A Data Flow Retrospective

How It All Began

Jack Dennis

MIT Computer Science
and
Artificial Intelligence
Laboratory

1974 – 1975: Data Flow Years

- April 1974: Symposium on Programming, Paris. Dennis: "First Version of a Data Flow Procedure Language".
- January 1975: Second Annual Symposium on Computer Architecture, Houston. Dennis and Misunas: "A Preliminary Architecture for a Basic Data-Flow Processor".
- August 1975: 1975 Sagamore Computer Conference on Parallel Processing:
  - ✓ Rumbaugh: "Data Flow Languages"
  - ✓ Rumbaugh: "A Data Flow Multiprocessor"
  - ✓ Dennis: "Packet Commincation Architecture"
  - ✓ Misunas: "Structure Processing in a Data-Flow Computer"

The symposium included a spontaneous afternoon tutorial on data flow concepts presented by Jack Dennis.

Roots

- Asynchronous Digital Logic: Muller, Bartky
- Control Structures for Parallel Programming: Conway, McIlroy, Dijkstra
- Abstract Models for Concurrent Systems: Petri, Holt.
- Theory of Program Schemes: Ianov, Paterson
- Structured Programming: Dijkstra, Hoare
- Functional Programming: McCarthy, Landin

Asynchronous Digital Logic - 1963

Asynchronous Logics and Application to Information Processing

DAVID E. MULLER
University of Illinois

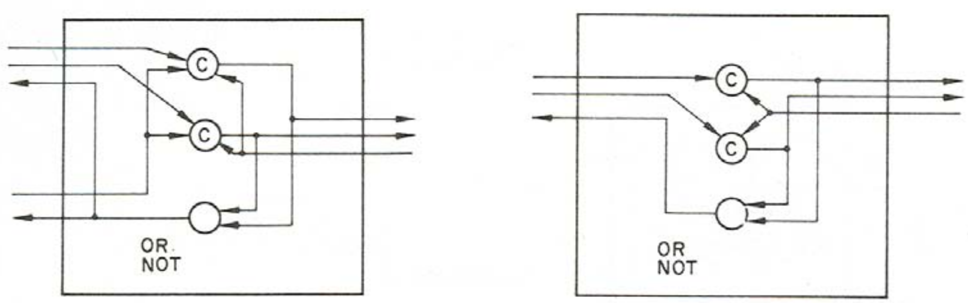
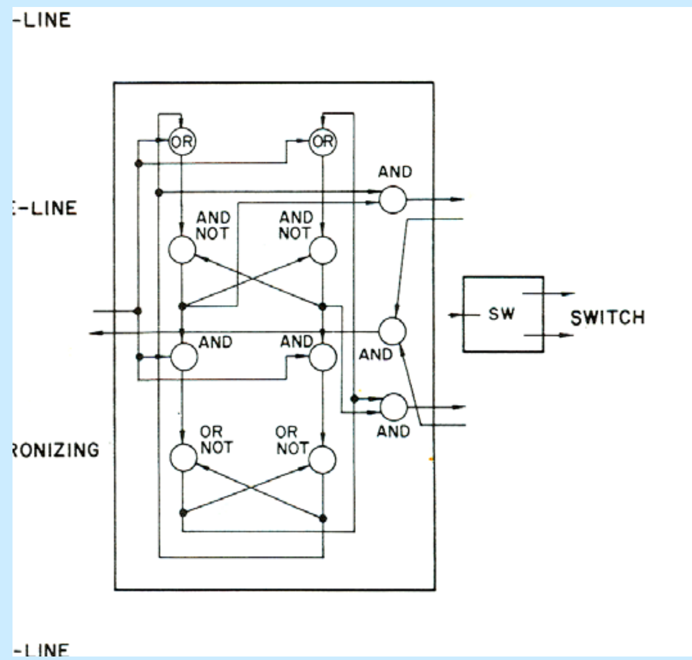


FIG. 1 FIG. 2



Dennis: 1970 Asynchronous Control Modules

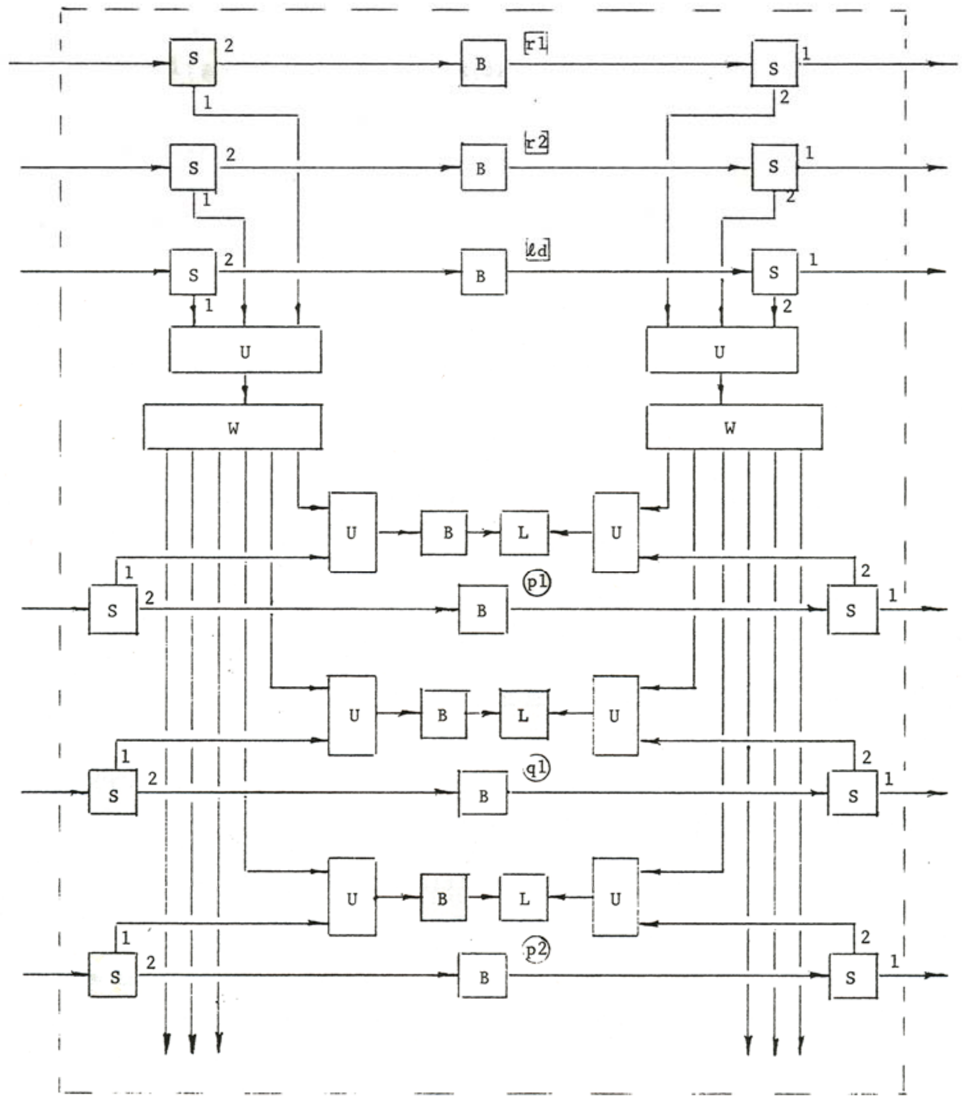


Figure 31. Control structure for channel 0 of one scoreboard section.

Programming
Control
Structures
Conway: 1963

A MULTIPROCESSOR SYSTEM DESIGN

Melvin E. Conway
Directorate of Computers, USAF
L. G. Hanscom Field
Bedford, Mass.

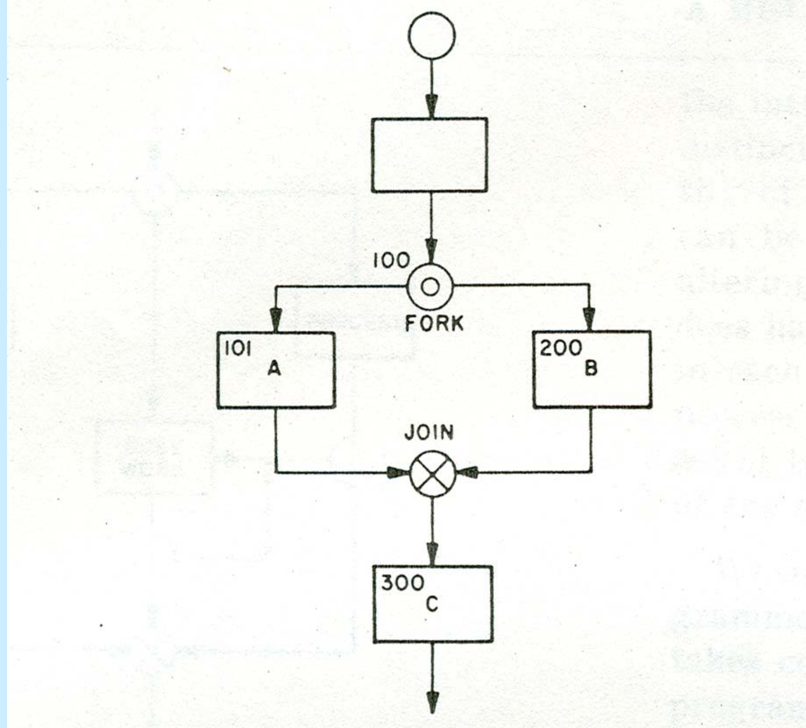


Figure 1. Conventions for drawing fork and join.

Coroutines: McIlroy: 1968

COROUTINES: SEMANTICS IN SEARCH OF A SYNTAX

by M. Douglas McIlroy

Oxford University and

Bell Telephone Laboratories, Incorporated.

ABSTRACT: Unlike subroutines, coroutines may be connected, and reconnected, in nonhierarchical arrangements. Coroutines are particularly useful for generating and processing data streams. Semantics for coroutines are developed and examples are given.

Dijkstra 1965: Co-operating Sequential Processes

CO-OPERATING SEQUENTIAL PROCESSES

```
"begin integer number of queuing portions;
      number of queuing portions:= 0;
      parbegin
      producer: begin
                again 1: produce the next portion;
                         add portion to buffer;
                         V(number of queuing portions);
                         goto again 1
                end;
      consumer: begin
                again 2: P(number of queuing portions);
                         take portion from buffer;
                         process portion taken;
                         goto again 2
                end
      parend
end".
```

Ianov: Program Schemata: 1957, 1964

On Ianov's Program Schemata*

J. D. Rutledge

International Business Machines Corp.,† Yorktown Heights, N. Y.

Abstract. Ianov has defined a formal abstraction of the notion of program which represents the sequential and control properties of a program but suppresses the details of the operations. For these schemata he defines a notion corresponding to computation and defines equivalence of schemata in terms of it. He then gives a decision procedure for equivalence of schemata, and a deductive formalism for generating schemata equivalent to a given one. The present paper is intended, first as an exposition of Ianov's results and simplification of his method, and second to point out certain generalizations and extensions of it. We define a somewhat generalized version of the notion of schema, in a language similar to that used in finite automata theory, and present a simple algorithm for the equivalence problem solved by Ianov. We also point out that the same problem for an extended notion of schema, considered rather briefly by Ianov, is just the equivalence problem for finite automata, which has been solved, although the decision procedure is rather long for practical use. A simple procedure for generating all schemata equivalent to a given schema is also indicated.

Paterson 1968:

Program

Schemas

MATHEMATICAL FOUNDATIONS

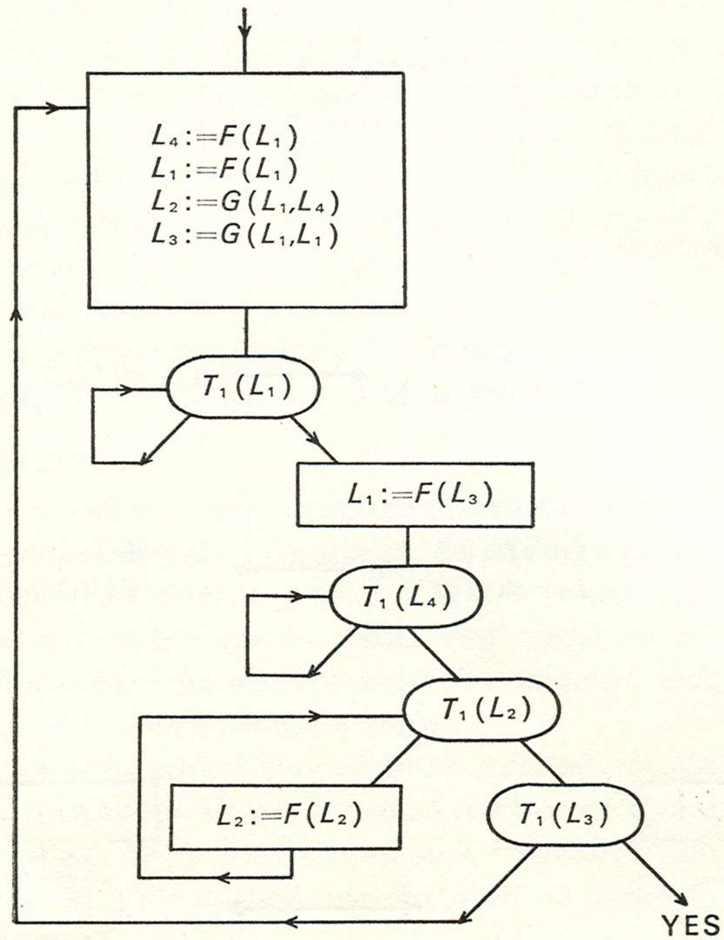


Figure 4. Schema P'

Karp and Miller 1968: Parallel Program Schemata

Parallel Program Schemata

RICHARD M. KARP*

University of California, Berkeley, California 94720

AND

RAYMOND E. MILLER

IBM Watson Research Center, Yorktown Heights, New York 10598

Received April 15, 1968

ABSTRACT

This paper introduces a model called the parallel program schema for the representation and study of programs containing parallel sequencing. The model is related to Ianov's program schema, but extends it, both by modelling memory structure in more detail and by admitting parallel computation. The emphasis is on decision procedures, both for traditional properties, such as equivalence, and for new properties particular to parallel computation, such as determinacy and boundedness.

Karp, Miller

Parallel

Program

Schema

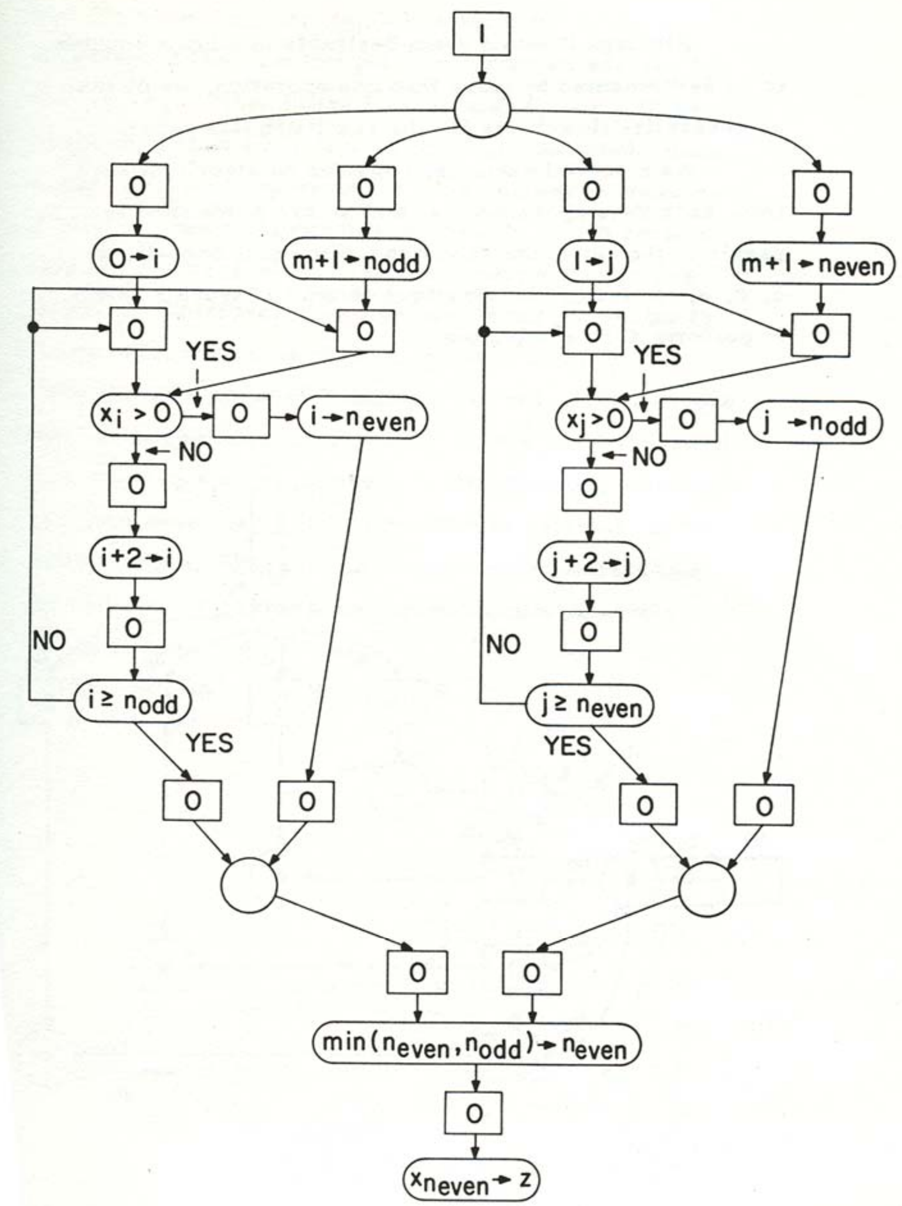
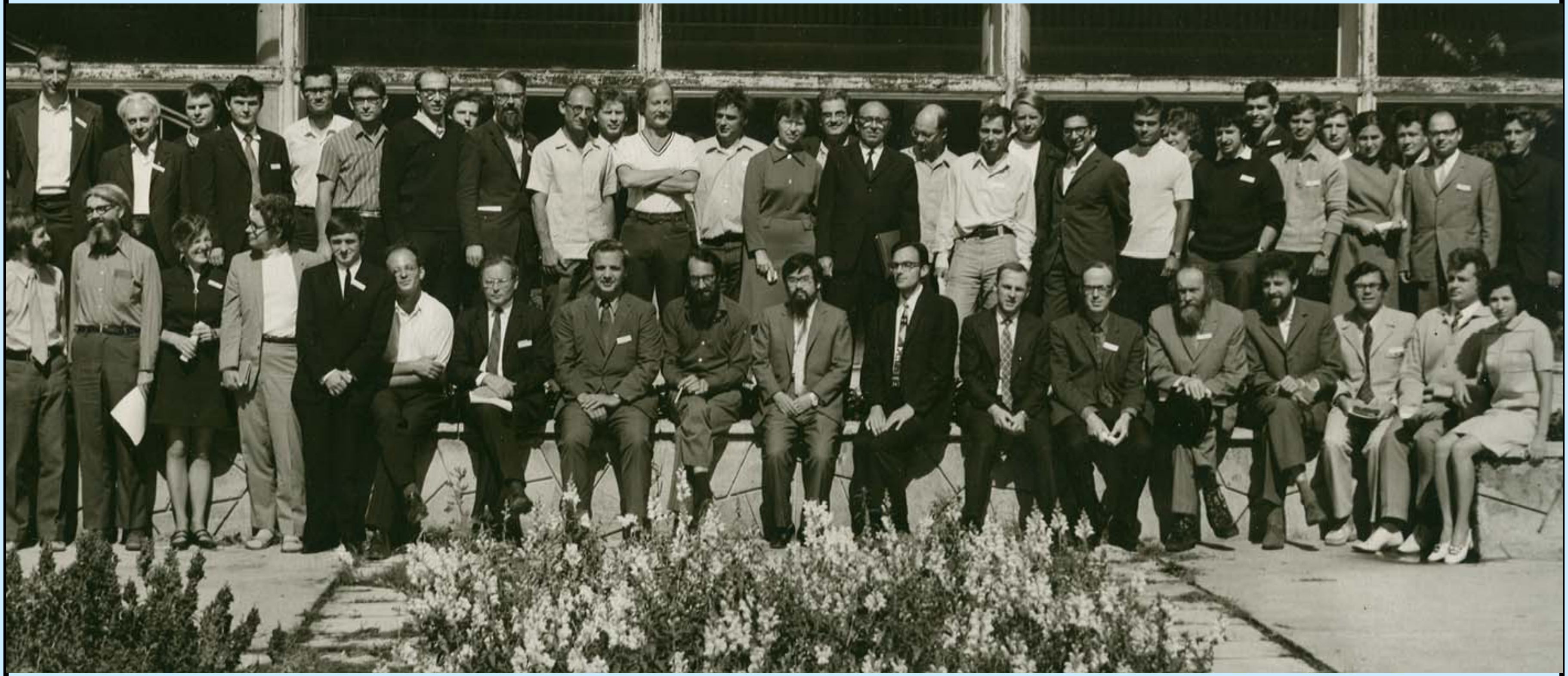
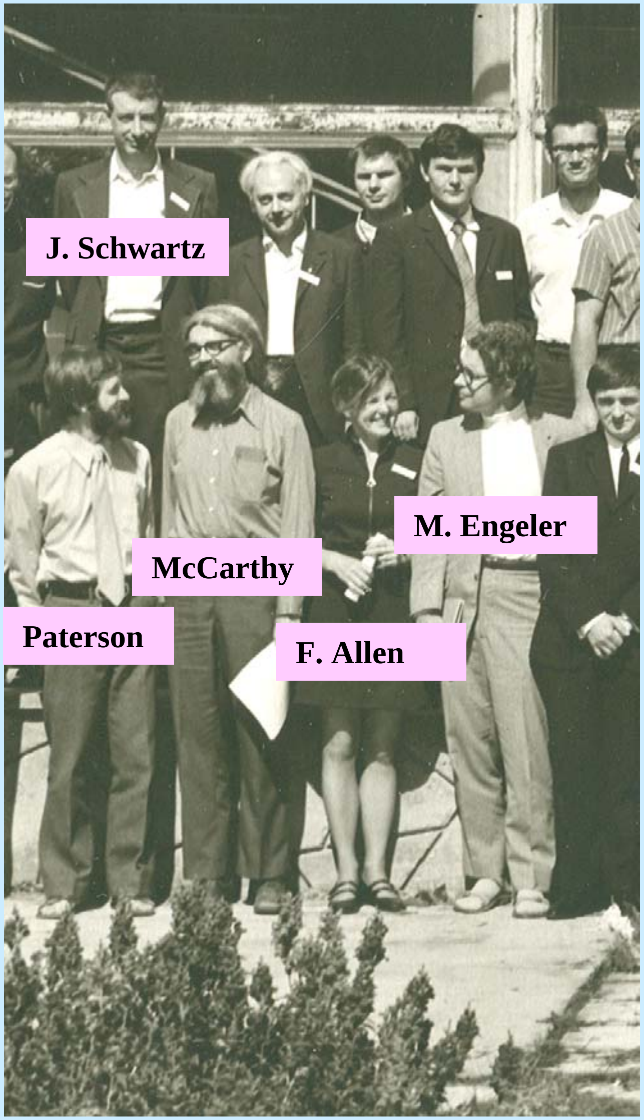


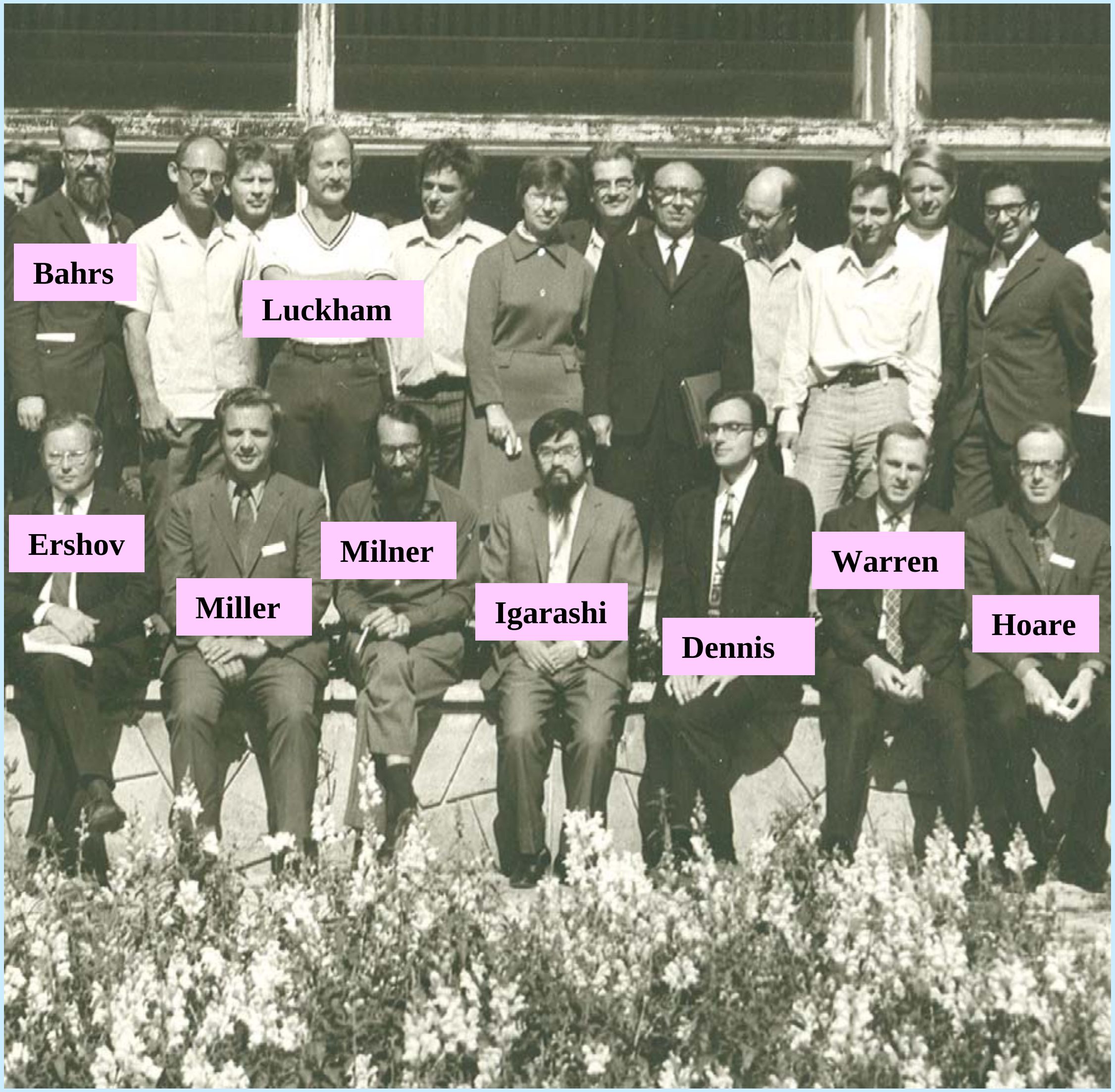
Figure 2.

Symposium on Theoretical Programming
Novosibirsk – 1972



Notables – Novosibirsk - 1972





MIT - 1964

- IBM announces System 360.
- Project Mac selects GE 645 for Multics.
- I decide to pursue research on relation of program structure to computer architecture.
- "Machine Structures Group" formed.

Computation Structures Group: 1964 - 1975

- 1968: Dennis: "Programming Generality, Parallelism and Computer Architecture"
- 1967: Jorge Rodriguez. "A Graph Model for Parallel Computations"
- 1972: Dennis, Fosseen, Linderman: "Data Flow Schemas"
- I 1974: Dennis, Misunas: "A Data Flow Processor for Signal Processing"
- 1975: Dennis, Misunas: "Preliminary Architecture for a basic Data Flow Processor"

Dennis: IFIP 1968

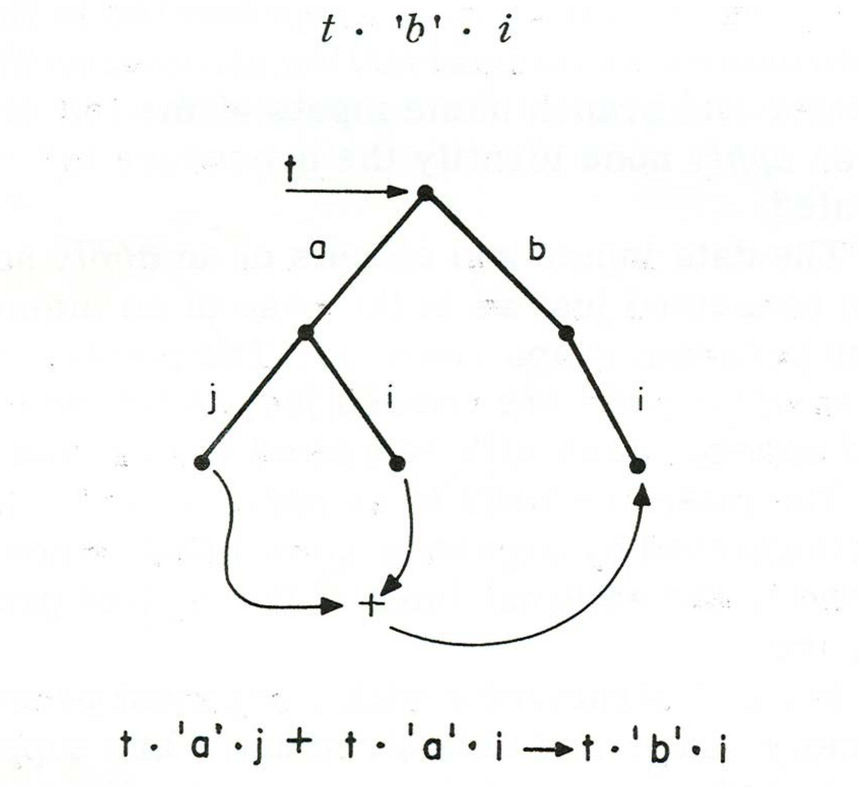


Fig. 3. A computation on a structure.

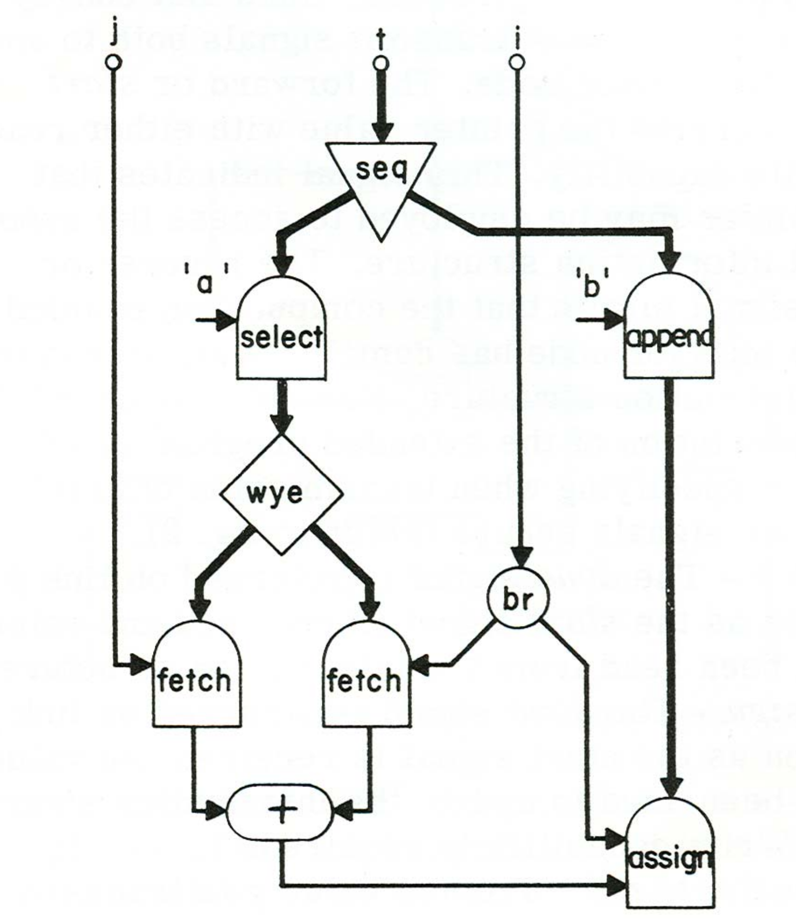
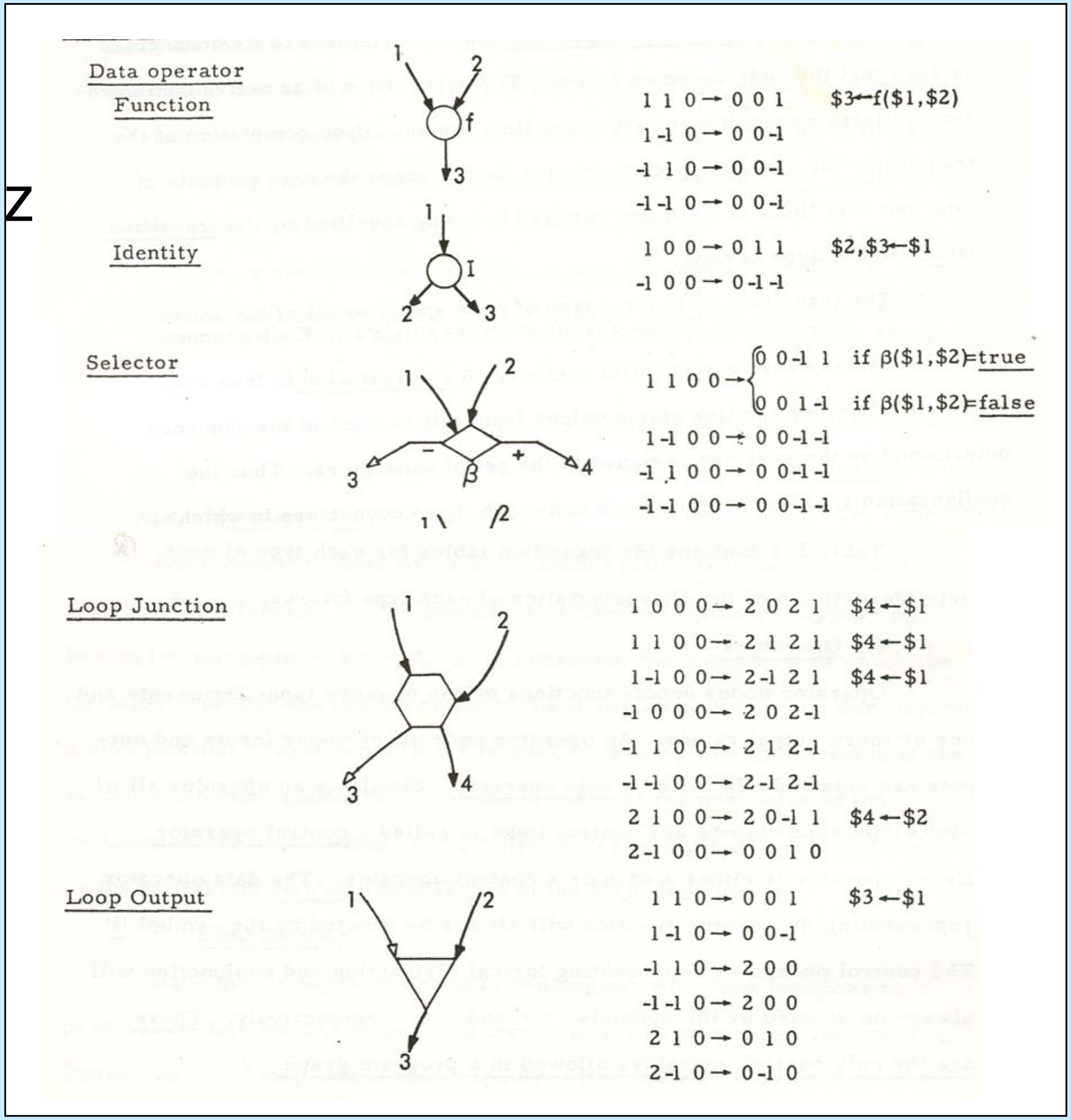


Fig. 4. An extended program graph.

Jorge Rodriguez Program Graphs - 1967



Dennis' Data Flow Schema Language - 1972

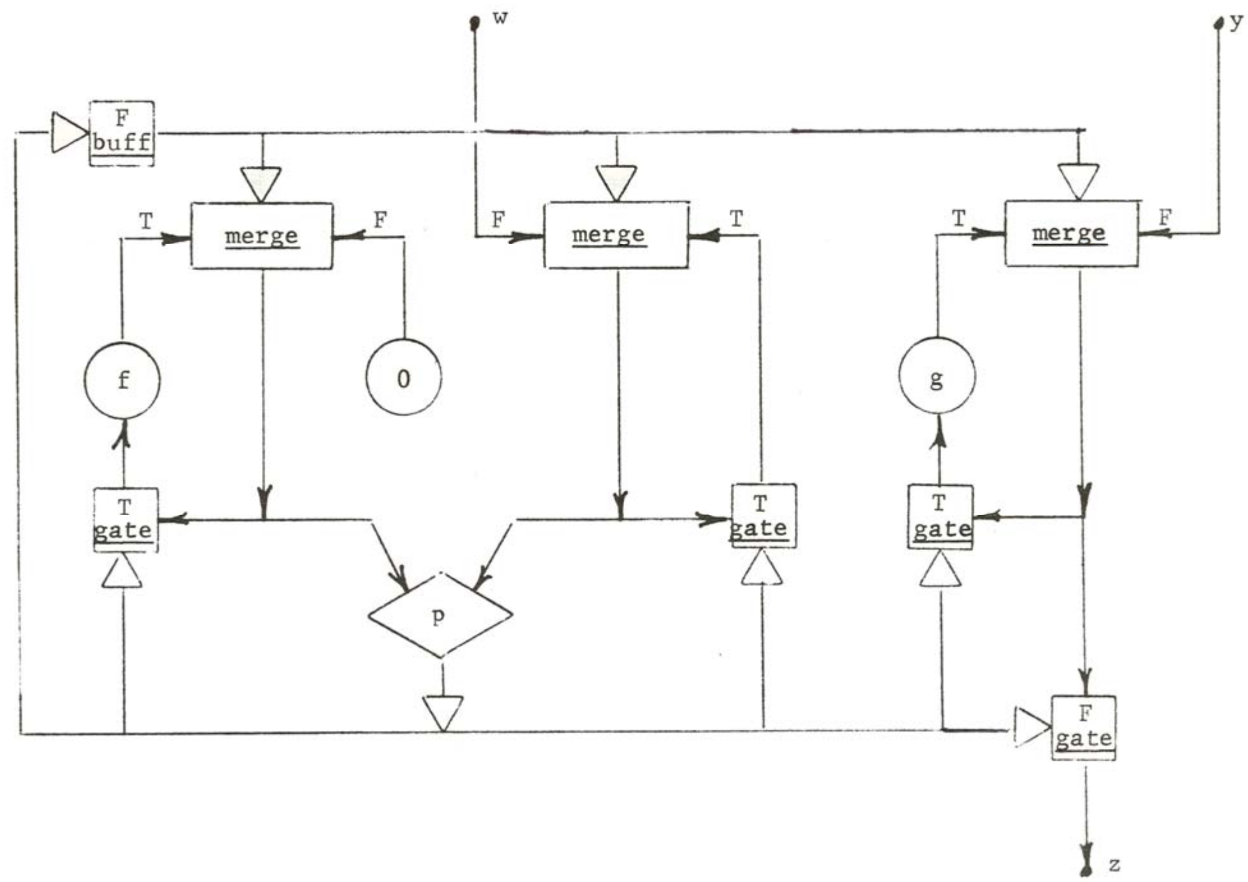


Figure 27. Data-flow schema with iteration.

Dennis-Misunas Architecture 1975

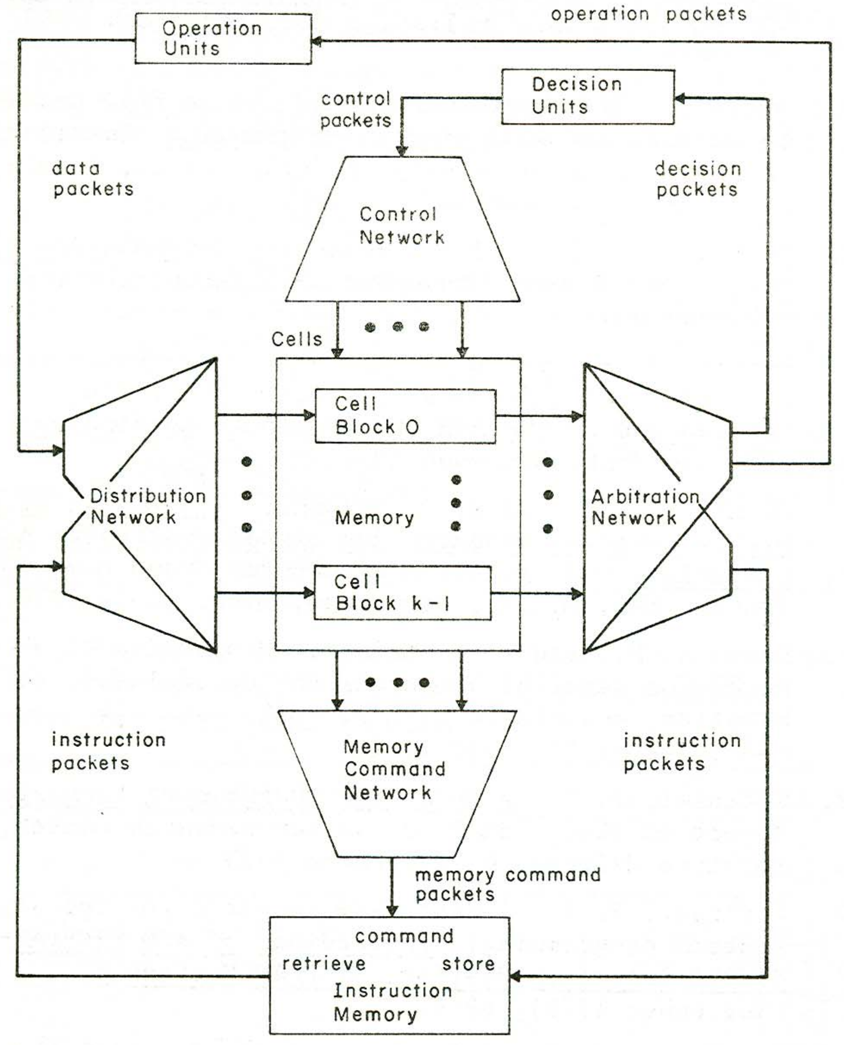


Figure 14. Organization of the basic data-flow processor with auxiliary memory.

Jim Rumbaugh's Data Flow Multiprocessor - 1975

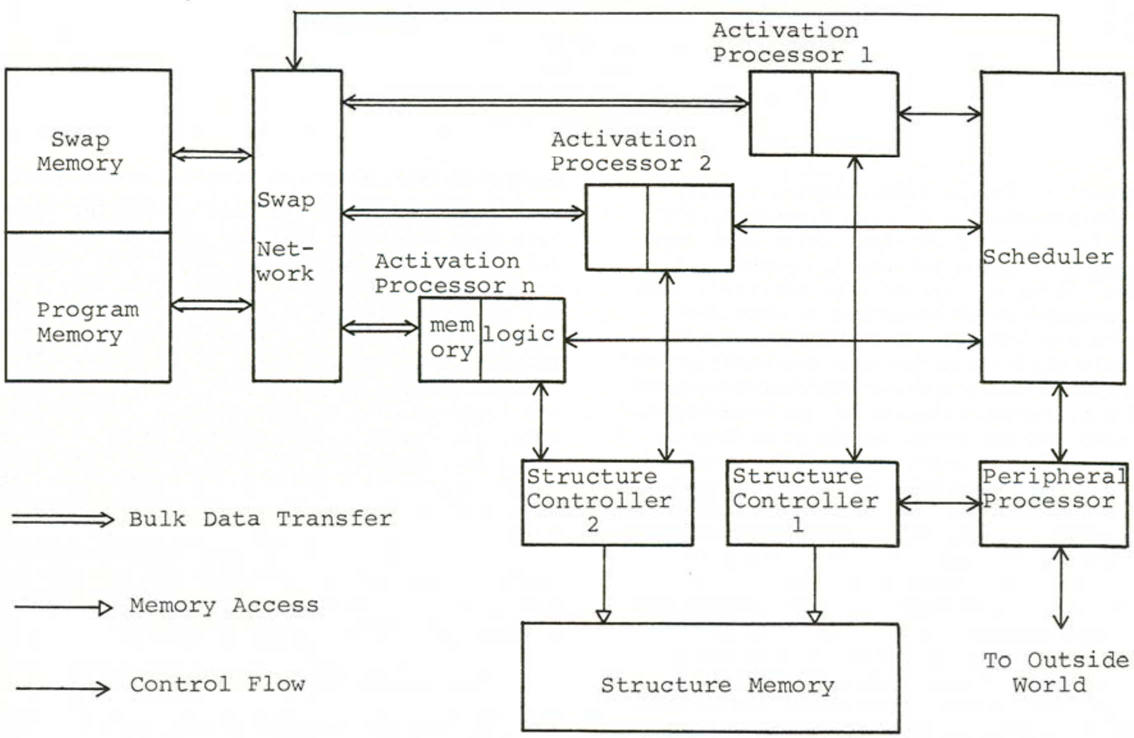


Fig. 1. Structure of the Data Flow Multiprocessor

Related Work

- 1968: Duane Adams: "A Computation Model with Data Flow Sequencing"
- 1966: Burt Sutherland "On-Line Graphical Specification of Computer Procedures"
- 1978: Al Davis: "The Architecture and System Method of DDM1: A Recursively Structured Data Driven Machine"
- Projects at TI, ESL, Hughes, NEC, NTT, Loral

Sutherland
1966

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

LINCOLN LABORATORY

ON-LINE GRAPHICAL SPECIFICATION OF COMPUTER PROCEDURES

W. R. SUTHERLAND

Group 23

ABSTRACT

A promising area of application for recently developed computer graphics techniques is computer programming. Two important considerations in using an interactive graphics system for drawing programs are (1) the form of a pictorial programming notation and (2) methods for making a computer execute the program once drawn. These topics are discussed in the context of an experimental graphical programming system running on the Lincoln Laboratory TX-2 Computer. This system uses a block notation for programs and can execute the drawn program with an interpreter. Improved graphical input languages for drawing programs and program notations which combine appropriate features of pictorial and written languages are needed before applications in this area are practical. The benefits to be expected from a graphical approach to programming include (1) automatic documentation, (2) debugging assistance, and (3) natural expression of parallel processes.

Enter Arvind

- 1962: Richard Kain earns MIT ScD with Project MAC and joins faculty at University of Minnesota.
- 1969 Arvind graduates from IIT Kanpur, enters U. Minn., to study Computer Science, and is inspired by Computer Architecture courses taught by Professor Kain.
- 1973 Arvind completes thesis with Professor Kain on “Models for the Comparison of Memory Management Algorithms” and joins faculty at UC Irvine.
- 1975 Arvind and Gostelow publish report on “A New Interpreter For Data Flow Schemas And Its Implications For Computer Architecture”
- 1977 Arvind organizes first data flow workshop.

Workshop on
Data Flow and Reduction Languages

Department of Information and Computer Science
University of California, Irvine
Irvine, CA 92717

April 21-22, 1977

List of Invitees

J. Backus - IBM

R. Barton - Burroughs

K. Berkling - GMD, Germany

J. D. Brock - MIT

T. C. Chen - IBM

B. Clark - Burroughs

A. Davis - Burroughs

J. Dennis - MIT

D. Friedman - Indiana University

P. Kosinski - IBM/MIT

E. Organick - University of Utah

K.-S. Weng - MIT

J. Williams - Cornell

D. Wise - Indiana University

Workshop Schedule

21 April (Thursday):

Time	Presentation
AM: 9:00-10:30	*Reduction Languages* - John Backus
10:30-11:00	Break
11:00-12:00	Discussion of Reduction Languages
12:00-1:30	Lunch
PM: 1:30-3:00	*Data Flow* - Jack Dennis
3:00-3:30	Break
3:30-5:00	Discussion of Data Flow
7:00	Dinner

22 April (Friday):

Time	Topic for Discussion
AM: 9:00-10:00	Why, or why not, data flow and reduction languages as a semantic basis for future software systems?
10:00-11:00	Discussion Break
11:00-12:00	Continuation of 9:00-10:00 topic, or other
12:00-1:30	Lunch
	Implications for future architectures:
1:30-3:00	Current work
3:00-3:30	Break
3:30-5:00	Might these architectures fail?

1977

Data Flow and Reduction Workshop

Irvine, California

March 21-22, 1977

1977

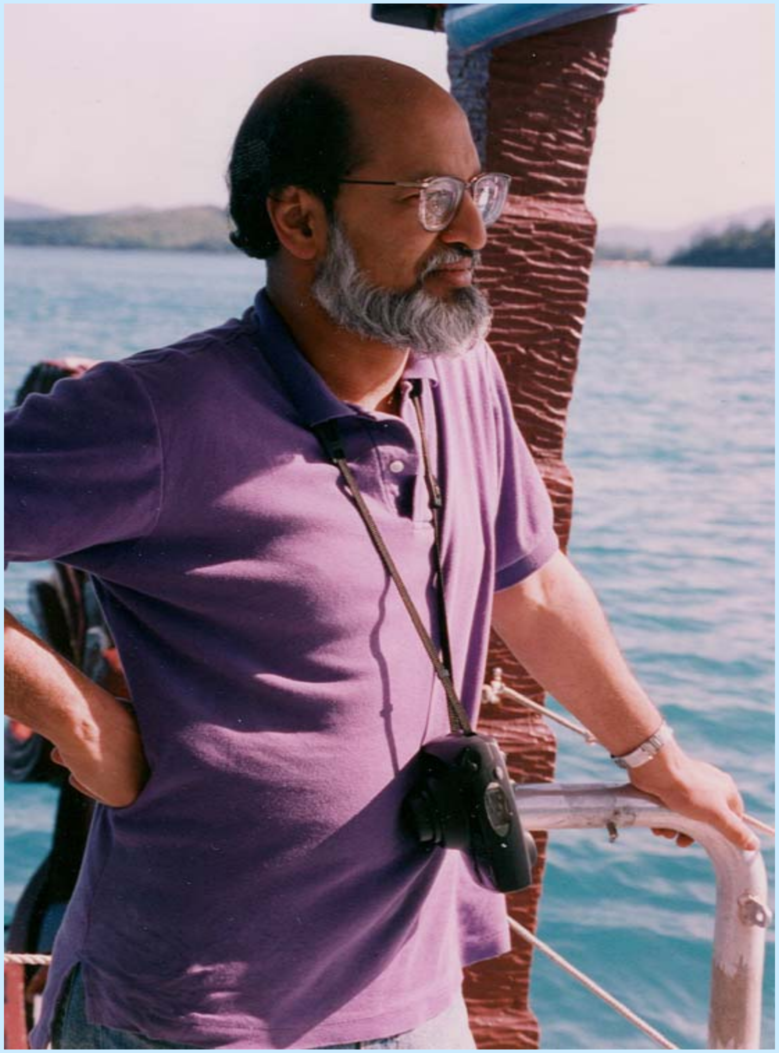
Data Flow and Reduction Workshop

David Dennis with Gita – April 1977

Data Flow Workshop
MIT Endicott House – 1977

Computation Structures Group
Technology Square – circa 1982

Data Flow Workshop
Hamilton Island – 1992



Arvind: Hamilton Island, 1992