BEOWULFS GO TO SEA

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ABSTRACT

As the size of crews continues to be reduced on modern warships, and at the same time the complexity of the tasks that warships have to handle continues to increase, the amount of computing power aboard a warship will have to increase dramatically. One of the most cost-effective ways of creating supercomputers is to cluster inexpensive off-the-shelf commodity computers so that they act as a single computer. Such a cluster is often referred to as a Beowulf cluster. We anticipate that Beowulf clusters will become commonplace features of the warships of the future. In addition, warships will be populated with many specialized intelligent devices and sensors.

We discuss some of the key issues involved in successfully taking Beowulf clusters to sea. Of special interest are the questions of how to best design ships for accommodating Beowulf clusters and how to build Beowulf clusters that are well suited for the battlefield environment and which can survive significant battle damage without losing all functionality. Lastly, we discuss how to use Beowulf clusters to provide a basis for supporting the intelligent behavior that we will need in the ships of the future.

KEY WORDS

Beowulf clusters, distributed computing cluster, expert systems, automation and control, decision making, survivability.

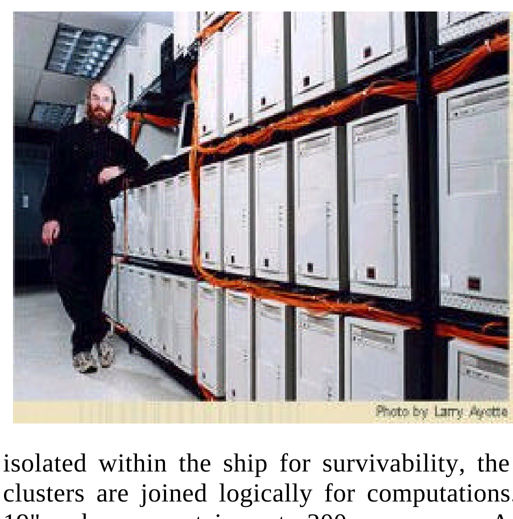
1. INTRODUCTION

Beowulf clusters are a recent invention and consists of putting together a number of COTS computer systems to achieve relatively inexpensive supercomputer performance. Beowulf clusters have become extremely popular lately, and the communities of enthusiasts maintain a website at http://www.beowulf.org that contains much interesting and useful information. Many institutions, including the University of Maine, have been placed into the list of "World's Top 500 Supercomputers" on Earth, by building a Beowulf cluster. The University of Maine's system (shown to the right) was number 336 on the list in the Fall of 2002. You can review the list at http://www.top500.org.

Beowulf clusters can serve as a springboard for later expert systems. Additionally, the concept supports the Navy's Transformational Roadmap (see http:// www.mccdc.usmc.mil/CEAB/files/OCT02CEAB/Naval_Transformation_Roadmap.pdf), whereby the distributed computing arrays could process massive amounts of data, and assist in the coordination of warships, which may be of modular design and may or may not be able to support a full spectrum of hardware. Beowulf clusters can be built in a distributed manner to enhance survivability, while at the same time supporting future expert based decision support software. The paper therefore, focuses on some potential system designs and the impacts to Navy operations and some shipbuilding impacts regarding the integration of the clusters.

2. DISTRIBUTED CLUSTERS

Distributed clusters are physically isolated clusters of computers, which for shipboard installation will likely take the form of 19" rack mount devices. Although physically



isolated within the ship for survivability, the distributed clusters are joined logically for computations. A single 19" rack may contain up to 200 processors. A single ship may contain up to 1600 processors, which might promote the vessel into the upper echelon of the "World's Top 500 Supercomputers" list.

The need for such a massive amount of computing power is driven by the increasing demands of the battlefield. When considering the rate at which technology advances and the inevitability of future expert systems, it becomes apparent that most existing expert systems may be limited due to integration costs. A neural network for example, might have to be designed as a completely separate system, with cost prohibitive rip-out and installation. It would almost have to wait until a new class of ship to be constructed so the technology could be inserted into the baseline design.

Since sensor and smart device technology will rapidly advance by 2010, it seems clear that we must focus on the underlying issue, which is the decision support function.

The Navy's history of acquisitions by systems introduces a complex marriage of shipboard systems from a wide range of vendors and technologies. Ships of the future must function with a heterogeneous computing environment since it is unlikely that all computing will be from a single source.

Current state of the art in automation and control systems for shipboard applications, including commercial vessels is the PLC (Programmable Logic Controller) technology. Advances will most likely eliminate PLC's in lieu of smarter, smaller, faster devices, providing the devices can demonstrate the durability and ruggedness that PLC's, which were bred for the industrial environment, have. Another issue that needs to be faced by future computing standards is the shielding of computing systems so that they neither leak information, nor are affected by external electrical disturbances. Future expert systems must therefore be very flexible to accommodate past, present and future automation technologies. It is clear that the decision support capabilities of future expert systems must control ship level automation plants. The computing control hierarchy aboard the future ship looks like:

- Expert System
- Ship Level Automation
- System level Automation
- Device Level Automation

Since Navy acquisition seems to follow systems, the majority of shipboard state of the art in automation now lies within the System Level Automation category. Advances in technology are increasing the Device Level Automation and Ship Level Automation systems.

Contemporary computing systems are largely reactionary. It is clear that future expert system must be predictive. Once established, the computing power, as devices evolve, will migrate down into the structure into the device level distributed automation.

Investigation into Beowulf cluster software today, will pave the way ahead for integrating tomorrow's ship level decision support software into device level automated devices, for extremely capable non-centralized control schemas.

3. NAVY OPERATIONAL IMPACTS

Some example applications for a distributed cluster within the Navy are:

- Expert System Platform
- Remote Computing Platform for LCS
- Scientific Data Collection
- Meta-Data Analysis

Computer prediction may be possible if the computer can collect enough information. The triggering of an event may not be apparent to today's automation and control plants. Refrigeration vendors will only automate their refrigeration devices. Pump vendors will only automate their own pumps. Of course, each vendor will tend to use a proprietary system that will be completely independent of all other shipboard systems. A powerful computer system, such as the proposed 1600 node Beowulf cluster sitting on top of the automation plant could monitor the entire ship, and integrate the behavior of all systems into a coherent system. This capability will permit anticipating the failure of various components and the creation of a strategy to deal with that failure.

Remote computing may be also be necessary for tomorrow's warships. If future ships are designed such that their coordination is external, then a remote craft, such as a destroyer, will be required to process all the battle space information, and to coordinate the mission. External control would remove some local computational requirements, but may still leave the responsibility of managing organic shipboard operations. Each ship will have its own war fighting capability, but battle coordination will be supplied externally. This is similar to aircraft being externally controlled by AWACS aircraft for example. Beowulf clusters would contain the processing horsepower to coordinate large military efforts.

Scientific data collection utilizing the processing power of Beowulf clusters could make future combat events more predictable and controllable. The data could also be used for modeling and simulation, and to train future war fighters. The in-situ research could be invaluable for future expert based systems. The U.S. Military has been toying with the idea of uniformed scientists for several years now. ("Scientific Warriors", *Acquisition Review Quarterly* - Fall 2002, Vol.9, No. 4, Page 299) The shipboard distributed Beowulf clusters would represent a perfect opportunity to place scientists in the field. The analysis of the warship under real-life scenarios, using the Beowulf Cluster, will shed some insight into system predictability and methods and manners for which to increase the response time of a vessel with minimal human input to the system.

Meta-Data analysis by Beowulf clusters will allow extensive data mining, and support research into important areas of database applications, such as data access frequency, information sources, etc. This analysis could be useful in increasing the overall ship level decision making process, with the goal of implementing Rules of Engagement into the control system. RoE integrated into the ship-level control system can allow the vessel to respond to situations in more subtle and appropriate ways. It is clear that the battlefield situations of the future will often involve interaction with non-standard and guerrilla types of combat. During extreme combat situations, available ship electrical power can be transferred to weapons and propulsion without any human intervention for example.

The United States must be committed to bringing research to the front line. Future expert systems will be based on today's distributed cluster. Technology will continue to improve significantly, and it is conceivable that by 2010 one computer chip might replace be the equivalent of many of today's chips. Nevertheless, Beowulf systems will still be able to combine the power of many discrete systems into one coherent and very powerful system. To do this correctly, however, requires that we begin planning today. Additionally, future distributed systems functioning together with Beowulf Cluster software embedded in them can also achieve the super computer capabilities which a rack mounted system can. Thus, decision-making software for the vessel can reside completely dispersed throughout all of the distributed control devices.

While the goal is to use as much as possible from the COTS world, there are requirements that are unique to the naval battle environment. Commercial systems typically do not have to survive the shocks that would be expected in a battle or have the need to operate in situations where parts of the system might be physically destroyed. Today, shipboard-computing research is limited, as today's equipment is designed for a specific task, such as C4I computers, which form the core of dedicated combat workstations. Shipboard distributed Beowulf Clusters can not only function if impaired, but can provide a processing source for the utilization of multi-functional consoles, and applications not specifically written to function on a dedicated processor. The system itself allocates software to processors as necessary.

4. SHIPBUILDER IMPACTS

There are a variety of benefits from the tight integration of clusters. If 19" rack mount devices are used, a fully loaded rack with 200 processors will use relatively little space, power and HVAC, and will add little weight to the ship. The distributed nature of a Beowulf cluster would permit the cluster to be separated among 4 geographical areas within a vessel, thereby limiting shipboard impact of running those services. (When compared to traditional consoles, which require a wider dispersal of services). Workstation connections to the cluster can also be accomplished with minimal impact.

It is instructive to consider some of the factors that must be considered in successful adaptation of Beowulf clusters to the shipboard environment.

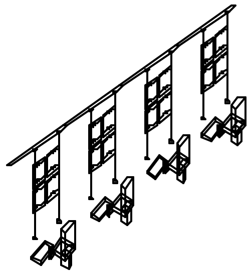
Shipboard electrical services to the distributed cluster should be redundant and incorporate automatic bus transfer scenarios. The goal is to enable clusters to survive and be able to run software even on a minimal number of processors.

HVAC services for the distributed clusters are minimal and comparable to current shipboard computing consoles. A typical 19" rack with 200 processors for example may require on the order of 800-900 BTU of HVAC. It appears that many promising low-energy consuming chips are on the horizon, so that the HVAC requirements could be considerably less. A direct ventilation pickup would handle the heat output.

The goal is to standardize on a 19" rack configuration to simplify designing the space. 19" rack or "Blade" type processors make maintenance simple, since defective units can be easily removed. Having large numbers of identical COTS units replacing many specialized computing devices will drive down ship acquisition costs, reduce the time of construction, and extend the overall life cycle of the ship. Of course, this would put more requirements on the software necessary to run the ship.

With the popularity of Beowulf clusters, it is clear that an increasing quantity of computing intensive applications will be redesigned to take advantage of clusters. Nevertheless, it is clear that it will not be possible to run a warship using off-the-shelf software any time soon.

Additional impacts to shipbuilding manifest in the utilization of similar consoles. With similar consoles, software resident on the distributed cluster would be fair game for the operator, and with redundant connections, the consoles become truly multi-functional and survivable. Shipboard impacts are minimized with new and unique mounting methods, which may present 4 monitors to the user and a chair with an integrated keyboard/trackball feature plus integrated audio communications. The monitor suspension is based on shock equipped cables, and welded pad-eyes. The shipbuilder impact when compared to traditional foundation work and shock proofing for today's 600-900lbs+ consoles becomes apparent. At the same time, the visual HMI interface is increased two-fold



over today's consoles, which on average may only have two monitors. The flat panel designs and the capability to utilize four monitors at once to represent an even larger visual capability are represent a technology already in existence. If you were to open most existing consoles, you might find a common computer underneath. It is the software, which has the capability to drive dedicated consoles away from today's concepts. Tomorrow's concepts will need to be more sophisticated in software, and much simpler in hardware.

An important disadvantage to installing a distributed cluster on an existing warship lies within the capability to employ 19" racks. Although 19" racks require minimal room, most of today's existing warships lack the space for the racks, and it can be expected that it will be some time before the multi-role workstation is accepted.

One of the most interesting facets of utilizing distributed clusters, resides in their powerful capability of survivability. If three out of four clusters were damaged, the single cluster would carry the load. Within that single cluster, many processors could be malfunctioning and the cluster could continue to service the vessel. By this point, extreme damage would have had to occur.

Redundancy in the clusters may also pose some interesting solutions in fault tolerant software voting applications, making the vessel even more robust.

There are many areas regarding the application of the distributed clusters, which need to be explored. By setting the technology in place today, the U.S. Navy will be prepared for tomorrow's expert systems.

5. CONCLUSION

We have hinted at some of the advantages and difficulties associated with putting Beowulf clusters on warships. It is clear that the dramatic increase in computation required by the modern battlefield and the attractive economics of Beowulf clusters will provide the impetus for sending Beowulf clusters to sea.

BIW and the University of Maine System are planning to conduct extensive future research into using Beowulf clusters to control the warship of the future. Initial experiments will involve the connection of up to five Beowulf clusters to begin simulation of the large shipboard Beowulf cluster proposed in this paper. Two of the clusters are located at the University of Maine, one of which is the supercomputer pictured at the beginning of the paper. Two of the clusters are located at the University of Southern Maine, and the final cluster is located at BIW's Advanced Technology Ship Computing Lab.

While exploring the Expert System / Ship Level phenomenon with the distributed clusters, the effort will serve to focus on the future inevitability of integrating the research into distributed device level components.

These experiments will provide a deeper understanding about the use of distributed clusters in US Navy applications and will form the basis for a shipboard trial on a suitable vessel in the near future.

The truly intelligent ship is clearly on the horizon.

In addition, the agent expertise collected through the Agent Institute and other AI related research at the University of Maine will be brought to bear on designing the system of the future.

BIOGRAPHY AND CONTACT INFORMATION

George Markowsky has worked on a wide variety of projects both at IBM and at the University of Maine, where he currently chairs the Department of Computer Science, and also the Department of Mathematics and Statistics. Prior to coming to the University of Maine, he worked at IBM's Thomas J. Watson Research Center. Dr. Markowsky has published extensively. More information about his various projects, including his work on homeland security can be found at his website (http://www.cs.umaine .edu/~markov) and at his homeland security website (http://homeland.maine.edu). His e-mail address is markov@maine.edu.

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Presented at the Thirteenth International Ship Control Systems Symposium (SCSS) in Orlando, Florida, on 7-9 April 2003.