DataCutter: Middleware for Filtering Very Large Scientific Datasets on Archival Storage Systems

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Multi-dimensional Datasets

Spatial/multi-dimensional multi-scale, multi-resolution datasets
- Satellite data processing
- Coupled simulation systems
- The Virtual Microscope

Applications access a subset of the dataset
- Subsetting done by using spatial indexes (e.g., R-trees)

Processing can be performed before returning data to client
- Often to reduce volume of data
Applications

Pathology

Volume Rendering

Surface
Groundwater
Modeling

Satellite
Data Analysis

Processing Remotely Sensed Data

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A Motivating Scenario

Sample Application:
- generate 3D reconstructed view from new set of sensor readings (computationally intensive)
- compare features with reference db

Configuration:
- remote data server - reference db
- sensor host - large raw readings
- parallel computation farm available

How to design application?

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Application:

- process relevant raw readings
- generate 3D view
- compute features of 3D view
- find similar features in reference db
- display new view and similar cases
A Motivating Scenario (2)

Application:
- process relevant raw readings
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- find similar features in reference db
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Reference DB
feature list

Extract ref
Data Server

3D reconstruction
Computation Farm

WAN

Client PC

View result

View result

Extract ref
Sensor

Extract raw

Raw Dataset
sensor readings

Reference DB

Extract raw

Raw Dataset
Tools to Manage Storage Hierarchy

Mass Storage:
- Load subset of data from tertiary storage into disk cache or client
- Access data from distributed data collections
- Preprocess close to data sources

Fast secondary storage:
- Tools for on-demand data product generation, interactive data exploration, visualization
- Target closely coupled sets of processors/disks
DataCutter Middleware

Targets multi-dim datasets in archival storage systems

Subsetting through *Range Queries*

- range defines a hyperbox in the multi-dimensional attribute space underlying the dataset
- retrieve items whose coordinates fall within box

Restricted application processing as *Filters*

- intended to execute near (LAN) storage system
- purpose is to reduce amount of data transmitted to client
DataCutter Architecture

Segments: (File, Offset, Size) (File, Offset, Size)

Client

Range Query

Segment Data

Client Interface Service

Indexing Service

Filtering Service

Filter

Data Access Service

DataCutter

Archival Storage System

Archival Storage System

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Subsetting

Datasets are partitioned into segments
  - used to index the dataset, unit of retrieval

Indexing very large datasets
  - Multi-level hierarchical indexing scheme
  - Summary index files -- for a collection of segments or detailed index files
  - Detailed index files -- to index the individual segments
Application Filters

**Purpose:** Specialized user code for processing data segments before returning them to the client

- based on Active Disks [Acharya, Uysal, Saltz]
- **filters** are the unit of computation
  - high level tasks
  - `init,process,finalize` interface
- **streams** are how filters communicate
  - unidirectional buffer pipes
Placement

The dynamic assignment of filters to particular hosts for execution is **placement** (mapping)

Possible Optimization Goals:

**Communication**
- leverage filter affinity to dataset (contrast with Distributed Storage)
- minimize communication volume on slower connections
- co-locate filters with large communication volume

**Computation**
- expensive computation on faster, less loaded hosts
Current Software Infrastructure

Prototype implementation of filter framework

- C++ language binding
- one thread for each instantiated filter
- manual placement; wide-area execution service

Prototype indexing/data access service

- UNIX filesystem, HPSS archival storage
- R-tree indexes supported
- being integrated with NPACI Storage Resource Broker (SRB)
class MyFilter : public Filter_Base {
public:

    int init(int argc, char *argv[]) { … };
    int process(stream_t st[]) { … };
    int finalize(void) { … };

};
Filter Connectivity / Placement

[filter.A]
outs = stream1 stream3

[filter.B]
ins = stream1
outs = stream2

[filter.C]
ins = stream2 stream3

[placement]
A = host1.cs.umd.edu
B = host2.cs.umd.edu
C = host3.cs.umd.edu
Execution Service

1. Read
Specs
Filter/Stream Placement

Filter lib
Application Console

2. Query

Directory
name host port
**** **** ****

3. Exec

AppExec Daemon
EXEC

filter A
Application
host1.cs.umd.edu

filter B
Application
host2.cs.umd.edu

filter C
Application
host3.cs.umd.edu

Directory Daemon
dir.cs.umd.edu:6000
Application: Virtual Microscope

- Interactive software emulation of high power light microscope for processing/visualizing image datasets
- 3-D Image Dataset (100MB to 5GB per focal plane)
- Client-server system organization
- Rectangular region queries, multiple data chunk reply

- pipeline style processing

```
read_data decompress clip zoom view
```
Experimental Setup

- UMD 10 node IBM SP (1 4CPU, 3 2CPU, 6 1CPU)
- HPSS system (10TB tape storage, 500GB disk cache)
- 4GB JPEG compressed dataset (90GB uncompressed), 180k x 180k RGB pixels (200 x 200 image chunks)
- 250GB JPEG compressed dataset (5.6TB uncompressed), 1440k x 1440k RGB pixels (1600 x 1600 image chunks)
- Queries: 4500x4500 q1-q5,q6; 9000x9000 q7; 18000x18000 q8 pixels
- {server}--{client}
  - server host = SP node (1CPU or 2CPU nodes)
  - client host = User Workstation (SPARC 10 or Ultra1)
Experimental Setup (2)

<table>
<thead>
<tr>
<th>Filter</th>
<th>Total Volume</th>
<th>Volume / Chunk</th>
</tr>
</thead>
<tbody>
<tr>
<td>read_data</td>
<td>3.60 MB</td>
<td>102.52 KB</td>
</tr>
<tr>
<td>decompress</td>
<td>83.42 MB</td>
<td>2373.04 KB</td>
</tr>
<tr>
<td>clip</td>
<td>57.83 MB</td>
<td>1645.02 KB</td>
</tr>
<tr>
<td>zoom (no)</td>
<td>57.83 MB</td>
<td>1645.02 KB</td>
</tr>
<tr>
<td>zoom (8)</td>
<td>.90 MB</td>
<td>25.70 KB</td>
</tr>
</tbody>
</table>

4GB dataset

$q_5$ sample volume
Experiment: Dataset Tiling

Setup: 4GB dataset, cold cache

Point: dataset organization can be controlled, and affects performance
Experiment: Computation / Volume

Setup: 4GB dataset, warm cache

Point: amount of computation and communication makes a significant difference for efficient placement.
Experiment: Server Load

Setup: 4GB dataset, zoom 8, warm cache

Point: server load has a dramatic effect on efficient placement.
Experiment: Cold vs. Warm Cache

Setup: 250GB dataset, zoom 8

Point: q1-q5 dominated by HPSS access, tape storage location dependent
Experiment: Scaling Query Size

Setup: 250GB dataset, zoom 8

Point: q6-q8 larger, but not dominated as much HPSS access, network volume still important
Experiment: Filter Overhead

Point: overhead is not very large for the unoptimized filter prototype

6% - 30% overhead
Future Work

- New applications
  - Database (Sort, Select/Project/Join)
  - Visualization
  - Satellite data processing
- Automated placement of filters
- Tighter integration with NPACI Storage Resource Broker (SRB)
Related Work

Application Level
- AppLeS
- Client/Server Sockets

Programming Models
- Legion
- DataCutter
- Harmony

Infrastructure Services
- SRB
- Globus
- NWS
- DPSS

Resource Level
- Grid available Resources
- User specified Resources

- HPC++
- JavaRMI, DCOM, CORBA
- NetSolve, Ninf
- Condor Pool
- Idle Resources
<End of Talk>
Filter Environment

Filter constraints
- communicate with other filters *only* using streams
- cannot change stream endpoints
- may disclose dynamic allocation of memory/scratch space before execution

Advantages
- location independence
- easier scheduling of resources
- filter stop and restart is defined explicitly in model
Manual Restructuring Process

Application

Decompose

Target Configuration

Some set of filters

f₁ → f₃ → f₅

f₂ → f₄

Placement / Schedule

Execute Application
SRB/DataCutter integration

API for SRB clients to

- create indexes (R-tree index)
- subset data sets
- carry out restricted filter operations on portions of files (data segments) before returning them to the client (to perform filtering or aggregation to reduce data volume)
- only one filter can run per query
SRB/DataCutter System

Storage Resource Broker (SRB)

File SID | DBLobjID | ObjSIDs | Range Query

SRB I/O and MCAT API

Indexing Service
Filtering Service
DataCutter
Filter

Application (SRB client)

Resource

User

MCAT

Application Meta-data

Distributed Storage Resources

- DB2, Oracle, Illustra, ObjectStore
- HPSS, UniTree
- UNIX, ftp
Extensions to Filter Framework

- cost model based placement
- externalize filter library (inter-application)
- dynamic attachment
  - partial filter graphs left running (server applications)
- history feedback into cost models
- parallel filters

1
2
2
2
3
Adaptive Placement

Applications expose *unit-of-work*

- unit of work boundaries are when decisions are made
- a decision to modify placement is made globally
  - new instance created, and all *new* work uses it
  - for filters with state, model defines explicit state transfer
    - old instance sends data over temporary special stream to new instance from `<old>::finalize()` to `<new>::init()`
    - not really “migrated”, but effect is similar without high cost
  - ex: many clients or server load high, push filters toward clients
Why not XXX programming model?

- Ex: MPI, PVM, etc. (can be used instead)
  - decide which machines to use based on dataset affinity
  - detect where running and use functional parallelism to control which filters runs
  - add disclosure of comm. pattern and resource usage
  - add mechanism for shutting down nodes and adding new during computation for adaptation

Why use filter-stream programming model
- because it provides these services in a natural way
- encourages minimized state and resource usage
What will not work well?

- Fine grained tasks
- Fine coordination between filters
- Long request-response chains with dependencies between queries
Annotation Detail

- **Static annotations**
  - host (cpu_power, cost)
  - filter (cpu_time, size_transform, num_transform, content_transform)
  - stream (size_unit)

- **Runtime properties**
  - host (cpu_load, memory_free, scratch_space_free)
  - network (bw, latency, jitter)
Related Projects

**ADR (Active Data Repository) [Chang et al.]**
- Support optimized associative access and processing of persistent multi-dimensional data
- Customizable for various applications
- Integrate and overlap a wide range of order-independent user-defined aggregation operations with data retrieval
- Target a shared-nothing architecture with disk farm
- Compiler to generate ADR code from Titanium, a Java dialect
- Caching proxy for co-located clients
Related Projects

- Active Disks [Uysal, Acharya, Saltz]
  - Putting significant processing and memory on disks
  - Execution of data-intensive parts of algorithms on disk resident processors
  - Stream-based programming model