REPORT:

B. Mustafa Pulat is a senior engineer in the Material Handling Engineering Department of AT&T Network Systems at the AT&T Oklahoma City Works in Oklahoma City, Oklahoma. Mr. Pulat joined AT&T in 1985 and is involved in system development, modeling, and just-in-time deliveries. He has a B.Sc. and M.Sc. in industrial engineering from the Middle East Technical University in Ankara, Turkey, and a Ph.D. in industrial engineering from North Carolina State University. **Alan P. W. Hewett** is a member of technical staff in the Manufacturing Engineering Systems Development Department of AT&T Bell Laboratories in Columbus, Ohio. He joined the company in 1978 and designs and develops software for the Material Operations Velocity System (MOVES), a system that automates material

AUTOMATING MANUAL STOREROOM ZONES IN A FACTORY

Moving, storing, and controlling material efficiently is one of the most challenging problems of manufacturing. In the last twenty years, several different technologies were developed for this purpose, including the *automated storage and retrieval system* (AS/RS), which featured advancements in real-time control of machines by computers. Today's AS/RS makes total material-handling system integration a reality. This paper describes the experience of the AT&T Oklahoma City Works with such a system.

Introduction

In November 1985, the Oklahoma City Works began a miniload AS/RS after several years of preparation. The system is designed to automate manual storeroom zones, thereby improving the receiving, storage, selecting, and accumulation functions of piece-parts materials management at the plant. In addition, the system is responsible for auditing, administrative, and maintenance functions. Construction started in midsummer 1984.

The definition and development of the computer software and hardware architectures were the result of a joint effort between the Oklahoma City Works and AT&T Bell Laboratories systems engineering and development groups.
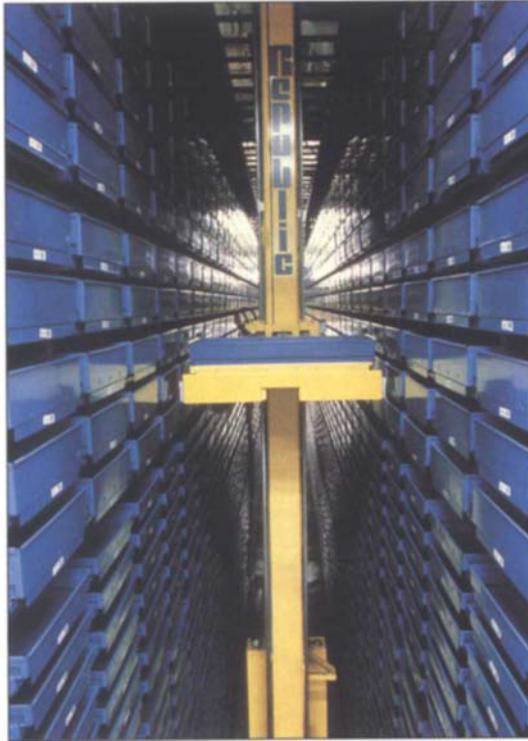
Material Flow

The AS/RS is composed of nine aisles with aisle-captive storage-and-retrieval cranes (robots). (See Figure 1.) The AS/RS receives material from a number of sources, including the receiving dock, the Integrated Circuit Reliability Test and Firmware shop, other manufacturing and kit shops, external storage areas, the shortage fill area, and other areas within AS/RS control (e.g., accumulator aisles).

Receiving. Material arrives at AS/RS receiving stations in a tote or in a self-contained form (such as a box) with a receiving or in-transit document. Operators enter material identifier information into the MOVES-AS/RS software system (Material Operations Velocity System)[1] using a video display terminal (VDT). MOVES-AS/RS then makes suggestions about the routing of the material, such as delivery to the shortage fill area or to stocking locations. (See Figure 2.) Totes are used to move material between functional areas in the AS/RS. The operator may split the material into several totes, routing some to the shortage fill area and some to the stocking area. Bar-coded *stock keeping identifier* (SKI) labels are applied to the totes or self-contained loads leaving the receiving stations.

Containers may be scanned three times between the receiving stations and stocking positions via fixed-position, moving-beam laser scanners. The first scanner routes the totes containing shortage material to the shortage fill

87

conveyor. A second scanner diverts the totes to the correct stocking aisle. The third scanner reads the bin location in the code and instructs an S/R (storage/retrieval) robot via MOVES-AS/RS to retrieve the proper storage bin. The bin is the storage medium within the rack structures. By the time a tote arrives for stocking, the associated bin is delivered to the stocking station, minimizing operator idleness and preserving the movement of materials.

At the mezzanine stocking station, an operator uses a hand-held laser scanner to confirm that the bin identifier label and the SKI label on the tote match. (See Figure 3.) The bin is then stocked with material from the tote. The crane automatically delivers the bin to its rack address after the operator signals that the stocking function is complete. Empty totes are

circulated via an overhead cable trolley conveyor.

Withdrawal. Orders to be retrieved (*selects*) are generated daily by an AT&T material requirements planning (MRP) system called IMPAC. (IMPAC stands for Integrated Manufacturing and Production Control System.) Withdrawals can also be locally originated transactions (for example, window withdrawals). Each select image has one or more select lines showing a part number, the quantity needed, and a select ID (an identification number).

MOVES-AS/RS assigns the select lines for each select to aisles and operators at the floor-level pick-and-delivery (P/D) stations. Bins are delivered to an operator's work queue. As a bin is delivered to a select position, a select screen shows the information necessary for this operation. First, the bin is verified by scanning the bar code affixed to the bin. When the operator has selected the required amount, a label is printed to be attached to the material. A second label attached to the tote identifies the accumulator aisle assigned to the select ID. This label is generated after all items for a select ID have been picked or when an operator intervenes (e.g., the tote is full). The operator then routes the tote to the accumulator lines. The bin is released for take-away by the S/R robot.

Withdrawals for a given select ID are always routed to the same accumulator station. As a tote arrives, the operator verifies the material and processes that portion of the select. After the last operation is done on a select ID, a copy of the select image is printed at the corresponding accumulator station sorted by drop zone. The operator sorts the material by drop zone and stages it for delivery to the shop.

Hardware

The AS/RS hardware system consists of an AT&T 3B20A processor, configured

Figure 2. Material flow in an automated storage and retrieval system (AS/RS).
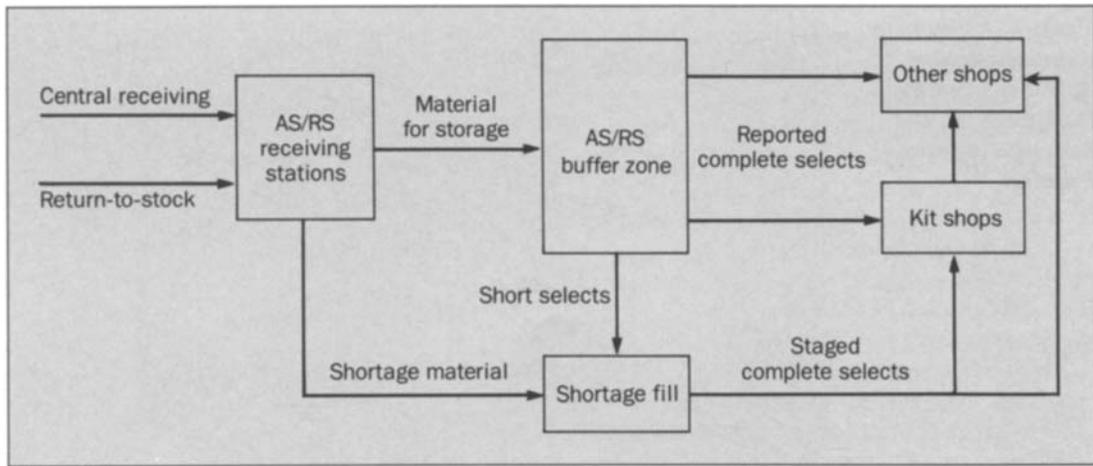
Figure 3. At the stocking station, robot cranes return bins to storage after operators have stocked them.


with 16 megabytes of primary memory. A second 3B20A processor, similarly configured, serves as a "warm" standby and is available as a test machine for new software releases of MOVES-AS/RS. Secondary, permanent storage is provided by fourteen 340-kilobyte fixed-media disks. There is a 1600-bytes-per-inch tape drive for tape backups. The hardware is configured to maximize processing and I/O (input/output) performance. Software communication with operators is conducted via AT&T 5425 terminals and 5310 printers. (See Figure 4.) Bar-code label printers for material identification and fixed-position and hand-held laser scanners for rapid data entry are also provided.

The Conveyance System. Material is routed through the intermediate destinations

Figure 4. AS/RS hardware architecture. IMPAC = Integrated Manufacturing and Production Control System.
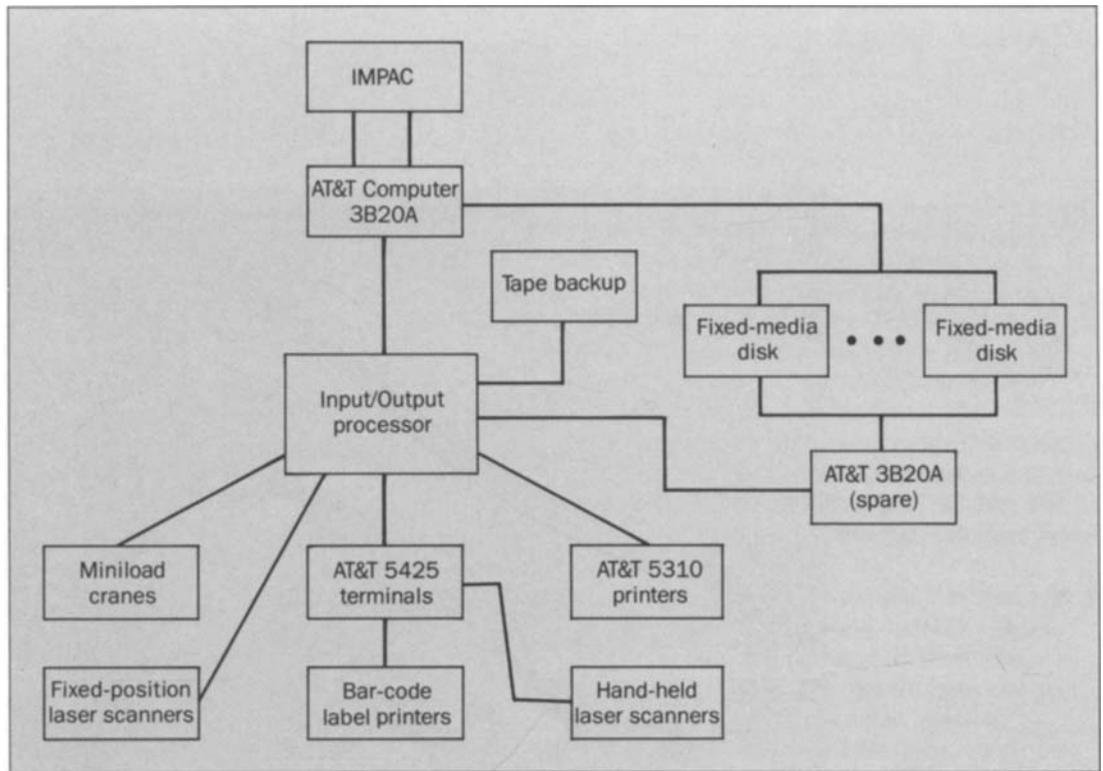
Figure 5. Hardware available at a pick-and-delivery station.


via a series of powered, zero-pressure roller and belt conveyors and chain-driven roller conveyors. A high-speed positive sorting system diverts totes to the proper accumulation line. Totes are supplied to and removed from operator stations via a self-sustaining overhead cable trolley conveyor.

P/D Stations. Pick-and-delivery stations are at floor level. (See Figure 5.) Material flows in a horseshoe pattern through each station. Inbound bins are queued on an elevated roller conveyor. An elevator lowers the next bin in the work queue down to the operator level. The bin on which work has been completed is lowered to an outbound bins queue for crane pickup.

Rack Structure. Each bin storage structure (or rack) is a freestanding, two-sided configuration, with 35 bays and 45 rows. Each bin may be sectioned with dividers into as many as four slots. Bins can handle up to 250 lb of load.

Cranes. S/R robots have a single mast with one lateral shuttle (or extractor) to store

Figure 6. Aisle-captive storage-and-retrieval crane (a) with bin extractor (b). The extractor fits on the u-shaped frame of the crane mast.
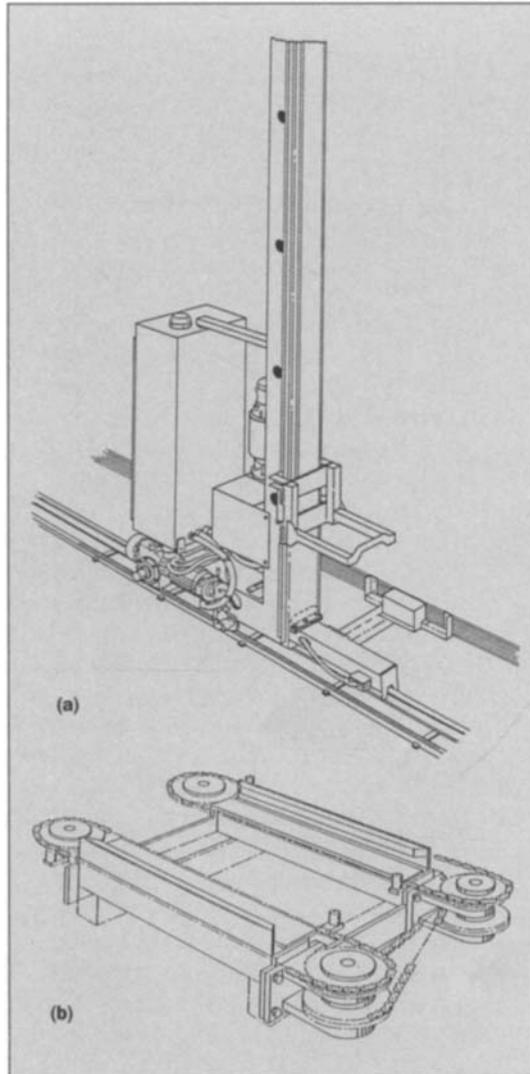
or retrieve loads. (See Figure 6.) The shuttle has provisions for monitoring and rejecting bins that exceed predetermined dimensions. The mast is supported on a track and guided at the top by guide rails for accurate vertical alignment. The S/R robot accepts sequential instructions moving rectilinearly and adhering to a Tchebeychev travel model.[2] Electrical power is supplied to each S/R machine by a power rail mounted at the bottom of the aisle. A deceleration sensor brings the crane to a safe and smooth stop before it contacts the mechanical end stops.

Preventive Maintenance. Daily preventive maintenance records and required maintenance schedules are stored on a microprocessor. The microprocessor assists in locating faults by displaying possible causes and associated repairs.

Software

MOVES-AS/RS is a collection of UNIX® System V software processes written in C programming and shell command languages. MOVES-AS/RS uses the System V, Release 2.0.3 swapping version of the UNIX operating system using the Tuxedo™ database management system and the FE 4.1 forms package. The UNIX system, Tuxedo system, and FE forms package are all standardly supported AT&T software products.

As in any system-supporting operation, a number of processes are associated with administrative and maintenance functions (e.g., audits, reports, and displays). Additionally, there are processes that interact with each of the operators (i.e., storeroom receiving, stocking, selecting and accumulating).

A rather sophisticated process translates the daily material plan (i.e., the list of select images) from the IMPAC system and locally entered withdrawals into a *select* schedule. Selects are placed onto queues by logical store and select type. They are then sequentially assigned from each queue according to an administratively determined sequence and priority scheme. When a select is assigned, it is important to retrieve all its associated parts in a short time frame to maximize responsiveness and minimize material loss through disassociation of the related parts.

Crane Handler. At the heart of MOVES-AS/RS is the crane handler subsystem, which manages the work flow. (See Figure 7.) The crane handler subsystem consists of one crane handler process and multiple stocking, selecting, and bar-code-reading "child" processes.
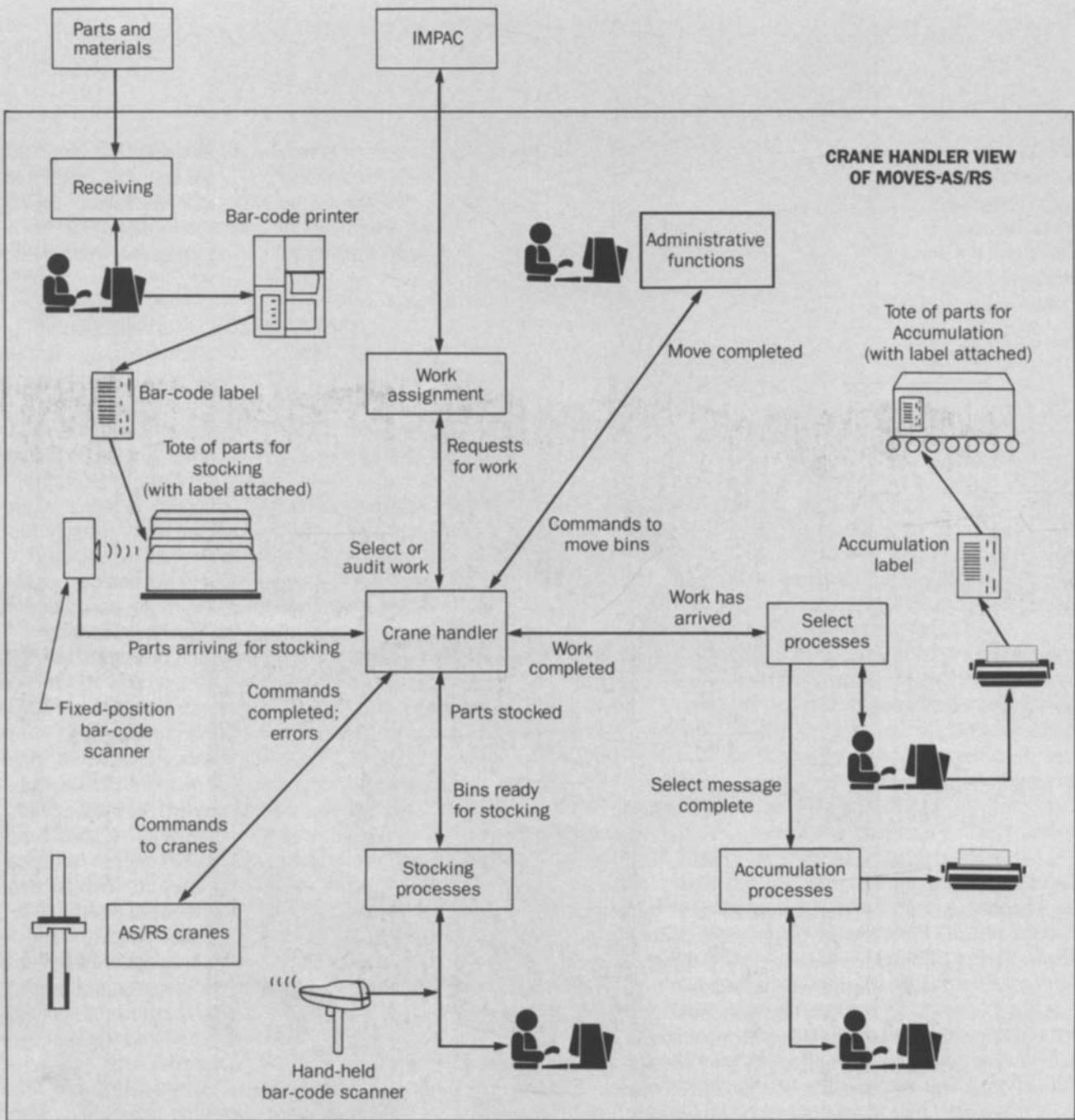
91

Figure 7. MOVES-AS/RS software architecture, focusing on the crane handler subsystem.

The exact number of child processes depends on the system configuration. Specifically, the crane handler subsystem:
- Requests bins from the AS/RS
- Informs operators when and how to stock parts into and select parts from retrieved bins
- Produces labels to identify selected parts
- Responds to exceptions that arise from invalid operator inputs.

The S/R robots occasionally experience problems in moving bins and the crane handler must be responsive to AS/RS exceptions as they occur.

In the crane handler memory is a model of the hardware and operators under its control. The model includes information about which S/R machines are in service, the outstanding commands to the AS/RS, the bins currently unavailable, the bins being serviced, the status of each bin being serviced, and the current activity of each selecting and stocking operator. The creation and proper maintenance of the model is the subsystem's most significant task.

The crane handler interacts with the S/R machines through logic units that control the cranes. Working from its memory model and scheduling input it receives, the crane handler directs each S/R robot to fetch and store bins for stocking and selecting. As long as its model is valid, the crane handler may service the AS/RS strictly on its own. If the model is violated (e.g., an S/R machine is placed into manual mode), the crane handler then requires human assistance to identify bins that are currently being serviced and to restore the model.

The crane handler attempts to stock material as quickly as it arrives at a stocking station. The crane handler has no prior knowledge of the arrival schedule. It depends on input it receives from a laser scanner. When a tote is scanned, the crane handler fetches the bin into which the material is to be stocked.

The bin and an informative screen of stocking directions are ready at the appropriate stocking station when the tote arrives.

The selecting schedule is known. The crane handler requests work from the assignment process. The work is requested according to priorities established by an administrator. Every effort is made within other constraints to use the operators working at the selecting stations. The effect is that operators are kept busy meeting the material plan.

Conclusion

Automated storage and retrieval systems are highly specialized material handling systems that require considerable capital investment. The savings, benefits, and advantages they provide must be enough to justify the substantial expenditure.

The miniload AS/RS at the AT&T Oklahoma City Works is expected to pay for itself in two and one-half years. We have improved labor efficiency and material velocity in just one year. Select accuracy has increased by about 20 percent. We have observed an improvement of at least 15 percent in inventory on-hand balance accuracy. Compared to the manual zones that were replaced, space use has increased by a minimum of 50 percent. With real-time data transfers, we have eliminated a one-day lag in inventory updating and have streamlined MRP scheduling.

AS/RS contributes to pilferage control and reduces material damage. It offers a controlled, safe, clean, challenging, and enjoyable environment for workers. Workers' skills have been upgraded, leading to improved job satisfaction. Employees are no longer viewed as "parts pickers"; they have become "system operators."

93

the resources and information during prepara-
tion of this manuscript, and to Scott Speicher
for editorial comments.

References
1. R. L. Franks et al., "Productivity Improvement
   Systems for Manufacturing," *AT&T Technical Jour-
   nal*, Vol. 66, No. 5, September/October 1987, pp.
   61-76.
2. Y. A. Bozer and J. A. White, "Travel-Time Models
   for Automated Storage/Retrieval Systems," *Trans-
   actions, Institute of Industrial Engineers*, Vol. 16,
   No. 4, December 1984, pp. 329-338.

Biographies (continued)
*handling in AT&T factories. He has a B.A. in chem-
istry from Kalamazoo College, a Ph.D. in
chemistry from Yale University, and has done
postdoctoral work in both chemistry and com-
puter science at Harvard University.*