Introduction
and
Database Technology

By EM Bakker

Introduction

- Databases and Data Mining Projects at LIACS
    - Biological and Medical Databases and Data Mining
        - CMSB (Phenotype Genotype), DIAL CGH DB
        - Cyttron: Visualization of the Cell
    - GRID Computing
        - VLe: Virtual Lab e-science environments
        - DAS3 super computer

- Fundamentals of Databases and Data Mining
    - Database integration
    - Data Mining algorithms
    - Content Based Retrieval

DBDM2009

Chapters 1-7:

- Introduction
- Data Preprocessing
- Data Warehouse and OLAP Technology: An Introduction
- Advanced Data Cube Technology and Data Generalization
- Mining Frequent Patterns, Association and Correlations

- Classification and Prediction
- Cluster Analysis

Advanced Data Mining (Ch. 8-11)

- Mining data streams, time-series, and sequence data
- Mining graphs, social networks and multi-relational data
- Mining object, spatial, multimedia, text and Web data
    - Mining complex data objects
    - Spatial and spatiotemporal data mining
    - Multimedia data mining
    - Text mining
    - Web mining
- Applications and trends of data mining
    - Mining business & biological data
    - Visual data mining
    - Data mining and society: Privacy-preserving data mining
- Additional (often current) themes could be added to the course

[R] Evolution
of
Database Technology

Evolution of Database Technology

- 1960s:
  - Data collection, database creation, IMS (hierarchical database system by IBM) and network DBMS
- 1970s:
  - Relational data model, relational DBMS implementation
- 1980s:
  - RDBMS, advanced data models (extended-relational, OO, deductive, etc.)
  - Application-oriented DBMS (spatial, scientific, engineering, etc.)
- 1990s:
  - Data mining, data warehousing, multimedia databases, and Web databases
- 2000s
  - Stream data management and mining
  - Data mining and its applications
  - Web technology (XML, data integration) and global information systems

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The Future of the Past

- **The Past and Future of 1997:** Database Systems: A Textbook Case of Research Paying Off. By: J.N. Gray, Microsoft 1997

- **The Future of 1996:** *Database Research: Achievements and Opportunities Into the 21st Century. By:* Silberschatz, M. Stonebraker, J. Ullman. Eds. SIGMOD Record, Vol. 25, No. pp. 52-63 March 1996

- **"One Size Fits All":** An Idea Whose Time Has Come and Gone. By: M. Stonebraker, U. Cetintemel. Proceedings of The 2005 International Conference on Data Engineering, April 2005, http://ww.cs.brown.edu/~ugur/fits_all.pdf

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"Database Systems:
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J.N. Gray, Microsoft
1997
http://www.cs.washington.edu/homes/lazowska/cra/database.html

Industry Profile (1994)

- The database industry $7 billion in revenue in 1994, growing at 35% per year.
- Second only to operating system software.
- All of the leading corporations are US-based: IBM, Oracle, Sybase, Informix, Computer Associates, and Microsoft
- Specialty vendors: Tandem ($1 billion/year) of fault-tolerant transaction processing systems, and AT&T-Teradata, ($500 million/year, data mining systems)
- Small companies for application-specific databases: -- text retrieval, spatial and geographical data, scientific data, image data, etc.
- Emerging group of companies: object-oriented databases.
- Desktop databases an important market focused on extreme ease-of-use, small size, and disconnected operation.

Worldwide Vendor Revenue Estimates from RDBMS Software, Based on Total Software Revenue, 2006 (Millions of Dollars)

Company	2006	2006 Market Share (%)	2005	2005 Market Share (%)	2005-2006 Growth (%)
Oracle	7,168.0	47.1	6,238.2	46.8	14.9
IBM	3,204.1	21.1	2,945.7	22.1	8.8
Microsoft	2,654.4	17.4	2,073.2	15.6	28.0
Teradata	494.2	3.2	467.6	3.5	5.7
Sybase	486.7	3.2	449.9	3.4	8.2
Other Vendors	1,206.3	7.9	1,149.0	8.6	5.0
Total	**15,213.7**	**100.0**	**13,323.5**	**100.0**	**14.2**

Source: Gartner Dataquest (June 2007)

Historical Perspective (1960-)

- Companies began automating their back-office bookkeeping in the 1960s.
- COBOL and its record-oriented file model were the work-horses of this effort.
- Typical work-cycle:
    1. a batch of transactions was applied to the old-tape-master
    2. a new-tape-master produced
    3. printout for the next business day.
- **CO**mmon **B**usiness-**O**riented **L**anguage (COBOL 2002 standard)

COBOL Code

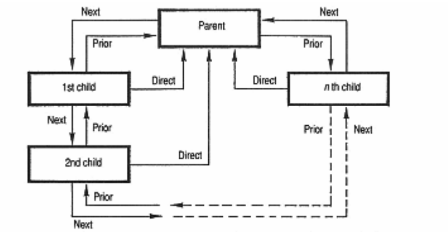
```
01  LOAN-WORK-AREA.
        03  LW-LOAN-ERROR-FLAG          PIC  9(01)       COMP.
        03  LW-LOAN-AMT                 PIC  9(06)V9(02) COMP.
        03  LW-INT-RATE                 PIC  9(02)V9(02) COMP.
        03  LW-NBR-PMTS                 PIC  9(03)       COMP.
        03  LW-PMT-AMT                  PIC  9(06)V9(02) COMP.
        03  LW-INT-PMT                  PIC  9(01)V9(12) COMP.
        03  LW-TOTAL-PMTS               PIC  9(06)V9(02) COMP.
        03  LW-TOTAL-INT                PIC  9(06)V9(02) COMP.
*
    004000-COMPUTE-PAYMENT.
*
        MOVE 0 TO LW-LOAN-ERROR-FLAG.

        IF (LW-LOAN-AMT ZERO)
           OR
          (LW-INT-RATE ZERO)
           OR
          (LW-NBR-PMTS ZERO)
           MOVE 1 TO LW-LOAN-ERROR-FLAG
           GO TO 004000-EXIT.

        COMPUTE LW-INT-PMT = LW-INT-RATE / 1200
           ON SIZE ERROR
              MOVE 1 TO LW-LOAN-ERROR-FLAG
              GO TO 004000-EXIT.
```

Historical Perspective (1970’s)

- Transition from handling transactions in daily batches to systems that managed an on-line database that could capture transactions as they happened.
- At first these systems were ad hoc
- Late in the 60’s, "network" and "hierarchical" database products emerged.
- A network data model standard (DBTG) was defined, which formed the basis for most commercial systems during the 1970’s.
- In 1980 DBTG-based Cullinet was the leading software company.

Network Model

- hierarchical model: a tree of records, with each record having one parent record and many children



A closed chain of records in a navigational database model (e.g. CODASYL), with ***next pointers***, ***prior pointers*** and ***direct pointers*** provided by keys in the various records.

- network model: each record can have multiple parent and child records, i.e. a lattice of records

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Historical Perspective

DBTG problems:

- DBTG used a procedural language that was
  - low-level
  - record-at-a-time
- The programmer had to navigate through the database, following pointers from record to record
- If the database was redesigned, then all the old programs had to be rewritten

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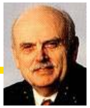
The "relational" data model



The "relational" data model, by Ted Codd in his landmark 1970 article *"A Relational Model of Data for Large Shared Data Banks"*, was a major advance over DBTG.

- The relational model unified data and metadata so that there was only one form of data representation.
- A non-procedural data access language based on algebra or logic.
- It was easier for end-users to visualize and understand than the pointers-and-records-based DBTG model.
- Programs could be written in terms of the "abstract model" of the data, rather than the actual database design => programs were insensitive to changes in the database design.

The "relational" data model

- Both industry and university research communities embraced the relational data model and extended it during the 1970s.
- It was shown that a high-level relational database query language could give performance comparable to the best record-oriented database systems. (!)
- This research produced a generation of systems and people that formed the basis for IBM's DB2, Ingres, Sybase, Oracle, Informix and others.
- The SQL relational database language was standardized between 1982 and 1986.
- By 1990, virtually all database systems provided an SQL interface (including network, hierarchical and object-oriented database systems, in addition to relational systems).

The database research agenda of the 1980’s

- geographically distributed databases
- parallel data access.
- Theoretical work on distributed databases led to prototypes which in turn led to products.
  - *Note: Today, all the major database systems offer the ability to distribute and replicate data among nodes of a computer network.*
- Execution of each of the relational data operators in parallel => hundred-fold and thousand-fold speedups.
  - *Note: The results of this research appear nowadays in the products of several major database companies.* Especially beneficial for data warehousing, and decision support systems; effective application in the area of OLTP is challenging.

USA funded database research period 1970 - 1996:

- Projects at UCLA gave rise to Teradata
- Projects at CCA (SDD-1, Daplex, Multibase, and HiPAC) pioneered:
  - distributed database technology
  - object-oriented database technology
- Projects at Stanford created:
  - deductive database technology
  - data integration technology
  - query optimization technology.
- Work at CMU gave rise to
  - general transaction models and
  - ultimately to the Transarc Corporation.
- Other projects at: AT&T, the University of Texas at Austin, Brown, Harvard, Maryland, Michigan, MIT, Princeton, and Toronto, etc.

Ingres at UC Berkeley in 1972

Inspired by Codd's work on the relational database model, (Stonebraker, Rowe, Wong, and others) a project that resulted in:

- the design and build of a relational database system
- the query language (QUEL)
- relational optimization techniques
- a language binding technique
- storage strategies
- pioneering work on distributed databases

The academic system evolved into Ingres from Computer Associates.
Nowadays: PostgreSQL; also the basis for a new object-relational system.

Further work on:

- distributed databases
- database inference
- active databases (automatic responsing)
- extensible databases.

System R

- Codd's ideas were inspired by the problems with the DBTG network data model and with IBM's product based on this model (IMS).
- Codd's relational model was very controversial:
  - too simplistic
  - could never give good performance.

- IBM Research chartered a 10-person effort to prototype a relational system => a prototype, System R (evolved into the DB2 product)

- Defined the fundamentals on:
  - query optimization,
  - data independence (views),
  - transactions (logging and locking), and
  - security (the grant-revoke model).
- SQL from System R became more or less the standard.

- The System R group further research:
  - distributed databases (project R*) and
  - object-oriented extensible databases (project Starburst).

The Future of 1997 (Gray)

- Database systems continue to be a key aspect of Computer Science & Engineering.
- Representing knowledge within a computer is one of the central challenges of the field. Database research has focused primarily on this fundamental issue.

(1/3)

The Future of 1997 (Gray)

- There continues to be active and valuable research on:
  - representing and indexing data,
  - adding inference to data search: inductive reasoning
  - compiling queries more efficiently,
  - executing queries in parallel,
  - integrating data from heterogeneous data sources,
  - analyzing performance, and
  - extending the transaction model to handle long transactions and workflow (transactions that involve human as well as computer steps).
  - The availability of very-large-scale (tertiary) storage devices has prompted the study of models for queries on very slow devices.

(2/3)

The Future of 1997 (Gray)

- Unifying object-oriented concepts with the relational model.

- New datatypes (image, document, drawing) are best viewed as the methods that implement them rather than the bytes that represent them.

- By adding procedures to the database system, one gets active databases, data inference, and data encapsulation. The object-oriented approach is an area of active research.

(3/3)

The Future of 1996

Database Research: Achievements and Opportunities Into the 21st Century.

Silberschatz, M. Stonebraker, J. Ullman Eds.

SIGMOD Record, Vol. 25, No. 1
pp. 52-63
March 1996

Conclusions of the Forum (1996)

- The database research community plays a foundational role in creating the technological infrastructure from which database advancements evolve.
- Next-generation database applications enabled by the explosion of digitized information over the last five years will require the solution to significant new research problems:
  - support for multimedia objects
  - distribution of information
  - new database applications
  - workflow and transaction management
  - ease of database management and use

Conclusions of the Forum (cont'd)

- A new research mandate for the database community is provided by the technology developments of the recent past (of 1996)-- the explosions in hardware capability, hardware capacity, and communication (including the internet or "web‟ and mobile communication).

New Research Achievements (1996)

- Object-Oriented and Object-Relational Database Systems
  - Commercial systems available (in contrast to 1990)
  - new breeds (deductive object oriented databases, …)

- Support for new Data Types
  - GIS
  - Temporal Data (TSQL2)
  - Multimedia

- Transaction Processing

Transaction Processing (1996)

- Requirements and definitions during 1970’s and early 1980’s
- Alternative’s to atomic transactions already studied from 1970 onward.
- Some commercial products support replicated data, allowing consistent views of the same information to exist at various nodes of a network.
- Some object-oriented systems now support "long transactions," where data is "checked out" and not restored for hours or days.
- Some commercial database systems also support "versions and configurations," the ability to construct a history of related objects ("versions" of that object) and to combine specific versions of different objects into "configurations.‟

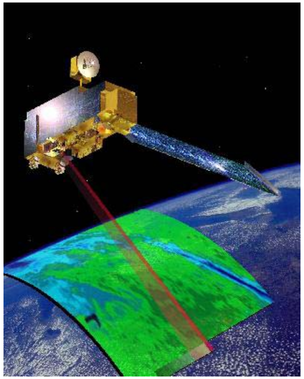
New Database Applications (1996)

- EOSDIS (Earth Observing System Data and Information System)
- Electronic Commerce
- Health-Care Information Systems
- Digital Publishing
- Collaborative Design

EOSDIS (Earth Observing System Data and Information System)

Challenges:

- Providing on-line access to petabyte-sized databases and managing tertiary storage effectively.
- Supporting thousands of information consumers with very heavy volume of information requests, including ad-hoc requests and standing orders for daily updates.
- Providing effective mechanisms for browsing and searching for the desired data,



Electronic Commerce

Heterogeneous information sources must be integrated. For example, something called a "connector‟ in one catalog may not be a "connector‟ in a different catalog

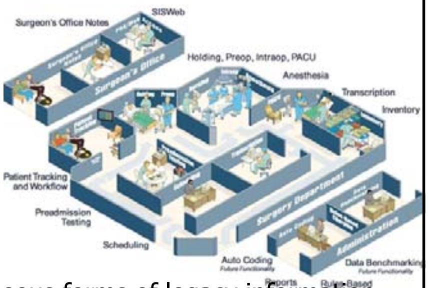
- "schema integration‟ is a well-known and extremely difficult problem.

Electronic commerce needs:

- Reliable
- Distributed
- Authentication
- Funds transfer.

Health-Care Information Systems

Transforming the health-care industry to take advantage of what is now possible will have a major impact on costs, and possibly on quality and ubiquity of care as well.



Problems to be solved:

- Integration of heterogeneous forms of legacy information.
- Access control to preserve the confidentiality of medical records.
- Interfaces to information that are appropriate for use by all health-care professionals.

Digital Publishing

- Management and delivery of extremely large bodies of data at very high rates. Typical data consists of very large objects in the megabyte to gigabyte range (1996)
- Delivery with real-time constraints.
- Protection of intellectual property, including cost-effective collection of small payments and inhibitions against reselling of information.
- Organization of and access to overwhelming amounts of information.

The Information Superhighway

Databases and database technology will play a critical role in this information explosion. Already Webmasters (administrators of World-Wide- Web sites) are realizing that they are database administrators…

New Research Directions (1996)

- Problems associated with putting multimedia objects into DBMSs.
- Problems involving new paradigms for distribution of information.
- New uses of databases
  - Data Mining
  - Data Warehouses
  - Repositories
- New transaction models
  - Workflow Management
  - Alternative Transaction Models
- Problems involving ease of use and management of databases.

Distribution of Information (1996)

- Degree of Autonomy
- Accounting and Billing
- Security and Privacy
- Replication and Reconciliation
- Data Integration and Conversion
- Information Retrieval and Discovery
- Data Quality

Support for Multimedia Objects (1996)

- Tertiary Storage (for petabyte storage)
  - Tape silos
  - Disk juke-boxes
- New Data Types
  - The operations available for each type of multimedia data, and the resulting implementation tradeoffs.
  - The integration of data involving several of these new types.
- Quality of Service
  - timely and realistic presentation of the data?
  - gracefully degradation service? Can we interpolate or extrapolate some of the data? Can we reject new service requests or cancel old ones?
- Multi-resolution Queries
  - Content Based Retrieval
- User Interface Support

Ease of Use (1996)

- Intelligent tools for system managers
- Electronic Wizards
- Intelligent support for performance enhancement
- Electronic physical database design tool for index selection and database schema design

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“One Size Fits All”:
An Idea Whose Time Has Come and Gone.

M. Stonebraker, U. Cetintemel

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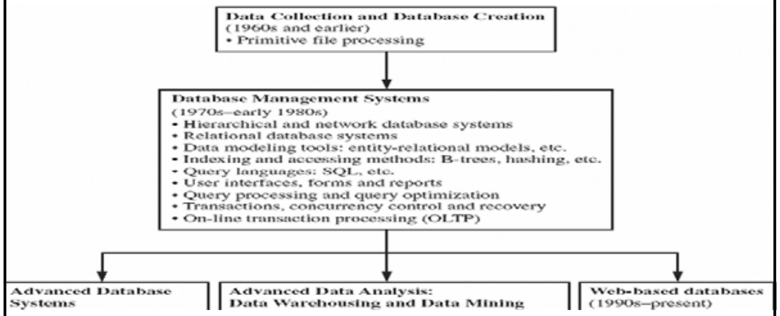
DBDMS Services Overview



Data Collection and Database Creation
(1960s and earlier)
- Primitive file processing

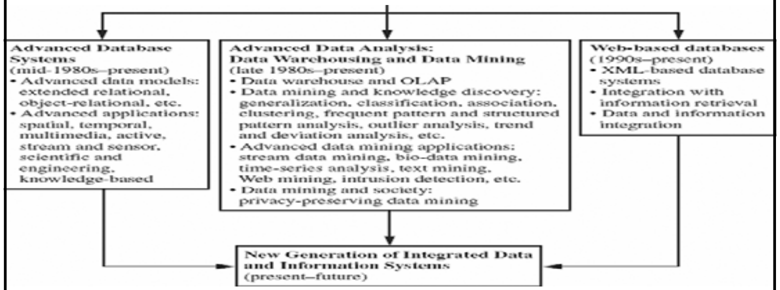
Database Management Systems
(1970s–early 1980s)
- Hierarchical and network database systems
- Relational database systems
- Data modeling tools: entity-relational models, etc.
- Indexing and accessing methods: B-trees, hashing, etc.
- Query languages: SQL, etc.
- User interfaces, forms and reports
- Query processing and query optimization
- Transactions, concurrency control and recovery
- On-line transaction processing (OLTP)

Advanced Database Systems

Advanced Data Analysis: Data Warehousing and Data Mining

Web-based databases
(1990s–present)

DBDMS Services Overview



Advanced Database Systems
(mid-1980s–present)
- Advanced data models: extended relational, object-relational, etc.
- Advanced applications: spatial, temporal, multimedia, active, stream and sensor, scientific and engineering, knowledge-based

Advanced Data Analysis: Data Warehousing and Data Mining
(late 1980s–present)
- Data warehouse and OLAP
- Data mining and knowledge discovery: generalization, classification, association, clustering, frequent pattern and structured pattern analysis, outlier analysis, trend and deviation analysis, etc.
- Advanced data mining applications: stream data mining, bio-data mining, time-series analysis, text mining, Web mining, intrusion detection, etc.
- Data mining and society: privacy-preserving data mining

Web-based databases
(1990s–present)
- XML-based database systems
- Integration with information retrieval
- Data and information integration

New Generation of Integrated Data and Information Systems
(present–future)

DBMS: "One size fits all."

Single code line with all DBMS Services solves:

- Cost problem: maintenance costs of a single code line
- Compatibility problem: all applications will run against the single code line
- Sales problem: easier to sell a single code line solution to a customer
- Marketing problem: single code line has an easier market positioning than multiple code line products

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DBMS: "One size fits all."

- To avoid these problems, all the major DBMS vendors have followed the adage "put all wood behind one arrowhead".

In this paper it is argued that this strategy has failed already, and will fail more dramatically off into the future.

Data Warehousing

- In the early 1990's, a new trend appeared: Enterprises wanted to gather together data from multiple operational databases into a data warehouse for business intelligence purposes.
- A typical large enterprise has 50 or so operational systems, each with an on-line user community who expect fast response time.
- System administrators were (and still are) reluctant to allow business-intelligence users onto the same systems, fearing that the complex ad-hoc queries from these users will degrade response time for the on-line community.
- In addition, business-intelligence users often want to see historical trends, as well as correlate data from multiple operational databases. These features are very different from those required by on-line users.

Data Warehousing

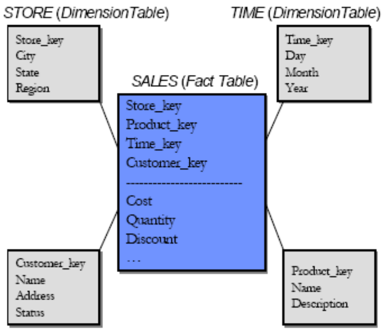
Data warehouses are very different from Online Transaction Processing (OLTP) systems:

- OLTP systems have been optimized for updates, as the main business activity is typically to sell a good or service.
- In contrast, the main activity in data warehouses is ad-hoc queries, which are often quite complex.
- Hence, periodic load of new data interspersed with ad-hoc query activity is what a typical warehouse experiences.

Data Warehousing

The standard wisdom in data warehouse schemas is to create a fact table:

"who, what, when, where" about each operational transaction.



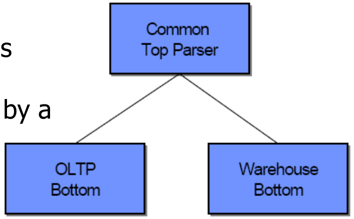
Data Warehousing

- Data warehouse applications run much better using bit-map indexes
- OLTP (Online Transaction Processing) applications prefer B-tree indexes.
- materialized views are a useful optimization tactic in data warehousing, but not in OLTP worlds.
- normal ("virtual") views find acceptance in OLTP environments.

Data Warehousing

As a first approximation, most vendors have a
- warehouse DBMS (bit-map indexes, materialized views, star schemas and optimizer tactics for star schema queries) and
- OLTP DBMS (B-tree indexes and a standard cost-based optimizer), which are united by a common parser

Index	Gender	F	M
1	Female	1	0
2	Female	1	0
3	Unspecified	0	0
4	Male	0	1
5	Male	0	1
6	Female	1	0

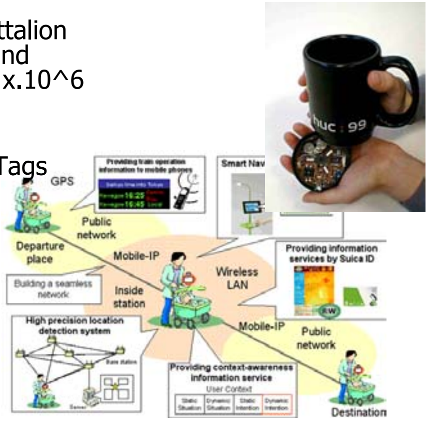

Common Top Parser

OLTP Bottom

Warehouse Bottom

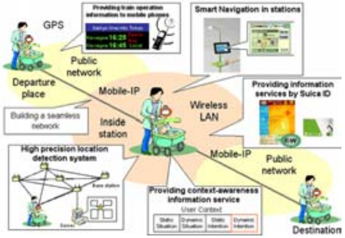
Emerging Sensor Based Applications

- Sensoring Army Battalion of 30000 humans and 12000 vehicles => x.10^6 sensors
- Monitoring Traffic
- Amusements Park Tags
- Health Care
- Library books
- Etc.



Emerging Sensor Based Applications

- There is widespread speculation that conventional DBMSs will not perform well on this new class of monitoring applications.
- For example: *Linear Road*, traditional solutions are nearly an order of magnitude slower than a special purpose stream processing engine



Example: An existing application: financial-feed processing

- Most large financial institutions subscribe to feeds that deliver real-time data on market activity, specifically news, consummated trades, bids and asks, etc. for example: Reuters, Bloomberg and Infodyne
- Financial institutions have a variety of applications that process such feeds. These include systems that
  - produce real-time business analytics,
  - perform electronic trading,
  - ensure legal compliance of all trades to the various company and SEC rules
  - compute real-time risk and market
  - exposure to fluctuations in foreign exchange rates.
- The technology used to implement this class of applications is invariably “roll your own”, because application experts have not had good luck with off-the-shelf system software products.

Example: An existing application: financial-feed processing

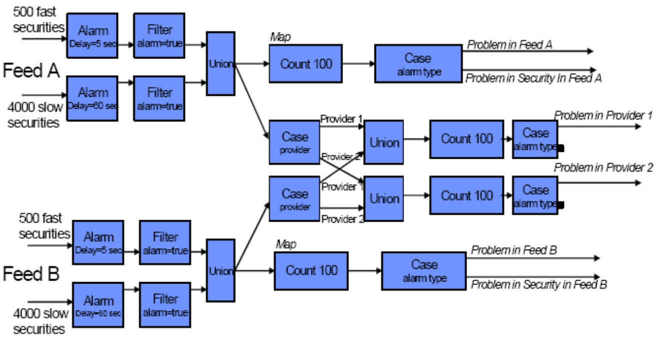
Example Streaming stock ticks:

- Specifically, there are 4500 securities, 500 of which are "fast moving".

Defined by rules:

- A stock tick on one of these securities is late if it occurs more than five seconds after the previous tick from the same security.
- The other 4000 symbols are slow moving, and a tick is late if 60 seconds have elapsed since the previous tick.

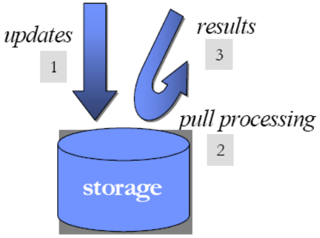
Stream Processing



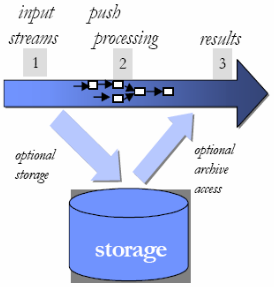
Performance

- The example application was implemented in the StreamBase stream processing engine (SPE) [5], which is basically a commercial, industrial-strength version of Aurora [8, 13].
- On a 2.8Ghz Pentium processor with 512 Mbytes of memory and a single SCSI disk, the workflow in the previous figure can be executed at 160,000 messages per second, before CPU saturation is observed.
- In contrast, StreamBase engineers could only coax 900 messages per second from an implementation of the same application using a popular commercial relational DBMS.

Why?: Outbound vs Inbound Processing

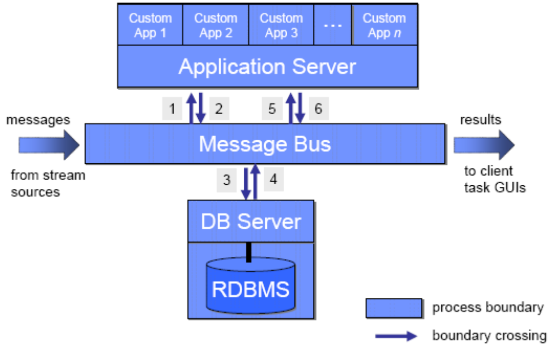


RDBMS
(Outbound Processing)



StreamBase
(Inbound Processing)

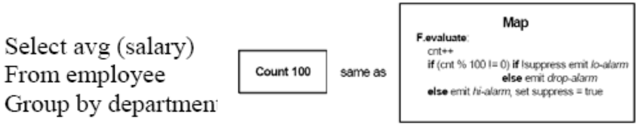
Inbound vs Outbound Processing



Outbound vs Inbound Processing

- DBMSs are optimized for outbound processing
- Stream processing engines are optimized for inbound processing.
- Although it seems conceivable to construct an engine that is either an inbound or an outbound engine, such a design is clearly a research project.

Other Issues: Correct Primitives


```
Select avg (salary)
From employee
Group by departmen
```

```
F.evaluate:
    cnt++
    if (cnt % 100 != 0) if !suppress emit lo-alarm
                        else emit drop-alarm
    else emit hi-alarm, set suppress = true
```

- SQL systems contain a sophisticated aggregation system, whereby a user can run a statistical computation over groupings of the records from a table in a database.
- When the execution engine processes the last record in the table, it can emit the aggregate calculation for each group of records.
- However, streams can continue forever and there is no notion of "end of table".
- Consequently, stream processing engines extend SQL with the notion of time windows.
- In StreamBase, windows can be defined based on clock time, number of messages, or breakpoints in some other attribute.

Other Issues: Integration of DBMS Processing and Application Logic

- Relational DBMSs were all designed to have client-server architectures.
- In this model, there are many client applications, which can be written by arbitrary people, and which are therefore typically untrusted.
- Hence, for security and reliability reasons, these client applications are run in a separate address space from the DBMS.

Other Issues: Integration of DBMS Processing and Application Logic

- In an embedded processing model, it is reasonable to freely mix
  - application logic
  - control logic and
  - DBMS logic

This is what StreamBase does.

Other Issues: High Availability

- It is a requirement of many stream-based applications to have high availability (HA) and stay up 7x24.
- Standard DBMS logging and crash recovery mechanisms are ill-suited for the streaming world
- The obvious alternative to achieve high availability is to use techniques that rely on Tandem-style process pairs
- Unlike traditional data-processing applications that require precise recovery for correctness, many stream-processing applications can tolerate and benefit from weaker notions of recovery.

Other Issues: Synchronization

- Traditional DBMSs use ACID transactions to provide isolation (among others things) between concurrent transactions submitted by multiple users. (heavy weight)
- In streaming systems, which are not multi-user, such isolation can be effectively achieved through simple critical sections, which can be implemented through light-weight semaphores.

ACID = Atomicity, Consistency, Isolation (transactions can be executed in isolation), Durability

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One Size Fits All?

One Size Fits All?

- Data warehouses: store data by column rather than by row; read oriented
- Sensor networks: flexible light-way database abstractions, as TinyDB; data movement vs data storage
- Text Search: standard RDBMS too heavy weight and inflexible
- Scientific Databases: multi dimensional indexing, application specific aggregation techniques
- XML: how to store and manipulate XML data