# An Architecture for Using Tertiary Storage in a Data Warehouse

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# Motivation

- AT&T has huge data warehouses.
  - Data from billing, operations, network operations, etc.
  - In the form of billions of small objects (50 bytes)
  - Complex “decision support” and data mining queries.
- Very large data sets are difficult to store on-line
  - Cost of purchase
  - Cost of maintenance.
- Tape-resident data is difficult to query
  - Data is exported from databases - interface mismatch.
  - Tape management software does not support analyses
    - Aggregation queries over multi-terabyte data sets.

# “Decision Support” Queries

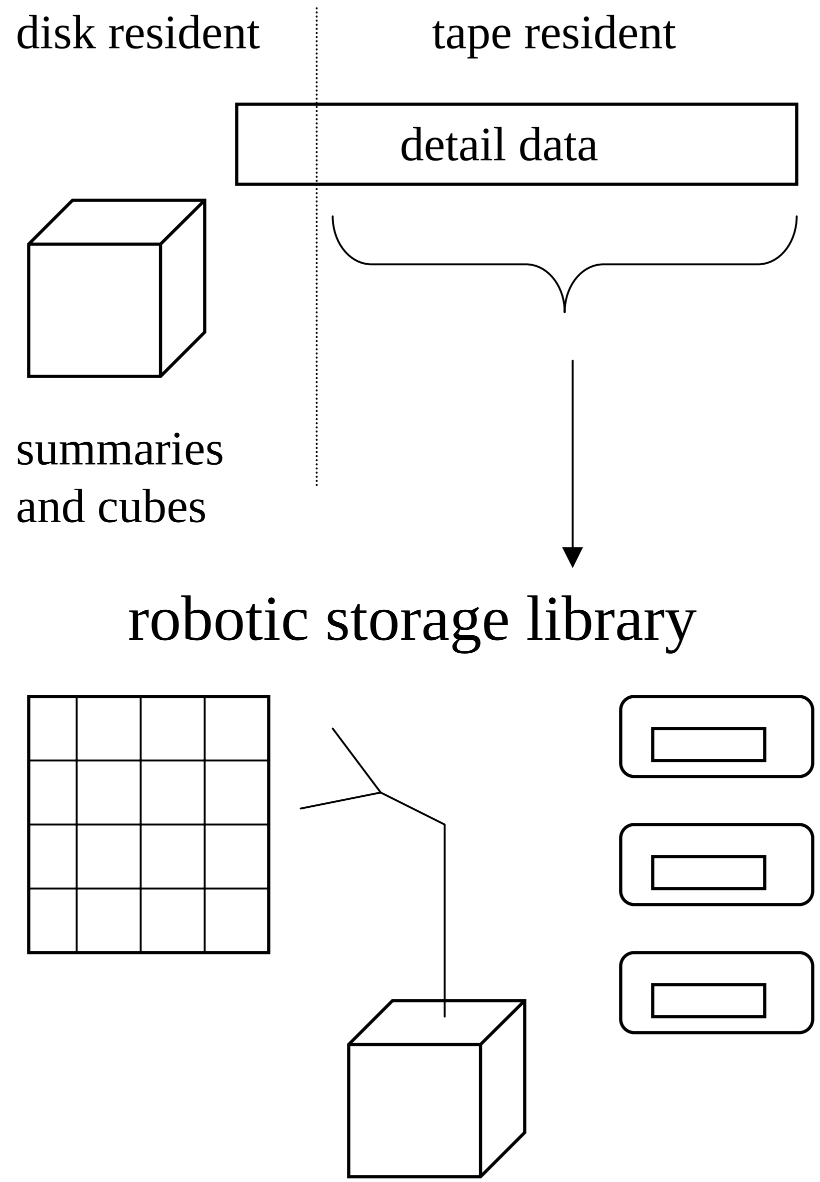
- Summarize large collections of data (aggregation).
  - Multiple levels of aggregation
  - Multiple dimensions of aggregation
  - “Data cubes”
- Use the aggregates for comparisons
  - “What fraction of total sales are made in California, by week, during 1996?”
  - “What fraction of total 1996 sales made in California are made in Orange County on Mondays?”
  - “Show the yearly/monthly/hourly volume of telephone traffic between pairs of area codes.”

# More complex queries

- “Complex” aggregation
  - “For each connection, count the number of packets exchanged between call setup and teardown”
  - “For each customer, what is the most common destination of calls with above-average length.”
  - “Which stores are favored by customers that make large purchases?”
- Data mining queries
  - Association rules (which objects tend to appear together)
  - Multidimensional distribution analysis (is it changing?)
  - Decision trees, etc.
- Needle-in-the-haystack
  - List all calls made to or from 212-555-4321 during the last 5 years.

# Tape-resident data warehouses

- *Detail data* : Finest granularity information.
- *Summaries* : Precomputed aggregate tables.
- Summaries and the head of the detail data is on-line.
- Tail of detail data is on tape.
- Use disk-resident data whenever possible to answer ad-hoc queries.
- Query tape-resident data when necessary.
- The detail data sets are a few multi-terabyte detail data tables.
- Queries on tape resident data frequently range over terabytes.



# Challenges

- Existing DBMSs do not integrate well with tertiary storage
  - Tape storage is inherently sequential.
  - Conventional DBMS query evaluation algorithms require random access.
    - “Cross-product” joins
- Management of very large collections of small objects presents storage problems
  - Indices may be too large to store on-line.
- Existing tape management software not appropriate
  - Terabyte scale, data intensive queries
  - Control over data layout.
  - Control over scheduling.

Pkt(Source, Dest, ts, StartCall, EndCall)

```
create view Temp as
  select R.Source, R.Dest, R.ts, EndTime=min(S.ts)
  from Pkt R, Pkt S
  where R.Source=S.Source AND R.Dest=S.Dest AND
        R.ts <= S.ts AND R.StartCall=1 and S.EndCall=1
  group by R.Source, R.Dest, R.ts

select T.Source, T.Dest, T.ts, count(*) from Pkt R, Temp T
where R.Source=T.Source AND R.Dest=T.Dest AND
      R.ts>=T.ts and R.ts<=T.EndTime
group by T.Source, T.Dest, T.ts
```

# Decision support queries on tape data

- Our target is large-scale aggregation queries
  - Usually, we want to build a new summary table.
    - We can’t predict every query in advance.
    - Similar problems occur with scientific data sets.
- Long sequential scans
  - Aggregation queries over the entire data set.
    - Or dense subsets.
  - Small “dimension tables” stored on disk.
  - Multiple passes for complex aggregation.
- Temporal nature of warehouse data permits localization.
  - Many optimizations are possible to reduce memory use.
  - Joins are localized -- “cross product” is rare.

# Requirements

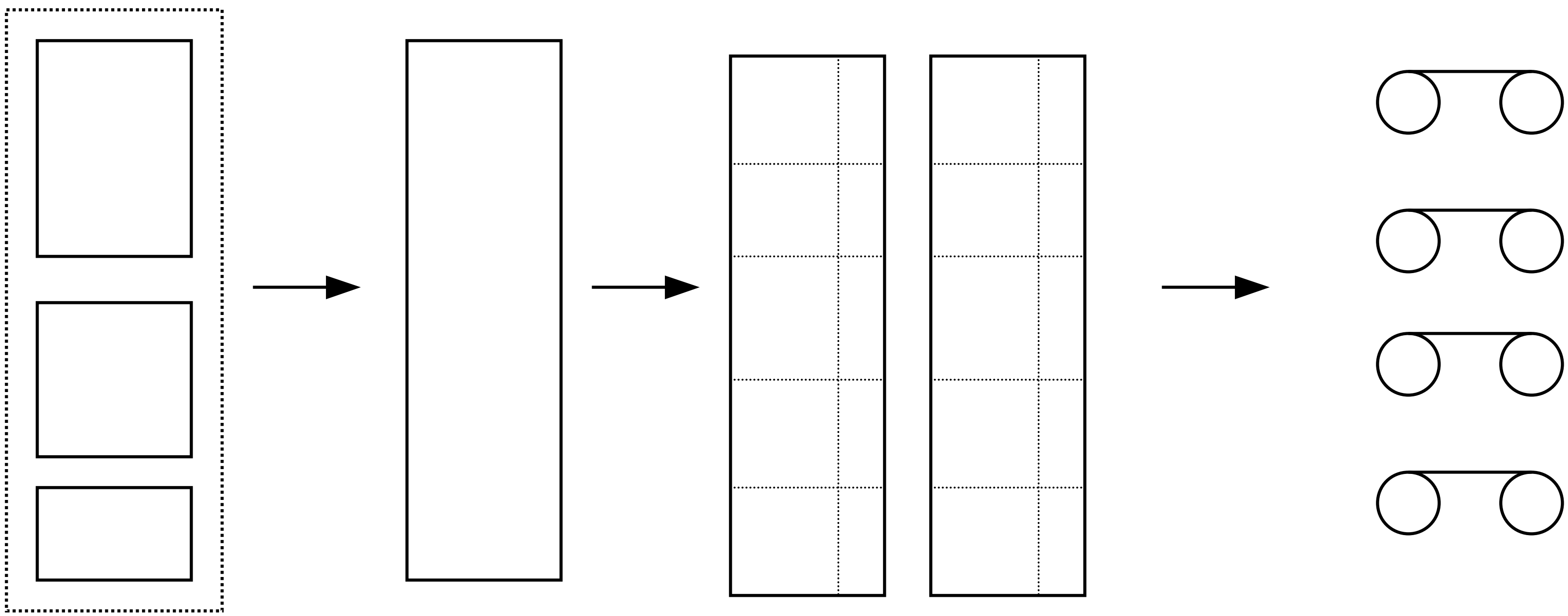
- High sequential throughput
  - Parallel I/O
    - Partition data set, perform concurrent reads.
  - Parallel processing
    - CPU use is still a consideration
  - Lightweight architecture
    - Transactions are done somewhere else.
  - Tape to memory transfers
    - Caching does not help a sequential scan through a terabyte.
- Database features
  - Control over data layout
  - Indexing
  - Declarative access
    - Enable parallel access and scheduling
  - Access methods for decision support queries

# Target System

- High end server
  - O(1 Gbyte) of main memory
  - O(1 Tbyte) on-line storage
  - O(10) processors
- Moderate to large size robotic storage library
  - Tape storage
  - 10 to 100 Mbyte/sec aggregate transfer rate.

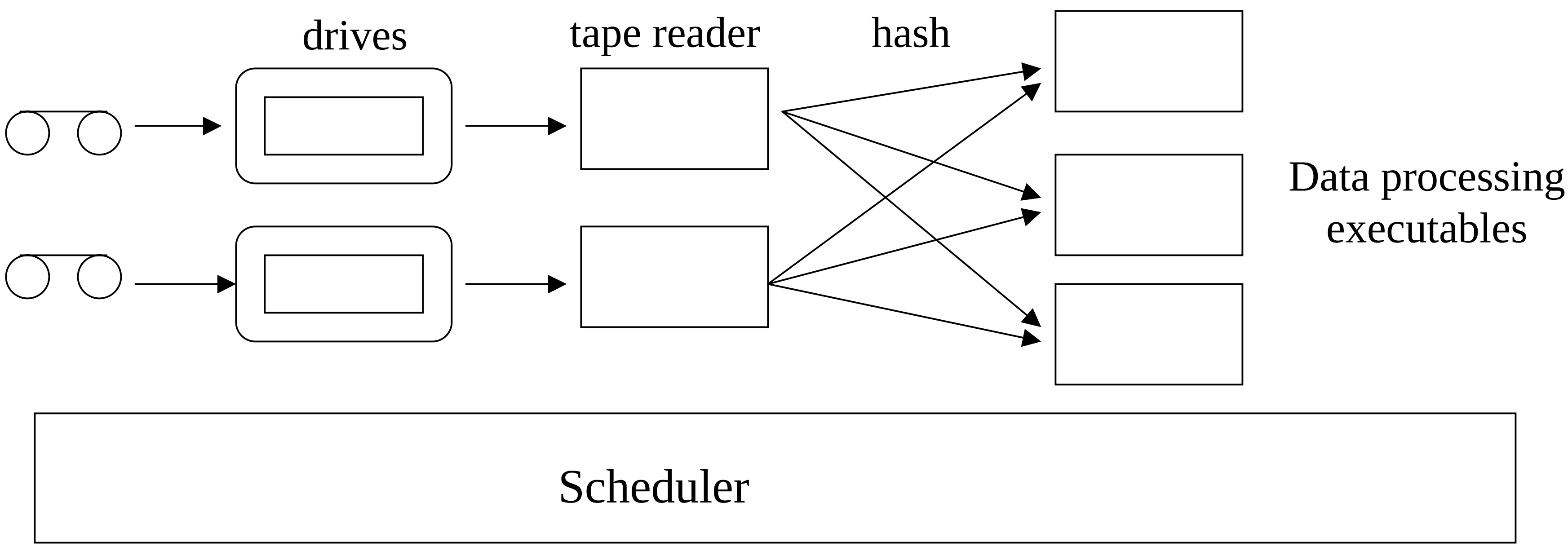
# Ingest

- Move detail data from disk-resident representation to tape-resident representation.
- Create horizontal and (perhaps) vertical partitions.
- Multiple sort orders.
- Allocate to tapes.



# Query

- Input:
  - List of tape partitions to access.
  - Executable for processing the data.
  - Hash function.
- Execution:
  - Start the processing executables.
  - Pick a schedule for accessing tape partitions.
  - Use the hash function to route tuples from tape to executable.



# Access Methods

- Single pass, no correlated accesses.
- Single pass, correlated accesses
  - e.g., join a partitioned table.
- Multiple pass

- Joins to disk resident data done at processing executables.
- Build queries out of basic access methods.

# Test Implementation

- Large Unix database server
- Robotic storage library with four DLT4000 tape drives.
- Network monitoring data
- Ingest step :
  - Extract a 60 Gbyte table from the database, reformat it.
  - “Stripe” it across 3 tapes (stripe unit is 500 Mbytes).
- Query
  - Complex aggregation query
    - groups are defined by tuple sequences.
  - Re-use a query written for disk-resident data.
  - Proper handling of sequences that span horizontal partitions.
  - Obtained 5.2 Mbyte/sec processing rate (maximum is 5.7 Mbyte/sec)

# Related Research

- Tertiary storage system performance characterization
- Indexing tape-resident detail data
- Query languages

# Performance Characterization

- Query optimization requires precise information about device performance.
  - Layout, scheduling, indexing.
- Precise data on tertiary storage system component performance is lacking
  - Disk drives relatively well understood.
  - Wide variety of tape drives, robotic storage libraries.
  - Many quirks.
- Related paper in this conference.

# Indexing detail data

- Motivation : look up calls made to/from a phone number
  - Required for law enforcement
  - Terabytes of small records
  - 1 per billion selectivity, or less.
- Dense indices do not scale.
  - 10% of 10 terabytes is 1 terabyte.
  - In this case, index size is equal to data size.
- Coarse indices
  - Indicate regions on tape where a record will exist.
    - Short seeks are slow
  - Aggressive use of compressed bitmaps.
  - 20 to 1 index size reduction, or greater.
- See *Coarse Indices for a Tape-based Data Warehouse*, Int'l Conf. on Data Engineering 1998, pg. 231-240

# Query Languages

- Conventional DBMSs rely on joins.
  - Complex aggregation queries frequently involve a self-join.
- Computing tape-to-tape joins is prohibitively expensive
  - Load part of one table into memory, scan the other table.
  - Many passes, the number of passes increases with table size.
- Most complex aggregation queries require only 1 pass
  - I.e., hand-written query plans make 1 pass.
  - More complex queries can require another pass.
- Multi-feature extension to SQL
  - Chatziantoniou and Ross
  - Join-free query plans that use long sequential scans.
- Optimize for tape-resident data
  - Reduce the number of passes over the data, often to 1 pass.
  - Reduce memory usage.

# Conclusions

- Tape-resident decision support data warehouses are desirable.
  - Existing practice is to export the tail of the detail data from the database.
  - Difficulty of access discourages use.
- Tape-resident decision support data warehouses are feasible.
  - Restrict the universe of queries to those that can be answered efficiently.
  - This set of queries covers a surprisingly large class of interesting queries.
- Work on efficient access.
  - Ensure high-throughput sequential access.
  - Get the most out of  sequential access.