the largest contributions have come from Intel and AMD, who provided much of the code to support hardware virtual machines. This enabled Xen to be one of the first hypervisors to support these processor extensions.

What's more, because Xen is freely available, several other projects have adopted it. Major Linux distributions such as Debian, Red Hat, SUSE, and Ubuntu now include Xen packages and have contributed code back into the project, along with useful tools for using Xen. Some contributors have taken on the effort of porting Xen to other architectures and porting other operating systems to run directly on the hypervisor. Xen has been used to run paravirtualized OpenSolaris, FreeBSD, and NetBSD, among others. Xen now runs on the Itanium architecture, and work is underway to port it to the ARM processor. The latter is particularly exciting because it will enable Xen to run on "nontraditional" devices, such as mobile phones.

As we look to the future, some of the most interesting uses of Xen are in the research community. Xen appeared at the Symposium on Operating Systems Principles (SOSP) in 2003, and has formed the basis of a variety of research, both within and outside of its original research group. One of the earliest papers written about Xen was from Clarkson University, where a group of researchers repeated the results in the SOSP paper. The authors remarked that open source software improves computer science because it enables repeated research and, in turn, strengthens any claims made about performance or other characteristics. More recent research work has led directly to interesting new features in Xen. One particular example is *live migration*, which enables a virtual machine to be moved between physical computers with only a negligible period of downtime. This was detailed in a paper in 2005, and was added to Xen in version 2.0.

Further Reading

This chapter could only scratch the surface of the Xen project, and the relevant research papers are the best source of further details.

These first two papers describe the architecture of Xen 1.0 and 2.0, respectively:

> Barham, Paul, et al. "Xen and the art of virtualization," *Proceedings of the 19th ACM Symposium on Operating System Principles*, October, 2003.

> Fraser, Keir, et al. "Safe hardware access with the Xen virtual machine monitor," *Proceedings of the 1st OASIS Workshop*, October, 2004.

The following papers describe some of the new chipset and processor technology that has been developed to aid virtualization:

> Ben-Yehuda, Muli, et al. "Using IOMMUs for virtualization in Linux and Xen," *Proceedings of the 2006 Ottawa Linux Symposium*, July, 2006.

> Dong, Yaozu, et al. "Extending Xen with Intel virtualization technology," *Intel® Technology Journal*, August, 2006.