Budget Beowulfs:
A Showcase of Inexpensive Clusters for Teaching PDC

Joel C. Adams
(Organizer) Calvin College
adams@calvin.edu

Jacob Caswell
St. Olaf College
caswell@stolaf.edu

Suzanne J. Matthews
U.S. Military Academy
suzanne.matthews@usma.edu

Charles Peck
Earlham College
charliep@cs.earlham.edu

Elizabeth Shoop
Macalester College
shoop@macalester.edu

David Toth
Centre College
david.toth@centre.edu

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1. SUMMARY

In response to the shift to multicore processors, the ACM-IEEE CS2013 curriculum recommendations [1] include parallel and distributed computing (PDC) as a new core knowledge area. Some of the key concepts in PDC are the distinctions between shared-memory, distributed-memory, and heterogeneous system architectures.

Most CS educators would agree that providing students with hands-on experience improves their students' learning. Given the ubiquity of multicore processors, it is quite easy to give today's students hands-on experience developing software on shared-memory architectures. By contrast, providing students with hands-on experience developing software for distributed architectures has typically required access to a Beowulf cluster, the price of which was beyond the reach of many institutions. However, hardware manufacturers have recently begun producing a variety of inexpensive "system on a board" multiprocessors. Creative CS educators are using these multiprocessors to design and build inexpensive Beowulf clusters, and using them to provide students with hands-on experience with shared-memory, distributed-memory, and heterogeneous computing paradigms.

In this special session, several PDC educators will bring, present, and demonstrate their innovative Beowulf clusters; each designed and built using a different inexpensive multiprocessor board.

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2. SESSION OBJECTIVE
Most CS educators have heard of the *Raspberry Pi* [9], but many are unaware of more powerful system-on-a-board computers, such as Adaptiva's *Parallella* [3], the *CubieBoard2* [5], the Nvidia *Jetson* [7], or the *ODROID-U3* [6]. In this session, our primary objective is to give CS educators the opportunity to:

1. Learn about these inexpensive multiprocessor boards;
2. See how their peers have used them to build clusters; and
3. Hear how their peers are using those clusters to teach PDC.

A secondary objective is our hope that, by showcasing the innovative work of these CS educators, we can inspire other CS educators to create their own clusters – some undoubtedly using multiprocessors that are not yet invented – and thus unleash a wave of innovation in PDC education.

3. SESSION OUTLINE
Some of these "system on a board" multiprocessors are no bigger than a credit card. Thanks to these diminutive sizes, each presenter will bring his or her entire cluster to the conference. Before the session begins, the presenters will set up their clusters for display and demonstration on tables at the front of the room.

In the first 25 minutes of the session, each presenter will give a 5-minute, 5-slide "lightning talk" on his or her cluster, including its specifications and how they use it to teach PDC.

The middle 25 minutes will be a "Group Q&A" in which audience members can direct questions to the presenters as a group.

The last 25 minutes will be a "Show&Tell" session in which the presenters will move to their clusters and audience members can approach and interact with the presenters individually.

Table 1 presents a concise overview of the session.

What	Who	Duration
Introduction	Joel Adams	3 min.
StudentPi and *StudentParallella*	Suzanne Matthews	5 min.
PIsToGo	Jacob Caswell	2 min.
HSC-1 and *HSC-2*	David Toth	5 min.
Rosie	Elizabeth Shoop	5 min.
LittleFe	Charlie Peck	5 min.
Group Q&A	Audience	25 min.
Show&Tell	Everyone	25 min.

Table 1. Session Overview

This 75-minute session is thus one third presentations, a third all-group Q&A, and a third Show&Tell.

In the remainder of this section, we provide descriptions for each presenter and the cluster he or she will present. For each of these clusters, the total cost includes everything needed to build the system (interconnect, parts, shipping, etc.), except for a monitor, mouse, and keyboard. The presenters' slides and the disk images for their clusters will be archived at *csinparallel.org* [4].

3.1 Joel Adams (Organizer)

Dr. Adams is a professor of computer science at Calvin College. He has designed and built four Beowulf clusters, including Microwulf [2], a portable sub-$2500 system that was the first cluster to break the $100/GFLOP barrier. He will introduce each presenter, and moderate the Q&A and Show&Tell segments.

3.2 Suzanne Matthews

Dr. Matthews is an assistant professor of computer science at the United States Military Academy. She will present two clusters:

- *StudentPi* has 4 Raspberry Pi nodes. Each node has an ARM 1176JSFS (700 MHz) CPU, a videocore 4 GPU, 512MB RAM, and 4GB of microSD storage. The nodes are connected using Gigabit Ethernet. The total cost was $240 ($60/core).
- *StudentParallella* has 4 Parallella nodes. Each node has a Zynq 7000-series dual core ARM A9 (1 GHz) CPU, an Epiphany coprocessor with 16 (800 MHz) cores, 1 GB RAM, and 16GB of microSD storage. The nodes are connected using Gigabit Ethernet. The total cost was $650 (~$10/core).

3.3 Jacob Caswell

Jacob is a sophomore CS and Physics major at St. Olaf College. He will present *PIsToGo*, a complete five-node passively cooled Raspberry Pi cluster-in-a-briefcase that cost $300 (~$60/core).

3.4 David Toth

Dr. Toth is an assistant professor of computer science at Centre College. He will present two "Half-Shoebox Clusters", each of which is about half the size of a shoebox:

- *HSC-1* has two CubieBoard2 nodes. Each node has an ARM Cortex-A7 dual-core (1GHz) CPU, 1 GB RAM, and 4 GB of micro-SD storage. The nodes are connected with 100 Mbps Ethernet. The total cost was $198.27 (~$50/core).
- *HSC-2* has two ODROID-U3 nodes, each with a Samsung Exynos 4412 ARM Cortex-A9 quad-core (1.7GHz) CPU, 2 GB RAM, and 8 GB of micro-SD storage. The nodes are connected with 100 Mbps Ethernet. The total cost was $211.28 (~$26/core).

3.5 Elizabeth Shoop

Dr. Shoop is a professor of computer science at Macalester College. She will present *Rosie*, a cluster with six Nvidia Jetson-TK1 nodes. Each node has an ARM Cortex-A15 quad core (2.2GHz) CPU, a Kepler GPU with 192 (950MHz) CUDA cores, and 2GB RAM. The nodes share a 500GB hard disk and are connected with Gigabit Ethernet. The total cost was $1350 (~$56/ARM core; ~$1.70/ARM+CUDA core).

3.6 Charles Peck

Dr. Peck is a professor of computer science at Earlham College. He will present *LittleFe* [8], the original cluster-in-a-suitcase. LittleFe has six custom-built nodes. Each has an Intel dual-core Atom (1.8GHz) CPU, an Nvidia ION2 GPU with 16 (475 MHz) CUDA cores, and 2 GB RAM. The nodes share a 160GB disk, and are connected with Gigabit Ethernet. The total cost was $2500 (but *LittleFe Buildout* participants get theirs for free!), including a shock- and water-proof carrying case.

4. EXPECTATIONS

We believe that hands-on exercises in which students must apply abstract concepts improve their understanding of those concepts. However, the hardware needed for students to experience some PDC topics (e.g., scalability) has traditionally been expensive.

The clusters featured in this session range in price from $200 to $2500, making them much more affordable than traditional Beowulf clusters. One instructor is using a lab fee to provide each student with his or her own personal cluster! People attending this session will thus learn about a range of clusters at a variety of prices, how CS educators are using those clusters, and will have the opportunity to ask detailed questions to those educators.

As a result, this session will be of interest to anyone who is interested in PDC or is teaching a course that covers PDC topics. Such courses include: *Algorithms*, *Computer Architecture*, *Computer Organization*, *Graphics*, *Operating Systems*, *Parallel Computing, Software Engineering*, *System Fundamentals*, the *Senior Capstone* course, and others. This special session will thus be of interest to instructors from a wide variety of CS courses.

5. SPECIAL SESSION SUITABILITY

The presenters will bring, display, and demonstrate their clusters, making this 75-minute session a "show and tell" style session. During the first third, the audience will receive an overview of all the systems being presented. The middle third's "Group Q&A" will allow the audience to engage with the presenters in a format that lets everyone hear all questions and answers. In the final third's "Show&Tell" session, presenters will concurrently demonstrate their clusters to interested audience members, who can move from cluster to cluster, view the clusters up close, and ask detailed questions. This session's structure will thus be quite different from that of a typical paper or a panel session.

6. REFERENCES

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7. REFERENCES

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