DS256:Jan17 (3:1)

Tutorial: Apache Storm

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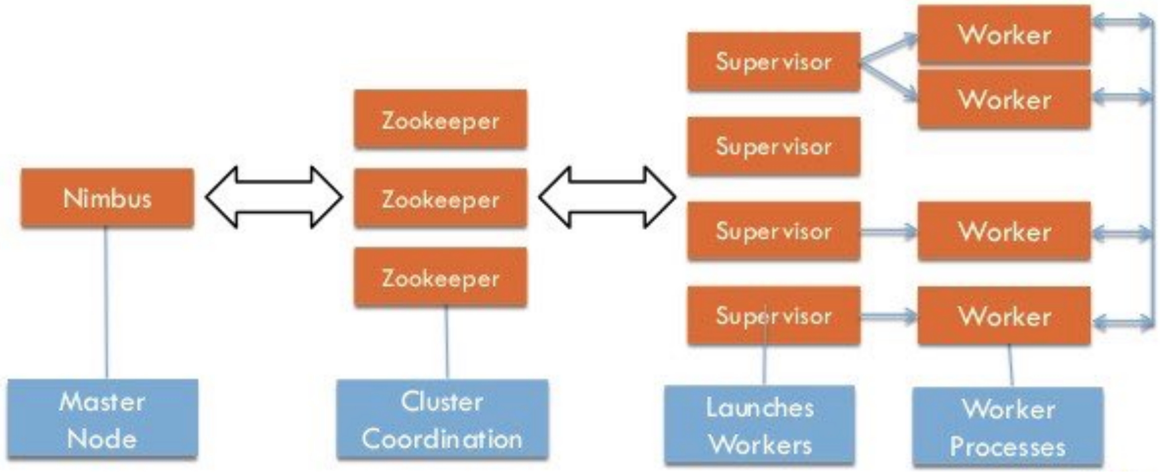
Apache Storm

- Open source distributed realtime computation system
- Can process million tuples processed per second per node.
- Scalable, fault-tolerant, guarantees your data will be processed
- Does for realtime processing what Hadoop did for batch processing.
- Key difference is that a MapReduce job eventually finishes, whereas a topology processes messages forever (or until you kill it).

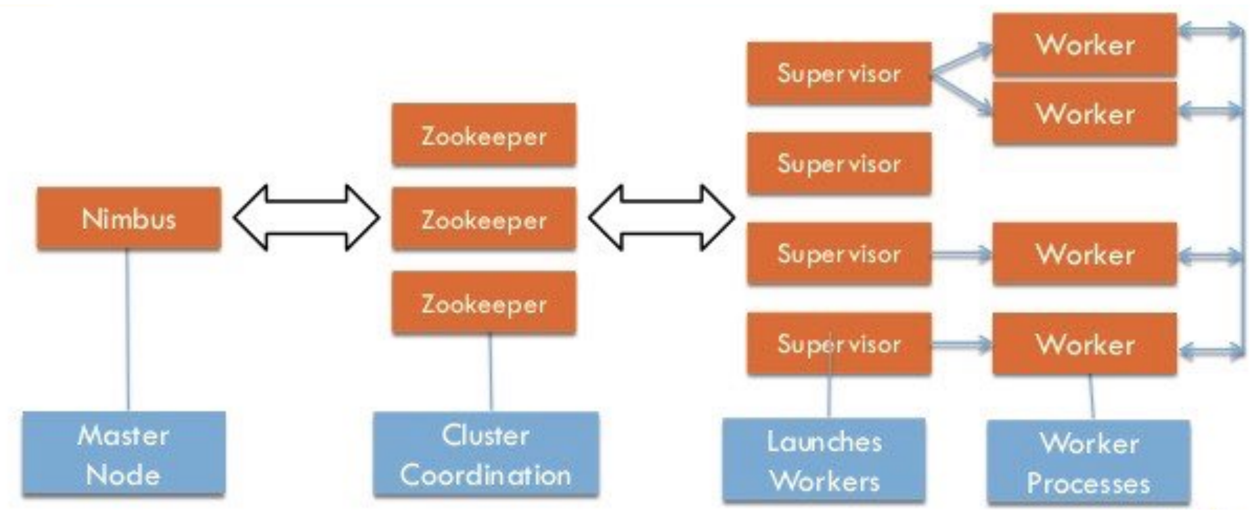
Storm Architecture:

- Two kinds of nodes on a Storm cluster: Master node and the worker nodes
  - **Master node**
    »runs a daemon called "Nimbus"
    »distributing code around the cluster, assigning tasks to machines, and monitoring for failures.
  - **Worker node**
    » runs a daemon called the "Supervisor"
    » listens for work assigned by nimbus to its machine and starts and stops worker processes
    »Worker process executes a subset of a topology, a running topology consists of many worker processes spread across many machines.



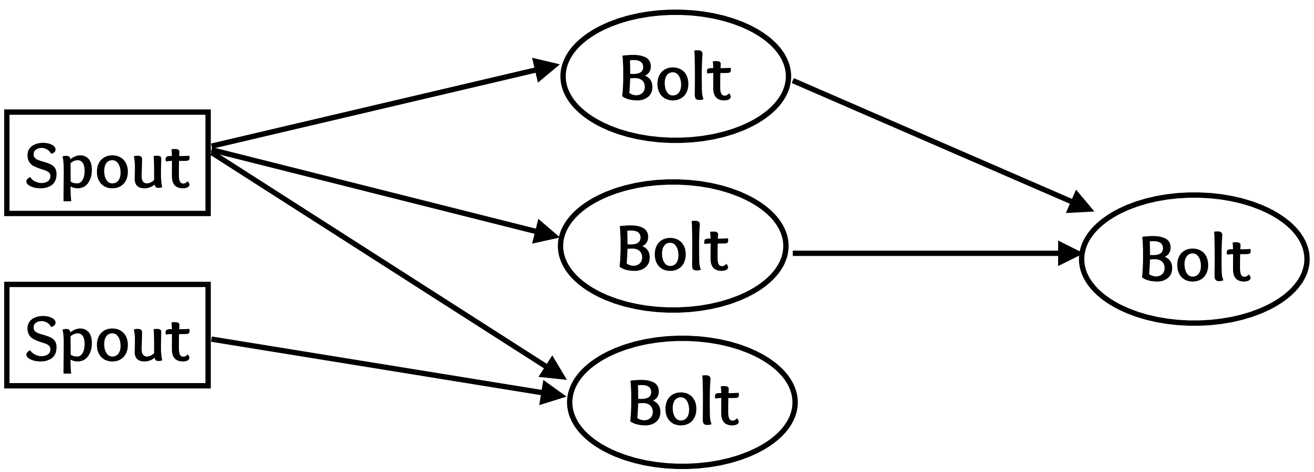
Storm Architecture:

- Zookeeper
  - Coordination between Nimbus and the Supervisors is done through a Zookeeper cluster
  - Nimbus daemon and Supervisor daemons are fail-fast and stateless, state is kept in Zookeeper
    »can kill Nimbus or the Supervisors and they'll start back up like nothing happened.



Key abstractions

- Tuples: an ordered list of elements.
- Streams: an unbounded sequence of tuples.
- Spouts: sources of streams in a computation (e.g. a Twitter API)
- Bolts:
  - process input streams and produce output streams.
  - run functions (filter, aggregate, or join data or talk to databases).
- Topologies: Computation DAG, each node contains processing logic, and links between nodes indicate how data streams



Topology Example

```
TopologyBuilder builder = new TopologyBuilder();
builder.setSpout("words", new TestWordSpout(), 10);
builder.setBolt("exclaim1", new ExclamationBolt(), 3)
        .shuffleGrouping("words");
builder.setBolt("exclaim2", new ExclamationBolt(), 2)
        .shuffleGrouping("exclaim1");
```

- Contains a spout and two bolts, Spout emits words, and each bolt appends the string "!!!" to its input
- Nodes are arranged in a line
  - e.g. spout emits the tuples ["bob"] and ["john"], then the second bolt will emit the words ["bob!!!!!!"] and [“john!!!!!!"]
- Last parameter, ***parallelism***: how many threads should run for that component across the cluster
- ***"shuffle grouping"*** means that tuples should be randomly distributed to downstream tasks.

Spout and Bolt

- Processing logic implements the *IRichSpout* & *IRichBolt* interface for spouts & bolts.
- ***open/prepare method*** provides the bolt with an OutputCollector that is used for emitting tuples from this bolt, **executed once.**
- **Execute** method receives a tuple from one of the bolt's inputs, **executes for every tuple.**
- Cleanup method is called when a Bolt is being shutdown, **executed once.**

```
public static class ExclamationBolt implements IRichBolt {
    OutputCollector _collector;

    @Override
    public void prepare(Map conf, TopologyContext context, OutputCollector collector) {
        _collector = collector;
    }

public void nextTuple() {
    Utils.sleep(100);
    final String[] words = new String[] {"nathan", "mike", "jackson", "golda", "bertels"};
    final Random rand = new Random();
    final String word = words[rand.nextInt(words.length)];
    _collector.emit(new Values(word));
}
    public void cleanup() {
    }

    @Override
    public void declareOutputFields(OutputFieldsDeclarer declarer) {
        declarer.declare(new Fields("word"));
    }

    @Override
    public Map<String, Object> getComponentConfiguration() {
        return null;
    }
}
```

Stateful bolts (from v1.0.1)

- Abstractions for bolts to save and retrieve the state of its operations.
- By extending the **BaseStatefulBolt** and implement **initState(T state)** method.
- **initState method** is invoked by the framework during the bolt initialization (after prepare()) with the previously saved state of the bolt.

```
public class WordCountBolt extends BaseStatefulBolt<KeyValueState<String, Long>> {
private KeyValueState<String, Long> wordCounts;
private OutputCollector collector;
...
    @Override
    public void prepare(Map stormConf, TopologyContext context, OutputCollector collector) {
      this.collector = collector;
    }
    @Override
    public void initState(KeyValueState<String, Long> state) {
      wordCounts = state;
    }
    @Override
    public void execute(Tuple tuple) {
      String word = tuple.getString(0);
      Integer count = wordCounts.get(word, 0);
      count++;
      wordCounts.put(word, count);
      collector.emit(tuple, new Values(word, count));
      collector.ack(tuple);
    }
...
}
```

Stateful bolts (from v1.0.1)

- The framework periodically checkpoints the state of the bolt (default every second).
- Checkpoint is triggered by an internal checkpoint spout.
- If there is at-least one **IStatefulBolt** in the topology, the checkpoint spout is automatically added by the topology builder.
- Checkpoint tuples flow through a separate internal stream namely **$checkpoint**
- Non stateful bolts just forwards the checkpoint tuples so that the checkpoint tuples can flow through the topology DAG.

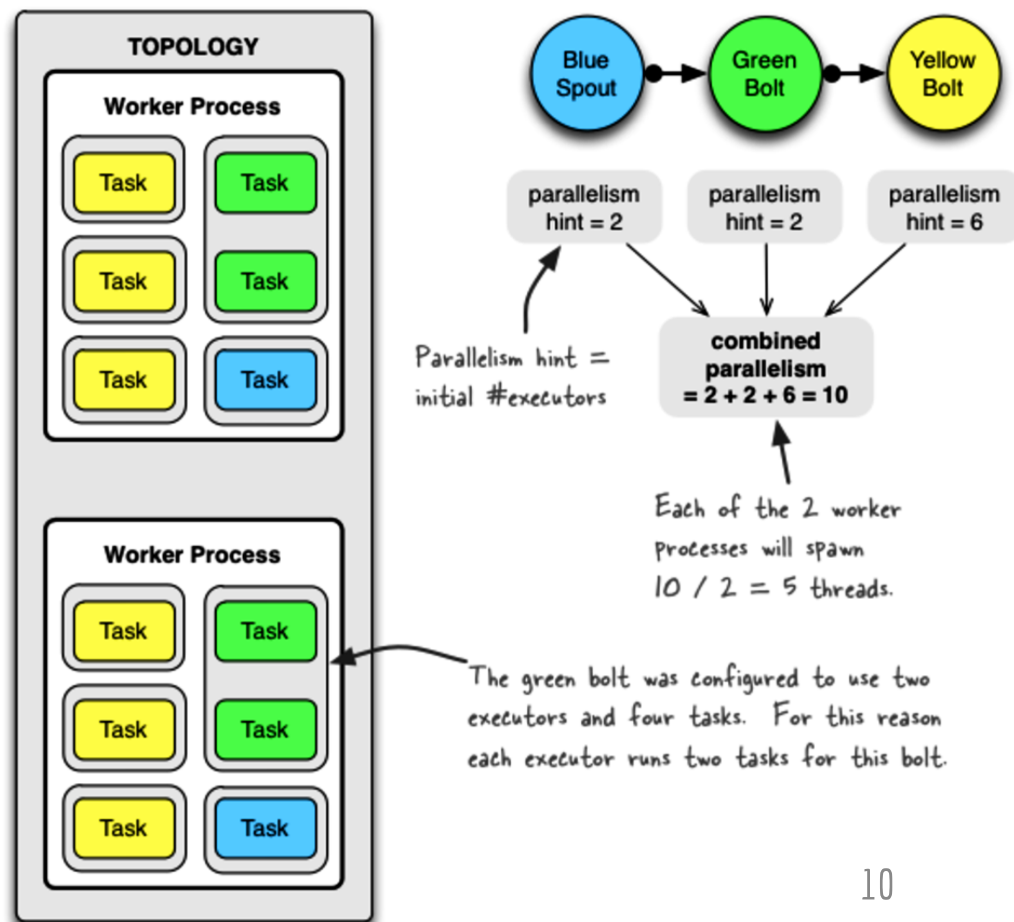
```
                 default                                default                  default
[spout1]   ---------------> [statefulbolt1] ----------> [bolt1] --------------> [statefulbolt2]
                          |                 ---------->          -------------->
                          |                  ($chpt)                  ($chpt)
                          |
[$checkpointspout] _______| ($chpt)
```

Example of a running topology

- Topology consists of **three components:** one BlueSpout and two bolts,GreenBolt and YellowBolt
- #worker processes=2
- for green Bolt:
    - #executors =2
    - #tasks = 4

Configuring the parallelism of a simple Storm top

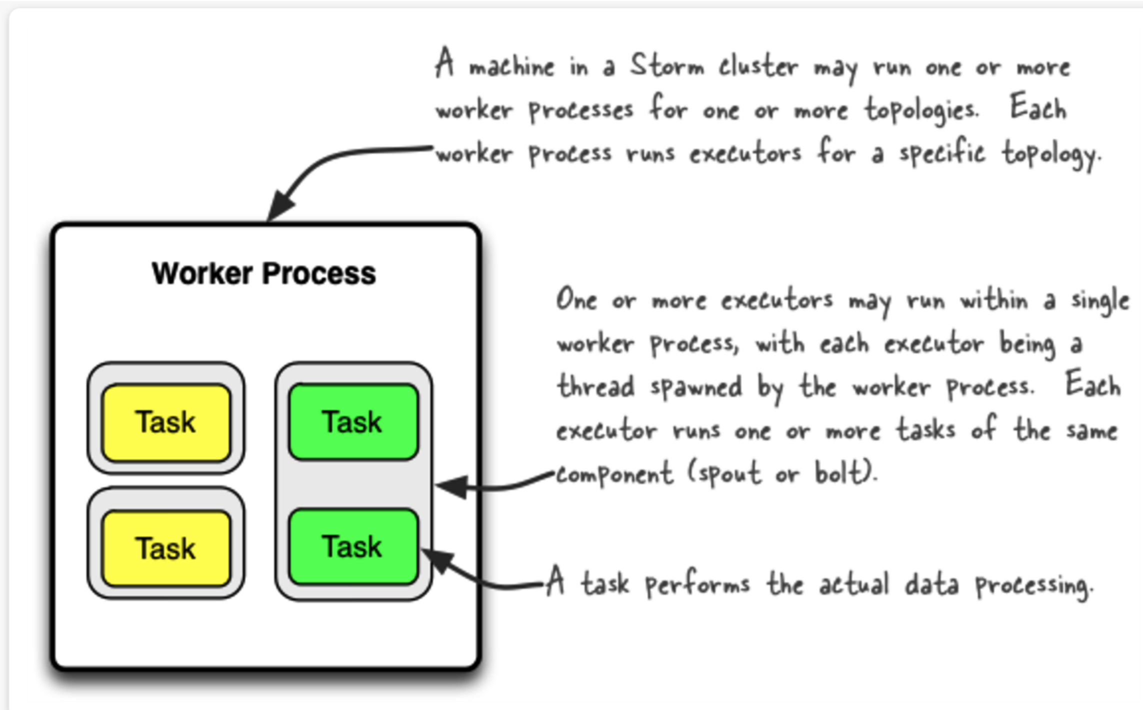
```
Config conf = new Config();
conf.setNumWorkers(2); // use two worker processes

topologyBuilder.setSpout("blue-spout", new BlueSpout(), 2);

topologyBuilder.setBolt("green-bolt", new GreenBolt(), 2)
               .setNumTasks(4)
               .shuffleGrouping("blue-spout");

topologyBuilder.setBolt("yellow-bolt", new YellowBolt(), 6)
               .shuffleGrouping("green-bolt");

StormSubmitter.submitTopology(
        "mytopology",
        conf,
        topologyBuilder.createTopology()
    );
```



Running topology: worker processes, executors and tasks

- Worker processes executes a subset of a topology, and runs in its own JVM.
- An executor is a thread that is spawned by a worker process and runs within the worker's JVM ***(parallelism hint)***.
- A task performs the actual data processing and is run within its parent executor's thread of execution.

- \# threads can change at run time, ***but not # tasks***
- **#threads <= #tasks**

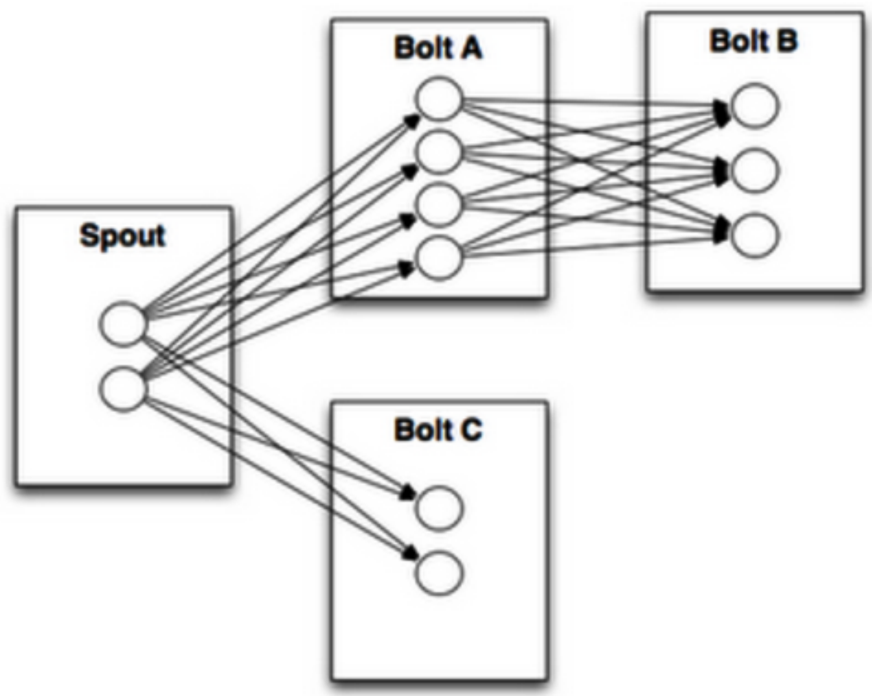


Updating the parallelism of a running topology

- Rebalancing: Increase or decrease the number of worker processes and/or executors without being required to restart the cluster or the topology, but not tasks.
- e.g. To reconfigure the topology "mytopology" to use 5 worker processes, # the spout "blue-spout" to use 3 executors.
  - **storm rebalance mytopology -n 5 -e blue-spout=3**
- Demo:

Stream groupings

- Stream grouping defines how that stream should be partitioned among the bolt's tasks.
  - **Shuffle grouping:** random distribution, each bolt is guaranteed to get an equal number of tuples
  - **Fields grouping:** stream is partitioned by the fields specified in the grouping
  - **Global grouping:** entire stream goes to a single one of the bolt's tasks.
  - **All grouping:** The stream is replicated across all the bolt's tasks.
  - etc ..



Guaranteeing Message Processing

- Storm can guarantee ***at least once processing***.
- Tuple coming off the spout triggers many tuples being created based on it forming ***Tuple tree***.
- **"fully processed" tuple:** tuple tree has been exhausted and every message in the tree has been processed ***(within a specified timeout)***.
    - Spout while emitting provides a "**message id**" that will be used to identify the tuple later.
    - Storm takes care of **tracking the tree of messages** that is created.
    - **if fully processed**, Storm will call the **ack method** on the originating Spout task with its message id.
    - **if tuple times-out** Storm will call the **fail method** on the Spout.

Guaranteeing Message Processing…

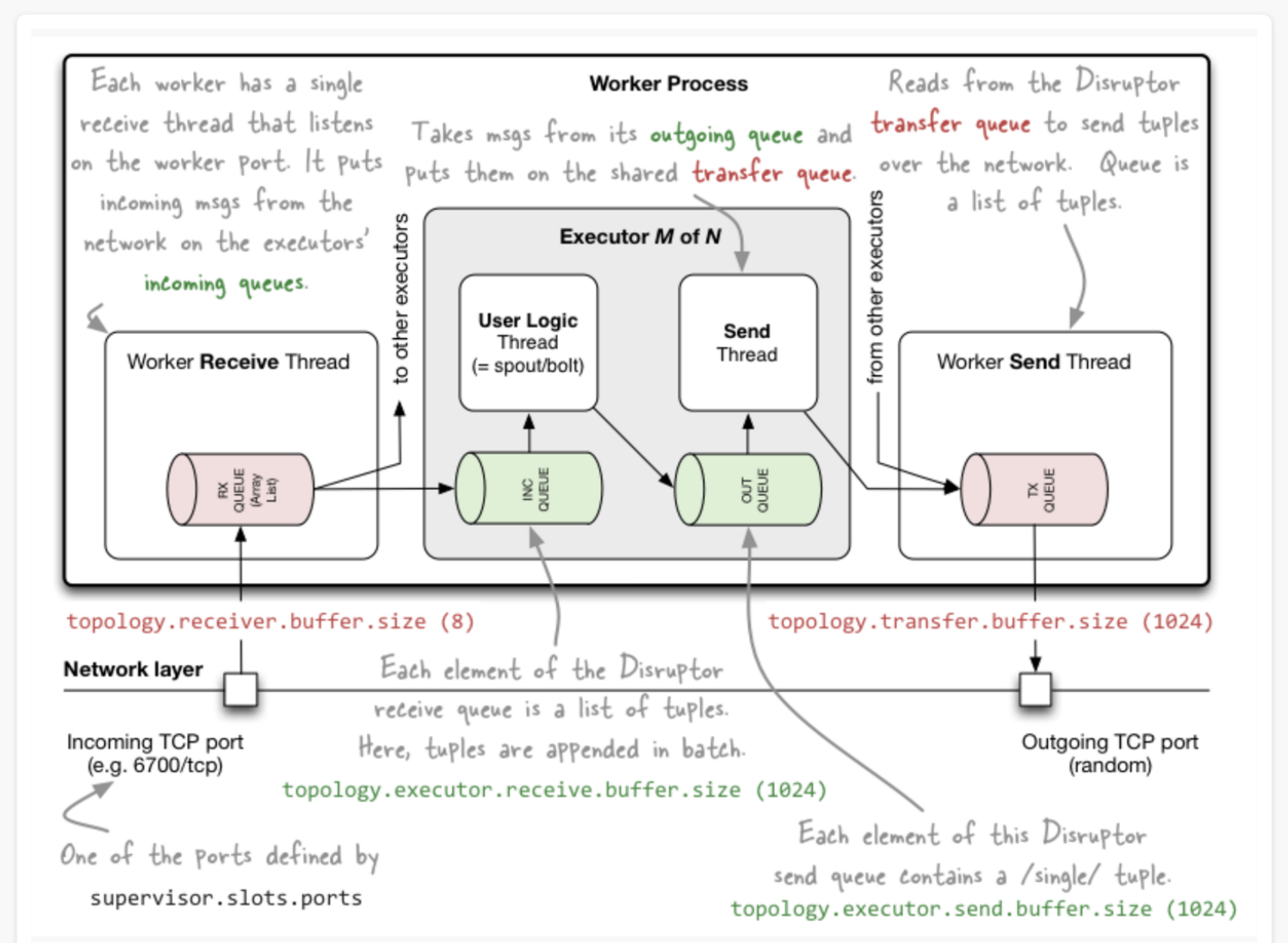
- Things user have to do to achieve at-least once semantics.
  - **Anchoring**: creating a new link in the tree of tuples.
  - **Acking**: finished processing an individual tuple.
  - **Failing**: to immediately fail tuple at the root of the tuple tree, to replay faster than waiting for the tuple to time-out.

```java
public class SplitSentence extends BaseRichBolt {
        OutputCollector _collector;

        public void prepare(Map conf, TopologyContext context, OutputCollector collector) {
            _collector = collector;
        }

        public void execute(Tuple tuple) {
            String sentence = tuple.getString(0);
            for(String word: sentence.split(" ")) {
                _collector.emit(tuple, new Values(word));
            }
            _collector.ack(tuple);
        }

        public void declareOutputFields(OutputFieldsDeclarer declarer) {
            declarer.declare(new Fields("word"));
        }
    }
```

Anchoring (`_collector.emit(tuple, new Values(word));`)

Acking (`_collector.ack(tuple);`)

Internal messaging within Storm worker processes



Resource Scheduling for DSPS

- Scheduling for the DSPS has two parts:
  - *Resource allocation -*
    - *Determining* the appropriate degrees of parallelism per task (i.e., threads of execution)
    - Amount of computing resources per task (e.g., Virtual Machines (VMs)) for the given dataflow
  - *Resource mapping -*
    - *Deciding* the specific assignment of the threads to the VMs ensuring that the expected performance behavior and resource utilization is met.

Resource Allocation

- For a given DAG and input rate, allocation determines the number of resource slots(ρ) for DAG & number of threads(*q*), resources required for each task.
- Resource allocation algorithms:
    - *Linear Storm Allocation (LSA)*
    - *Model Based Allocation (MBA) [3]*
- Requires input rate to each task for finding the resource needs and data parallelism for that task.

- # of slots:

$$\rho = \max\left(\left\lceil \sum_{t_i \in \mathbb{T}} (c_i) \right\rceil, \left\lceil \sum_{t_i \in \mathbb{T}} (m_i) \right\rceil\right)$$

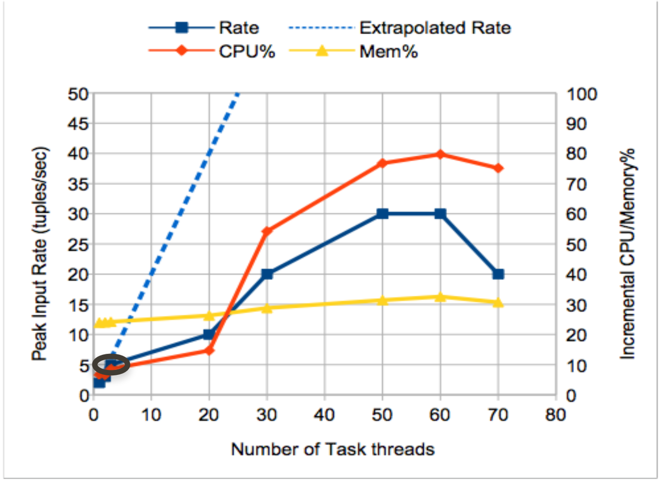
[3] Model-driven Scheduling for Distributed Stream Processing Systems, Shukla,et al {under review}

Linear Storm Allocation

Pseudocode:

```
AllocateLSA(G,Ω){
  for each task in DAG
    while(input rate for task ti > Peak rate with 1 thread)
      {
        add 1 thread
        decrease required rate by Peak rate with 1 thread
        increase resources allocated with that required for 1 thread
      }
    if(remaining input rate for task ti>0)
      {
        increase number of threads by 1
        set input rate to zero
        add resources by scaling remaining rate with peak rate
      }
  return <#threads,CPU%,Memory%> for each task
```

- e.g. For 105 tuples/sec rate.
  - Threads=(52 thread * 2 tuples/sec)+(1 thread*1 tuple/sec)
  - CPU% =52*6.73+3.3=353%
  - Memory%=52*23.92+11.16=1255.8%
  - Required #Slots=ceil (353%,1255.8%)=13



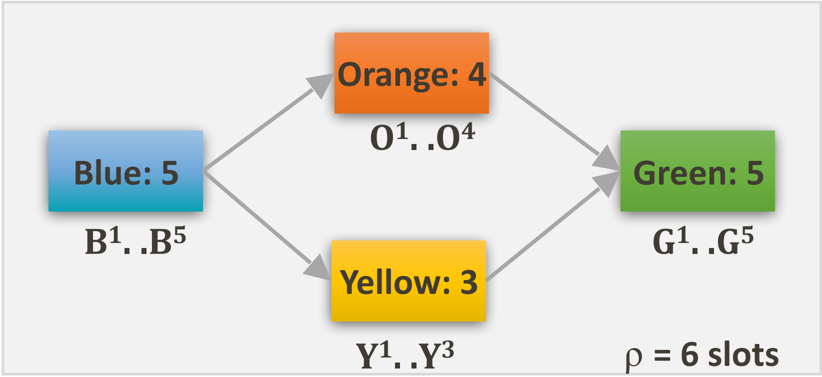
Default Mapping

- Not "resource aware", so does not use the output of the performance model
- Threads are picked in any arbitrary order for mapping
- For each thread, next slot is picked in round-robin fashion
- Unbalanced load distribution across the slots

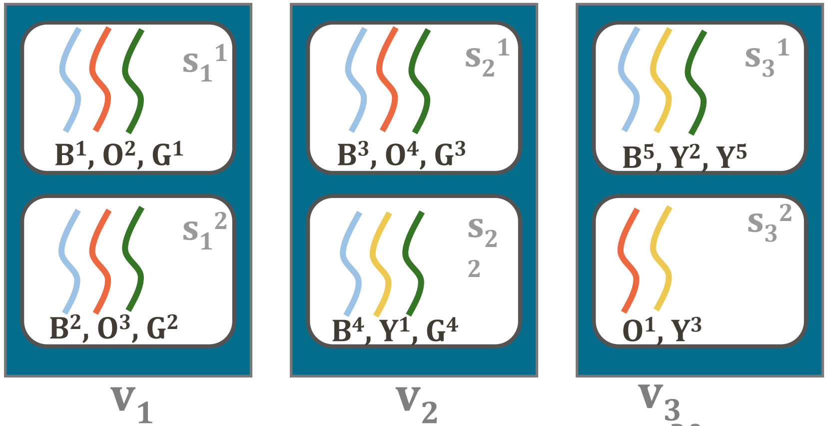
Pseudocode:

```
MapDSM(R,S){
  M<- new map()
  get the list of slots
  for each thread
    pick slots in round robin manner
    store mapping of thread to slot in M
  return M
```

DAG with Thread Allocation for Tasks using Model



Default Storm Mapping (DSM)

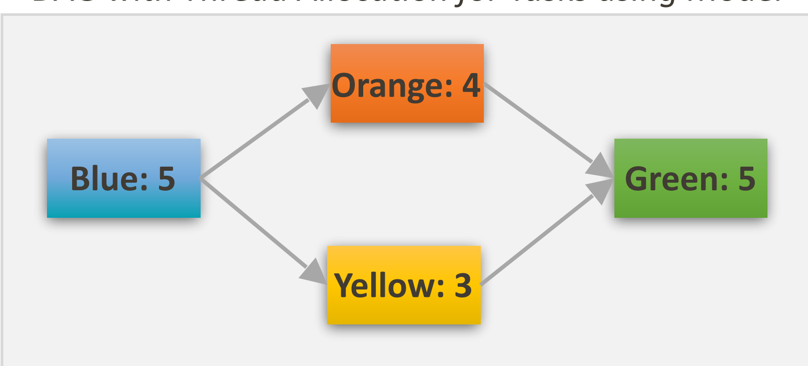


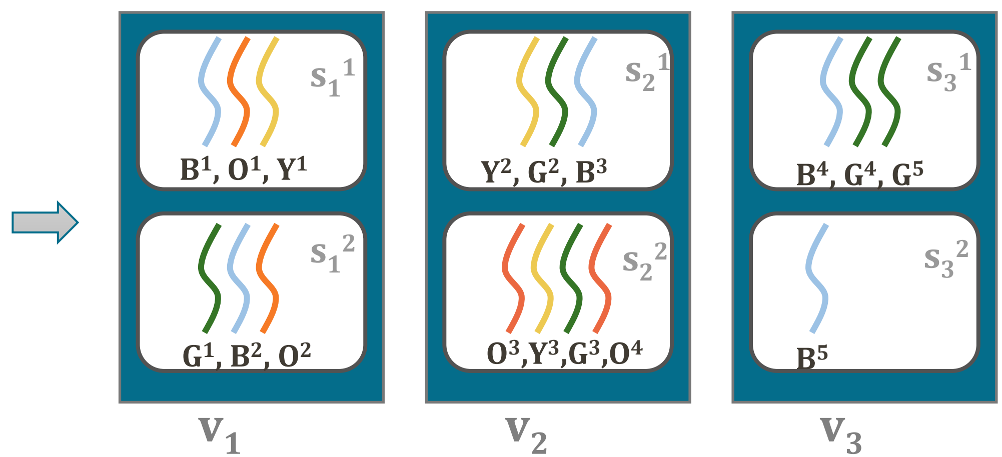
Resource Aware Mapping[4]

- Use only resource usage for single thread from the performance model
- "Network aware", places the threads on slots such that communication latency between adjacent tasks is reduced
- Threads are picked in order of BFS traversal of the DAG for locality.
- Slots are chosen by *Distance function (minimum value)* based on the available and required resources, and a network latency measure

$$d = w_M \times (M_j - \bar{m}_i)^2 + w_C \times (C_j - \bar{c}_i)^2 + w_N \times \mathrm{NWD{\small IST}}(\widehat{v}, v_j)$$

DAG with Thread Allocation for Tasks using Model





[4] Peng et.al. R-storm: Resource-aware scheduling in storm, in: Middleware 2016

References

- Apache Storm concepts

  http://storm.apache.org/releases/current/Concepts.html
- Understanding the Parallelism of a Storm Topology

  http://www.michael-noll.com/blog/2012/10/16/understanding-the-parallelism-of-a-storm-topology/
- Model-driven Scheduling for Distributed Stream Processing Systems, Shukla et. al. {under review}
- R-storm: Resource-aware scheduling in storm, Peng et.al.,in: Middleware 2016