Cluster Computing with the BeagleBone Black

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Modern day supercomputers are conventionally composed of many worker-computers called nodes, controlled by a single master-computer node. This relationship is called cluster computing. For many years, the typical choice of computer for low-end clusters has been the Raspberry Pi, an embedded board, due to its quick processing speed and affordable price. However, its recent inflation in price has made this embedded board less reasonable for the everyday enthusiast. In addition, this problem is scaled much more for a cluster computer since many embedded boards are needed. A worthy alternative is the Beaglebone Black (BBB), since it is much less expensive and boasts similar capabilities. Since most data involving cluster computing revolves around the Raspberry Pi (RPI), the relationship between the quantity of BBB microcomputers to the cluster's overall processing speed is not clear. This research aims to explore the capability of the BBB in the world of cluster computing in comparison to the Raspberry Pi. Specifically, three factors will be analyzed for the two embedded boards. Firstly, the processing speed achieved using up to eight nodes will be recorded for each candidate. Second, the power consumption for each candidate will be calculated for the same number of nodes, since a quicker computer may not be worth the cost if it requires significantly more power. Third, the cost of each candidate will be factored into the data to determine the processing speed in comparison to its cost. This will allow for a direct comparison between the value of the two candidate embedded boards.

The objectives of this research were to compare the BBB and the RPI in the scope of cluster computing. Since the RPI is becoming increasingly difficult to source, interest in similar embedded boards is increasing. The three points to compare between the two embedded boards are processing speed, power consumption, and physical cost. To compare these, the Message Passing Interface (MPI) was utilized in order to create a cluster computing system using eight BBB embedded boards. Two resource intensive test programs were written to be run on both this system as well as a similar RPI system previously built by Dr. Vincent Weaver [3][4]. Both the processing speed and power consumption were measured for both test programs, in order to determine if the BBB could be used in the stead of a RPI in cluster computers.

To compare the two embedded boards, two computing tasks were conducted, in order to allow for better interpretation of the results. For each test, the program was run using more and more embedded boards, starting with just a single board, and ending with eight. Though the RPI cluster can utilize much more than eight embedded boards, the budget of the project allowed for a maximum of eight BBB embedded boards to be purchased. For this reason, the two boards could only be compared with up to eight boards. The first task [1] involves the cluster counting to powers of two and listing the amount of prime numbers below as well as the time taken. The number 131072 (2^{17}) was chosen to count up to as it was large enough to show significant variance between the two types of embedded boards and the number of boards, while not taking so long that testing proved unreasonably long. The important data is not the amount of prime numbers returned, but rather the amount of time it took to count them, since it proves to be a good measure of processing power. In addition, a power meter was used to measure the power needed to fuel the cluster during processing. The second test [2] involved multiplying two 500 by 500 matrices. This task is arduous for a single processor, and splitting up the work between boards in a cluster allows the processing speed to increase, similarly to how people work faster when they work together. Once again, the important data was not the resulting matrix, but rather the time it took to compute the matrix. In addition, the power meter was used once again to measure power draw of the cluster while running.

The processing speed and power consumption were recorded for comparison during each test. The first test showed that the BBB embedded board computes the task faster than the RPI. Although both the BBB and the RPI tend to take less time to compute the task with each additional board, the BBB both start out faster with only one embedded board and tend to take even less time with each additional embedded board than the RPI. In addition, the BBB takes less power per additional board. This was tested all the way up to eight embedded boards. The second test did not yield results as simple as the previous test. The BBB starts out taking almost four times as long to compute the 500x500 matrix than the RPI at only one embedded board. However, with increasing numbers of embedded boards, the BBB cluster grows more comparable to the RPI cluster. In addition, the RPI cluster once again takes more power to compute the task than the BBB cluster. The results were plotted and are shown in a later section. Using these results, three comparisons were made regarding processing speed, power consumption, and physical cost, to determine the capabilities of the BBB against the RPI.

The speed at which a task can be completed is one of the most important aspects of a cluster computer. From both conducted tests, the BBB embedded board performed to a degree either comparable or better than the RPI embedded boards. Therefore, the everyday enthusiast is better off choosing the BBB for general computing tasks such as the two that were tested. However, more research needs to be conducted for tasks that involve a visual aspect. It is a well-known fact in the embedded board community that the BBB is not extremely capable for these types of tasks, while the RPI excels. Since this is not in the scope of this research, it was determined that the BBB is the better choice of the two embedded boards for general computing when only considering processing speed.

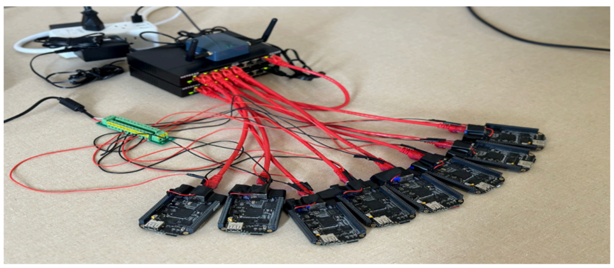
The cost of power consumption is also important, especially for the everyday enthusiast. Even if one board outperforms another in processing speed, if it requires much more power it may not be worth the cost. For both conducted tests, the BBB cluster required much less power per embedded board than the RPI cluster. In addition, since both embedded boards need the same support electronics to function, expanding the cluster out to increasing amounts of embedded boards will result in the same conclusion. For this reason, it was determined that the BBB is the best choice regarding power consumption.

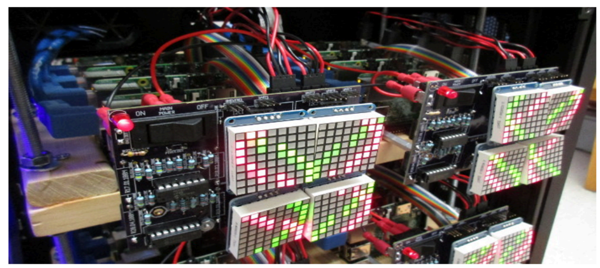
The final aspect to be considered for the everyday enthusiast is the initial purchase cost of the chosen embedded board. The BBB embedded board costs approximately $60 each, while the RPI used in this test costs upwards of $35 dollars each. However, despite the RPI 2 used in this research having a relatively cheap price, lead time for these embedded boards will take tens of weeks, making acquiring one extremely difficult. In addition, the RPI's latest models may have more processing speed, but they also cost much more and require even more power. All of this considered, the BBB was chosen to be the best choice of the two regarding initial cost of purchase.

Since the processing speed, power consumption, and physical cost sections of this research determined that the BBB is the best choice, it was concluded that the BBB is the better of the two options for a cluster that will compute these types of numerical tasks. This research is significant for both the everyday enthusiast, as well as for teaching applications. Hobbyists that are looking for an alternative to the mainstream RPI embedded board for non-graphical applications can save money knowing that they will achieve results comparable to or better than what they would achieve with the RPI. For teaching applications, whether or not the school or the students are bearing the cost of embedded boards for educational use, the BBB can be used as a substitute when the RPI is either too expensive or has too great of a yield time. In addition, BBB offers many of the same operating systems available on the RPI. This allows for a seamless transition between using the two embedded boards. However, something to consider is support. Since the RPI has been used by millions of people and the BBB has not been in the mainstream, the online support for troubleshooting and modification is not as readily available for the BBB as it is for the RPI. This makes some issues take much longer to solve for some issues, but for most issues, the solution is identical or greatly similar to what it would be for the RPI.

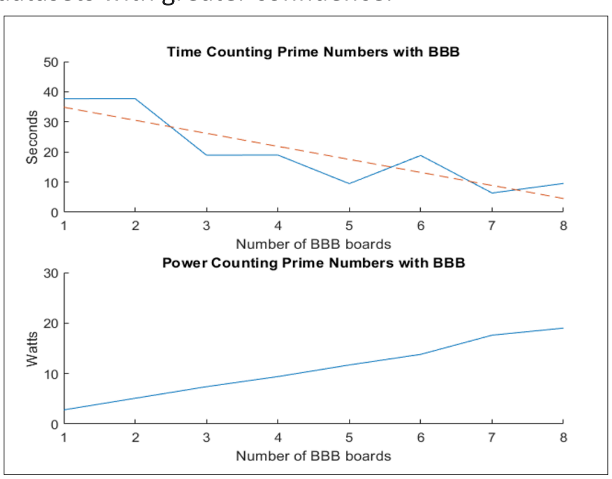
My Progress during this research was consistent throughout the entire period, gathering significant data and extracting conclusions that were both accurate and relevant. Also, I was able to use my skills earned from my time at the University of Maine Orono, independent projects, and internships, in addition to developing my knowledge in embedded systems and cluster computing, while achieving the goal of the research.

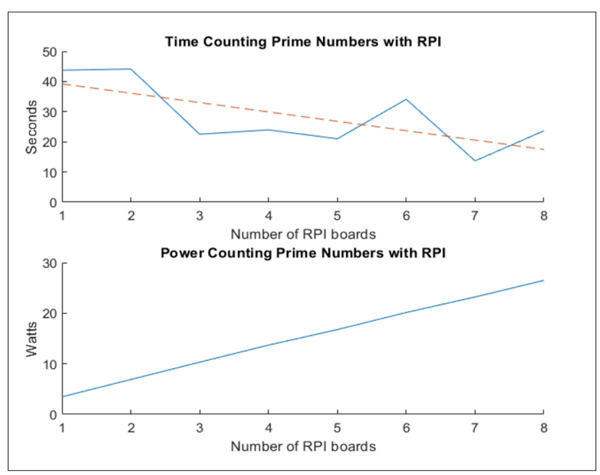
Shown below on the left is the setup used to test the BBB cluster computer, while the right shows the RPI cluster built by Dr. Vincent Weaver [3][4]. These two systems were used to gather information for comparison.



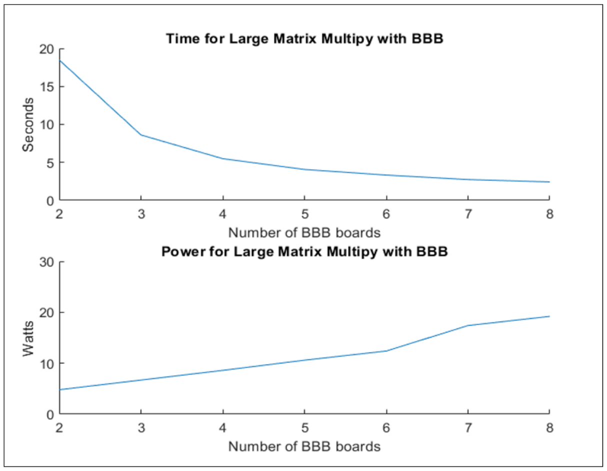


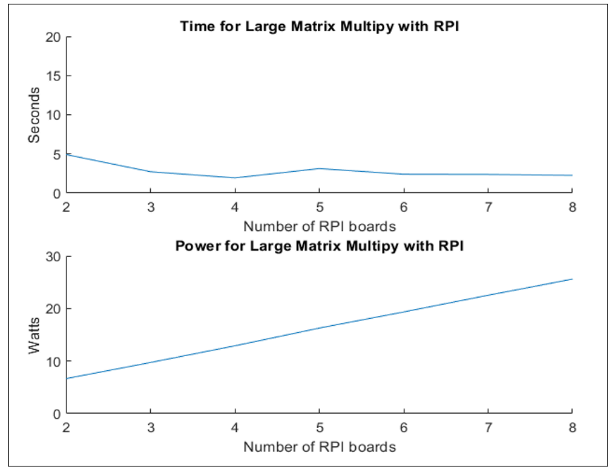
Shown below is the first test which counted prime numbers up to 2^{17}. The two systems shown above were used to gather these results. The left figure shows both the processing speed with growing numbers of BBB embedded boards, as well as the power consumption. The blue line shows the actual data gathered, while the orange dashed line shows the best fit relationship. The right figure shows the data gathered from the RPI using the same task. The line of best fit was generated since the actual data tends to jump around. This effect occurred due to the inefficiencies of MPI. Since the program had the same effect on both embedded boards, it was determined that neither would have an advantage over the other, validating the gathered results. In addition, the line of best fit was used to compare the two datasets with greater confidence.





Shown below is the second test which conducted a large matrix multiply. The left figure shows both the processing speed with growing numbers of BBB embedded boards, as well as the power consumption. The right figure shows the data gathered from the RPI using the same task.





This research and report was conducted by Dyllon Dunton, an electrical and computer engineering double major from the University of Maine Orono, with mentorship from Dr. Vincent Weaver, a computer engineering professor also from the University of Maine Orono with a PhD in Electrical and Computer Engineering from Cornell University [4]. The two test programs used to gather data from the two cluster computing systems were written by Azar Feyziyev [1] and Asantha Lahiru [2]. These two programs were acquired from github where they were posted for public use.

[1] A. Feyziyev, “Openmpi/mpi-prime.c at master · Feyziyev007/openmpi,” GitHub, https://github.com/feyziyev007/openmpi/blob/master/mpi-prime.c (accessed May 17, 2023).

[2] A. Lahiru, “MPI matrix multiplication,” Github, https://gist.github.com/AshanthaLahiru/bfa1a631f6af05af93e98538eeca3018 (accessed May 17, 2023).

[3] M.F. Cloutier, C. Paradis, V.M. Weaver. "A Raspberry Pi Cluster Instrumented for Fine-Grained Power Measurement", MDPI Electronics 2016 5, 61.

[4] “Vince Weaver - Electrical & Computer Engineering - University of Maine,” Electrical & Computer Engineering, https://ece.umaine.edu/faculty/vince-weaver/ (accessed May 17, 2023).