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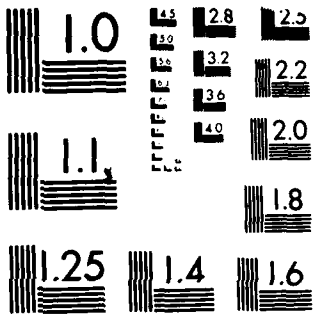


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During this period the investigators produced 24 papers with 13 published and 11 submitted or in preparation. Titles include, "Wafer scale integration of systolic arrays," "An approximation algorithm for Manhattan routing," "Barel sets and circuit complexity," "A complexity theoretical approach to randomness," "Topological complete subgraphs of a random graph," "Largest component in the k-cube," "Sorting in clogn parallel steps," and "Parallel computation using meshes of tress."




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AFOSR-TR- 84-0461

Scientific Progress Report for

AFOSR-82-0326.

D. Kleitman (Principal Investigator), T. Leighton, G. Miller, M. Sipser

Research centers on applying the asymptotic methods of theoretical computer science and combinatorics to problems in the design of VLSI cicuits. Typical problems under investigation include: finding compact layouts for specific networks; developing fast layout algorithms which may be used as computer aided design tools; and developing a theory for predicting which functions have compact layouts.

## Description of Specific Research Topics

### I. Design and Analysis of Efficient Algorithms for NP-Complete Problems (D. Kleitman, T. Leighton, M. Sipser)

Research is centered on finding algorithms for certain important NP-complete problems such as graph bisection and bin packing. Optimal polynomial-time algorithms for such problems are not likely to exist, so efforts are devoted to finding fast algorithms that are good on the average, and to finding fast algorithms that are guaranteed to always find a solution which is close to the optimal solution.

### II. Theory of Parallel Computation (D. Kleitman, T. Leighton, G. Miller)

Research is centered on the theory of parallel computation using fixed-connection networks. Particular attention is given to the [illegible] analysis of efficient algorithms and networks for such [illegible] problems as sorting, Fourier transform, convolution, matrix multiplication and integer arithmetic. Application of this work to the development of supercomputers is a primary concern.

III. Fault-tolerant Computation (T. Leighton, G. Miller, D. Kleitman)

Research is centered on the develoment of algorithms for constructing networks (e.g., systolic arrays) in an environment that contains faulty elements (e.g., processors or wires). The object is to identify the faults, and build the networks using only correctly functioning elements. Some effort may also be devoted to systems that are fault-correcting and/or dynamically fault-tolerant.

IV. Theory of VLSI Circuit Design (T. Leighton, G. Miller)

Research is centered on the theoretical aspects of VLSI circuit design. Topics include channel routing, conversion of 2-dimensional layouts into 3-dimensional layouts, gate array routing, wafer-scale integration, communication complexity, retiming and bounds for area, time, crossing number, contact cuts and wire length. Emphasis is placed on theoretical problems that arise in practice.

V. Computational Complexity (M. Sipser)

Research is centered on the fundamental questions concerning the limits of efficient algorithms. For example, the travelling salesman problem is solvable in principle on a computer, but only very slowly using the currently best methods. To determine whether there are much faster algorithms for problems of this type or if, in fact, they are inherently complex and cannot be solved quickly is a major goal of the research. Progress to date on weaker computation models has contributed to mathematical logic and the theories of parallel computation and programmable logic arrays.

VI. Random Sequences (M. Sipser)

Professor Sipser is exploring various definitions of randomness and pseudo-randomness from a complexity theoretic viewpoint. This has already improved our understanding of the power of probabilistic computation and promises further insights in this area.

VII. Communication Complexity (M. Sipser)

This is an important parameter when attempting to determine the area/time tradeoff in a VLSI implementation of a function. Professor Sipser is developing methods for obtaining good bounds on this complexity measure.

VIII. Algebraic Techniques in the Design of Efficient Algorithms (T. Leighton, G. Miller)

Substantial progress has been made in classifying problems as either solvable in polynomial time or NP-hard. Yet many problems still remain unclassified with respect to these measures. This is particularly true of problems that have a strong algebraic component, such as testing primality, factoring integers, determining the genus of a graph and analyzing the geometry of numbers. Ongoing reseach in this area is centered on developing the algebraic techniques necessary to solve such problems. Emphasis is also placed on the applications of these problems in areas such a coding theory, hashing theory, cryptography, random number generation, graph isomorphism testing and graph coloring.

## IX. Combinatorial Algorithms (D. Kleitman, T. Leighton, G. Miller)

Research is centered on the develoment of fast algorithms for problems of a combinatorial nature. Particular attention is focused on algorithms for linear programming that work well on average, and the problem of decomposing a complex plane region into the minimum number of simple regions -- such as rectangles. The work has a large number of applications to combinatorial optimization problems and certain aspects of VLSI design.

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DEPARTMENT OF MATHEMATICS

Room 2-236
617/253-4389

March 22, 1984

Dr. Robert N. Buchal
Progress Manager
Directorate of Mathematical
and Information Sciences
Bolling Air Force Base
Washington, DC 20332

Dear Dr. Buchal:

Enclosed is the list of papers supported by our contract, as you requested.

Sincerely yours,

Daniel J. Kleitman
Head, Department of Mathematics

Enclosure

## Papers Supported by the Contract (up to Oct. 1 1983)

1. F. T. Leighton and C. E. Leiserson, "Wafer-Scale Integration of Systolic Arrays," *Proceedings of the 23rd Annual IEEE Conference on Foundations of Computer Science*, November 1982, pp. 297-310. (Also appears as MIT-LCS TM #236.)
2. B. S. Baker, S. Bhatt and F. T. Leighton, "An Approximation Algorithm for Manhattan Routing," *Proceedings of the 15th Annual ACM Symposium on Theory of Computing*, April 1983, pp. 477-486. (Also appears as MIT-VLSI TM #82-129 and MIT-LCS TM #238.)
3. M. Sipser, "Borel Sets and Circuit Complexity," *Proceedings of the 15th Annual ACM Symposium on Theory of Computing*, April 1983, pp. 61-69.
4. M. Sipser, "A Complexity Theoretic Approach to Randomness," *Proceedings of the 15th Annual ACM Symposium on Theory of Computing*, April 1983, pp. 330-335.
5. D. Dolev, F. T. Leighton and H. Trickey, "Planar Embeddings of Planar Graphs," MIT-LCS TM #237.
6. F. T. Leighton, *Complexity Issues in VLSI: Optimal Layouts for the Shuffle-Exchange Graph and Other Networks*, MIT Press, Cambridge, Massachusetts, to appear.
7. S. N. Bhatt, F. T. Leighton and C. E. Leiserson, "A Framework for Solving VLSI Graph Layout Problems," *Journal of Computer and System Sciences*, to appear.
8. F. T. Leighton and A. Rosenberg, "Three-Dimensional Circuit Layouts," *Proceedings of the 1983 IEEE International Conference on Circuit Design*, Rye, New York, to appear.
9. F. R. K. Chung, F. T. Leighton and A. L. Rosenberg, "Diogenes: A Methodology for Designing Fault-Tolerant VLSI Processor Arrays," *Proceedings of the 1983 International Conference on Fault-Tolerant Computing*, Milan, Italy, to appear.
10. F. T. Leighton, "Parallel Computation Using Meshes of Trees," *Proceedings of the 1983 Workshop on Graphtheoretic Concepts in Computer Science*, Osnabruck, West Germany, to appear.
11. R. M. Karp, F. T. Leighton, R. L. Rivest, C. D. Thompson, U. Vazirani and V. Vazirani, "Global Wire Routing in Two-Dimensional Arrays," in preparation.
12. F. Berman, F. T. Leighton, P. Shor and L. Snyder, "Generalized Planar Matching," in preparation.
13. D. S. Franzblau and D. J. Kleitman, "Generating Intervals and Covering by Rectangles," in ~~preparation~~. to appear Proc May 1984 conference ACM

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March 23, 1984

Dr. Robert N. Buchal
Progress Manager
Directorate of Mathematical
and Information Sciences
Bolling Air Force Base
Washington, DC 20332

Dear Dr. Buchal:

Enclosed is an additional list of publications that was prepared with Air Force contract support during the period October 1982 to October 1983.

Sincerely yours,

Daniel J. Kleitman /MLP

Daniel J. Kleitman
Head, Department of Mathematics

Enclosure

PAPERS OF MIKLOS AJTAI PUBLISHED
BETWEEN OCT. 1982-OCT. 1983

1. $\Sigma_1^1$-formulae on finite structures,
   Annals of Pure and Applied Logic, 24 (1983) 1-48.

2. Sorting in c·logn parallel steps,
   Combinatorica, Vol. 3 (1983), 1-20
   with J. Komlós and E. Szemerédi.

3. Topological complete subgraphs of a random graph,
   Studia Sci. Math. Hung., Vol. 17 (1982)
   with J. Komlós and E. Szemerédi.

4. Largest component in the k-cube,
   Combinatorica, Vol. 2 (1982)
   with J. Komlós and E. Szemerédi.

5. An O(n·logn) sorting network,
   Proceedings of the 1983 ACM Symposium on the Theory of Computing,
   with J. Komlós and E. Szemerédi.

PAPERS WRITTEN OR SUBMITTED FOR PUBLICATION
IN THE SAME PERIOD

1. Hash Functions for Priority Queues,
   24th Annual Symp. on Foundations of Computer Science, 1983
   with M. Fredman and J. Komlós.

2. An O(n·logn) sorting network,
   Proceedings of the 1983 ACM Symposium on the Theory of Computing
   with J. Komlós and E. Szemeredi.
   (Listed among published papers as well.)

3. On optimal matchings,
   Submitted for publication (Combinatorica)
   with J. Komlós and G. Tusnády.

4. A time-lower bound for finding the rank function in Yao's model,
   in manuscript.

5. A nontrivial existential firstorder hierarchy on finite structures,
   in manuscript.

6. Explicit counting on firstorder structures,
   in preparation.