Parallelizing Sobel Edge Detection

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1 Literature Review

1.1 Edge Detection

Edge detection is a collection of mathematical methods which attempt to take in a digital image and identify the edges existing within it. It is an active area of research as the concepts used here are the foundation for many other fields - especially computer vision.

On a basic level, edge detection attempts to look for significant local change in image intensity. Discontinuities are either step discontinuities, or line discontinuities. The former is when we change rapidly from one value to another when going other a discontinuity. The latter involves the intensity of the image to change rapidly to a new value at some point, but then further down return to the same value [15, 16]. Unfortunately, real world images are often not as simple. Step edges turn into ramp edges and line edges become roof edges, with the changes of value occurring over a finite distance rather than abruptly [15]. Figure 1 demonstrates these differences.

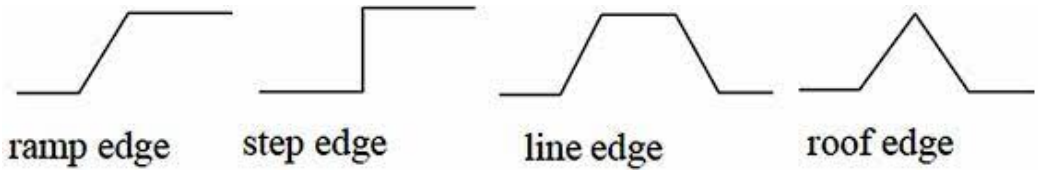

Figure 1: Examples of the four edge types

Edge detection algorithms attempt to detect significant local change in the image, while not letting the noise of the image get in the way. They quantify the image as an array of image intensity based on a continuous function [4, 29, 26, 25]. Commonly, a step edge would be associated with a local peak in the first derivative of the graph mapping values to location [15]. However, this results in too many edge points. The solution is to find points that have local maxima in gradient values and consider them edge points. The two main approaches here are the Laplacian and second directional derivative. We will now explore the main operators used in edge detection, both the first order and second order.

1.1.1 Roberts Cross Operator

One of the first edge detection operators proposed, the Roberts cross operator utilises discrete differentiation to approximate the gradient. It first applies the Gx and Gy mask, which are 2x2, to the entire image from where it proceeds to calculate the gradient magnitude [26].

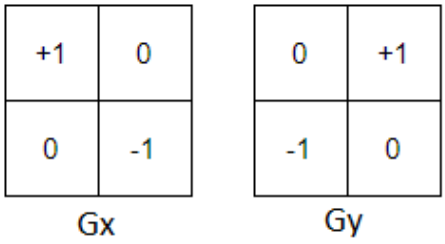

Figure 2: Roberts Operator Kernel

1.1.2 Sobel Edge Detection

This was the next main edge detection algorithm to come out, and one that is still prominently in use today. The Sobel operator uses a 3x3 image mask to convolute the image, using horizontal and vertical anchoring. The masks allow approximation in both the y and x direction, from where it can more accurately estimate the gradient[29].

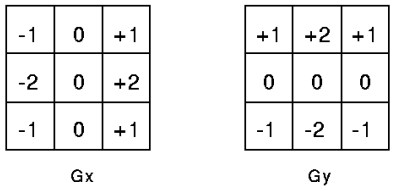

Figure 3: Sobel Operator Kernel

1.1.3 Prewitt Edge Detection

The Prewitt algorithm utilises a similar approach to the Sobel, however, it provided a slight computation speed improvement and also involves different kernels [25]. Note how the masks used for convolution do not place emphasis on the middle pixels as the Sobel kernels do.

1.1.4 Canny Edge Detection

The algorithm proposed by Canny et al. is a computationally effective algorithm that declares computational requirements for edge detection and proposes a highly effective circular operator meant to work on any scale [4].

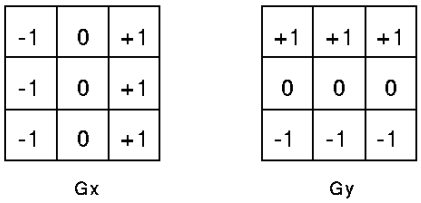

Figure 4: Prewitt Operator Kernel

1.1.5 Laplacian Edge Detection

Laplacian edge detection involves the estimation of the second derivative. The first step involves the use of a Gaussian filter to blur the image, making it smoother to work with. From there masks are used to create the resulting edge images (with various kernels being able to be used) but the kernels are meant to calculate the second order derivatives. One thing to note is that since we have one kernel with the Laplacian, it computers the result much faster. However, because it uses second derivatives, it is extremely sensitive to noise [15].

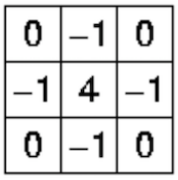

Figure 5: Laplacian Operator Kernel

1.2 Overall Edge Detection

The above mentioned operators are the ones most commonly used in current industry and academia[34]. The authors would like to mention other notable papers that have not made it into a section of their own, yet these papers have also provided effective algorithms and filter approaches yielding quality results [3, 11, 23, 12, 16].

1.3 Edge Detection Improvement

1.3.1 Algorithmic

One attempted approach in literature is to improve the problem of edge detection utilising improved algorithms. Dollar et al. attempt to obtain edge detection improvement through the use of effective algorithmic structure. Their approach is to implement a structured decision forest, which improves runtime, but at the cost of having a lower accuracy[7]. Other approaches have also been taken in academia, with the majority having a pattern of improving the runtime of the algorithms, but at the cost of the quality of output [17, 33, 20, 31, 10, 1] Some of these papers directly attempt to alter the main existing algorithms, such as the Canny or Sobel, while others attempt to alter the way the operators are utilised. Another algorithmic improvement carried out by Rosenfeld and Thurston [27] introduced

smoothing operations in order to reduce the noise of the image prior to differentiation, thus improving the edge quality. Another approach carried out by Hueckel [13, 14] involved fitting each image pixel with a step edge in a circular window. If the fit was accurate, it was safe to assume that an edge exists with the same parameters as the fitted model. This is called parametric fitting and has been attempted by other researchers as well, with varying success [6, 22, 21, 2]. Another approach taken is by changing the implementation side [28, 30] .

1.3.2 Parallelism

Parallelism is an alternate method that utilises parallel code architecture to enable the speed up of the edge processing algorithms. There have been multiple approaches taken to implementing parallel edge detection, but they can be split up into two methods: (1) Pipeline parallelism and (2) Data parallelism [8]. Pipeline parallelism is possible because image processing requires a sequence of tasks, which can then be run concurrently on different processors. This is an example of MIMD classification parallelism. This has two distinct disadvantages though - the first is that the rate of throughput is dictated by the slowest task, with the second being that the software becomes non saleable as it is difficult to decompose into arbitrary amounts of concurrent tasks[8]. Certain papers have attempted this and shown limited speedup when compared to SIMD [28]. Data parallelism is the alternate option, and is more general purpose. It allows to partition the image into sections which can be assigned to different processors. The processors carry out the same task on each of the segments and then one processor builds the final result. This is an example of SIMD classification. Previous literature has shown multiple examples, with varying success [31, 32, 5]. This paper will build off of previous work and attempt to recreate previous experiments and analyze multiple operators based on their carryover to parallel code.

Let us here take a moment to expand on the theory behind various parallelism approaches seen in literature. The basis of all parallelism stems from Flynn's taxonomy [9]. There are four main types of parallelism.

1. **SISD**: Single instruction, single data - this is the most common architecture that has a single uni-core processor operate on the one piece of data. Such an approach is typically used in normal program running

2. **SIMD**: Single instruction, multiple data - architecture where allows processors to run the same instructions on different pieces of data. Most commonly implemented by GPUs.

3. **MISD**: Multiple instruction, single data - architecture where many instructions are run on the same data. This architecture is not commonly used, but has potential applications such as flight control computers.

4. **MIMD**: Multiple instruction, multiple data - architecture that allows processors to function on various pieces of data independently. Such architecture can be commonly found in distributed systems.

In relation to our study, previous work has primarily worked with MISD based parallelism implementation approaches. When the CUDA based GPU programming language came out - there was a surge of papers exploring the GPU edge detection approach [18, 19, **?**, 19, 24]. While previous research has demonstrated that MISD approaches have

the highest efficiency of edge detection, we aim to expand on previous work by offering insight into other taxonomical approaches and comparing them.

2 Research Question

Our goal was to explore the various ways of re implementing the Sobel edge detection algorithm in parallel. We compare the various taxonomic implementations across three different variables: (1) efficiency of parallelism, (2) ease of implementation, and (3) quality of result.

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