A Multi-Wavelength Optical Content-Addressable Parallel Processor (MW-OCAPP) for High-Speed Parallel Relational Database Processing: Architectural Concepts and Preliminary Experimental System

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1.0 Introduction

This paper presents the preliminary experimental implementation results of an architecture for parallel database processing called MW-OCAPP. It features single-step multiple-comparand bit-parallel word-parallel symbolic computation in constant time. MW-OCAPP's multi-comparand approach offers a speedup of *m* over conventional word-parallel CAM-based systems, where *m* is the number of comparands to be compared.

Optoelectronic implementation of database machines has been proposed and discussed in literature since the late eighties [1,2]. Most of these proposed implementations harness the signal transport superiority of optics [3] combined with the processing power of electronics. One popular solution for very large database machines is the use of the content-addressable memory (CAM) model. The performance in manipulating non-numeric data can be significantly improved by using CAM versus location-addressable memory [4] due to its intrinsically parallel search capability. The combination of the CAM model and optics has given rise to optical associative processing [5] which is a key technique used in optical database processing.

MW-OCAPP is a comprehensive optical database processing unit that combines a parallel associative model of computation with high-speed multi-wavelength optical technology [6,7,8]. Figure 1 illustrates a structural organization of MW-OCAPP's processing model. The optical processing logic of MW-OCAPP consists of six modules: an optical Selection Unit, an optical Match-Compare Unit, an optical Equality Unit, an optical Magnitude Comparison Unit, an optical Relational Operations Unit, and an optical Output Unit. The MW-OCAPP architecture is designed in such a way as to implement a total of eleven database primitives. Most of these execute in a time-span that is independent of the problem size.

The inputs to MW-OCAPP are the comparand array (CA) and relational array (RA). Each row (tuple) of the CA is polarization logic encoded with different wavelengths by a multiwavelength source array and an electronically-addressable spatial light modulator. This form of encoding allows for the superposition and parallel processing of multiple comparands as they propagate through the Match-Compare and Equality units. Figure 2 illustrates the data representation model that is used to generate all subsequent higher-order relational operations. In this model, two representative words (CA1 and CA2) are compared with a Relational Array database containing five words. Three registers are generated (Equality, Greater-than and Less-than) that specify the tuple pairs that satisfy the given conditions (equal-to, greater-than less-than). Using this technique, MW-OCAPP can realize *difference*, *intersection*, *union*, *conditional selection*, *join*, *maximum*, *minimum*, *product*, *projection*, *division* and *update*.

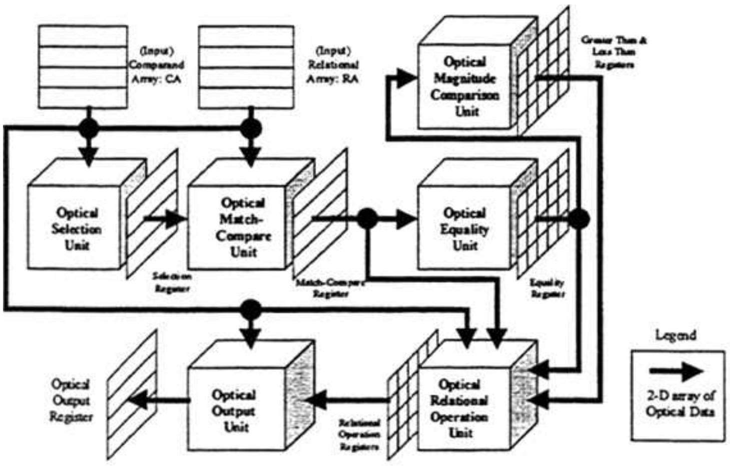


Figure 1: MW-OCAPP Schematic Organization

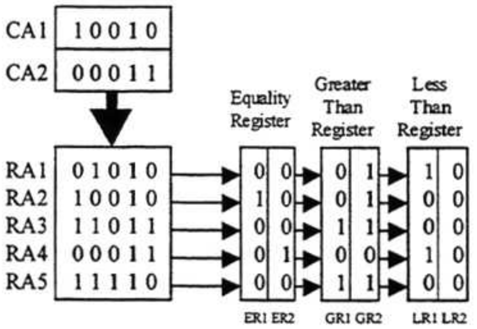
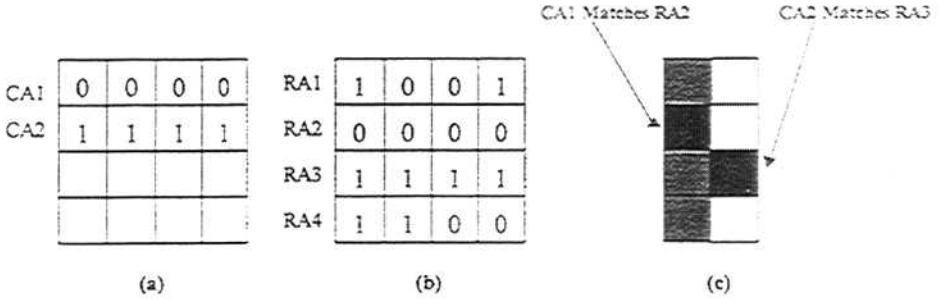


Figure 2: Data representation in MW-OCAPP. Two words in the Comparand Array (CA1 and CA2) are compared against five words in the Relational Array database (RA1 to RA5). Three optical registers are generated in parallel which are termed the Equality, Greater-than and Less-than Registers. For example, the equality registers, ER1 and ER2, contain a '1' corresponding to each word in the RA that exactly matches words CA1 and CA2 respectively.

2.0 Physical Demonstration of a Preliminary Version of MW-OCAPP

This section presents the physical demonstration of MW-OCAPP that has been done thus far. In this preliminary demonstration, the Equality Register that contains the "exact-match" information between each of the tuples in the RA and CA is generated. Figure 3 shows the bit patterns contained in the example RA and CA as well as the expected Equality Register that results from the operation. The Comparand Array (CA) contains two tuples, "0-0-0-0" and "1-1-1-1". These are compared against four tuples in the Relational Array (RA).



CA1	0	0	0	0
CA2	1	1	1	1

(a)

RA1	1	0	0	1
RA2	0	0	0	0
RA3	1	1	1	1
RA4	1	1	0	0

(b)

(c)

Figure 3: The experimental setup matches two tuples found in (a) the Comparand Array (CA) with the four tuples found in (b) the Relational Array (RA). The Equality Register that results (c) consists of two columns of differing wavelength and indicates that there is a match between CA1 and RA2 as well as CA2 and RA3. Non-illuminated (black) pixels indicate an exact match.

The experimental setup required to implement this is displayed in Figure 4. The vertically-polarized source radiation comes from a 2W argon ion laser in its multi-line configuration. This beam passes through an afocal beam expander lens system that broadens the beam to a 1.5cm width. This multi-line beam is now filtered to extract the 488.0 nm (blue) and 514.5 nm (green) spectral lines. One of these beams has its polarization rotated by placing a quarter waveplate in its path. This "color" will hold the results from CA2 and the other will hold the results from CA1. These two purified beams are recombined using a cube beamsplitter and impinge off of a FLC spatial light modulator. This SLM is a reflection-mode device that rotates the polarization states by 90 degrees of each of the addressed pixels. It is encoded with the four tuples contained in the relational array. This passes through a vertically-oriented polarizer and some imaging lenses that focus the plane down to a single column on the screen. A holographic grating is placed between the lens system and the screen in order to spatially separate the two color channels into individual columns. Figure 5 illustrates a photograph of the experimental setup.

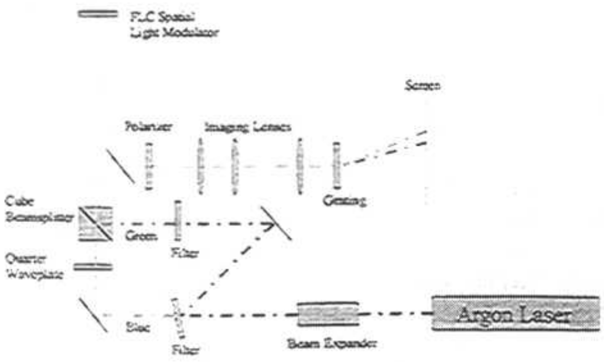


Figure 4: The experimental component layout

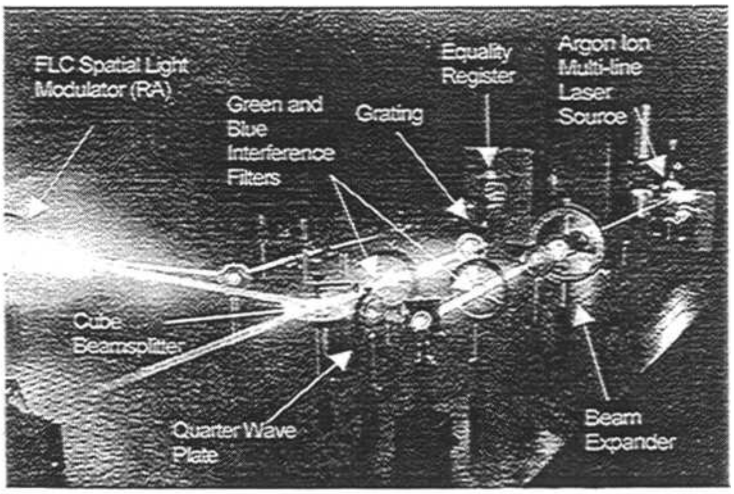
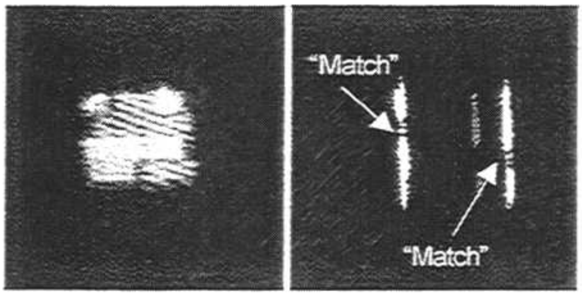


Figure 5: Demonstration system photograph

Figure 6 shows the Equality Register at two points in the imaging system. Figure 6a is an image of the light plane just prior to its passage through the imaging optics. Both the green and blue channels completely overlap. Figure 6b shows the Equality Register at the focal plane. Notice that there is a dark pixel in the second row of the first column and in the third row of the second column. Both of these locations correspond correctly to tuple "matches" predicted in Figure 3.



(a) (b)

Figure 6: The Equality Register at (a) just prior to wavelength demultiplexing, and (b) at best focus. The blurring is caused by the low shutter speed required to image the registers combined with the page-swap refreshing of the FLC SLM.

3.0 Conclusions

In this paper, an optical associative processing system called MW-OCAPP is presented. It harnesses a unique method of wavelength and polarization-multiplexing of dataplanes to achieve a high level of parallelism. Optical implementation is made possible by exploiting the non-interactive behavior of coincident light-planes of differing wavelength. This architecture offers database systems constant-time parallel equality and magnitude comparison of multiple comparands with multiple tuples in a relational array. When compared with conventional iterative word-parallel magnitude comparison schemes where w is the wordlength and n is the number of comparands to be operated on, MW-OCAPP's magnitude comparison algorithm offers a speedup of wn. This performance suggests a substantial performance improvement over previous designs in database operations such as sorting which typically use the magnitude comparison operation repetitively. Additionally, MW-OCAPP's multi-comparand approach offers a speedup of m over conventional word-parallel CAM-based systems, where m is the number of comparands to be compared.

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