# Resource Management and Scheduling in Distributed Stream Processing Systems

Group 6

Fahim Ferdous (20216010)

Shah Abul Hasnat Chowdhury (17301143)

MD. Esadulhaq (17301148)

# About The Paper

- Authors
  - Xunlyun Liu
  - Rajkumar Buyya
- Resource management for DSPS
  - Structure of DSPS
  - Provides a taxonomy
  - Directions for research
  - Review of the literature

# About DSPS

- Analyse real-time data in real-time
- Uses small or no buffering
- Example use cases
  - Stock market
  - Self driving cars
  - Data from IoT devices

# Main Research Topics

- Resource provisioning
- Operator parallelisation
- Task scheduling

# Structure of DSPS

- Topology
  - Operators to operators
- The Distributed System
  - Multiple operators
  - Multiple tasks in each operators
- Infrastructure
  - Machines execute scheduled tasks
  - Minimize the inter node traffic
  - Cloud, on-premise or hybrid infra

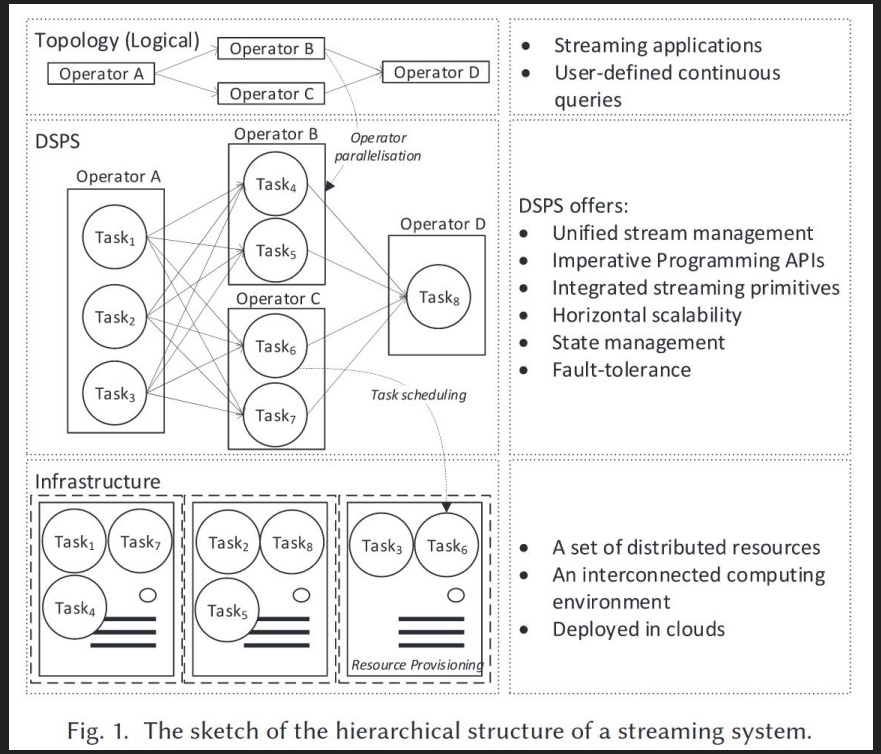



Fig. 1. The sketch of the hierarchical structure of a streaming system.

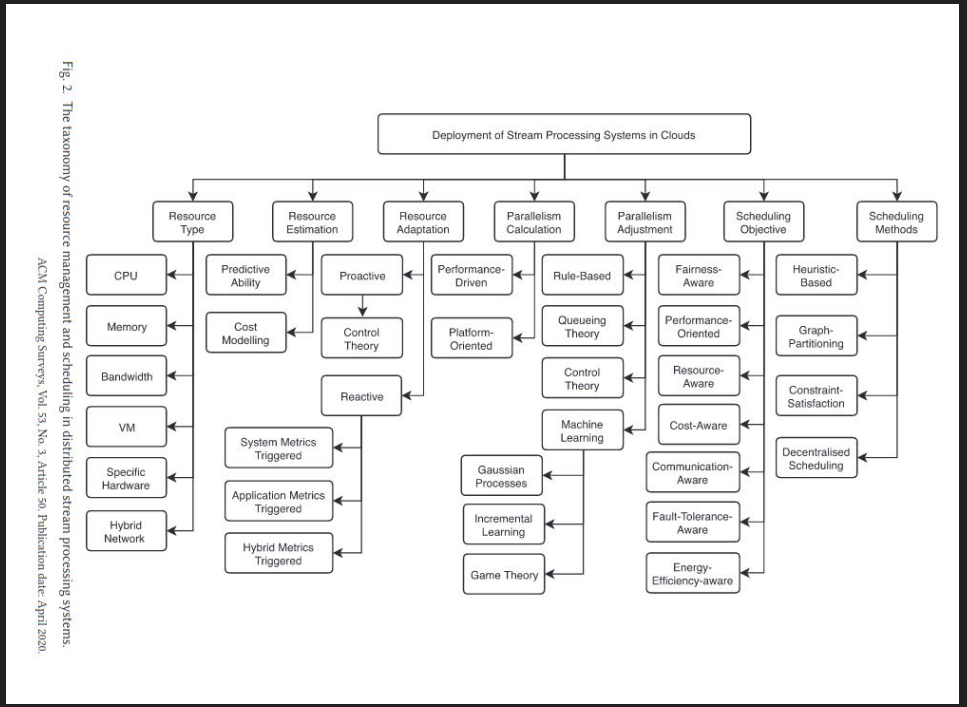
Source: https://dl.acm.org/doi/10.1145/3355399

# Background

- Resource provisioning
  - Resource estimation
  - Resource adaptation
- Operator parallelisation
  - Parallelism calculation
  - Parallelism adjustment
- Task scheduling
  - Minimize inter-node communication
  - Minimize contention
  - Performance oriented mapping

# Taxonomy

- Resource
  - Type
  - Estimation
  - Adaption
- Parallelism
  - Calculation
  - Adjustment
- Scheduling
  - Objective
  - Methods

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# Resource Abstraction

- Includes
  - CPU
  - Memory
  - Network
    - Bandwidth
    - Latency
- Excludes
  - Storage
    - Block
    - File
    - Object

# Resource Types

- Virtual Machines
  - Pricing
  - Specific config
  - Containers as alternatives
- Specific Hardwares
  - FPGA
  - GPU
  - TPU
  - Sensors
- Hybrid Network
  - Cloud AND on-premise
  - Fog and edge
  - In-network computing
  - Mobile devices
  - HPC networking techs

# Service-level agreement (SLA)

A service-level agreement (SLA) defines the level of service expected by a customer from a supplier. Usually, SLAs are between companies and external suppliers, but they may also be between two departments within a company.

# RESOURCE ESTIMATION

Determines the bare minimum of resources to meet SLA

Two characteristics of resource estimation method.

1. Predictive Ability

   **Time series analysis** and **Queueing theory** are the two most common methods for metric prediction from the point of view of methodology.

## 2. Resource Cost Modelling

- **Minimal Cost Model:**

  Bin packing is the most common strategy to model the minimal resource cost based on the compact task placement.

- **Reliability-oriented Model:**

  Storm extension & Rollback-Recovery Scheme

- **Contention-aware Model:**

  Resource cost model that tracks and confines the CPU utilization level

- **Load-balancing-oriented Model:**

  Focuses on the fair utilization of available resources

- **Distribution-based Model:**

  Mixture Density Networks, a statistical machine learning model.

# RESOURCE ADAPTATION

Vertical scaling & SASO features.

Horizontal scaling approaches into two main types.

1 Proactive Adaptation

**To obtain the optimal reconfiguration trajectory over the prediction horizon & Real Time resource management.**

2 Reactive Adaptation

**Reactive scaling strategy that reacts to latency constraint violations with appropriate scaling actions.**

# PARALLELISM CALCULATION

Two widely used strategies. Platform-oriented parallelization is the second strategy whereas performance-driven parallelization is the first.

1 Performance-driven Parallelisation

**The accurate profiling of both operator inputs and the capacity of each streaming task.**

2 Platform-oriented Parallelisation

**Enough streaming tasks for the communication-intensive operators**

# PARALLELISM ADJUSTMENT

Aims to prevent excessive operator parallelism from using up all the resources.

1 Rule-based Approaches

**In order to dynamically alter the degree of parallelism in response to the ongoing variations in workload and system performance, an iterative adjustment process is required.**

2 Queueing Theory

**An adaptive data parallelization middleware was created by Mayer that determines a stationary distribution of the queue length under a specific level of parallelization.**

3 Control Theory

**Different MPC-based algorithms addressed, which explores the target application's ideal configuration under dynamic operational conditions.**

4 Machine Learning and Game Theory

**The optimal parallelism is determined as the system reaches the agreement of Nash equilibrium. Game theory is explored to formulate the elastic parallelism scaling problem as a non-cooperative game.**

# Scheduling Objectives

- Resource allocation
- Oscillating placement of tasks

There are seven main scheduling objective to analyze and compare alternative scheduling objectives within the same scope

| | |
|---|---|
| 1. Fairness aware-Scheduling<br><br>● used as default<br>● popular | 2. Performance-oriented scheduling<br><br>● Latency<br>● SLA-centric practice |
| 3. Resource-aware Scheduling<br><br>● Streaming infrastructure<br>● workload | 4. Cost-aware Scheduling<br>● Cost of hosting<br>● Cost related to data transmission |

5.Communication-aware Scheduling

- Trace
- Inter node communication

6. Fault-tolerant Scheduling

- Failure in a stream processing system

7. Energy-efficient Scheduling

- Reducing overall energy use
- Workload reduction

# Scheduling Methods

Scheduling methods explain the design and implementation of associated schedulers in detail

1. Heuristic-based scheduling
   - Optimization
2. Graph-Partitioning-based scheduling
   - Underestimate the cost of scheduling

3. Constraint-Satisfaction-based Scheduling

- Max-min fairness

4. Decentralized Scheduling

- Intersection of reusable tasks and streams

# Gap Analysis and Future Directions

Many research efforts have investigated the resource management and scheduling in distributed streaming system. In this section we discuss the gaps that have been found in those research paper and suggest potential future direction on this front.

- Fine-grained Profiling
- Straggler Mitigation
- Transparent State Management
- Resource-availability-aware Scheduling

- Energy-efficient Scheduling
- Cost Efficiency with Different Pricing Models
- Container-based Deployment
- Integration of Different DSPSs

# Summary