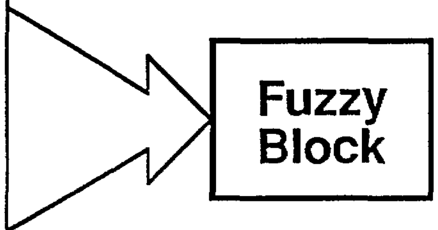
Automatic Code Generator



- Fast, accurate code generation without programming
- Generates real-time code or callable procedures
- Allows programmers to focus on performance critical modules code optimization, and system integration
- Interfaces to target hardware through standard software layer

Fuzzy Logic Block Construction

```
IF ERR IS SMALL;
THEN TORQUE IS LOW;

IF ERR IS BIG;
THEN TORQUE IS HIGH;

DATA ERR;
RANGE [0 2.5];
...
SMALL [1, 0.5, 0, 0, 0];
BIG     [0, 0, 0, 0.5, 1];
...

Connective : Min-Max
Defuzzification: Centroid
```



- **Primitive text interface for rule development**
- **Integrates fuzzy logic into a powerful control system development environment**
- **Supported by MATRIXx's C and Ada code generators**

S. Chiu
Rockwell Science Center

Fuzzy Block: Defining Membership Functions

```
TYPE = RT/Fuzzy                              ID = 26

            BLOCK NAME                     INPUTS         OUTPUTS
                                             2               8
Access Name : CLASSES
                              Access Field
NEG_MEDIUM SIN(PI*(X+0.5))**9;
NEG_SMALL  SIN(PI*(X+0.25))**9;
ZERO       SIN(PI*X)**9;
POS_SMALL  SIN(PI*(X-0.25))**9;
POS_MEDIUM SIN(PI*(X-0.5))**9;

Connective Method........ : Max-Min
Implication Method....... : Mamdani
Defuzzification Method... : Centroid
Aggregation Method....... : Arithmetic
                    1-by-6 Database Parameters
    0.1      0.      1.       0.       0.       1.
Number of Points in Curve : 50
Optimization Preference.. : Speed
                    1-by-2 Linearization Delta
    0.004    0.04
          Input External_Signals                    Output Labels
 1 "Angle"                              1 "Force"
 2 "Delta"                              2 "Rule 1"
                                        3 "Rule 2"
                                        4 "Rule 3"
                              COMMENTS

        VIEW_INPUT        COLOR  ICON     IN_PINS   OUT_PINS  LABELS
CANCEL  External_Signals    6    Special  Show_All  Show_All    ON     DONE
```

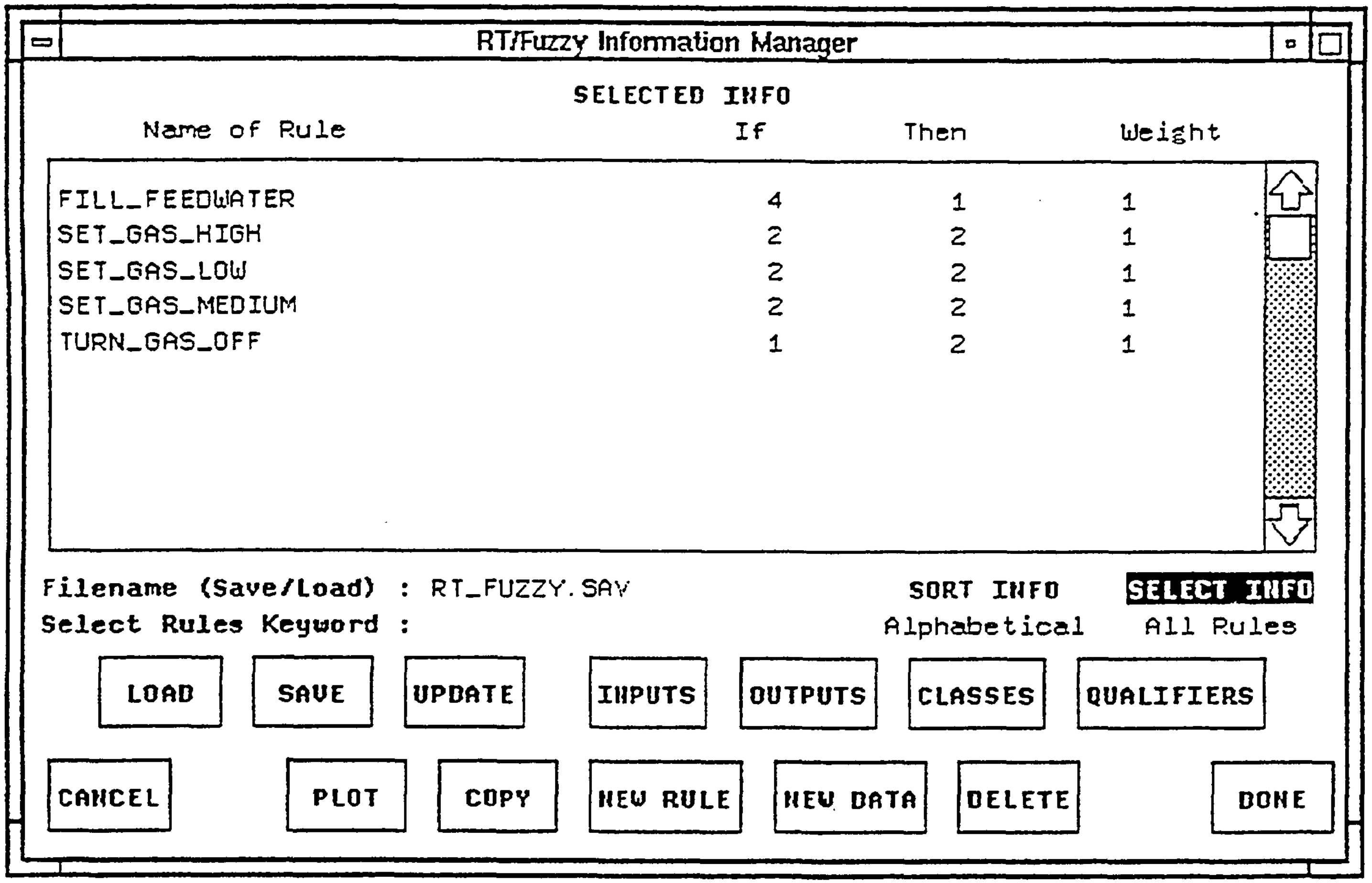
S. Chiu
Rockwell Science Center

Fuzzy Block: Defining a Rule

```
TYPE = RT/Fuzzy                                   ID = 26

            BLOCK NAME                     INPUTS          OUTPUTS
                                             2               8
Access Name : RULE NS_PS
                            Access Field
RULE NS_PS;
IF ANGLE IS NEG_SMALL AND;
   DELTA IS POS_SMALL;
THEN FORCE IS ZERO;
     RULE_3;
WEIGHT 1;
Connective Method........ : Max-Min
Implication Method....... : Mamdani
Defuzzification Method... : Centroid
Aggregation Method....... : Arithmetic
                        1-by-6 Database Parameters
    0.1      0.      1.      0.      0.      1.
Number of Points in Curve : 50
Optimization Preference.. : Speed
                        1-by-2 Linearization Delta
    0.004    0.04
        Input External_Signals                  Output Labels
 1 "Angle"                               1 "Force"
 2 "Delta"                               2 "Rule 1"
                                         3 "Rule 2"
                                         4 "Rule 3"
                              COMMENTS

        VIEW_INPUT        COLOR   ICON     IN_PINS   OUT_PINS  LABELS
CANCEL  External_Signals    6    Special   Show_All  Show_All    ON     DONE
```

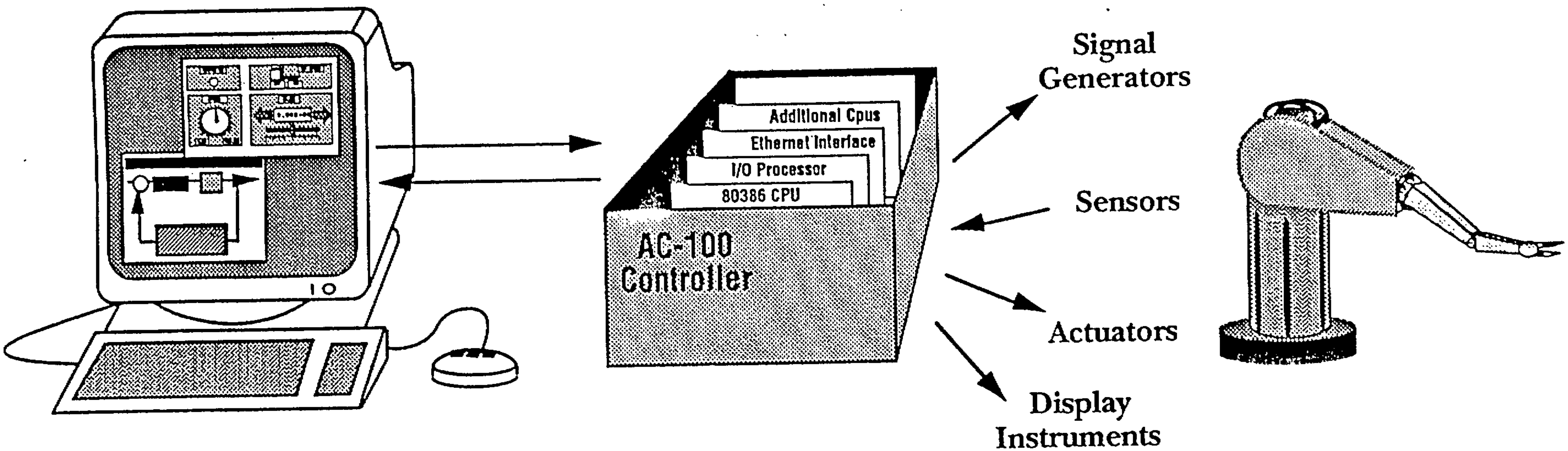
S. Chiu
Rockwell Science Center

Fuzzy Block: The Rulebase Information Manager



S. Chiu
Rockwell Science Center

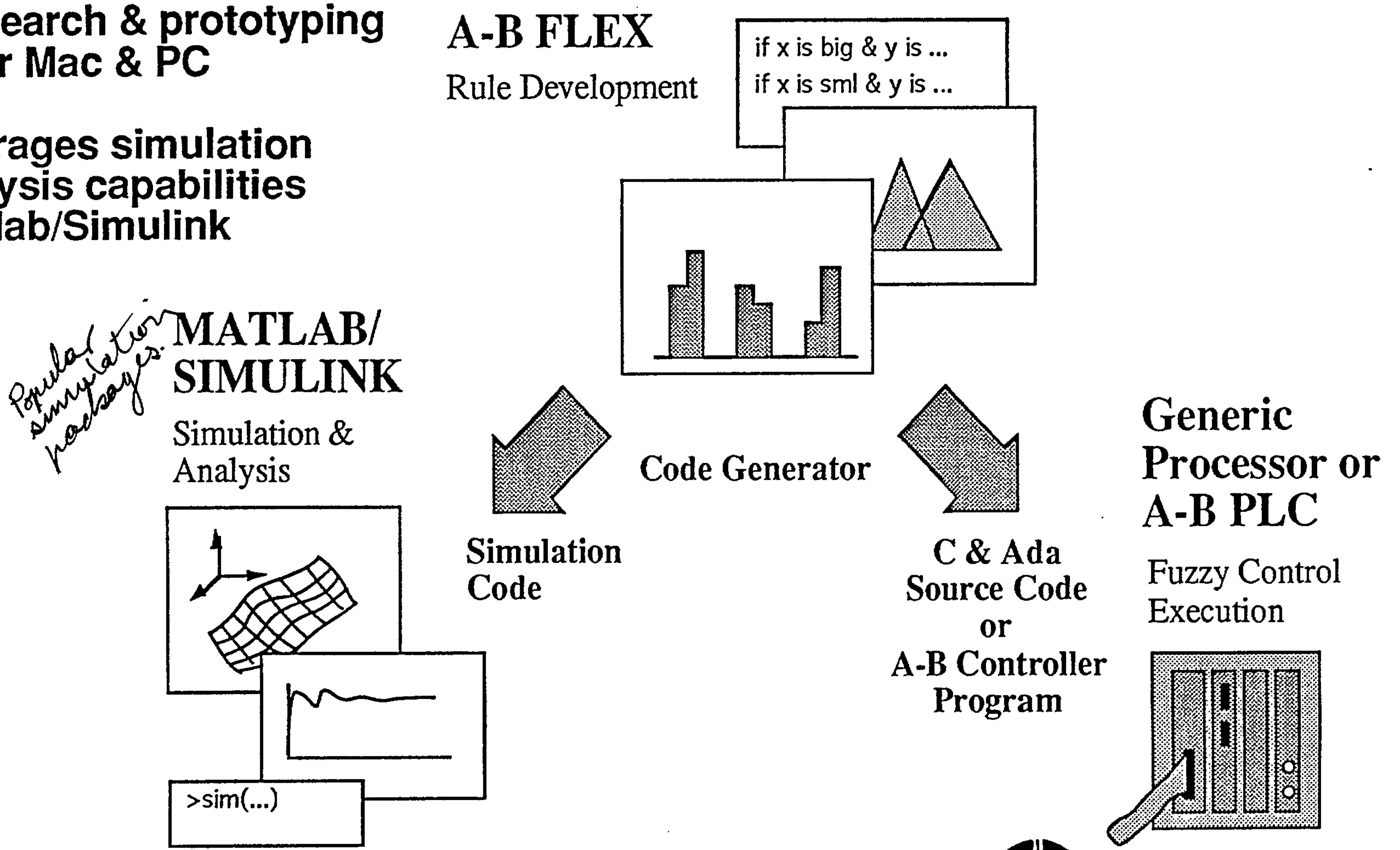
AC-100 Real-Time Testing and Debugging



- Interactive control algorithm debug
  - Display sensor measurements
  - Alter actuator commands
  - Tweak control algorithm variables

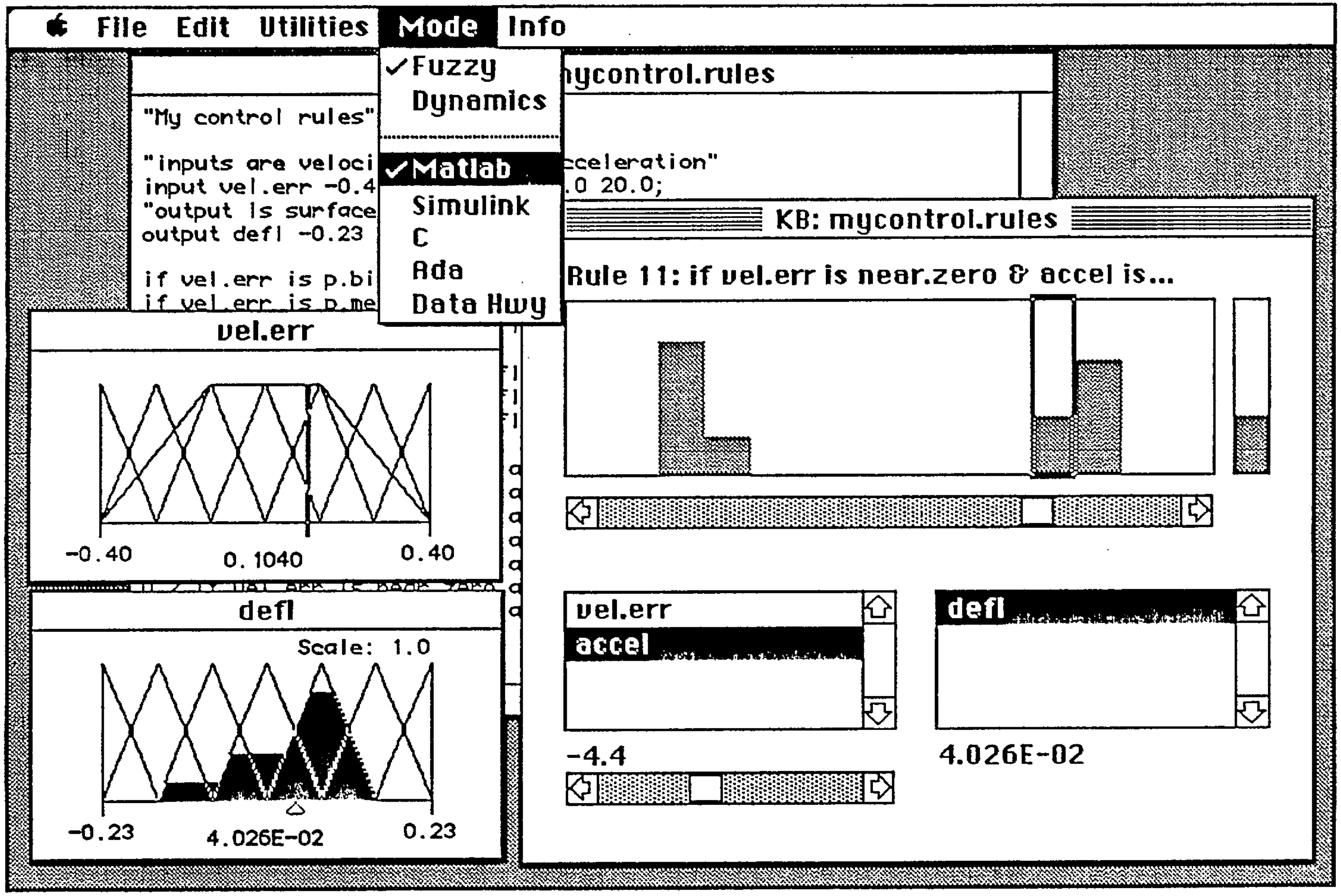
A-B FLEX
(Allen-Bradley Fuzzy Logic EXplorer)

- A research & prototyping tool for Mac & PC
- Leverages simulation & analysis capabilities of Matlab/Simulink



Rockwell International
Science Center

A-B FLEX Screen



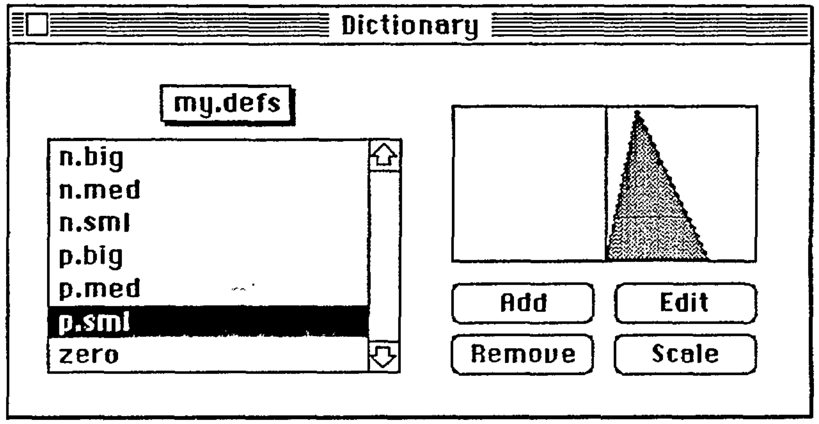
Rockwell International

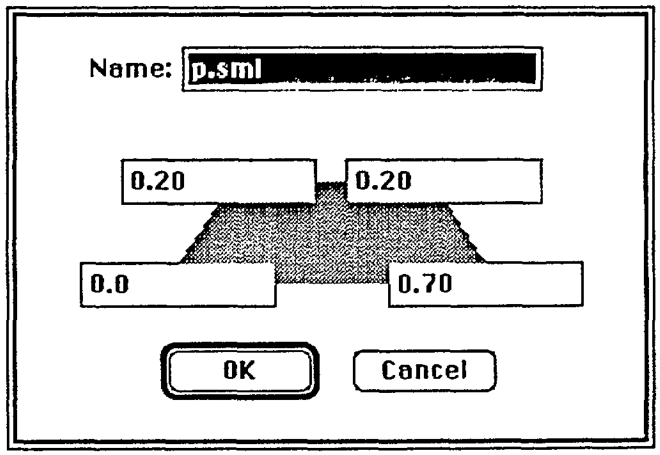
Science Center

Defining Rules & Membership Functions

Text Edit: mycontrol.rules

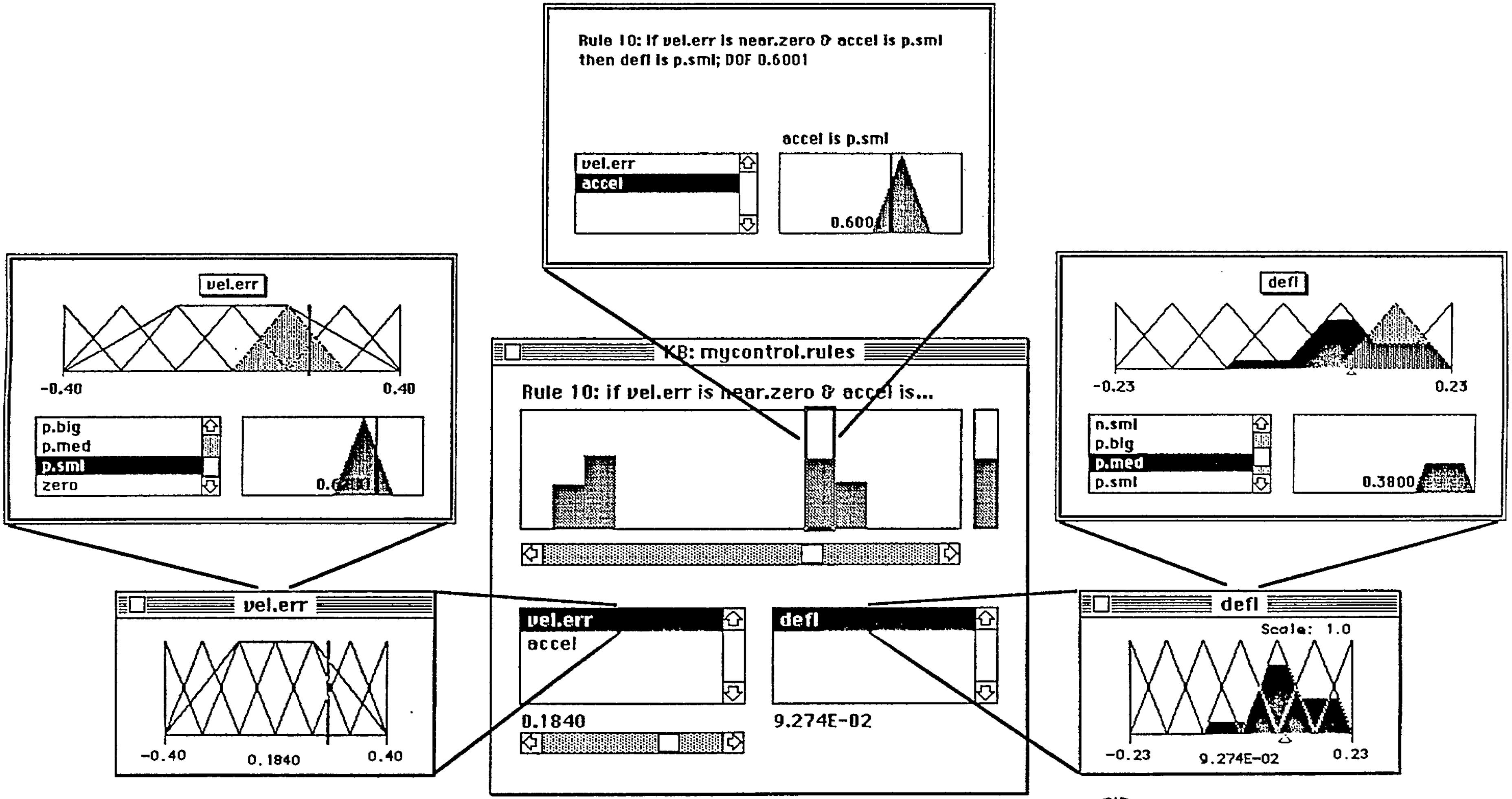
```
"inputs are velocity error and acceleration"
input vel.err -0.5 0.5 accel -20.0 20.0;
"output is surface deflection"
output defl -0.23 0.23;

if vel.err is p.big then defl is p.big;
if vel.err is p.med then defl is p.med;
if vel.err is p.sml then defl is p.sml;
if vel.err is zero then defl is zero;
if vel.err is n.sml then defl is n.sml;
if vel.err is n.med then defl is n.med;
if vel.err is n.big then defl is n.big;

0.3 if vel.err is near.zero and accel is p.big then defl is p.big;
0.2 if vel.err is near.zero and accel is p.med then defl is p.med;
0.2 if vel.err is near.zero and accel is p.sml then defl is p.sml;
0.3 if vel.err is near.zero and accel is zero then defl is zero;
0.2 if vel.err is near.zero and accel is n.sml then defl is n.sml;
0.2 if vel.err is near.zero and accel is n.med then defl is n.med;
0.3 if vel.err is near.zero and accel is n.big then defl is n.big;
```





Rockwell International
Science Center

Rule Base Inspector



Rockwell International

Science Center

Process Simulation Interface

- **Save a rule base as a MATLAB function or SIMULINK block definition**

Save as MATLAB function, e.g., "mydecision( )"

In MATLAB, use the function interactively by:

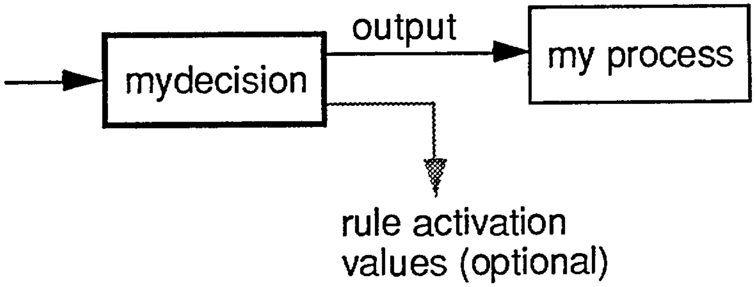
> x = [0.2 16]   (set input values, for 2-input case)
> y = mydecision(x)   (output values are returned in y)

Can incorporate the function in any MATLAB program

Save as SIMULINK block definition

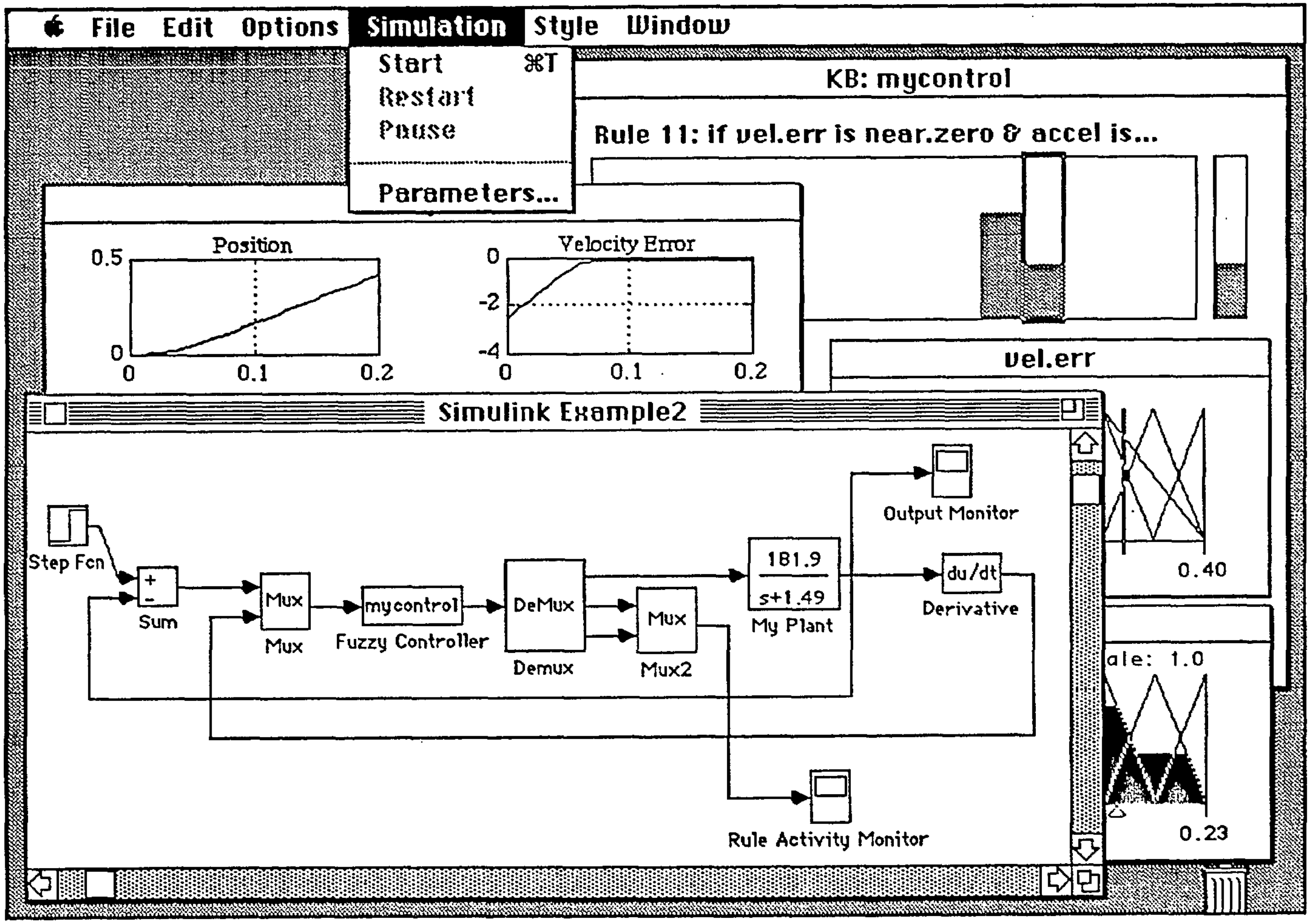
In SIMULINK:

- create a graphical block using the given name
- specify sampling time for the block
- connect with other blocks



Rockwell International
Science Center

A-B FLEX with SIMULINK

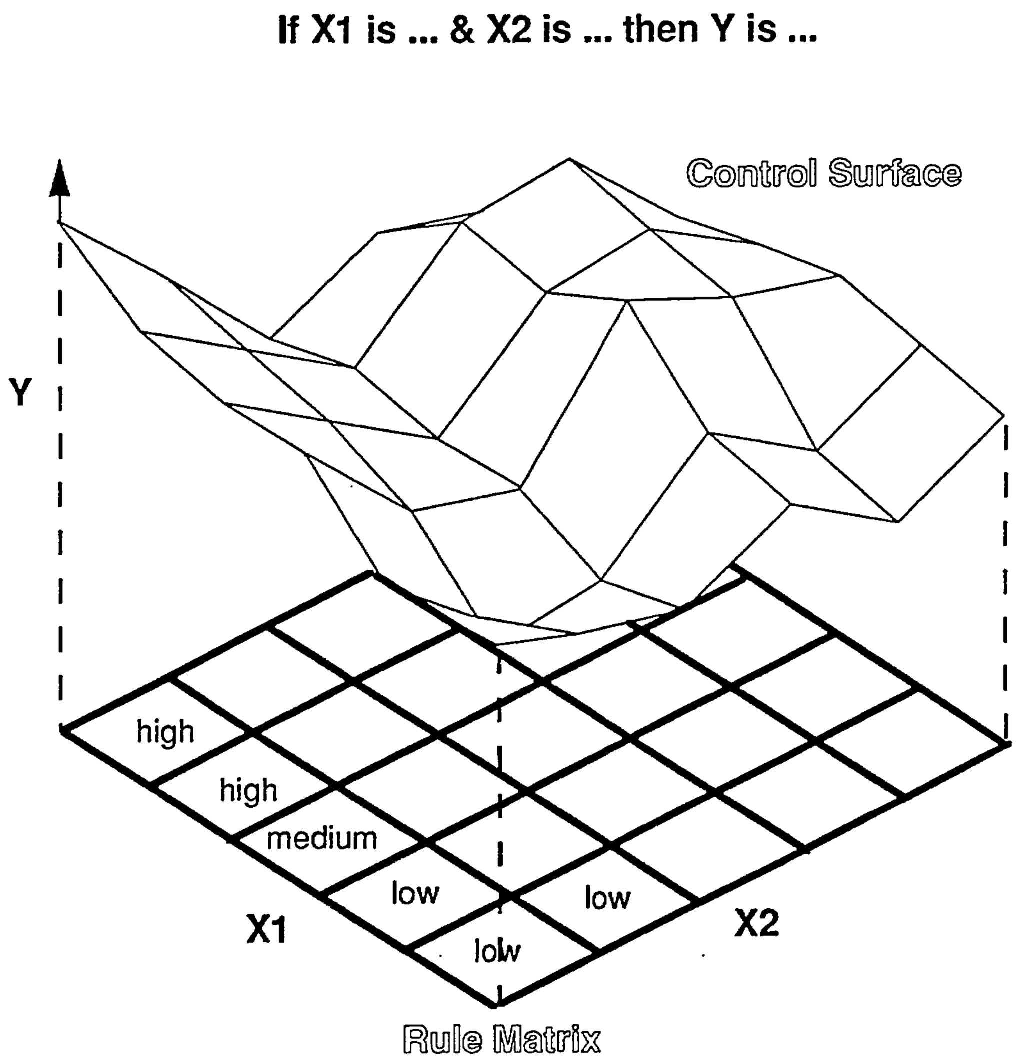


Rockwell International
Science Center

from 1 man co. in San Diego

Manifold Graphics Editor

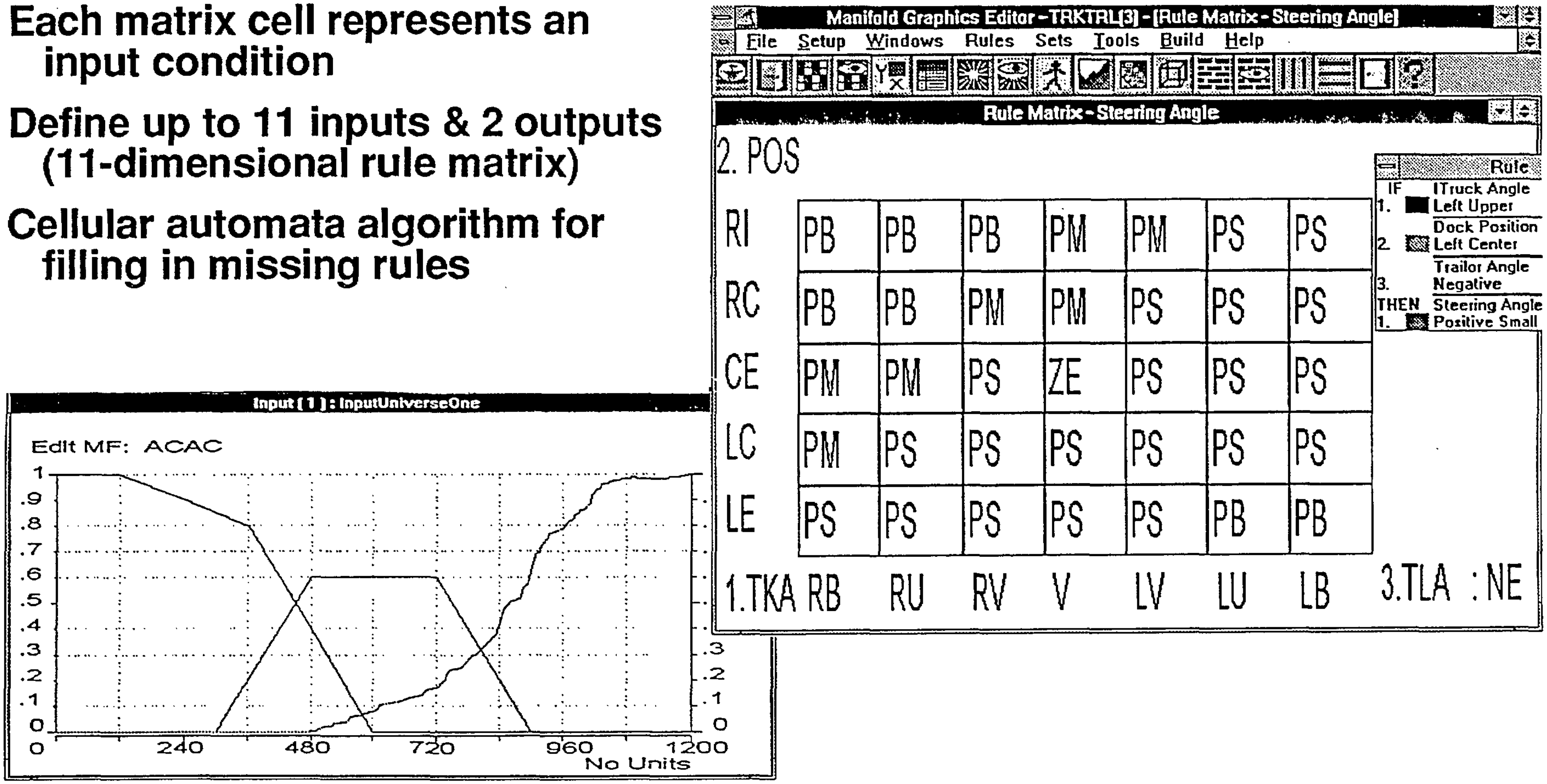
- A highly intuitive rulebase editor for building a high-dimensional control surface
- Generates knowledge base data files in C, Basic, Fortran, & various microcontroller assembly languages
- Generates knowledge base files in TILShell, FIDE, & Fuzz-C formats
- User must provide inference code
- Runs under Windows



S. Chiu
Rockwell Science Center

Manifold Graphics Editor: Editing Rules

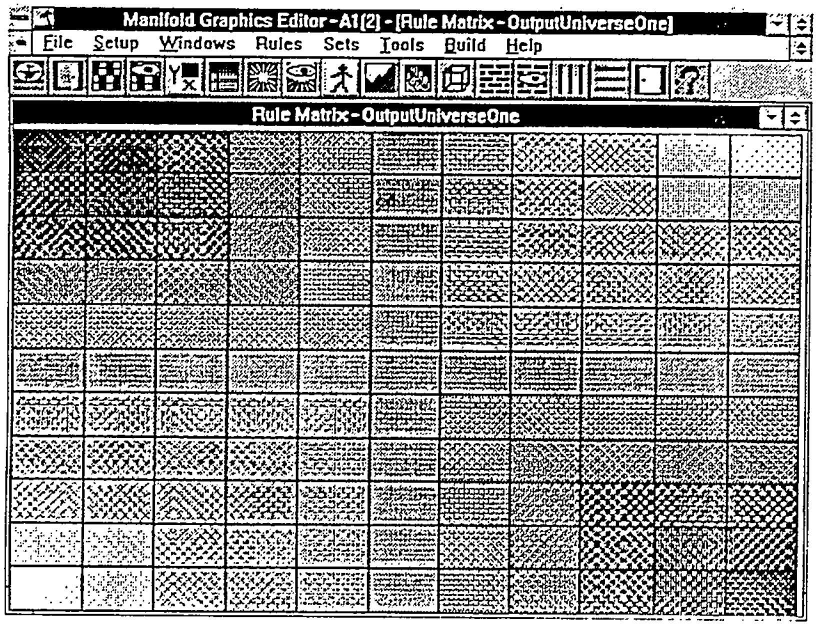
- Each matrix cell represents an input condition
- Define up to 11 inputs & 2 outputs (11-dimensional rule matrix)
- Cellular automata algorithm for filling in missing rules

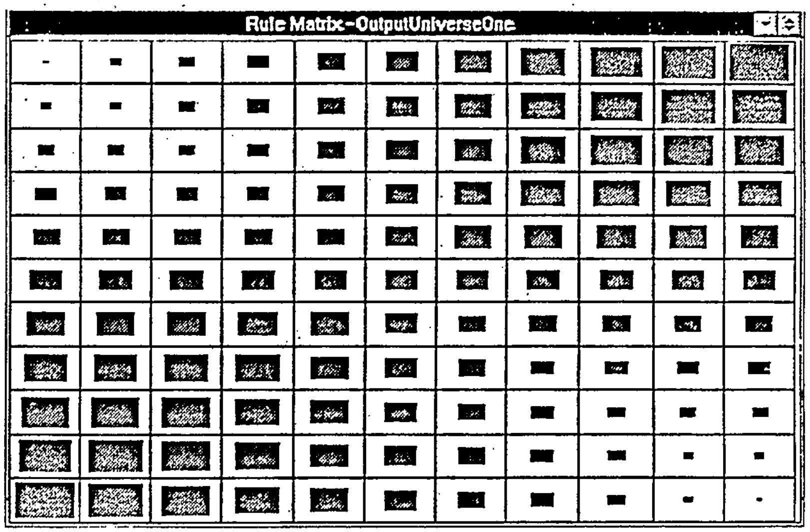


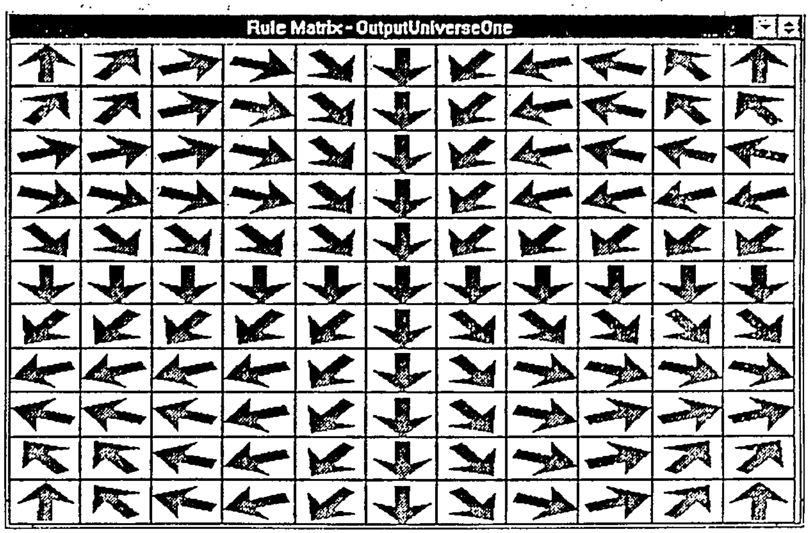
S. Chiu
Rockwell Science Center

Displaying Rule Matrix via Graphic Cues

- Cell content cued by text, color, shape size, arrow direction
- Provides mental picture of control surface



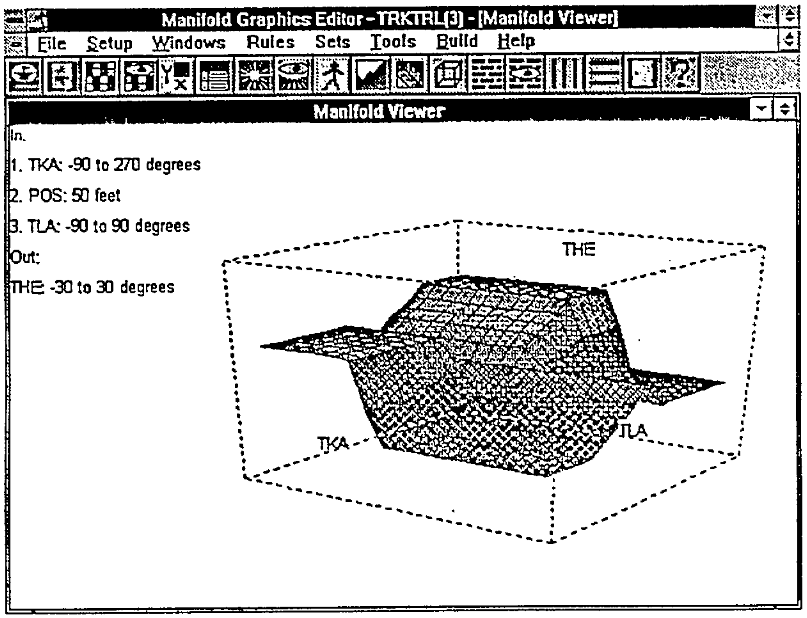


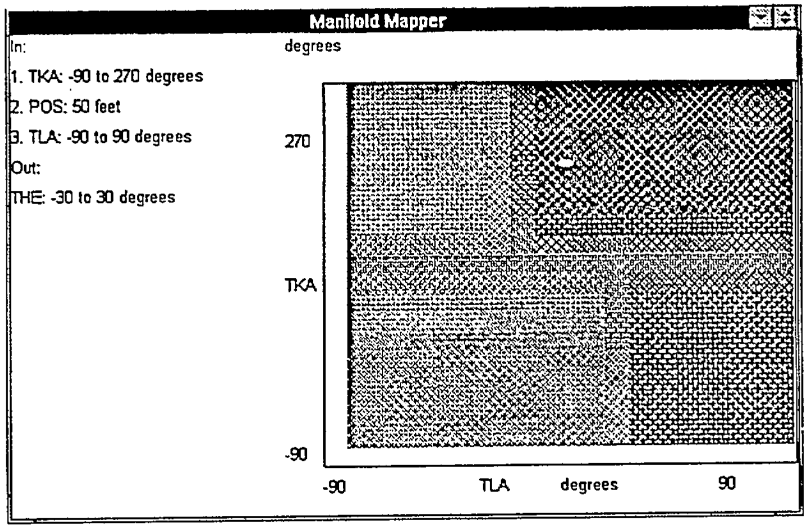


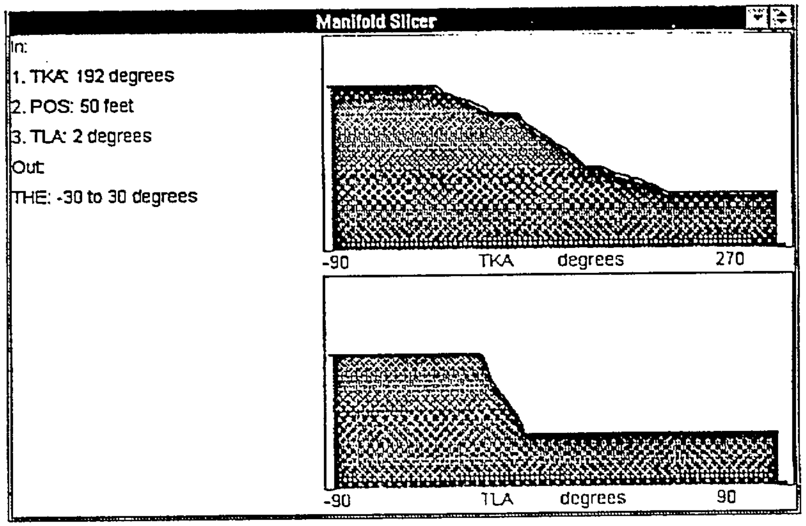
S. Chiu
Rockwell Science Center

Displaying the Control Surface

- Shows 3-D surface + 2-D contour & cross sections
- Rule matrix intuitively correlated with control surface







S. Chiu
Rockwell Science Center

Fuzz-C

C Preprocessor for Fuzzy Logic

- Translates a knowledge base definition file into C code
- Not an environment; run program using DOS command line
- Call fuzzy functions from C and vice versa

Knowledge Base Definition

```
/* a LIGUISTICS block defines an input variable */
LINGUISTICS Temperature TYPE int MIN 30 MAX 100 {
   MEMBER Warm {60 70 80}
   MEMBER Hot {70, 80, 100, 100}
}
.
.
/* a CONSEQUENCE block defines an output variable and its
defuzzification method */
CONSEQUENCE FanSpeed TYPE int MIN 0 MAX 1000 DEFUZZ CG {
   MEMBER Low {200}
   MEMBER High {1000}
   ACTION { print_me(FanSpeed); }  /* execute this function
                                     after output is computed */
}

/* a FUZZY block defines the rules; the resultant C
inference function will have the same name as this block */
FUZZY GetFanSpeed {
   IF Temperature IS Hot AND DeltaTemp IS Increasing
       THEN FanSpeed IS High
   IF Temperature IS Warm OR IsMorning()
       THEN FanSpeed IS Low
}
```

Generated Code

```
/* The user sets/retrieves
input/output variable
values directly through
the variable names, which
are declared as global */

int Temperature;
int DeltaTemp;
int FanSpeed;

/* the inference func */
void GetFanSpeed(void) {
   :
```

Using Generated Code

```
Temperature = input1;
DeltaTemp = input2;
GetFanSpeed();
output1 = FanSpeed;
```

S. Chiu
Rockwell Science Center

Comparison of Software Tools

Software	Platform	Cost	Comments
CubiCalc	IBM PC	$500 (1) $800 (2) $2500 (3)	• Excellent for exploring fuzzy control & prototyping • Has all essential capabilities & more • Built-in numerical comp. & process simulation language • Easy to use & flexible • Ideal for non-programmers & education
TILShell	IBM PC, Sun	$1800 (3) $3500, (3) + rule learning + on-line debugger	• Sophisticated CASE-like tool, packed with features • High flexibility in memb. fn. & rule definition; allows user-defined fuzzy operators • Built-in numerical comp. & process simulation language • Graphical debugging features • Debug & tune rules during simulation or on-line • Rule learning module available • Compilers available for Mistsubishi, Hitachi, & Intel microcontrollers & Togai's FC110 fuzzy chip
FIDE	IBM PC	$1000, (2) + 8-bit μ $3500, (2) + 8,16,32-bit μ + MATLAB	• Define entire knowledge base in one text file • Unique "tracer" debugger • Easily integrates user C code modules for simulation • Includes compiler for Motorola μ-controllers • Compiler available for Omron's FP-3000 fuzzy chip • A practical, low-cost tool for microcontroller applications

(1) Basic software environment without code generator. (2) Software environment with C run-time library.
(3) Software environment with C source code generator.

S. Chiu
Rockwell Science Center

Comparison of Software Tools

Software	Platform	Cost	Comments
fuzzyTech	IBM PC	Many versions avail. from $1000 - $6900 $2500 (3) $6900, (3) + on-line debugger	• Can define rules via Fuzzy Assoc. Map matrix • Only one type of connective operator per rulebase • Graphical debugging features • Dynamics simulation via external program • Debug & tune rules during simulation or on-line • Rule-learning module available ($900) • Target hardware-specific versions available for Intel, Siemens, & SGS Thomson microcontrollers & INFORM's FUZZY-166 chip
MATRIXx RT/Fuzzy	Sun, HP, Apollo, VaxStation	$5000 (1) ($15000 for MATRIXx SystemBuild)	• An add-on block to MATRIXx SystemBuild • Primitive user interface for rule development • High flexibility in memb. fn. definition & inferencing • Simulation support for multi-discipline, integrated sys. • Code generation requires interface to AutoCode ($5K) and AutoCode itself ($19K for C, $25K for Ada)
A-B FLEX	IBM PC, Mac	TBD (4) ($800 for Matlab; $3000 for Simulink)	• Designed for research & fast prototyping • Graphical debugging features • Dynamics simulation & analysis via Matlab/Simulink • Auto. program download to A-B factory controller

(1) Software environment witout code generator. (3) Software environment with C source code generator.
(4) Software environment with C & Ada source code generators.

S. Chiu
Rockwell Science Center

Comparison of Software Tools

Software	Platform	Cost	Comments
Manifold Graphics Editor	IBM PC	$500	• A highly intuitive control surface editor • Currently, has the only high-dimension, conventional (i.e., not Fuzzy Assoc. Map) rule matrix editor • Supports only matrix editor - limited rule structure • Generates data files (i.e., "include" files) in C, Basic, Fortran, & many microcontroller assembly languages • Generates knowledge base files in TILShell, FIDE, & Fuzz-C format • Intended for experienced fuzzy system developers
Fuzz-C	IBM PC	$150	• Translaes text description of knowledge base into C code • Purely a code translator, not an environment • Allows fuzzy rules to call C functions

S. Chiu
Rockwell Science Center

Company Addresses

For information on development tools, contact:

CubiCalc: HyperLogic Corp., 1855 E. Valley Parkway, Suite 210, Escondido, CA 92027, USA, (619) 746-2765.
TIL Shell: Togai InfraLogic Inc., 5 Vanderbilt, Irvine, CA 92718, USA, (714) 588-3800.
fuzzyTech: INFORM Software Corp., 1840 Oak Street, Evanston, IL 60201, USA, (708) 866-1838.
FIDE: Aptronix Inc., 2150 N. First St., San Jose, CA 95131, USA, (408) 428-1888.
R/T Fuzzy: Integrated Systems Inc., 3260 Jay St., Santa Clara, CA 95054, USA, (408) 980-1500.
A-B FLEX: Allen-Bradley Co,. 747 Alpha Dr., Highland Heights, OH 44143, USA, (216) 646-3436; Contact person: Mr. Chia Day.
Manifold Graphics Editor: Fuzzy Systems Engineering, 12223 Wilsey Way, Poway, CA 92064, USA, (619) 748-7384.
Fuzz-C: Byte Craft Ltd., 421 King St., North Waterloo, Ontario, Canada N2J 4E4, (519) 888-6911.

Some software not included in the presentation:

FUZZYSOFT (similar to fuzzyTech): GTS Trautzl GmbH, Gottlieb-Daimler-Straße 9, D-2358 Kaltenkirchen, Germany, (04191) 8711.
NeuFuz (rule learning program): National Semiconductor, 2900 Semiconductor Dr., Santa Clara, CA 95052, USA, (800) 272-9959.
FuziCalc (fuzzy spreadsheet program): FuziWare Inc., 316 Nancy Lynn Lane, Suite 10, Knoxville, TN 37919, USA, (615) 588-4144.

IMPACT OF FUZZY THEORY ON SCIENCE AND TECHNOLOGY*

Professor Dr. I. B. Türkşen
Principal Investigator - MRCO
University of Toronto
Toronto, Ontario
M5S 1A4

Tel: 416-978-1278
Fax: 416-978-1280
e-mail: turksen@ie.utoronto.ca

* Supported in part by:

a) MRCO - Manufacturing Research Corporation of Ontario
b) NSERC - Natural Science and Engineering Council of Canada
c) Industrial Technology Transfer Companies

TRADITION OF QUEST AND RESPECT FOR

WHAT IS QUANTITATIVE AND PRECISE

AND DISDAIN FOR

WHAT IS QUALITATIVE AND IMPRECISE

"BEING" AND HENCE
"NOTHINGNESS"
PARAMENIDES OF ELEA

"BECOMING" AND HENCE
"GRADEDNESS"
HERACLITUS OF EUPHESUS

"THE LAW OF CONTRADICTION"

"THE LAW OF EXCLUDED MIDDLE"

METAPHYSICS -ARISTOTLE (384-322 BC)

LOGIC CHANGES FROM ITS VERY FOUNDATIONS IF WE ASSUME THAT IN ADDITION TO TRUTH AND FALSEHOOD THERE IS ALSO SOME THIRD LOGICAL VALUE OR SEVERAL SUCH VALUES [1920]
LUKASIEWICZ (1978-1955)

QUANTIFIERS: $\exists$, $\forall$.

ALL TRADITIONAL
LOGIC HABITUALLY
ASSUMES THAT PRECISE
SYMBOLS ARE BEING
EMPLOYED. IT IS,
THEREFORE, NOT
APPLICABLE TO THIS
TERRESTIAL LIFE BUT
ONLY TO AN IMAGINED
CELESTIAL EXISTENCE,
LOGIC TAKES US
NEARER TO HEAVEN
THAN OTHER STUDIES.

BERTRAND RUSSELL

L. A. ZADEH-FUZZY THEORY

THREE SEMINAL PAPERS
THREE INNOVATIVE IDEAS

i) FUZZY SETS - (1965)

ii) COMPOSITIONAL RULE OF INFERENCE (1973)

iii) GENERALIZED SYLLOGISMS (1985)
INTRODUCTION OF FUZZY QUANTIFIERS TO SYLLOGISMS

i) REPRESENTATION

ii) - iii) INFERENCE

– "BEING" AND HENCE "NOTHINGNESS"

KNOWLEDGE REPRESENTATION

AS A CONSEQUENCE OF HAVING THE CAPABILITY TO DEAL WITH:

(A)FUZZY PREDICATES;

(B) FUZZY TRUTH VALUES;

(C) FUZZY QUANTIFIERS;

(D) FUZZY PROBABILITIES; AND

(E) FUZZY HEDGES.

FUZZY LOGIC HAS A FAR GREATER EXPRESSIVE POWER THAN TRADITIONAL SYSTEMS OF LOGIC.

CLASSICAL APPROACH

1. TWO VALUED LOGIC
   a) LAW OF EXCLUDED MIDDLE
   b) LAW OF CONTRADICTION
   c) LAW OF EQUIVALENCE

⋮

2. ANALYTICAL EQUATIONS
   a) LINEAR AND NON-LINEAR
   b) DIFFERENTIAL & INTEGRAL
   c) POINT- TO - POINT

⋮

$$M \rightarrow P$$

FUZZY APPROACH

1. MULTI AND INFINITE VALUED LOGICS

   QUALIFIED {
   a) EXCLUDED MIDDLE
   b) CONTRADICTION
   c) EQUIVALENCE
   }

   ⋮

2. RULE BASES

   a) LINGUISTIC & COGNITIVE

      i) LINGUISTIC VARIABLES

      ii) LINGUISTIC VALUES

      iii) CONNECTIVES

   b) CLUSTER TO CLUSTER

   ⋮

$$[M' \circ [M \rightarrow P]] \rightarrow P'$$

PROPERTIES OF DATA

1. CLASSICAL APPROACH
   a) ABSOLUTE SCALE •
   b) RATION SCALE +
   c) INTERNAL SCALE AVE
   d) ORDINAL SCALE (MAX, MIN)

MAXIMALLY SPECIFIC
- CAN NOT EXPlOIT TOLERENCE -

2. FUZZY APPROACH
   a) ORDINAL SCALE (T, S)
   b) INTERVAL SCALE (AVE)
   c) RATIO SCALE +
   d) ABSOLUTE SCALE •

MINIMALLY SPECIFIC
-CAN EXPLOIT TOLERENCE -

SCALE TYPE	ADMISSIBLE TRANSFORMATION
ORDINAL	MONOTONIC
	$\phi^* = f(\phi)$
INTERVAL	POSITIVE LINEAR
	$\phi^* = c_1\phi + c_2,\ c_1>0$
RATIO	SIMILARITY
	$\phi^* = c_1\phi$
ABSOLUTE	IDENTITY
	$\phi^* = 1 \cdot \phi$

HARDNESS, TEMPERATURE, LENGTH, MEMBERSHIP, PROBABILITY, COUNT

MAX, MIN, AVERAGE, ADDITION, MULTIPLICATION

LINGUISITIC CONNECTIVES

"AND", "OR", "IF . . . THEN"

EXPRESS A MULTIPLICITY OF MEANINGS REFLECTING DIFFERENT **SEMANTIC** INTERACTION OF ITS CONSTITUENT PROPOSITIONS WITH EACH OTHER AND OTHER KNOWLEDGE.

INTERCLAUSAL RELATIONSHIPS OF "AND" CONNECTIVE (PETERSON AND MCCABE, 1987)

i) COORDINATION OR ADDITIVE: EXPRESSING CO-OCCURENCE OF INDEPENDENT EVENTS

ii) TEMPORAL (BETTER EXPRESSED BY "THEN"): INDICATING TEMPORAL AND/OR CAUSAL SEQUENCE

iii) CAUSAL (BETTER EXPRESSED BY "BECAUSE" OR "SO")

iv) ADVERSATIVE (BETTER EXPRESSED BY "BUT")

SYMMMETRIC - ASYMMETRIC CONJUNCTION: "AND" (FILLENBAUM, 1977)

1. "HE HAD A COFFEE AND READ THE PAPER"

   - SYMMMETRIC, UNORDERED (COMMUTATIVITY AXIOM)

2. a) "HE DIED AND WAS BURIED"

   b) "HE WAS BURIED AND DIED"

ORDERED: TEMPORAL AND/OR CAUSAL

(NON-COMMUTATIVITY AXIOM)

A FUZZY EXPERT SYSTEM FOR COST-ACCOUNTING

a)

IF PRODUCTION EFFORT IS **HIGH**
"AND" PRICE IS **LOW**

"AND" PROFITIBILITY IS **HIGH**
THEN SET FLAG TO 1

b)

IF FLAG IS 1 "AND" LABOUR
INTENSITY IS **LOW**

"AND" PRIORITY SCHEDULE
DISPLACEMENT IS **LOW**

THEN SOLUTION IS SYSTEM 1

SYMMETRIC - ASYMMETRIC DISJUNCTION: "OR" (FILLENBAUM, 1977)

1. "IT WILL BE SUNNY OR THE SKYDOME ROOF WILL BE CLOSED"

   SYMMETRIC, UNORDERED
   (COMMUTATIVITY AXIOM)

2. "YOU'D BETTER LEAVE OR HE'LL GET MAD"

   ORDERED: TEMPORAL AND/OR CAUSAL
   (NON-COMMUTATIVITY AXIOM)

Alternative Definitions for Fuzzy-Set Intersection

- Zadeh Intersection:

$$(A \cap B)(x) = \min\,[A(x), B(x)]$$

- Product Intersection:

$$(A \cap B)(x) = A(x)\ \ B(x)$$

- Lukasiewicz Intersection

$$(A \cap B)(x) = \max\,[A(x) + B(x)-1, 0]$$

Operators that satisfy reasonable axioms for a truth-funcional definition of intersection are called *triangular norms* (or *T- norms)*

Alternative Definitions for Fuzzy-Set Union

- Zadeh Union:

$$(A \cup B)(x) = \max [A(x), B(x)]$$

- Product Union:

$$(A \cup B)(x) = A(x) + B(x) - A(x)\, B(x)$$

- Lukasiewicz Union

$$(A \cup B)(x) = \min [A(x) + B(x), 1]$$

Operators that satisfy reasonable axioms for a truth-funcional definition of union are called *triangular conorms* (or *T- conorms)*

De Morgan Triples

De Morgan Laws for Conventional Sets:

$$\overline{A \cap B} = \overline{A} \cup \overline{B}$$

$$\overline{A \cup B} = \overline{A} \cap \overline{B}$$

- Triples consisting of an Intersection operator, Union operator, and Complement functions that generalize the DeMorgan Laws are called *DeMorgan triples.*

<u>Examples</u>:

- Zadeh: $\{\min(\alpha,\beta), \max(\alpha,\beta), 1-\alpha\}$
- Product: $\{\alpha\beta, \alpha + \beta - \alpha\,\beta, 1-\alpha\}$
- Lukasiewicz: $\{\max(\alpha + \beta - 1, 0), \min(\alpha + \beta, 1), 1- \alpha\}$

AXIOMS

- BOUNDARY
- MONOTONICITY
- COMMUTATIVITY
- ASSOCIATIVITY
- DISTRIBUTIVITY
- IDEMPTENCY
- ABSORPTION

•
•
•

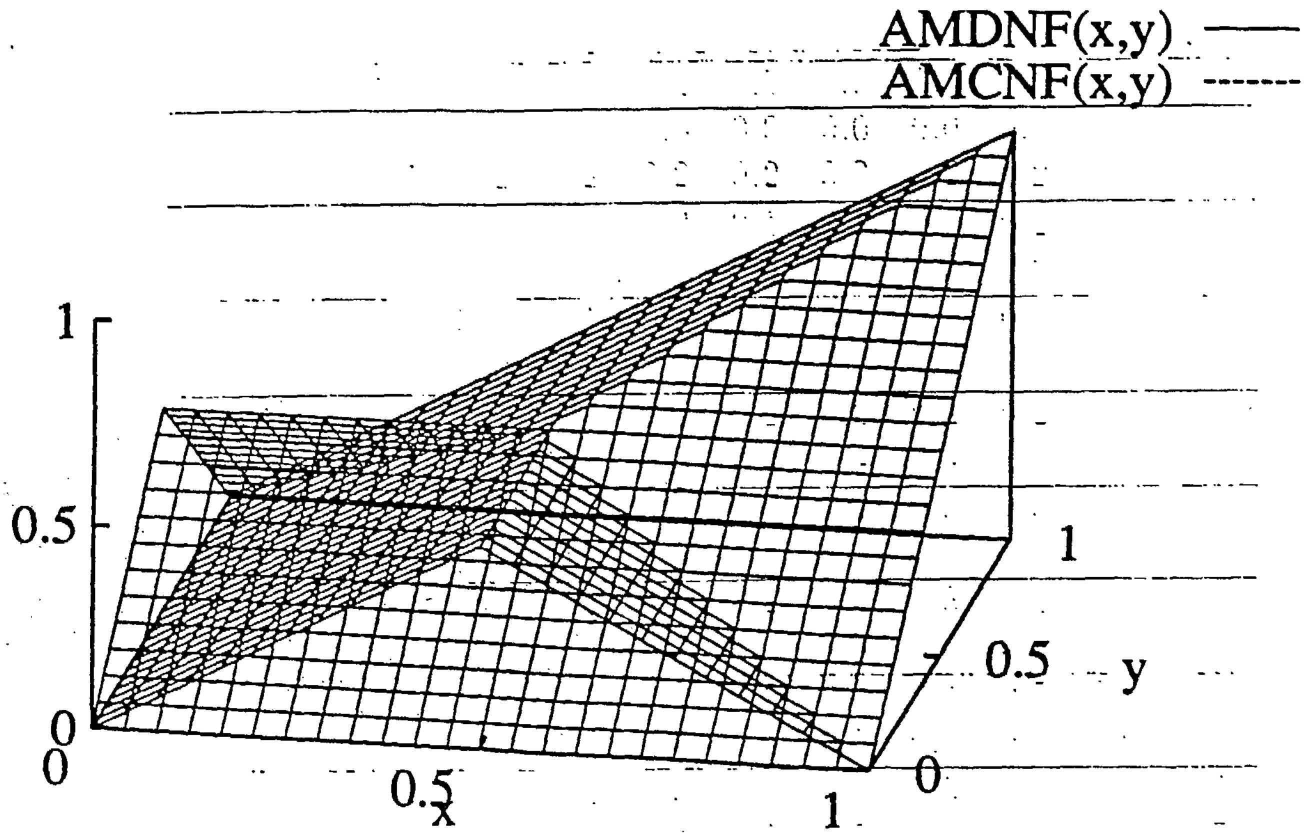
EXCLUDED MIDDLE

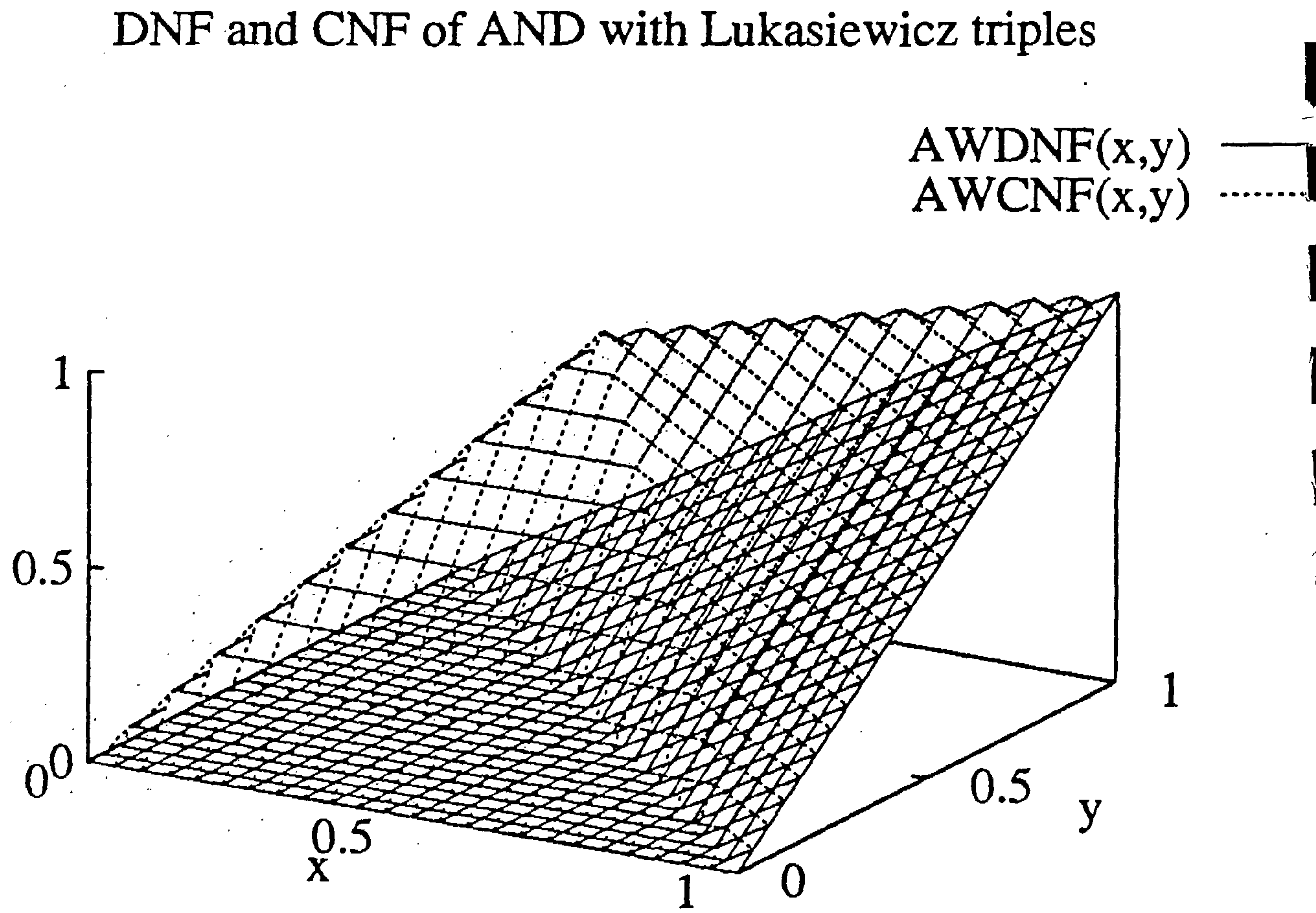
CONTRADICTION

$$A \cup \overline{A} = I, \; A \cup \overline{A} \subseteq I$$

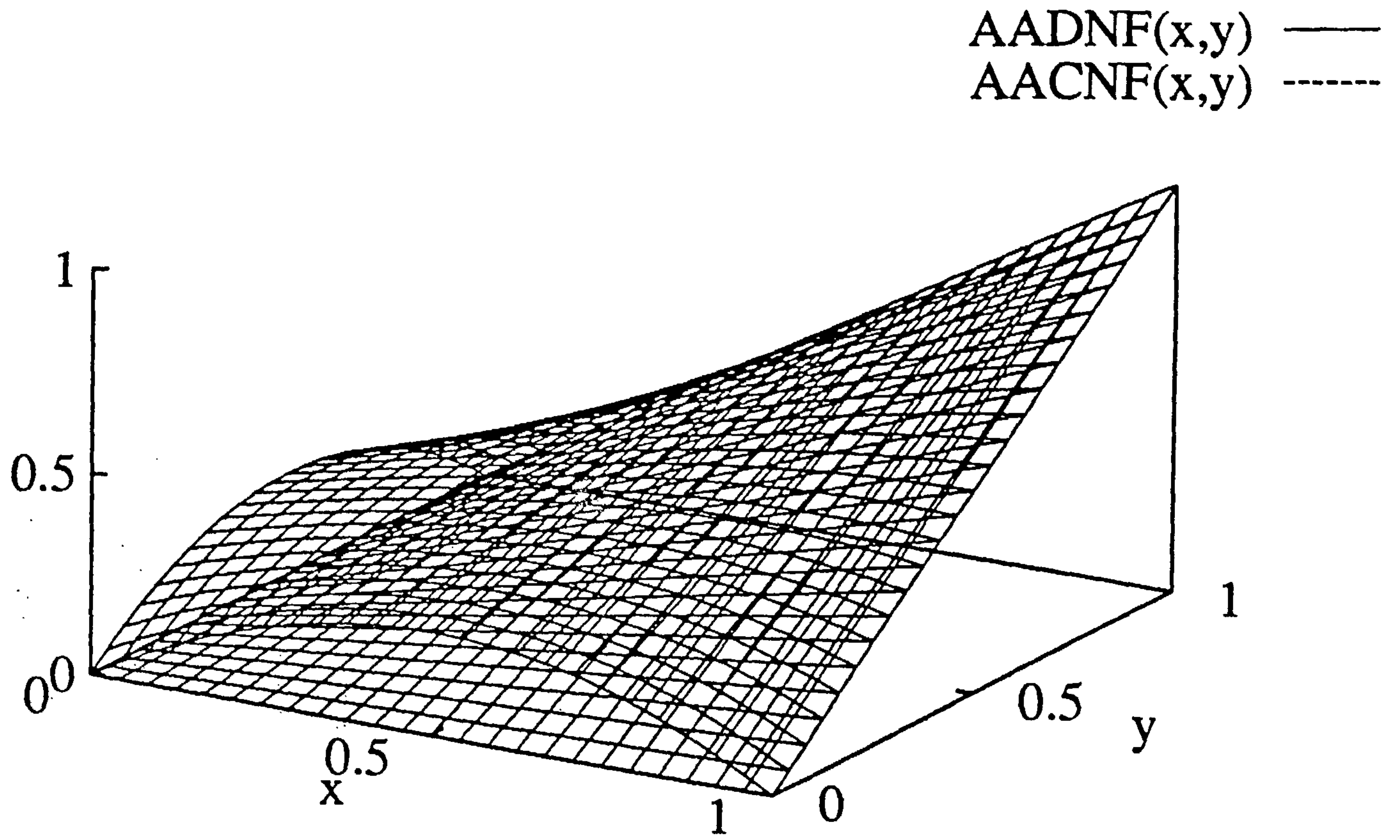
$$A \cap \overline{A} = \varnothing, \; A \cap \overline{A} \supseteq \varnothing$$

DNF and CNF of AND with <min,max,N>




DNF and CNF of AND with Lukasiewicz triples
AWDNF(x,y)
AWCNF(x,y)
1
0.5
0
0
0.5
x
1
0
0.5
1
y

DNF and CNF of AND with Algebraic triples



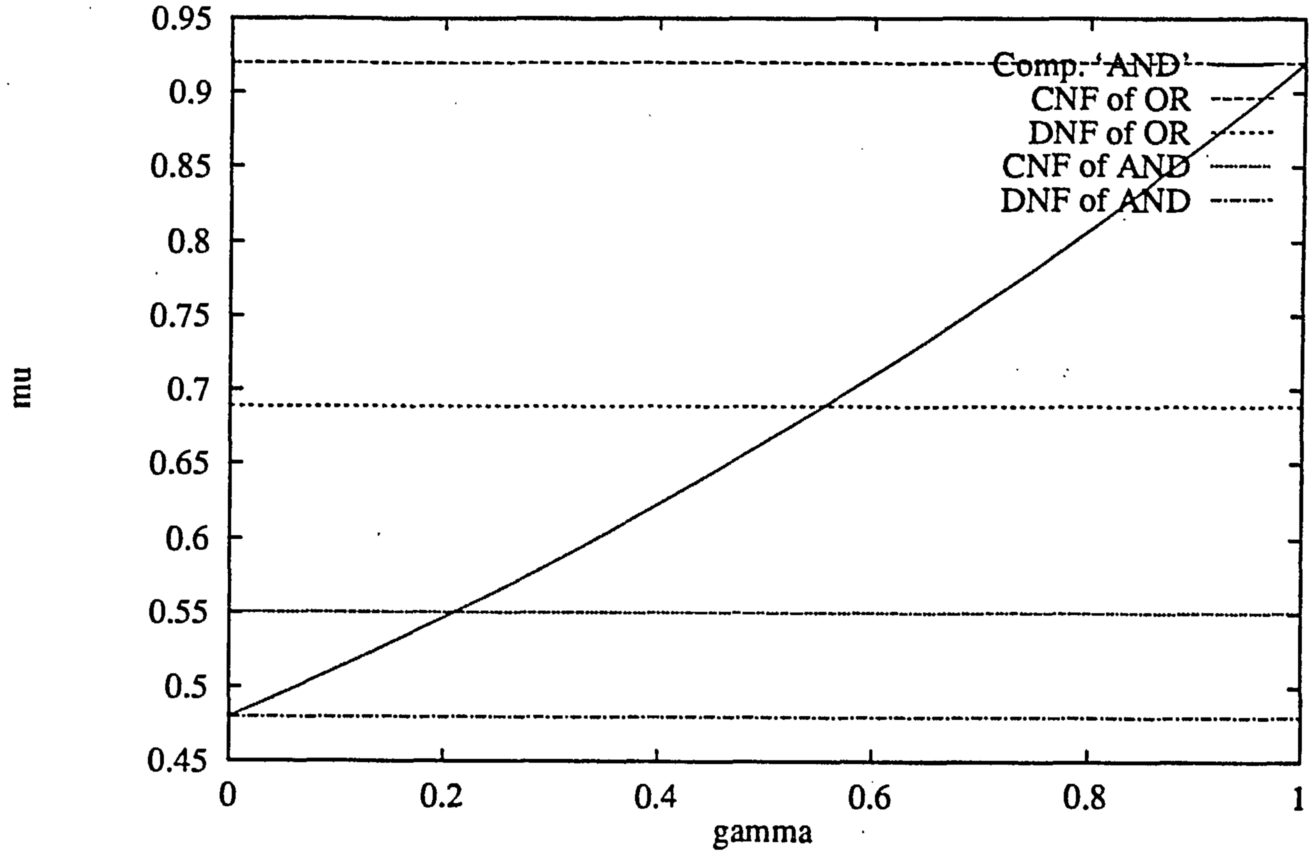
COMPENSATORY 'AND'

$$\mu_{A\,\theta B} = \mu_{A\cap B}^{1-\gamma}\ \mu_{A\cup B}^{\gamma} \qquad (1)$$

or as:

$$\mu A\,\theta B = (1-\gamma)\,\mu A\cap B + \gamma\,\mu A\cup B \qquad (2)$$

Figure 1: IVFS "A AND B", "A OR B", expressed in DNF and CNF and "Exponential Compensatory AND" using algebraic sum–product for realization of t–conorm and t–norm for $\mu_A = 0.8, \mu_B = 0.6$ and $\gamma \in [0, 1]$.



S–Implications

Definition 1 *S-implications are functions* $f_S\colon [0,1] \times [0,1] \to [0,1]$ *defined by*

$$f_S(a,b) = S(1-a,b)$$

where S is a continuous t-conorm.

Examples:

$S(a,b)$	$f_S(a,b)$	
$a \vee b$	$(1-a) \vee b$	Kleene-Dienes
$a+b-ab$	$1-a+ab$	Reichenbach
$1 \wedge a+b$	$1 \wedge 1-a+b$	Łukasiewicz

R–Implications

Definition 2 *R-implications are functions* $f_R\colon [0,1] \times [0,1] \longrightarrow [0,1]$ *defined by*

$$f_R(a,b) = \sup\{\, x \in [0,1] \mid T(a,x) \leq b \,\}$$

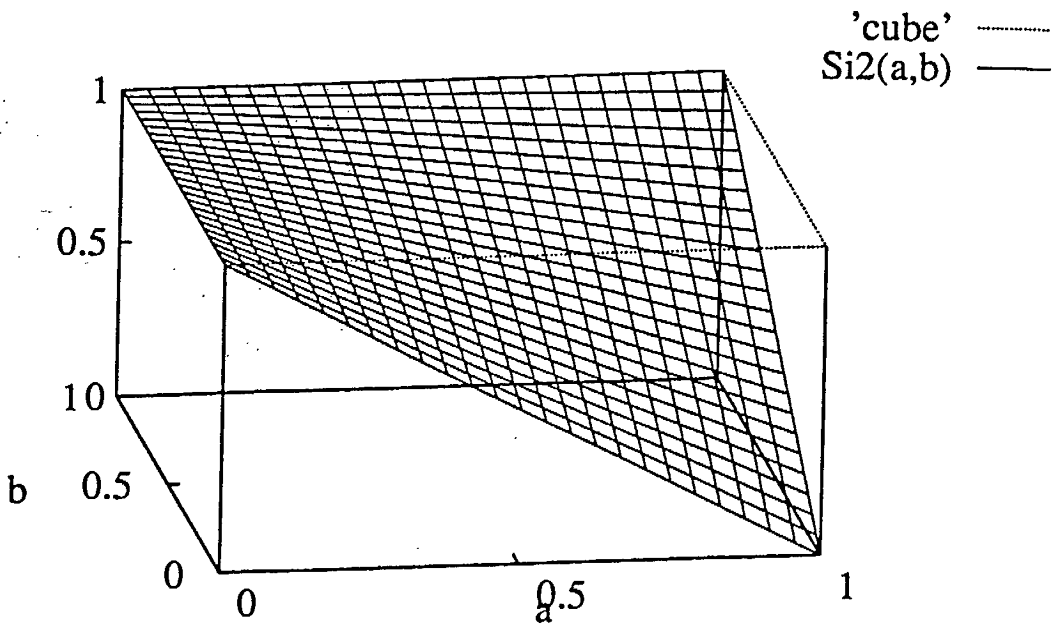
for which a continuous t-norm T exists.

Examples:

$T(a,b)$	$f_R(a,b)$	
$a \wedge b$	$\begin{cases} 1, & \text{if } a \leq b; \\ b, & \text{otherwise.} \end{cases}$	Gödel
ab	$\begin{cases} 1, & \text{if } a = 0; \\ 1 \wedge \frac{b}{a}, & \text{otherwise.} \end{cases}$	Goguen
$0 \vee a + b - 1$	$1 \wedge 1 - a + b$	Łukasiewicz

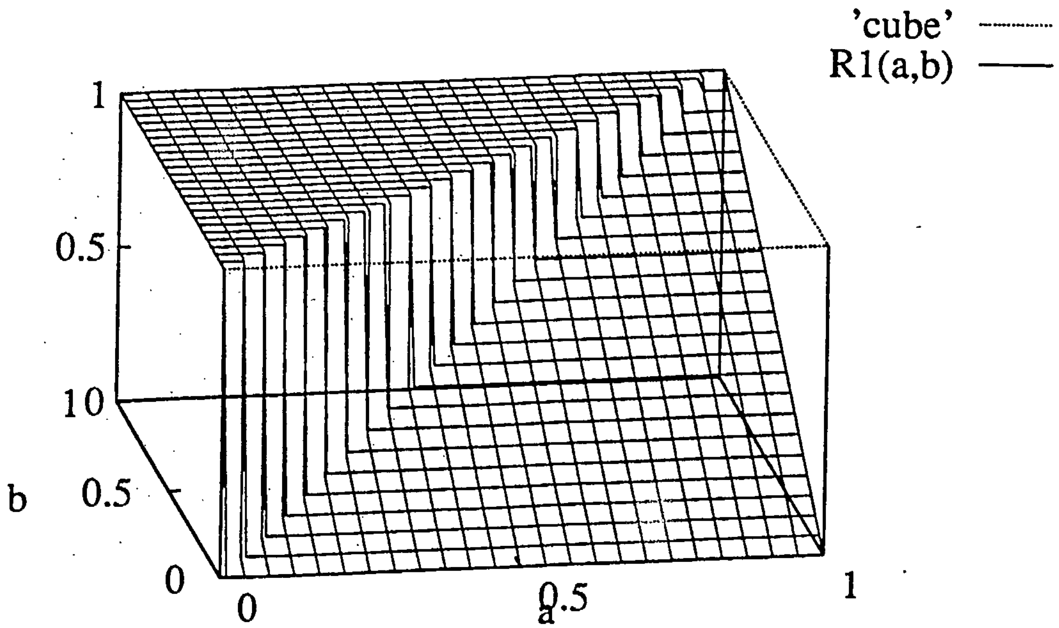
Reichenbach Implication:

$$f_S(a,b) = 1 - a + ab$$



Gödel Implication:

$$f_R(a,b) = \begin{cases} 1, & \text{if } a \leq b; \\ b, & \text{otherwise.} \end{cases}$$



From axiomatic point of view, the following properties have been requested for a 2–place operation I that represents an implication function, Dubois and Prade (1991):

I1: if $a \le a'$ then $I(a,b) \ge I(a',b)$,

I2: if $b \ge b'$ then $I(a,b) \ge I(a,b')$,

I3: $I(0,b) = 1$ (falsity implies anything),

I4: $I(1,b) = b$ (tautology cannot justify anything),

I5: $I(a,b) \ge b$,

I6: $I(a,a) = 1$ (identity principle),

I7: $I(a, I(b,c)) \le I(b, I(a,c))$ (exchange principle),

I8: $I(a,b) = 1$ iff $a \le b$ (implication defines an ordering),

I9: $I(a,b) = I(n(a), n(b))$ for some strong negation n (contraposition law),

I10: I is continuous.

General form of S and R-implications

S and R-implications could be merged into a single family provided that the class of t-norms is enlarged to *non–commutative conjunction operators*, Dubois and Prade 1984).

The general form of the implication functions is:

$$f_{\mathcal{M}}(a,b) = \sup\{\, x \in [0,1] \mid \mathcal{M}(a,x) \leq b \,\}. \qquad (1)$$

t-norm $T(a,b)$	Pseudo-conjunction $T^*(a,b)$
$a \wedge b$	$\begin{cases} 0, & \text{if } a+b \leq 1; \\ b, & \text{otherwise.} \end{cases}$
ab	$\begin{cases} 0, & \text{if } a = 0; \\ 0 \vee \frac{a+b-1}{a}, & \text{otherwise.} \end{cases}$
$0 \vee a+b-1$	$0 \vee a+b-1$

It is also possible to enlarge the class of t–conorms to *non–commutative disjunction operators* (N) to generate the R–implications through the form $N(1-a,b)$.

The general form of the implication functions becomes:

$$f_N(a,b) = N(1-a,b) \tag{2}$$

t-cnorm $S(a,b)$	Pseudo-disjunction $S^*(a,b)$
$a \vee b$	$\begin{cases} 1, & \text{if } a+b \geq 1; \\ b, & \text{otherwise.} \end{cases}$
$a+b-ab$	$\begin{cases} 1, & \text{if } a=1; \\ 1 \wedge \frac{b}{1-a}, & \text{otherwise.} \end{cases}$
$1 \wedge a+b$	$1 \wedge a+b$

If N is chosen as a t-conorm S in (2) then the implication is an S-implication.

If N is chosen as a pseudo–disjunction in (2) then the implication is an R-implication.

APPROXIMATE REASONING

INFERRING CONCLUSIONS FROM A FUZZY RULE BASE AND AN OBSERVATION

A. SOME OF OUR CONCERNS

i) REASONING METHODS FOR DECISION AND CONTROL

ii) PRESERVATION OF CLASSICAL RESULTS

Rules of Inference

1. Modus Ponens

$p \to q$
p
$\therefore\ q$

2. Modus Tollens

$p \to q$
$\neg q$
$\therefore\ \neg p$

3. Hypothetical Syllogism

$p \to q$
$q \to r$
$\therefore\ p \to r$

B. SOME OF THE APPROACHES

ii) EFFECTIVE HEURISTICS

ZADEH-MAMDANI-ASSILIAN: FUZZY GRAPH

WANG-MENDEL: FAM, . . .
SUGENO, ET.AL.: P, P-G, P & P-G

TÜRKŞEN: IVCRI

TÜRKŞEN, ET. AL: IVAAR

TÜRKŞEN, ZHAO: ILFSI

MUKAIDONO, SHEN, DING, WANG: RPIV-REVISION PRINCIPLE AND ITS VARIATIONS

iii) DEFUZZIFICATION METHODS
CGM
MMVM

fuzzy reasoning is based on linguistic rules

$$R^1 : \text{if } X_1 \text{ is } A_1^1 \text{ and} \dots \text{and } X_J \text{ is } A_J^1 \text{ then } Y \text{ is } B^1$$

$$\vdots \qquad \vdots$$

$$R^I : \text{if } X_1 \text{ is } A_1^I \text{ and} \dots \text{and } X_J \text{ is } A_J^I \text{ then } Y \text{ is } B^I$$

$$\frac{X_1 \text{ is } A_1' \text{ and} \dots \text{and } X_J \text{ is } A_J'}{Y \text{ is } B'}$$

(i)ZADEH'S COMPOSITIONAL RULE OF INFERENCE (POINT-VALUED)(CRISP CONNECTIVES)

• Implication:

$$R^{i}=A^{i}\rightarrow B^{i}$$

• Aggregation of antecedent:

$$A^{i}=\bigcap_{j=1}^{J} A_{j}^{i}$$

• Aggregation of observations:

$$A'=\bigcap_{j=1}^{J} A_{j}'$$

• Compositional Rule of Inference: (CRI)

$$B^{i'}=A'\circ R^{i}$$

• The final estimation of consequence:

$$B'=\biguplus_{i=1}^{I} B^{i'}$$

where $\uplus \in \{\vee, \wedge\}$

The point-valued membership value of inferred consequence

$$h_{B'}(y) = \biguplus_{i=1}^{I} \sup_{x_1,,x_J} [T\{ \bigwedge_{j=1}^{J} h_{A_j'}(x_j), (\bigwedge_{j=1}^{J} h_{A_j^i}(x_j) \rightarrow h_{B^i}(y))\}]$$

where $h_{A_j^i}(x_j)$, $h_{A_j'}(x_j)$, $h_{B^i}(y)$, and $h_{B'}(y)$ are the corresponding membership function values for the fuzzy sets, A_j^i, A_j', B^i, B', respectively, and T is t-norms operator.

sup-min operations in the model

$$h_{B'}(y) = \biguplus_{i=1}^{I} [\sup_{x_1,,x_J} (\bigwedge_{j=1}^{J} h_{A_j'}(x_j)) \wedge (\bigwedge_{j=1}^{J} h_{A_j^i}(x_j) \rightarrow h_B^{\,i}(y))] .$$

IMPLICATION: " → "

$$h_{Rc}^{i}(x,y) = h_{A}^{i}(x) \wedge h_{B}^{i}(y) \qquad \text{(Mamdani)}$$

$$h_{Ra}^{i}(x,y) = (1 - h_{A}^{i}(x) + h_{B}^{i}(y)) \qquad \text{(Lukasiewicz)}$$

$$h_{R\Delta}^{i}(x,y) = \frac{h_{B}^{i}(y)}{h_{A}^{i}(x)} \wedge 1 \qquad \text{(Goguen)}$$

$$h_{Rg}^{i}(x,y) = \begin{cases} 1, & h_{A}^{i}(x) \le h_{B}^{i}(y) \\ h_{B}^{i}(y), & h_{A}^{i}(x) > h_{B}^{i}(y) \end{cases} \qquad \text{(Gödel)}$$

where $h\ (x,y)$ means;

$$h_{R^{i}}(x_{j}, y) = \bigwedge_{j=1}^{J} h_{A_{j}^{i}}(x_{j}) \rightarrow h_{B}^{i}(y) \quad .$$

MODUS PONENS

$$A \to B$$

$$A$$

$$\frac{}{B}$$

$$A \circ (A \to B) = A \circ (\neg A \cup B)$$

$$a_i \in A, b_j \in B \qquad a_i, b_j \in \{0,1\}$$

A = (1/1, 1/2, 0/3) B = (0/1, 1/2, 1/3)

$$\neg A \cup B = \begin{array}{c} \\ 0 \\ 0 \\ 1 \end{array}\begin{array}{c} \begin{array}{ccc} 0 & 1 & 1 \end{array} \\ \begin{pmatrix} 0 & 1 & 1 \\ 0 & 1 & 1 \\ 1 & 1 & 1 \end{pmatrix} \end{array}$$

$$A \circ (A \rightarrow B) = (1,\ 1,\ 0) \begin{pmatrix} 0 & 1 & 1 \\ 0 & 1 & 1 \\ 1 & 1 & 1 \end{pmatrix}$$

$$= (1,\ 1,\ 0)$$

$$b_j = \bigvee_i a_i \wedge (\neg a_i \vee b_j)$$

GENERALIZED MODUS PONENS

$$\frac{\begin{array}{l} A \rightarrow B \\ A' \end{array}}{B'}$$

$a \in A,\ b \in B,\ a' \in A',\ b' \in B'$

$A' \circ (A \rightarrow B)$

$A' \circ (\neg A \cup B)$

$\tilde{b}_j = \bigvee_i a'_i \wedge (\neg a_i \vee b_j)$

$A = (1/1,\ .7/2,\ 0/3)$

$B = (0/1,\ .6/2,\ 1/3)$

$A' = (1/1,\ .6/2,\ .2/3)$

$$\neg A \vee B = \begin{array}{c|ccc} & 0 & .6 & 1 \\ \hline 0 & 0 & .6 & 1 \\ .3 & .3 & .6 & 1 \\ 1 & 1 & 1 & 1 \end{array}$$

$$(1, .6, .2) \begin{pmatrix} 0 & .6 & 1 \\ .3 & .6 & 1 \\ 1 & 1 & 1 \end{pmatrix} =$$

$$(.3, .6, 1) = B' \neq B$$

$\alpha = .3$ $\qquad$ $B'_{\alpha = .3} = B$

B. SOME OF THE APPROACHES

i) FORMAL LOGICAL MODELS

ZADEH'S: CRI

ZAHEH'S: INTERPOLATIVE
REASONING

ZAHEH'S: SYLLOGISTIC REASONING

DUBOIS-PRADE, TRILLAS-VALVERDE:
DESIRABLE CHARACTERISTICS
DECOMPOSITION-INFERENCE

FUZZY GRAPH-INTERPOLATION: FGI
ZADEH-MAMDANI-ASSILIAN

$$h_{B'}(y) = \bigvee_{i=1}^{I}[\bigvee_{x_1,\dots,x_J}(\bigwedge_{j=1}^{J} h_{A'_j}(x_j)) \wedge \{\bigwedge_{j=1}^{J}(h_{A^i_j}(x_j) \wedge h_{B^i}(y))\}]$$

$$= \bigvee_{i=1}^{I}[\bigwedge_{j=1}^{J}\{\bigvee_{x_j}(h_{A'_j}(x_j) \wedge h_{A^i_j}(x_j))\} \wedge h_{B^i}(y) \quad .$$

FGI IS A "REDUCTION" TYPE INFERENCE

000 INFERENCE METHODS - I

00 GENERALIZED MODUS PONES: GMP(CRI)

(ZADEH, 1973)

0 SINGLE RULE: A -> C

$$A' \circ (A \to C) = C'$$

a) EXPANSION TYPE INFERENCE

$C \subseteq C'$ ALWAYS

b) REDUCTION TYPE INFERENCE

$C' \subseteq C$ ALWAYS

c) OTHER TYPES

AT TIMES $C \subseteq C'$

AT OTHER TIMES $C' \subseteq C$

d) IF A' = A, THEN USUALLY

$$A' \circ (A \to C) \neq C$$

000 INFERENCE METHODS - II

00 GENERALIZED MODUS PONES

0 INFERENCE WITH MULTIPLE RULES (TURKSEN-TIAN, 1992)

a) FITA

$A' \circ (A_k \rightarrow C_k) = C'_k \quad K=1,\ldots,K,$

$C' = \oplus C'_k$

b) FATI

$R = \oplus R_k = \oplus(A_k \rightarrow C_k)$

$C' = A' \circ R = A' \circ [\oplus(A_k \rightarrow C_k)]$

i) TYPE OF AGGREGATION (COMBINATION) OPERATOR?

$\oplus \in \{T,S\}, \quad \oplus \in \{\wedge,\vee\}$

000 INFERENCE METHODS - II

00 GENERALIZED MODUS PONES

0 INFERENCE WITH MULTIPLE RULES (TURKSEN-TIAN, 1992)

ii) TYPE OF INFERENCE?

1)EXPANSION TYPE, $C \subseteq C'$: $\oplus = \wedge$

2)REDUCTION TYPE, $C' \subseteq C$: $\oplus = \vee$
(SUBJECT TO CONSTRAINTS
AND CONDITIONS)

MP1 - IF $A' = A_{k^*}$ THEN $C' = C_{k^*}$

i.e., $C' = \bigoplus_k C_k = C_{k^*}$

MP2 - IMPLICATION CONSTRAINTS

000 INFERENCE METHODS - I

00 GENERALIZED MODUS PONES

0 SINGLE RULE

b) RESPONSES TO P1:

i) $\alpha\text{-cut} = \bigvee_i (a_i \wedge (1-a_i))$

(TURKSEN - YAO, 1984)
FROM "DNF" AND "CNF"
REPRESENTATION

ii) PSEUDO-CONJUNCTION
(DUBOIS-PRADE, 1984, 1989)
(TABLES 1 AND 2)

$$f_M(a,b) = \sup\{x \in [0,1] \mid M(a,x) \leq b\}$$

iii) Given "$\circ$", THEN DERIVE "$\rightarrow$"
(DUBOIS-PRADE, 1984, 1991)

iv) Given "$\rightarrow$", THEN DERIVE "$\circ$"
(TRILLAS-VALVERDE, 1985)

Compositional Rule of Inference

Single antecedent inference with fuzzy input and fuzzy output.

$$
\begin{array}{rl}
\text{Rule:} & (A \Rightarrow C) \\
\text{Observation:} & A' \\
\hline
\text{Conclusion:} & \qquad\qquad C^*
\end{array}
$$

Or in short,

$$C^* = A' \circ_{\mathcal{M}} (A \Rightarrow C),$$

where $\circ_{\mathcal{M}}$ is the *Max–$\mathcal{M}$* composition.

In membership domain,

$$C^* = A' \circ_{\mathcal{M}} (A \Rightarrow C), \text{ becomes}$$

$$\mu_{C^*}(k) = \vee_i \mathcal{M}[\mu_{A'}(i), \mu_A(i) \Rightarrow \mu_C(k)], \ \forall k.$$

Dubois & Prade (1984) and Trillas & Valverde (1984) identified the functions for $\Rightarrow$ and $\mathcal{M}$ that should be used together so that C^* will satisfy the following four properties P1–P4.

Desired Properties of Inference:

P1- $C \subseteq C^*$,
P2- $C^* = C$ when $A' = A$,
P3- If $A' \subseteq A''$ then $C^{*\prime} \subseteq C^{*\prime\prime}$,
P4- For $A' = \overline{A}$, $C^* = I$.

Suggested operator selection table:

	Implication: $\Rightarrow$	Operator: $\mathcal{M}$
1-	Gödel	minimum
2-	Goguen	product
3-	Łukasiewicz	bold–intersection
4-	Kleene–Dienes	$\mathcal{M}$(minimum)
5-	Reichenbach	$\mathcal{M}$(product)

Where:

Implication	$a \Rightarrow b$
Gödel	$\begin{cases} 1, & \text{if } a \leq b; \\ b, & \text{otherwise.} \end{cases}$
Goguen	$\begin{cases} 1, & \text{if } a = 0; \\ 1 \wedge \frac{b}{a}, & \text{otherwise.} \end{cases}$
Łukasiewicz	$1 \wedge 1 - a + b$
Kleene–Dienes	$(1 - a) \vee b$
Reichenbach	$1 - a + ab$

and,

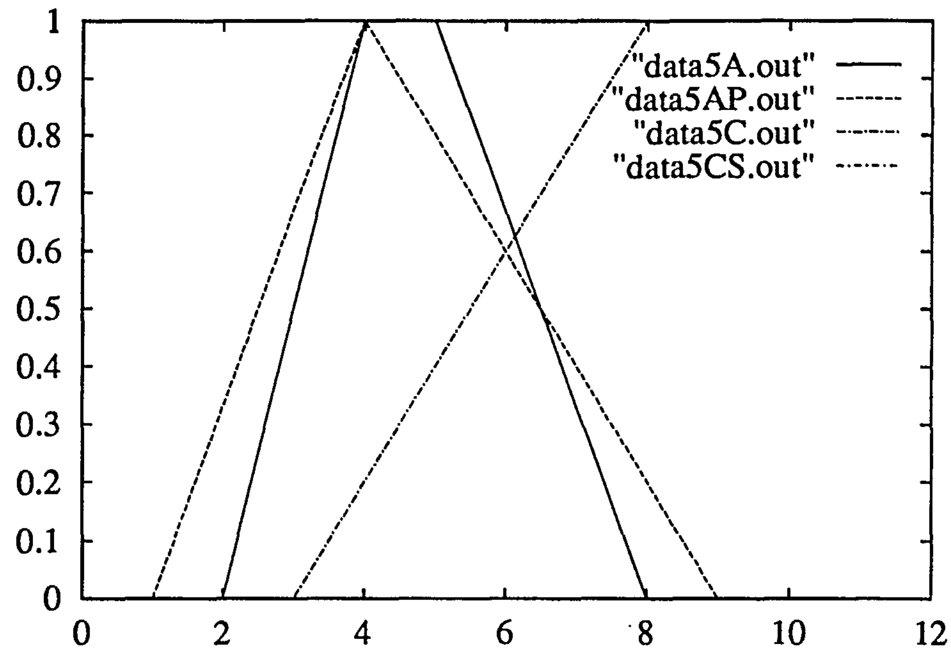
Operator	$\mathcal{M}(a,b)$
minimum	$a \wedge b$
product	ab
bold–intersection	$0 \vee a+b-1$
$\mathcal{M}$(minimum)	$\begin{cases} 0, & \text{if } a+b \leq 1; \\ b, & \text{otherwise.} \end{cases}$
$\mathcal{M}$(product)	$\begin{cases} 0, & \text{if } a=0; \\ 0 \vee \frac{a+b-1}{a}, & \text{otherwise.} \end{cases}$

Max–min composition with Kleene-Dienes implication is also among the most popular operator combinations, inspite of the fact that it violates property P2.

Consider

$$A = (0/1, 0/2, .50/3, 1/4, 1/5, .66/6, .33/7, 0/8, 0/9, 0/10)$$
$$C = (0/1, 0/2, 0/3, .20/4, .40/5, .60/6, .80/7, 1/8, 1/9, 1/10)$$
$$A' = (0/1, .33/2, .67/3, 1/4, .80/5, .60/6, .40/7, .20/8, 0/9, 0/10)$$

throughout the examples.



What is C^*?

Example 1: *Max–min–Gödel* composition.

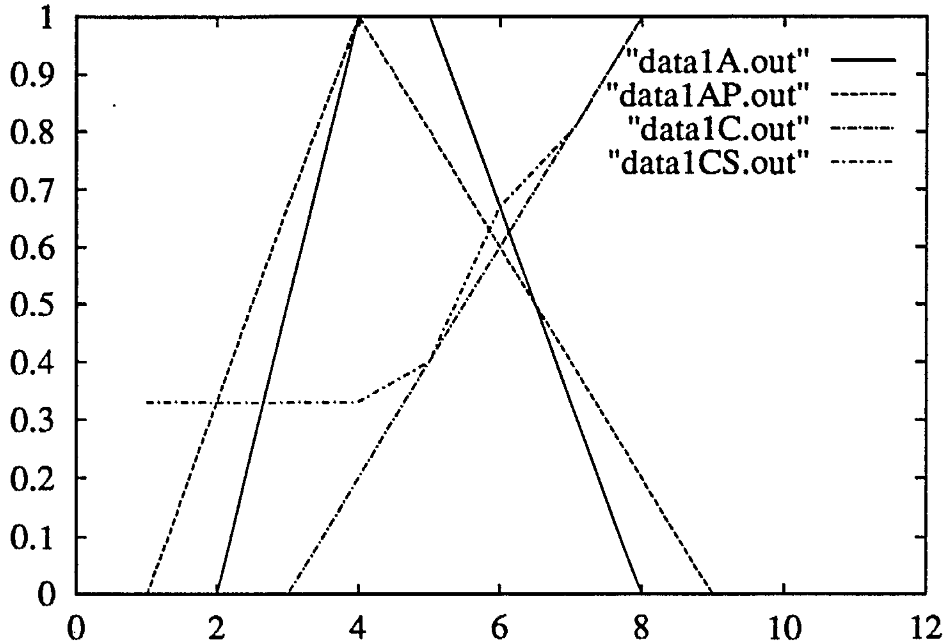
$$\mu_{C^*}(k) = \vee_i \left[\mu_{A'}(i) \wedge \mu_A(i) \Rightarrow \mu_C(k)\right], \ \forall\, k$$

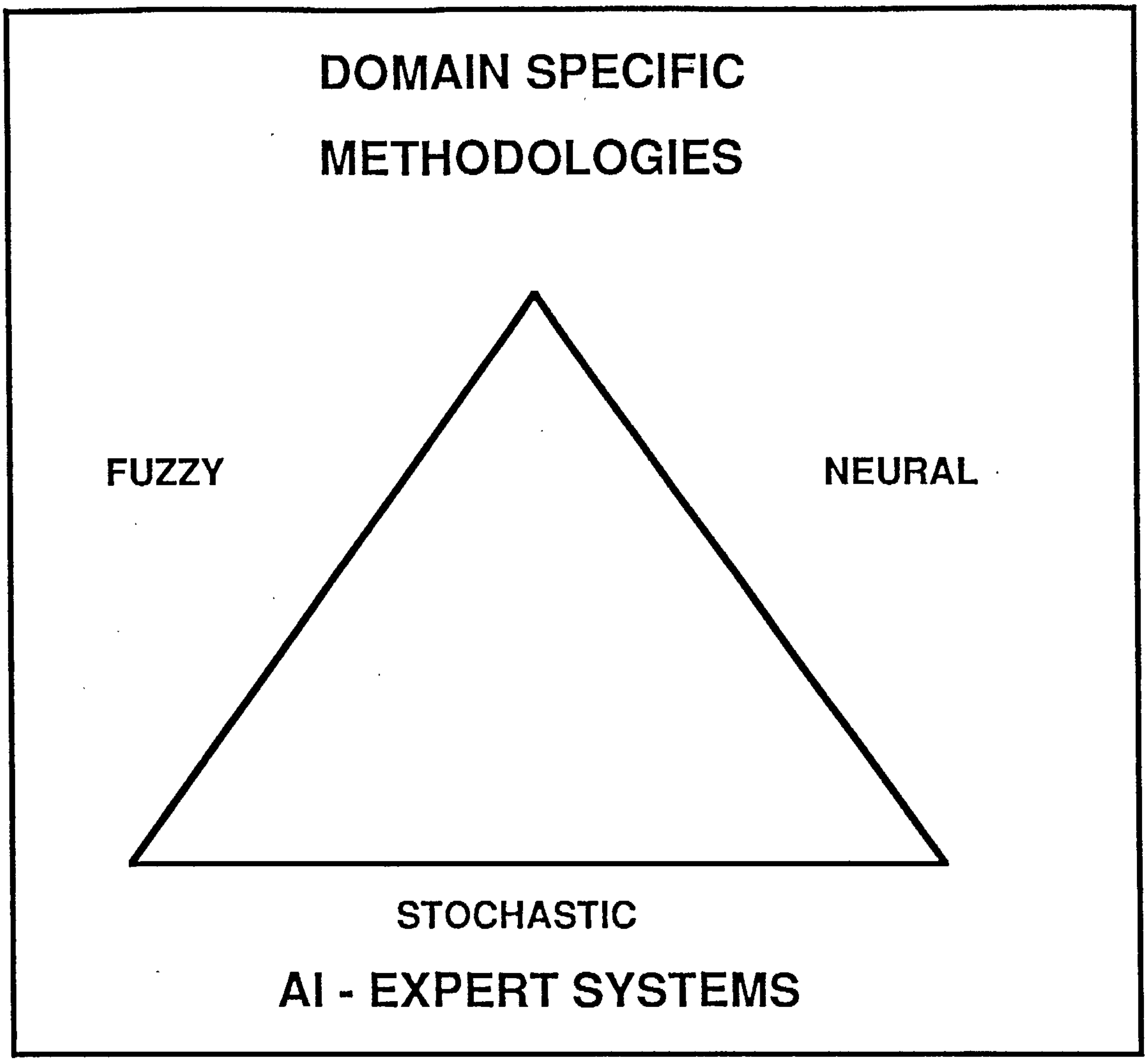
where,

$$\mu_A(i) \Rightarrow \mu_C(k) = \begin{cases} 1, & \text{if } \mu_A(i) \le \mu_C(k); \\ \mu_C(k), & \text{otherwise.} \end{cases}.$$

$$\begin{bmatrix} 0.00 \\ 0.33 \\ 0.67 \\ 1.00 \\ 0.80 \\ 0.60 \\ 0.40 \\ 0.20 \\ 0.00 \\ 0.00 \end{bmatrix} \wedge \begin{bmatrix} 1.0 & 1.0 & 1.0 & 1.0 & 1.0 & 1.0 & 1.0 & 1.0 & 1.0 & 1.0 \\ 1.0 & 1.0 & 1.0 & 1.0 & 1.0 & 1.0 & 1.0 & 1.0 & 1.0 & 1.0 \\ 0.0 & 0.0 & 0.0 & 0.2 & 0.4 & 1.0 & 1.0 & 1.0 & 1.0 & 1.0 \\ 0.0 & 0.0 & 0.0 & 0.2 & 0.4 & 0.6 & 0.8 & 1.0 & 1.0 & 1.0 \\ 0.0 & 0.0 & 0.0 & 0.2 & 0.4 & 0.6 & 0.8 & 1.0 & 1.0 & 1.0 \\ 0.0 & 0.0 & 0.0 & 0.2 & 0.4 & 0.6 & 1.0 & 1.0 & 1.0 & 1.0 \\ 0.0 & 0.0 & 0.0 & 0.2 & 1.0 & 1.0 & 1.0 & 1.0 & 1.0 & 1.0 \\ 1.0 & 1.0 & 1.0 & 1.0 & 1.0 & 1.0 & 1.0 & 1.0 & 1.0 & 1.0 \\ 1.0 & 1.0 & 1.0 & 1.0 & 1.0 & 1.0 & 1.0 & 1.0 & 1.0 & 1.0 \\ 1.0 & 1.0 & 1.0 & 1.0 & 1.0 & 1.0 & 1.0 & 1.0 & 1.0 & 1.0 \end{bmatrix} = \begin{bmatrix} 0.33 \\ 0.33 \\ 0.33 \\ 0.33 \\ 0.40 \\ 0.67 \\ 0.80 \\ 1.00 \\ 1.00 \\ 1.00 \end{bmatrix}$$

Example 1: *Max–min–Gödel* composition, *continued.*



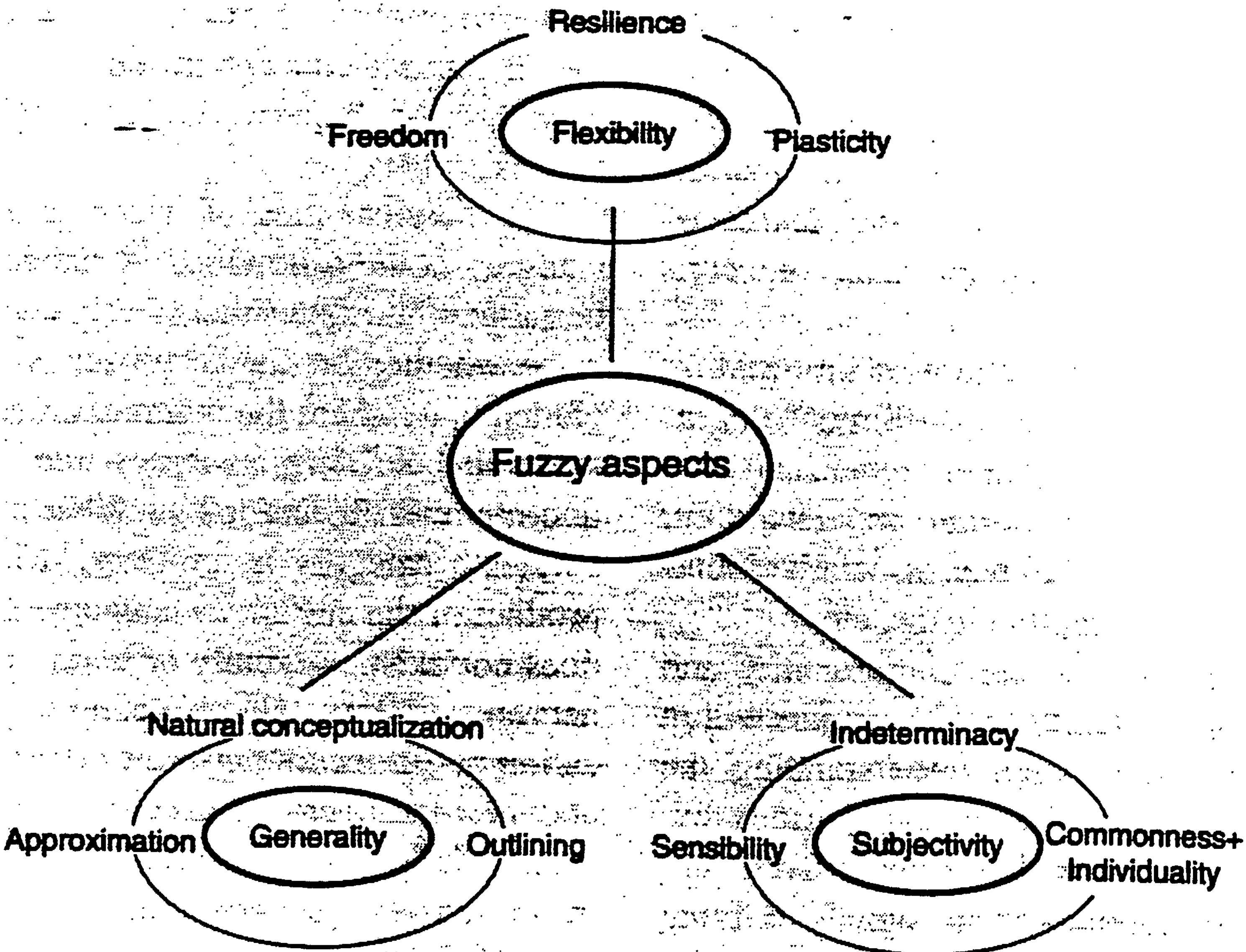


FUZZY THEORY ENHANCES AND ENRICHES CAPABILITIES OF CLASSICAL THEORIES AND METHODOLOGIES.

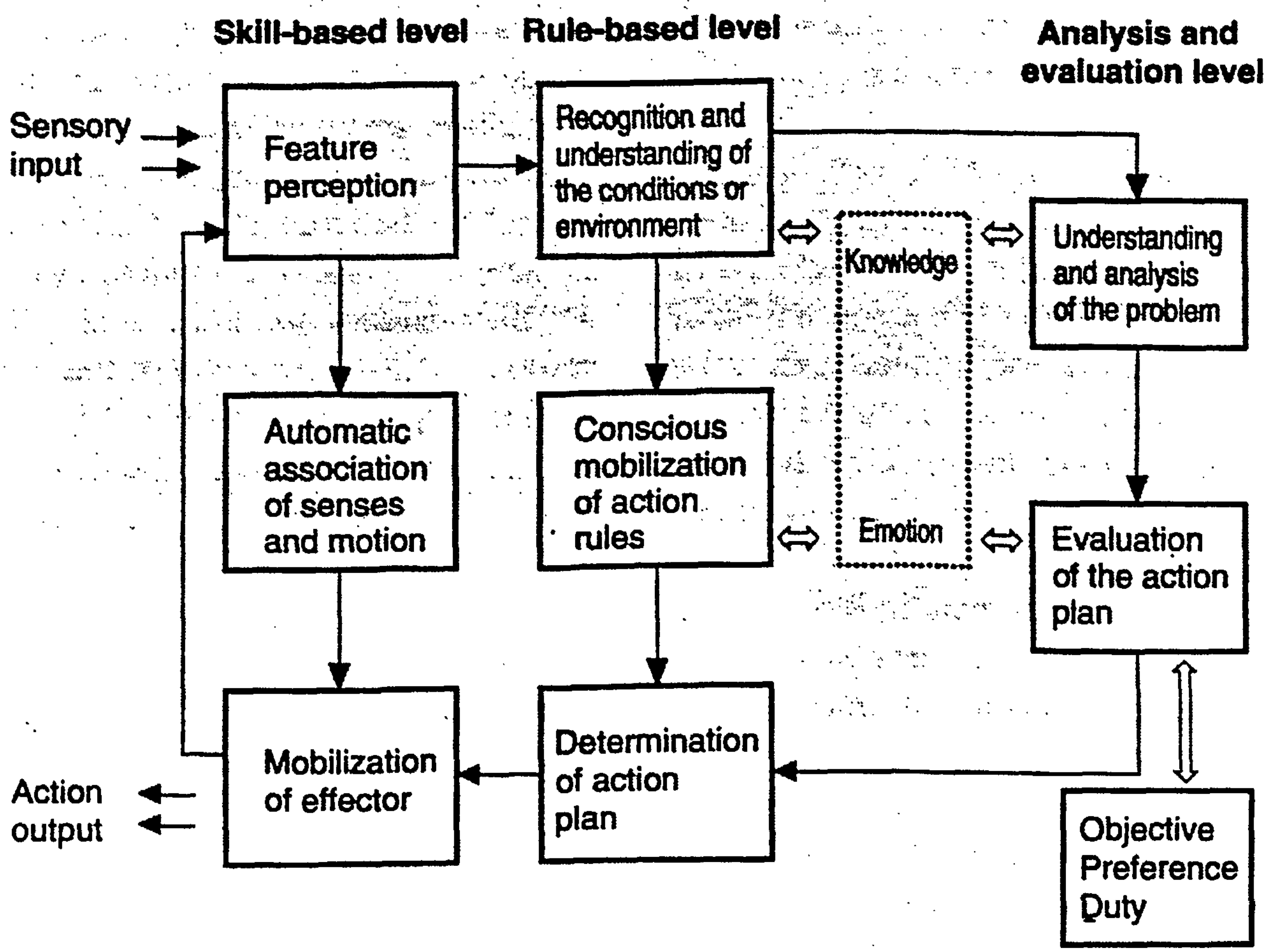
Levels of Information Processing in Human Communication

Table 1

LEVEL	INFORMATION PROCESSING	EXAMPLES
I Senses	Symbol	Sound, line, color
II Recognition	Signal	Language, contours (shape)
III Understanding (of micro knowledge)	Local meaning	Meanings of words, single objects
IV Understanding (of macro knowledge)	Global meaning	Meanings of sentences, complex objects
V Understanding (of emotions and intentions)	Impression, conception	Association, imagination, the arts, personality



Aspects of fuzziness in human information processing



Framework of human information processes in decision making

SUMMARY

FUZZY SETS AND LOGICS HAS A DEFINITE IMPACT

ON

1) OUR SCIENTIFIC THINKING AND MODEL BUILDING

   a) KNOWLEDGE REDPRESENTATION

   b) APPROXIMATE REASONING

2) OUR TECHNOLOGICAL IMPLEMENTATION

   a) FLEXIBLE

   b) ROBUST

   c) ENERGY SAVING

   d) COST EFFECTIVE

⋮

APPLICATIONS OF FUZZY THEORY*

Professor Dr. I. B. Türkşen
Principal Investigator - MRCO
University of Toronto
Toronto, Ontario
M5S 1A4

Tel: 416-978-1278
Fax: 416-978-1280
e-mail: turksen@ie.utoronto.ca

* Supported in part by:

a) MRCO - Manufacturing Research Corporation of Ontario
b) NSERC - Natural Science and Engineering Council of Canada
c) Industrial Technology Transfer Companies

B. APPROACHES (CONT')

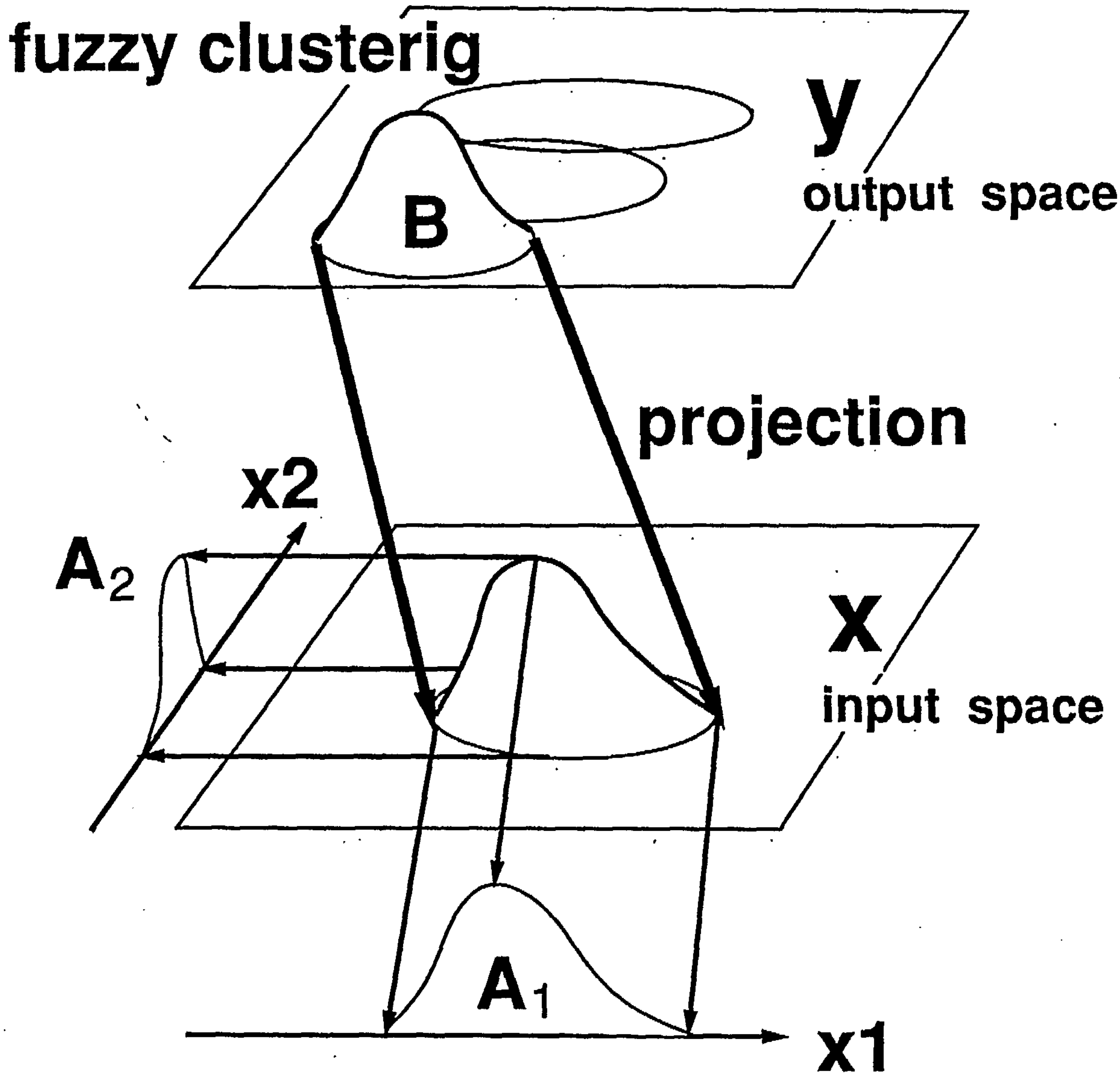
II) INPUT OUTPUT

A) FUZZY CLUSTER ANALYSIS
(BEZDEK - SUGENO)

B) FUZZY ASSOCIATIVE
MEMORY
(WANG - MENDEL)

C) INDUCTIVE LEARNING
FUZZY CLASSIFICATION
(QUINLAN - TURKSEN - ZHAO)

Formation of Fuzzy Rules based on Fuzzy Clustering



R; If x1 is A_1 and x2 is A_2 then

y is B.

Steps in Fuzzy Reasoning

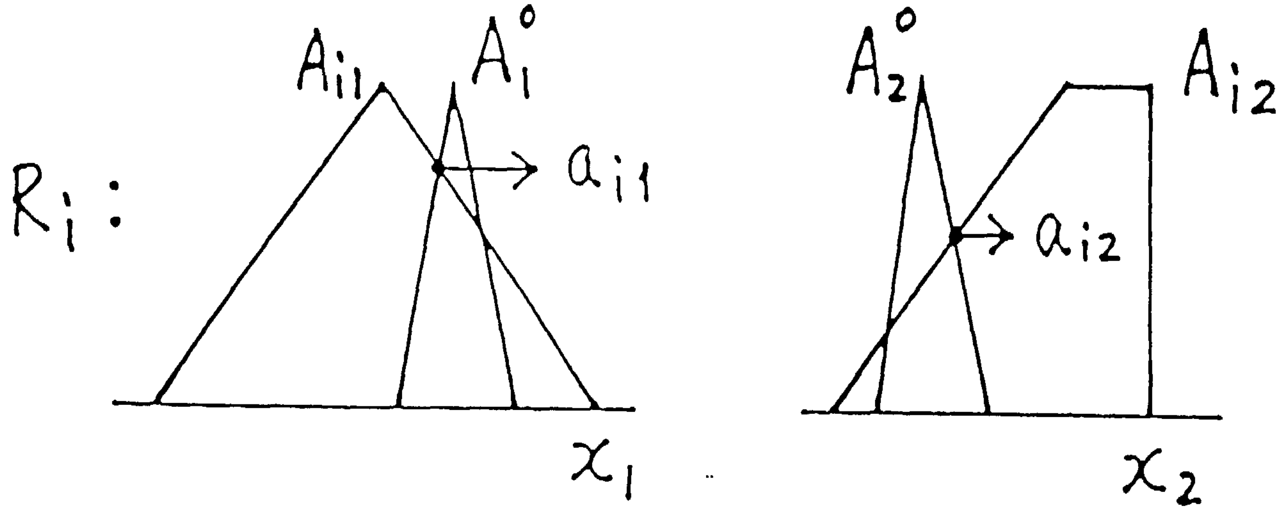
(1) Compatibility of Premises

(2) Reasoning by Single Rule

(3) Aggregation and Defuzzification

Compatibility of Premise with Fuzzy Input

$$w_i = a_{i1} * a_{i2}$$



A_1°, A_2° : Fuzzy Inputs

$$a_{i1} = \max_{x_1} [A_{i1}(x_1) \wedge A_1^\circ(x_1)]$$

(1) Compatibility of Premises

$$w_i = A_{i1}(x_1^\circ) \otimes A_{i2}(x_2^\circ)$$

x_1°, x_2° : singleton inputs

$\otimes$: min or multiplication

2) Reasoning by Single Rule

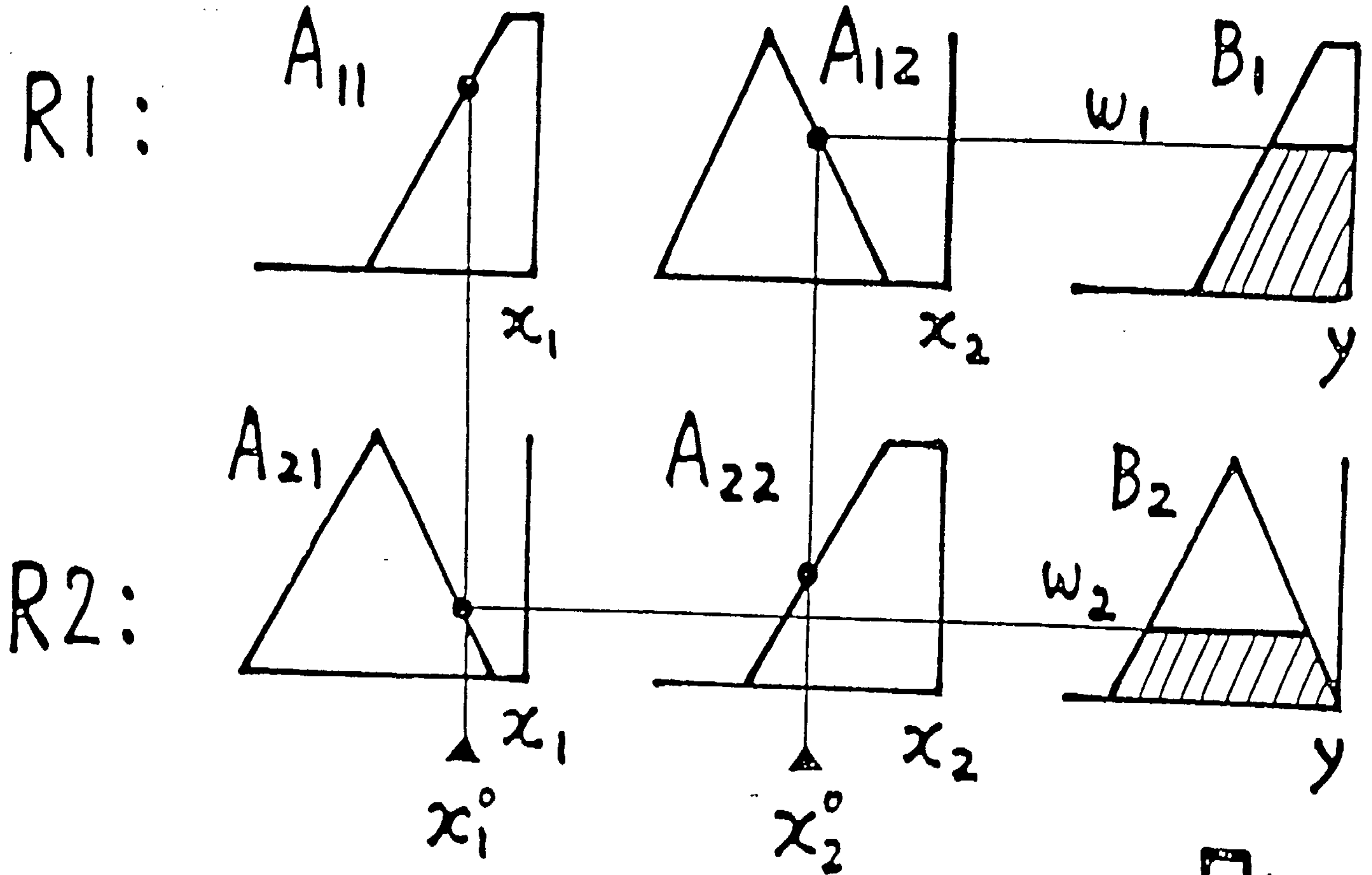
$$B_i^*(y) = w_i \otimes B_i(y)$$

B_i : Consequent of a Rule

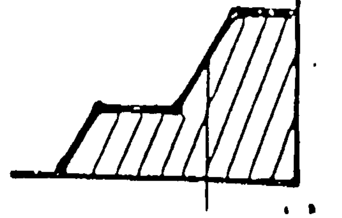
B_i^* : Result by Reasoning

$\otimes$: min or multiplication

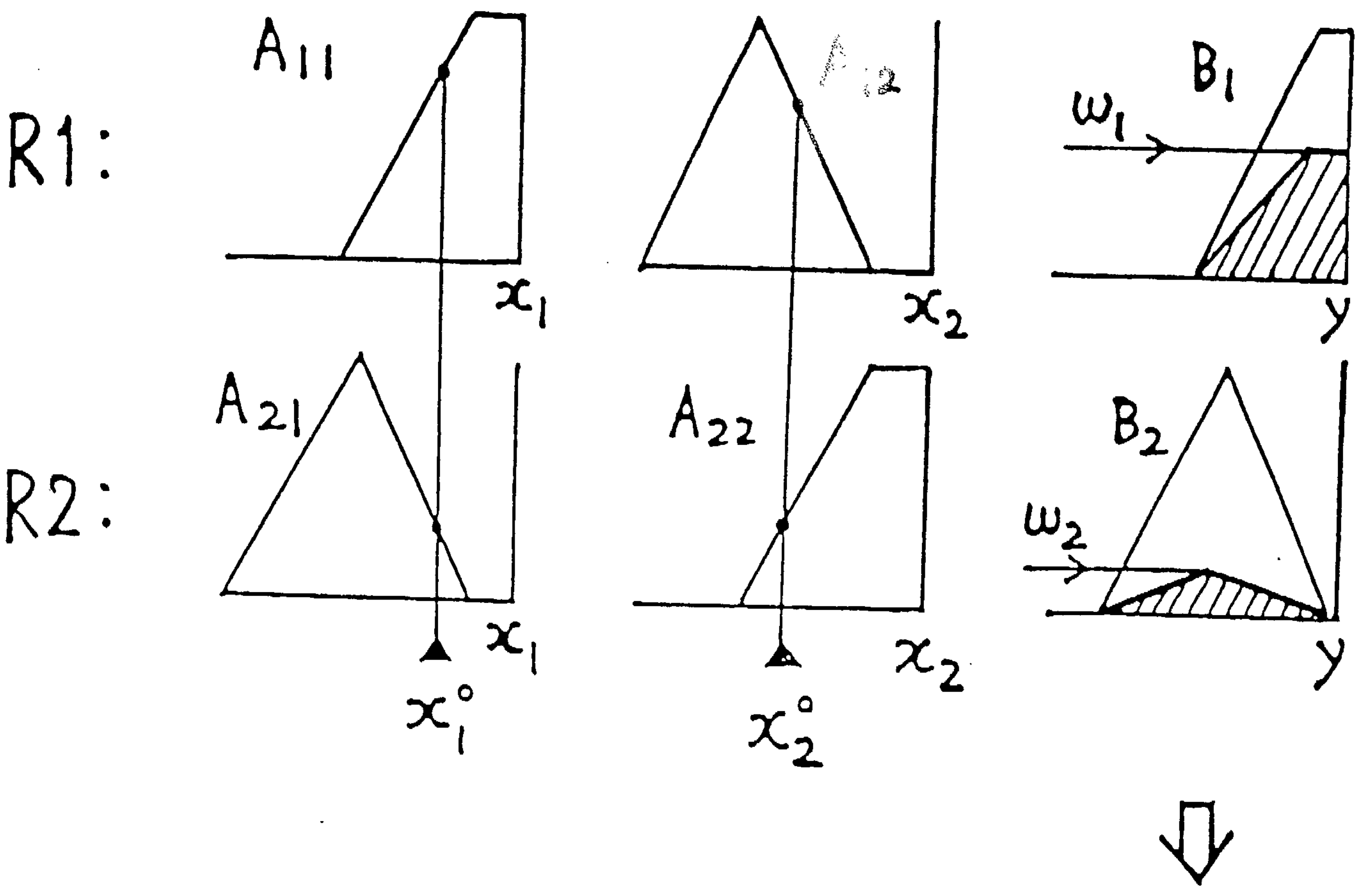
Mamdani's Method of Reasoning for Fuzzy Control



Min-Max Aggregation

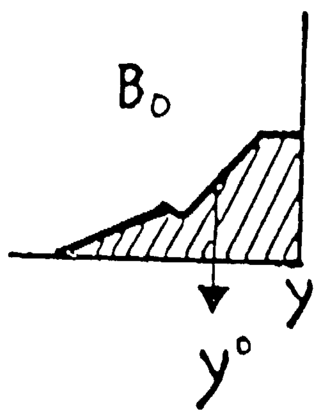


Modified Mamdani's Method

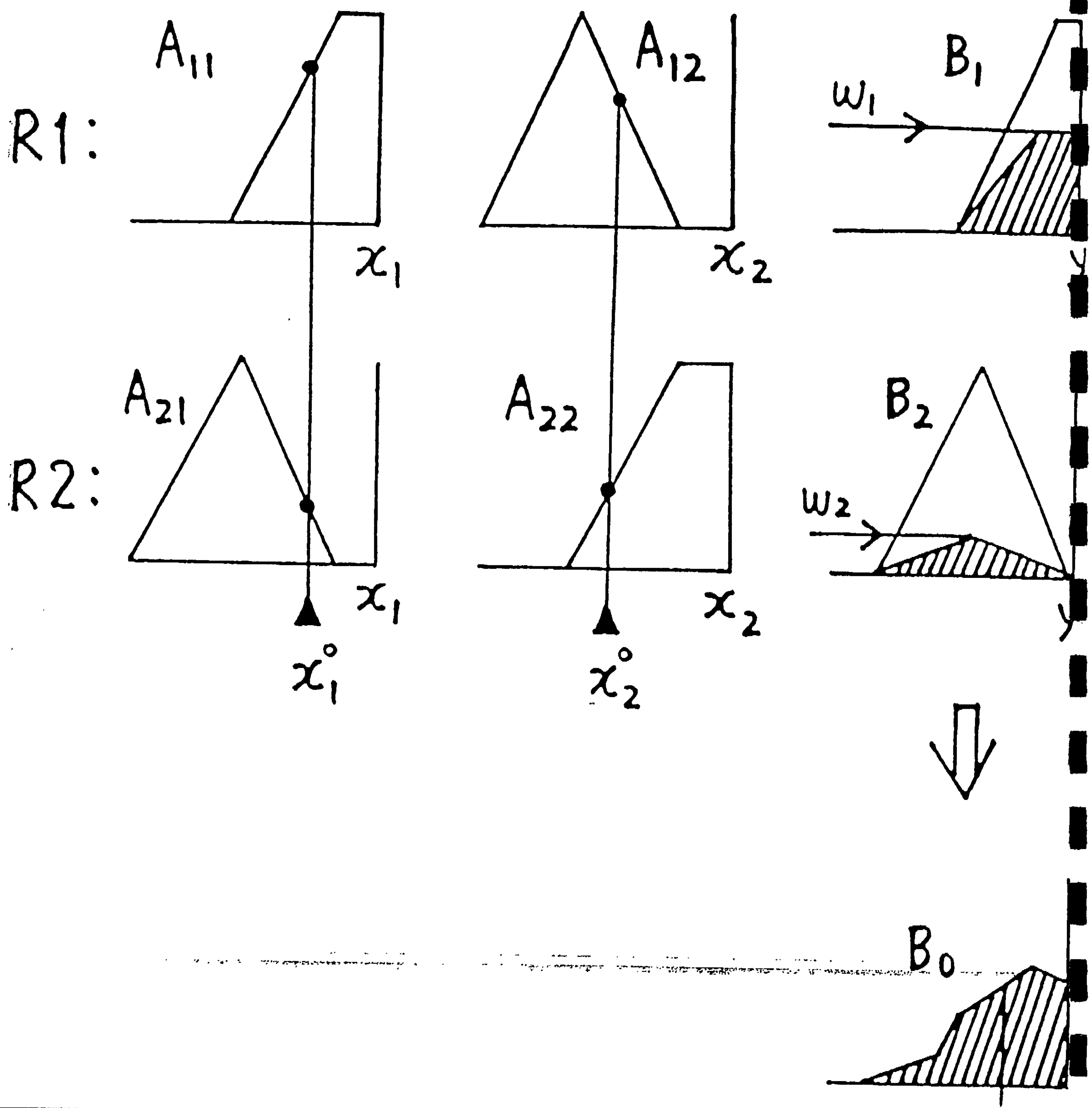


Multiplication

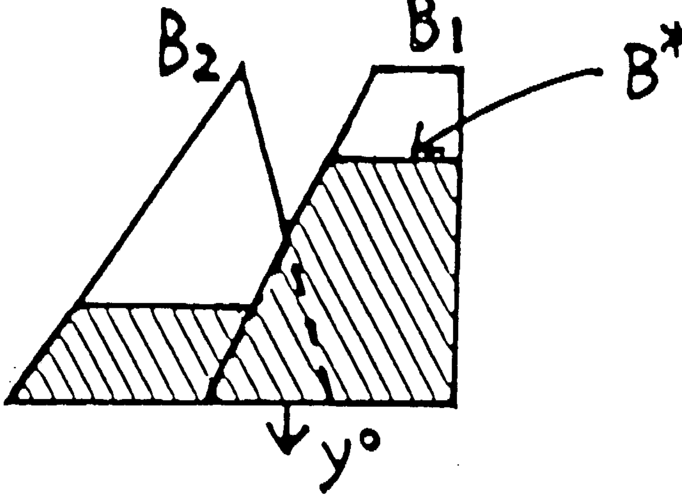
-Max Aggregation



Multiplication - Additive Aggregati

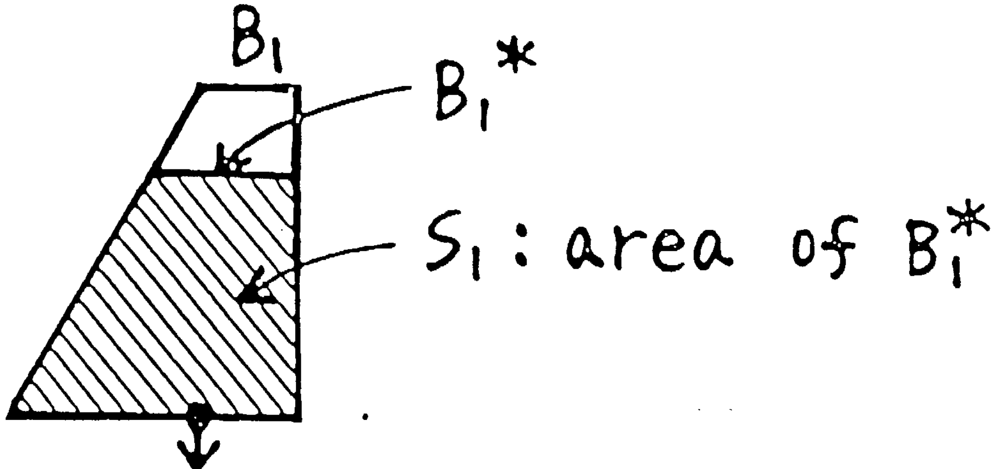


Center of Gravity Method

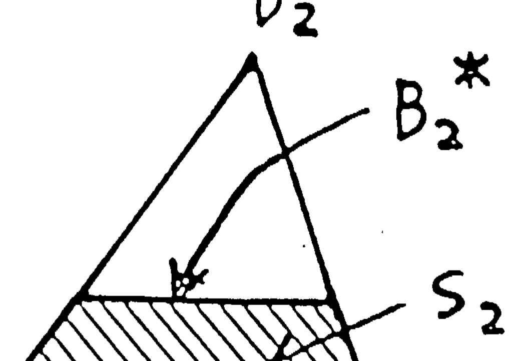


$$y^{o} = \frac{\int B^{*}(y)\, y\, dy}{\int B^{*}(y)\, dy}$$

Area Method



b_1 : center of gravity of B_1

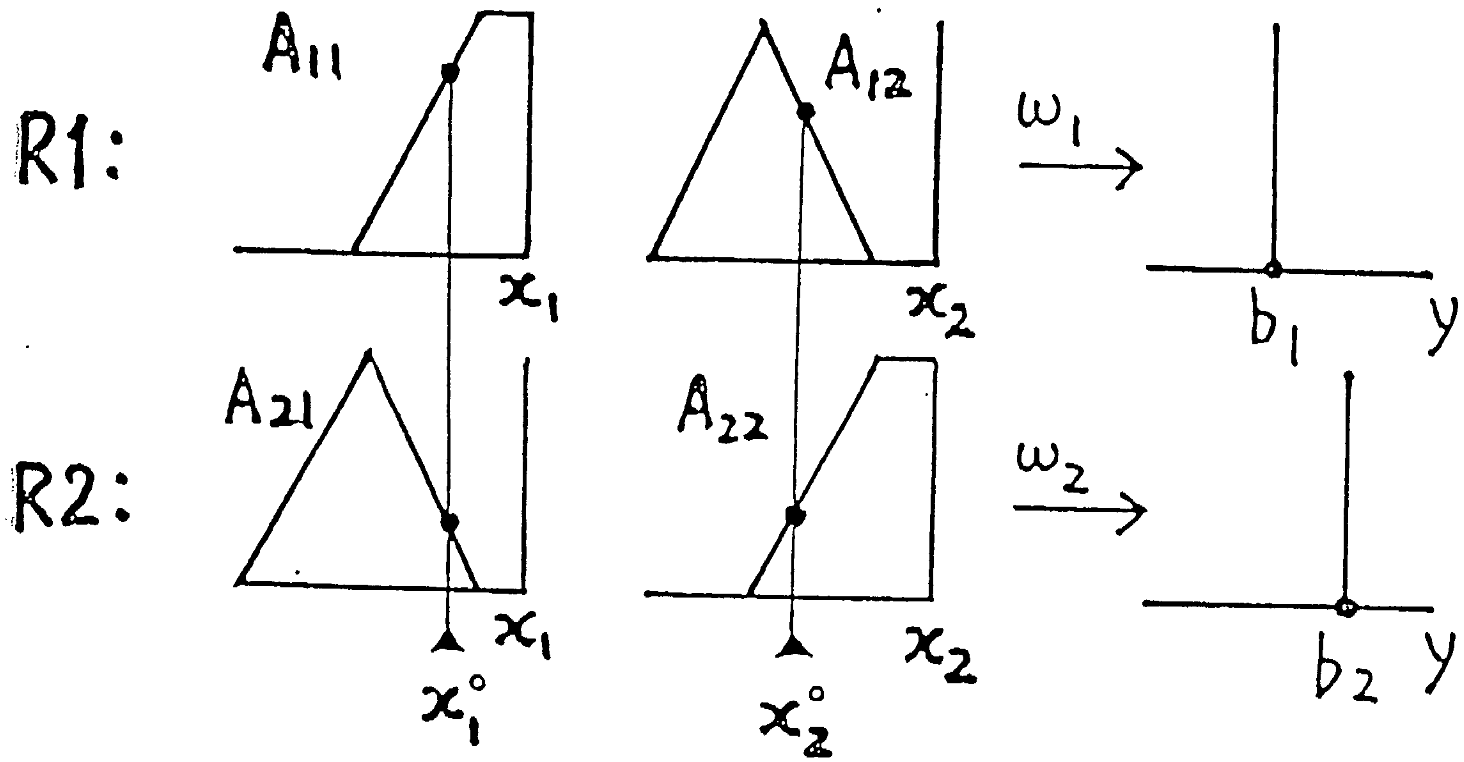


$$y^{o} = \frac{b_1 S_1 + b_2 S_2}{b_1 + b_2}$$

S_2 : area of B_2^*

b_2 : center of gravity of B_2

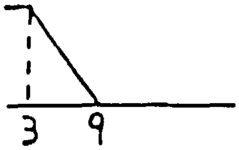
Fuzzy Control Rules with Singleton Consequents



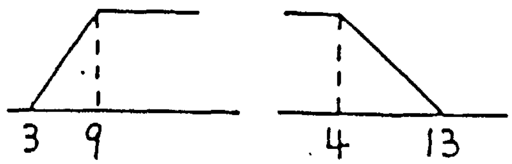
(1) $$y^0 = \frac{w_1 b_1 + w_2 b_2}{b_1 + b_2}$$

(2) $y^0 = b_i$ with the greatest compatibility w_i

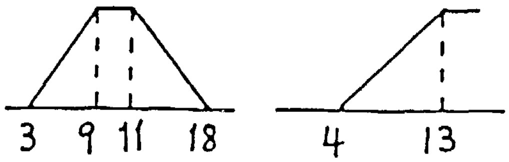
Fuzzy Control Rules with Functional Consequents

R1: 

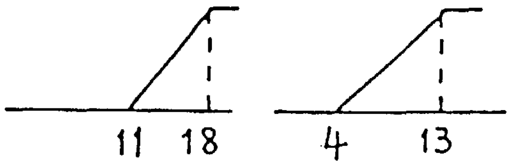
$\rightarrow y^1 = 1.0x_1 + 0.5x_2 + 1.$

R2: 

$\rightarrow y^2 = 0.1x_1 + 4.0x_2 + 1.$

R3: 

$\rightarrow y^3 = 0.9x_1 + 0.7x_2 + 9.$

R4: 

$\rightarrow y^4 = 0.2x_1 + 0.1x_2 + 0.2$

R^i: if x_1 is A_{i1} and x_2 is A_{i2} ⋯

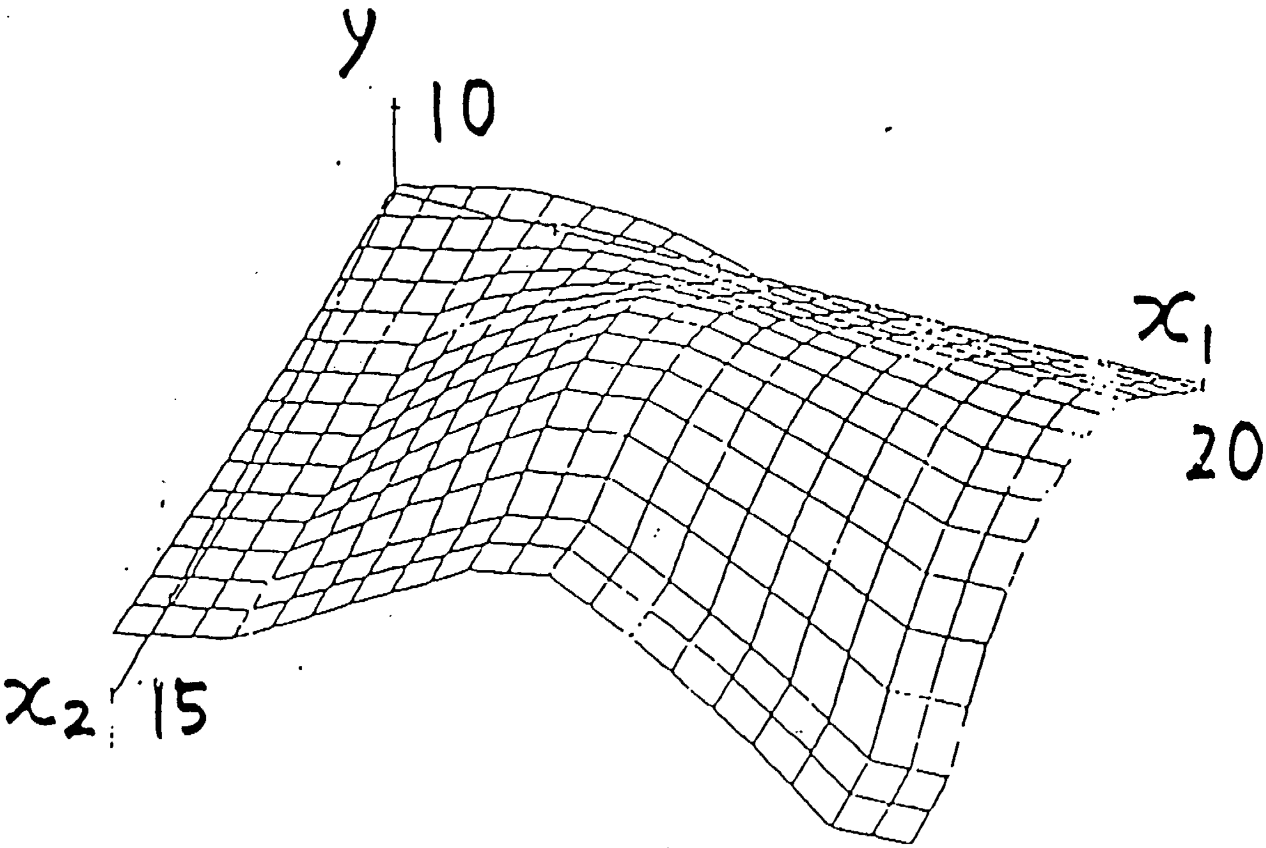
then $y^i = f^i(x_1, x_2, \cdots)$

$$w^i \triangleq \prod_j A_{ij}(x_j^0)$$

$$y^0 = \Sigma w^i y^i / \Sigma w^i$$

$$= \Sigma w^i f^i(x^0) / \Sigma w^i$$

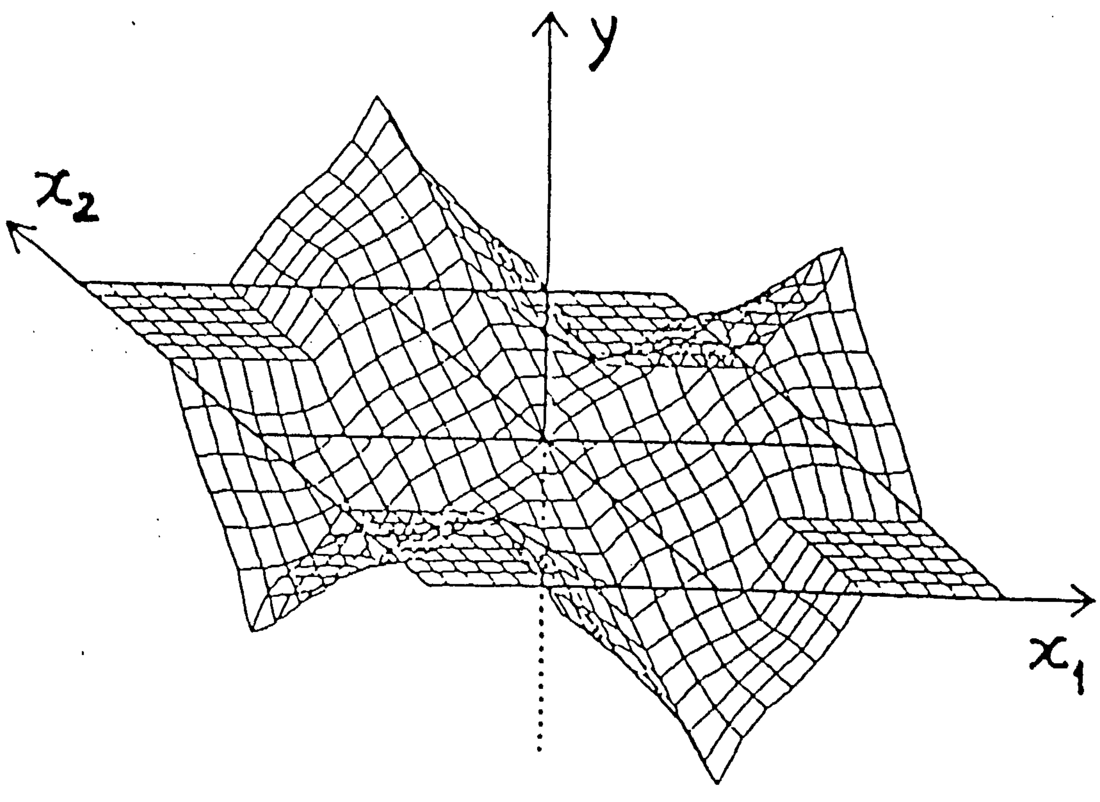
INPUT - OUTPUT RELATION

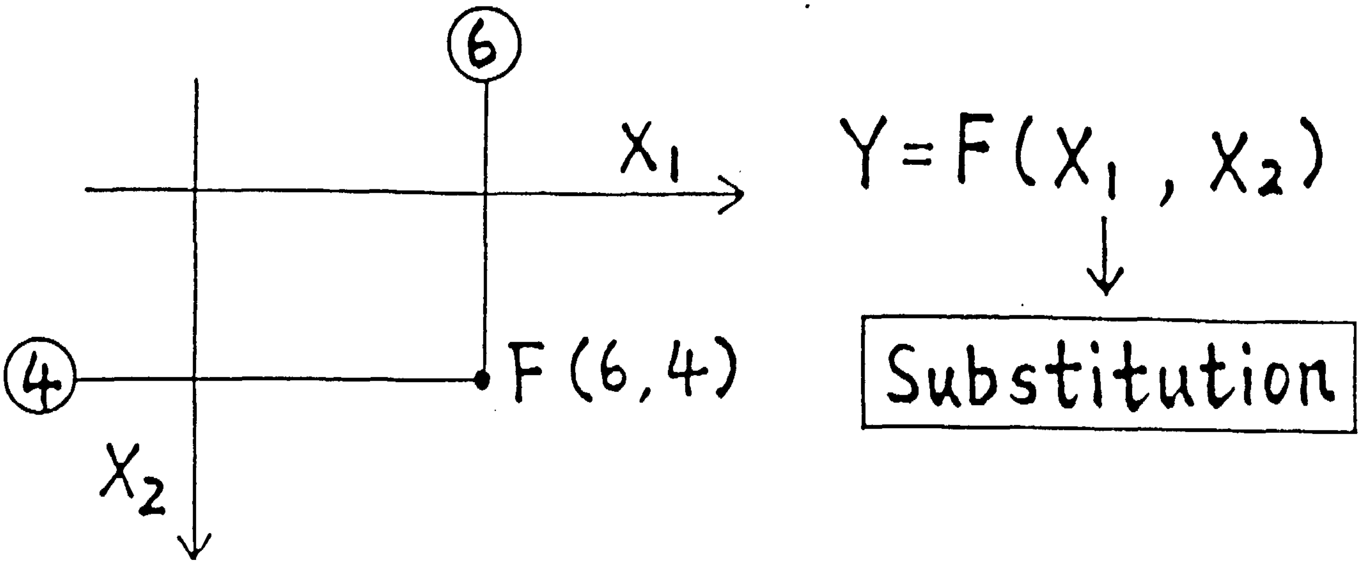


Characteristic of Fuzzy Rule Table

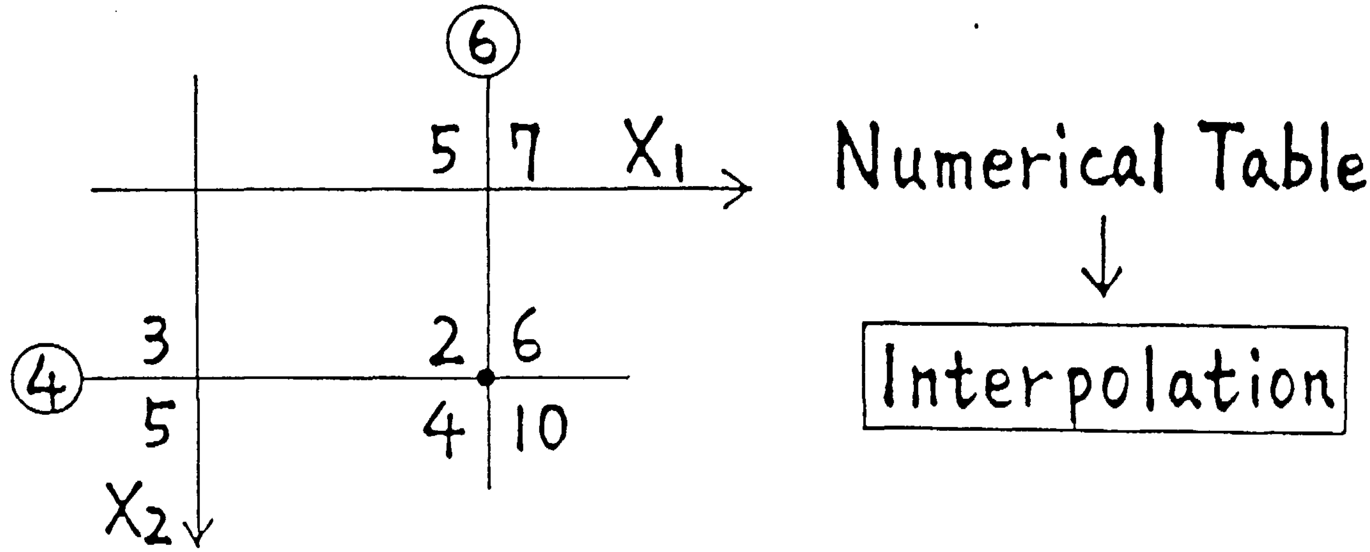
$$(x_1, x_2) \rightarrow y$$

x_1 \ x_2	NB	NM	NS	ZO	PS	PM	PB
NB				NB			
NM				NM			
NB				NS			
ZO	NB	NM	NS	ZO	PS	PM	PB
PS				PS			
PM				PM			
PM				PB			

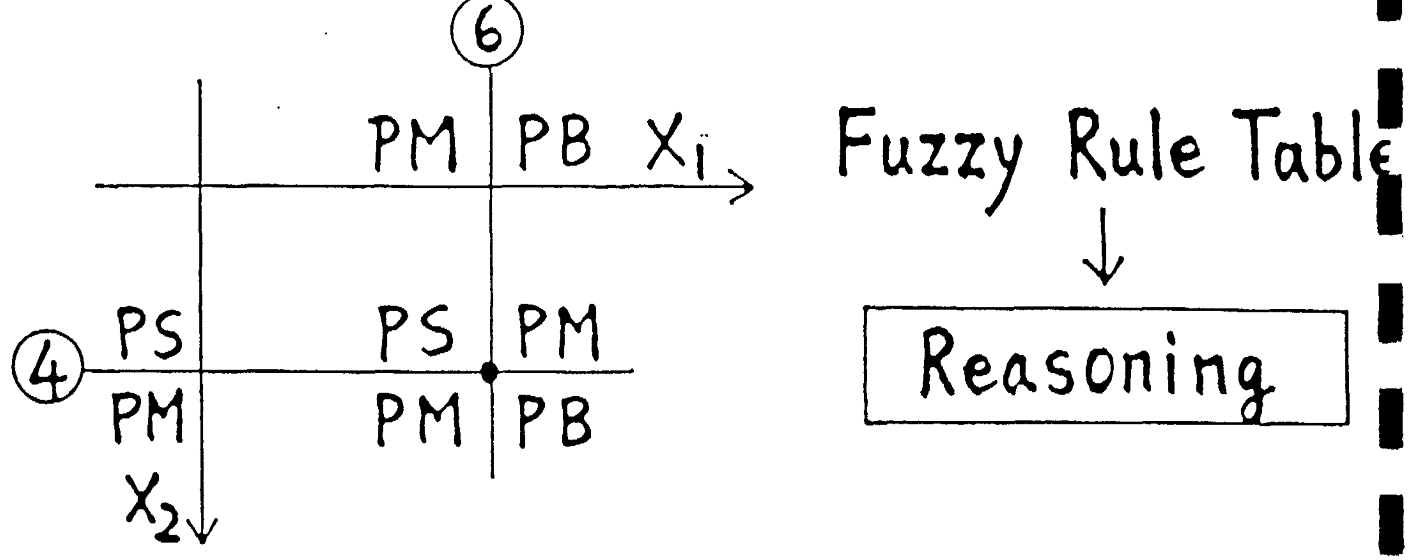




6
X1
4
F (6,4)
X2
Y = F (X1 , X2)
Substitution



6
5
7
X1
3
2
6
4
5
4
10
X2
Numerical Table
Interpolation



6
PM
PB
X1
PS
PS
PM
4
PM
PM
PB
X2
Fuzzy Rule Table
Reasoning

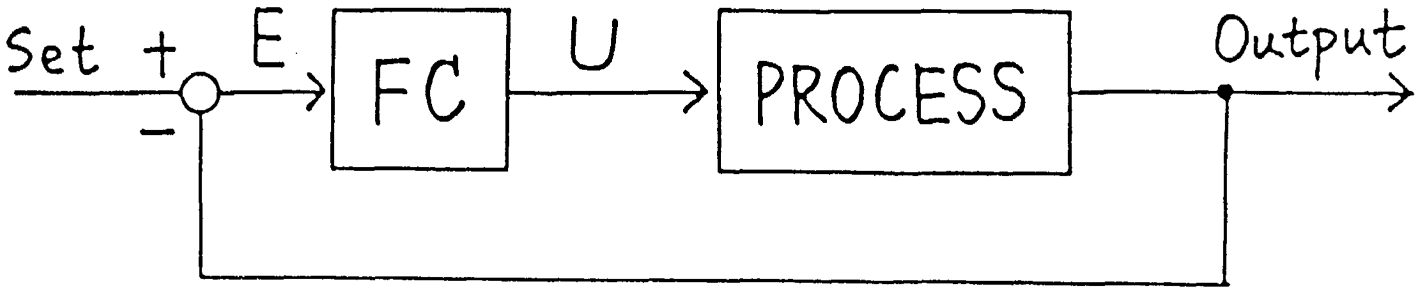
Design Elements in Fuzzy Control

1. Rule Format
2. Reasoning Method
3. Structure
   - 3.1 Premise Variables
   - 3.2 Fuzzy Partition of Premise Space
   - 3.3 Number of Rules
4. Parameter: Membership Function

Design of Fuzzy Controller

1) Operator's Experience
2) Control Engineer's Knowledge on Objective System
3) Use of Symulator/Experiment
4) Fuzzy Model of Operator's Control Actions
5) Fuzzy Model of Objective System

FUZZY CONTROL



FUZZY CONTROL RULE

E = Error, ΔE = Change of Error

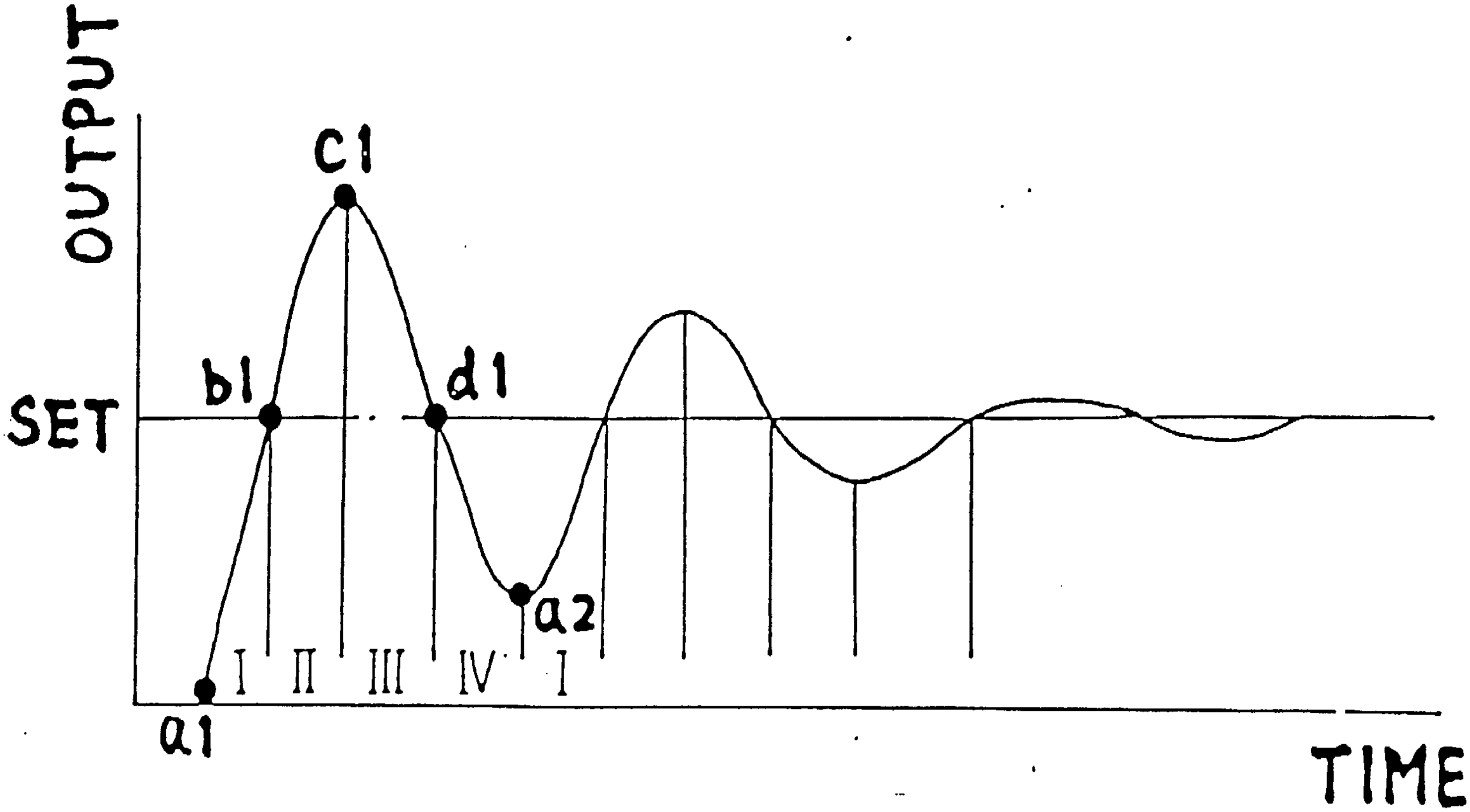
U = Control, ΔU = Change of Control

1) E = Negative Big, ΔE = Zero

→ ΔU = Positive Big

2) E = Negative Small, ΔE = Positive Medium

→ ΔU = Negative Small



a1) $E = NB, \ \Delta E = ZO \rightarrow \Delta U = PB$

b1) $E = ZO, \ \Delta E = PB \rightarrow \Delta U = NB$

c1) $E = PB, \ \Delta E = ZO \rightarrow \Delta U = NB$

d1) $E = ZO, \ \Delta E = NB \rightarrow \Delta U = PB$

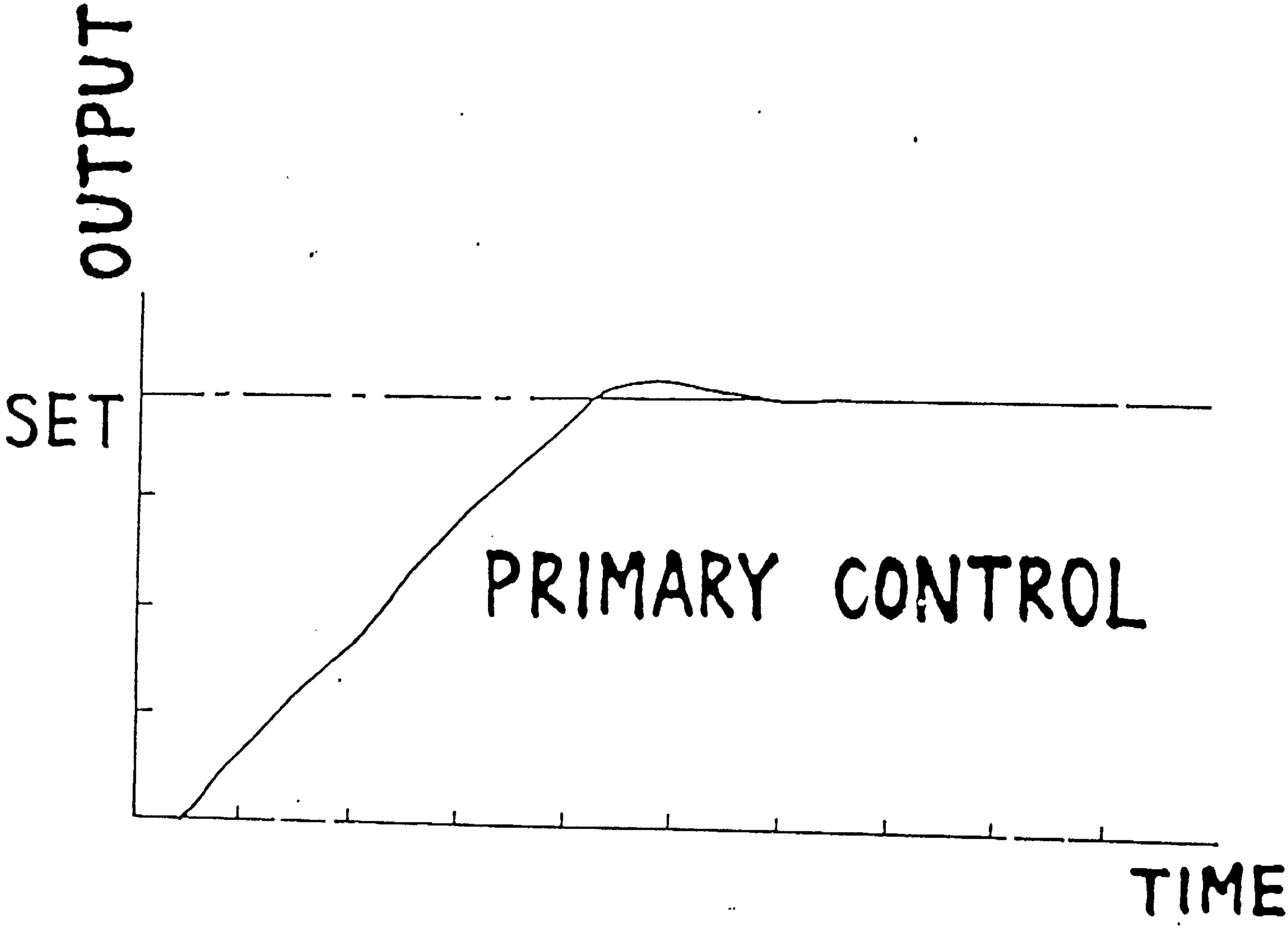
a2) $E = NM, \ \Delta E = ZO \rightarrow \Delta U = PM$

b2) $E = ZO, \ \Delta E = PM \rightarrow \Delta U = NM$

Primary Rule Table

		ΔE						
		NB	NM	NS	ZO	PS	PM	PB
	NB				PB			
	NM				PM			
	NS				PS			
E	ZO	PB	PM	PS	ZO	NS	NM	NB
	PS				NS			
	PM				NM			
	PB				NB			

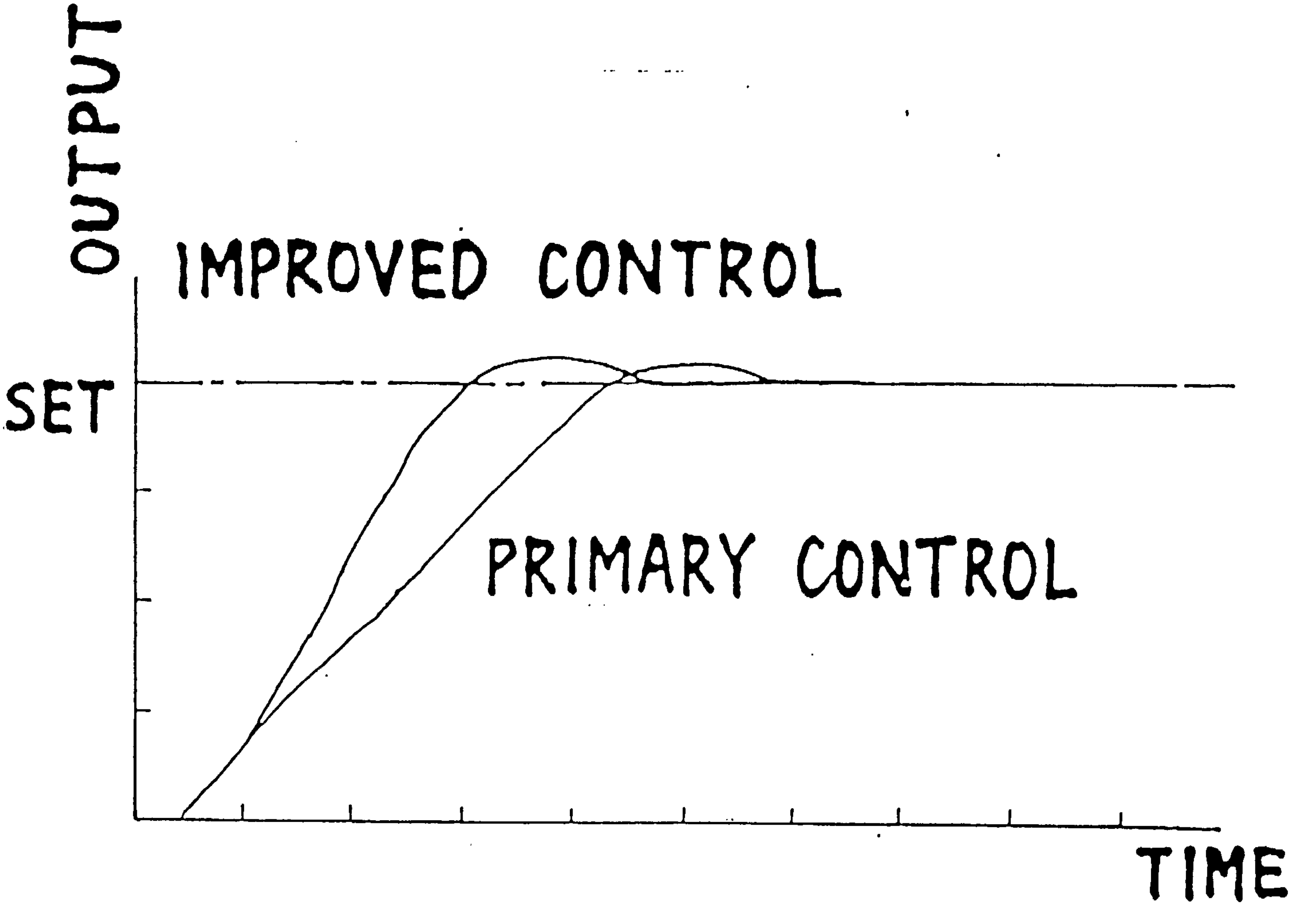
Results of fuzzy control



Improved Rule Table

E \ ΔE	NB	NM	NS	ZO	PS	PM	PB
NB				PB	PM		
NM				PM			
NS				PS	ZO		NM
ZO	PB	PM	PS	ZO	NS	NM	NB
PS	PM		ZO	NS			
PM				NM			
PB			NM	NB			

Results of fuzzy control



SUGENO'S METHOD

• i-th rule

R^i : IF X_1 is A_1^i AND ... AND X_J is A_J^i THEN Y is B^i, $(i=1,,,I)$,

(i) Position type reasoning method

• DETERMINATION OF SINGLETON CONSEQUENT FORM

R^i : if X_1 is A_1^i and ... and X_J is A_J^i then Y is b^i,

$(1 \le i \le I)$.

$$b^i = v_{fi} = \frac{\sum_{n=1}^{N} (h_{in})^w y_n}{\sum_{n=1}^{N} (h_{in})^w}$$

• Final estimation of the consequence

$$y = \frac{\sum_{i=1}^{I} h^i b^i}{\sum_{i=1}^{I} h^i}$$

where

$$h^i = h_{A_1^i}(x_1^0) \cdot \ldots \cdot h_{A_J^i}(x_J^0)$$

(ii) Position-Gradient type fuzzy model

$$R^{i}\ :\ if\ X_1\ is\ A_1^{i}\ and\ \dots\ and\ X_J\ is\ A_J^{i}\ then\ Y\ is\ b^{i}$$

$$and\ \frac{\partial Y}{\partial X_1} is\ c_1^{i}\ and\ \dots\ and\ \frac{\partial Y}{\partial X_j}\ is\ c_J^{i}$$

$$(1 \le i \le I)$$

•Final estimation of the consequence

$$y = \frac{\sum_{i=1}^{I} \{\psi(n,i)\cdot(b^{i} + \sum_{j=1}^{J}(d_j(i,n)\cdot c_j^{i})\}}{\sum_{i=1}^{I}\psi(n,i)}$$

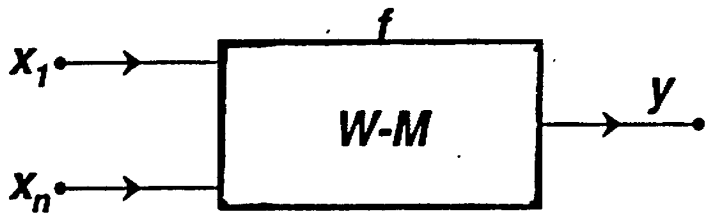
where

$$\psi(n,i) = \exp\{-D(n,i)\}$$

$$D(n,i) = \min_{\lambda} \sqrt{\sum_{j=1}^{J}(x_j^0 - x_j^{ic})^2}\ ;\ x_j^{ic} \in \{x_j \mid h_{A_j^i}(x_j) = 1, x_j \in X_j\}\ ,$$

UNIVERSAL APPROXIMATOR

Wang-Mendel n-input one-output approximator



$$x = (x_1, \ldots, x_n) \quad , \quad y = f(x)$$

$$f(x) = \frac{\Sigma_{i=1}^{K} \bar{y}^i m^i}{\Sigma_{i=1}^{K} m^i} = \frac{\Sigma_{i=1}^{K} \bar{y}^i \Pi_{1 \le j \le n}[m_j^i(x_j)]}{\Sigma_{i=1}^{K} \Pi_{1 \le j \le n}[m_j^i(x_j)]}$$

$$m^i = \Pi_{1 \le j \le n}[m_j^i(x_j)]$$

= **degree of match for i-th rule**

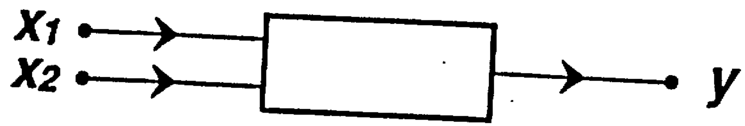
$\bar{y}^i$ = **center of output for i-th rule**

theorem

> ***f is capable of approximating to any desired accuracy any real continuous function from a compact set***
> $Q = [a_1, b_1] \times \cdots \times [a_n, b_n] \subset R^n$
> ***to the real line R***

INDUCTION OF FUZZY RULES FROM NUMERICAL OBSERVATIONS

Wang-Mendel approach



• problem : given m input-output pairs

$$(x_1^{(1)}, x_2^{(1)}, y^{(1)}), (x_1^{(2)}, x_2^{(2)}, y^{(2)}), \ldots$$

derive n fuzzy if-then rules of the form

$$Y \text{ is } B_l \text{ if } (X_1 \text{ is } A_{l1} \text{ and } X_2 \text{ is } A_{l2})$$

• algorithm.

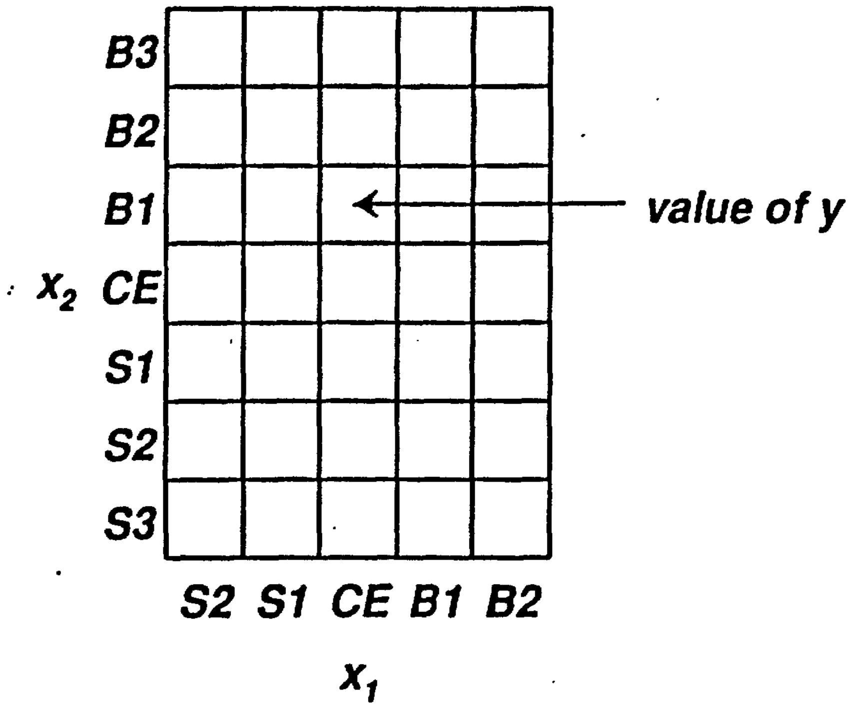
1. Treat x_1, x_2, y as linguistic variables with 2N+1 values

SN, ..., S1, CE, B1, ..., BN
(SN ← small, CE ← center, BN ← big)

N, SN, ..., S1, CE, B1, ..., BN are variable dependent

WANG-MENDEL ALGORITHM

2. ***Set up a FAM (fuzzy associative memory) bank for fuzzy if-then rules***

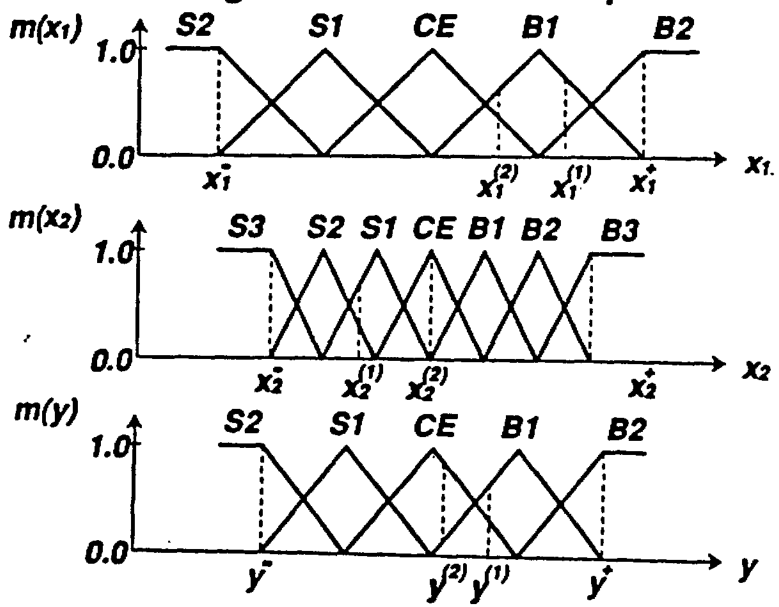


$$y \text{ is } B_3 \text{ if } x_1 \text{ is } CE \text{ and } x_2 \text{ is } B_1$$

WANG-MENDEL ALGORITHM

3. generate fuzzy rules

given an input-output pair $(x_1^{(1)}, x_2^{(1)}; y^{(1)})$
assign the pair to a cell in FAM with maximal grades of membership



$x_1^{(1)}$ is assigned to B1
$x_2^{(1)}$ is assigned to S1
$y^{(1)}$ is assigned to CE
induced rule :

y is CE if x_1 is B_1 and x_2 is S_1

WANG-MENDEL ALGORITHM

4. **assign a degree to each rule**

$(x_1^{(1)}, x_2^{(1)}; y^{(1)}) \rightarrow$ y is CE if x_1 is B_1 and x_2 is S_1

$$D(rule) = m_{B1}(x_1^{(1)})m_{S1}(x_2^{(1)})m_{CE}(y^{(1)})m^{(1)}$$

↑ degree ↑ goodness of data pair

conflict resolution

if there is a conflict in consequents, choose the rule which has the highest degree

5. **use weighted centroid defuzzification**

for jth rule

$$m_{O^j}^{j} = m_{I_1^j}(x_1)m_{I_2^j}(x_2)$$

↑ output ↑ input

$\bar{y}_j =$ centroid of jth rule

WANG-MENDEL ALGORITHM

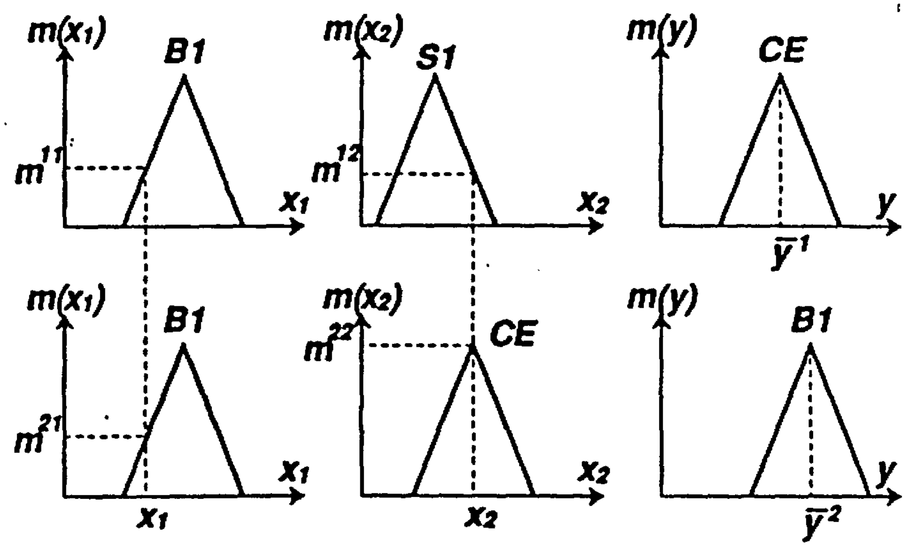
output

$$y = \frac{\sum_{j=1}^{k} m_{b^j}^{j} \bar{y}^j}{\sum_{j=1}^{k} m_{b^j}^{j}}$$

- *example*

rule 1 : y is CE if x_1 is B_1 and x_2 is S_1

rule 2 : y is $B1$ if x_1 is B_1 and x_2 is CE



$$y = \frac{m_{CE}^{1}\bar{y}^1 + m_{B1}^{2}\bar{y}^2}{m_{CE}^{1} + m_{B1}^{2}} \qquad m_{CE}^{1} = m^{11}m^{12} \qquad m_{B1}^{2} = m^{21}m^{22}$$

(iii)TURKSEN'S IVAAR

Characteristic feature of AAR

1)***Similarity measures and/or subsethood measures*** are used for ***pattern matching*** between rules and their observations to determine the rules to be fired.

2)And Approximate reasoning is carried out through the ***modification of each rule consequent*** by pattern matching measures without CRI.

AAR with point-valued fuzzy sets(PVAAR)

Generally, the final consequence derived through PVAAR, as, the aggregation of modified original consequent of each rule which is defined as follows:

$$h_{B'}(y) = \biguplus_{i} f(h_{B^i}(y), SM^i)$$

where f is the modification function which gives the "Expansion" modification or "Reduction" modification of $h_{B^i}(y)$, and SM^i is a similarity measure of i-th rule between antecedents and observations.

Selection of f and SM^i has wide flexibility.

If we chose f="$\wedge$", and

$$SM^i[A', A^i] = \bigwedge_{j=1}^{J} \sup_{x_j}(h_{A'_j}(x_j) \wedge h_{A^i_j}(x_j)) \quad ,$$

and $\uplus$=" $\bigvee_{i=1}^{I}$ ", then it is the equivalent form to MCRI

With the values of SM, the rules which satisfy the following conditions are fired.

$$\tau < SM^i$$

where τ is an appropriate threshold.

There are two types of modification which which were proposed by Turksen, namely:

1)Expansion form:

$$h_{B_{ex}^{i}}=\min\left(1,\frac{h_{B^{i}}}{SM^{i}}\right)$$

2)Reduction form:

$$h_{B_{re}^{i}}=SM^{i}\cdot h_{B^{i}}$$

AAR with interval-valued fuzzy set(IVAAR)

A similarity measure between antecedents and observations is calculated for both the upper bound and the lower bounds as follows:

$$SM^{iL} = SM[L^{i}_{AND}(J),\ L'_{AND}(J)]$$

$$SM^{iU} = SM[U^{i}_{AND}(J),\ U'_{AND}(J)]$$

where SM is a similarity measure defined with a Disconsistency measure, S, as a distance measure. That can be defined generally:

$$SM[A,B] = 1 - S[A,B] = \sup_{x \in X} h_{A \cap B}(x),\quad A, B \in X\ .$$

TABLE II. Specification of Model Variables and Rules*

	Number of variables	Number of rules
EXAMPLE(a)	2	6
EXAMPLE(b)	2	5
EXAMPLE(c)	3	4

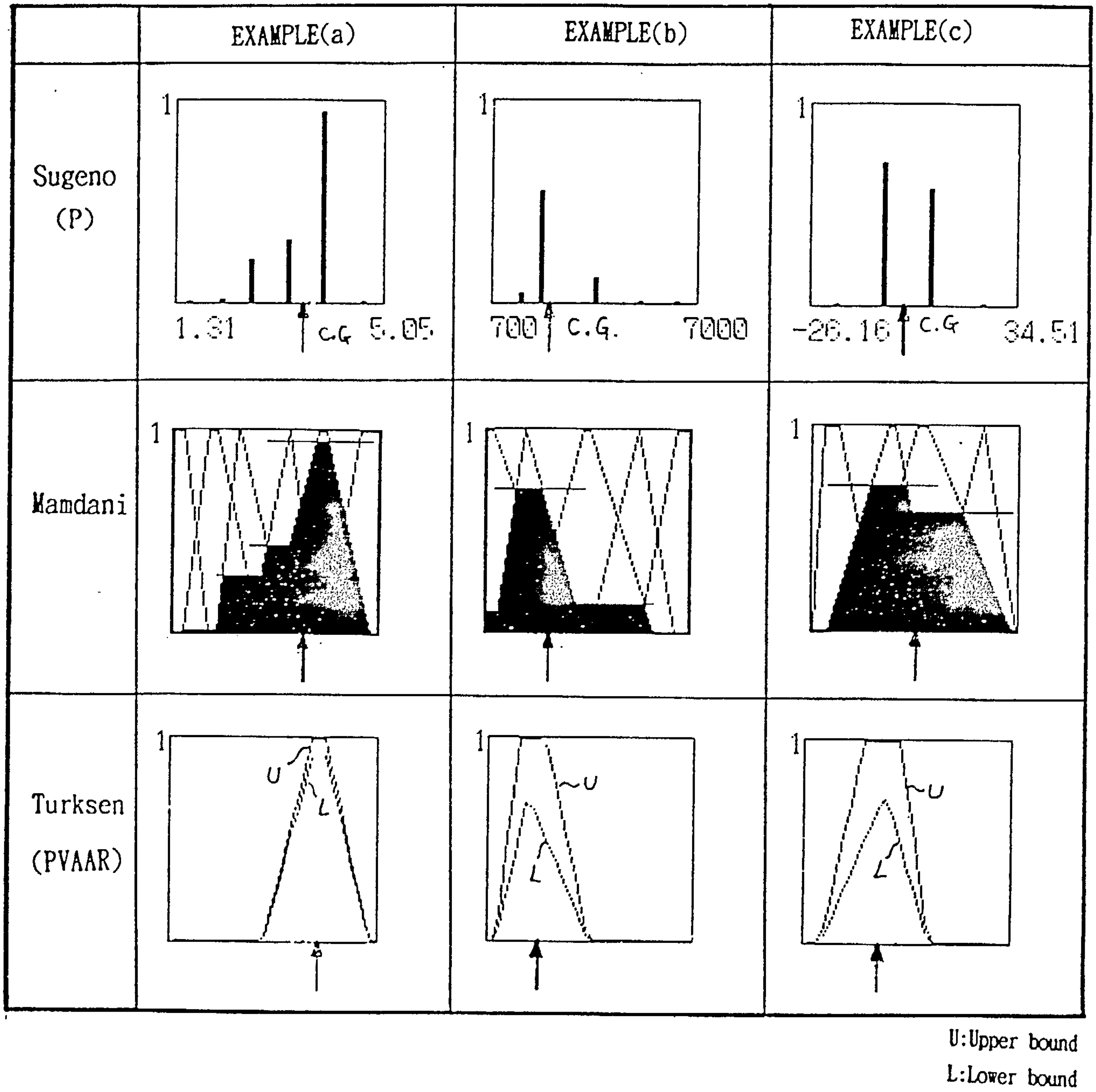
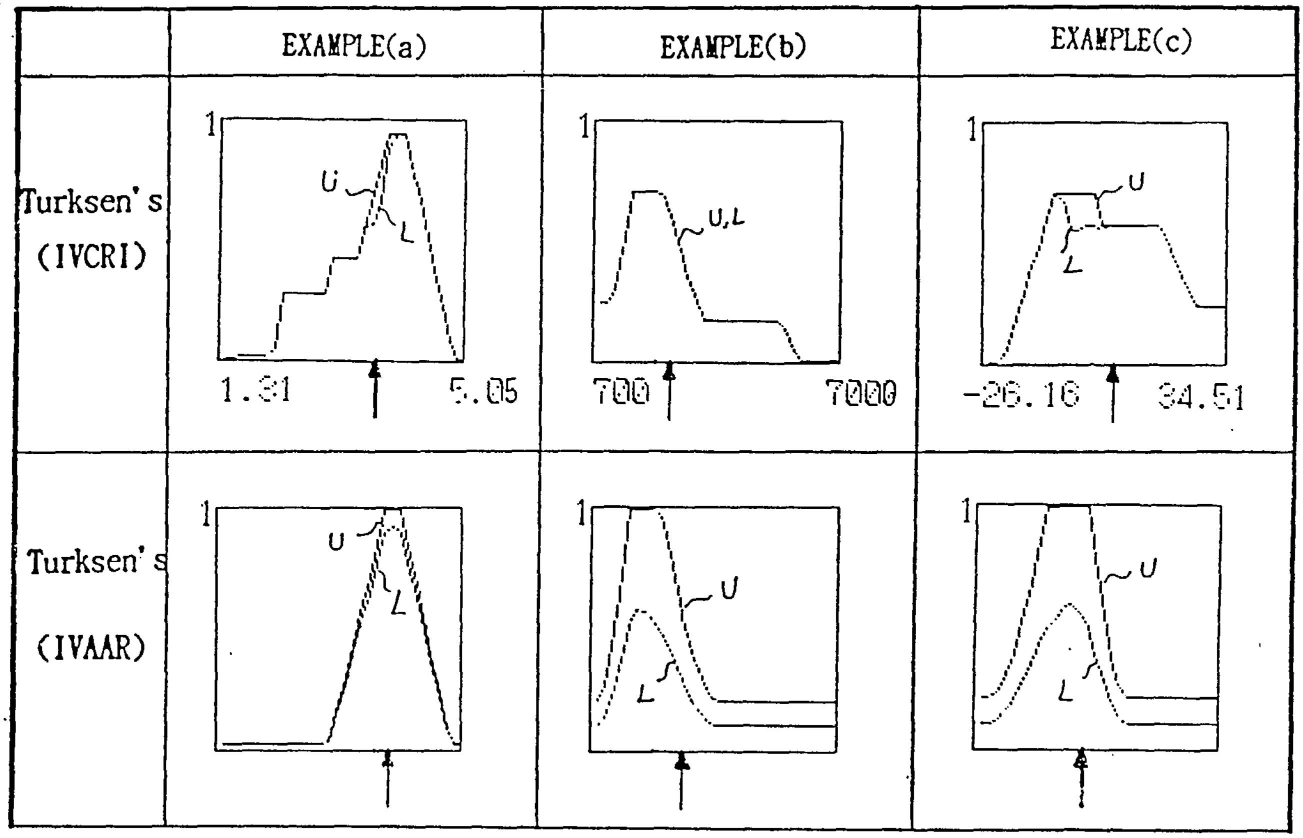


Fig. 3(a) Examples of consequences by Point-Valued reasoning methods



U:Upper bound
L:Lower bound

Fig. 3(b) Examples of consequences by Interval-Valued reasoning methods

TABLE 2

PREDICTION ACCURACY FOR COMPARISON AMONGST DIFFERENT APPROACHES

	Sugeno' (P&P-G)	Sugeno' (P)	Sugeno' (P-G)	Mamdani'	Turksen' (IVCRI)	Turksen' (IVAAR)	Proposed (ILFSI)
G1	19/25 =76%	18/25 =72%	20/25 =80%	18/25 =72%	21/25 =84%	14/25 =56%	84%
G2	34/35 =97%	34/35 =97%	29/35 =83%	34/35 =97%	32/35 =91%	33/35 =94%	97%
G3	42/50 =84%	41/50 =82%	40/50 =80%	41/50 =82%	39/50 =78%	43/50 =86%	84%

Package available - job shop scheduler. "Better than Mark Fox constraint based system."

FLES – Fuzzy Logic Expert System Scheduler

Main Menu

[1] Part Route Information
[2] Order Information
[3] Schedule Generation
[4] Knowledge Base
[5] Reports and Statistics
[6] Order Generation

ENTER: Select   Esc: Exit

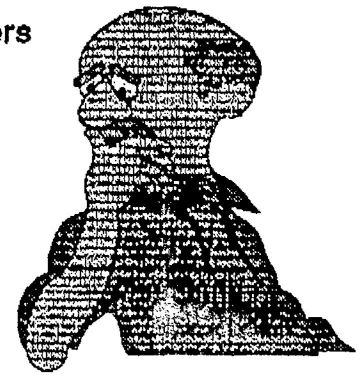
What is the Problem ?

Customer Orders

Due Dates

WIP

Down-Up M/C



Meet Due dates

Reduce Cycle Time

Reduce WIP

Reduce Cost

Step 1: Define Linguistic Variables

what are the lot variables in a fab ?

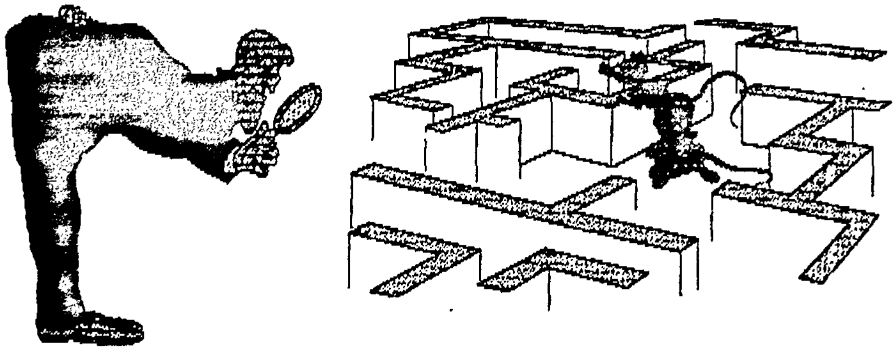
- priority of a lot (hot lot)
- slack time (due date - work left)
- earliest start date (input parts)
- remaining processing time

Step 2: Use Linguistic Values

quantify variables using linguistic values

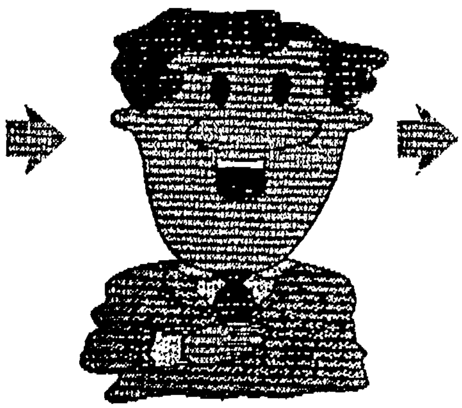
- Very Low (VL)
- Low (L)
- Somewhat Low (SL)
- Medium (M)
- Somewhat High (SH)
- High (H)
- Very High (VH)

Step 3: Rule Selection - Pattern Matching



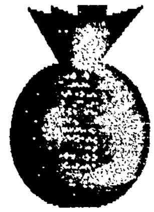
pattern matching by similarity measures

Step 4: Inferencing

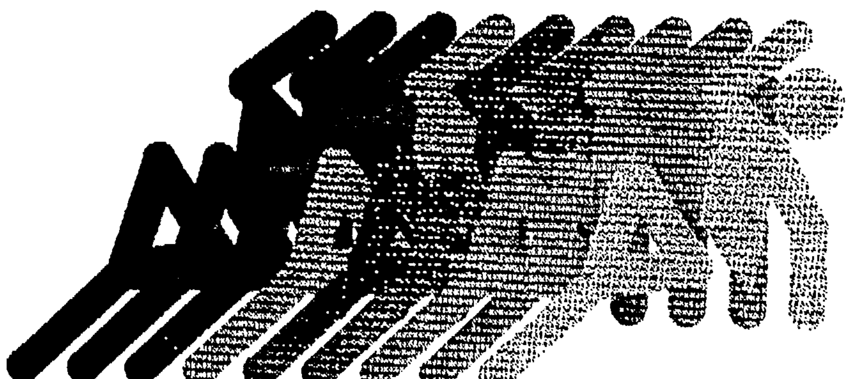
Observation  Expert Advice

FLES versus Well-known Dispatching Rules

- shorter cycle times
- less tardy jobs
- less WIP
- no more overloaded systems
- self-learning decision engine



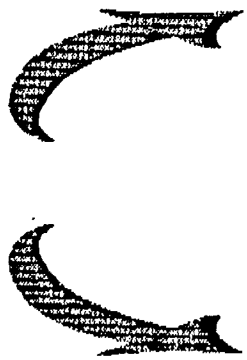
Software Demo



FLES

How Does FLES Work ?

Step 1 : User Input > Observed System State



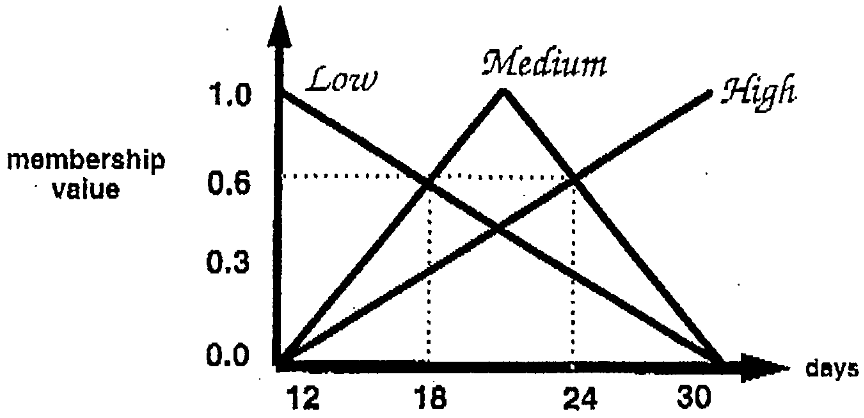
priority, slack time,
earliest start date → job release

priority, slack time,
remaining processing time → job dispatch

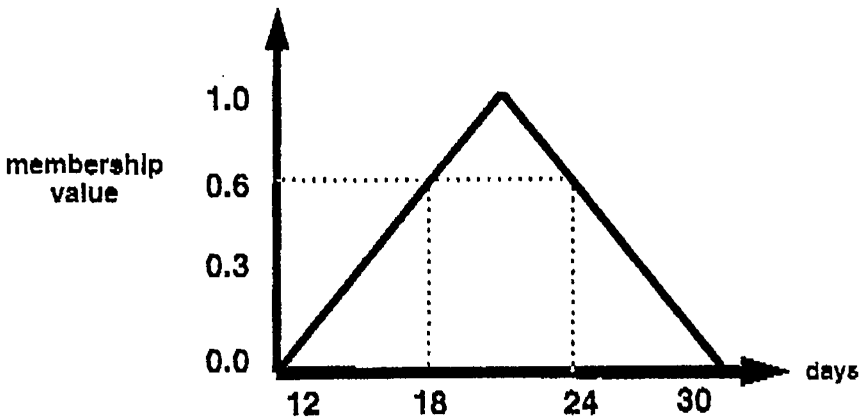
Step 2: Fuzzify User Input

10 days of due date	*High* Due Date
Priority 1 lot	*Very High* Priority
2 days of slack time	*Medium* Slack Time
1.5 days of work left	*Low* Remaining Time
Can start after 2 days	*Somewhat Low* Earliest Start Date

Step 3: Define Fuzzy Sets



cycle time with fuzzy sets



medium cycle time

Step 4: Construct the Rule Base

expert's knowledge is specified in the form of production rules

IF premise THEN conclusion

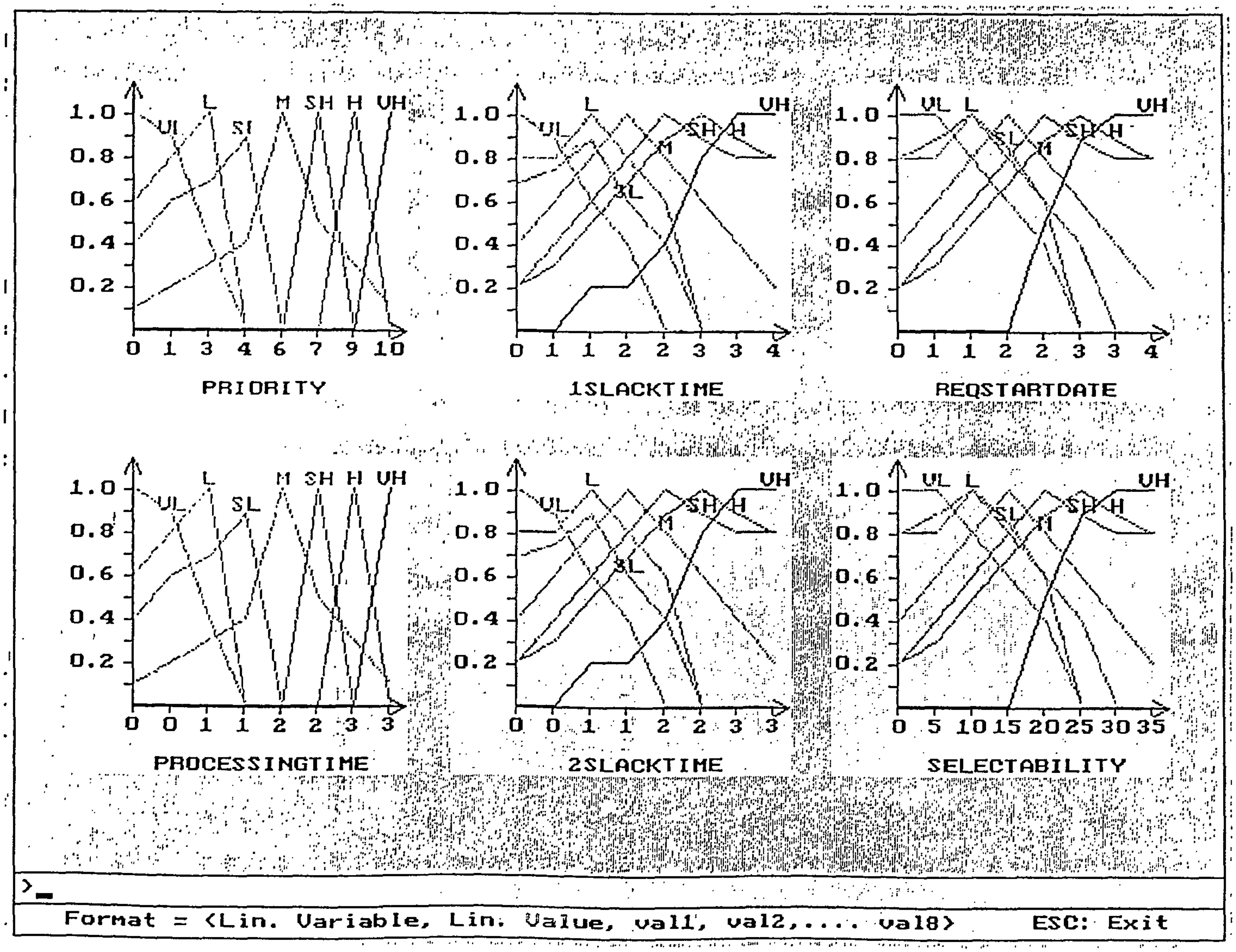
Rule Base in FLES

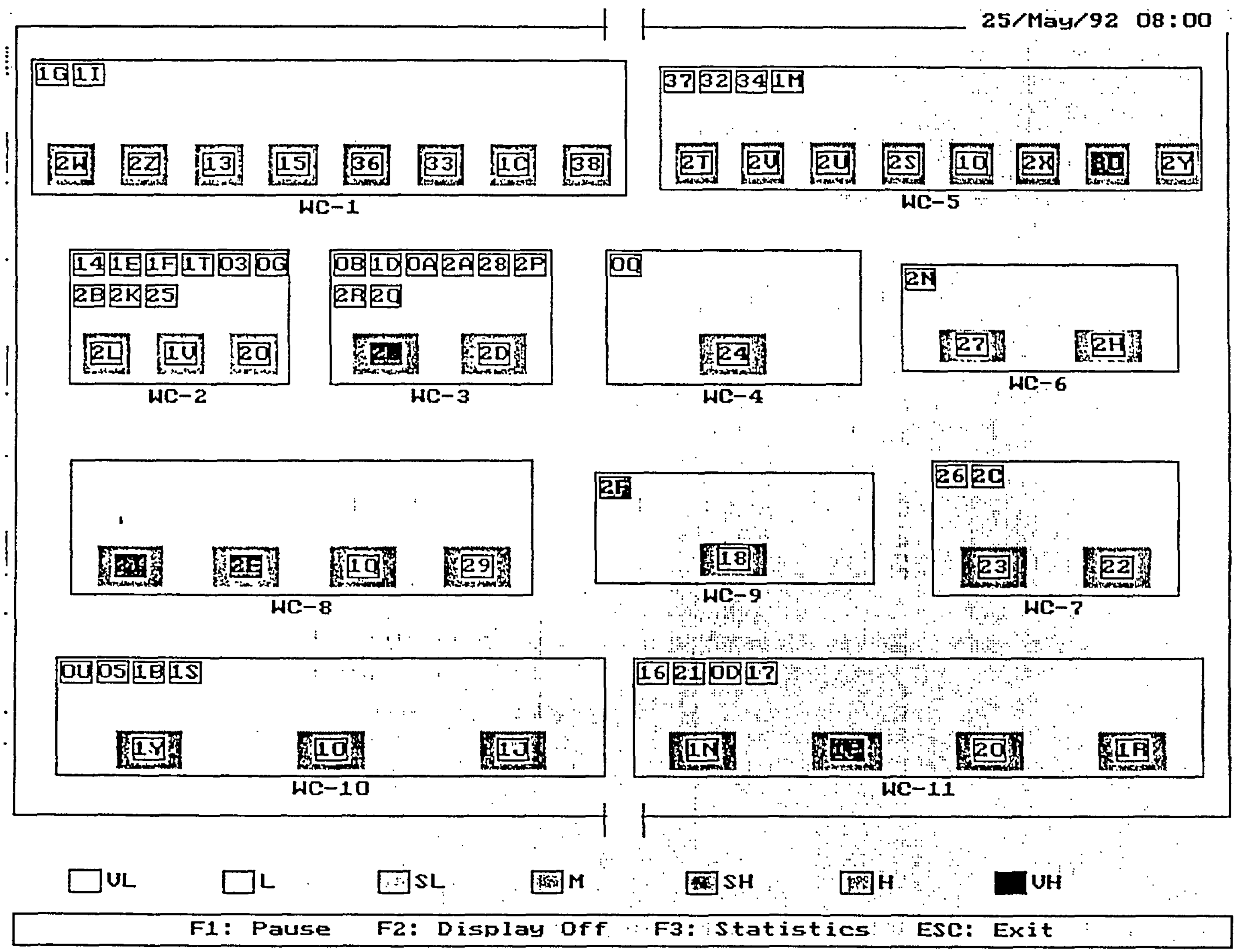
IF priority is high *AND* slack time is low *AND* due date is low

THEN selectability of the lot for releasing is high

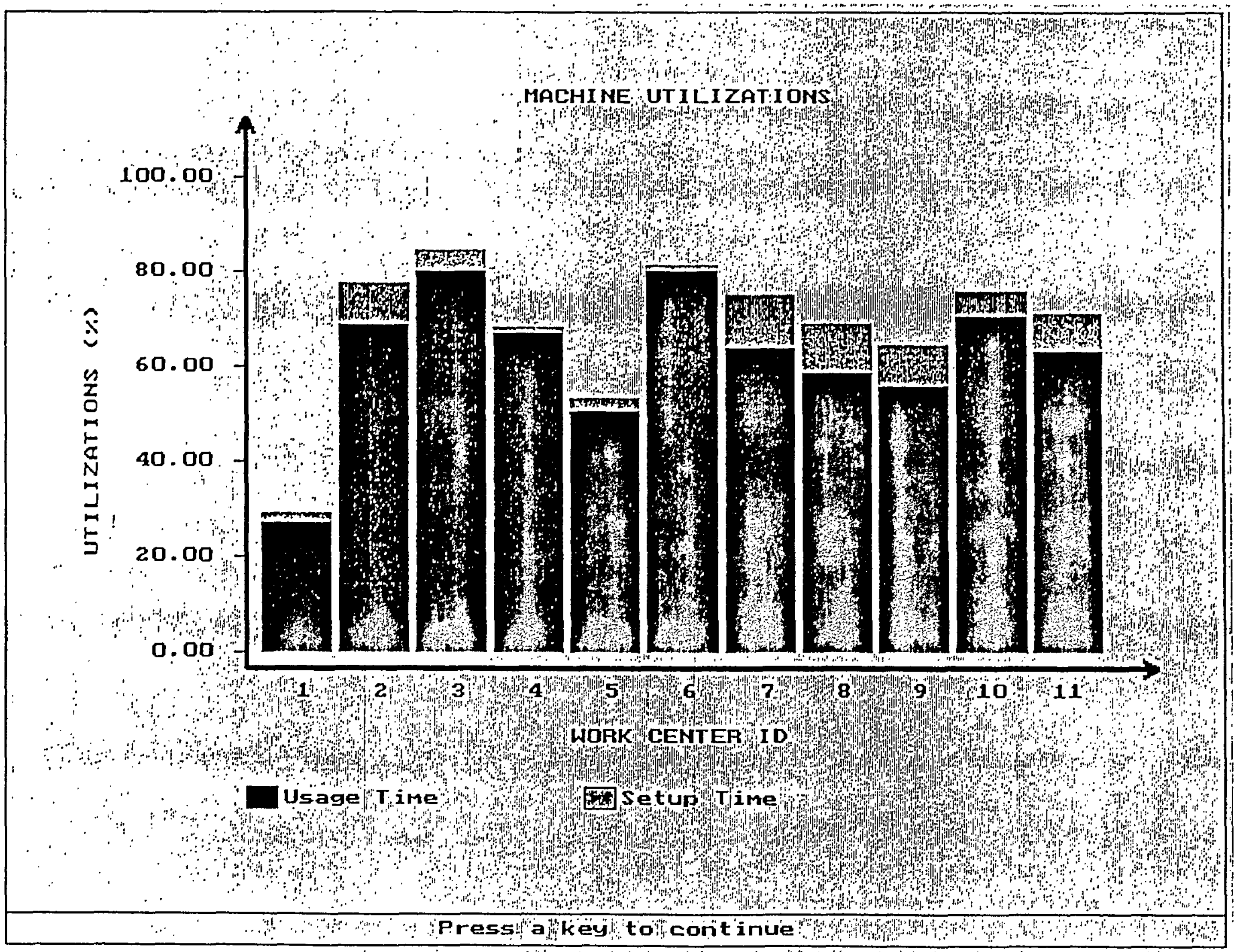
IF priority is low *AND* slack time is high *AND* remaining processing time is low

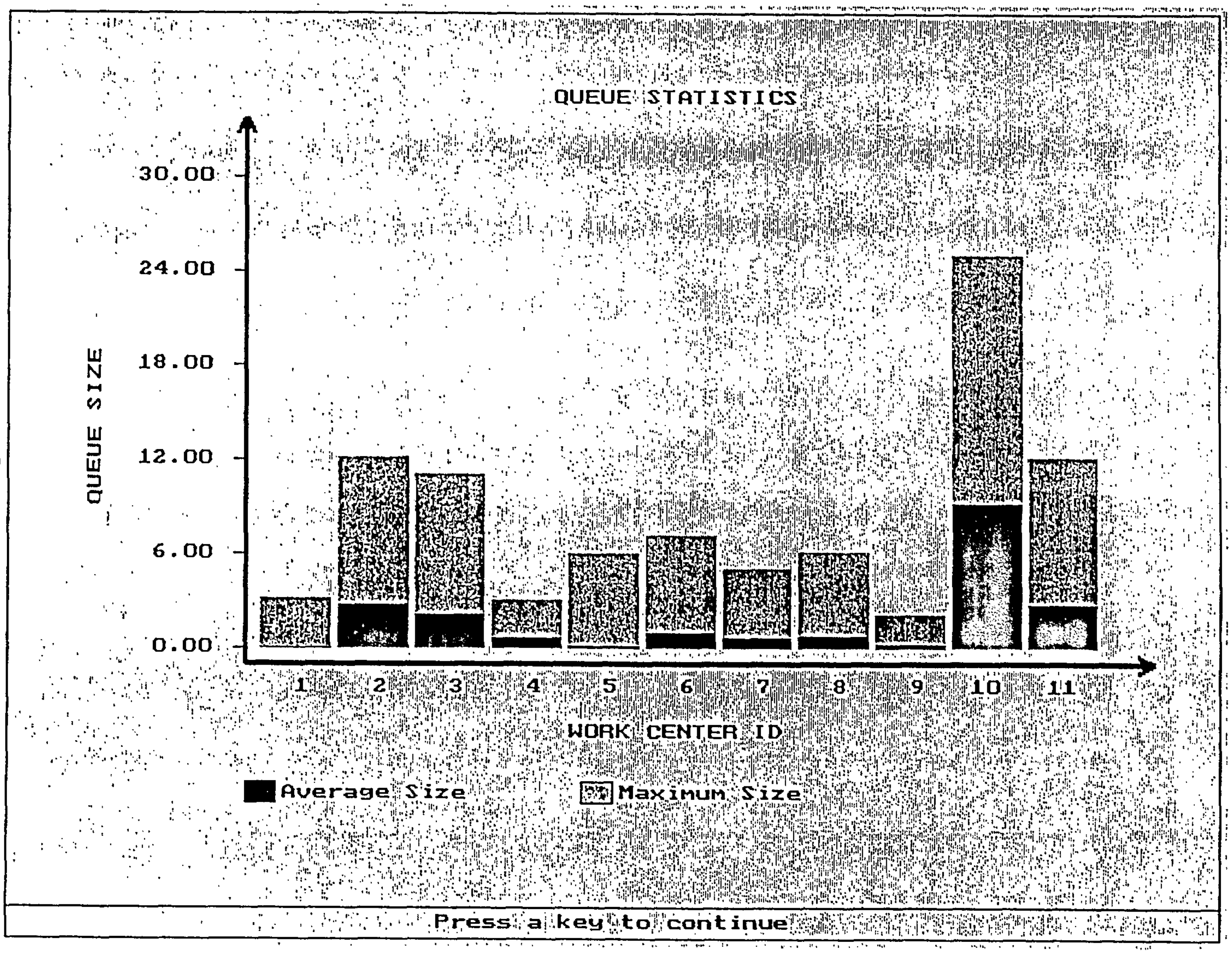
THEN selectability of lot for next dispatching is low

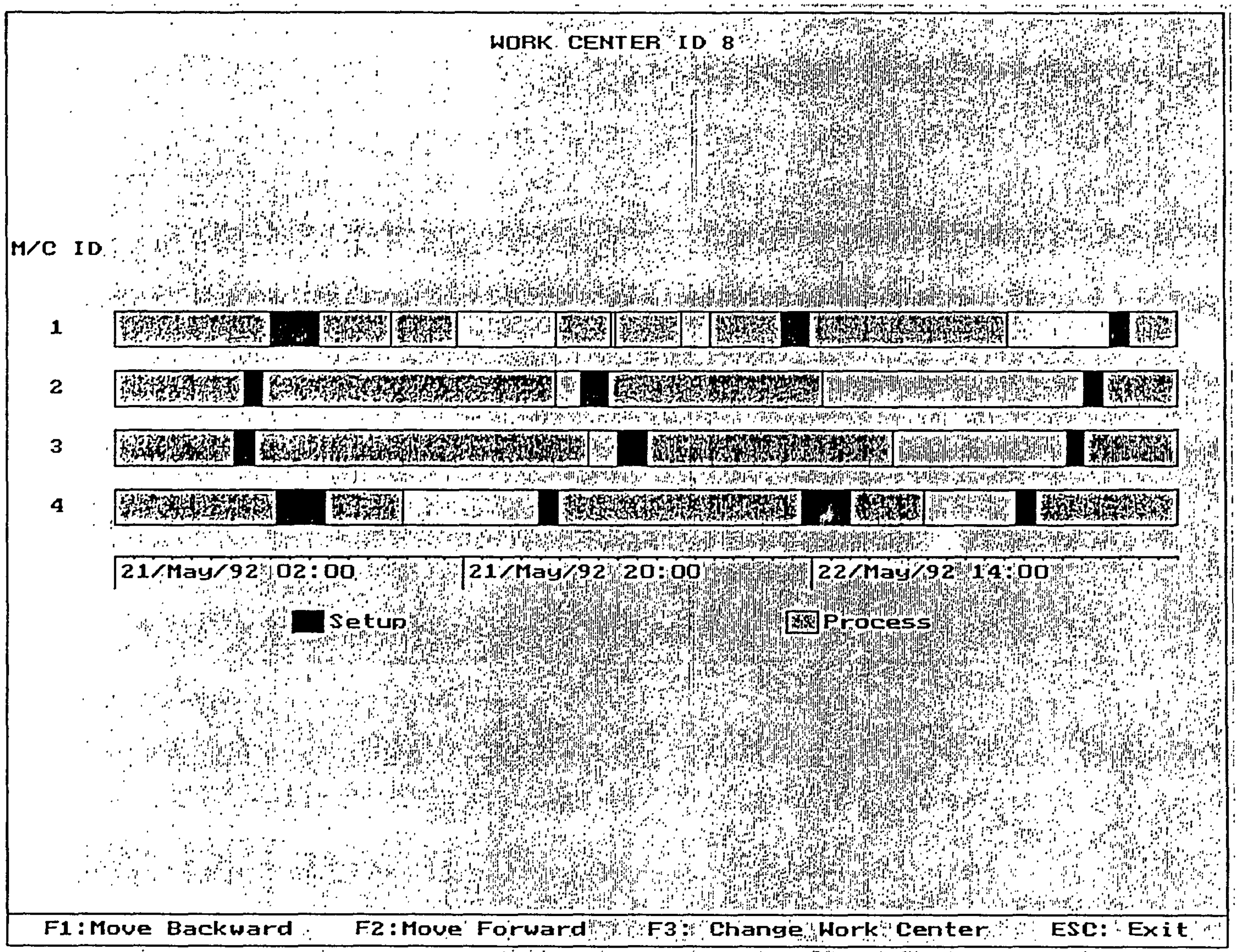

PRIORITY
1SLACKTIME
REQSTARTDATE
PROCESSINGTIME
2SLACKTIME
SELECTABILITY
VL L SL M SH H VH
1.0 0.8 0.6 0.4 0.2
0 1 3 4 6 7 9 10
0 1 1 2 2 3 3 4
0 5 10 15 20 25 30 35
>
Format = <Lin. Variable, Lin. Value, val1, val2,.... val8>
ESC: Exit



25/May/92 08:00
WC-1
WC-5
WC-2
WC-3
WC-4
WC-6
WC-8
WC-9
WC-7
WC-10
WC-11
VL
L
SL
M
SH
H
VH
F1: Pause
F2: Display Off
F3: Statistics
ESC: Exit


MACHINE UTILIZATIONS
UTILIZATIONS (%)
100.00
80.00
60.00
40.00
20.00
0.00
1
2
3
4
5
6
7
8
9
10
11
WORK CENTER ID
Usage Time
Setup Time
Press a key to continue


QUEUE STATISTICS
QUEUE SIZE
30.00
24.00
18.00
12.00
6.00
0.00
1
2
3
4
5
6
7
8
9
10
11
WORK CENTER ID
Average Size
Maximum Size
Press a key to continue

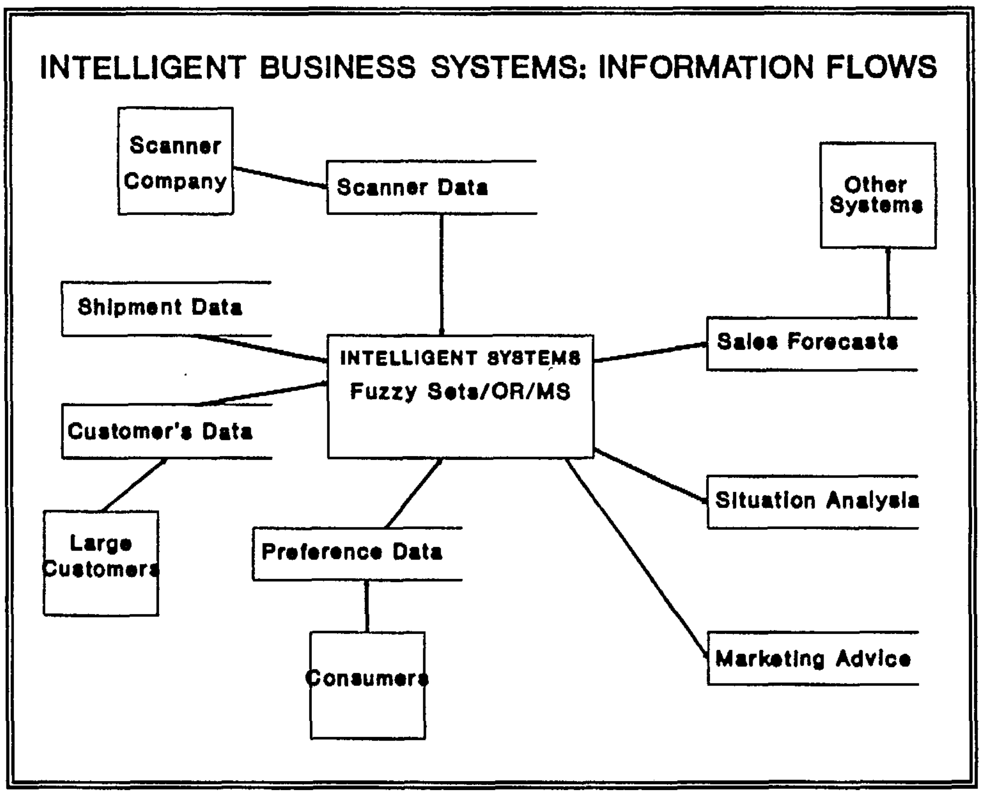

WORK CENTER ID 8
M/C ID
1
2
3
4
21/May/92 02:00
21/May/92 20:00
22/May/92 14:00
Setup
Process
F1:Move Backward
F2:Move Forward
F3: Change Work Center
ESC: Exit

INTELLIGENT BUSINESS SYSTEMS

- Integrate fuzzy set expert systems, conventional expert systems and OR/Management Science models as needed

- Preference data from consumers can combined with scanner, shipment and customer data

- Market share estimates continually update other systems, such as distribution and production scheduling



CONSUMER PREFERENCE MODELS

CONSUMERS:

- Use linguistic ratings ("very good")

- Often use linguistic attributes ("roomy interior" for car instead of 95 cu. feet)

- Differ as to salient attributes, attribute values and the meaning of linguistic ratings

- Provide meaningful ratings for only a small number of individually adjusted product profiles

PREFERENCE MODELS:

- Must accurately represent ratings in the model

- Must allow individual variations in attributes, attribute values and rating definitions

- Should be easily implemented with a small number of profile ratings using automated data collection software

- High predictive validity and accurate market share estimation for product design and market segmentation

PREFERENCE MODELS

LINGUISTIC PREFERENCE MODEL:

$$\mu_{B'}(y_j, m) = \sum_{I=1}^{T} \frac{w_i}{\sum_{K=1}^{T} w_k} \times \mu_{A_i}(x_j, m)$$

Where:

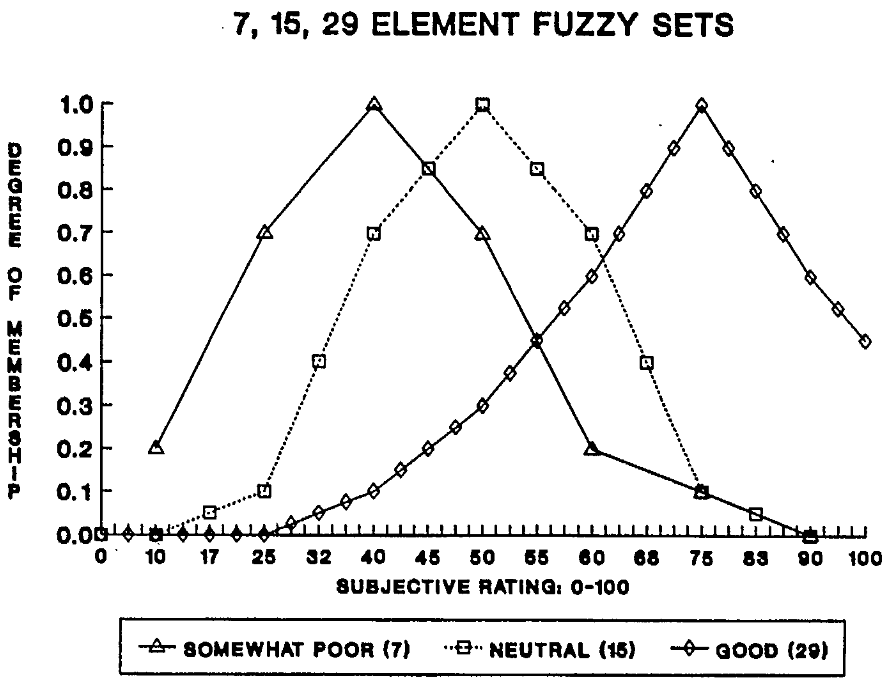
- μ is the fuzzy set membership function for A, B, B'
- A_i is the linguistic rating for the *ith* attribute
- B_i , B'_i are the actual and predicted overall ratings
- m is a holdout product profile
- x_j , y_j are domain values (0-100 subjective evaluations)
- w_i are elicited attribute importance weights (1-7)

CRISP VECTOR MODEL:

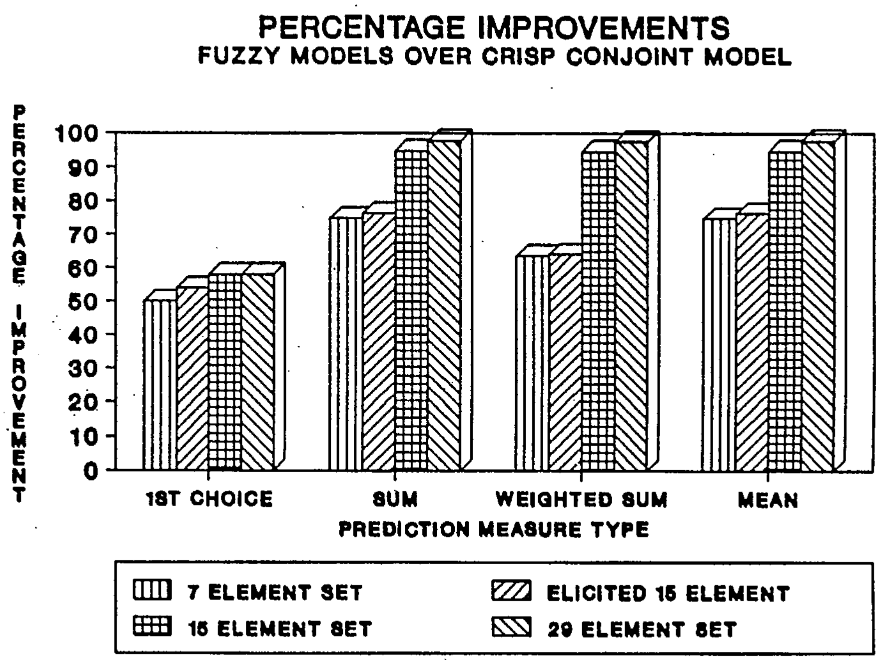
$$y(m) = \sum_{I=1}^{T} (w_i \times e_i(m)) + w_0$$

Where:

- $y(m)$ calculated overall evaluation
- $e_i(m)$ is evaluation of the *ith* attribute (1-7)
- w_i are individually estimated attribute importance weights (OLS regression from 18 estimation profiles)



(N)= # of domain elements



7,15,29 elements pre-defined sets
15 element elicited sets

PREDICTION RESULTS

Prediction Measure:	Naive Model	Crisp Model	Fuzzy Model*
1st choice rate:	17%	48%	76%
Sum of choices:	31	135	263
Weighted sum measure:	56	287	559
Overall Improvement (Fuzzy -Crisp):			**83%**
Mean prediction:	0.28	0.97	1.89
t-value of mean (fuzzy - crisp):			0.92 ($p < .001$)

N = 139, * Standard pre-defined 15 element sets

MARKET SHARE PREDICTION

MARKET SHARE MODEL:

The probability of choosing a given alternative *m* from a choice set is given by

$$P(m) = \left(e^{\beta y(m)} \,/\, \sum_{P=1}^{6} e^{\beta y(p)} \right)$$

Where:

- $P(m)$ is the probability of selecting holdout product m, given a crisp preference score $y(m)$

FUZZY TO CRISP CONVERSION:

$$y(m) = \sum_{N=1}^{15} \left(\mu_{B'}(y_n, m) \times n \right) \;/\; 15$$

Where:

- $y(m)$ converted crisp preference score
- $\mu_{B'}(y_n, m)$ is the membership function for holdout m
- n is the weight for each set element, as well as the summation index for domain elements y_n

MARKET SHARE ESTIMATES

Attribute Level	Crisp Conjoint		Fuzzy Conjoint	
	Error	Corr.	Error	Corr.
Pizza Product:				
Good Level:	6.26	0.627	5.31	0.917[a]
Average Level:	6.02	0.828[b]	4.74	0.901[a]
Poor Level:	4.00	0.866[b]	3.32	0.906[a]
Car Product:				
Good Level:	10.34	-0.191	5.95	0.412
Average Level:	11.73	0.044	5.98	0.298
Poor Level:	7.51	0.538	5.28	0.837[a]

[a] $p < .01$. [b] $p < .05$. Abs. = Absolute Value

Error = Mean absolute market share error (predicted - actual)
Corr. = Correlation between predicted and actual share
Levels are the average of all 4 attributes for all subjects (n = 104 for pizza, 96 for compact car).

CONCLUSIONS

- High rates of predictive validity (> 80% 1st choice) by representing ratings with fuzzy sets

- Improved accuracy of market share estimates

- Greater improvement for subjects that prefer, or for products that involve, linguistic attribute information

- Adaptive computer software combined with simple but flexible models improve predictive validity with less data

- Good results over 4 studies, 300 subjects, 2 products and relative to existing conjoint models

SUMMARY OF EXPERIMENTS

Experiment:	N	CC	FC	% Adv.
Written Studies	63	57%	71%	35%
Software #1	62	65%	71%	33%
Software #2	50	50%	82%	138%
Software #3	139	48%	76%	83%
Average	314	53.5%	75.0%	72%

N = Number of subjects
CC = Crisp Conjoint Model 1st choice rate (6 holdouts)
FC = Fuzzy Conjoint Model 1st choice rate (6 holdouts)
% Adv. = Overall improvement FC - CC (3 measures)

Japanese History of Fuzzy Engineering Research

1972 Working Group on Fuzzy Systems, TIT

1972 → 1981 Annual report "General Problems on Fuzzy Systems"

1972 Workshop on Fuzzy Systems by Society for Instrumentation and Control Engineers

1983 Fuzzy Control Application to Water Purification Process, Fuji Elec. & TIT

1984 IFSA Japan Chapter

1984 → present Annual Symposium on Fuzzy Syste

1987 Fuzzy Control Application to Subway in Sendai City, Hitachi

1987 Second IFSA Congress, Tokyo

1987 1st "Fuzzy Vogue"

1988 International Workshop on Fuzzy Systems Application in Iizuka

1989 → 1994 LIFE Project, MITI

1989 → 1993 Fuzzy Systems Research Project, STA

1989 Society for Fuzzy Theory and Systems (SOFT)

1989 Fuzzy Control Application to Hot Water Supply Unit for Home Use, Matsushita

1989 Honda Prize to Prof. Zadeh

1990 2nd "Fuzzy Vogue"

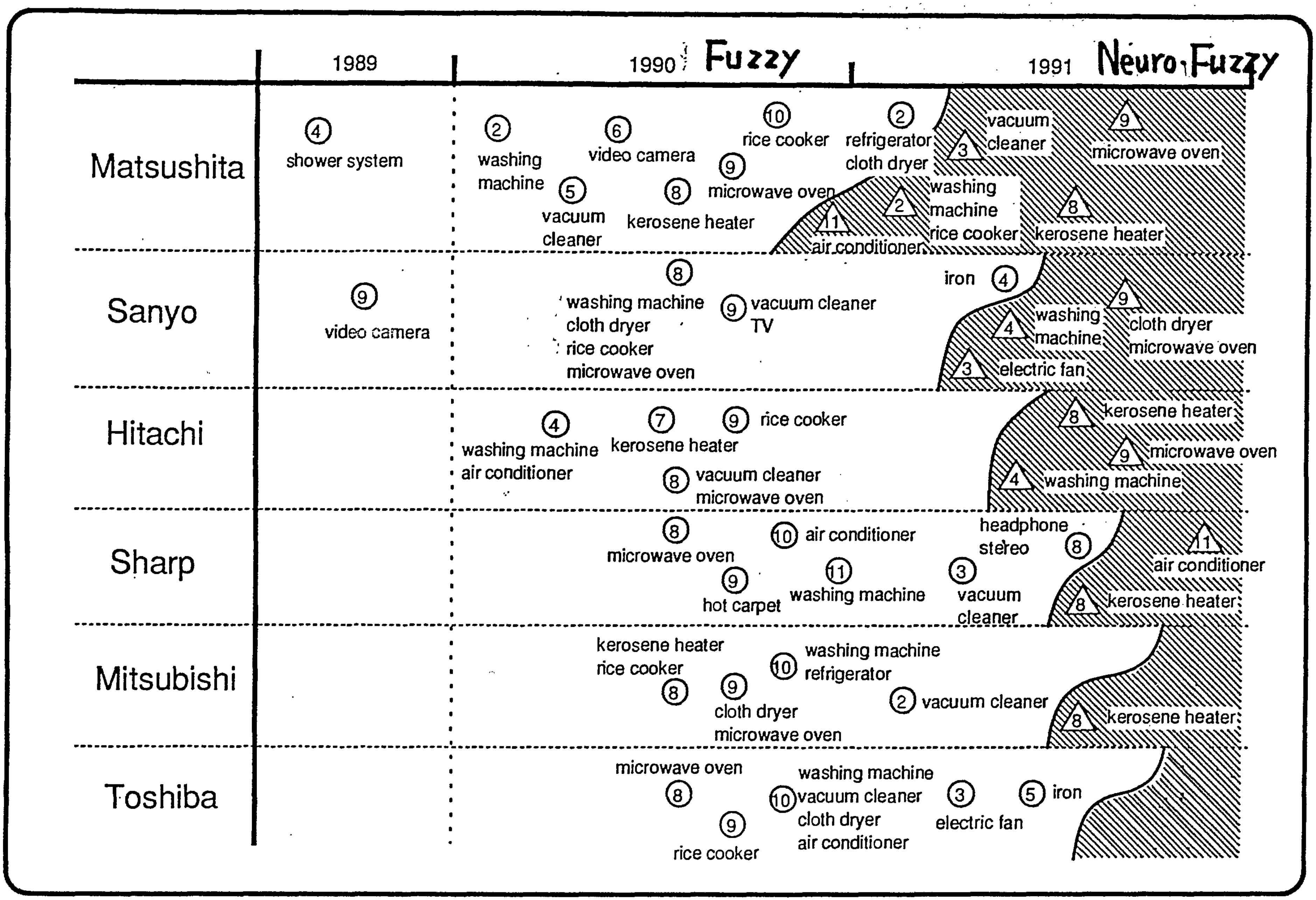
1990 International Conference on
Fuzzy Logic & Neural Network,
Iizuka

1990 Sino-Japan Joint Meeting on
Fuzzy Sets and Systems, Beijing

1991 International Fuzzy Engineering
Symposium, Yokohama

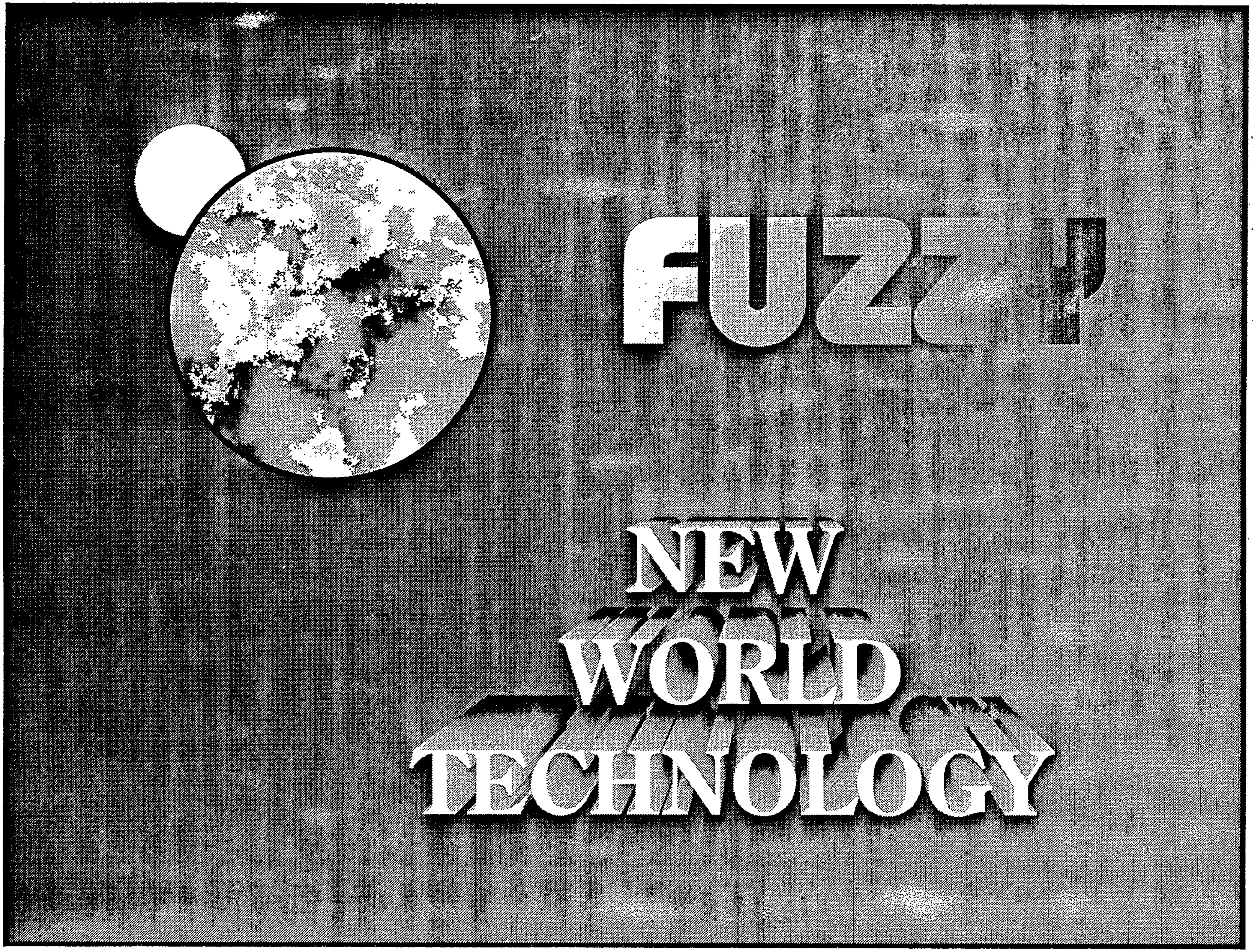
1991 AI-Fuzzy Center

1992 Korea-Japan Joint Symposium
on Fuzzy Systems, Seoul

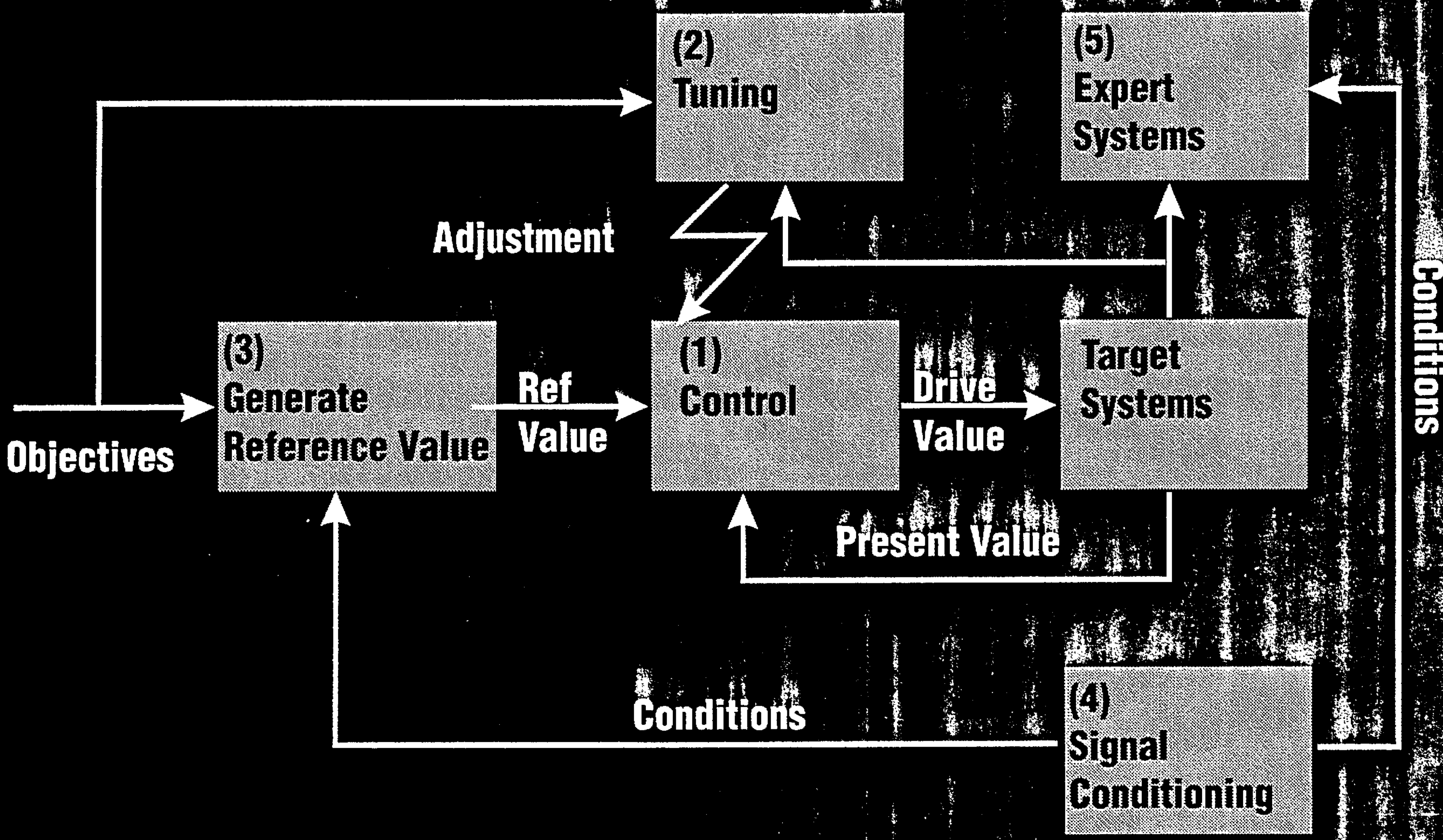

1989
1990 Fuzzy
1991 Neuro-Fuzzy
Matsushita
4 shower system
2 washing machine
6 video camera
5 vacuum cleaner
8 kerosene heater
10 rice cooker
9 microwave oven
2 refrigerator cloth dryer
11 air conditioner
3 vacuum cleaner
2 washing machine rice cooker
9 microwave oven
8 kerosene heater
Sanyo
9 video camera
8 washing machine cloth dryer rice cooker microwave oven
9 vacuum cleaner TV
iron 4
4 washing machine
3 electric fan
9 cloth dryer microwave oven
Hitachi
4 washing machine air conditioner
7 kerosene heater
9 rice cooker
8 vacuum cleaner microwave oven
8 kerosene heater
9 microwave oven
4 washing machine
Sharp
8 microwave oven
10 air conditioner
9 hot carpet
11 washing machine
headphone stereo 8
3 vacuum cleaner
11 air conditioner
8 kerosene heater
Mitsubishi
kerosene heater rice cooker 8
10 washing machine refrigerator
9 cloth dryer microwave oven
2 vacuum cleaner
8 kerosene heater
Toshiba
microwave oven 8
9 rice cooker
10 washing machine vacuum cleaner cloth dryer air conditioner
3 electric fan
5 iron

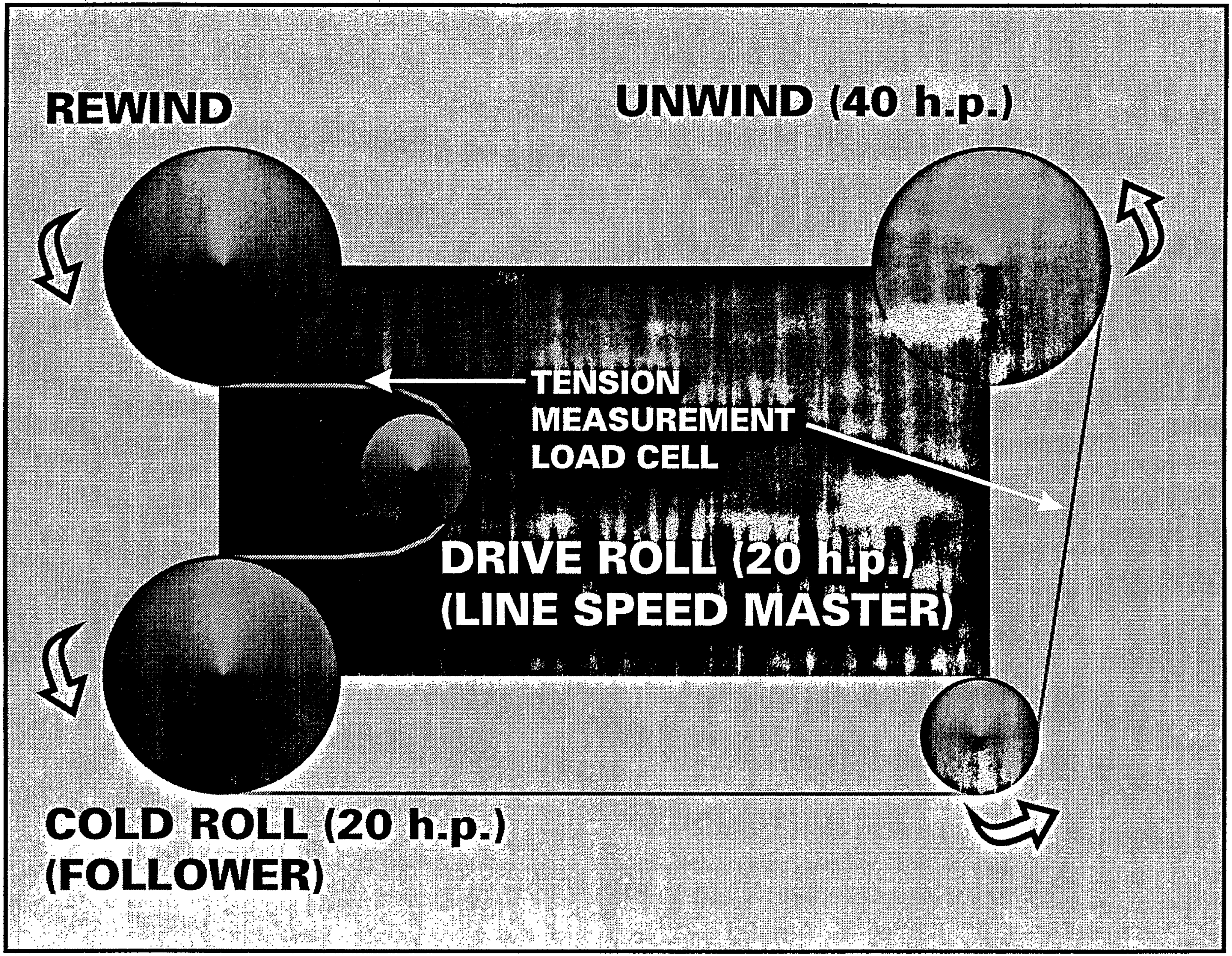
FUZZY LOGIC:
A NEW WORLD TECHNOLOGY

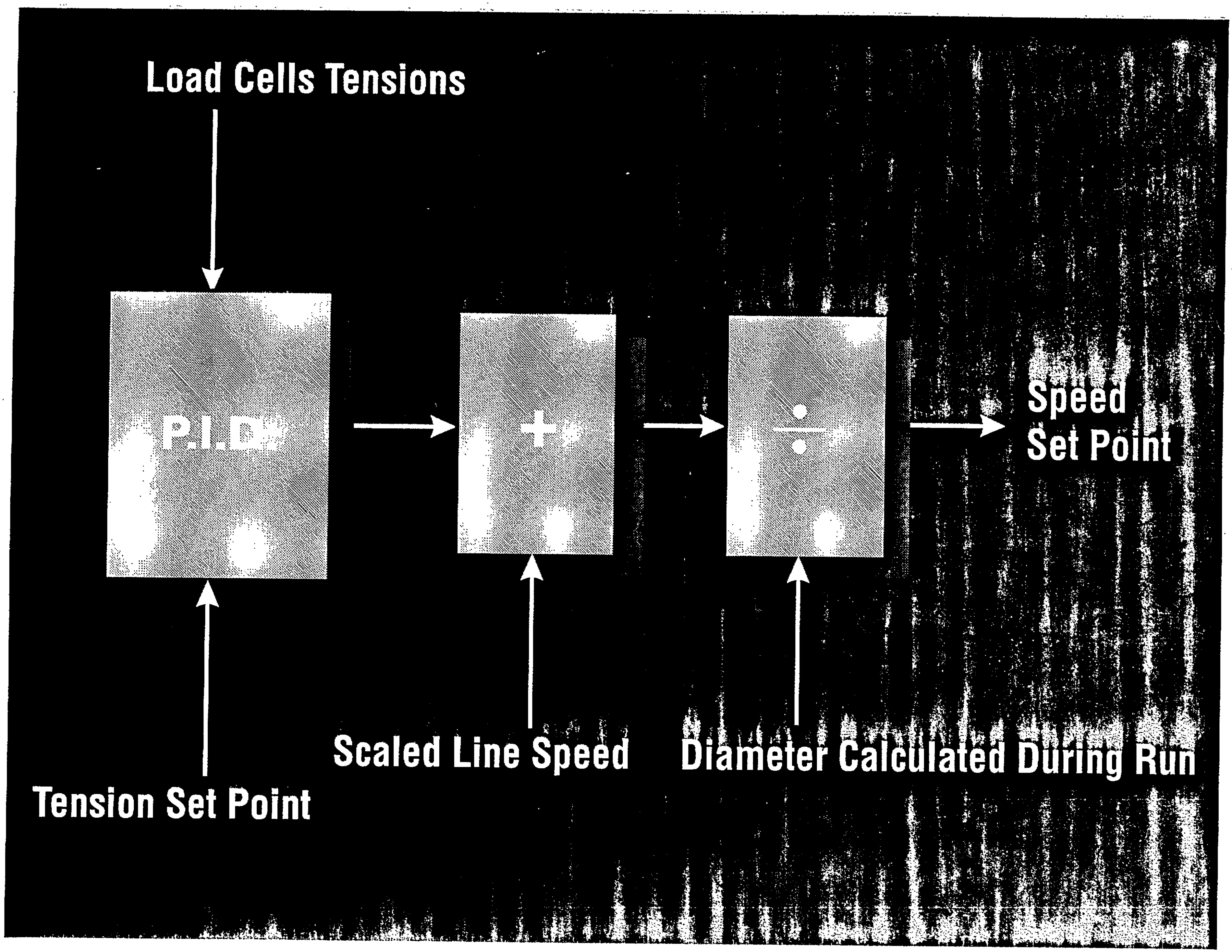
OMRON Canada Inc.

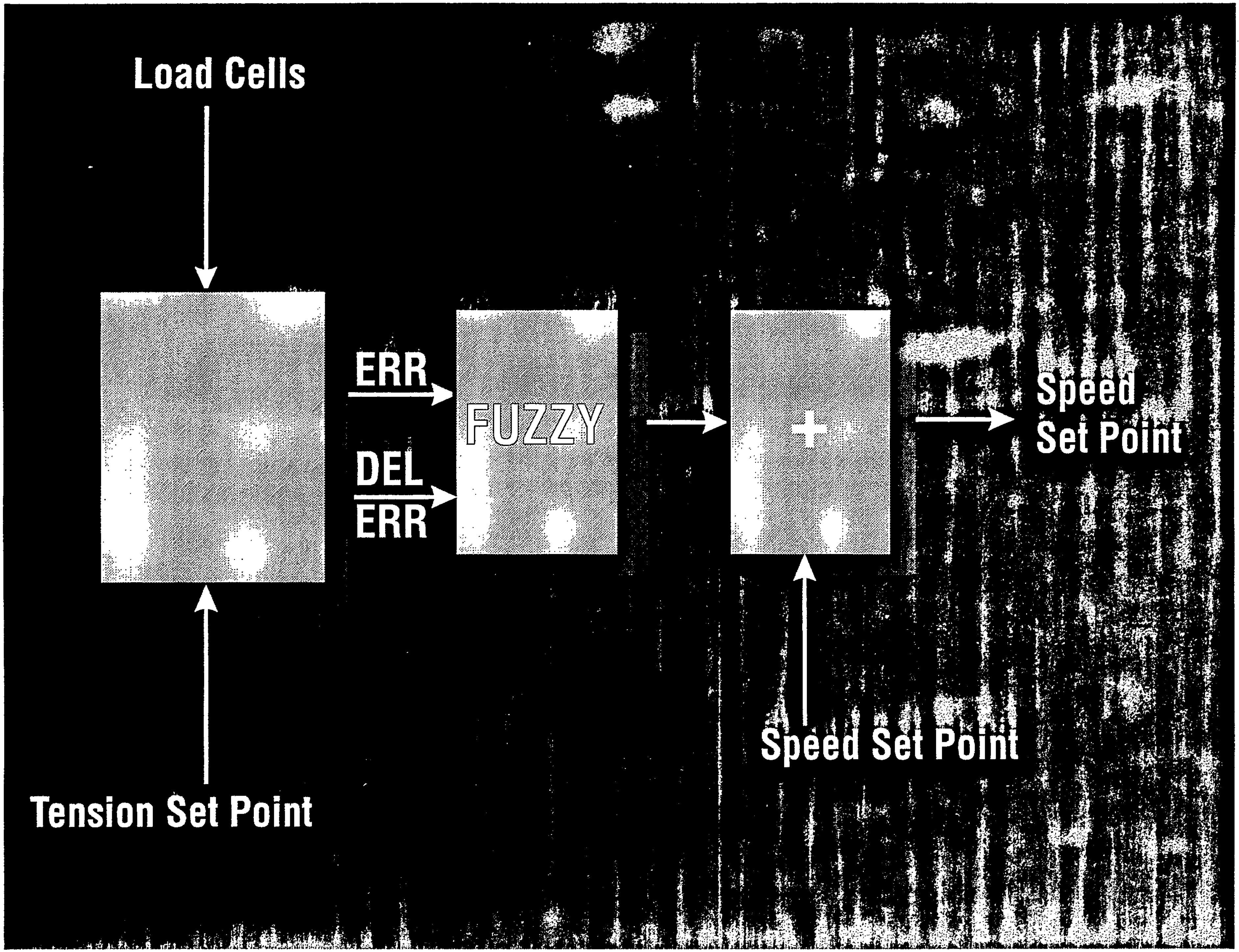

FUZZY
NEW
WORLD
TECHNOLOGY

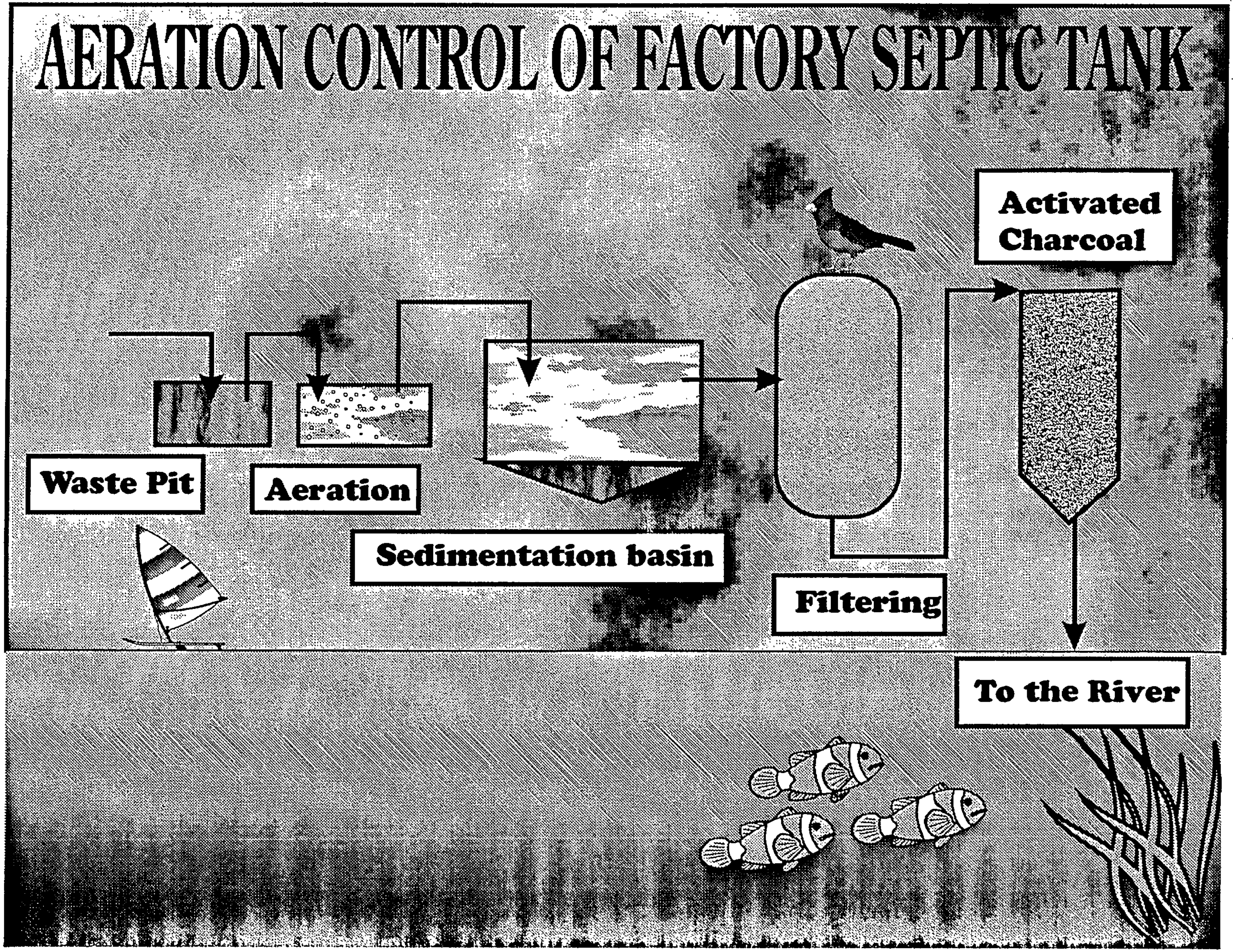
WHERE TO EMPLOY FUZZY




REWIND
UNWIND (40 h.p.)
TENSION
MEASUREMENT
LOAD CELL
DRIVE ROLL (20 h.p.)
(LINE SPEED MASTER)
COLD ROLL (20 h.p.)
(FOLLOWER)


Load Cells Tensions
P.I.D.
+
÷
Speed Set Point
Scaled Line Speed
Diameter Calculated During Run
Tension Set Point

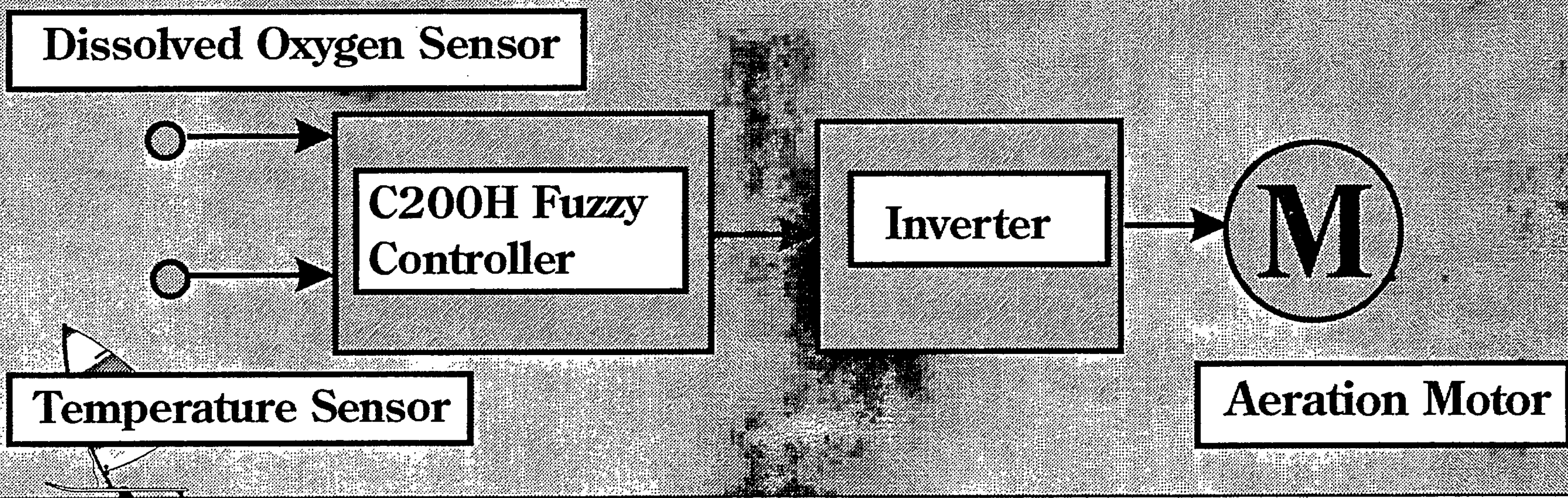

Load Cells
ERR
DEL
ERR
FUZZY
+
Speed
Set Point
Speed Set Point
Tension Set Point

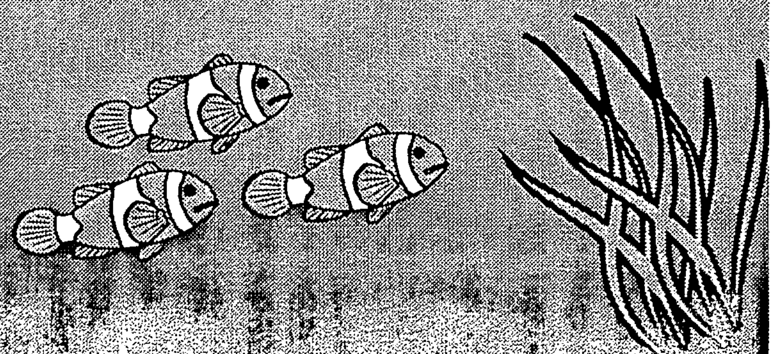

AERATION CONTROL OF FACTORY SEPTIC TANK
Activated Charcoal
Waste Pit
Aeration
Sedimentation basin
Filtering
To the River

EFFECTS

Stabilizes the quantity of oxygen contained in the sewage of septic tank system (1.2 to 1.8 from 0.3 to 5.0 ppm).

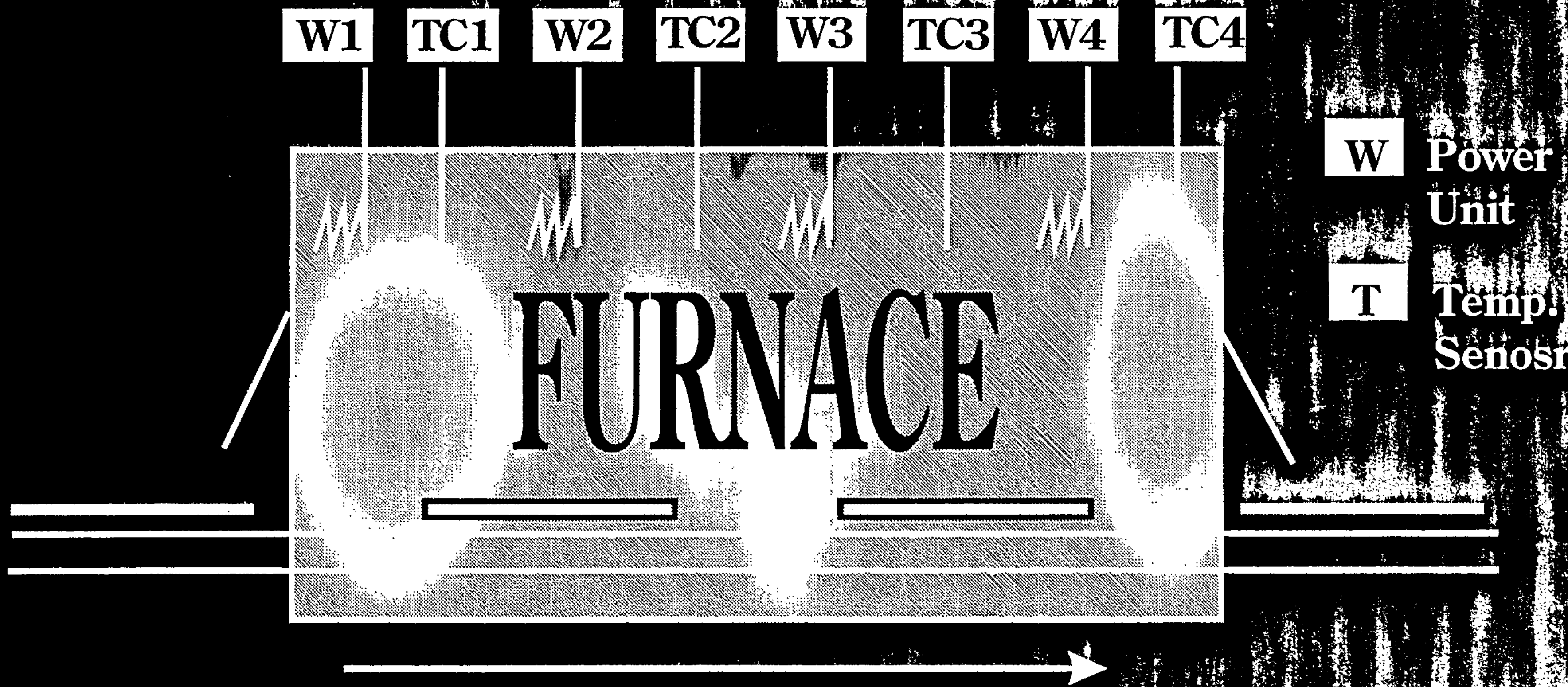
Reduces the electricity required by the system by 22%





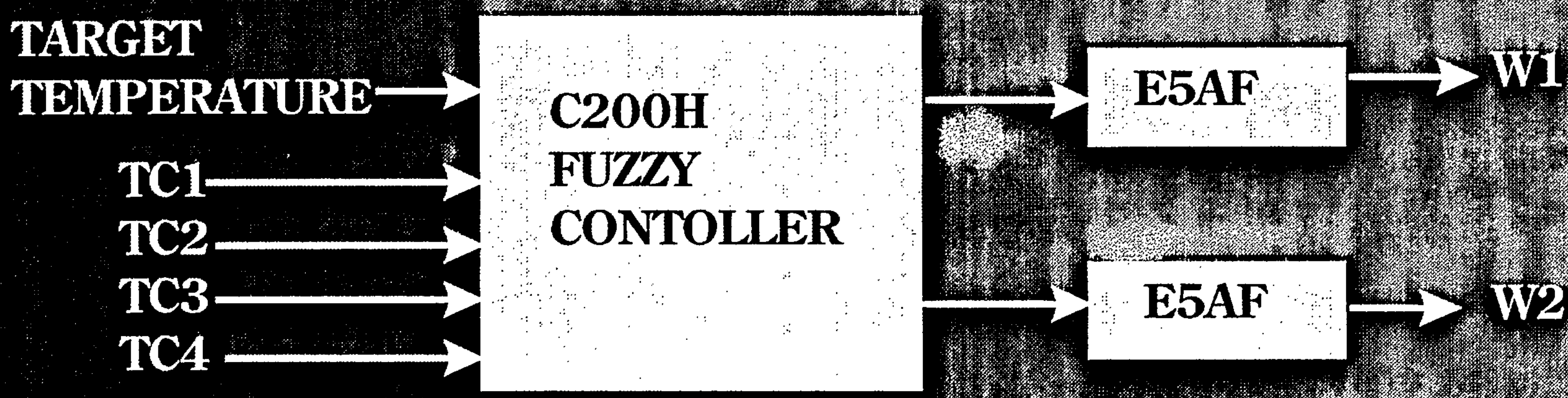
TEMPERATURE CONTROL OF REINFORCED GLASS FURNACE

In a conventional large furnace, the internal temperature is not uniform and does vary due to the interference by the adjacent heaters. Fuzzy Inference makes it possible to keep the temperature of every part of the furnace uniform.

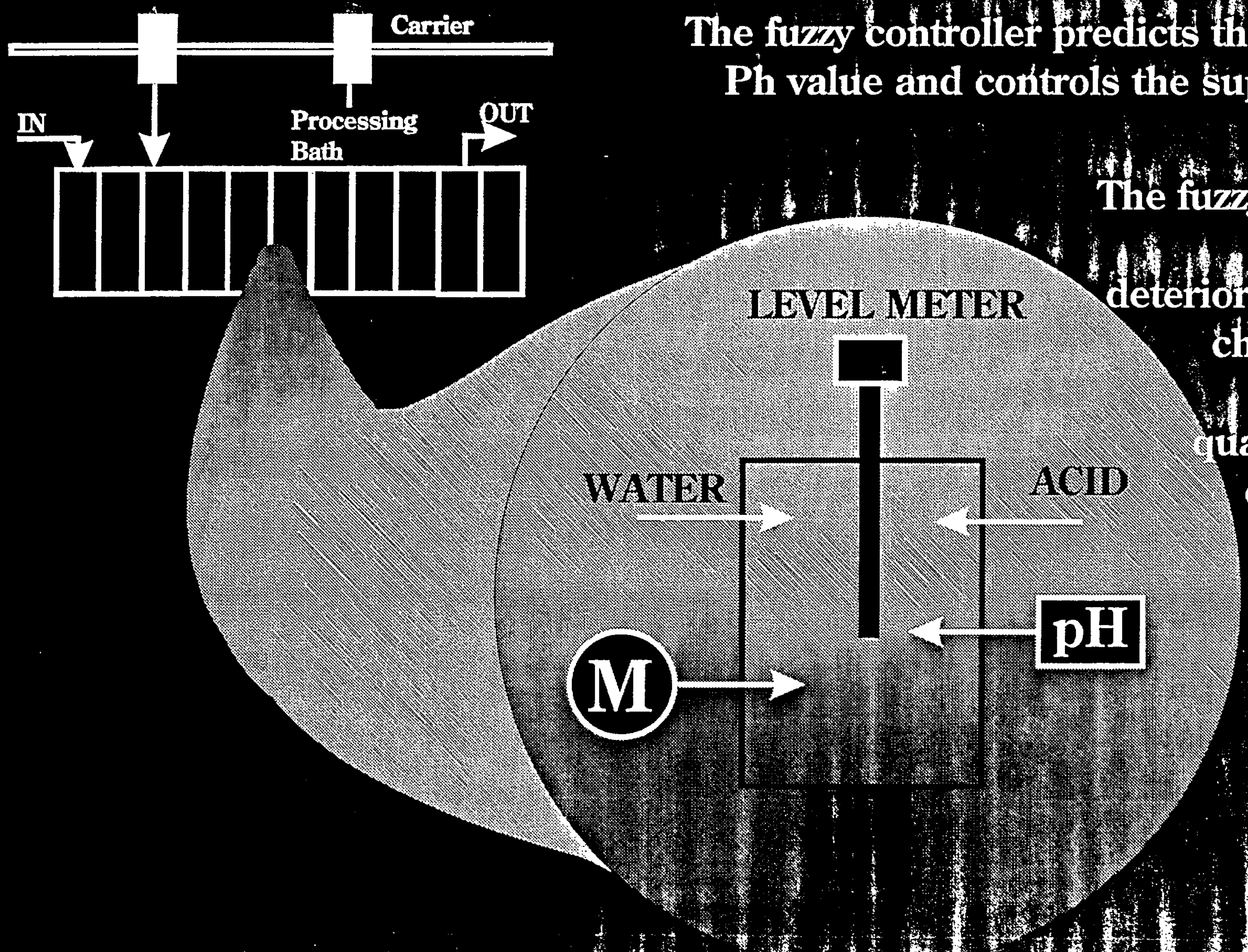


EFFECT

Improves the quality of reinforced glass processed by a furnace by reduced temperature fluctuations.



CONCENTRATION CONTROL OF PLATING CHEMICAL



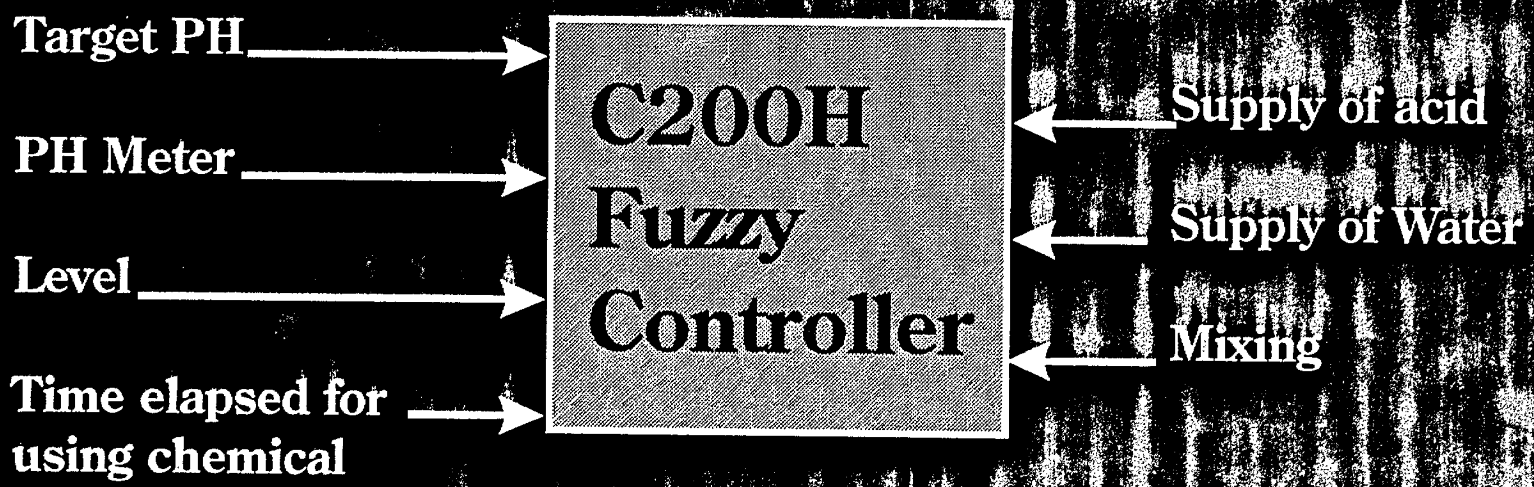
The fuzzy controller predicts the change in Ph value and controls the supply of acid and water

The fuzzy controller judges the deterioration of the chemical and adjusts the quantity of the chemical to be added to the system

EFFECTS

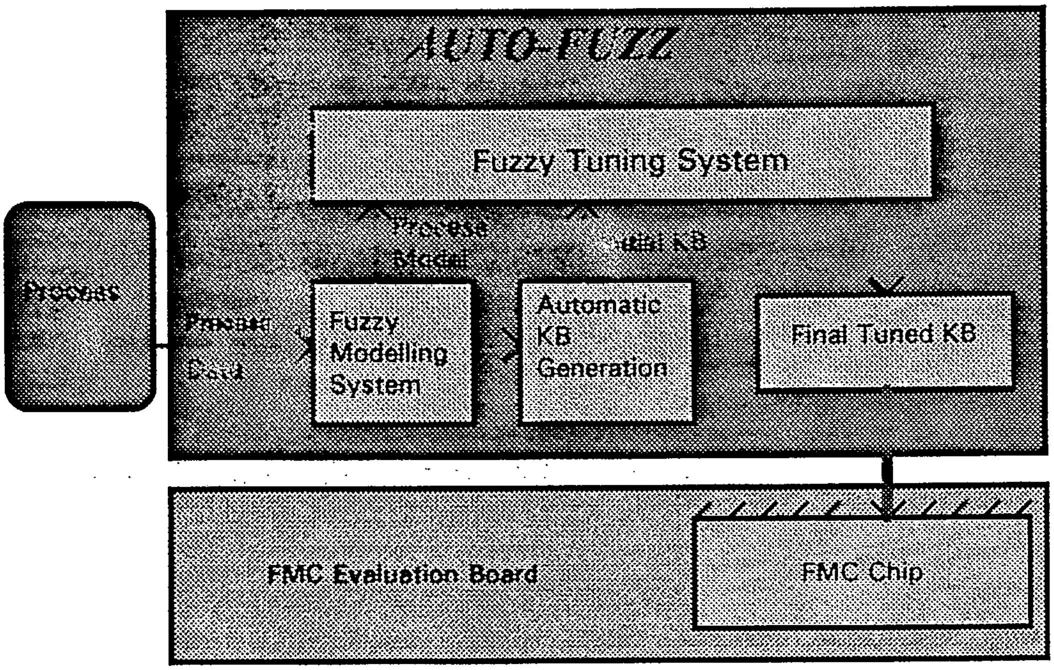
Reduces the quantity of chemicals used in a plating system and improves the quality of plating by keeping the concentration of the chemicals consistent.

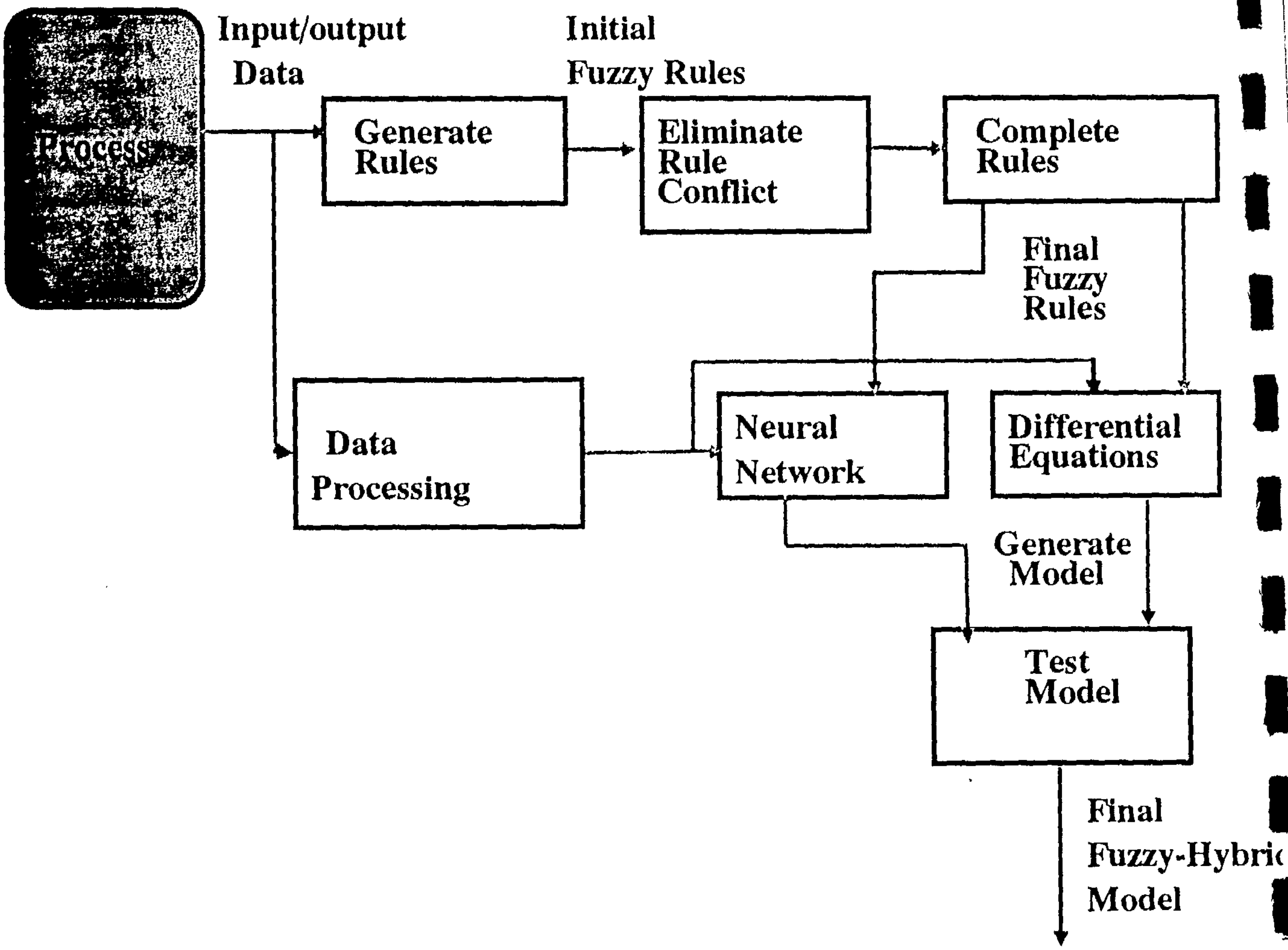
Well-trained operators are not required to operate a fuzzy-controlled plating system because the complicated fine-tuning of the system is handled automatically.



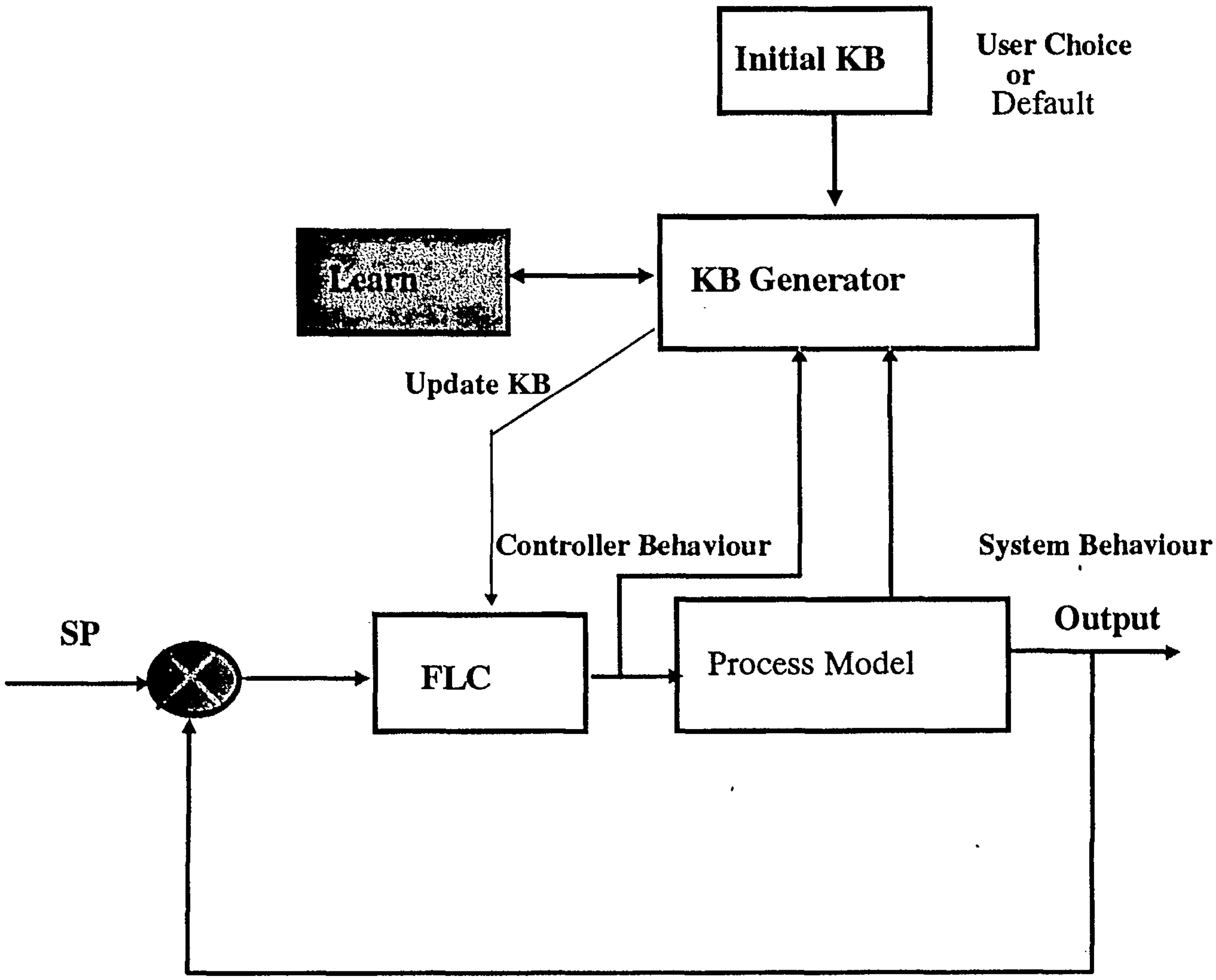
AutoFuzz: A System For Automatic Fuzzy Controller Applications Development

Dr. Talib Janabi
Director of Technology
Mentalogoc Systems Inc. (MSI)
Markham, Ontario

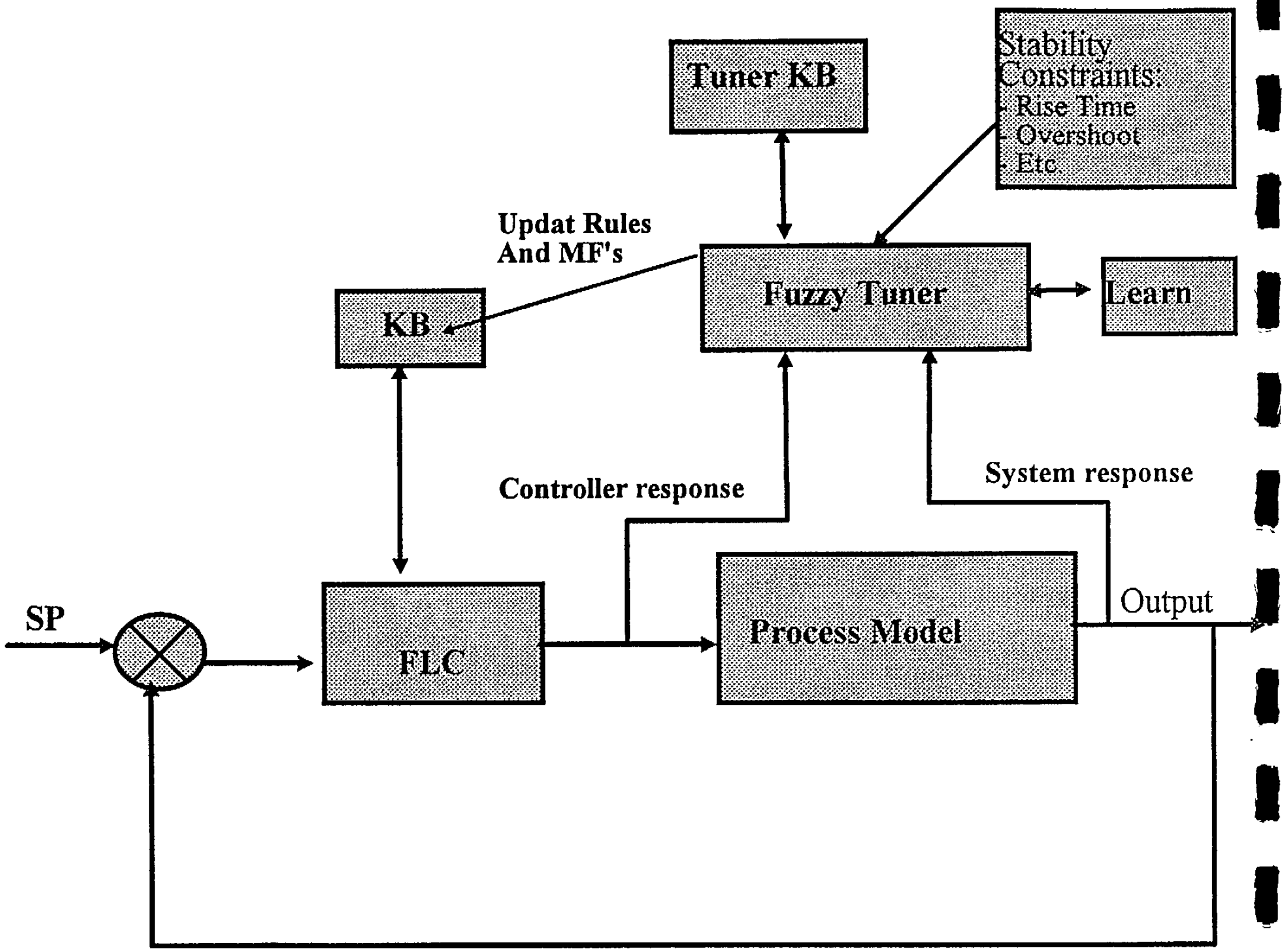

AUTO-FUZZ
Fuzzy Tuning System
Process Model
Initial KB
Process
Process Data
Fuzzy Modelling System
Automatic KB Generation
Final Tuned KB
FMC Evaluation Board
FMC Chip



MSI HYBRID MODELLING



MSI KNOWLEDGE-BASE GENERATOR



MSI FUZZY TUNER

WHAT IS AUTO-FUZZ ?

AUTO-FUZZ IS AN ADVANCED FUZZY EXPERT SYSTEM FOR AUTOMATIC FUZZY KNOWLEDGE BASE GENERATION AND OPTIMIZATION. IT:

- OPERATES COMPLETELY AUTOMATICALLY
- OR AS INTERACTIVE DESIGN TOOL

OPTIONS ARE GIVEN TO YOU TO:

- INTERFER TO OPTIMIZE THE SOLUTION
- CHANGE SPECIFICATIONS
- DECLARE YOUR CONSTRAINTS ON THE PROCESS RESPONSE
- RELAX THESE CONSTRAINTS
- OR MAKE THEM MORE STRINGENT TO ELIMINATE OVERSHOOTS AND OBTAIN FASTER RISE TIME

ADVANTAGES OF AUTOFUZZ

- EASY TO LEARN
- SIMPLE TO USE
- IT REDUCES THE APPLICATION DEVELOPMENT TO NO MORE THAN A SIMPLE EASY EXERCISE
- NON EXPERIENCED ENGINEER MAY TAKE A DAY TO GENERATE THE OPTIMIZED KNOWLEDGE-BASE
- EXPERIENCED ENGINEERS WILL TAKE FEW HOURS, OR EVEN FEW MINUTES TO GENERATE THEIR OPTIMIZED KNOWLEDGE-BASE
- YOU CAN GENERATE MANY OPTIMIZED KNOWLEDGE BASES FOR DIFFERENT CONSTRAINTS AND CHOOSE THE ONE YOU PREFER

WHAT DOES AUTOFUZZ NEED FROM YOU ?

- IT NEEDS INPUT/OUTPUT DATA FROM YOUR PROCESS

- AUTOFUZZ WILL GENERATE A MODEL OF YOUR PROCESS TO WORK ON WHETHER YOUR DATA IS LINEAR OR NON-LINEAR

- IF YOU ALREADY HAVE YOUR MODEL, AUTOFUZZ WILL WORK ON YOUR MODEL WHETHER IT IS LINEAR OR NON-LINEAR

WHAT IS THE AUTOFUZZ MODELLING SYSTEM?

- IT IS AN EXPERT SYSTEM WHICH USES INPUT/OUTPUT DATA TO GENERATE A HYBRID MODEL:

  - FUZZY-MATHEMATICAL

  - FUZZY-NEURAL

- IT GENERATES FUZZY RULES
- ELEMINATE RULE CONFLICT
- GENERATE EXTRA RULES TO REPRESENT KNOWLEDGE UNREVIELLED BY DATA

AUTOFUZZ AUTOMATIC KNOWLEDGE-BASE GENERATOR

THE AUTOFUZZ AKBG IS:

- **INCORPORATES MACHINE LEARNING AND INTELLIGENT DECISION MAKING TO GENERATE THE FUZZY RULES AND MEMBERSHIP FUNCTIONS FOR THE APPLICATION**
- **OPTIMIZES THE NUMBER OF FUZZY RULES AND MEMBERSHIP FUNCTIONS**
- **GENERATES THE KNOWLEDGE-BASE REQUIRED FOR YOUR APPLICATION :**
  - **OBJECTIVELY**
  - **IN A VERY SHORT TIME.**

IT FREES YOU FROM THIS PAINSTAKING AND TIME CONSUMING EFFORT

THE AUTOFUZZ TUNER

THE AUTOMATIC FUZZY TUNER IS:

- A POWERFUL INTELLIGENT SYSTEM FOR TUNING AND OPTIMIZING THE FUZZY CONTROLLER KNOWLEDGE-BASE
- EMPLOYS ADVANCED AND INTELLIGENT METHODS IN ITS SEARCH FOR OPTIMUM SOLUTIONS
- IT AUTOMATICALLY ADJUSTS THE CONTROLLER KNOWLEDGE BASE TO OBTAIN CONSISTENT AND OPTIMIZED FUZZY RULES AND MEMBERSHIP FUNCTIONS TO YIELD OPTIMUM PROCESS RESPONSE
- YOU CAN DECLARE YOUR REQUIREMENTS AND CONSTRAINTS ON THE RESPONSE PARAMETERS
- MSI FUZZY TUNER IS A NEW GENERATION OF FUZZY EXPERT SYSTEMS AND THE FIRST OF ITS KIND FOR THE SOLUTION OF THE FUZZY KNOWLEDGE-BASE OPTIMIZATION

Learning Systems Development

Fuzzy Process Modeling

(A Hybrid of Mathematical and Fuzzy Modeling)

Automatic Fuzzy Rules Generation

(Advanced Reinforcement Learning)

Fuzzy Process Modeling and Behaviour Prediction

- Neural and Fuzzy Modeling
- Inductive and Fuzzy Learning

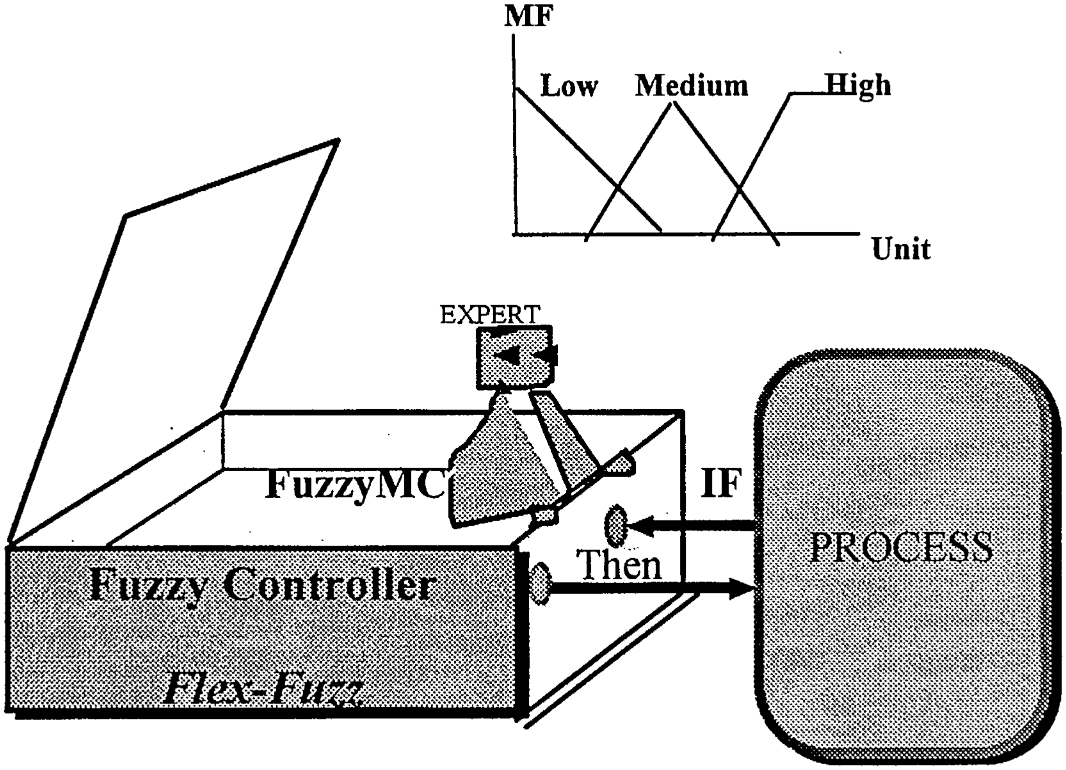
The Canadian Industrial Fuzzy Control Systems
Overview of MSI Fuzzy Logic Technology Developments

Dr. Labib Sultan

Director of Research and Development

Mentalogic Systems Inc. (MSI)
Markham, Ontario L3R 9R6

MSI Fuzzy Technology
Overview



MSI Fuzzy:
"Friendly, Powerfull and Low Cost"

Mentalogic Systems Inc.
(MSI)

Established in 1991 Under the Canadian Federal Law

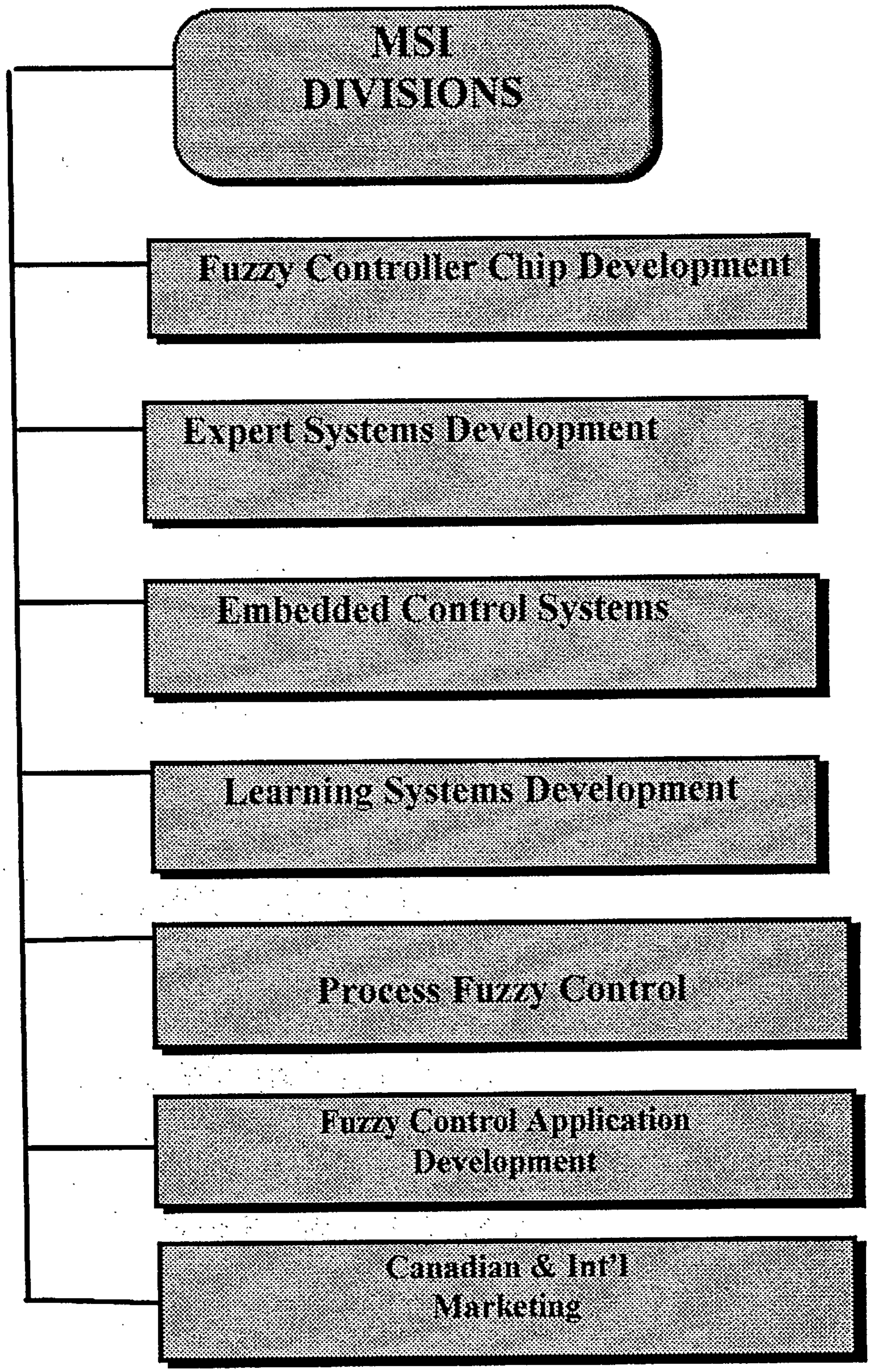
Specilaizes in Fuzzy Logicand AI Based Technology
(Systems Development and Industrilization)

The R&D involves Five Departments and More than 20 Scientists and Engineers

Good linkage with the Canadian Industriy, Government and Research communities

Growing International Role in Fuzzy Technology

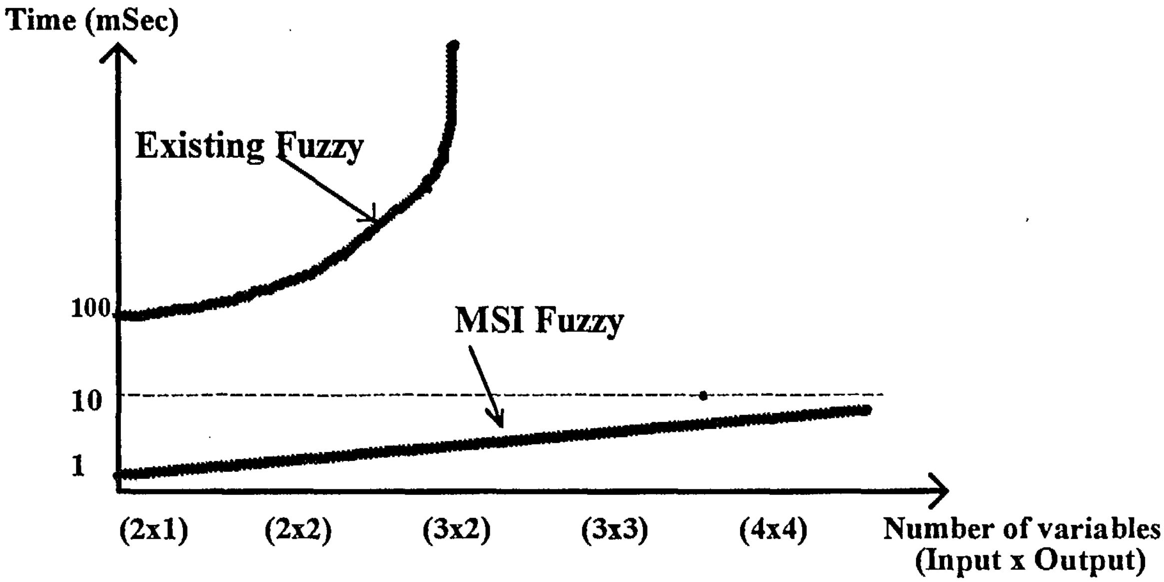
More than 12 basic Fuzzy technology products will be avilable to the Market in 1994 and other 8 basic Fuzzy technology products are planned for 1995


MSI DIVISIONS
Fuzzy Controller Chip Development
Expert Systems Development
Embedded Control Systems
Learning Systems Development
Process Fuzzy Control
Fuzzy Control Application Development
Canadian & Int'l Marketing

MSI Fuzzy Controller Development

- Development of High-Performance Fuzzy Inference Engine (The CT-FLC)
- Development of Real-Time Fuzzy Reasoning Machine for Fuzzy Coordinator and Multiple FLC and Fuzzy-PLC in one FMC.
- Development of Fuzzy Microcontroller Chips (FMC) (Motorola, Intel, NSC, Zilog, NEC, etc.)
- Development of Application Evaluation Systems for the FMC
- Design of Special Purpose Fuzzy Controller ASIC Chips

<u>A Comparison Between the Real-Time Response and Memory Requirement of MSI and Existing Fuzzy Solutions</u>



The Application Input x Output Variables	*The estimated memory required by MSI fuzzy controller chip (k Byte)*	*The estimated memory required by the existing fuzzy controller chips (K Byte)*
1x1	*0.2*	*1.2*
2x1	*0.4*	*4*
3x1	*0.8*	*6*
4x1	*1.2*	*8*
2x2	*2*	*8*
3x2	*3*	*24*
3x3	*6*	*36*
4x4	*16*	*72*

Cost Comparision Between Fuzzy Controller Solutions and Traditional MP Based Solutions

Item of Evaluation	*MSI Fuzzy Solution*	*Existing Fuzzy Solution*	*Traditional MPU Solution*
Average time of development	*1-4 weeks*	*3-6 months*	*12-18 months*
Average Cost of development	*Low*	*Medium*	*High*

Fuzzy Microcontroller Chips Supported by MSI in 1994

FMC Chip Code	Description
FMC-M68HC11	FMC - Motorola M68HC11
FMC -M68HC05	FMC - Motorola M68HC05
FMC -M68HC08	FMC - Motorola M68HC08
FMC -NSC-COP8	FMC - NSC COP8 family
FMC -NSC-HPC16	FMC - NSC HPC16
FMC-I8051	FMC - Intel I8051 family.
FMC-Z8	FMC - Zilog Z8 family

EMBEDDED FUZZY CONTROL DEVELOPMENT

Fuzz-Flex
A Series of Fuzzy Controllers for Fast and Low-Cost Fuzzy Applications Development

AC Fuzz-Drive ***DC Fuzz-Drive***

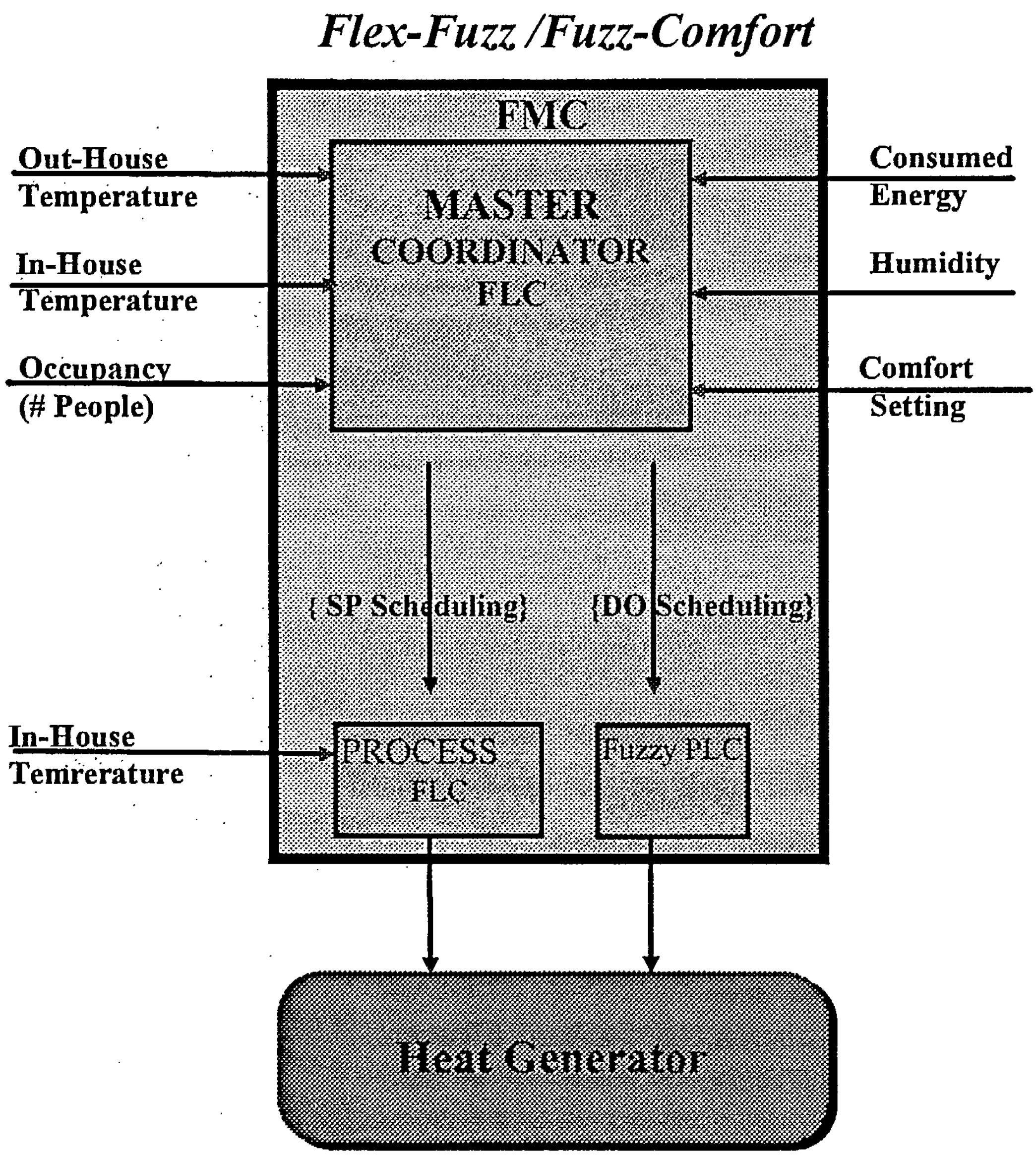
A Series of Fuzzy Controller Drivers for AC and DC Motors

Fuzz-Comfort

A sereies of Fuzzy Controllers for Home and Office Buildings Heating, Ventilation and Air Coditioning Systems (HVAC)

Fuzz-NET
Low-Cost Distributed Fuzzy Control System

Home and Industrial HVAC Control



MSI Fuzzy Technology Products for Embedded Control Applications (1994)

Product Code	Product Designation
	Fuzzy Controller Design Stations (FCDS) and Expert Systems
FCDS-Emb-01	Fuzzy Controller Design Station with "*MSI-Fuzz*" system for FMC Customization and Evaluation
FCDS-Sim-01	Fuzzy Controller design Station for Training and Simulation
FCDS-Emb-02	Fuzzy Controller Design Station with "*Auto-Fuzz*" system for Automatic Fuzzy KB Generation and Tuning
FCDS-Emb-03	Fuzzy Controller Development Station with "*Quick-Fuzz*" for the Customization of "*Flex-Fuzz*" Fuzzy Controller Boards
	Fuzzy Microcontroller Chips (FMC)
FMC-M68HC11	FMC - Motorola M68HC11
FMC-M68HC05	FMC - Motorola M68HC05
FMC-M68HC08	FMC - Motorola M68HC08
FMC-NSC-COP8	FMC - NSC COP8 family
FMC-NSC-HPC16	FMC - NSC HPC16
FMC-I8051	FMC - Intel I8051 family.
FMC-Zilog-Z8	FMC - Zilog Z8 family
	Evaluation Boards for FMC
MSI-EVB-HC11	Evaluation board for Motorola MCU M68HC11
MSI-EVB-HC05	Evaluation board for Motorola MCU M68 HC05
MSI-EVB-HC08	Evaluation board for Motorola MCU M68HC08
MSI-EVB-COP8	Evaluation board for NSC MCU COP8
MSI-EVB-HPC16	Evaluation board for NSC HPC 16
MSI-EVB-I8051	Evaluation board for Intel MCU I8051
MSI-EVB-Z8	Evaluation board for Zilog MCU Z8
	Fuzzy Controller Boards *"Flex-Fuzz"* Series
FLCB-HPC	Fuzzy Controller Board with NSC HPC FMC
FLCB-MHC11	Fuzzy Controller Board with Motorola HC11 FMC
FLCB-I8751	Fuzzy Controller Board with Intel I8751 FMC
	Input-Output Boards with Auto-calibration
MSI-AIO-1.0	General purpose I/O board with 8 channels analog input and 4 channels analog output with facilities for sensor and signal auto-calibration

Fuzzy Expert System Development

MSI-Fuzz
Expert System for the Customization and
Evlaution of Fuzzy Microcontroller Chips (FMC)

AUTO-Fuzz
Expert System for Process Modeling
Expert System for Fuzzy KB Auto-Generation
Expert System for Fuzzy Controller Auto-Tunning

Quick-Fuzz

- Expert System for Fast Fuzzy Controller Applications Development
- Expert System for Multiple Fuzzy Controllers and Fuzzy PLC Configuration and Coordination

(To Customize ***Flex-Fuzz*** Series of Fuzzy Controllers)

Monitoring-Fuzz

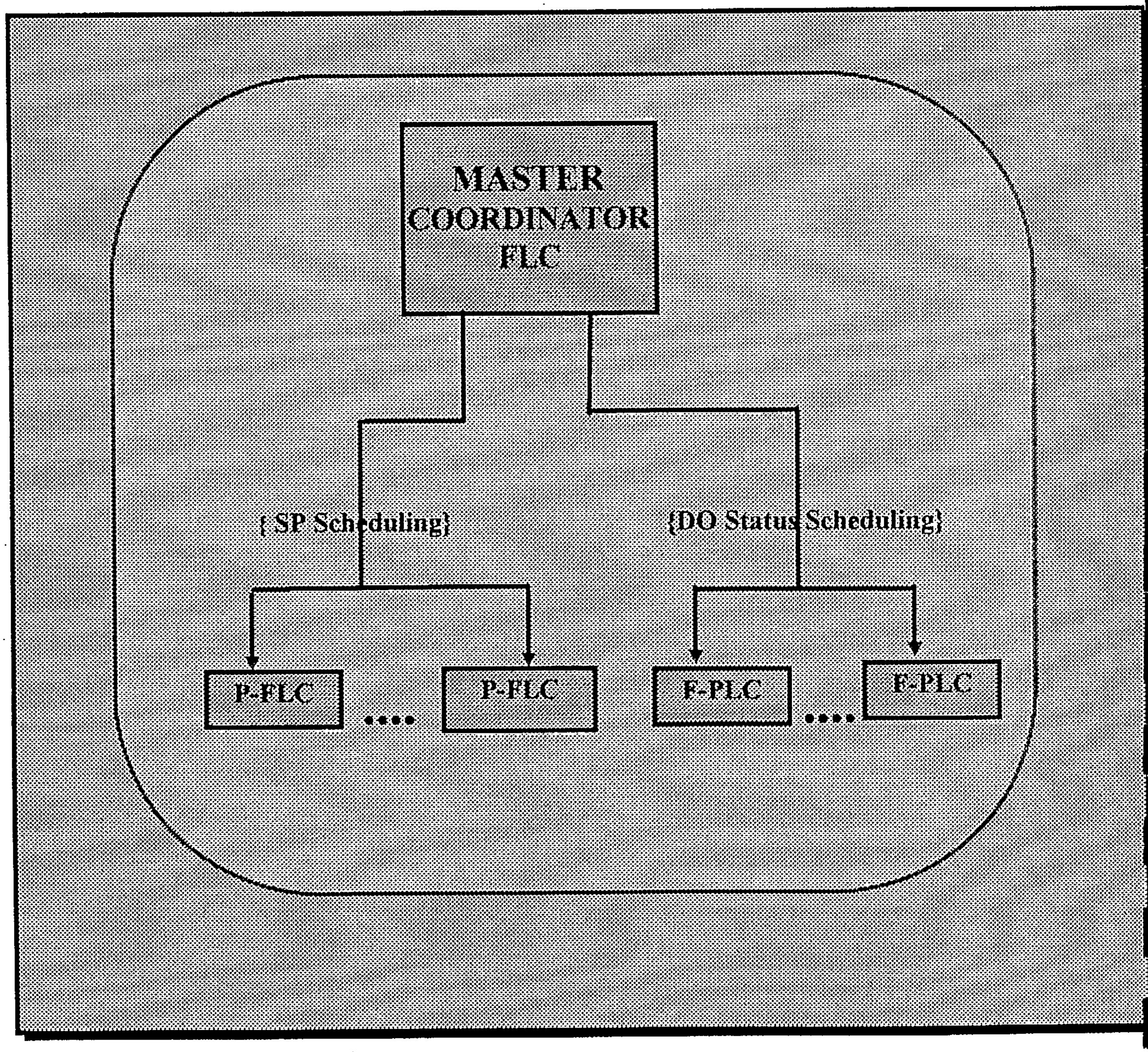
Expert System For Process Monitoring
Expert System for Production Management and Planning

PROCESS FUZZY CONTROL

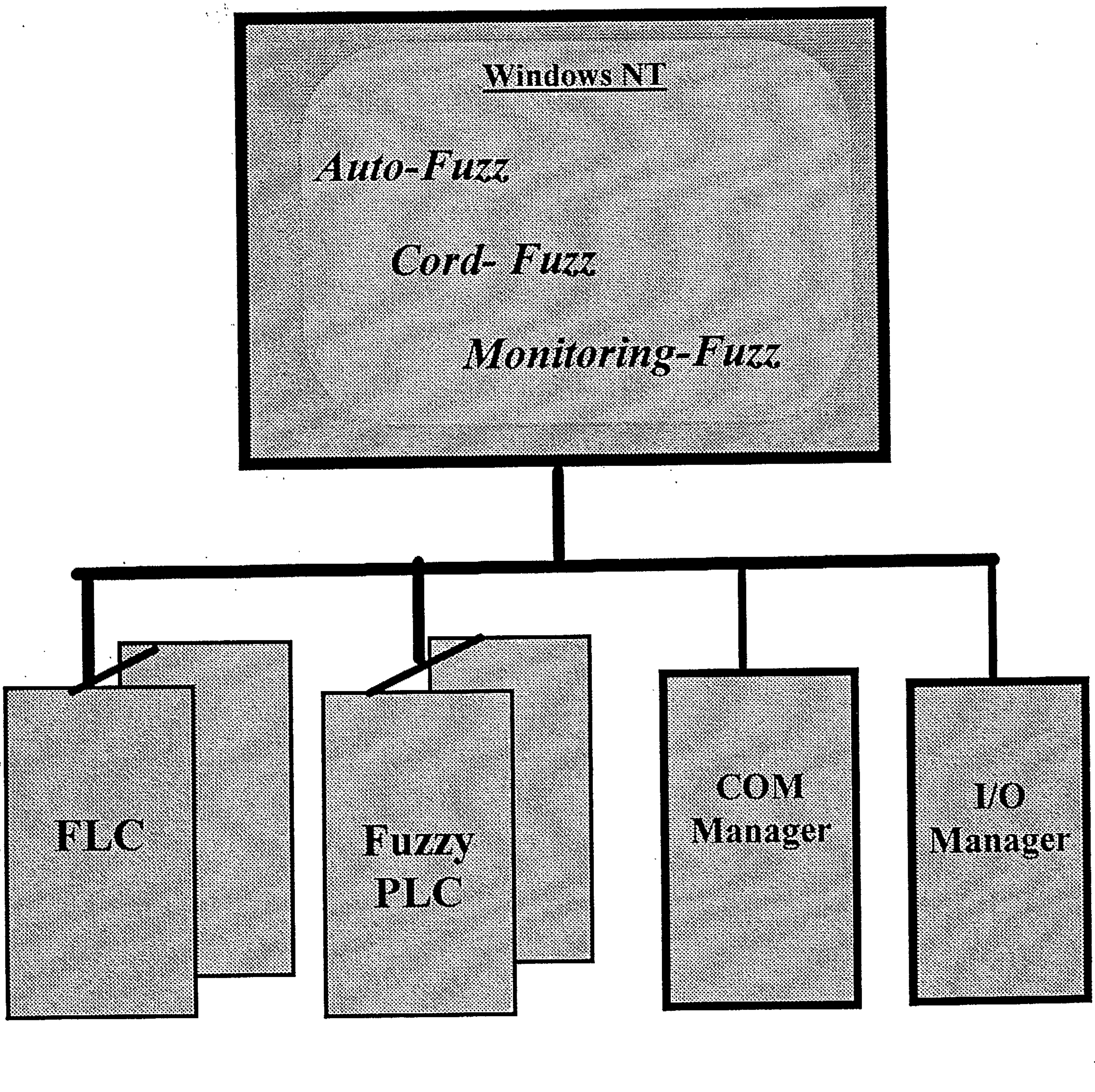
- Design of Fuzzy Controller Boards
(VME, STD 32, PC BUS, Multibus, ISBX)
- Development of DFCS
(Distributed Fuzzy Control System)
With Automatic KB Generation and Tuning
- Development of Fuzzy Monitoring System
- Development of Fuzzy Expert System for
Production Management, Planning and
Scheduling

"Quick-Fuzz/ Cord -Fuzz"

Expert System For The Configuration and Co-ordination of Multiple FLCs and Fuzzy PLCs

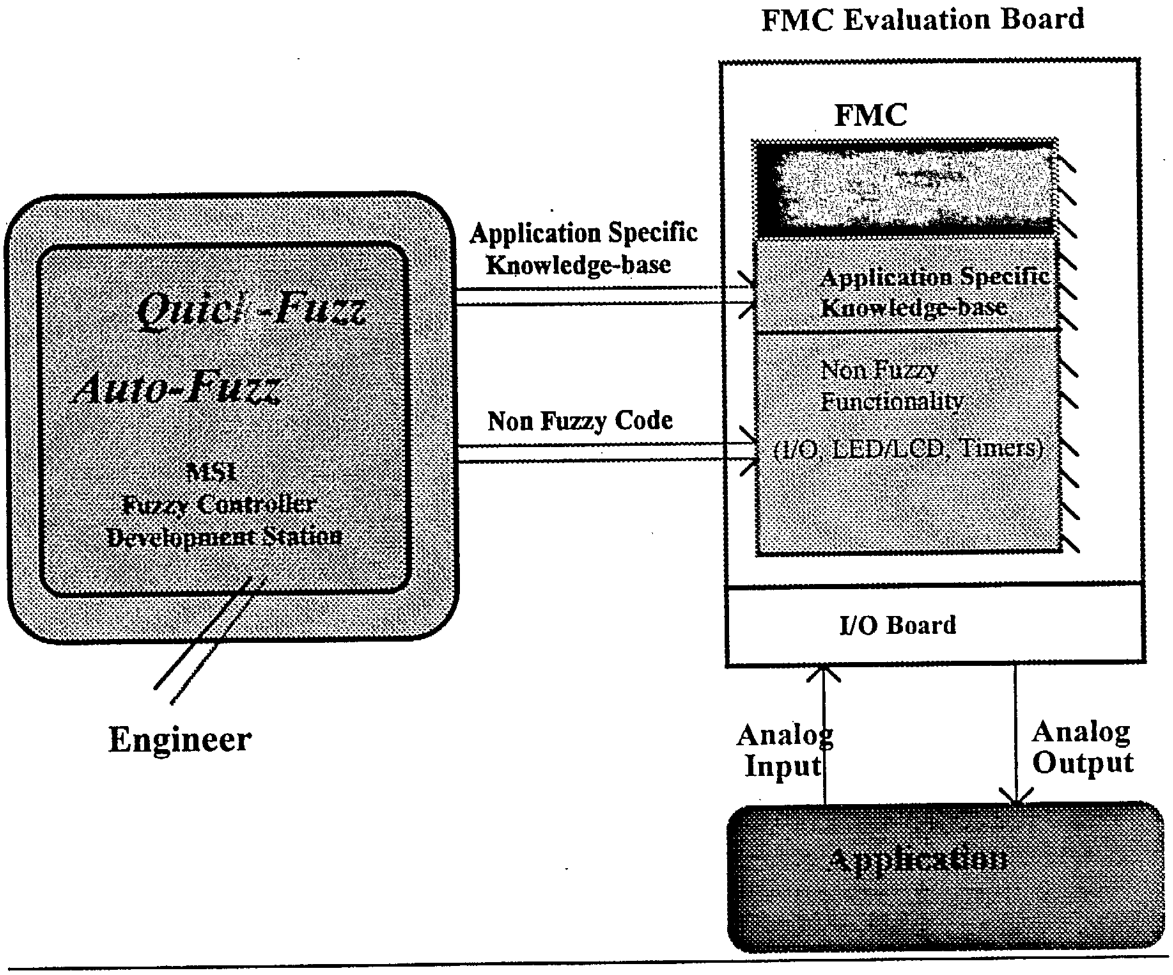


DFCS - Distributed Fuzzy Control System



MSI Fuzzy Technology Products for the Process Control Industry (1994)

Product Code	Product Designation
	Expert Systems for The Process Industry
MSI-Fuzz	Fuzzy Controller Design System for the Controller Customization and Evaluation
Auto-Fuzz	Fuzzy Controller KB Auto-Generation and Auto Tuning Expert System
Quick-Fuzz	Multiple Fuzzy Controller Configuration and Co-ordination System (P-FLC, F-PLC, and M-FLC).
Monitor-Fuzz	Monitoring System for the Fuzzy Distributed Control System (FDCS).
	Fuzzy Controllers for Stndard Bus Systems
FLC-VME	Fuzzy Controller Board for VME BUS
FLC- STD-32	Fuzzy Controller Board for STD 32 BUS
FLC- PC BUS	Fuzzy Controller Board for PC BUS
ISBX	Fuzzy Controller for Intel SBX
DFCS	Distributed Fuzzy Control System with Standard BUS and Configuration System
	Fuzzy Controller Boards "Flex-Fuzz" Series
FLCB-HPC	Fuzzy Controller Board with NSC HPC FMC
FLCB-MHC11	Fuzzy Controller Board with Motorola HC11 FMC
FLCB-I8751	Fuzzy Controller Board with Intel I8751 FMC


FMC Evaluation Board
FMC
Application Specific
Knowledge-base
Quick-Fuzz
Auto-Fuzz
MSI
Fuzzy Controller
Development Station
Application Specific
Knowledge-base
Non Fuzzy Code
Non Fuzzy
Functionality
(I/O, LED/LCD, Timers)
I/O Board
Engineer
Analog
Input
Analog
Output
Application

LOGIQUE FLOUE EN FABRICATION

EXEMPLE D'APPLICATION DE LA LOGIQUE FLOUE POUR LE CHOIX DES CONDITIONS DE COUPE EN TOURNAGE

Présenté par

Marek Balazinski
Professeur adjoint

ÉCOLE POLYTECHNIQUE
Campus de l'Université de Montréal
2900, rue Édouard Montpetit
C.P. 6079, succursale «Centre-ville»
Montréal (Québec) H3C 3A7
Téléphone : (514) 340-4015
Télécopieur : (514) 340-5867

Subvention CRSNG OGP1N 013

Mars 1994

INTRODUCTION

1. OBJECTIF

- Concevoir un logiciel de choix de conditions de coupe simple, efficace, bon marché et destiné principalement aux PME.

2. POURQUOI LA LOGIQUE FLOUE?

- Efficacité dans des conditions incertaines;

- possibilité unique d'exprimer la connaissance qualitative d'un expert en forme linguistique proche du langage courant (exemple : si le matériau est dur et si la profondeur de coupe est petite, ALORS la vitesse de coupe sera grande;

- compression des données et grande vitesse d'exécution.

BASE THÉORIQUE DU LOGICIEL FUZZY-FLOU

1. MOTEURS D'INFÉRENCE

$$U' = (A', B', \ldots, C') \circ R \qquad (1)$$

où : U' - conclusion

A', B' - variables linguistiques (observations)

O - règle de composition d'inférence

R - base de règles (connaissances)

LE LOGICIEL FUZZY-FLOU PEUT UTILISER QUATRE MOTEURS D'INFÉRENCE

$$U'(u) = \max_{r} \sup_{\substack{x\in \boldsymbol{X}\\ y\in \boldsymbol{Y}\\ \dots\\ z\in \boldsymbol{Z}}} \min\left[\min(C'(z),\dots,B'(y),A'(x)),\min(A_i^{(r)}(x),B_j^{(r)}(y),\dots C_p^{(r)}(z),U_k^{(r)}(u))\right] \quad (2)$$

représenté symboliquement par MAX-SUPMIN-MIN-MIN (abrégé par MA-SMI-MI)

$$U'(u) = \max_{r} \sup_{\substack{x\in \boldsymbol{X}\\ y\in \boldsymbol{Y}\\ \dots\\ z\in \boldsymbol{Z}}} \left[(C'(z)\cdot\dots\cdot B'(y)\cdot A'(x))\cdot(A_i^{(r)}(x)\cdot B_j^{(r)}(y)\cdot\dots\cdot C_p^{(r)}(z)\cdot U_k^{(r)}(u))\right] \quad (3)$$

représenté par MAX-SUPPROD-PROD-PROD (abrégé par MA-SPR-PR)

$$U'(u) = \sum_{r} \sup_{\substack{x\in \boldsymbol{X}\\ y\in \boldsymbol{Y}\\ \dots\\ z\in \boldsymbol{Z}}} \min\left[\min(C'(z),\dots,B'(y),A'(x)),\min(A_i^{(r)}(x),B_j^{(r)}(y),\dots C_p^{(r)}(z),U_k^{(r)}(u))\right] \quad (4)$$

représenté par SUM-SUPMIN-MIN-MIN (abrégé par SU-SMI-MI)

$$U'(u) = \sum_{r} \sup_{\substack{x\in \boldsymbol{X}\\ y\in \boldsymbol{Y}\\ \dots\\ z\in \boldsymbol{Z}}} \left[(C'(z)\cdot\dots\cdot B'(y)\cdot A'(x))\cdot(A_i^{(r)}(x)\cdot B_j^{(r)}(y)\cdot\dots\cdot C_p^{(r)}(z)\cdot U_k^{(r)}(u))\right] \quad (5)$$

représenté respectivement par SUM-SUPPROD-PROD-PROD (abrégé par SU-SPR-PR).

LOGICIEL FUZZY-FLOU

MATÉRIEL NÉCESSAIRE

- IMB AT 286, 386, 486 et compatibles
- carte graphique EGA, VGA

CAPACITÉS

- 4 moteurs d'inférence
- 300 règles au maximum
- Chaque règle peut contenir jusqu'à **5 conditions** et **2 conclusions indépendantes.**
- Chaque condition et conclusion peut utiliser jusqu'à **11 variables linguistiques.**
- «Defuzzification» par le centre de gravité.

CE LOGICIEL PEUT ÊTRE UTILISÉ COMME

- système d'aide à la décision et
- contrôleur.

EXEMPLE DE CHOIX ET DE MODIFICATIONS DES CONDITIONS DE COUPE EN TOURNAGE

CHOIX DES CONDITIONS DE COUPE

(données d'entrée selon Machining Data Handbook)

- dureté du matériau à usiner
- profondeur de coupe
- contenu en carbone
- usinabilité

CONCLUSIONS

- vitesse de coupe
- avance de coupe

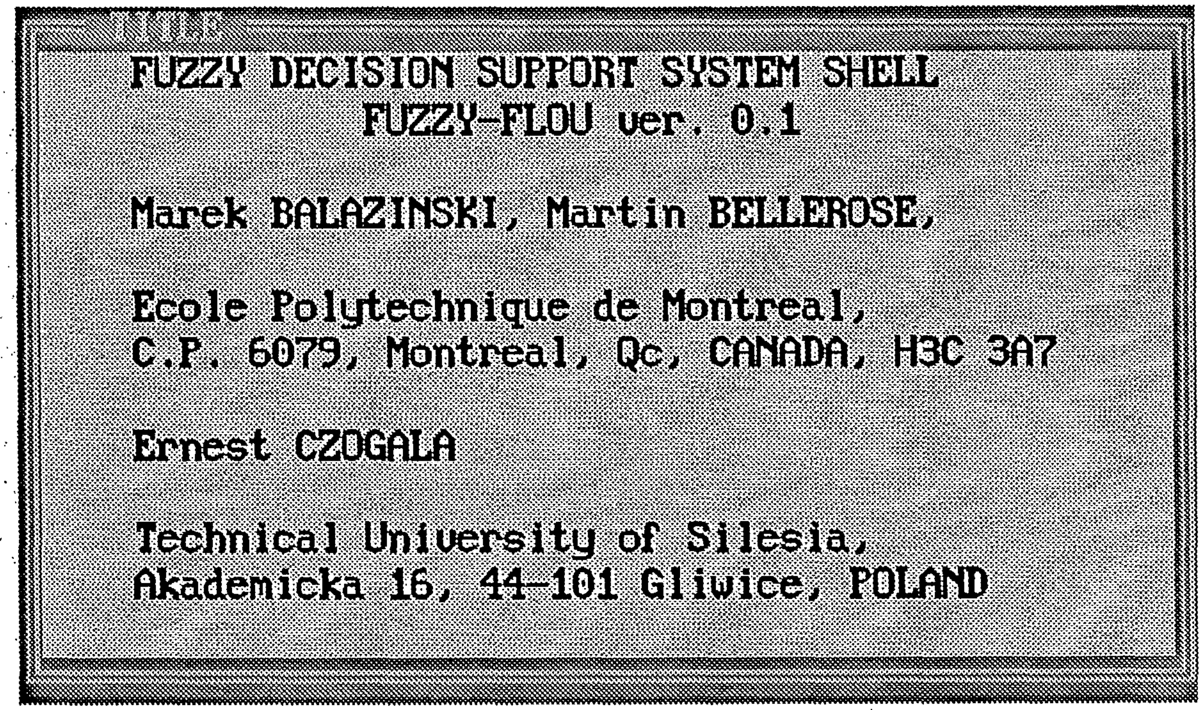
MODIFICATIONS DES CONDITIONS DE COUPE POUR LES ADAPTER AU SYSTÈME «MACHINE-PIÈCE-OUTIL» PARTICULAIRE

DONNÉES D'ENTRÉE

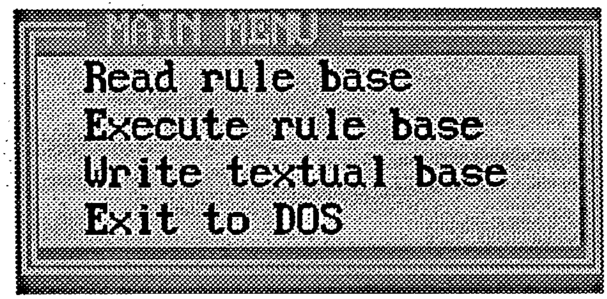
- qualité de la machine
- rigidité du système «machine-pièce-outil»
- précision d'usinage désirée

CONCLUSIONS

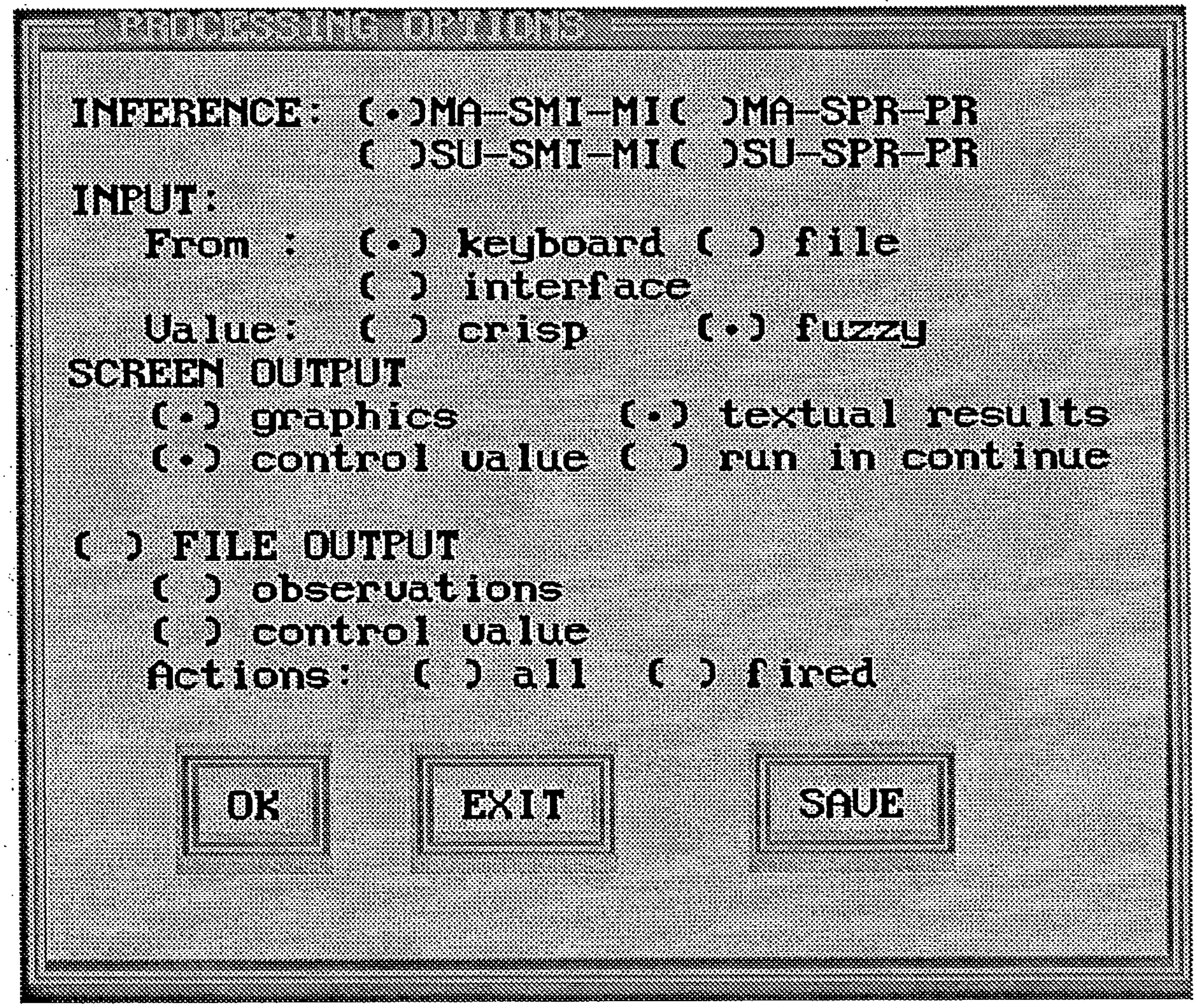
- facteur multiplicatif de vitesse de coupe
- facteur multiplicatif de l'avance



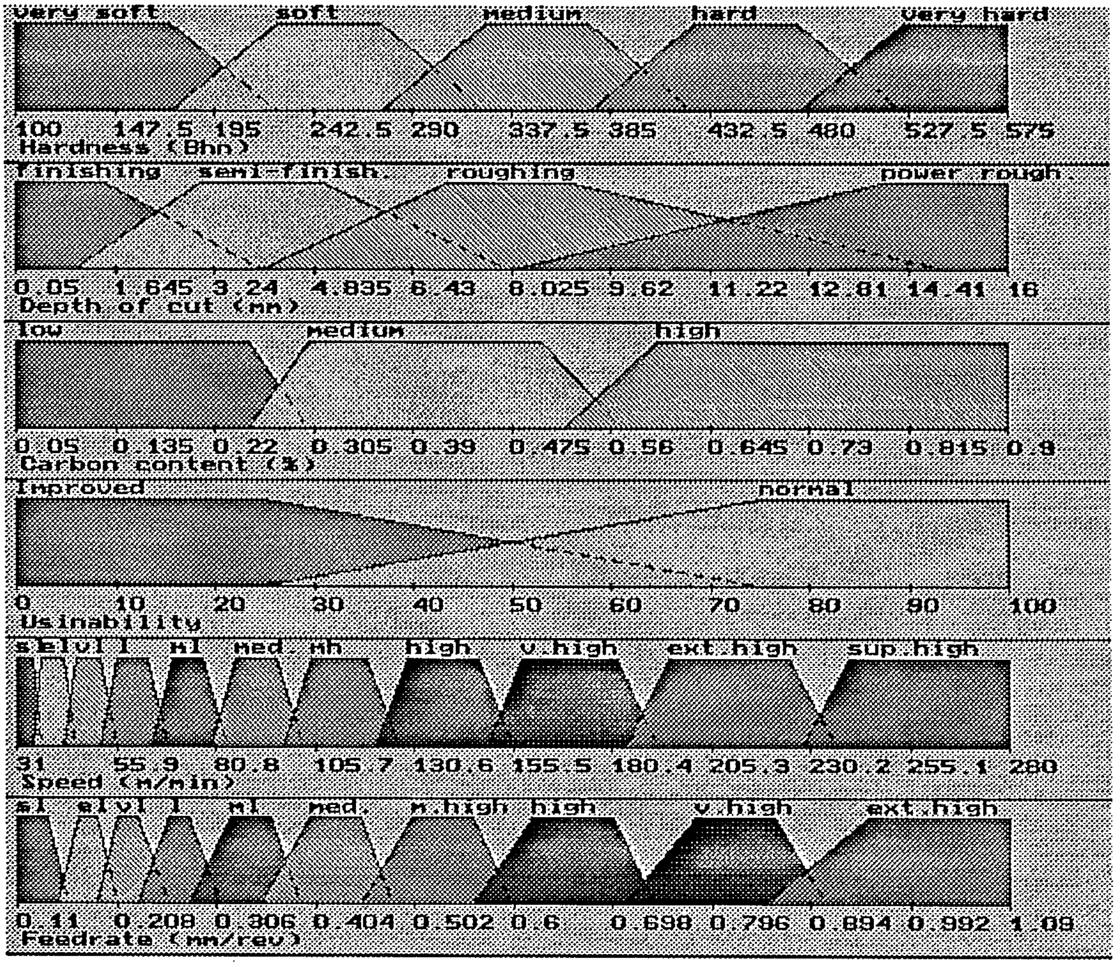
PAGE TITRE DU SYSTÈME AIDE À LA DÉCISION FUZZY-FLOU



MENU PRINCIPAL DU LOGICIEL FUZZY-FLOU



OPTIONS D'UTILISATION DU LOGICIEL FUZZY-FLOU



REPRÉSENTATION GRAPHIQUE DES VARIABLES LINGUISTIQUES,
DES CONDITIONS ET DES CONCLUSIONS
POUR LE CHOIX DES CONDITIONS DE COUPE

EXEMPLE DES DONNES ET DES REGLES "coupeang.dat"

```
# 1 Hardness (Bhn)
( 100 175 0 50 1 very soft )
( 225 275  50 50 1 soft )
( 325 375 50 50 1 medium )
( 425 475 50 50 1 hard )
( 525 575 50 0 1 very hard )
# 1 Depth of cut (mm)
( 0.05 1.5 0 2.5 1 finishing )
( 3 5 2 3 1 semi-finish.)
( 7 9 3 6 1 roughing )
( 14 16 6 0 1 power rough. )
# 1 Carbon content (%)
( 0.05 0.25 0 0.05 1 low )
( 0.30 0.50 0.05 0.07 1 medium )
( 0.60 0.90 0.08 0.00 1 high )
# 1 Usinability
( 0 25 0 50 1 Improved)
( 75 100 50 0 1 normal)
~ 1 Speed (m/min)
( 31 35 0 2 1 sl )
( 37 43 2 3 1 el )
( 46 52 3 4 1 vl )
( 56 64 4 5 1 l )
( 70 78 5 6 1 ml )
( 86 96 6 7 1 med. )
( 105 119 7 8 1 mh )
( 129 147 8 9 1 high )
( 158 182 9 10 1 v.high )
( 195 225 11 12 1 ext.high )
( 240 280 12 0 1 sup.high )
~ 1 Feedrate (mm/rev)
( 0.11 0.14 0.0 0.02 1 sl )
( 0.17 0.19 0.02 0.02 1 el )
( 0.21 0.23 0.02 0.03 1 vl )
( 0.26 0.28 0.03 0.03 1 l )
( 0.32 0.36 0.04 0.03 1 ml )
( 0.40 0.45 0.05 0.03 1 med. )
( 0.50 0.56 0.05 0.04 1 m.high )
( 0.62 0.70 0.06 0.04 1 high )
( 0.78 0.86 0.07 0.05 1 v.high )
( 0.95 1.09 0.10 0.00 1 ext.high )
*
( 1 1 1 1 11 2 )
( 1 2 1 1 10 7 )
( 1 3 1 1 8 9 )
( 1 4 1 1 7 10 )
( 2 1 1 1 11 2 )
( 2 2 1 1 10 7 )
( 2 3 1 1 9 9 )
( 2 4 1 1 7 10 )
( 1 1 2 1 10 2 )
( 1 2 2 1 9 7 )
( 1 3 2 1 8 9 )
( 1 4 2 1 7 10 )
( 2 1 2 1 9 2 )
( 2 2 2 1 8 7 )
( 2 3 2 1 7 9 )
( 2 4 2 1 6 10 )
( 3 1 2 1 8 2 )
( 3 2 2 1 7 7 )
( 3 3 2 1 6 9 )
( 4 1 2 1 6 1 )
( 4 2 2 1 5 4 )
( 4 3 2 1 3 6 )
( 5 2 2 1 4 1 )
( 5 2 2 1 2 2 )
( 5 2 2 1 1 4 )
( 1 1 1 2 9 2 )
( 1 2 1 2 8 7 )
( 1 3 1 2 7 9 )
( 1 4 1 2 6 10 )
( 2 1 1 2 8 2 )
( 2 2 1 2 7 7 )
( 2 3 1 2 6 9 )
( 2 4 1 2 5 10 )
( 2 1 2 2 8 2 )
( 2 2 2 2 7 7 )
( 2 3 2 2 6 9 )
( 2 4 2 2 4 10)
( 3 1 2 2 7 2 )
( 3 2 2 2 6 6 )
( 3 3 2 2 5 7 )
( 4 1 2 2 5 1 )
( 4 2 2 2 4 4 )
( 4 3 2 2 3 6 )
( 5 1 2 2 4 1 )
( 5 2 2 2 2 2 )
( 5 3 2 2 1 4 )
( 2 1 3 2 8 2 )
( 2 2 3 2 7 7 )
( 2 3 3 2 5 9 )
( 2 4 3 2 4 10 )
( 3 1 3 2 7 2 )
( 3 2 3 2 6 6 )
( 3 3 3 2 4 7 )
( 4 1 3 2 5 1 )
( 4 2 3 2 4 4 )
( 4 3 3 2 3 6 )
( 5 1 3 2 4 1 )
( 5 2 3 2 2 2 )
( 5 3 3 2 1 4 )
```

EXEMPLE DES DONNES ET DES REGLES EN FORME LINGUISTIQUE "coupeang.reg"

PREMISSE Hardness (Bhn)
very soft= (100 175 0 50 1 very soft)
soft= (225 275 50 50 1 soft)
medium= (325 375 50 50 1 medium)
hard= (425 475 50 50 1 hard)
very hard= (525 575 50 0 1 very hard)

PREMISSE Depth of cut (mm)
finishing= (0.05 1.5 0 2.5 1 finishing)
semi-finish.= (3 5 2 3 1 semi-finish.)
roughing= (7 9 3 6 1 roughing)
power rough.= (14 16 6 0 1 power rough.)

PREMISSE Carbon content (%)
low= (0.05 0.25 0 0.05 1 low)
medium= (0.3 0.5 0.05 0.07 1 medium)
high= (0.6 0.9 0.08 0 1 high)

PREMISSE Usinability
Improved= (0 25 0 50 1 Improved)
normal= (75 100 50 0 1 normal)

CONCLUSION Speed (m/min)
sl= (31 35 0 2 1 sl)
el= (37 43 2 3 1 el)
vl= (46 52 3 4 1 vl)
l= (56 64 4 5 1 l)
ml= (70 78 5 6 1 ml)
med.= (86 96 6 7 1 med.)
mh= (105 119 7 8 1 mh)
high= (129 147 8 9 1 high)
v.high= (158 182 9 10 1 v.high)
ext.high= (195 225 11 12 1 ext.high)
sup.high= (240 280 12 0 1 sup.high)

CONCLUSION Feedrate (mm/rev)
sl= (0.11 0.14 0 0.02 1 sl)
el= (0.17 0.19 0.02 0.02 1 el)
vl= (0.21 0.23 0.02 0.03 1 vl)
l= (0.26 0.28 0.03 0.03 1 l)
ml= (0.32 0.36 0.04 0.03 1 ml)
med.= (0.4 0.45 0.05 0.03 1 med.)
m.high= (0.5 0.56 0.05 0.04 1 m.high)
high= (0.62 0.7 0.06 0.04 1 high)
v.high= (0.78 0.86 0.07 0.05 1 v.high)
ext.high= (0.95 1.09 0.1 0 1 ext.high)

RULE 1
IF Hardness (Bhn) is very soft
AND Depth of cut (mm) is finishing
AND Carbon content (%) is low
AND Usinability is Improved
THEN Speed (m/min) is sup.high
AND Feedrate (mm/rev) is el

RULE 2
IF Hardness (Bhn) is very soft
AND Depth of cut (mm) is semi-finish.
AND Carbon content (%) is low
AND Usinability is Improved
THEN Speed (m/min) is ext.high
AND Feedrate (mm/rev) is m.high

RULE 3
IF Hardness (Bhn) is very soft
AND Depth of cut (mm) is roughing
AND Carbon content (%) is low
AND Usinability is Improved
THEN Speed (m/min) is high
AND Feedrate (mm/rev) is v.high

RULE 4
IF Hardness (Bhn) is very soft
AND Depth of cut (mm) is power rough.
AND Carbon content (%) is low
AND Usinability is Improved
THEN Speed (m/min) is mh
AND Feedrate (mm/rev) is ext.high

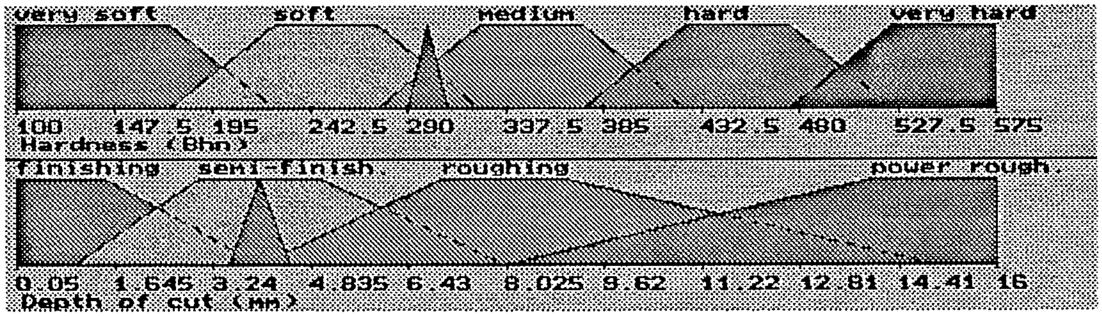
RULE 5
IF Hardness (Bhn) is soft
AND Depth of cut (mm) is finishing
AND Carbon content (%) is low
AND Usinability is Improved
THEN Speed (m/min) is sup.high
AND Feedrate (mm/rev) is el

RULE 6
IF Hardness (Bhn) is soft
AND Depth of cut (mm) is semi-finish.
AND Carbon content (%) is low
AND Usinability is Improved
THEN Speed (m/min) is ext.high
AND Feedrate (mm/rev) is m.high

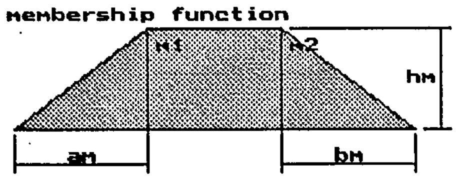
RULE 7
IF Hardness (Bhn) is soft
AND Depth of cut (mm) is roughing
AND Carbon content (%) is low
AND Usinability is Improved
THEN Speed (m/min) is v.high
AND Feedrate (mm/rev) is v.high

RULE 8
IF Hardness (Bhn) is soft
AND Depth of cut (mm) is power rough.
AND Carbon content (%) is low
AND Usinability is Improved
THEN Speed (m/min) is mh
AND Feedrate (mm/rev) is ext.high

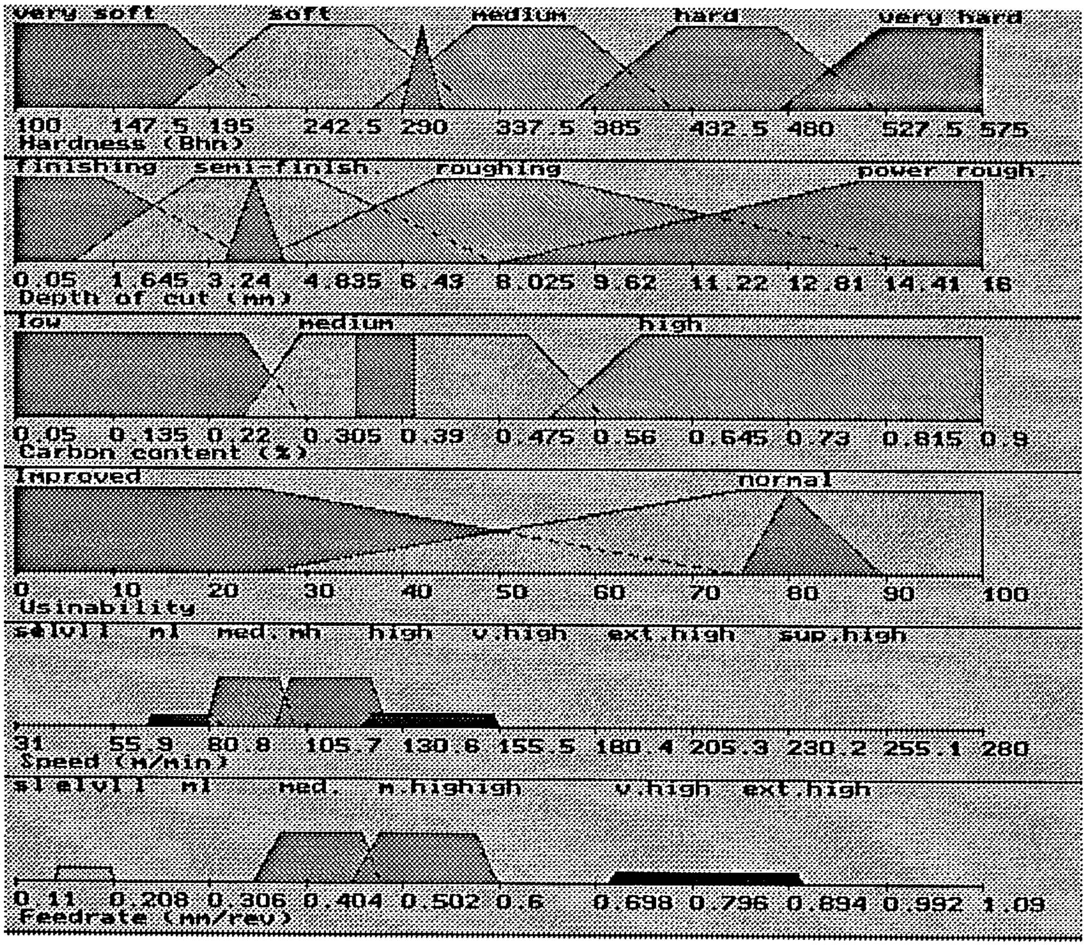
RULE 9
IF Hardness (Bhn) is very soft
AND Depth of cut (mm) is finishing
AND Carbon content (%) is medium

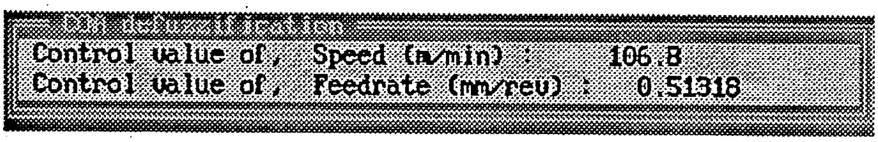


Input observation 2 Depth of cut (mm)
m1= 4
m2= 4
am= 0.5
bm= 0.5
hm= 1

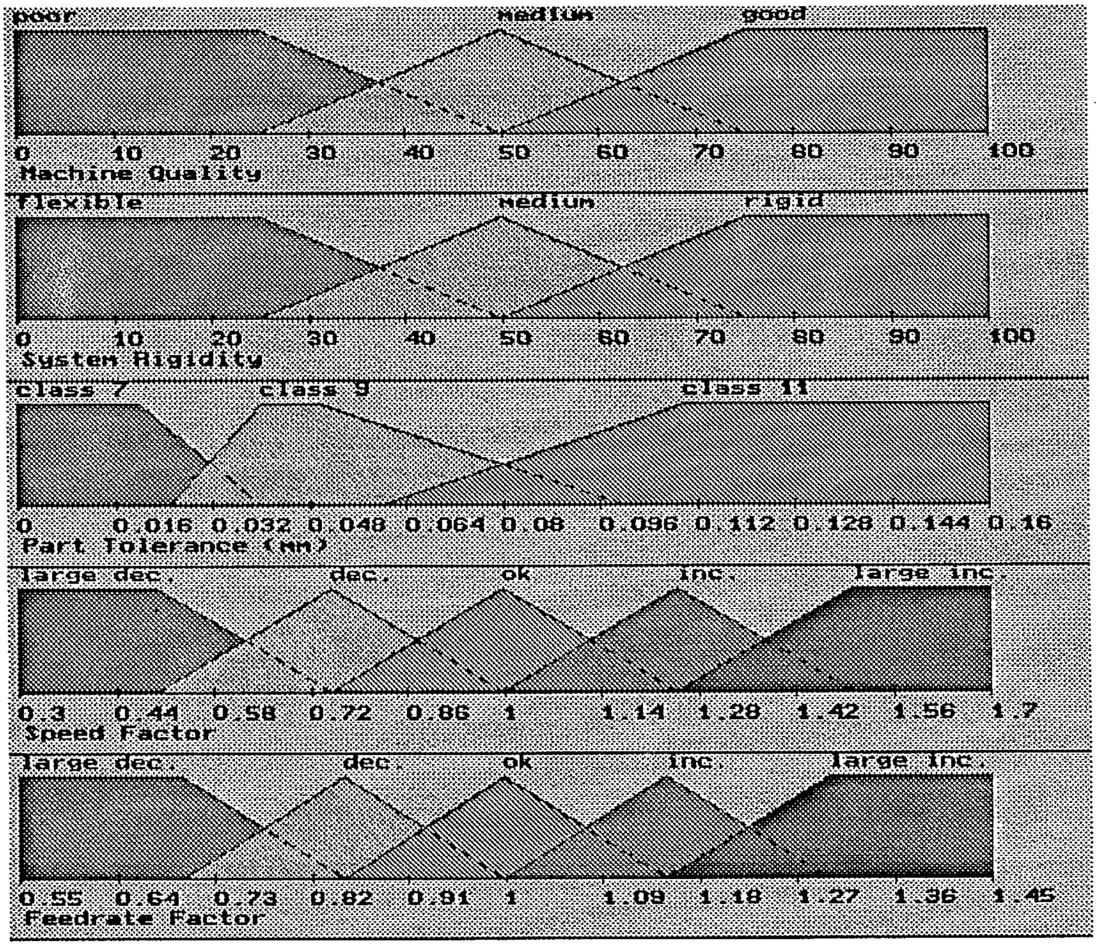


EXEMPLE D'INTRODUCTION DES OBSERVATIONS POUR LE CHOIX DES CONDITIONS DE COUPE

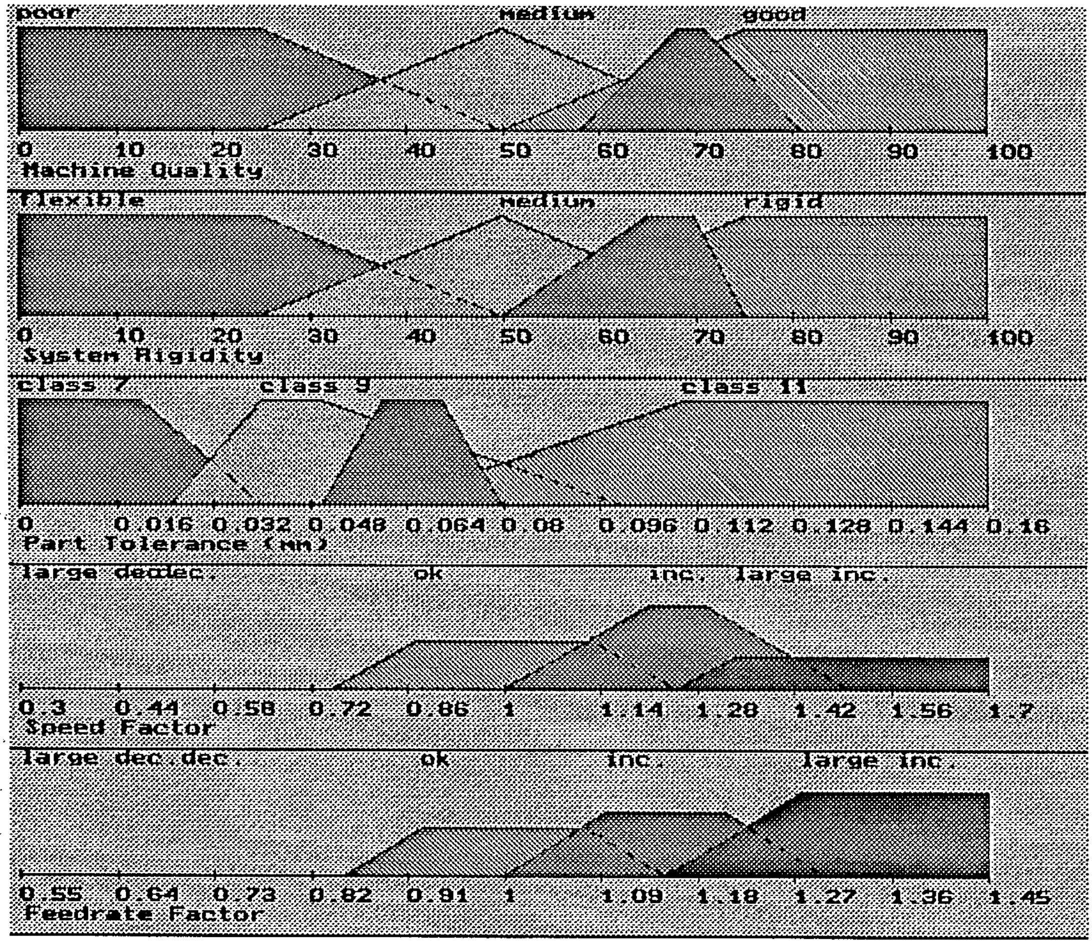




EXEMPLE DE CHOIX DES CONDITIONS DE COUPE
CONCLUSIONS EN FORME LINGUISTIQUE ET NUMÉRIQUE



REPRÉSENTATION GRAPHIQUE DES VARIABLES LINGUISTIQUES DES CONDITIONS ET DES CONCLUSIONS POUR LA CORRECTION DES CONDITIONS DE COUPE



Control value of, Speed Factor : 1.2276
Control value of, Feedrate Factor : 1.193

EXEMPLE DE LA CORRECTION DES CONDITIONS DE COUPE
CONCLUSIONS EN FORMES LINGUISTIQUE ET NUMÉRIQUE

CONCLUSION

L'exemple présenté montre que la logique floue est un outil approprié pour traiter les problèmes de fabrication :

- La méthode de raisonnement approximatif est appropriée pour le problème du choix des conditions de coupe parce qu'elle permet d'utiliser la connaissance heuristique disponible dans les ateliers de fabrication.

- Les performances et la robustesse de cette méthode sont adéquates pour les applications pratiques dans les ateliers de fabrication.

- Grâce à la compression des données, le nombre de règles est considérablement réduit.

- L'utilisation des variables linguistiques simplifie la préparation de la base de connaissances et facilite la consultation.

@ AutoSoft

AutoSoft

5655, Élie Avenue, #404
St. Hubert, (Québec)
J3Y 6P3

Specialiston ind. control

SYSTÈMES DE CONTRÔLES - LOGIQUE FLOUE
CONTROL SYSTEMS - FUZZY LOGIC

Bruno Arnold
Stéphane Brûlé
Mario Deschênes
Jean-François Ouellet

9 mars 1994

@AutoSoft

AutoSoft
5655, av. Élie, #404
Saint-Hubert, (Québec)
J3Y 6P3
Tél.:(514) 656-2323
Fax:(514) 656-1009

Bruno Arnold
Stéphane Brulé
Mario Deschênes
Jean-François Ouellet

RÉSUMÉ D'EXPOSÉ

1. Description du projet

Notre projet est le développement d'algorithmes d'adaptation autour de la logique floue afin de la rendre auto-corrective.

Le projet vise à rehausser significativement le calibre des régulateurs analogiques avec l'approche S.I.F.A.N.A.

Ces techniques logicielles sont ensuite intégrées dans l'automate AutoSoft. Elles permettent alors d'agir concrètement sur un procédé quelconque.

2. Survol de la logique floue classique

Il s'agit d'une approche intuitive contrairement à une approche de modélisation. Son but est de quantifier des phénomènes dont nous ne possédons qu'une perception qualitative du fonctionnement.

L'annexe "A" du plan d'affaires peut être considéré comme référence de base.

La logique floue apporte cependant quelques contraintes à l'utilisateur car les ajustements sont très longs et ne s'effectuent que par "essais et erreurs", d'où le besoin d'un système adaptatif.

3. Sommaire du SIFANA

Le mot SIFANA signifie : **S**ystème d'**i**nférence **f**lou **à** **n**oeuds **a**daptatifs.

L'approche SIFANA :
- est intuitive
- possède très peu de paramètres à configurer
- est à la portée d'un opérateur averti
- est auto-adaptative
- accepte plus d'un capteur en entrée et en sortie

Ce système est applicable autant pour les procédés qui sont linéaires ou non, peu ou non connus, chaotiques et dont la dynamique peut varier.

Le schéma bloc décrit son architecture de fonctionnement.

4. **Résultats obtenus**

Exemple d'un pendule inverse :

- quelle approche doit prendre un utilisateur de SIFANA;
- apprentissage : résultats des antécédences et des conséquences;
- essai d'un asservissement type avec un angle de 10 degrés;

5. **Avantages majeurs**

1- réduction du temps de mise en oeuvre;
2- protège contre les impondérables;
3- ouvre de nouvelles avenues au contrôle de procédés complexes.

6. **Impacts sociaux**

1- Le SIFANA permet d'augmenter la popularité des technologies à logique floue afin de viser une certaine reconnaissance ou acceptance de la part de l'industrie du contrôle.

2- Libère l'ingénieur des contraintes de modélisation et d'optimisation.

7. **Marchés visés**

Industriels :
- neutralisation du pH;
- neutralisation du pH simultanément avec la régulation du chlore;
- contrôle des générateurs d'ozone haute puissance d'Envitech Inc.;
- régulation de procédés chimiques;
- régulation générale et/ou formation en systèmes flous.

Commerciaux (contrôle du bâtiment) :

- aide à l'optimisation des économies d'énergie avec les experts en contrôle du bâtiment de Contrologie Inc.

8. **Impacts du projet sur l'entreprise en phase de démarrage**

Phases du projet :
1) Étude de faisabilité
2) Recherche théorique et choix des méthodes
3) Orientation du projet vers un SIFANA
4) Développements mathématiques et théoriques du système
5) Programmation et premiers essais du système
6) Tests avec procédés simulés
7) Tests avec des procédés réels (pendule inverse et pH-cl)
8) Mise en marché et support des clients (formation, etc.)

Seules les étapes 7 et 8 restent à compléter.

Ce projet s'intègre dans le système de contrôle actuel d'AutoSoft et devrait apporter une croissance et des emplois intéressants tel qu'estimé dans le plan d'affaires.

@AutoSoft

Bruno Arnold
Stéphane Brûlé
Mario Deschênes
Jean-François Ouellet

AutoSoft
5655, Elie ave., #404
St. Hubert (Québec)
J3Y 6P3
Tel.:(514) 656-2323
Fax:(514) 656-1009

ABSTRACT

1. Project Description

This project consists in the development of adaptation algorithms to modify actual fuzzy logic techniques into a general adaptive regulation control system.

The main goal is to significantly increase performance and grade of analog regulators with the Adaptive Network-based Fuzzy Inference System - ANFIS - approach.

Our physical control system, named AutoSoft, applies those sophisticated software techniques. Once combined, they generate all necessary concrete actions on a process.

2. Overview of classical fuzzy logic

The control approach under fuzzy logic is intuitive, rather than modelling as in common design approach. Fuzzy concept's goal is to quantify phenomena of which we only have qualitative perception.

Appendix A, contained in the business plan, can be considered a basic reference.

In spite of its advantages, fuzzy logic imposes many constraints on the user in the adjustment of fuzzy sets: the longest part of a fuzzy startup. Furthermore, these settings can only be done on a "trial and error" basis, reinforcing the need for an adaptive system.

3. Adaptive Network-based Fuzzy Inference System (ANFIS)

The ANFIS approach:
- is intuitive
- has only a few parameters to configure
- is self-adaptive
- accepts many inputs as well as outputs

ANFIS is suitable for processes being either linear or non-linear, either well known, misunderstood or chaotic, and of which dynamics may vary.

4. Results obtained

Example of an inverted pendulum:

- the approach the ANFIS' user should take;
- results of the final antecedents and the final consequences;
- attempting a closed-loop control with a starting angle of 10 degrees;

5. Major advantages

1- reduced start up time;
2- protection against imponderables;
3- new possibilities for complex processes.

6. Social impacts

1- Increased acceptance of fuzzy technologies brought by ANFIS could reach a point of global recognition in industrial control.
2- Relieves engineers of the modelling and optimization burden.

7. Target markets

Industrial:
- pH neutralization;
- pH neutralization and chlorination regulation simultaneously;
- high power ozone generator control;
- chemical process regulation;
- fuzzy system training and seminars.

Commercial (building environment control): - help in optimizing energy savings.

8. Competitive situation

In our opinion, AutoSoft is the absolute leader in its field. There is no other similar system currently on the market. However, a definite trend towards fuzzy logic is predictable as some of the largest controller manufacturers show interest in it. Moreover, no one offers self-adaptive features in their fuzzy products.

9. Consequences of this project on our starting company

Project's steps:
1) Feasibility study
2) Theoretical research and orientation on the ANFIS approach
3) System development, programming and system's first tries
4) Tests with a simulated process
5) Tests with real processes (inverted pendulum and pH-Cl)
6) Production, sales and customer support (training, etc.)

We are now at step 5.

This project is part of AutoSoft's control system. As shown in our business plan, it should achieve above average growth and create many employments.

@ AutoSoft

Block diagram of ANFIS (fuzzy controler) and a process

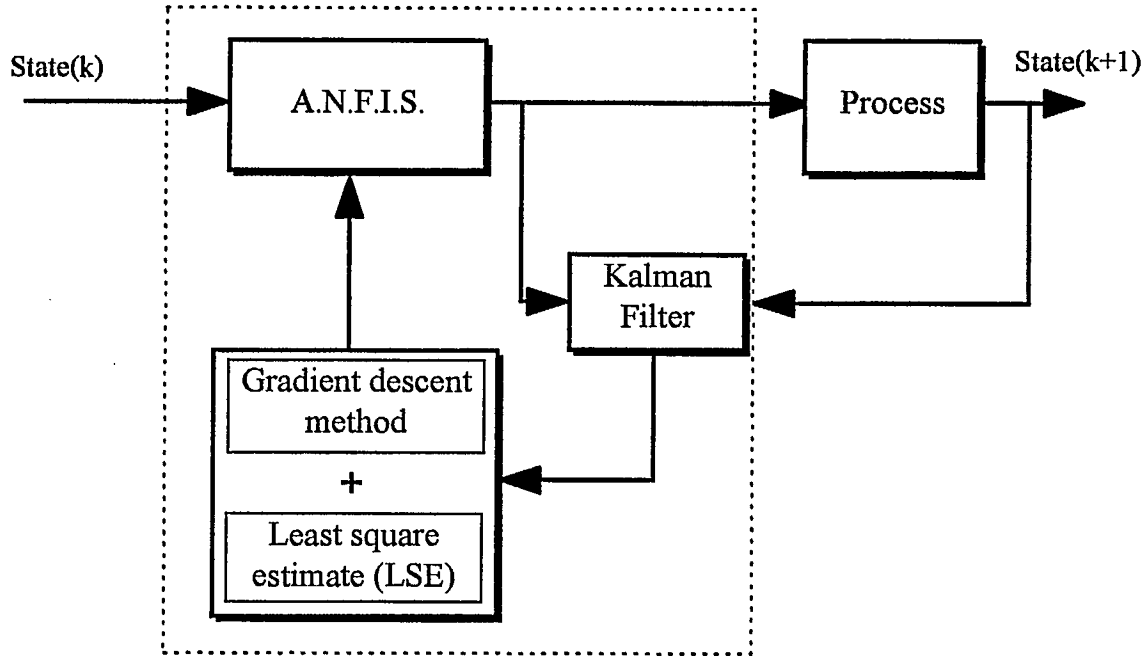


Figure 1

@ AutoSoft

ANFIS : Adaptive-Network-Based Fuzzy Inference System

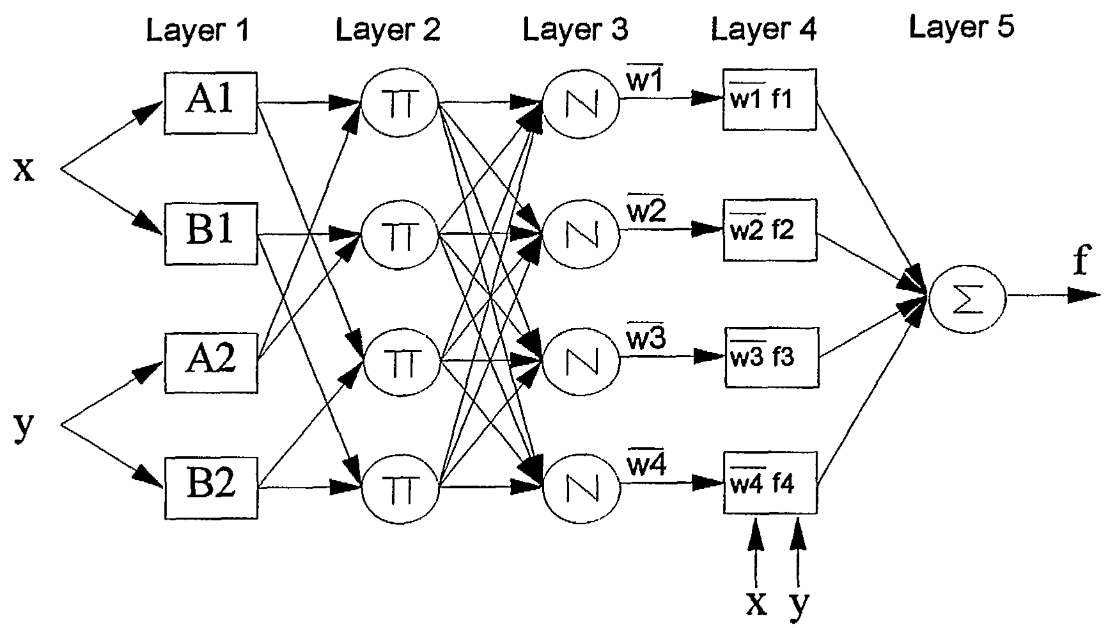


Figure 2

@ AutoSoft

Example of an inverted pendulum

$$\ddot{\Theta} = \frac{g*\sin\Theta + \cos\Theta * \left(\frac{-F - m*l*\Theta^2*\sin\Theta}{m_c+m}\right)}{l*\left(\frac{4}{3} - \frac{m*\cos^2\Theta}{m_c+m}\right)}$$

theta:	angle of the pole
g:	acceleration due to gravity 9.8 m/s^2
m_c:	mass of the cart 1.0 kg
m:	mass of pole 0.1 kg
l:	half-length of pole 0.5 m
F:	force applied in newtons

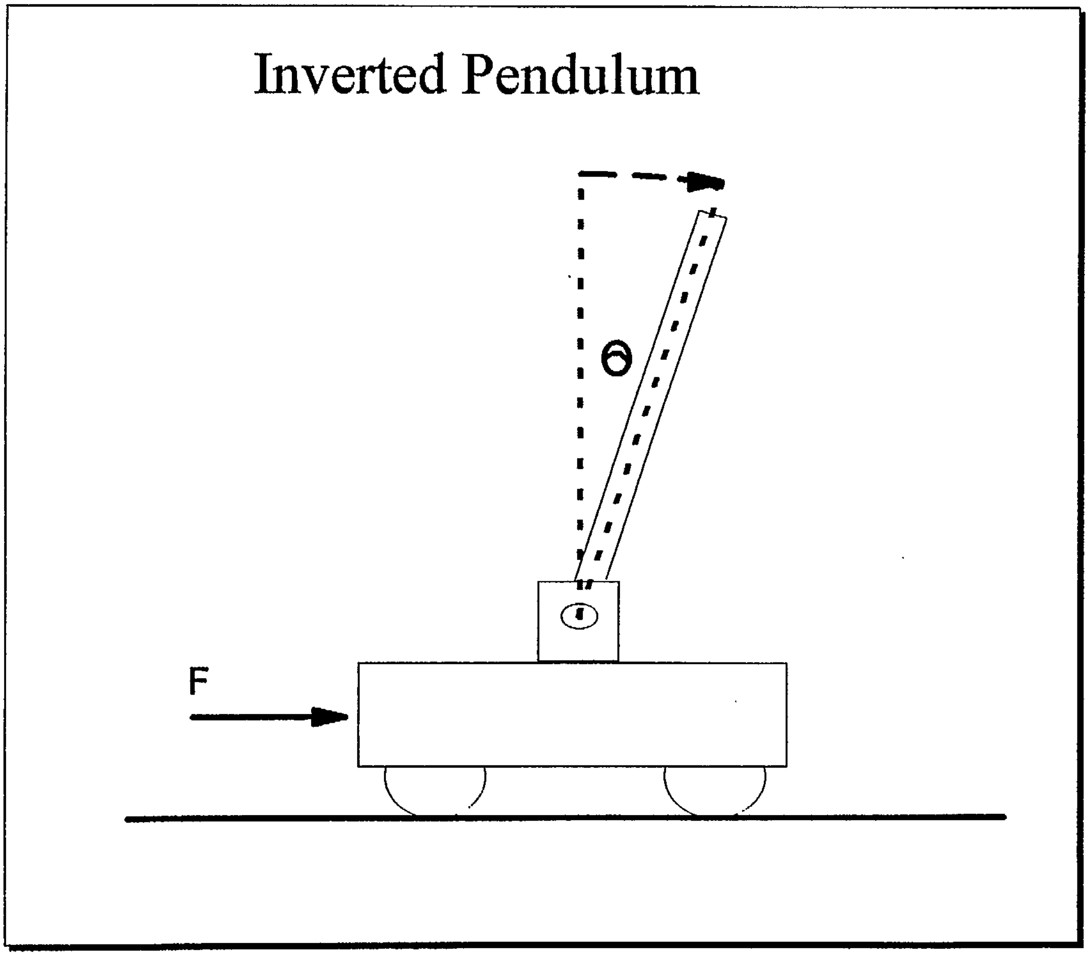


Figure 3

@ AutoSoft

Initial and final fuzzy sets for the inverted pendulum

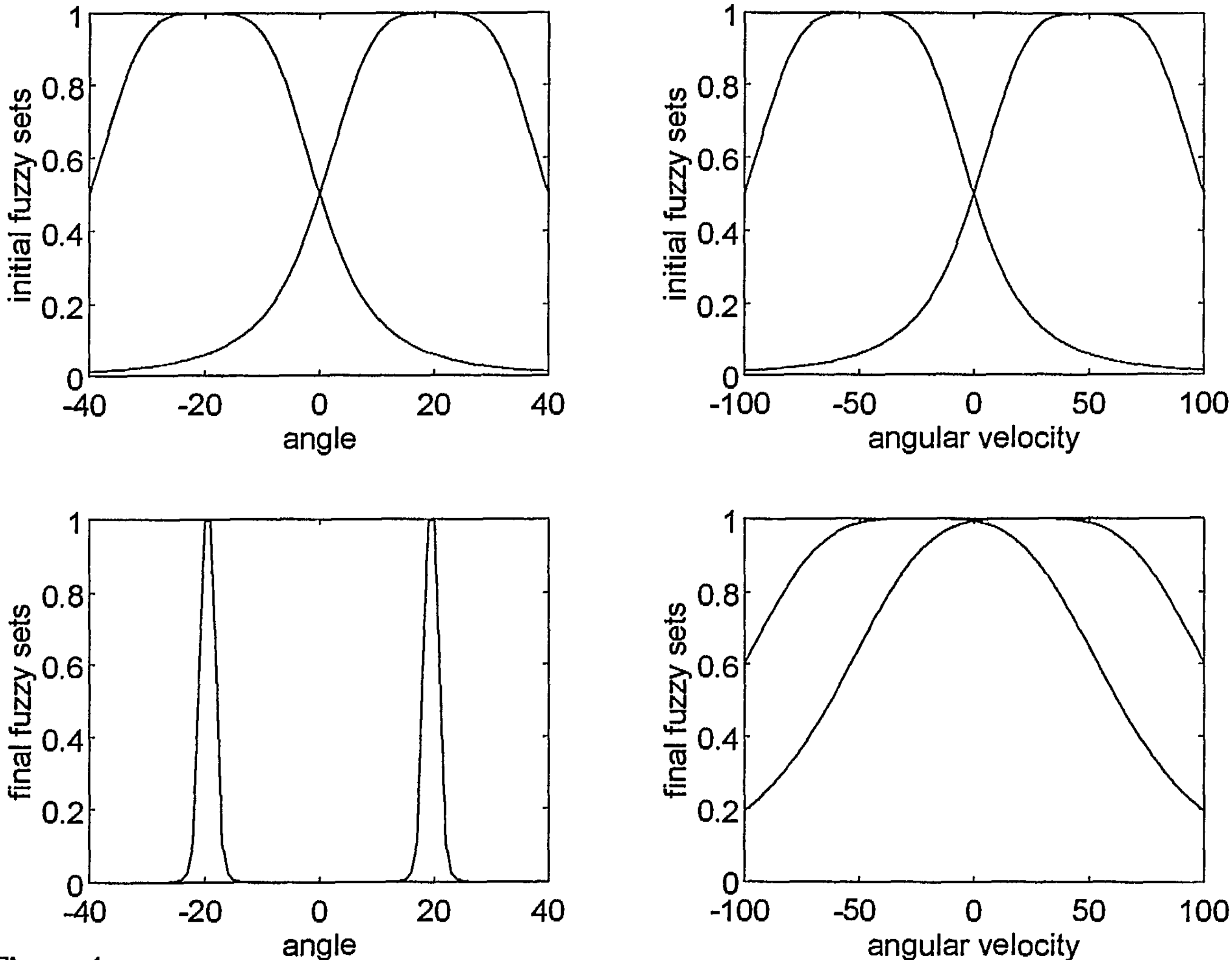


Figure 4

@ AutoSoft

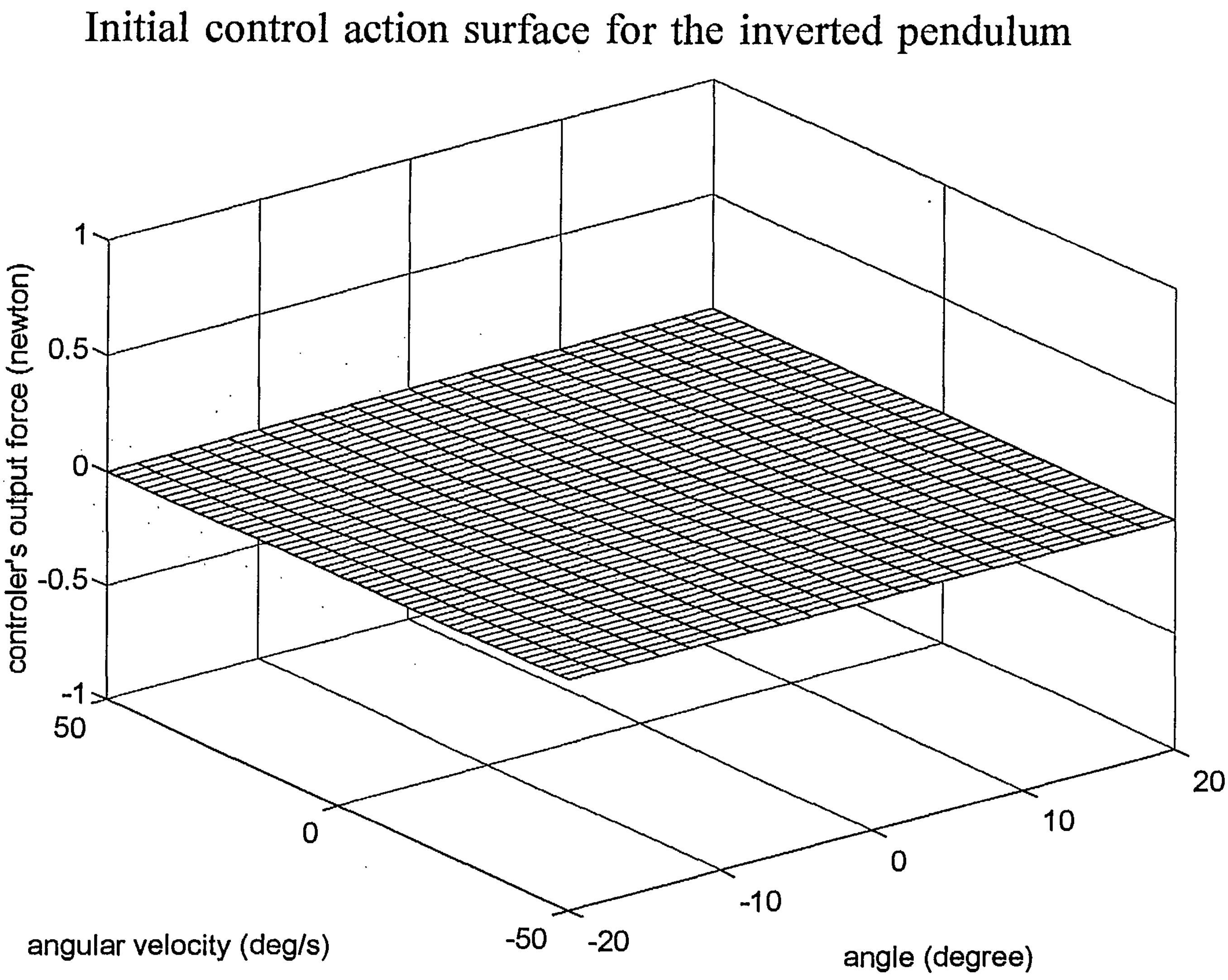


Figure 5

@ AutoSoft

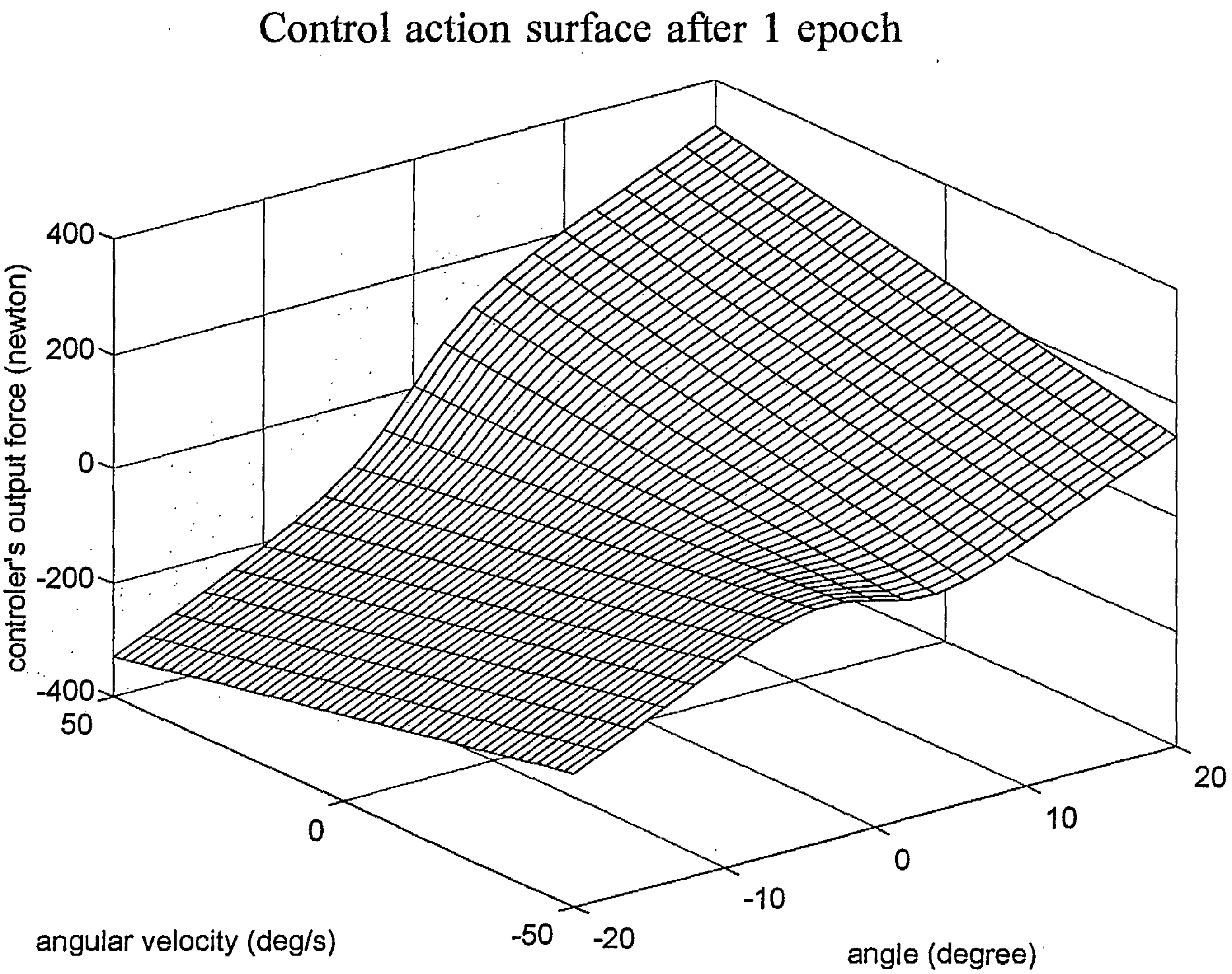


Figure 6

@ AutoSoft

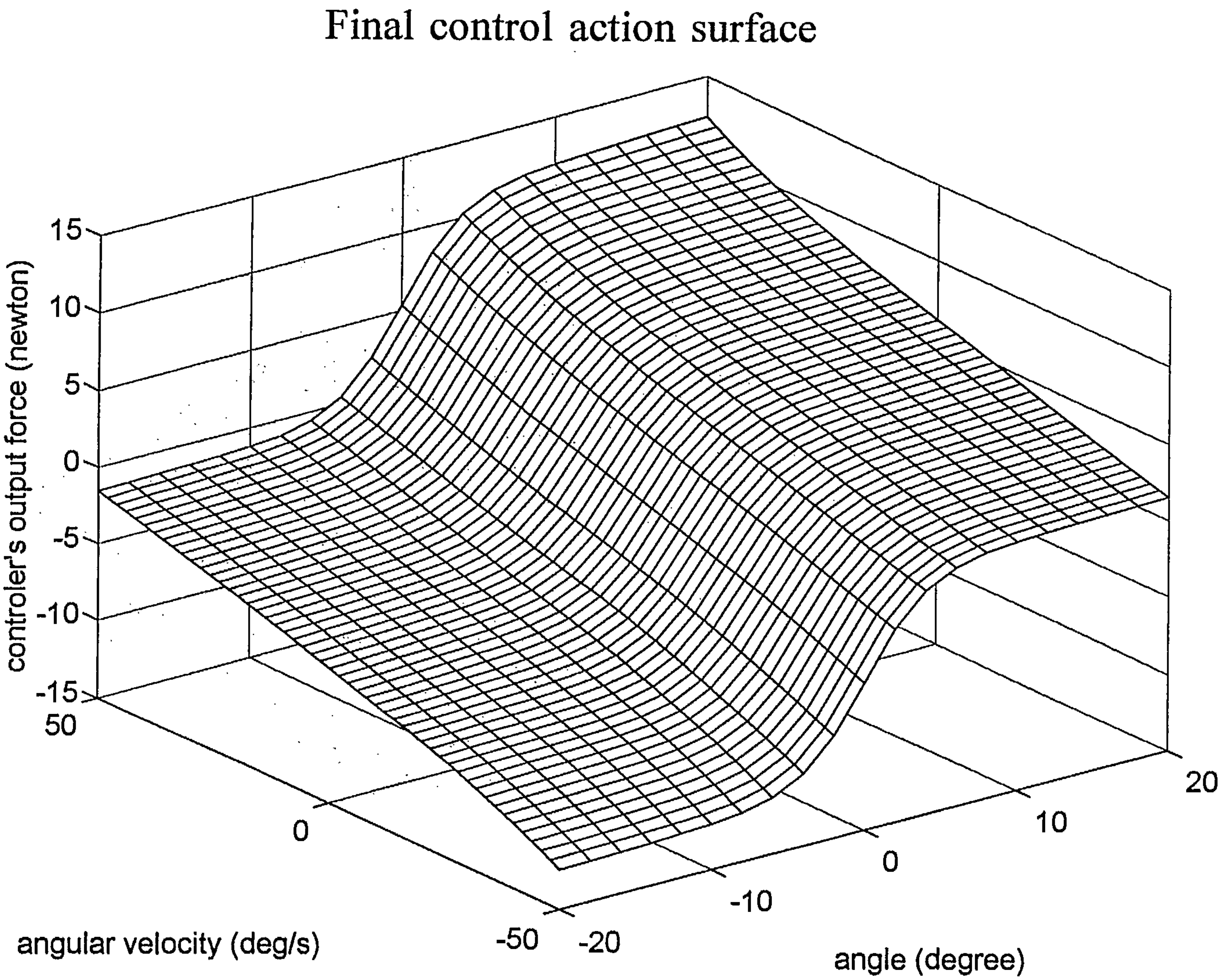


Figure 7

@ AutoSoft

Some results for the inverted pendulum

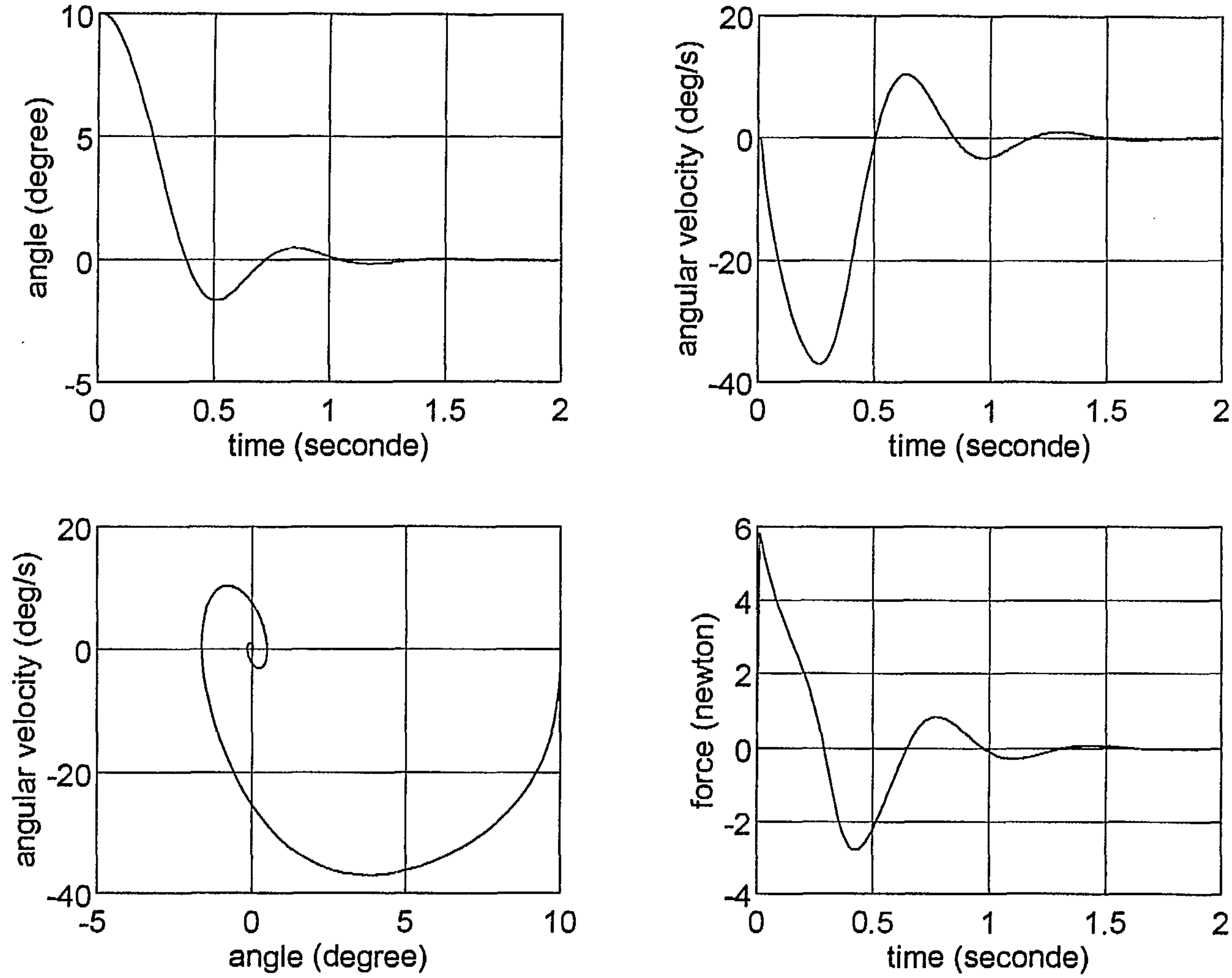


Figure 8

Comparison between 1st order PID controler and ANFIS in ON-LINE learning mode for motor velocity control

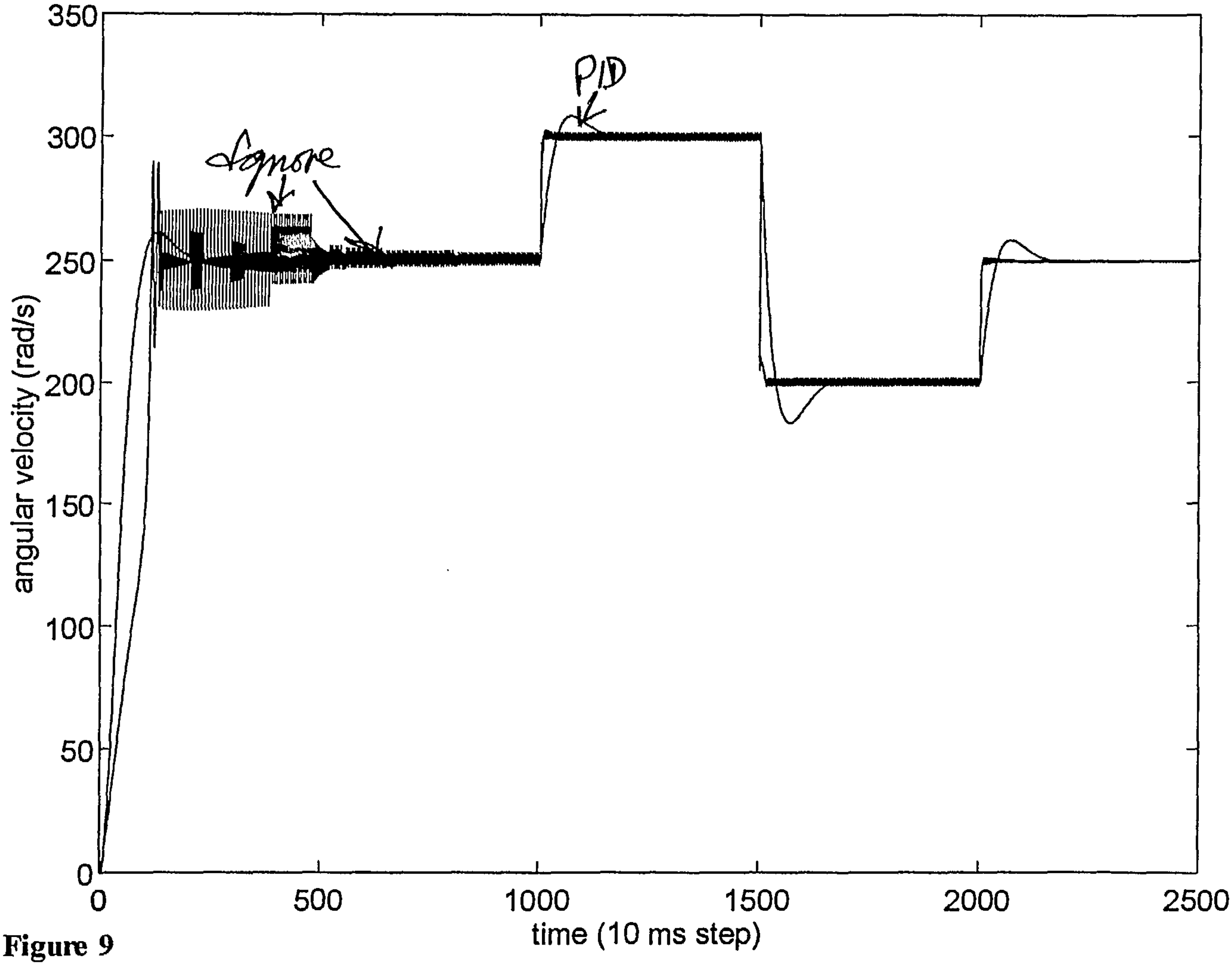


Figure 9