PARALLEL IMAGE PROCESSING

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Abstract This chapter reviews basic work on parallel image processing and analysis, with emphasis on work done at the Computer Vision Laboratory at the University of Maryland. It describes parallel computers suitable for image processing tasks, including meshes, pyramids, and hypercubes, and discusses parallel algorithms for pixel-level and region-level processing.

1. INTRODUCTION

Image processing and analysis are computationally intensive because of the complexity of the operations and the quantity of data that need to be processed. Most images range in size from $256 \times 256$ to $1024 \times 1024$, so that up to three megabytes of data need to be processed for one color image. Computational complexity is $O(N^2)$ for an $N \times N$ image for simple operations such as point or local operations, and is even higher for more complex tasks such as image restoration and image compression. In real-time video processing, tens of images must be processed every second.

The computational requirements of image processing and analysis often exceeded the capabilities of the general-purpose computers built before the 1990's. Parallel processing has long been recognized as a solution to the time complexity problem, making it possible to achieve the speed necessary for real-time applications. In 1958 Unger [60] proposed using "cellular array" computers for parallel image processing. Since then, numerous algorithms suitable for implementation on cellular arrays have been developed. Later, other parallel architectures were introduced, and many parallel computers, including some dedicated to image processing and computer vision, have been built. Some of these computers are research prototypes, while others are commercially available. Parallel
image processing algorithms and software systems and tools have been
designed and implemented on these computers.

Nowadays, computers have become very fast, and the interest in par-
allel systems for image processing and analysis has subsided somewhat.
However, this interest still persists, as is evident from the number of
papers presented at recent conferences [5, 7, 27, 54, 72] on the subject.
The IEEE International Workshop on Computer Architectures for Ma-chine Perception and the SPIE Conference on Parallel and Distributed
Methods for Image Processing, both held in the year 2000, were quite
well attended.

Parallel image processing and analysis has been of interest at the
Computer Vision Laboratory of the University of Maryland in College
Park for many years. As early as the mid 1960's, research on sequen-
tial/parallel computing was already under way at CVL [26, 44, 56].
At the same time, software was developed that took advantage of the
ability of mainframe computers to perform logical operations in parallel
on all the bits of a machine word. The PAX language, originally
written at the University of Illinois to simulate the ILLIAC III [23],
was improved and expanded at CVL for use on the UNIVAC 1108,
PDP-10, IBM 360, and CDC 6600 [17, 55]. This led to much work at
CVL on cellular array automata [12, 24, 32, 33, 34, 67, 68, 71], cel-

dular mesh-connected computers [15, 16, 21, 43], pyramid computers
[11, 18, 35, 36, 38, 49, 53] and cellular computers with arbitrary graph
structures [2, 9, 22, 25, 31, 45, 46, 47, 64, 69, 70]. CVL also participated
in Defense Advanced Research Project Agency (DARPA) parallel pro-
cessing efforts by hosting a 128-node Butterfly, a WARP systolic array
processor, and a Connection Machine. Algorithms and software were de-
signed to be executed on these parallel machines. CVL was also involved
in DARPA's efforts to design image processing and analysis benchmarks
for parallel computers [61, 62].

This paper reviews some of the basic work on parallel image processing
and analysis, emphasizing work done at CVL [2, 3, 6, 9, 11, 12, 15, 16,
17, 18, 20, 21, 22, 23, 26, 24, 25, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40,
41, 42, 43, 45, 46, 47, 48, 49, 50, 53, 56, 61, 62, 64, 65, 66, 67, 68, 69,
70, 71]. It emphasizes single-image computations at the pixel, feature,
and region levels. Section 2 introduces parallel computers suitable for
image processing tasks; some of the systems described have actually been
built, and some are proposed models. Section 3 presents some parallel
algorithms for pixel-level processing to illustrate the techniques used
and the problems encountered. Region-level computation is discussed in
Section 4.