Stream Processing Environmental Applications in Jordan Valley

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Abstract

Database system architectures have been gone through innovative changes, specially the unifications of algorithms and data via the integration of programming languages with the database system. Such an innovative changes is needed in Stream-based applications since they have different requirements for the principal of stream data processing system. For example, the monitoring component requires query processing system to detect user-defined events in a timely manner as in real time monitoring system. Furthermore, stream processing fits a large class of new applications for which conventional DBMSs fall short since many stream-oriented systems are inherently geographically distributed and the distribution offers a scalable load management and higher availability.

This paper presents statistical information about metrological data such as the weather, soil and evapotranspiration as collected by the weather stations distributed in different locations in Jordan Valley. In addition, it shows the importance of Stream Processing in some real life applications, and shows how the database systems can help researcher in building prototypes that can be implemented and used in a continuous monitoring system.

Keywords: Stream Processing, Environment Metrological Data, Sensors.

1. INTRODUCTION

Data is increasingly generated by instruments that monitor the different types of sensors, which can be used to run a machine or represent the core of other machines as in environment monitoring, medical applications and others. Not only that, but web features have become as necessity for many applications in order to support remote access facilities. This has huge implications for how applications would be structured. Also, DBMSs are now considered as object containers, where Queues are the first objects to be added, since they are the basis for transaction processing and workflow applications. Therefore, database systems should consider that new techniques in XML and xQuery will be the main data structure and access pattern as most of programming experts believe [1].

Monitoring applications enable users to continuously observe the current state of a system, and receive alerts when interesting combinations of events occur. Monitoring applications exist in various domains, such as sensor-based environment monitoring (e.g., air quality monitoring, car-traffic monitoring), military applications (e.g., target detection, platoon tracking), network monitoring (e.g., intrusion detection), and computer-system monitoring [2]. Although for a comparison purpose of historical data, stream processing operators are being added to the DBMS; as a result of the size of the database become larger and larger and the increased amount of external data arrival as streams. Since the incoming data is compared against millions of queries rather than queries searching millions of records, the need for huge main memories and sequential disk access have become a necessity. Therefore, Database systems are now expected to be self-managing, self-healing, and always running.

Stream Processing Engines (SPEs) known as Stream-Base [3], stream databases [4] or data stream managers [5], [6] have emerged as new classes of software systems that enable low latency processing of streams of data arriving at high rate. SPEs continuous query processors [7], complex event processing engines, or event stream processors [8] are also software systems that handle data processing requirements of monitoring applications. In these systems, an application-logic takes the form of a dataflow composed of a relatively small set of operators (e.g., filters, aggregates, and correlations). In addition, a new class of data intensive applications may be defined, in which these applications require a continuous and low latency processing of large volumes of information that "stream in" from data sources at high rates. Also, stream processing applications have emerged in several different domains motivated by different needs [9]. Moreover, stream processing run a continuous query processing, in which the Naïve approach uses every new arrival of data item to evaluate all registered continuous queries. If the data satisfies all predicates of the continuous queries, then the result of these queries will be sent to the interested users [10].

Figure 1 illustrates an example of distributed SPEs that performs a computation spread across four nodes. When a stream goes from one node to another, the nodes are called upstream and downstream neighbors respectively [11]. The upstream nodes receive the raw data from sources for a preprocessing stage. Whereas, the downstream nodes process the user queries based on the output the upstream nodes. In Figure 1, Node1 and Node2 are upstream neighbors for the downstream nodes Node3 and Node4. [11]

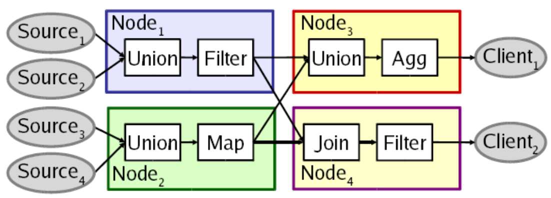

FIGURE 1: An example of distributed SPEs Query diagram.

2. DESIGN CONSIDERATIONS

In every design of SPEs there are some issues that should be considered such as: communication, computation, dynamic adaptation and flexibility. A brief discussion of each of these considerations is presented next.

Communication: This issue is very related to the sensors themselves; since the sensors varies in operation modes, some of them are wireless and battery operated, others are connected directly to the Internet or remotely connected. The operation modes constraints have an affect on the communication resource usage. A key design goal for Task-Cruncher is thus to minimize the redundancy in communication. If data requests from multiple applications have similar temporal characteristics, the sensors should send the minimum amount of data that satisfies all application requests [12].

Computation: This task should be performed at the main servers that are responsible for gathering data from several sensors to do some indexing and calculations in order to make it available for applications and their queries. The large number of sensors and applications to be served imply that the server resource usage per sensor and per task on online data streams cannot be very high. As the number of tasks increases, it is no longer efficient to perform the aggregation required by multiple applications in isolation. For instance, two wireless cameras might be imaging a scene and many applications' requests this panoramic image that would be generated by stitching the images from these two cameras. Clearly, if the server can detect that more than one application has requested the result of the same computation, then the panoramic image generated from this computation would be stitched only once per frame. Then, the stitched generated image is sent to all the requesting applications.

Dynamic Adaptation: This issue arises when different applications and queries are running using the shared sensors.

Flexibility: This issue arises when different types of computations are occurring at the same time (overlapping). For instance, many primitive operations in sensing tasks can occur concurrently in which both distributive and algebraic operations (such as Sum, Max, Average, etc.) are used. In this case, the final result would be computed from partial results over disjoint partitions of input values.

3. ENVIRONMENT MONITORING

Prototypes for monitoring the health of natural environments [13, 14] have been proposed and developed. Previous work [15] in environmental monitoring has generated efficient protocols and improved the communication between different locations. By combining data from different weather stations (sensor networks) [16, 17] as in Figure 2, and from location-sensing devices [18, 19] can be used to determine the location of each station. Sensor data could come from wireless sources, then stored in a temporary storage device in order to be collected manually or automatically by the network administrator. More complex processing of wide-spread streams could occur at wired, stable nodes (land line telephone and modem), or wireless via GSM line and modem. After the data is collected, a Data Collection Network (DCN) should be constructed as a robust infrastructure for discovery, querying, and delivery of weather station data. In addition, a DCN should be assembled to scale up to a large number of concurrent applications for pulling data from a vast number of weather stations. This process is carried out using an Internet-based overlay network in which the nodes act as both routers and stream processing engines, as in LoggerNet software [16]. LoggerNet is configured to save the data at a certain directory on a PC or on a server. This process can also be called "store-then-process" as in traditional DBMSs (such as Oracle, IBM DB2, and Microsoft SQL Server). This process is designed to support such traditional types of applications; since it is inadequate for high-rate and low-latency stream processing. Furthermore, there is a need to develop some mechanisms to allow streaming applications to interact with databases without introducing significant computational overhead that could affect the performance of the processing of streaming data [20].

FIGURE2: Sample of weather stations in Jordan

Data sources as illustrated in Figure 3 are continuously producing streams of information. These streams are then continuously processed and the results are pushed to client applications [21]. In order to understand any type of application, the properties of that application should be easy to understand. In order to achieve such properties of any application, the following features of a stream processing should be satisfied [22]:

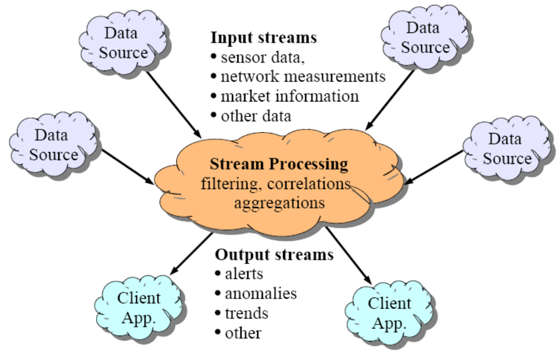

FIGURE 3: High-level view of stream

1. *A continuous-query processing model*: In a traditional DBMS, clients issue one-time queries against stored data (e.g., "Did any source attempt more than 100 connections within a one minute period?"). In a stream processing application, clients submit long duration monitoring queries that must be processed continuously as new input data arrives (e.g., "Alert me if a source attempts more than 100 connections within a one minute period"). Clients submitting continuous queries expect periodic results or alerts when specific combinations of inputs occur.
2. *A push-based processing model*: In a stream processing application, one or more data sources (e.g., sensor networks, ticker feeds, network monitors) continuously produce information and push the data to the system for processing. Client applications passively wait for the system to push them periodic results or alerts. This processing model contrasts with the traditional model, where the DBMS processes locally stored data, and clients actively pull information about the data when they need it.
3. *Low latency processing*: Many stream processing applications monitor ongoing phenomena and require low latency processing of input data. For instance, in a network monitoring, current information about ongoing intrusions is more valuable than stale information about earlier attacks. SPEs strive to provide low-latency processing but do not make any hard guarantees.
4. *High and variable input data rates*: In many stream processing applications, data sources produce large volumes of data. Input data rates may also vary greatly. For instance, a denial of service (DoS) attack may cause large numbers of connections to be initiated. If network monitors produce one data item per connection, the data rates on the streams they produce will increase during the attack. As the data rates vary, the load on an SPE also varies because query operators process data arriving at a higher rate.

In addition, a typical streaming environment has a large number of concurrent overlapping continuous queries. Sharing the query execution is a primary task for query optimizers to address scalability. The current efforts for shared query execution focus on sharing execution at the operator level [21]. Examples of such efforts are covered in the "Monitoring Continuous Queries over Streaming Locations" [23], and in the "Challenges in Dependable Internet-Scale Stream Processing" [24].

4. RELATED WORK

There are some current projects that focus on stream data processing such as the NIAGARA system [25] that proposes architecture for Continuous Queries (CQs) with group optimization techniques. The Fjord [26] project has an architecture which supports both a continuous data stream and a traditional static data set by connecting the push-based operators with the pull-based operators via queues. The STREAM [27] project is trying to build a general data processing architecture that can support the functionalities of both database management system (DBMS) and data stream management system (DSMS). Finally, the Aurora system [28] presents an architecture to process data streams with some Quality of Service (QoS) requirements by decoupling a CQ into a few predefined operators.

5. CURRENT SP APPLICATION IN JORDAN

This section presents the experience of the data stream processing application called the Irrigation Management Information System (IMIS) conducted by the National Center for Agricultural Research and Extension (NCARE) in Jordan [29].

This application is a package that can provide irrigation personnel (farmers) with real time estimates of irrigation requirements and scheduling. In addition, this application helps to initiate and sustain a technology transfer program concerning the issues of when and how much water is needed to irrigate in order to maximize the usage of water efficiently.

In general, the purpose of environmental projects is to evaluate the spatial variability of water consumption of irrigated agriculture under limited water resources conditions.

The objectives of the IMIS project are to: [30]

1- Establish an IMIS based on real time meteorological data, soil characteristics, water quality, crop type, and current irrigation system efficiently.
2- Develop an infrastructure and information management tools for rapid and accurate dissemination of irrigation scheduling information.
3- Adopt state-of-the-art models for predicting crop irrigation requirements.
4- Establish an irrigation scheduling criteria for major crops in the Jordan valley.
5- Establish a data network that can easily be used by other relevant national institutions through improved classification of data entry, retrieval and communications.

5.1. Weather Station Components

Each station of the IMIS project consists of following components as shown in Figure 4:

- Three-meter-long tower.
- Data logger for multiple sensor inputs: This is a data acquisition card that can read analog signals and convert them into digital signals in order to read them by computer (+12, -12, +5 and -5 Volts).
- Cellular phone modem/land line.
- Battery with solar panels.
- Meteorological sensors:
  - Wind speed and direction.
  - Solar radiation.
  - Barometric pressure.
  - Temperature.
  - Relative humidity.
  - Precipitation.
- Soil sensors:
  - Moisture Content.
  - Temperature.

The sensors are designed for long-term installation under adverse environmental conditions. These sensors can be categorized in terms of their functionality as illustrated next:

Air Temperature Sensors: these sensors can be thermostats, thermocouples, or RTDs (as standard sensor models).

Air Temperature and Relative Humidity sensors: These are two separate sensors packaged in the same sensor housing.

Barometric pressure sensors: These sensors measure the fluctuations in the pressure exerted by the atmosphere. Such sensors require protection from condensing humidity, precipitation, and water ingress and they are typically housed within the datalogger (inside an environmental enclosure).

Evaporation Gauges: These sensors are used to determine the evaporation rate by measuring the changing water level in an evaporation pan.

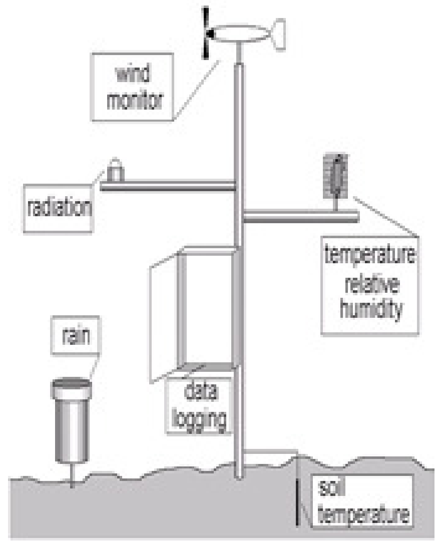

FIGURE 4: A Typical Automated Metrological Station

Leaf wetness sensors: These sensors are used to accomplish the following duties:

- Measuring the electrical resistance of a water film on the leaf surface.
- Detecting a change in a sensor length and weight.
- Appling to mock leaves and to emulate periods of leaf wetness after rainfall, dew, or spray.

Soil Temperature Sensors: These sensors can be either Thermostats, thermocouples, thermocouple wire, or averaging thermocouples.

Solar Radiation Sensors: These sensors can be pyranometers, net radiometers or quantum sensors. Such sensors are designed to measure the various aspects of the energy imparted by the sun on the Earth's surface.

Wind Speed and Wind Direction: The output of these sensors (the wind vanes and the anemometers) can be used in research project, air quality monitoring, and general purpose meteorological applications.

Data loggers and Data Acquisition Systems: These are simply Multiplexers devices that may be added to augment measurement and control capabilities that include:

- Measuring most sensors.
- Providing non-volatile data storage and on-board battery-backed clock.
- On-board data processing.
- Initiating measurement and control functions based on time or event.
- Controlling external devices such as pumps, motors, alarms, freezers, valves, etc.
- Using PC support software or keyboard/display to program.
- Operating independently of AC power, computers, and human interaction.
- Consuming minimal power from a 12 V-DC power source.
- Interfacing with on-site and telecommunication devices such as telephone modems (including cellular and voice-synthesized), short haul modems, radio transceivers, satellite transmitters, and Ethernet interfaces.
- Operating in temperature range of -25° to 50ºC.

5.2. Weather Station Benefits

The IMIS project has the following benefits as results of using automated weather stations [28]:

1. Preconfigured and custom automated weather stations.
2. Stations that can measure most commercially available meteorological sensors.

3. Communications options that do include phone, cell phone, voice-synthesized phone, satellite (DCP), and radio.
4. Stations that can operate reliably in harsh environments.
5. Data loggers that can provide an on-site statistical and mathematical capabilities.
6. Batteries and solar panels that allows long-term and remote operations.
7. Stations are easily expandable in such away that add new sites or add sensors to existing sites.
8. Powerful software that can support programming, data retrieval, and data display.

Furthermore, data are typically viewed and stored in the units of your choice (e.g., wind speed in mph, m/s, and knots). Measurement rates and data recording intervals are independently programmable, allowing calculation of 15-minute, hourly, and/or daily data values, for example, using 1-minute or 1-second measurements. Conditional outputs, such as rainfall intensity and wind gusts, can also be recorded. The program can be modified at any time to accommodate different sensor configurations or new data processing requirements. If needed, channel capacity can be expanded using multiplexers, including a model designed specifically for thermocouples [28].

5.3. System Architecture

The IMIS system architecture as shown in Figure 5 consists of the following modules:

- Weather Stations.
- Data collocation Software.
- DataBase Server.
- Firewall.
- Java application and ASP.net.

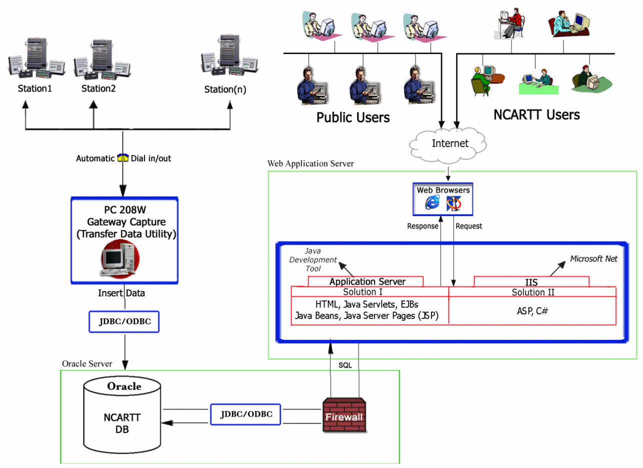

FIGURE 5: System Architecture Modules.

In this architecture, the data will be collected by the sensors (located in the weather stations) in a predefined schedule or when needed (in the data logger). A software called Loggernet, or PC2000 [16] is used to gather the data and merge it in one file (as a text file). Then, this merged data will be imported by a tool into an Oracle database serve to be used by the application server for process manipulation. Users (farmers/ researchers/ others) can access the application website to do certain types of searches (depending on their needs).

The Application server has several functions related to both the normal users and the system administrators as shown in Figure 6. Some of these functions are listed below:

- Manage the user accounts (normal users or system administrator) login process.
- Manage the time and the way of importing data from the stations.
- Manage stations (Add/Delete/Modify).
- Manage countries (Add/Delete/Modify), since many countries may participates in this project (future works).

- Manage parameters (add/delete) new sensors.

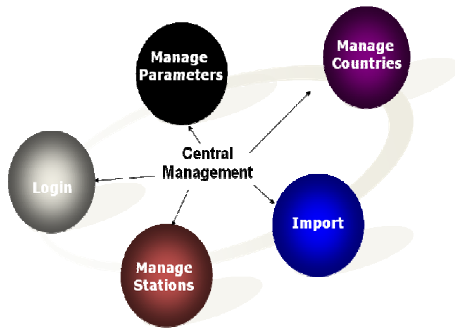

FIGURE 6: Application server functions

Users of the IMIS system would be able to do any of the following functions:

- Display General Information.
- Search and Generate Statistics and reports from the weather stations readings (daily, monthly, yearly .etc).
- Calculate Irrigation Requirements.
- Calculate Chilling Requirements.
- Display Information about weather stations.

Whereas, the administrator would be able to do any of the above function in addition to the following:

- Admin Users Management.
- Stations Management.
- Crops Management.
- Raw Data Management.
- Web Site Statistics.
- Weather station Management.

5.4. IMIS Generated information

The IMIS system would be able to generate various useful information needed by end users. For example, the Irrigation water requirements are based on real metrological data form automated weather stations that are distributed all over Jordan. Data are being collected on a hourly basis; results are submitted on a daily basis. To calculate the EvaporTanspiration (ET), the Modified Penman-Monthieth equation (eq. 1) is used [30]. For more details on the derivation of this equation refer to Monteith and Unsworth [31] and to Campbell [32].

$$ET_O = \frac{\Delta(R_n - G)}{\lambda(\Delta + \gamma^*)} + \frac{\gamma^* M_W (e_a - e_d)}{R\Theta r_v (\Delta + \gamma^*)} \qquad \text{Eq. 1}$$

Where:

ETo: Potential evaporation (kg m-2 s-1 or mm s-1).
Rn: Net Radiation (kW m-2).
G: Soil heat flux density (k W m-2).
Mw: Molecular mass of water (0.018kg mol-1).
R: Gas constant (8.13 X 10-3 kJ mol-1 K-1).
Θ: Kelvin temperature (293K).
ea-ed: Vapor pressure deficit of the air (kPa).
λ: Latent heat of vaporization of water (2450 kJ kg-1).
rv: Canopy plus boundary layers resistance for vapor (s m-1).
Δ: Slope of the saturation vapor pressure function (Pa oC-1).
γ*: Apparent psychrometer constant (Pa oC-1).

Furthermore, users of the IMIS system can get more benefits from the data generated from the stations in computing other useful information such as (Pipes Pressure and Smooth Flow in Pipes) using the formulas presented in equations eq. 2 through 5 respectively [33, 34, 35].
For example, the Darcy-Weisbach Formula (as illustrated in equation eq.2) is used for the analysis of pressure in pipe systems and it can be applied readily to open channel flow systems:

$$h_f = f\left(\frac{L}{D}\right)\frac{V^2}{2g} \qquad \text{Eq. 2}$$

Directly used Formula:

$$h_f = 1.21x10^{10}\left(\frac{Q}{C}\right)^{1.852}\left(D^{-4.871}\right)L \qquad \text{Eq. 3}$$

The smooth flow in pipes is measured by the Hazen Williams Formula (equations eq. 4 and eq.5) in SI units:

$$V = 0.85C_{HW}R_H^{0.63}S^{0.54} \qquad \text{Eq. 4}$$

Manning Formula:

$$V = \frac{1}{n}R_H^{2/3}S^{1/2} \qquad \text{Eq. 5}$$

Hence, IMIS system can be considered as a source of knowledge for users since the results can be customized depending on their needs. Furthermore, the Short Message Services (SMSs) of Mobile phones have recently been added to the IMIS to enable the farmers/users to send requests via an SMS messages to ask for a certain type of information. As a result the IMIS system helps the researchers, the farmers, the experts and even the students in both the research and a real work fields.

5.5 Development Stages

The IMIS system development is done via several stages. The first stage is the understanding of the type of data generated from the weather stations. In the second stage a site visit is required to understand the communications between the stations and the application server. In the third stage a meeting with system owners should be carried out in order to understand their requirements and to get more information about what types of information is needed. In the fourth stage the application developer will build use cases depending on collected information to be discussed with the customers in order to get their feedback. After the application is being developed the users can start requesting information/data as explained in section 5.4.

6. CONCLUSION AND FUTURE WORK

The restructuring of database systems to be used as web services and to integrate them with language runtimes have guided the researchers to establish what is known as Stream Processing. Stream Processing allows researchers and entrepreneurs to add new algorithms and other subsystems to the DBMS. Databases are evolving from SQL-engines to data integrators and mediators that provide a transactional and non-procedural access to data in various forms.

Fortunately, most innovations in database systems are traced back to the research prototypes that had been implemented after being published in research papers. Stream Processing of a continuous monitoring system is an example of such innovations. In such a system, we get the benefits and challenges of integrating history into this continuous monitoring system. IMIS idea came after long years of research and several experiments done by collaborative efforts of local and international researchers.

There are many beneficiaries from this IMIS project:

- Planners: Water allocation will be done on more robotic bases, and supply demand policy will be formulated.
- Water Sector: Increase water use efficiency in agriculture which will allow releasing water to other pressing needs.
- Agricultural Sector: Increase crop production by increasing the water use efficiently.
- Farmers: Reduction of cost which is translated to a higher return.
- National Economy:
  - Increase national income by increasing the irrigated area as a result of improving irrigation management efficiently.
  - Improve and sustain the agricultural system which will stabilize the social life of farmers in the Jordan Valley.
- Environment:
  - Minimizing hazard pollution through good irrigation management practices, and minimum use of fertilizers.
  - Expansion of irrigated areas through saving water.
  - Improvement of water quality (surface, drainage, and ground water) by implementing fertilization and other appropriate agriculture practices.

As a future work, the system can be used as an early warning system for farmers, especially during the winter when temperature goes down below zero. Also other related sensors can be added into these stations such as sensors to monitor the amount of chemical materials in the air or the soil, and other sensors may be added such as radio logical sensors to measure the radiation around the areas of the stations.

7. ACKNOWLEDGMENT

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