Storage Management and Data Mining Problems in High Energy Physics Applications

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Data Organization and Indexing of Large High Energy Physics Data

Collaboration	# members /institutions	Date of first data	# events/year	total data volume/year-TB
STAR	350/35	1999	10^7-10^8	300
PHENIX	350/35	1999	10^9	600
BABAR	300/30	1999	10^9	80
CLAS	200/40	1997	10^{10}	300
ATLAS	1200/140	2004	10^9	2000

STAR: Solenoidal Tracker At RHIC
RHIC: Relativistic Heavy Ion Collider

Data Organization for Efficient Retrieval of Very Large Datasets

- **General problem area**
  - **how to cluster data in physical storage according to expected access patterns**
- **Observation**
  - **on parallel disks: distribute clusters to maximize parallel reads**
  - **on tape storage: keep cluster together to minimize tape mounts**

HENP Mass Storage Access

- **After event reconstruction, event properties (features) are extracted: called "level 1 n-tuples"**
- **Number of properties is large (50-100)**
- **e.g. momentum, no. of pions, transverse energy**
- **Multidimensional space is highly skewed and sparse**
- **Need to access events based on partial properties specification (usually ranges)**
- **Problem: re-organize event clusters on mass storage according to the property space**

Clusters in the M-Dim property space

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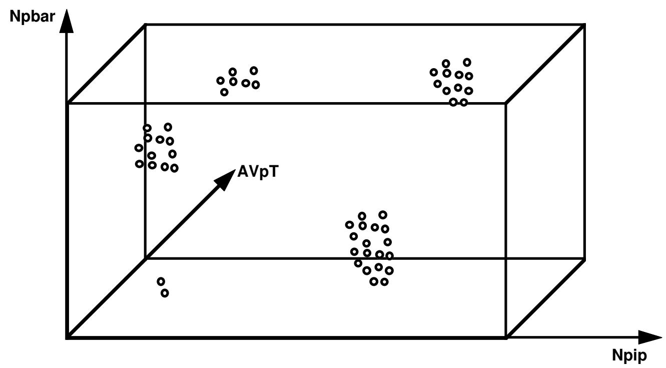

EXAMPLE OF EVENT PROPERTY VALUES

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I event 1	**I Np(3) 24**	**R AVpT(1) 0.325951**
I N(1) 9965	**I Npbar(1) 94**	**R AVpT(2) 0.402098**
I N(2) 1192	**I Npbar(2) 12**	**R AVpTpip(1) 0.300771**
I N(3) 1704	**I Npbar(3) 24**	**R AVpTpip(2) 0.379093**
I Npip(1) 2443	**I NSEC(1) 15607**	**R AVpTpim(1) 0.298997**
I Npip(2) 551	**I NSEC(2) 1342**	**R AVpTpim(2) 0.375859**
I Npip(3) 426	**I NSECpip(1) 638**	**R AVpTkp(1) 0.421875**
I Npim(1) 2480	**I NSECpip(2) 191**	**R AVpTkp(2) 0.564385**
I Npim(2) 541	**I NSECpim(1) 728**	**R AVpTkm(1) 0.435554**
I Npim(3) 382	**I NSECpim(2) 206**	**R AVpTkm(2) 0.663398**
I Nkp(1) 229	**I NSECkp(1) 3**	**R AVpTp(1) 0.651253**
I Nkp(2) 30	**I NSECkp(2) 0**	**R AVpTp(2) 0.777526**
I Nkp(3) 50	**I NSECkm(1) 0**	**R AVpTpbar(1) 0.399824**
I Nkm(1) 209	**I NSECkm(2) 0**	**R AVpTpbar(2) 0.690237**
I Nkm(2) 23	**I NSECp(1) 524**	**I NHIGHpT(1) 205**
I Nkm(3) 32	**I NSECp(2) 244**	**I NHIGHpT(2) 7**
I Np(1) 255	**I NSECpbar(1) 41**	**I NHIGHpT(3) 1**
I Np(2) 34	**I NSECpbar(2) 8**	**I NHIGHpT(4) 0**
		I NHIGHpT(5) 0

54 Properties, eventually 10^8 events

Size of HENP datasets on tape

- **STAR experiment**
  - **10^8 events over 3 years**
  - **1-10 MB per event: reconstructed data (DST tapes)**
  - **10^{15} total size**
  - **10,000 tapes per year (30 MB tapes)**

Manage Cluster Access

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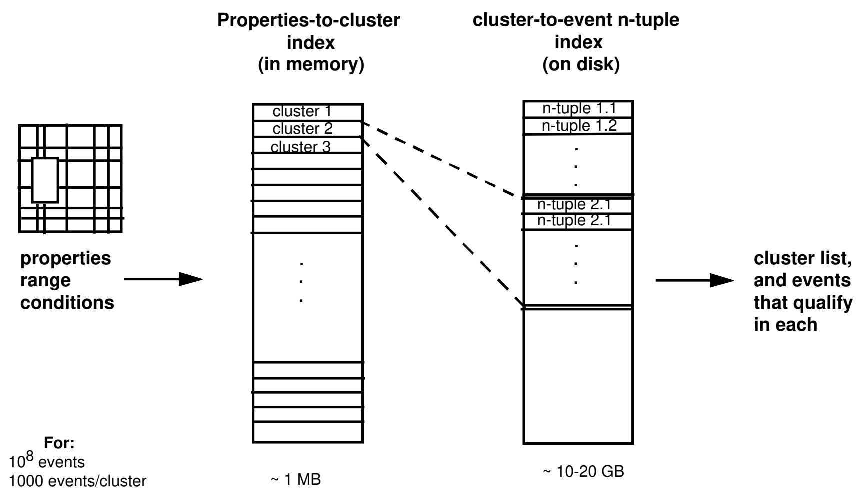

Size of indexes for STAR

- Index size
  - property space: 10^8 events x 200 bytes = 20 GB
  - index space: 10^5 clusters x 100 bytes = 10 MB
    (assume 1000 events/cluster)
- Problem
  - how to organize property space index

Main Tasks

- Discover event clusters
  - based on natural distribution - Data Mining
  - based on access patterns - consult physicists
  - simulate performance - data manager's workbench
- Manage cluster access
  - given a query, determine clusters to access,
    use multi-dimensional indexes to select events that qualify
- Reorganize DST tapes according to clusters
  - long process - done initially, then rarely
  - flow control - restart after interruption
- Cache management
  - determine if in cache, which incremental clusters to cache,
    which clusters to purge from cache

Events Clustering and Access: Main Components

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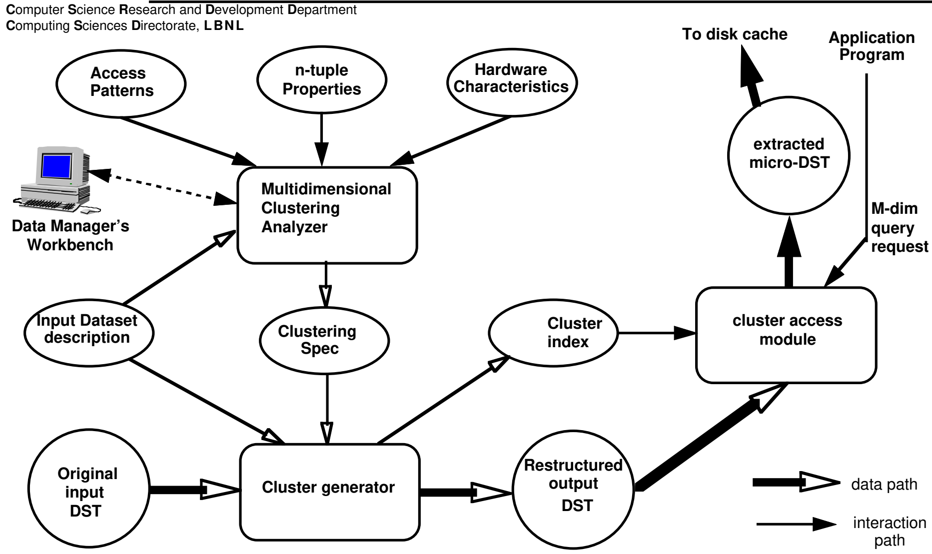

Discover events clusters

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- **Top down approach**
  - partition each dimension into "bins" (e.g. 1-2 GEV, ..., 1-3 pions, ...)
  - select subset of dimensions based on physicist's experience
  - analyze which events fall into the same "cell" (i.e. m-dim rectangles formed by the bins)
  - eliminate empty cells
  - combine cells to form similar size clusters
- **Assumption**
  - most queries are "range queries"

Discover events clusters

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- **Bottom up approach**
  - **select a subset of the dimensions (using physicist's hints initially)**
  - **partition space on each dimension successively**
  - **determine suitability of various indexing methods to high dimensionality and skewed distributions: K-D trees, Quad-trees, R-trees,...**
  - **Iterate for other dimension combinations**
- **Consult physicists**
  - **do cluster correlations matter?**
  - **get additional hints on preferred dimensions**

Top Down Cell Management

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- **Assume: 7 dimensions, 10 bins each**

  -- Number of cells: 10^7, 4 byte counters

  -- Number of bytes: $4x10^7$, 40 MB

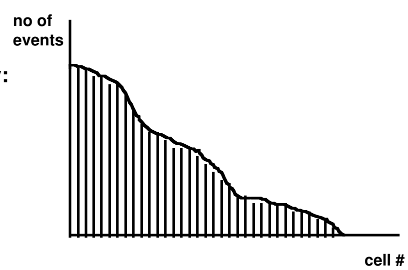
- **For e.g. small dataset 97% of cells are empty:**

  -- store only populated cells

  -- use hash tables to locate existing cells

  -- use 2 bytes for bin_id per property: ratio for p% full is: 200/ (n+2)p

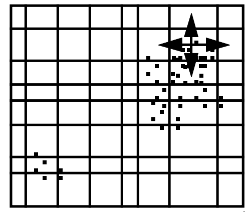
  -- No of bytes: for 7 dim, 3% => 5.4 MB



- **Sort cells by size (number of events)**

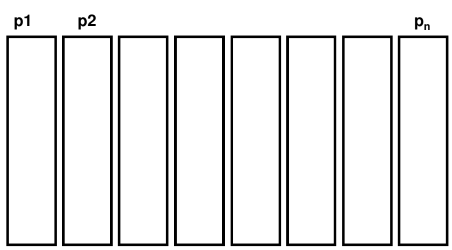
Cluster Identification

- **sort cells by size**
- **pick larger cell to start forming a cluster**
- **find all neighbors of "Manhattan distance" equal to 1**
- **include cells above a threshold**
- **iterate for all cells in cluster**
- **when no more cells above threshold, pick larger remaining cell and start forming a new cluster**
- **Display cluster distributions**



indexing over all properties

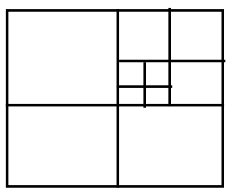
- **Assume 150 properties**
  - **Any combination of range queries**
  - **want to compute number of events**
- **possible solution: vertically partitioned file**
  - **idea: touch only properties in queries**
  - **each partition 10^8 x 4 bytes = 400 MB per partition**
  - **too expensive in space and time**



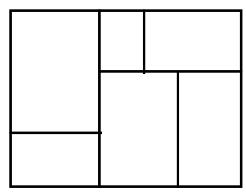
indexing over all properties

- other possible solutions
  - partitioning MD space (KD-trees, n-QUAD-trees, ...)
  - for high dimensionality - either fanout or tree depth too large
  - e.g. symmetric n-QUAD-trees require 2^{150} fanout
  - non-symmetric solutions are order dependent

QUAD-tree



KD-tree



Bit-Sliced indexing

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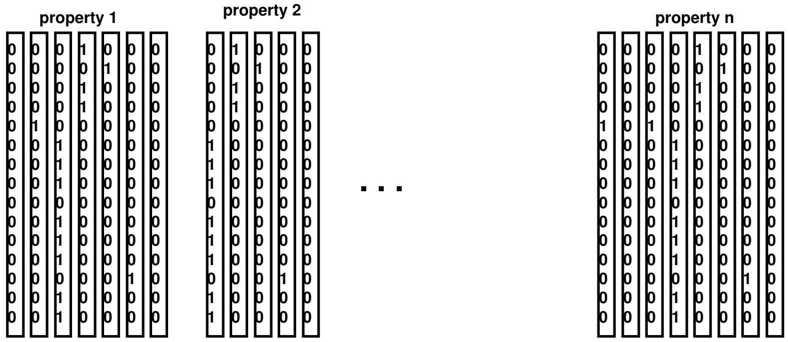
- partition each property into bins
- for each bin generate a bit vector
- compress each bit vector (run length encoding)

property 1 property 2 property n



Compression method

Uncompressed:
0000000000001111000000000 ......0000001000000000111111100000000 000000

Compressed:
12, 16, 1016,1017,1025,2025

Advantage:

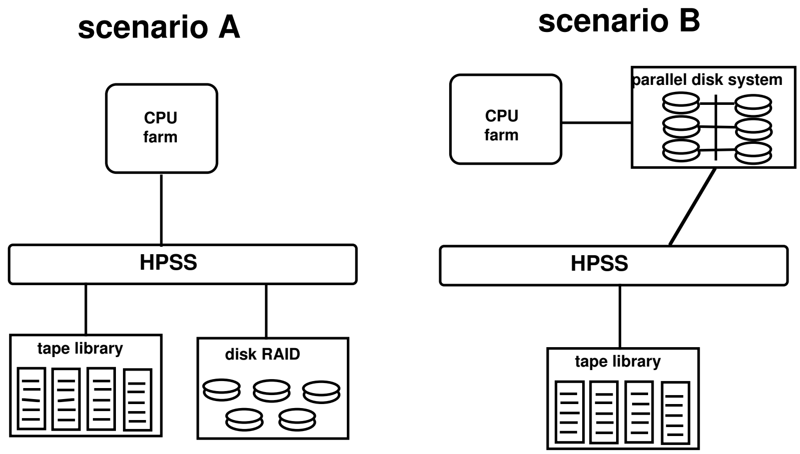
Can perform: AND, OR, COUNT operations on compressed data

Bit-Sliced indexing

- **Estimated size**
  - 100 properties X 10 bins X 10^8 bits = 10^{11} bits
  - compression factor (avg run length) = 1000
  - total size = 10^8 bits ~ 10 MB
- **Advantage**
  - only bit partitions need to be accessed (multiple bins per property are "or"ed, result for each property requested are "and"ed)
  - operations can be performed on compressed bit-slices
  - compressed bit-slices can be processed in paprallel
- **Disadvantage**
  - results can be given on bin boundaries only

Cache Management

Hardware scenarios



Cache Management Issues

- Scenario A
  - RAID more expensive than a Parallel Disk System (factor 2-3)
  - but, rely on HPSS to manage disk
  - storage management simplified
- Scenario B
  - a Parallel Disk System is cheaper, does not depend on RAID vendor
  - but, need to manage disk allocation
  - has control over placement of events on cache
- Planned initial pilot
  - Scenario A under NERSC

Reorganize DST tapes according to clusters

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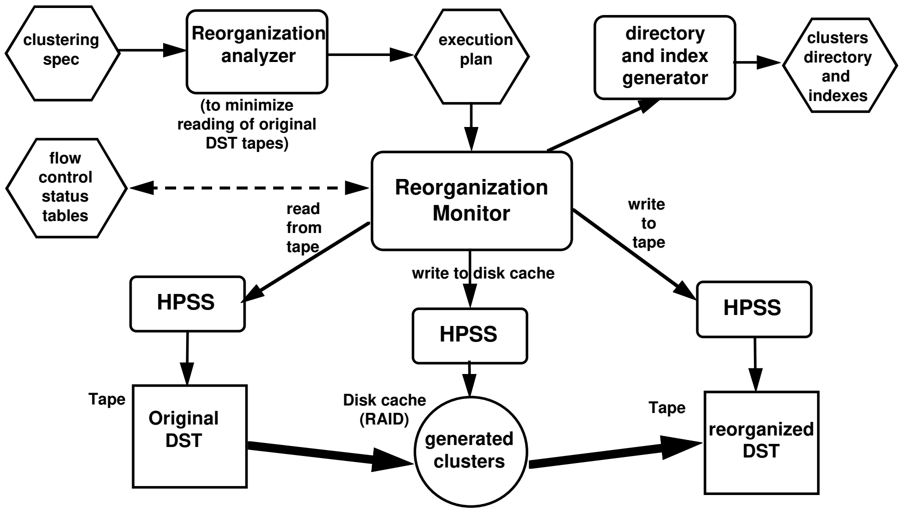

Open Problems

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- Discover event clusters in sparse high M-dim space given analyst guidance on bining
- Analyze the natural clustering of events by properties
- develop an efficicient index on high M-dim space
- develop a cache mangement policy for job mixes
- Simulate and test the effect of distributing events on disk cache by blocks vs. one event per disk
- The benefit of partial event data replication to accommodate conflicting access patterns

Open Problems (cont'd)

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- **The ability of HPSS to store files on tapes according to external specifications**
- **The ability of HPSS to perform "partial file reads" from tape storage**
- **The possibility and effectiveness of parallel tape management under HPSS**
- **The benefit of partial event data replication to accommodate conflicting access patterns**