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A Magnetic Associative Memory System

Most of the memory techniques in present use share the limitations imposed by the requirement that the location (or address) of the desired information be known. The addressable mode of memory operation in use today has imposed formidable requirements of housekeeping and data organization in many problems. Much of this could be eliminated if it became possible to retrieve a record directly from memory on the basis of the associated known information. Programing techniques for this kind of record retrieval are complex and time-consuming.

Stored information ordered on a particular field can be retrieved by carrying out a partitioning search routine on that field. Of course, if retrieval through any one of several fields is desired, several lists, each ordered on a separate field, must be provided. Each successful search requires $\log_2 N$ memory access cycles (for a memory of N words) as well as the associated execute times. (This does not include the time required for each initial ordering.) Unordered information can, of course, be retrieved by means of a serial-by-word scan of the entire memory. This is usually laborious since an average of $N/2$ accesses to memory are required.

An economical substitution of hardware for these programing and housekeeping tasks is the object of this research. Some previous work has described a cryogenic embodiment of the associative memory.[1-6] The purpose of this Letter is to briefly describe an approach we have taken with magnetic technology and to summarize some of the significant results obtained. A secondary purpose is the establishment in the literature of a set of basic definitions which will provide a common basis for future consideration.

As an illustration of the use and value of an associative memory, let us consider an information retrieval problem in which it is necessary to supply information to a customer regarding items of stock in the electrical switch class. In memory will be data on each stock item specifying item number, switch size, current capacity, voltage, et cetera. If the customer desires a switch of given current capacity and voltage, a simultaneous search on both fields for these values will produce all the information on the stock items which satisfy these requirements. It is this simultaneous search on all words at high speed and the ability to interrogate any field that gives the associative memory its advantage.

Definitions

An associative memory is a memory in which a data record is retrieved by specifying the information content of an arbitrary portion of its structure. This portion of the record will be called the *select pattern*. The associative region, or that portion of the memory word possessing associative properties, may extend over the entire word or may be bounded, extending over only a portion of the word defined by memory construction. In this Letter, a *memory word* will be used to refer to a register in memory while a *record* refers to customer data.

This physical bounding of the associative region gives rise to different classes of associative memories depending on the extent of the bounded region. The portion of the memory word that is specified in conjunction with the above physical boundary produces four different modes of operation. A memory in which the select pattern is confined only to a portion of the total memory word by construction will be called a *tag memory*. Referencing a particular tag in the tag memory calls forth the remaining portion of the memory word. An associative memory which permits the specification of any arbitrary bit pattern as the basis for the extraction of the record within which this pattern appears is called a *fully associative memory*. The operating modes of an associative memory system may be defined as in Table 1.

Table 1

Associative region	*Percent of information contents specified*	*Operating modes*
Partial	Total	Tag mode
Partial	Partial	Partial tag mode
Total	Total	Identical mode
Total	Partial	Fully associative

Memory functioning of the associative type is in contrast to present memories in which the data word is located in a specific memory register predetermined by the program and is retrieved by specifying the address of that register.

While this paper describes an approach toward fully associative operation, it will become apparent that it is capable of operation in any of the other modes as well.

Memory operation

For purposes of explanation of the memory operation, Figs. 1 and 2 are included and are not necessarily indicative of means of implementation of such a system.

Fundamental to the operation of the associative memory system is the operation of the basic storage cell—a nondestructive read element having the characteristics illustrated in Fig. 1. There are four possible outputs from the storage element (whose most practical embodiment could be a simple magnetic toroid): a small negative signal when a 0 is stored and the interrogation is for a 0; a large negative signal when a 1 is stored and the interrogation is for a 0; a small positive signal when a 1 is stored and the interrogation is for a 1; and a large positive signal when a 0 is stored and the interrogation is for a 1. Thus, under the condition of a mismatch between the stored information and the interrogating information, a large signal is generated. The role of the detector device (one per word), therefore, is to register only the first large signal regardless of polarity and to be insensitive to the small output signals.

With the above elementary function in mind, we may now consider the operation of the associative memory system shown in exploded block diagram in Fig. 2. With the detector plane and the switch core drive plane reset to their initial state, the input data, which may consist of a field of the desired word, an arbitrary, not necessarily dense, subset of the word set, or even the whole word itself, is placed in the data register. By means of AND gates with inputs from the mask control register there is provided an additional measure of control over the association process; i.e., the DON'T CARE condition. The output from the mask is in the form of drive pulses, whose polarity indicates whether a 1 or 0 is being searched for. In this memory system, the interrogation is done parallel by word, serial by bit; i.e., the bit planes are pulsed in time sequence. When a particular bit plane is energized, all the cores respond as explained before; the matching cores yielding a small signal which does not affect the detector cores, the mismatching cores generating a large signal which in turn switches the corresponding detector cores. Assuming a unique match, after the ripple interrogation is over, there is only one detector in the detector plane which has not been switched, corresponding to the desired word. By applying a pulse to all detectors in the detector plane in a direction opposite to that of the original reset pulse, only the detector belonging to the desired word will now switch, and the output will register on the two coordinate wires linking this detector. This in effect encodes the location information, which is then amplified by the sense amplifiers which in turn activate the X and Y drivers for the switch core drive plane. The switch core at the selected coordinates is activated, thus performing an internal decoding function. The secondary current of the selected switch core energizes the bit cores of the desired word, and the entire word is read out via the sense amplifiers at the lower left into the data output register. In the case of a nonunique match, the selected coordinates of the detector plane must be subject to further tests to eliminate a possible erroneous match.

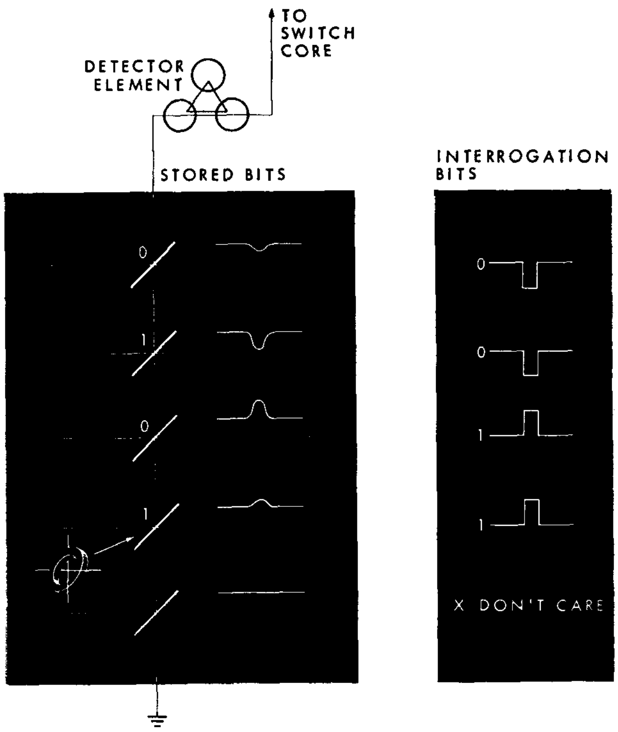


Figure 1 **Typical word register for a magnetic associative memory.**

To write associatively, the memory must be associatively searched to determine the locations of empty cells into which external data is written. As an aid to greater programing flexibility (and to assist in initial loading of the memory), the memory can be operated in a conventional addressable mode through the external X and Y address registers, as shown on the diagram.

Conclusions

This research has produced an experimental system for nondestructive readout in ferrite toroids and has developed methods of coupling the available signal energy into suitable detectors.

Results indicate that word lengths up to 36 bits with a passive detector are feasible; however, word lengths of 1000 bits are technically achievable with an active element as the detector.

Memory capacities of several hundred words appear technically feasible with a single interrogation driver; for larger sizes, parallel operation may be required.

The search and retrieval time for an associative memory previously described of N words requiring a search on 36 bits would be approximately 6 microseconds. For comparison purposes, the read-write cycle time when used as a conventionally addressed memory would be 2 microseconds.

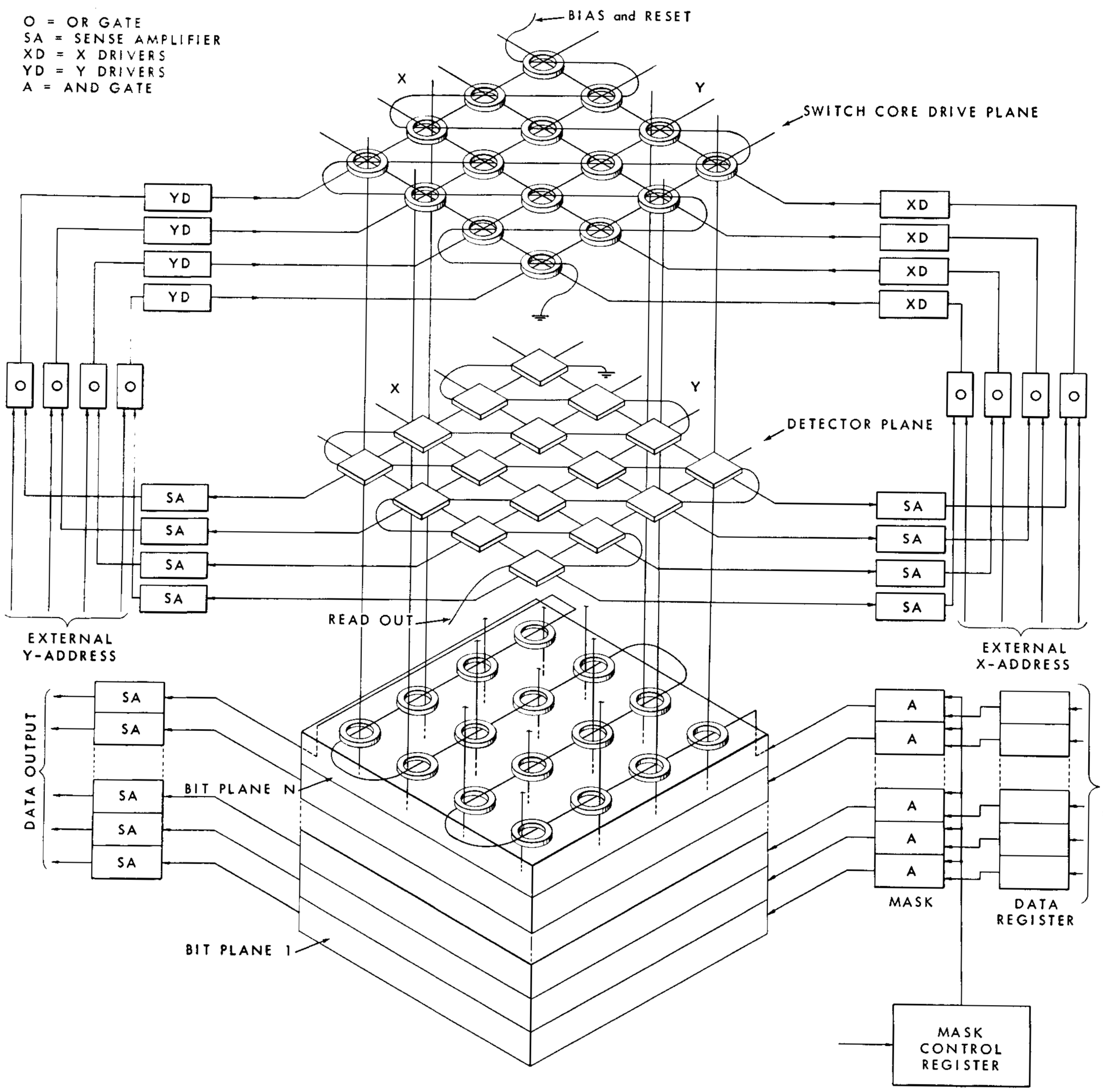
For this study, stable nondestructive readout of the storage element has been demonstrated for greater than 10^6 interrogations.

Technical feasibility has been shown for the following functions:

1. Associative search followed by either destructive or nondestructive readout of the word to be retrieved.
2. Associative search followed by a clear of information in the memory register identified with a subsequent write-in of new data.
3. Addressable operations identical with those stated above.
4. Full flexibility of mask operations.

A more comprehensive description of device and sys-

Figure 2 **Block diagram for a magnetic toroid associative memory subsystem.**



tem operation is being prepared for early publication in this journal.

Acknowledgment

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