Exploring Coarse-grain and Fine-grain Parallelism on SRC-6 Reconfigurable Computer

Volodymyr V. Kindratenko[1], Adam D. Myers[1,2], Robert J. Brunner[1,2]

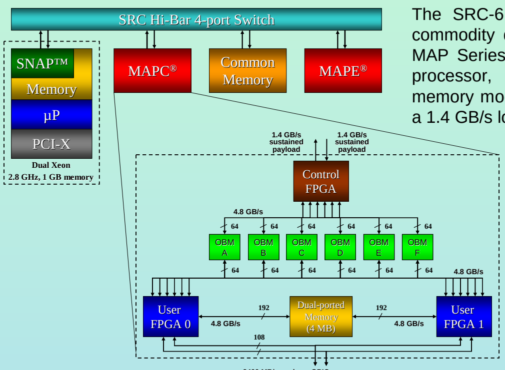
[1]National Center for Supercomputing Applications, [2]Department of Astronomy

University of Illinois, Urbana, IL 61801

Abstract

A parallel implementation of an algorithm for calculating the two-point angular correlation function is presented. The implementation utilizes a microprocessor and two reconfigurable processors on a dual-MAP SRC-6 reconfigurable computer. Two independent computational kernels are simultaneously executed on the reconfigurable processors while data pre-fetching from disk and initial data pre-processing are executed on the microprocessor. Parallel code sections are implemented using OpenMP. This approach allows us to achieve coarse-grain task-level parallelism via conventional multiprocessing and fine-grain instruction-level parallelism via the direct hardware execution of the code on field-programmable gate arrays (FPGAs). The overall end-to-end algorithm execution speedup achieved by this implementation is over 50x as compared to a sequential implementation of the algorithm executed on a single 2.8 GHz Intel Xeon microprocessor.

SRC-6 Reconfigurable computer



The SRC-6 MAPstation consists of a commodity dual-CPU Xeon board, one MAP Series C and one MAP Series E processor, and 8 GB common memory module, all interconnected with a 1.4 GB/s low latency Hi-Bar™ switch.

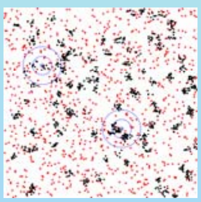
Code is developed in MAP C using Carte™ version 2.1. The Intel C version 8.1 compiler is used to generate the CPU side of the unified CPU-MAP executable.

The two-point angular correlation function (TPACF)

TPACF, $\omega(\theta)$, is, for many cosmological applications, the frequency distribution of angular separations θ between celestial objects in the interval $(\theta, \theta + \delta\theta)$

Example: red points are, on average, randomly distributed, black points are clustered:

- Red points: $\omega(\theta)=0$
- Black points: $\omega(\theta)>0$



TPACF varies as a function of angular distance:

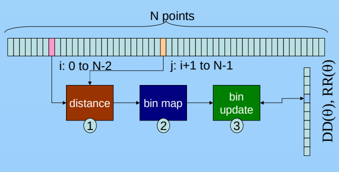
- Red: $\omega(\theta)=0$ on all scales
- Black: $\omega(\theta)$ is larger on smaller scales

The angular correlation function is calculated using Landy & Szalay's estimator:

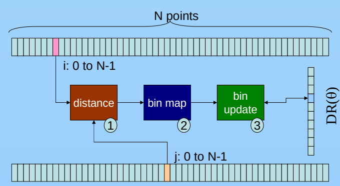
$$\omega(\theta) = \frac{DD(\theta) - 2DR(\theta) + RR(\theta)}{RR(\theta)}$$

where $DD(\theta)$ and $RR(\theta)$ are the autocorrelation function of the data and random points, respectively, and $DR(\theta)$ is the cross-correlation between the data and random points.

Autocorrelation



Cross-correlation



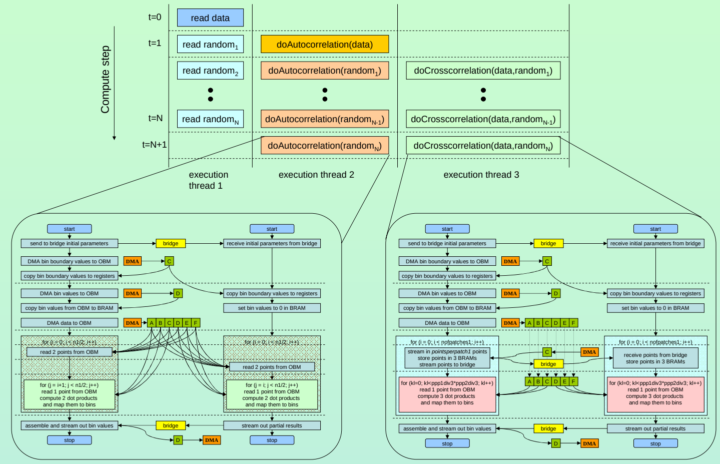
①
```
double dot = dotproduct(d1[i], d2[j]);
```

③
```
/* update bin value */
if (dot >= bin_edge[min])
    bin_count[min] += 1;
else if (dot < bin_edge[max])
    bin_count[max+1] += 1;
else bin_count[max] += 1;
```

②
```
/* binary search */
int k, min = 0, max = M;

while (max > min+1) {
    k = (min + max) / 2;
    if (dot >= bin_edge[k]) max = k;
    else min = k;
}
```

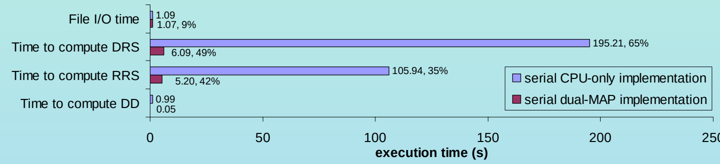
SRC-6 Implementation of TPACF

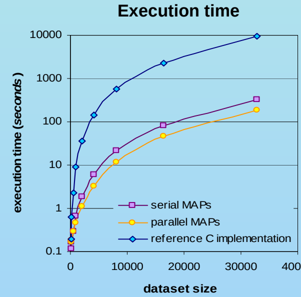


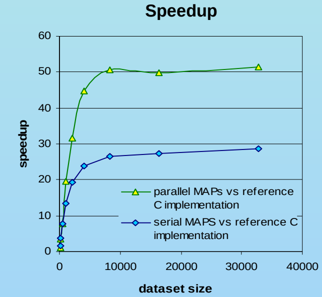
Resource Type	Total Available	Chip 1	Chip 2
Slice Flip Flops	67,584	47,491 (70%)	43,736 (64%)
4 input LUTs	67,584	28,008 (41%)	26,663 (39%)
Slices	33,792	30,396 (89%)	27,971 (82%)
Block RAMs	144	18 (12%)	16 (11%)
MULT18X18s	144	36 (25%)	36 (25%)

Resource Type	Total Available	Chip 1	Chip 2
Slice Flip Flops	88,192	67,815 (76%)	64,100 (72%)
4 input LUTs	88,192	44,883 (59%)	43,433 (49%)
Slices	44,096	44,094 (99%)	41,882 (94%)
Block RAMs	444	314 (70%)	312 (70%)
MULT18X18s	444	90 (20%)	90 (20%)

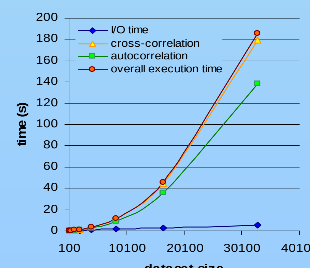
Performance

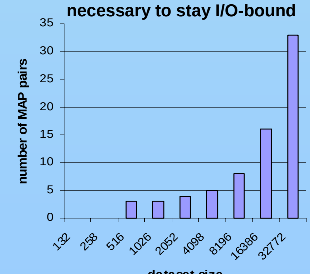






Scalability





Acknowledgements

This work was funded by the National Science Foundation grant SCI 05-25308 and by NASA grants NAG5-12578 and NAG5-12580. We would like to thank David Caliga, Dan Poznanovic, and Jeff Hammes, all from SRC Computers Inc., for their help and support with the SRC-6 system.