

# HDF5-FastQuery:

## *Accelerating Complex Queries on HDF Datasets using Fast Bitmap Indices*

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### 1 Introduction

Efficient analysis of large scientific datasets often requires a means to rapidly search and select interesting portions of data based on ad-hoc search criteria. We present our work on integrating an efficient searching technology named *FastBit* [2, 3] with HDF5. The integrated system named *HDF5-FastQuery* allows the users to efficiently generate complex selections on HDF5 datasets using compound range queries of the form  $(temperature > 1000) AND (70 < pressure < 90)$ . The *FastBit* technology generates compressed bitmap indices that accelerate searches on HDF5 datasets and can be stored together with those datasets in an HDF5 file. Compared with other indexing schemes, compressed bitmap indices are compact and very well suited for searching over multidimensional data – even for arbitrarily complex combinations of range conditions.

### 2 FastBit Indexing Technology

Bitmap indexing is a technique for processing complex, multi-dimensional ad-hoc queries on read-only data. They have been introduced into several commercial database systems by vendors such as Sybase, IBM and Oracle. *FastBit* is a specialized bitmap indexing technology for numeric data that uses a bitmap compression method designed to be more compute-efficient than the best available commercial implementations. The size of the compressed indices is typically about a third of the data size. *FastBit* facilitates very efficient multi-dimensional searches of scientific datasets.

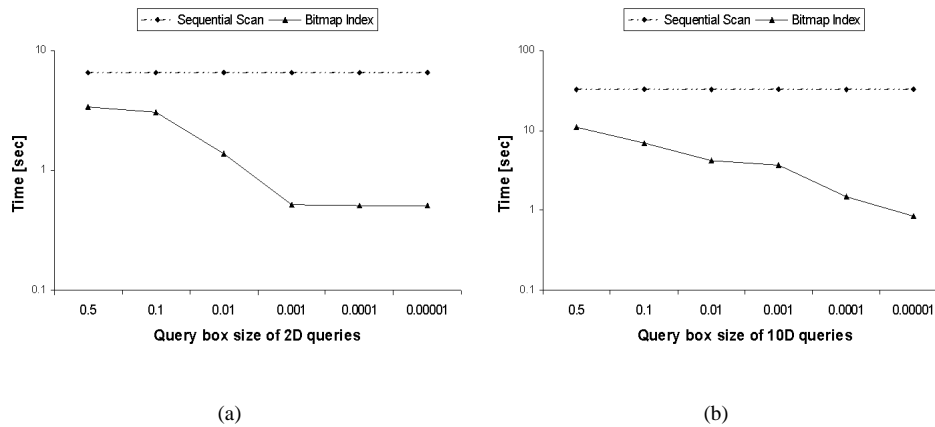
Figure 1 compares the performance of sequential scans to that of bitmap indices for processing multi-dimensional range queries. The sequential scan, where every element in the dataset must be evaluated against the query expression, is the most common approach for answering these types of queries in lieu of indexing technology. We see that the bitmap index significantly outperforms the sequential scan by a factor of 5 to 100, depending on the result size. We can also see that the smaller the query box size (i.e. the more selective the query), the higher is the performance advantage of the bitmap index.

### 3 HDF5-FastQuery

HDF5 supports complex selections based on multidimensional data coordinates (eg. hyperslab selection). *HDF5-FastQuery* extends the HDF5 selection mechanism to allow arbitrary range conditions on the data values contained in the datasets using the bitmap indices to accelerate the query. The *FastQuery* technology can efficiently support compound queries that span multiple datasets.

Our initial implementation uses a wrapper API that is designed to facilitate storage of time-series of multi-variable block-structured datasets which are common in the sciences. In the future, the storage organization can be expanded to accommodate more complex data schemas such as unstructured meshes, chemistry, and particle datasets. The API also allows us to seamlessly integrate the *FastBit* query mechanism for data selection with HDF5's standard hyperslab selection mechanism. Using the *FastQuery* API, one can efficiently select subsets of data from a HDF5 file using text-string queries.

The bitmap indices are stored in the same file as the datasets they refer to and are opaque to the general HDF5 functions. A query is posed to the API as a text-string such as  $(temperature > 1000) AND (70 < pressure < 90)$ , where the names specified in the range query correspond to the names of datasets in the HDF5 file. The *FastQuery* interface will then consult the stored bitmap indices that correspond to the specified dataset in order to accelerate the selection of elements in the datasets

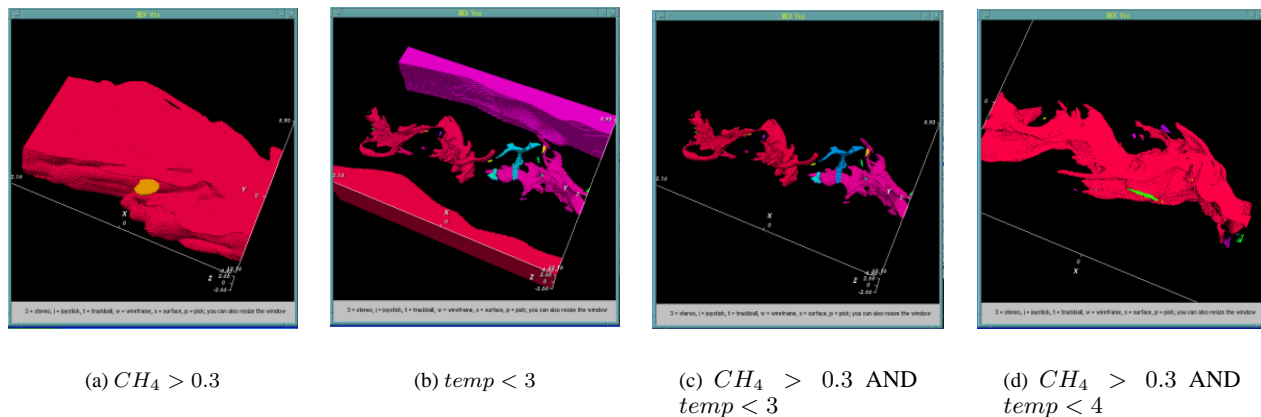


**Figure 1. Response time of multi-dimensional queries on a large combustion dataset. The bitmap index from FastBit significantly outperforms the sequential scan.**

that meet the search criteria. An accelerated query on the contents of a dataset requires only small portions of the compressed bitmap indices be read into memory, so extremely large datasets can be searched with little memory overhead. The query engine then generates an HDF5 selection that can be used to only read the elements from the dataset that are specified by the query string.

The FastBit technology is amenable to handling datasets and selections that are far larger than system memory. In recent experiments with data stored in 241Gigabyte data file[4], a search that consumed 2467 seconds using sequential scan was reduced to only 22.8 seconds using the bitmap indices. This same ability to handle out-of-core data selections will be available in the HDF5-FastQuery implementation.

## 4 Applications



**Figure 2. A visualization of flames in a high-fidelity simulation of methane-air jet. The images show the cells in a 3D block-structured dataset that were returned by the query.**

In addition to data analysis applications, we have applied bitmap indices for efficient query-based visualization within the DEX framework [1]. Figure 2 shows an interactive visualization process based on a large combustion simulation dataset. The example demonstrates how data is progressively interrogated to focus on cells that contain properties of interest.

## 5 Acknowledgment

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