Trip to Boston for Participation in CACSD'83

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TRIP TO BOSTON FOR PARTICIPATION IN CACSD'83

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LUND INSTITUTE OF TECHNOLOGY
MAY 1984
TRIP TO BOSTON FOR PARTICIPATION IN CACSD '83

Abstract

This report summarizes experiences and conclusions from participation in the second IEEE Computer Aided Control System Design Symposium. The travel was supported by STU under contract No 83-5184.
TRIP TO BOSTON FOR PARTICIPATION IN CACSD '83

Karl Johan Aström

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       Robotics lectures
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1. INTRODUCTION

There is a growing interest in computer aided design tools for control system engineering. This symposium was the 2nd symposium in this field arranged by the IEEE. Although we have done extensive research in this area we did not have possibilities to participate in the first symposium due to lack of funds. This time STU has generously provided travel support. The motivation for this is the planned program (ramprogram) in the field. The background for the symposium is summarized in Appendix A. The program for the symposium is listed in Appendix B. There were extremely good facilities for demonstration in the Kresge auditorium at MIT, where General Electric had supplied equipment for projection of colour video pictures on a big screen. There were about 300 participants. It was clear that the area now attracts substantial industrial interests. The participants, which are listed in Appendix C, were evenly distributed among industry and university. A list of participants is given in Appendix C. It is interesting to see from the program that there was an attempt to bringing in people from neighbouring fields, for example computer science and computer graphics. There were also presentations of the major projects.

2. PRESENTATIONS

The Department of Automatic Control at Lund Institute of Technology gave two presentations:

K.J. Aström:
"Computer aided control systems engineering - a tool for more realistic teaching"

H. Elmqvist:
"A graphical system for modeling and implementation of control systems"

The first lecture presented experiences from using Simmon in teaching. Live Simmon presentation was also given. The demonstrations went very well. The second demonstration dealt with results from the project LICS, which is supported by STU under project number 83-3647. This presentation went very well too in spite of the fact that the software was moved to an Apollo computer in a very short time and that special hardware was also brought
over for the demonstration. The list of the viewgraphs for my presentation is
given in Appendix D.

3. VISIT TO SSI

There were several companies who expressed an interest in commercial
exploitation of our software. A preliminary screening indicated that
Scientific Systems Inc. in Cambridge Mass was the most suitable partner. We
visited them on two occasions to discuss possibilities for them to market the
software in USA. We agreed that SSI should send us a business plan with a
proposal to be evaluated by STU. This has been followed up and we have
succeeded to team up SSI with Processdata AB in Nynäshamn to secure that
Swedish industry will be involved. Discussion of contract proposals are now
under way.

4. OTHER ACTIVITIES

In connection with the trip I was also invited to present a lecture at MIT on
"Automatic tuning of simple regulators". I also had the possibility to attend a
lecture series by professor Jacob Schwartz at Harvard University. A
presentation of this is included in Appendix F.

5. CONCLUSIONS

The visit was very worthwhile. It was encouraging to see that there is still a
considerable interest in our software developed under STU-contracts 73-3553,
75-2776 and 77-3548. We were delighted to see that these results were still in
the forefront of the field, in spite of the fact that this research results are
now quite old. It was also very encouraging to see the reception of the
graphics facilities developed by Hilding Elmqvist. This is way ahead of any
other graphics in the control systems field. The meeting with SSI may also
open up the possibilities for seriously marketing our software.
6. REFERENCE

APPENDIX A – BACKGROUND

THE SYMPOSIUM

Computer-Aided Control System Design (CACSD) has begun to emerge as an indispensable tool for the control system engineer. A CACSD capability, not only frees the engineer from routine and mundane tasks but also provides a vehicle whereby complex algorithms or control methodologies can be made available to and usable by those unfamiliar with the myriad of details that make the CACSD software efficient. A good CACSD system draws on expertise from many disciplines including aspects of computer science, computer engineering, applied mathematics (for example, using a trye and optimization), as well as control system engineering. The need for such breadth is partially responsible for the paucity of high quality CACSD software today.

One way of fostering a more mature CACSD discipline is to hold a number of workshops or symposiums which are focused on some of the more pertinent topics such as numerically stable algorithms, programming languages, graphic displays, new design procedures, man-machine interfaces, data-base management, control software engineering, and architectures for CACSD packages.

In May 1981, H.A. Spang III organized the first CACSD workshop in Schenectady and Troy, New York under the sponsorship of General Electric and Rensselaer Polytechnic Institute. As a result of this highly successful workshop, the Administration Committee of the IEEE Control Systems Society approved the formation of a Technical Committee on CACSD and appointed H.A. Spang III as the Chairman in June 1981. The Technical Committee was partitioned into two subcommittees: a subcommittee on “algorithms” with A.J. Laub as Chairman and a subcommittee on “design” with C.J. Herget as Chairman.

A Program Committee consisting of C.J. Herget (Chairman), A.J. Laub, E. Polak and D.Q. Mayne then organized the Berkeley Workshop which was held at the University of California, Berkeley in April 1982. The Berkeley Workshop was sponsored by the IEEE Control Systems Society which highlighted various aspects of that meeting in the December 1982 special issue of the Control Systems Magazine. As part of the Berkeley workshop, a strong computer science flavor was injected into some of the sessions. This was enhanced by live presentations of design packages and computer graphics. Some of the demonstrations were run on computers at Berkeley, while most were linked to a computer at the speaker’s home institution via telephone lines and modems. The audience was able to watch the presentations by using a television projection system to project the terminal’s video output onto the auditorium screen.

A motion was subsequently passed at the June 1982 Administration Committee meeting which established a Steering Committee consisting of C.J. Herget, A.J. Laub, and H.A. Spang III to administer and direct further “Symposia on CACSD” on a continuing basis under the auspices of the IEEE Control Systems Society.

This symposium responds to the rapidly growing interest within the IEEE Control Systems Society to develop new control technology through CACSD for the 1980s and beyond. The symposium will encompass two mutually complementary themes:

- Live demonstrations of CACSD packages using a large screen projection television set.
- Papers contributed on recent developments of relevance to CACSD.

The main objectives of the symposium are:

- To provide a forum for control system engineers to exchange ideas and discuss recent developments on control system design packages, algorithms, languages, database management, graphics, and computer system hardware.
- To explore the application of interactive computation and graphics.
- To identify future needs and trends in CACSD.

ORGANIZING COMMITTEE

Mr. Robert R. Strunce, Jr. (Chairman)
The Charles Stark Draper Laboratory, Inc.

Professor Michael Athans
Massachusetts Institute of Technology

Dr. Charles J. Herget
Lawrence Livermore National Laboratory

Professor Alan J. Laub
University of Southern California

Dr. H. Austin Spang, III
General Electric Research & Development Center
**WEDNESDAY, SEPTEMBER 28**

<table>
<thead>
<tr>
<th>Time</th>
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<tbody>
<tr>
<td>8:30</td>
<td>Registration in the Lobby of Kresge Auditorium</td>
</tr>
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</table>
| 9:00   | **INTRODUCTION**  
|        | Chair: R. Strunce  
|        | The C.S. Draper Laboratory, Inc.  
|        | **WELCOME**  
|        | C.S. Draper  
|        | The C.S. Draper Laboratory, Inc.  
|        | Improving The Quality and Productivity of the Control System Design Process  
|        | M. Athans  
|        | Massachusetts Institute of Technology                              |
| 10:00  | Break                                                               |
| 10:30  | **MODELING, IDENTIFICATION AND CONTROL**  
|        | Chair: A.J. Laub  
|        | University of Southern California                                   |
| 11:30  | Interactive Design and Evaluation of Advanced Spacecraft (IDES)  
|        | Computer-Aided Design System  
|        | L.B. Garrett  
|        | NASA Langley Research Center                                        |
| 12:00  | Lunch                                                               |
| 1:30   | **INTERFACE CONCEPTS**  
|        | Chair: P. Houpt  
|        | Massachusetts Institute of Technology                               |
| 2:00   | Functional System Architecture for Advanced Control Design and Analysis  
|        | L.J. Marggraff  
|        | ROLM                                                                |
| 2:30   | Concepts and Requirements for Multivariable Control Design Analysis Package  
|        | S. Pratt  
|        | Honeywell, Inc.                                                     |
| 3:00   | Break                                                               |
| 3:30   | **ADA LANGUAGE AND MICROPROCESSOR UTILIZATION**  
|        | Chair: A. Levis  
|        | Massachusetts Institute of Technology                               |
| 4:00   | Distributed Software for Embedded Computer Systems — An Experience with ADA  
|        | S. Fujita  
|        | Tokyo Institute of Technology, Japan                                |
| 4:30-  | Concurrent Computing With Microprocessors                           |
| 5:00   | E. Ducot and V. Klema  
<p>|        | Massachusetts Institute of Technology                               |
| 5:30-  | Reception                                                            |
| 7:00   | * Demonstration                                                     |</p>
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<td>On the Development of Electrical Engineering Analysis and Design Software for an Engineering Workstation</td>
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<td>G.K.F. Lee Colorado State University H. Elliott University of Massachusetts</td>
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<td>9:00</td>
<td>Two Interactive Programming Packages for Control Systems</td>
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<tr>
<td></td>
<td>M. Jamshidi University of New Mexico</td>
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<td>9:30</td>
<td>DELIGHT MIMO Project</td>
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<td></td>
<td>Chair: D. Frederick Rensselaer Polytechnic Institute</td>
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<td>10:00</td>
<td>Break</td>
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<tr>
<td>10:30</td>
<td>An Interactive Multivariable Control System Design Package</td>
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<tr>
<td></td>
<td>E. Polack and the University of California, Berkeley team</td>
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<td></td>
<td>D.Q. Mayne and the Imperial College London team</td>
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<tr>
<td></td>
<td>C.J. Herget and the Lawrence Livermore National Laboratory team</td>
</tr>
<tr>
<td>12:00</td>
<td>Lunch</td>
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<tr>
<td>1:30</td>
<td>CACSD WORKSTATION DEMONSTRATION</td>
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<td>Chair: C.J. Herget Lawrence Livermore National Laboratory</td>
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<td>2:15</td>
<td>CTRL-C: A Workbench for the Computer-Aided Design of Multivariable Control Systems</td>
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<td>A. Emami Naeni, J. Little, S. Bangert Systems Control Technology, Inc.</td>
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<td>3:00</td>
<td>Break</td>
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<td>RICPACK: Algorithms and Software for Matrix Riccati Equation</td>
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<td>W.F. Arnold and A.J. Laub University of Southern California</td>
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<td>4:00</td>
<td>An Algorithm for Eigenvalue Assignment in Multi-Input Systems</td>
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<td>R.V. Patel Concordia University, Canada</td>
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<td>4:30</td>
<td>Inner-Outer Factorization of Rational Matrices</td>
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<td>B-C Chang and J.B. Pearson Rice University</td>
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<td><strong>GRAPHICS</strong></td>
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<td>Lawrence Livermore National Laboratory</td>
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<td><strong>Graphical Interfaces to Data</strong></td>
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<td>C. Herot</td>
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<td>Computer Corporation of America</td>
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<td><strong>Use of Interactive Graphics for Controlling Complex Processes</strong></td>
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<td>B. Roberts</td>
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<td>Bolt Beranek and Newman Inc.</td>
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<td><strong>Speech, Gesture, and Graphical Context</strong></td>
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<td>R. Bolt</td>
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<td>Massachusetts Institute of Technology</td>
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<td>10:00</td>
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<td>10:30</td>
<td><strong>COMPUTER-AIDED CONTROL SYSTEM ENGINEERING</strong></td>
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<td><strong>DEMONSTRATIONS</strong></td>
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<td>Chair: M. Athans</td>
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<td></td>
<td>Massachusetts Institute of Technology</td>
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<tr>
<td>10:30</td>
<td>• <strong>Computer-Aided Control Systems Engineering</strong>—A Tool for More Realistic Teaching**</td>
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<td></td>
<td>K. J. Aström and B. Wittenmark</td>
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<tr>
<td>11:30</td>
<td>• <strong>A Graphical System for Modeling and Implementation of Control Systems</strong></td>
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<td>H. Elmqvist</td>
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<td>12:00</td>
<td><strong>Lunch</strong></td>
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<td>1:30</td>
<td><strong>FUTURE DIRECTIONS IN CASCD</strong></td>
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<td>Chair: H.A. Spang III</td>
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<td>General Electric Company</td>
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<td>1:30</td>
<td>• <strong>Second-Generation Software Plan for Computer-Aided Control System Design</strong></td>
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<td>J. H. Taylor</td>
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<td>General Electric Company</td>
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<td>2:00</td>
<td><strong>Flight Dynamics Laboratory Perspectives on CACSD</strong></td>
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<td>2:30</td>
<td>• <strong>Future Directions and Needs in CACSD: A View From the Chemical Industry</strong></td>
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<tr>
<td>3:00</td>
<td><strong>The DOE/EES/ORNL CACSD Development Effort: An Overview</strong></td>
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<td>3:30</td>
<td><strong>Break</strong></td>
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<tr>
<td>4:00-5:00</td>
<td><strong>WRAP-UP AND INFORMAL DISCUSSIONS</strong></td>
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<td>Chair: R. Strunce</td>
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<td>The C.S. Draper Laboratory</td>
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</table>
APPENDIX C - LIST OF PARTICIPANTS
Computer-Aided Control Systems Design Symposium
28 - 30 September 1983

LIST OF PARTICIPANTS

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APPENDIX D - VIEWGRAPHS FOR PRESENTATION
TOOLS FOR MORE REALISTIC TEACHING

K J Aström
DEPARTMENT OF AUTOMATIC CONTROL
LUND INSTITUTE OF TECHNOLOGY

1. INTRODUCTION
2. REVIEW OF TOOLS
3. SIMNON
4. EXAMPLES
5. FUTURE DIRECTIONS
6. CONCLUSIONS
WHAT CAN CAE OFFER?

MORE REALISTIC EXAMPLES
Non linearities
High frequency dynamics

LOOK AT PROBLEMS NOT EASILY AMENABLE TO ANALYSIS
Effects of sampling rates
Intersample behaviour

MODEL LIBRARIES
High fidelity models
Design on simple models
Validation on realistic models
Reproducibility

CONSEQUENCES FOR TEACHING
EXPERIENCES

AT OUR OWN DEPARTMENT
Elementary courses
Advanced courses
Projects
Research
Book writing
Model library

AT OTHER DEPARTMENTS
Control departments
Mathematics departments
Statistics departments

IN INDUSTRY
Portability
Hardware requirements
Educational requirements
Special features

1) Åström - Wittenmark
Computer-Controlled Systems
Theory & Design
Prentice Hall 1984
INTRAC

ONE MODULE FOR INTERACTION COMMON TO ALL PACKAGES

COMMAND ORIENTED
   Initiative stays with user but may be transferred to computer when needed

FEATURES
   Arguments
   Local and global variables
   Input-output, numbers and graphs
   Control of program flow
   Simplified dialog
   Macro facility

STRUCTURE
TOOLS FOR MORE REALISTIC TEACHING

1. INTRODUCTION

2. REVIEW OF TOOLS

3. SIMNON

4. EXAMPLES

5. FUTURE DIRECTIONS

6. CONCLUSIONS
EXAMPLES OF PACKAGES

SIMNON
INTERACTIVE SIMULATION LANGUAGE FOR NONLINEAR CONTINUOUS AND DISCRETE TIME SYSTEMS WITH FACILITIES FOR OPTIMIZATION AND USE OF EXPERIMENTAL DATA

IDPAC
INTERACTIVE LANGUAGE FOR IDENTIFICATION OF LINEAR SYSTEMS USING PARAMETRIC AND NON PARAMETRIC (COVARIANCES SPECTRA) METHODS

SYNPAC
STATE SPACE ORIENTED DESIGN PACKAGE FOR LINEAR SYSTEMS WHICH INCLUDES LQG, POLEPLACEMENT AND ROBUST DESIGNS FOR DISCRETE AND CONTINUOUS SYSTEMS

MODPAC
ANALYSIS AND TRANSFORMATIONS OF MODELS

POLPAC
POLYNOMIAL ORIENTED ANALYSIS AND DESIGN PACKAGE

LISPID

DYMOLA
TOOLS FOR MORE REALISTIC TEACHING

1. INTRODUCTION
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6. CONCLUSIONS
HIGH LEVEL PROBLEM SOLVING LANGUAGES

- VOCABULARY
  WORDS, DATA OBJECTS
- COMPOSITION RULES
  OPERATORS, GRAMMAR, SYNTAX
- MEANING
  SEMANTICS

THE LANGUAGE SHOULD BE:
- RICH TO SOLVE MANY PROBLEMS
- SIMPLE EASY TO LEARN
- EXTENDABLE

A CAD SYSTEM IS SIMPLY A LANGUAGE INTERPRETER
SIMULATION OF MIXED CONTINUOUS & DISCRETE TIME SYSTEMS

**CONTINUOUS SYSTEM**

\[ \frac{dx}{dt} = f(x, u, t) \]
\[ y = g(x, u, t) \]

**DISCRETE SYSTEM**

\[ x(t_{k+1}) = f(x(t_k), u(t_k), t_k) \]
\[ y(t_k) = g(x(t_k), u(t_k), t_k) \]

**CONNECTING SYSTEM**

[Diagram of connecting system]
DATA STRUCTURES

• CONTINUOUS SYSTEM
• DISCRETE SYSTEM
• CONNECTING SYSTEM
CONTINUOUS SYSTEM <id>

[INPUT <simple variable>]

[OUTPUT <simple variable>]

[STATE <simple variable>]

[DER <simple variable>]

[TIME <simple variable>]

[INITIAL]

{Computation of initial values of state}
{Compute output variables}
{Compute derivatives}
{Parameter assignment}
{Initial value assignment}

END
DISCRETE SYSTEM <name>

[INPUT <simple variable>*]

[OUTPUT <simple variable>*]

[STATE <simple variable>*]

[NEW <simple variable>*]

[TIME <simple variable>]

TSAMP <simple variable>

{Compute initial values for state output tsamp}

{Compute auxiliary variables}

{Compute output}

{Compute new values of state variables}

Update TSAMP

{Modify states in continuous systems}

{Assign parameters & initial values}

END
CONNECTING SYSTEM <name>

[TIME < simple variables>
[Compute auxiliary variables]
[Compute input variables]
[Parameter assignments]

END
SIMNON commands

1. UTILITIES
   ✔ EDIT
   GET
   LIST
   PRINT
   SAVE
   STOP

2. GRAPHIC OUTPUT
   ✔ AREA
   ASHOW
   ✔ AXES
   ✔ HCOPY
   ✔ SHOW
   ✔ SPLIT
   TEXT

3. SIMULATION COMMANDS
   ALGOR
   ✔ DISP
   ERROR
   ✔ INIT
   ✔ PAR
   ✔ PLOT
   ✔ SIMU
   ✔ STORE
   ✔ SYST
TOOLS FOR MORE REALISTIC TEACHING

1. INTRODUCTION
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EXAMPLE 1
PI CONTROL WITH ANTIWINDUP

CONNECTING SYSTEM CON
Time t
\( y_r[\text{REG}] = 1 \)
\( y[\text{REG}] = y[\text{PROC}] \)
\( u[\text{PROC}] = u[\text{REG}] \)
END
CONTINUOUS SYSTEM PROC

Input u
Output y
State
Der
END

DISCRETE SYSTEM PIREG

Input yr y
Output u
State i
New mi
Time t
Tsamp ts
...
END

CONNECTING SYSTEM

yr [PIREG] = 1
y [PIREG] = y [PROC]
u [PROC] = u [PIREG]
END
DISCRETE PI REGULATOR

DISCRETE SYSTEM REG

Input yr y
Output u
State i
New mi
Time t
Tsamp ts

e = yr - y
v = k*e + i
u = if v < ulow then ulow
    elseif v < uhigh then v
    else uhigh

mi = i + k*e*h/ti + h/tox*(u-v)
ts = t + h

h: 0.2
iti: 1
to: 1
ulow: -1
uhigh: -1

PARAMETER ASSIGNMENTS

DECLARATIONS

END
MACRO FIG 9
"Generates Fig 9
syst integr pireg con
store yr y[proc] upr
simu 0 40/wup
par ulow: -0.1
par unhgh: 0.1
simu /nowup
split 21
a show y/wup
show y/nowup
a show upr/wup
show upr/nowup
INFLUENCE OF SAMPLING RATE
IN POLE PLACEMENT CONTROL

CONNECTING SYSTEM CON
Time t
uc [req] = 1
u [proc] = u [req]
y [req] = u [proc]
END

IT IS VERY HARD TO
FIND OUT HOW THE RESPONSE
IS INFLUENCED BY u BY
ANALYSIS!
DISCRETE SYSTEM POLP

Input $y_c$ $y$

Tsamp $t_s$

"Compute desired discrete char pol
\[ p_1 = -2 \times \cos (w \times h \times \text{sqrt}(1-z^2)) \]
\[ p_2 = \exp(-2 \times z \times w \times h) \]

"Sampling continuous model $1/(s(s+1))$

\[ a_2 = \exp(-h/t_1) \]
\[ a_1 = -c(1+a_2) \]
\[ b_1 = h-t_1(1-a_2) \]
\[ b_2 = t_1-a_2*(t_1+h) \]

"Solution of Diophantine eq $AR+BS = PT$

"Output

$u = t_0 \times u_c - 50 \times y - 51 \times yold - r1 \times uold$

"Dynamics

myold = y
muold = y
$ts = t+h$

"Parameter assignments

END
TOOLS FOR MORE REALISTIC TEACHING

1. INTRODUCTION
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6. CONCLUSIONS
# THE FUTURE

<table>
<thead>
<tr>
<th>NUMERICS</th>
<th>SCENE OF 1970</th>
<th>SCENE OF 1980</th>
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<tbody>
<tr>
<td>Wilkinson &amp; Reinsch (1971)</td>
<td></td>
<td>EISPACE, LINPAC</td>
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<table>
<thead>
<tr>
<th>HARDWARE</th>
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<tr>
<td>64 Kbyte fast memory</td>
<td></td>
<td>1 Mbyte fast memory</td>
</tr>
<tr>
<td>1 Mbyte disc memory</td>
<td></td>
<td>300 Mbyte disc memory</td>
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<tr>
<td>Teletype</td>
<td></td>
<td>High resolution</td>
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<tr>
<td>Storage oscilloscope</td>
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<td>color graphics</td>
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<th>INTERACTION MODELS</th>
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<tr>
<td>Analog computer</td>
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<td>Logo</td>
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<tr>
<td>APL &amp; Basic</td>
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<td>Smalltalk</td>
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<tr>
<td>LISP</td>
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<td>Visicalc</td>
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<tr>
<td>FORTRAN</td>
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<td>Pascal</td>
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<tr>
<td>BASIC</td>
<td></td>
<td>Ada</td>
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<th>EXPERIENCES</th>
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<tr>
<td>None</td>
<td></td>
<td>Dozens</td>
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WORK IN PROGRESS

SIMPLIFIED DIALOG
GENTLE EXPERT GUIDANCE
DOCUMENTATION

DESIGN OF HL PROBLEM SOLVING
LANGUAGES
VOCABULARY
SYNTAX
SEMANTICS

GRAPHICS
SYSTEM DESCRIPTIONS
COLOR
ANIMATION

IMPLEMENTATION LANGUAGES

SMALL EXPERIMENTAL
SYSTEMS
INTERACTION PRINCIPLES

COMMANDS SHOULD BE
NATURAL
SELF-EXPLANATORY
SHORT
FLEXIBLE

SHORT FORMS
DEFAULT PARAMETERS
**THREE PHASES OF CAE**

<table>
<thead>
<tr>
<th>MENU DRIVEN DIALOG</th>
<th>COMMAND DIALOG</th>
<th>EXPERT GUIDED DIALOG</th>
</tr>
</thead>
<tbody>
<tr>
<td>OPERATORS + FIXED LOGIC</td>
<td>OPERATORS HELP COMMAND PROC.</td>
<td>OPERATORS + FLEXIBLE DATA DRIVEN LOGIC</td>
</tr>
<tr>
<td>EASY TO USE FOR THE PROBLEMS IT WAS DESIGNED FOR STRAIGHT JACKET END, OTHER.</td>
<td>FLEXIBLE BUT MORE DIFFICULT TO USE</td>
<td>FLEXIBLE AND EASY TO USE LEARNING FACILITY</td>
</tr>
</tbody>
</table>

DATA FILE

DATABASE

CONTROL STRUCTURE
TYPICAL COMMAND LANGUAGE INTERPRETER

NOTICE

MACROS

HIGH LEVEL PROBLEM SOLVING LANGUAGE

CONTROL STRUCTURES

AN INCREMENTAL COMPILER CAN BE BUILT IN A SIMILAR WAY.
TOOLS FOR MORE REALISTIC TEACHING

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CONCLUSIONS

- Come closer to reality with modest effort

- Model library

- Reproducable results
  - Easy to document
  - Easy to repeat
  - Easy to modify

- We have barely scratched the surface
APPENDIX E – LECTURES BY PROFESSOR JACOB SCHWARTZ
Vinton Hayes Lectures 1983–84

Professor JACOB T. SCHWARTZ
New York University

Theoretical Issues in Robotics

I. The Motion Planning Problem
   Monday, October 3 at 4 P.M.

II. Some Mathematics of Motion Planning

III. Computational Complexity of Motion Planning
   Tuesday, October 4 at 3:00 and 4:30 P.M.

IV. Frictional Effects in Close-Tolerance Robot Assembly

V. Geometry, Control, and Software Approaches for Dextrous Manipulation
   Thursday, October 6 at 3:00 and 4:30 P.M.

Lectures will be in
   Pierce Hall 209
   Division of Applied Sciences