An Optical Architecture Using Multiwavelength and Polarization Encoding for High-Speed Parallel Relational Database Processing

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ABSTRACT - An architecture for optical CAM-based parallel database processing is presented. It features compact design and constant-time parallel processing of database operations using wavelength and polarization division multiplexing techniques.

1.0 Introduction

Databases are emerging as the most important ingredients in information systems. They have penetrated all fields of the human endeavor and are no longer limited to business-oriented processing. Database systems are becoming the backbone of (1) business (investment, trade, retailing, insurance companies, etc.), computer-aided design and manufacturing, (3) medicine and pharmaceuticals, (4) geographic information systems, (5) defense-related systems, (6) multimedia (text, image, voice, video, and regular data) information systems, graphics-oriented processing, and object-oriented computing, among many others.

Searching, retrieving, sorting, updating, and modifying nonnumeric data can be significantly improved by the use of content-addressable memory (CAM) instead of location-addressable memory [1]. Unfortunately, large computers based on CAM architecture have not been realized due to the difficulty and high cost of implementing them in conventional electronic technology. Up to now, CAMs have been restricted to small auxiliary units in computer systems.

A novel architecture called Optical Content Addressable Parallel Processor (OCAPP) was introduced and demonstrated for implementing high-speed database operations [2, 3]. This has been extended to a new architecture called MW-OCAPP that utilizes wavelength and polarization division multiplexing [4, 5] to achieve a higher degree of parallelism and system integration than ever before. These enhancements enable us to process multiple data arguments at the same time and within the same space, thus greatly increasing the parallelism of the processor. The processor includes a new sub-unit that performs the intersection, difference and union operations simultaneously and in constant time.

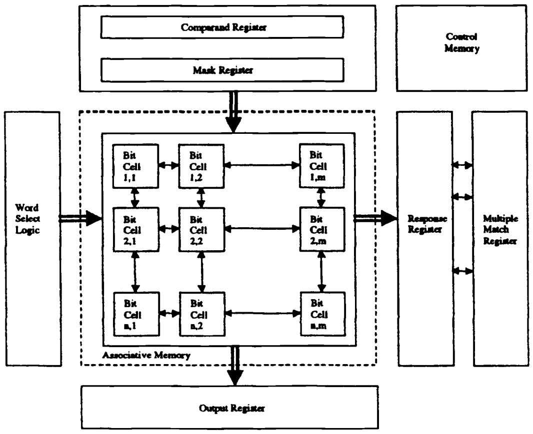

Figure 1: Associative Memory Processor Model

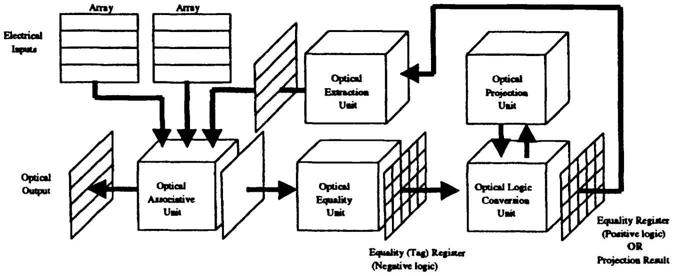

Figure 2: MW-OCAPP Schematic Organization

2.0 Overview of the MW-OCAPP Processor Architecture

Figure 1 illustrates the traditional content addressable memory (CAM) architecture. It consists of an array of *n* associative words, word select logic, comparand and mask registers that contain the search arguments, a response register, an output register and control memory that synchronizes the entire system [6]. MW-OCAPP extends the generic architecture to multiple-comparand associative processing. Figure 2 illustrates MW-OCAPP's associative processing model. The word select logic of the generic design has been replaced by the relational operations processing logic: Associative, Equality, Extraction, Projection and Logic Conversion Units. The Multiple Match register has been replaced by the Equality Registers. The function of the associative unit is analogous to the main associative memory array of a CAM where 2-D matching and multiple comparison with memory are accomplished.

MW-OCAPP can realize five database operations: intersection, difference, union, product and project. The optical processing logic of MW-OCAPP consists of five modules: an Associative Unit, an Equality Unit, an Extraction Unit, a Projection Unit and a Logic Conversion Unit. The inputs to the Associative Unit are the comparand array (CA) and relation array (RA). Each row (tuple) of the CA is polarization logic encoded at different wavelengths by a tunable semiconductor laser array and an electronically-addressable spatial light modulator. This form of encoding allows for the superimposing and parallel processing of comparands as they propagate through the associative and equality units. The optical Associative Unit produces a wavelength/polarization encoded light plane that holds the locations of all the mismatched bits. The optical Equality Unit takes this light plane and produces an output that represents the intersection locations of the CA and RA tuples. Next, this intersection result passes through the optical Logic Conversion Unit where it is converted from negative logic to positive logic that is required for subsequent relational operations.

The optical Projection Unit that is attached to the Logic Conversion Unit performs the projection operation. The projection operation forms a new relation by extracting certain tuples from a particular attribute. The Projection Unit utilizes the positive logic that it receives from the Logic Conversion Unit and performs a self-equivalency operation with the help of the Associative Unit to remove duplicate tuples in constant time.

The optical Extraction Unit can perform three operations simultaneously and in constant time: intersection, difference and union. The Extraction Unit acts on the result of the Logic Conversion Unit to make copies of it via wavelength multiplexing. This undergoes a transformation that produces a light plane that contains the row selection information for the union, difference and intersection operations. This light plane passes back to the Associative Unit where the tuples for these three operations are simultaneously extracted. The Extraction Unit provides additional motivation for using multiple-wavelength data processing. With multiple-wavelength processing, we manage to perform three operations concurrently and in the same space.

3.0 An Example Relational Operation: Equality

The five fundamental database operations that are currently implemented in MW-OCAPP are intersection, difference, union, product and project. Because of limited space, only the equality operation will be described here. The complete architecture will be made available at the conference. The equality operation tests multiple comparands against multiple relations in constant time. It accomplishes this by using multiwavelength and polarization multiplexing techniques that are outlined below.

Figure 4 illustrates the architecture contained within MW-OCAPP's Associative and Equality Units. Figure 3 shows the example input logic planes that are presented to the system, and the output logic plane that this system produces. The module description begins with a tunable semiconductor laser array. Each row (which will correspond to a separate tuple) radiates at a different wavelength. This wavefront passes through a polarizer where it becomes horizontally polarized. We now have a wavefront that is horizontally-polarized, and each "row" is at a different wavelength. The comparand array (CA) to be matched is written to an electronically-addressable spatial light modulator (EASLM) which polarization-encodes the light passing through it (Figure 4a). The encoded light plane passes through a lens array which broadcasts each of the rows (CA tuples) with different wavelengths over the full surface of the light plane. This multiplexed plane passes through another EASLM which is encoded with the relational array (RA) to be matched against (Figure 4b). The EASLM rotates the polarization(s) of the incident light according to the logic states of its pixels. The output passes through a vertical polarizer that removes all of the horizontally-polarized light. The resultant light plane contains all of the bit mismatch locations of each of the CA and RA tuple combinations. Here the light exits the Associative Unit.

These bit mismatch locations produced by the Associative Unit enter the Equality Unit and are funneled down to a single column. This column must now be wavelength demultiplexed into a plane that has a pixel count width equal to the number of tuples in the CA, and a pixel count height equal to the number of tuples in the RA. This can be accomplished using a holographic element that is fabricated to deflect light at an angle that is a function of its wavelength. The resulting light plane (Figure 4c) has three columns of light, each at a different wavelength. Since this result is in a negative logic format, everywhere there is no light present (2 pixels) there is a match between a tuple in the CA and a tuple in the RA. We can read from the diagram that there is a match between tuple #1 of the CA and tuple #2 of the RA. Similarly, there is another match between tuple #2 of the CA and tuple #1 of the RA.

The equality operation is an operation that is performed on multiple comparands simultaneously. Additionally, this is all done in constant time, independent of database size. It is clear that optics can achieve a substantial degree of parallelism.

4.0 Conclusions

In this paper, we presented an optical associative processing system called MW-OCAPP. The use of wavelength and polarization division multiplexing has been harnessed to increase the parallelism of the computational design. Not only can we perform multiple argument comparisons simultaneously, but we can process different relational operations simultaneously and in constant time. There are several hurdles that have not yet been addressed in this architecture. The first issue is one of database size. For the proposed examples, it was assumed that the databases were small such that they could be encoded in their entirety onto an SLM. In reality, databases will far exceed the spatial resolution of the light modulators. Iterations through the relational database will be necessary to bridge this size gap. Additionally, there are some issues surrounding the demultiplexing of laser light. Current optical technologies can handle over a thousand channels (separate wavelengths), but the task of fully separating each of these channels with minimal loss in signal power is daunting. The choice of tunable VCSELs [7] plays a large role in the usable bandwidth of the system. The second issue deals with the wavelength response of optical components. We assume that all elements are achromatic at the wavelengths of interest. In reality, some degree of dispersion will always exist in the optical system, and this will place a limit on the size of the optical path lengths used. Therefore, the multiple wavelength architecture may not be easily realized. In summary, multiple-wavelength associative processing may serve to be a good solution for today's and future demands on database processing. Currently, we are investigating various other relational operations such as (multi-wavelength) relative magnitude comparison, selection, join, update, and numeric processing.

Tuple 1	1	1	0	0
Tuple 2	1	0	0	1
Tuple 3	0	1	0	1

(a)

1	0	0	1	Tuple 1
1	1	0	0	Tuple 2
0	1	1	0	Tuple 3

(b)

		CA 1	CA 2	CA 3
RA	1	1	0	1
RA	2	0	1	1
RA	3	1	1	1

(c)

Figure 3: Example Input/Output Logical Planes for the Equality Operation; (a) Comparand Array; (b) Relational Array; (c) resultant match locations (negative logic)

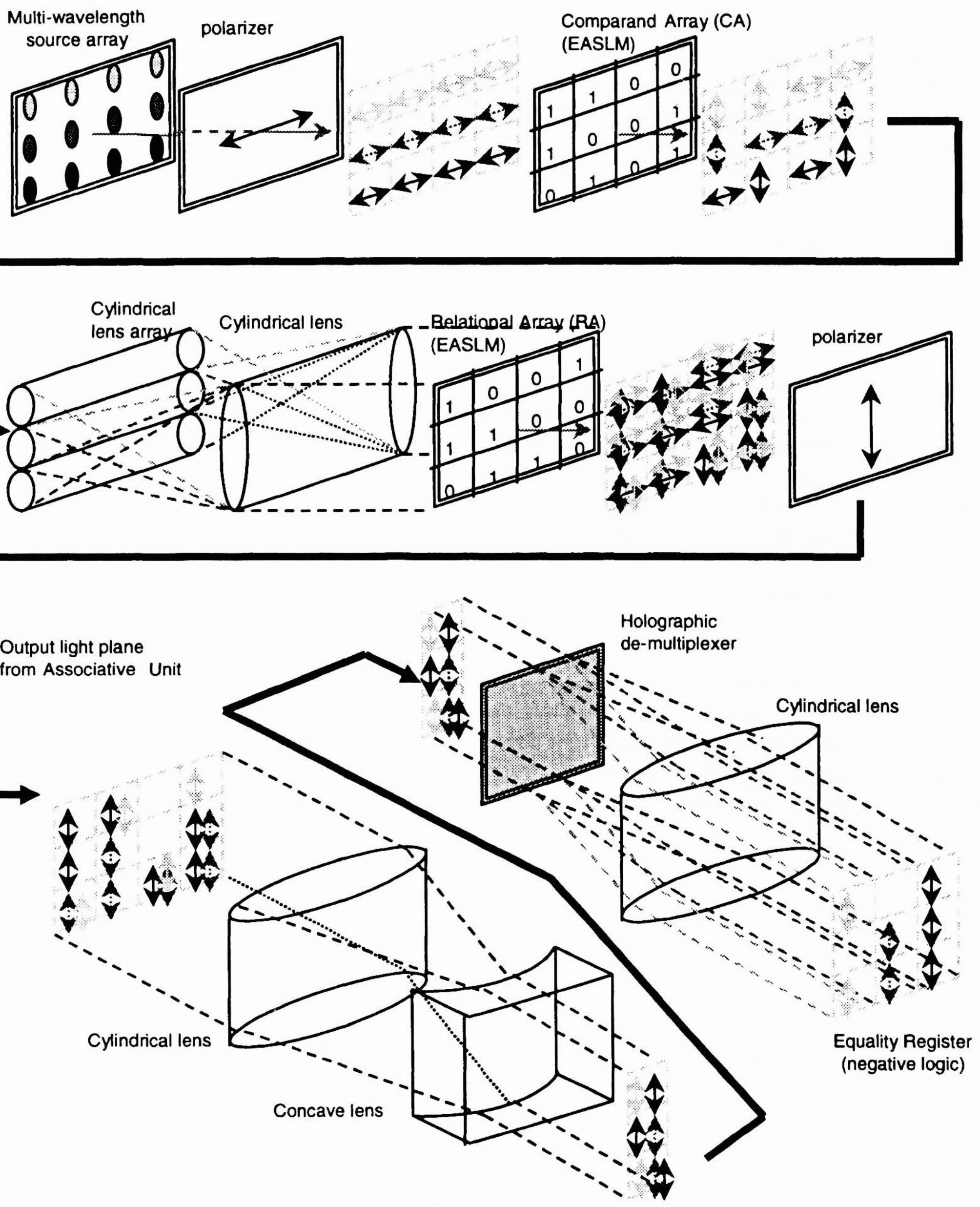

Figure 4: MW-OCAPP's Equality Unit

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