Energy-Efficient Computing and Computing for Efficient Energy Usage

Yanlei Diao and Prashant Shenoy
University of Massachusetts Amherst
{yanlei,shenoy}@cs.umass.edu

In recent years, sustainable computing (aka green computing) has emerged as a new research area in Computer Science. Existing research in this field has focused on energy-efficient computing, which broadly includes hardware and software techniques to make computing more energy-efficient. More recently, work in the area has begun to focus on computing for efficient energy usage, which broadly includes computing techniques (e.g., hardware, software, algorithms, optimizations) to green physical infrastructures and the natural environment.

In this whitepaper, we propose new data management research that addresses both topics. In particular, we propose to (1) exploit new hardware and software for energy efficient data management and (2) use large-scale data analytics to help build smart grids and smart buildings.

**Background of Participants:** Yanlei Diao has been working in the areas of data management systems since 1998. She has led a number of projects on sensor databases, RFID data management, data streams, large-scale data analytics, and uncertain data management.

Prashant Shenoy has a background in distributed systems. He has been active in the area of sensor networks, where he has led projects on the design of storage-centric sensors network and solar harvesting-based sensor nodes for environmental monitoring of rivers and forests.

Diao and Shenoy have worked together for five years on a number of projects. In an earlier project, we studied “energy-efficient data management for storage-centric sensor networks” [CIDR’07,RTCSA’10]. We exploited technology trends in flash memories and embedded platforms, and articulated a vision of a storage-centric sensor network where sensor nodes are equipped with high-capacity and energy-efficient local flash storage. We proposed substantial redesign of a distributed sensor database to fully exploit the presence of local storage and processing capability in order to reduce energy consumed in expensive communication.

This earlier work led to the next project “energy-efficient data management for large database systems” [VLDB’09]. In this project, we considered energy-efficient flash memory in the design of a database system, in particular, a new design of tree indexes due to the fundamentally different read and write characteristics of flash in comparison to magnetic disks. We developed a novel index structure to minimize accesses to flash as well as energy consumption.

Most recently, we have begun to work on “high-performance large-scale data analytics” [SIGMOD’11]. We examined, from a systems standpoint, what architectural design changes are necessary to bring the benefits of clustering computing, e.g., using the MapReduce model, to high-performance one-pass analytics. To address the limitations of existing systems, we propose a new data analysis platform that employs hash techniques to enable fast in-memory processing, and a new frequent key based technique to extend such processing to workloads that require a large key-state space. We demonstrated tremendous performance benefits over existing Hadoop-based data analysis systems.
Proposed Work: We propose two lines of new research to address energy-efficient data management and data analysis for efficient energy usage, respectively.

1. Exploiting new hardware and software for energy efficient data management. Unlike traditional database systems that are optimized for response time, we consider a new database system optimized for energy efficiency. First, we propose to use flash memory or its packaged devices like SSDs for energy-efficient storage. While we studied indexing techniques for such a storage system, the overall query optimization issue requires new research that determines the energy profile of each algorithm that implements a relational operator, the energy profile of a query plan, and the overall most energy-efficient plan for answering a query. Furthermore, we propose to consider a new trend of writing to raw flash memory at voltages lower than consumed nowadays to further reduce energy usage. This proposal leverages several facts including (a) writing to flash at a lower voltage can introduce errors, but only infrequently, (b) such errors are one-directional, e.g., bits that are supposed to be ‘1’ written as ‘0’, and (c) such errors can often be corrected using software solutions. We will examine this idea in the context of database systems, in particular, investigating which data structures can tolerate small errors or can be easily corrected in software, as well as the overall implications of such low voltage writes on query processing and optimization. We expect that this idea may be relevant to many of the OLAP workloads where the users are looking for big patterns rather than specific details.

2. Exploiting large-scale data analytics for smart grids and smart buildings. Our second proposed effort will broadly focus on large-scale data analysis for designing smart grids as well as smart buildings/homes. In the area of smart grids, we aim to support the design of a (sensor-based) monitoring infrastructure for the grid. We are also interested in the “boundary” between the smart grid and the home/office buildings. In this context, we plan to support demand-response approaches for home, which include intelligent scheduling of smart appliances as well as techniques for energy capping in the home.

To enable the design of smart grids and smart buildings/homes, large-scale data collection and data analysis will play a pivotal role. In our research, we will address questions like “what data can be collected/sensed from the consumer end?” and “what data can be collected From the grid?" We will use data to track: (a) profile of time vs. kwh consumed, (b) predictable future consumption, nature/timing of consumption – for e.g., turning on the washer/drier, (c) devices turned on at a particular point in time, and (d) schedule of available power, with prices of available power. Moreover, to address issues like “where should the PMUs be placed in the smart grid network?” we will perform measurements and tracking of wastage/theft in the smart grid. We will consider measurement and correlation at various levels to detect theft and/or waste. Furthermore, we also need algorithms for data processing and aggregation, for example, smoothing consumption profiles at different levels of the distribution hierarchy. We envision that large-scale data collection and data analysis will be used to address many of the questions above, including aggregation over a large number of nodes, homes, or buildings, clustering of data to find similar usage patterns, prediction of future consumption, and detection of anomalies such as wastage. Low-latency analysis will further provide real-time insights and allow timely actions to be taken to minimize energy consumption while maintaining the utility of the grid/building.