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14. ABSTRACT This project has made several significant contributions in enhancing the energy efficiency, performance and fault-tolerance of computer storage systems. First, we developed Power-Aware Virtual Memory (PAVM) that finds and aggregates unmapped and unused memory pages. By powering down unused memory ranks, we can save a significant amount of energy dissipated by the main memory with virtually no performance degradation. Second, we developed the Free Space File System (FS2) based on the popular Ext2 file system by replicating temporally-related data blocks then using the free disk space to place these blocks closer to one another on the disk and thus allowing the disk heads to move less. This results in higher performance, lower energy consumption and higher fault-tolerance at almost zero cost. Finally, we characterized the disk failure patterns and used it to place replicas of critical information on the disk so as to protect them from common disk failures. See related publications in http://kabru.eecs.umich.edu , especially http://kabru.eecs.umich.edu/papers/thesis/hai.pdf , for details.					
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Executive Summary

This project has made several significant contributions in enhancing the energy efficiency, performance and fault-tolerance of computer storage systems. First, we developed Power-Aware Virtual Memory (PAVM) that finds and aggregates unmapped and unused memory pages. By powering down unused memory ranks, we can save a significant amount of energy dissipated by the main memory with virtually no performance degradation. Second, we developed the Free Space File System (FS2) based on the popular Ext2 file system by replicating temporally-related data blocks then using the free disk space to place these blocks closer to one another on the disk and thus allowing the disk heads to move less. This results in higher performance, lower energy consumption and higher fault-tolerance at almost zero cost. Finally, we characterized the disk failure patterns and used it to place replicas of critical information on the disk so as to protect them from common disk failures.

See related publications in <http://kabru.eecs.umich.edu>, especially <http://kabru.eecs.umich.edu/papers/thesis/hai.pdf>, for details.

Participants

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- Hai Huang: PhD completed in 2006
- Chang-hao (Howard) Tsai: PhD completed in 2009
- Pradeep Padala
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Publications

- Pradeep Padala, Mustafa Uysal, Arif Merchant, Xiaoyun Zhu, Sharad Singhal, and Kang G. Shin, "Performance differentiation for multi-port arrays: A control-theoretic approach," *Fourth International Workshop on Feedback Control Implementation and Design in Computing Systems and Networks* (FeBID 2009), San Francisco, April 2009.
- Pradeep Padala, Karen Hou, Kang G. Shin, Xiaoyun Zhu, Mustafa Uysal, Zhikui Wang, Sharad Singhal, Arif Merchant, "Automated control of multiple virtualized resources," *ACM EuroSys 2009*, April 1--3, 2009, Nurnberg, Germany, pp. 13--26.
- Xiaoyun Zhu, Zhikui Wang, Sharad Singhal, Mustafa Uysal, Arif Merchant, Pradeep Padala, and Kang G. Shin, "How does control theory bring to systems research?" *ACM Operating Systems Review*, vol. 43, no. 1, pp. 62--69, January 2009.
- Chang-Hao Tsai, Yaoping Ruan, Sambit Sahu, Anees Shaikh, and Kang G. Shin, "Multi-tenancy for network management tools using virtualization," *Proc. 18th*

IFIP/IEEE International Conference on Distributed Systems: Operations and Management (DSOM 2007), San Jose, CA, October 2007.

- Hai Huang and Kang G. Shin, "Partial disk failures: Using software to analyze physical damage," *Proc. 20-th IEEE Conf. on Mass Storage Systems and Technologies (MSST'07)*, October 2007.
- Chang-Hao Tsai, Kang G. Shin, John Reumann, and Sharad Singhal, "Online Web cluster capacity estimation and its application to energy conservation," *IEEE Transactions on Parallel and Distributed Systems*, vol. 18, no. 7, pp. 932--945, July 2007.
- Pradeep Padala, Kang G. Shin, Xiaoyun Zhu, Mustafa Uysal, Zhikui Wang, Sharad Singhal, and Kenneth Salem, "Adaptive control of virtualized resources in utility computing environment," *ACM EuroSys 2007*, pp. 289--302.
- Hai Huang, "Exploiting Unused Storage Resources to Enhance Systems' Energy Efficiency, Performance, and Fault-Tolerance," PhD Thesis, 2006, <http://kabru.eecs.umich.edu/papers/thesis/hai.pdf>
- Hai Huang, Wanda Hung, and Kang G. Shin, "FS2: Dynamic data replication in free disk space for improving disk performance and energy-consumption," *Proc. 20-th ACM Symposium on Operating Systems Principles (SOSP'05)*, Brighton, UK, pp. 263--276, Oct.~24--26, 2005.
- Hai Huang, Kang G. Shin, Charles Lefurgy, and Tom Keller, "Improving energy efficiency by making DRAM less randomly accessed," *Proc. Int'l Symposium on Low Power Electronics and Design--2005 (ISLPED'05)*, San Diego, CA, August 2005.
- Hai Huang, Kang G. Shin, Charles Lefurgy, and Tom Keller, "Improving energy efficiency by making DRAM less randomly accessed," *Proc. Int'l Symposium on Low Power Electronics and Design--2005 (ISLPED'05)*, San Diego, CA, August 2005.