Deep Analysis with Apache Flink

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with Material from Asterios Katsifodimos, Alexander Alexandrov, Andra Lungu and Aljoscha Krettek

Outline

1. Flink Introduction
2. Machine Learning with Flink
3. Graph Analysis with Flink
4. Relational Queries with Flink
5. Research / Emma

Flink Introduction

What is Apache Flink

- Massive parallel data flow engine with unified batch- and stream-processing
- Evolved from the joint research project *Stratosphere* funded by DFG
- Now Apache top-level project
- About 120 contributors, highly active community

What is Apache Flink

Taken from
Database technology

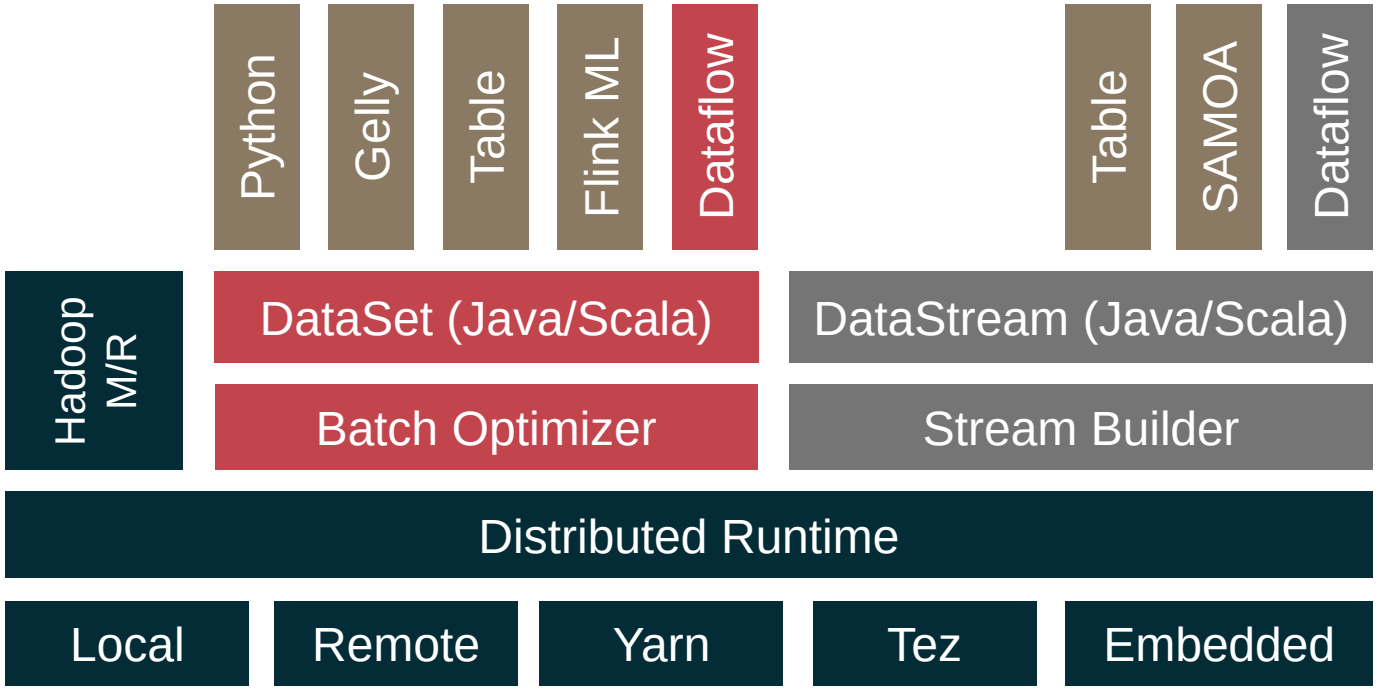
- Declarativity
- Query optimization
- Robust out-of-core

- Iterations
- Adv. dataflows
- General APIs

Taken from
MapReduce technology

- Scalability
- UDFs
- Complex data types
- Schema on read

System Stack

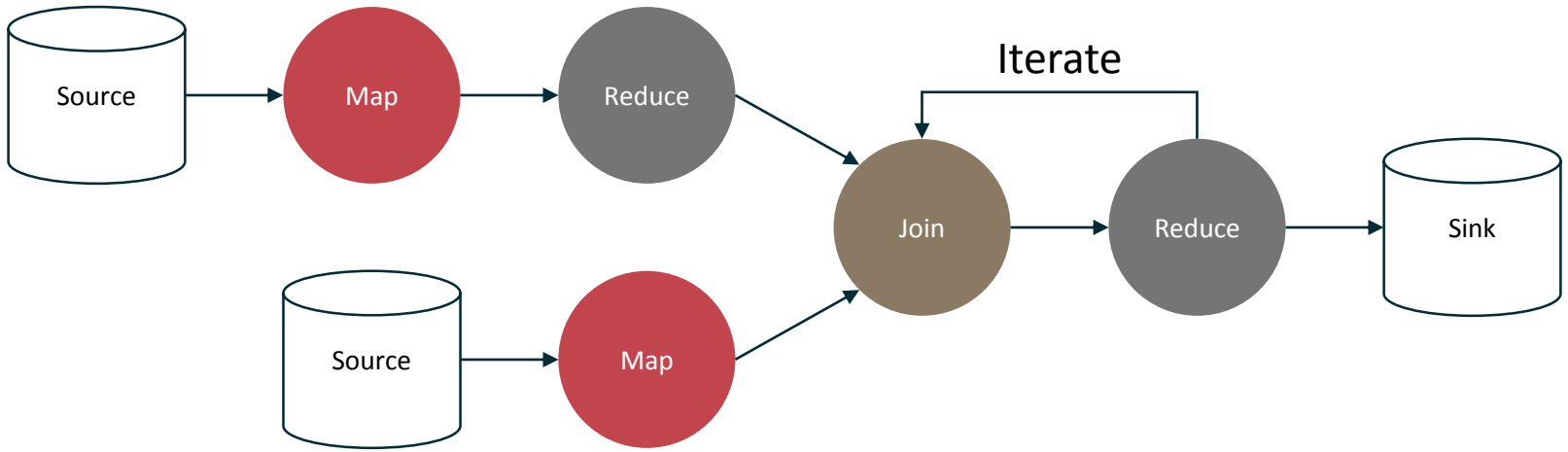


The case for Flink

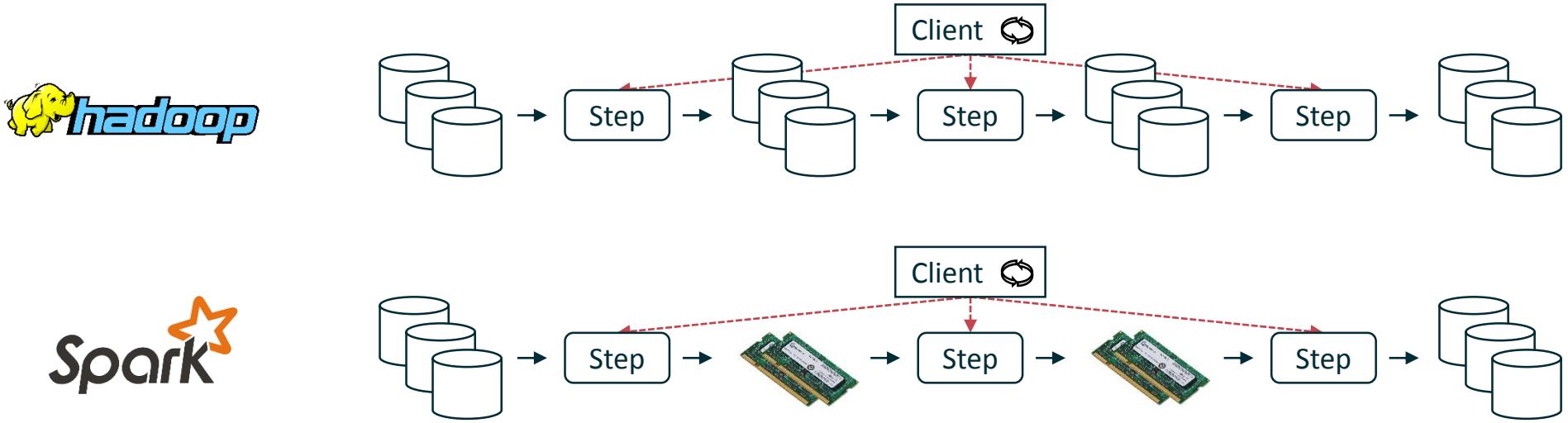
- Performance and ease of use
  - Exploits in-memory processing and pipelining, language-embedded logical APIs
- Unified batch and real streaming
  - Batch and Stream APIs on top of a streaming engine
- A runtime that "just works" without tuning
  - custom memory management inside the JVM
- Predictable and dependable execution
  - Bird’s-eye view of what runs and how, and what failed and why

Rich set of operators

Map, Reduce, Join, CoGroup, Union, Iterate, Delta Iterate, Filter, FlatMap, GroupReduce, Project, Aggregate, Distinct, Vertex-Update, Accumulators

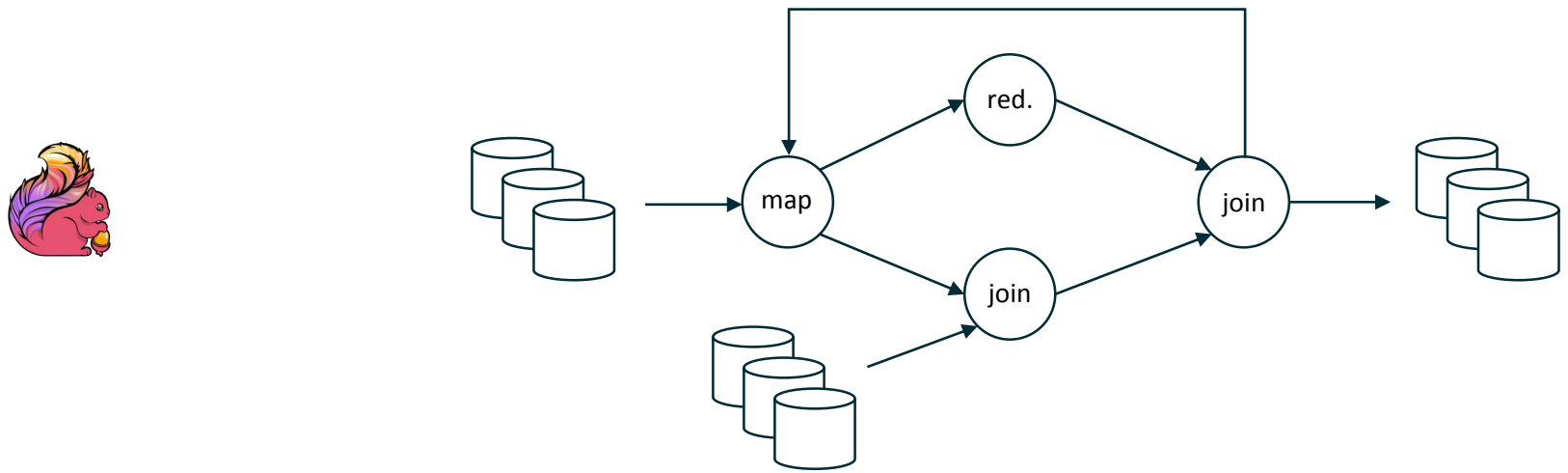


Built-in vs. driver-based looping



Loop outside the system, in driver program

Iterative program looks like many independent jobs



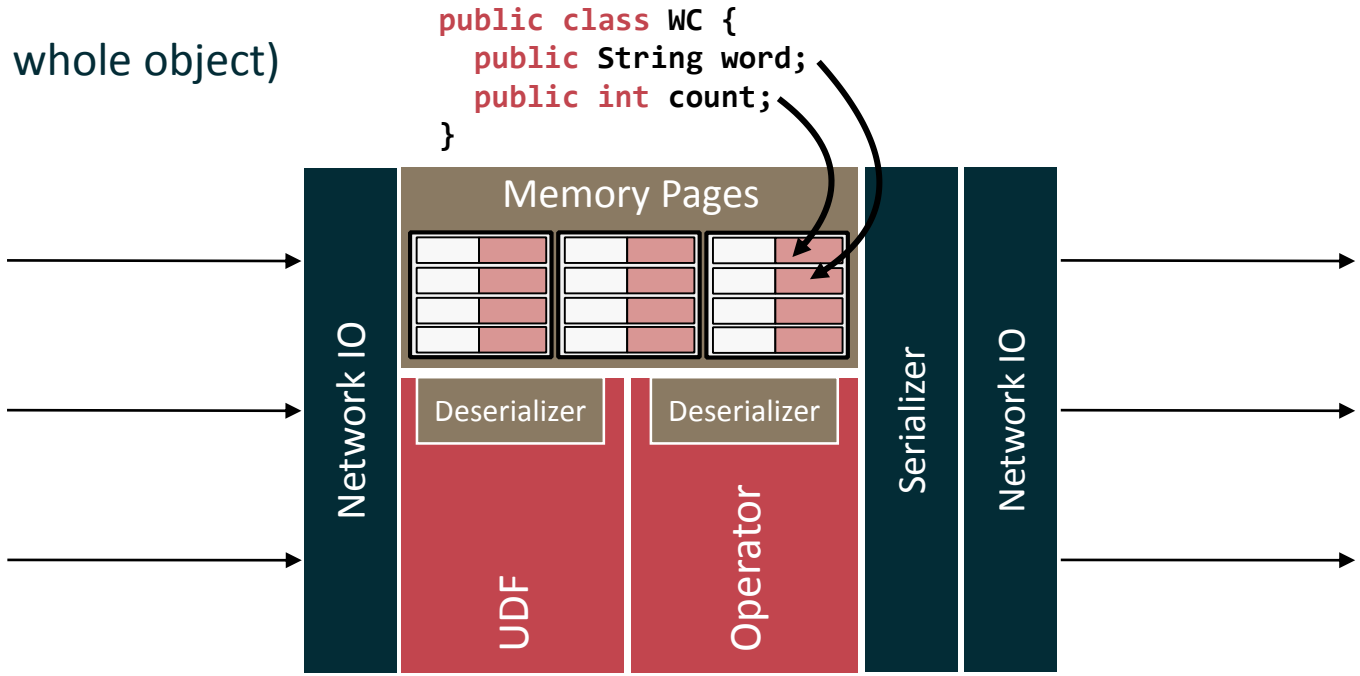
Dataflow with Feedback edges

System is iteration-aware, can optimize the job

Flink Runtime: Operators & UDFs

Language APIs automatically convert objects to tuples

- Tuples mapped to pages of bytes
- Operators work on pages
- Full control over memory, out-of-core enabled
- Address individual fields (not deserialize whole object)
- UDFs work on deserialized objects

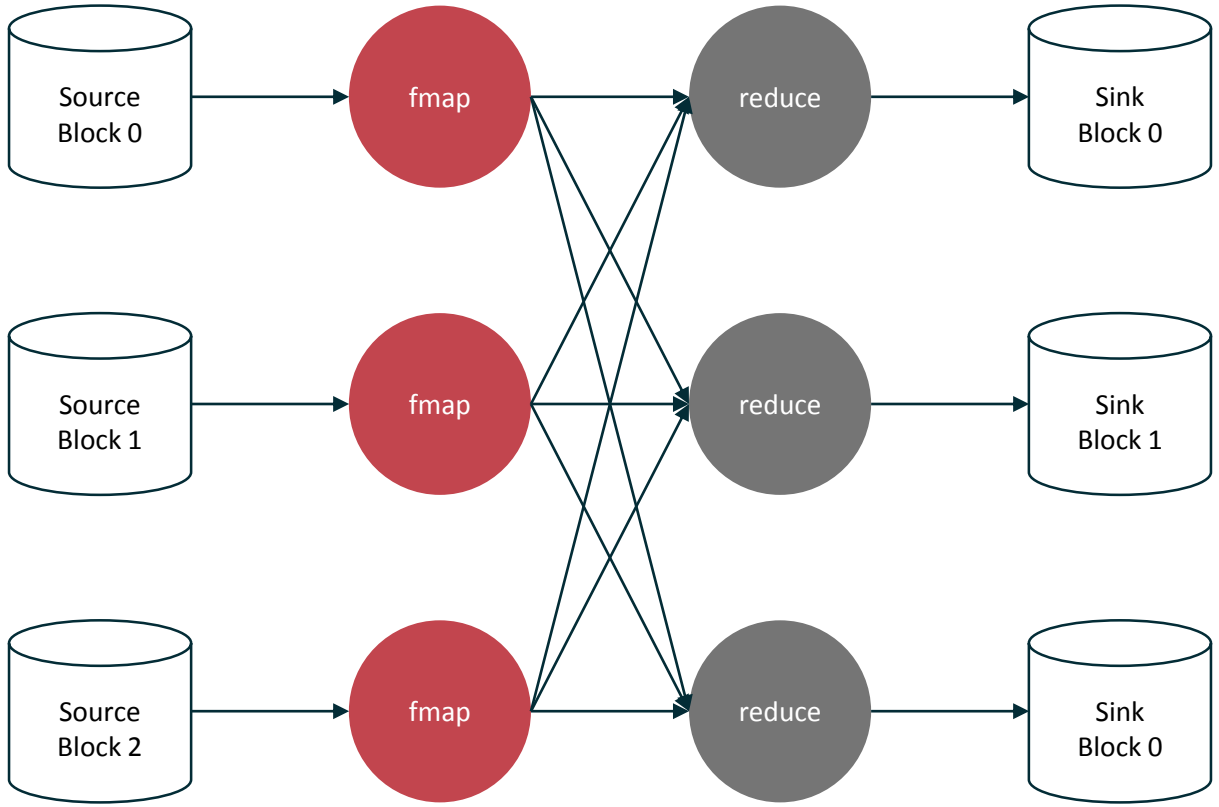



SAY "WORD COUNT"
ONE MORE TIME...

Wordcount: Program

```
case class Word (word: String, frequency: Int)

val env = ExecutionEnvironment.getExecutionEnvironment()

val lines: DataSet<String> = env.readTextFile(...)

lines
    .flatMap { line =>
      line.split(" ").map( word => Word(word, 1) )
    }
    .groupBy("word")
    .sum("frequency”)
    .print()

env.execute()
```

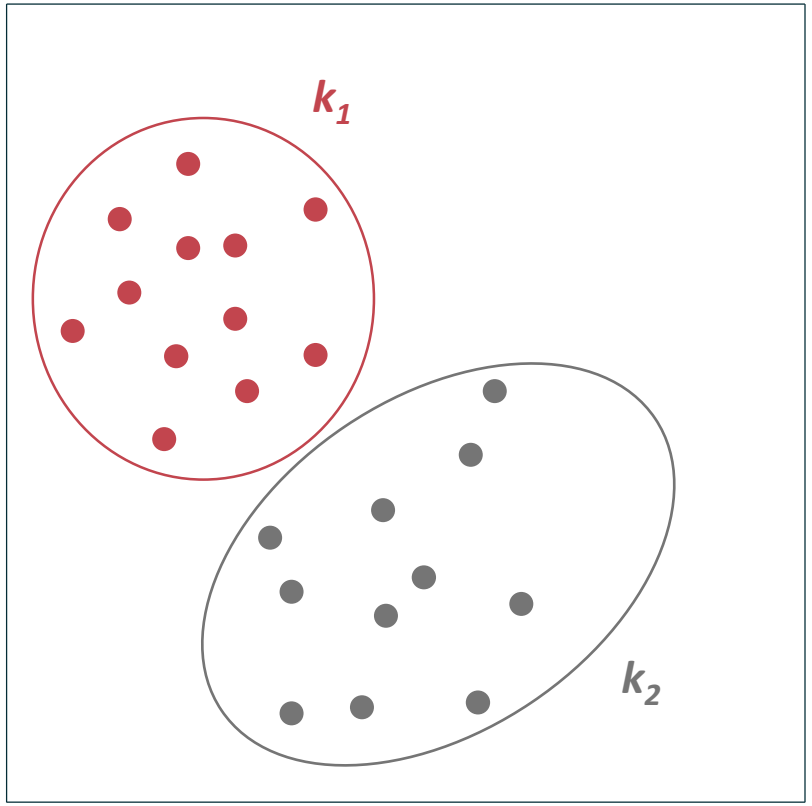
Wordcount: Execution



Machine Learning with Flink

K-Means Clustering

- Cluster analysis in data mining
- Partitions ***n*** observations into ***k*** clusters
- Assign points to cluster with smallest (euclidian) distance



k=2

K-Means Clustering

Input: set of observations $\boldsymbol{X} = \{x_1, x_2, \ldots, x_n\}$
number of clusters $\boldsymbol{k}$
convergence criteria $\boldsymbol{\xi}$

Result: set of clusters $\boldsymbol{C} = \{c_1, c_2, \ldots, c_k\}$

Init: select $\boldsymbol{k}$ data points as cluster centroids $\boldsymbol{C} = \{c_1, c_2, \ldots, c_k\}$

Compute:

do

foreach **x** in $\boldsymbol{X}$

assagin **x** to cluster with closest centroid

recompute centroid of each cluster

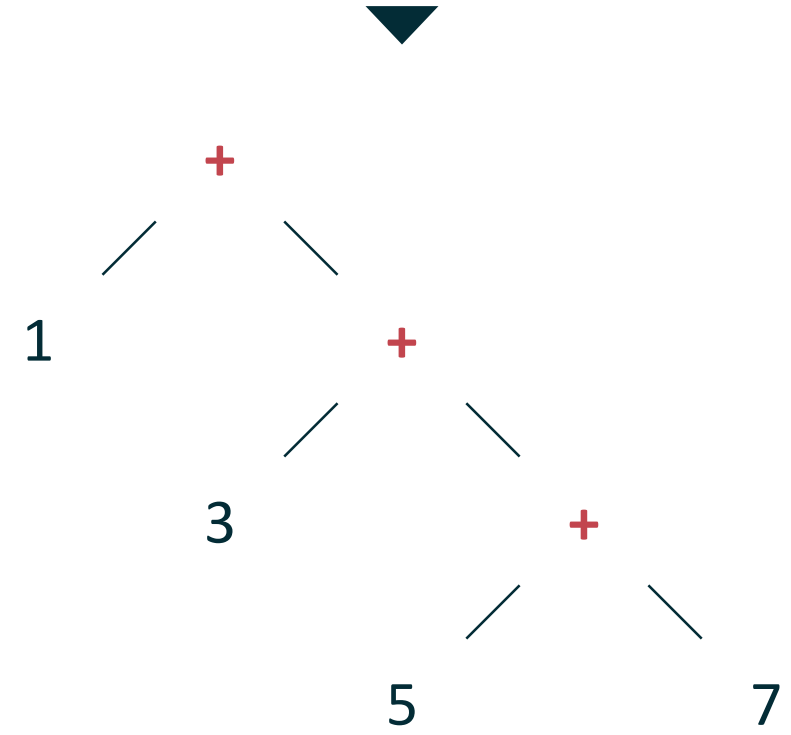
while $\boldsymbol{\xi}$ is not reached (or fixed number of iterations)

K-Means in Flink

```
// initialize
// points: n observations, centroids: initial k centroids
val cntrds = centroids.iterate(10) { currCentroids =>
  val newCntrds = points
    .map(findNearestCntrd).withBroadcastSet(currCentroids, "cntrds")
    .map( (c, p) => (c, p, 1L) )
    .groupBy(0).reduce( (x, y) =>
      (x._1, x._2 + y._2, x._3 + y._3) )
    .map( x => Centroid(x._1, x._2 / x._3) )

  newCntrds
}
```

Reduce

```
{1, 3, 5, 7}.reduce { (x, y) => x + y }
```



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    .map( x => Centroid(x._1, x._2 / x._3) )

  newCntrds
}
```

Machine learning library

- Recently started effort
- Currently available algorithms
  - Classification
  - Logistic Regression
  - Clustering
  - Recommendation (ALS)

Machine Learning Library

```
val featureExtractor = HashingFT()
val factorizer = ALS()

val clickstreamDS =
  env.readCsvFile[(String, String, Int)](clickStreamData)

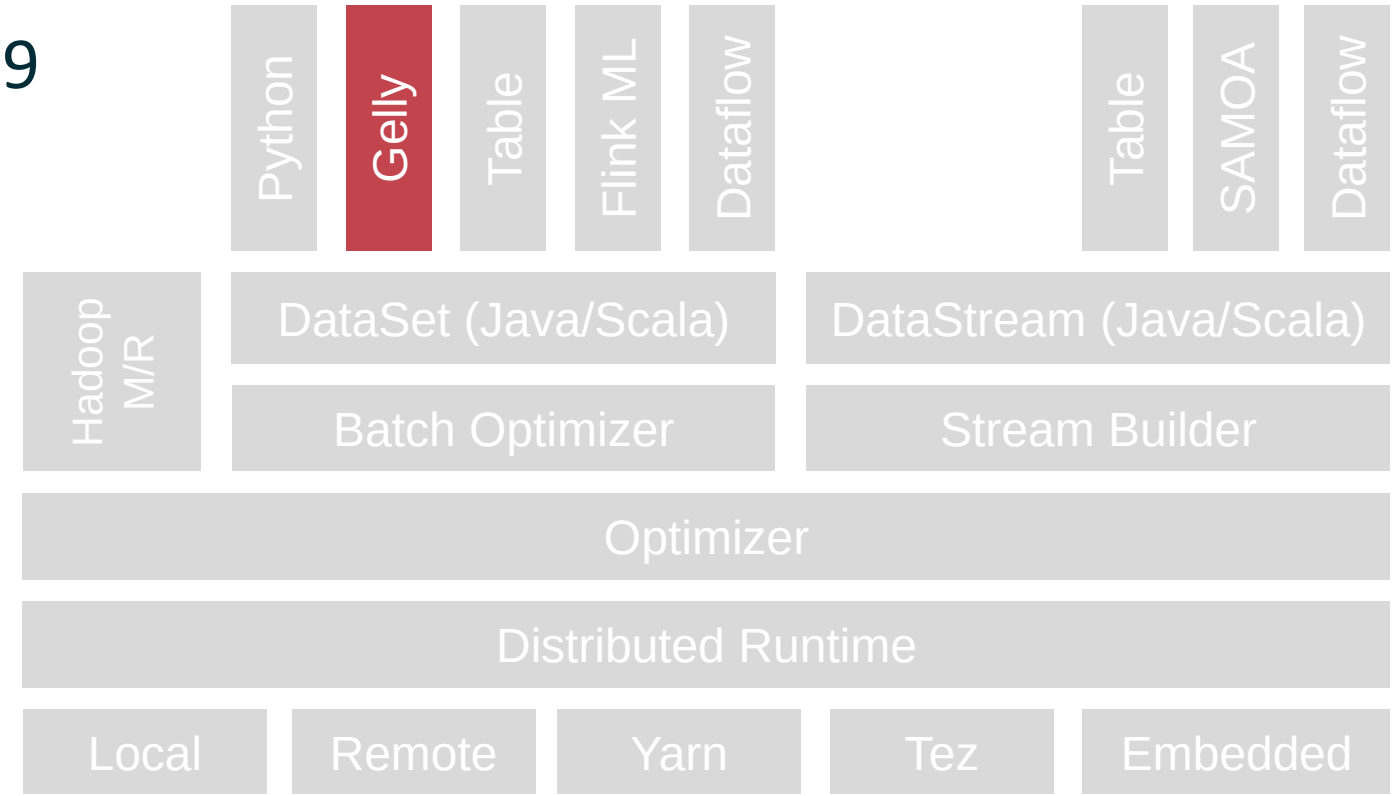
val parameters = ParameterMap()
  .add(HashingFT.NumFeatures, 1000000)
  .add(ALS.Iterations, 10)
  .add(ALS.NumFactors, 50)
  .add(ALS.Lambda, 1.5)

val factorization = pipeline.fit(clickstreamDS, parameters)
```

Graph Analysis with Flink

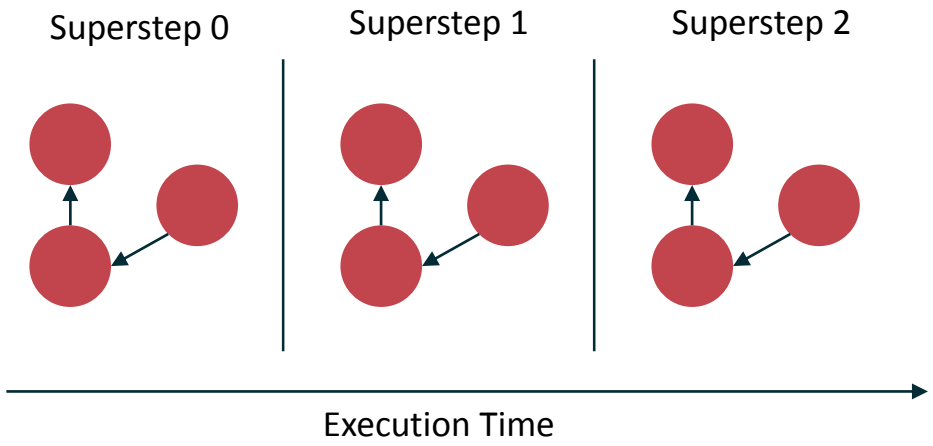
Gelly

- Large-scale graph processing API
- On top of Flink's Java API
- Official release in Flink 0.9

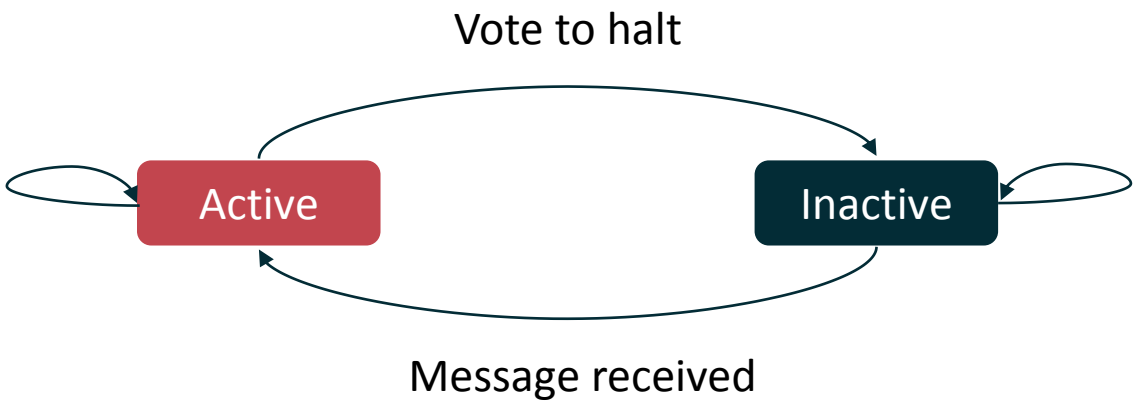


Execution model

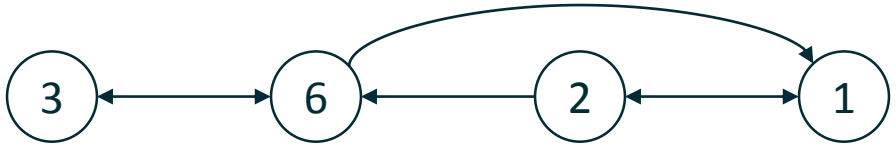
- Pregel-like or *Bulk Synchronous Parallel* (BSP) execution model
- *Synchronization barrier* after each superstep
- At each superstep
  - Receives messages from previous superstep
  - Modifies its value
  - Sends messages to vertices



Vertex State Machine

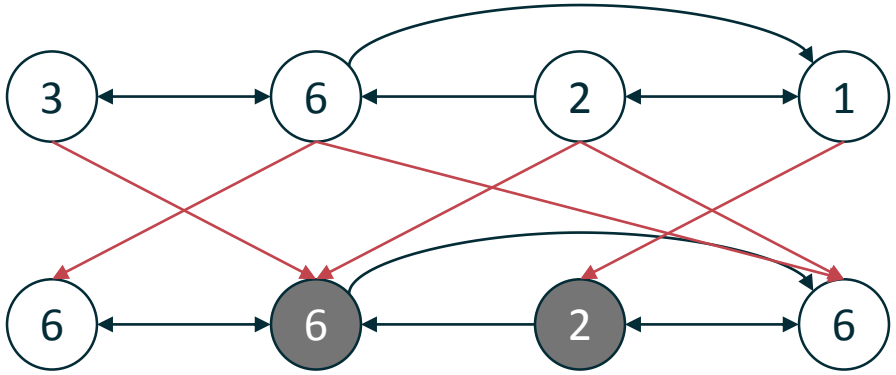


Example: Maximum Value



Red lines are messages, grey vertices voted to halt.

Example: Maximum Value



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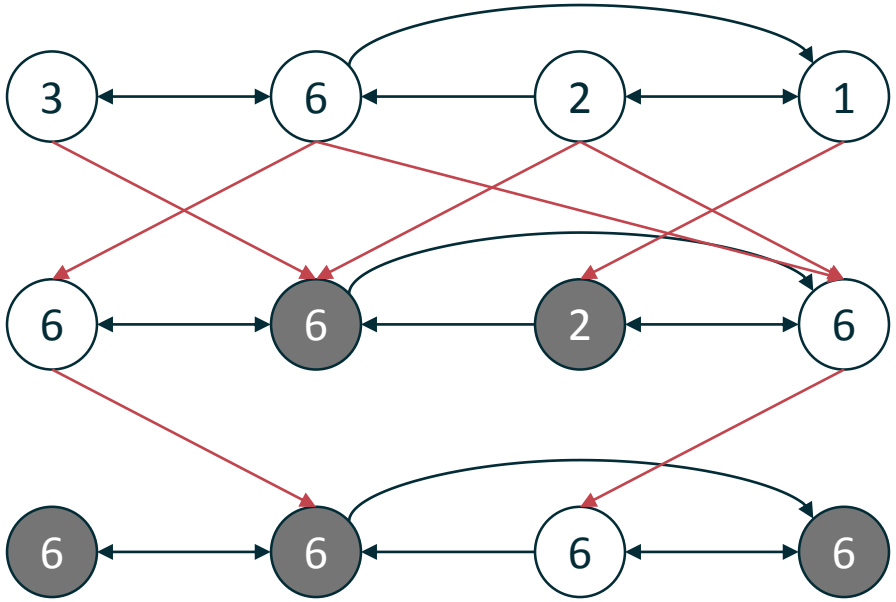

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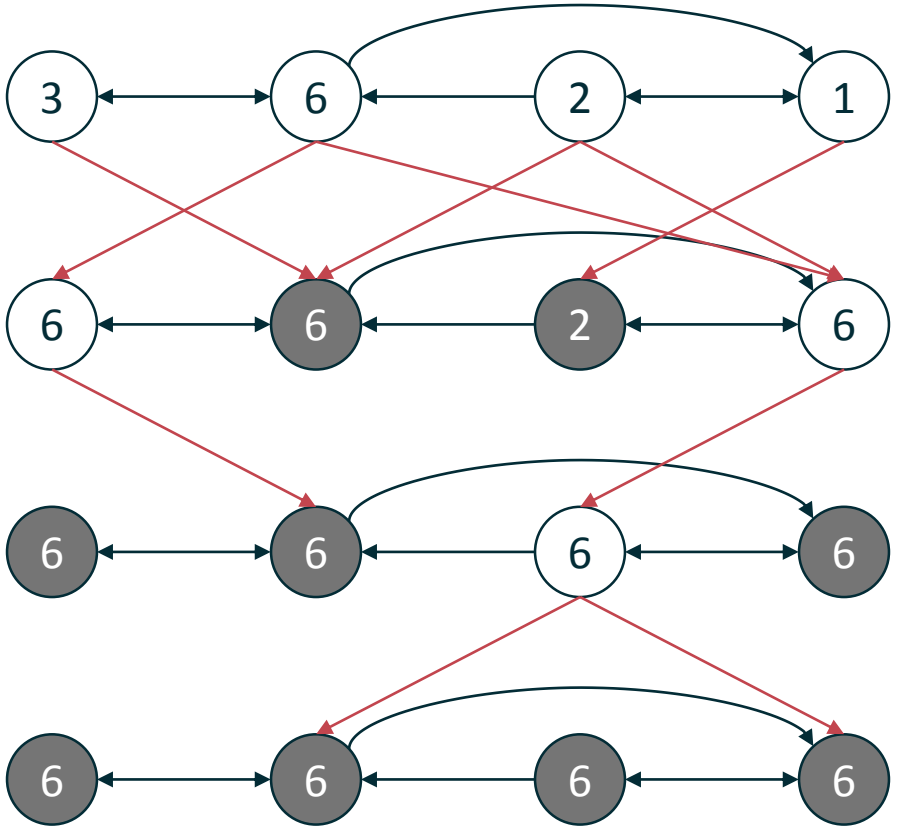

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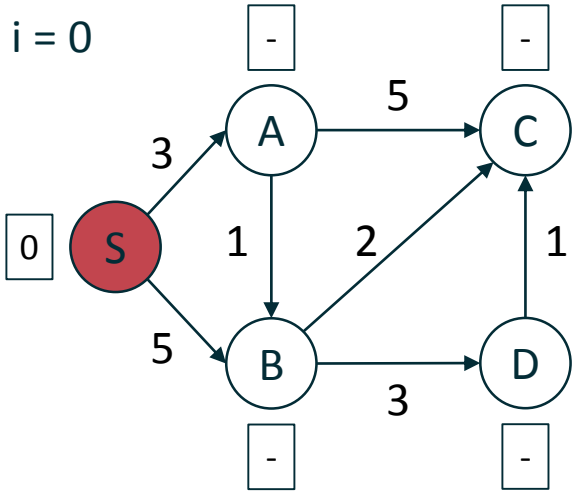
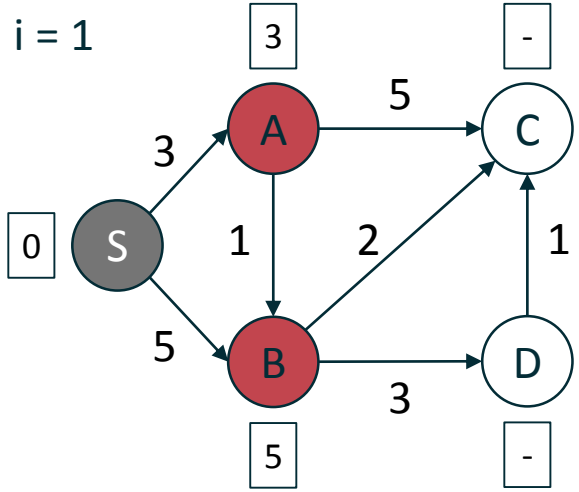
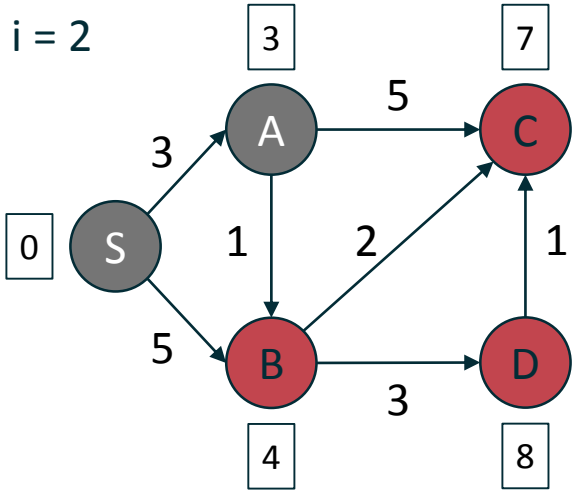
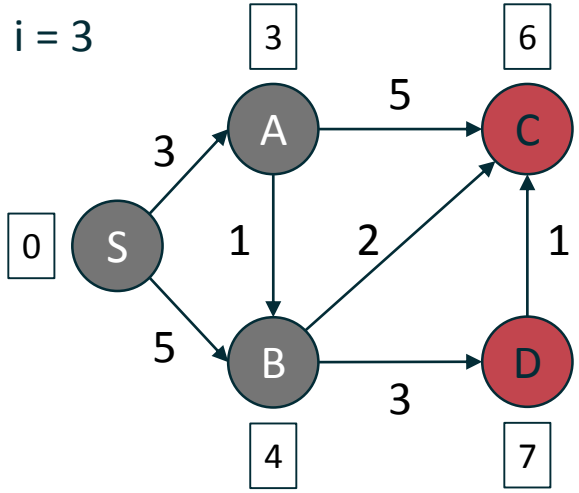
Single Source Shortest Paths (SSSP)









Red nodes are updated,
grey nodes are inactive

SSSP – Code snippet

```
shortestPaths = graph.runVertexCentricIteration(
  new DistanceUpdater(), new DistanceMessanger()).getVertices();
```

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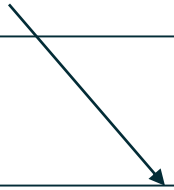

```
DistanceUpdater: VertexUpdateFunction

updateVertex(K key, Double value,
             MessageIterator msgs) {
  Double minDist = Double.MAX_VALUE;
  for (double msg : msgs) {
    if (msg < minDist)
      minDist = msg;
  }
  if (value > minDist)
    setNewVertexValue(minDist);
}
```

SSSP – Code snippet

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shortestPaths = graph.runVertexCentricIteration(
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```
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  }
  if (value > minDist)
    setNewVertexValue(minDist);
}
```

```
DistanceMessenger: MessagingFunction

sendMessages(K key, Double newDist) {

  for (Edge edge : getOutgoingEdges()) {
    sendMessageTo(edge.getTarget(),
      newDist + edge.getValue());
}
```

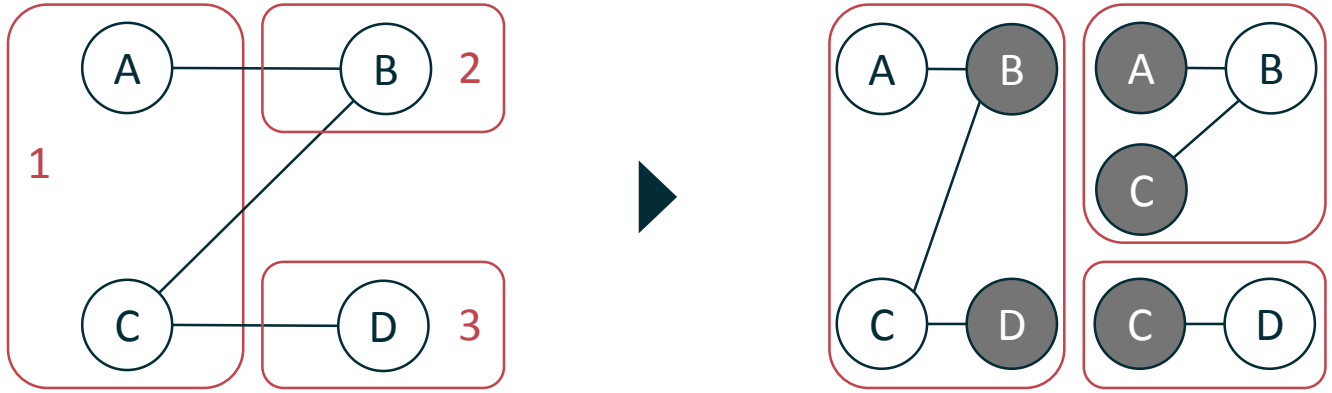
Graph Partitioning

- Real world graphs often have a power law distribution

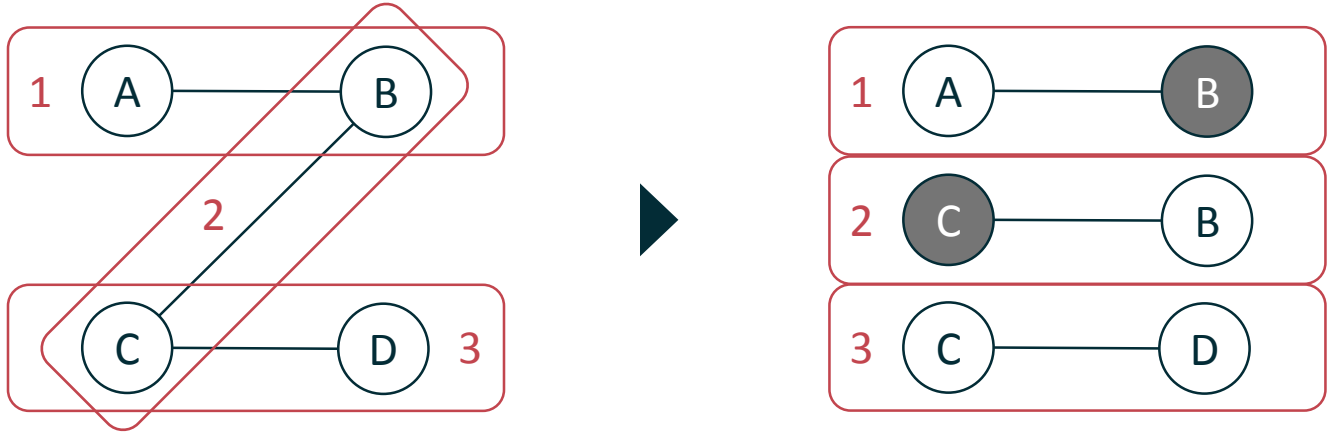
- Problem for BSP, as all nodes have to wait for stragglers at barrier

> Graph Partitioning

Partitioning



Edge-Cut



Vertex-Cut

* J. E. Gonzalez, Y. Low, H. Gu, D. Bickson, and C. Guestrin. *PowerGraph: Distributed graph-parallel computation on natural graphs.* In OSDI '12, pages 17–30, 2012

Relational Queries with Flink

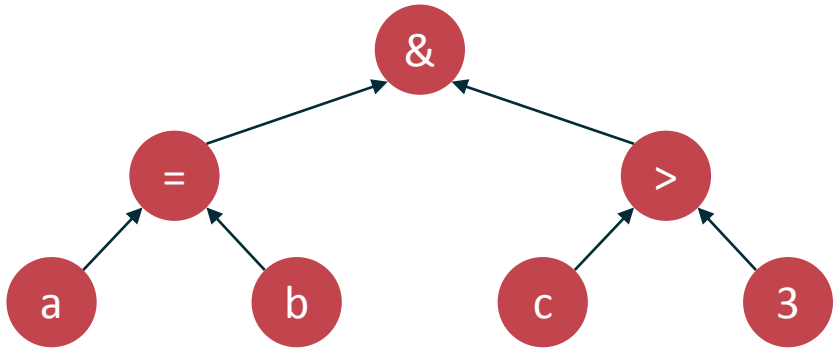
First Things First

```
Table activeUsers = users.join(clickCounts)
  .where(“id = userId && count > 10")
  .select(“username, count”);

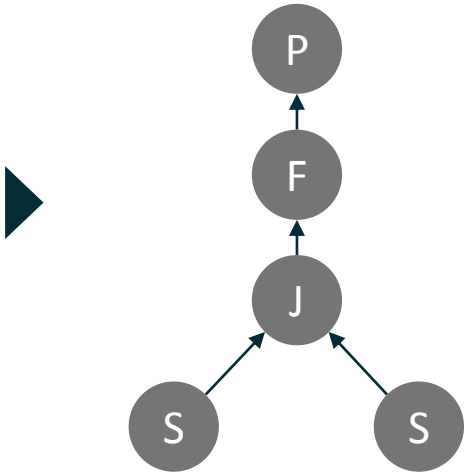
val activeUsers = users.join(clickCounts)
   .where('id === 'userId && 'count > 10)
   .select('username, 'count)
```

Under the Hood

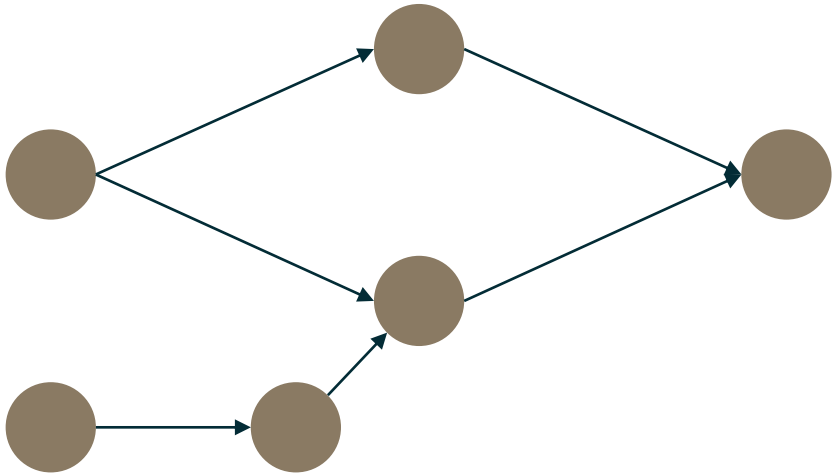
‘a === ‘b && ‘c > 3



AST



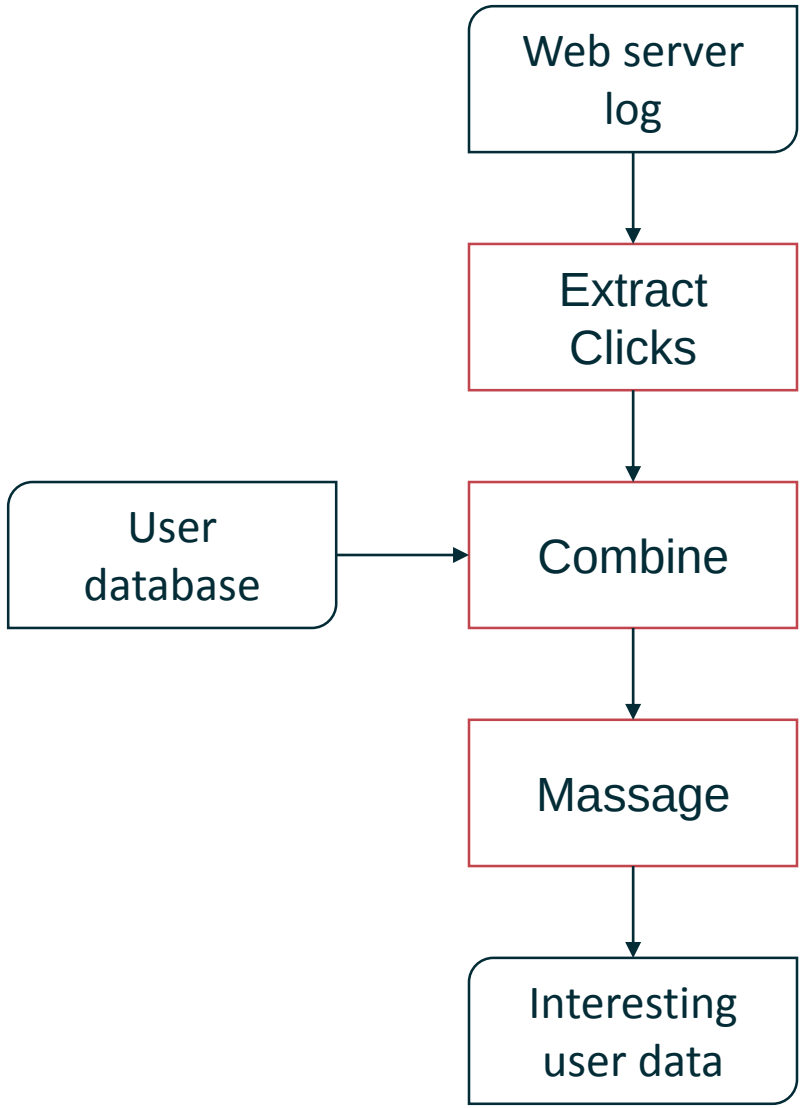
Logical Plan



Execution Plan

Log Analysis

- Collect clicks from a webserver log
- Find interesting URLs
- Combine with user data



Getting the clicks

```
ExecutionEvnironment env = ExecutionEnvironment.getExecutionEnvironment();

DataSet<String> log = env.readTextFile("hdfs:///log");

DataSet<Tuple2<String, Integer>> clicks = log.flatMap(
 (String line, Collector<Tuple2<String, Integer>> out) -> {
   String[] parts = in.split("*magic regex*");
   if (isClick(parts)) {
     out.collect(new Tuple2<>(parts[1], Integer.parseInt(parts[2])));
   }
 }
)
```

post	/foo/bar…	313
get	/data/pic.jpg	128
post	/bar/baz…	128
post	/hello/there…	42

Counting the clicks

```
TableEnvironment tableEnv = new TableEnvironment();

Table clicksTable = tableEnv.toTable(clicks, "url, userId");

Table urlClickCounts = clicksTable
.groupBy("url, userId")
.select("url, userId, url.count as count");
```

Getting the user information

```
Table userInfo = tableEnv.toTable(…, "name, id, …");

Table resultTable = urlClickCounts.join(userInfo)
 .where("userId = id && count > 10")
 .select("url, count, name, …");
```

Work with the result

```
class Result {
  public String url;
  public int count;
  public String name;
  …
}
DataSet<Result> set = tableEnv.toSet(resultTable, Result.class);
DataSet<Result> result =
  set.groupBy("url").reduceGroup(new ComplexOperation());
result.writeAsText("hdfs:///result");
env.execute();
```

Thank you for your attention

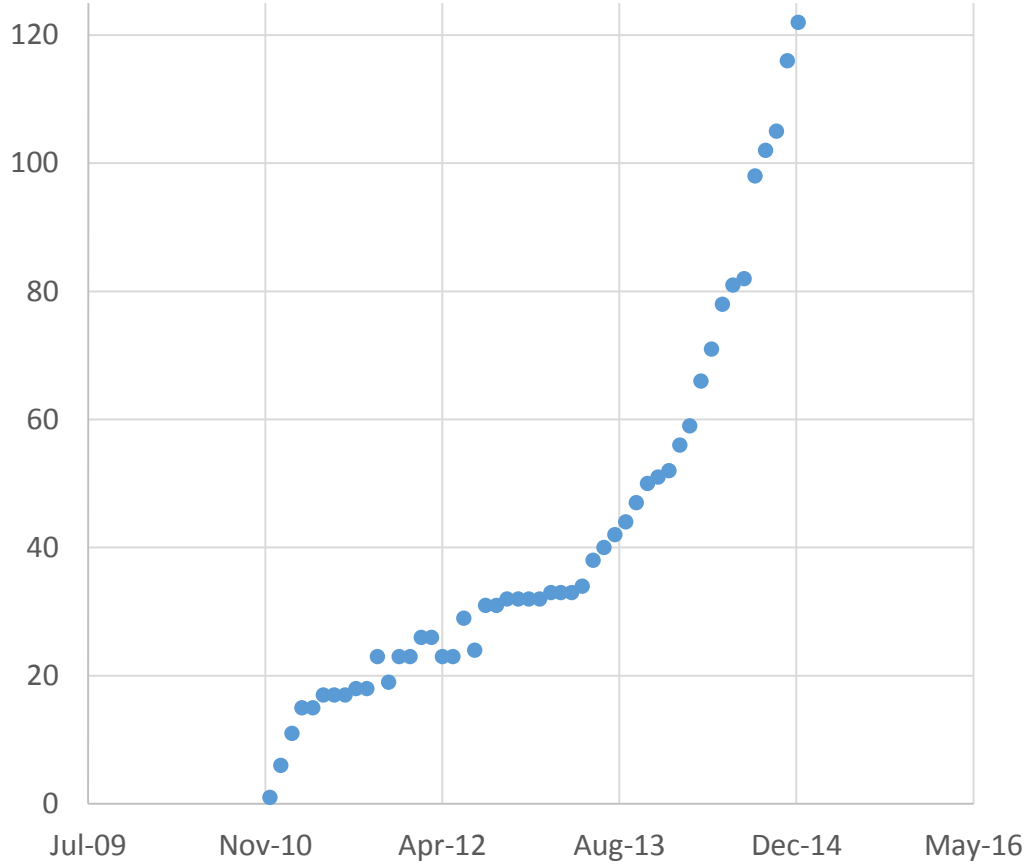
- Try it out
  https://flink.apache.org/

- Get involved
  https://github.com/apache/flink

  dev@flink.apache.org

  news@flink.apache.org

  @ApacheFlink



#unique contributors by git commits
(without manual de-dup)

Emma

Alexandrov, A., Kunft, A., Katsifodimos, A., Schüler, F., Thamsen, L., Kao, O., ... & Markl, V. (2015, May).

Implicit Parallelism through Deep Language Embedding.

In Proceedings of the 2015 ACM SIGMOD International Conference on Management of Data (pp. 47-61). ACM.

API Evolution and its Pitfalls

- Systems like Cascading, Spark, Flink rely on shallowly embedded APIs (“pure libraries”)
- Additional runtime features have to be exposed explicitly
- No holistic view of dataflow program

K-Means in Emma

```
while (change < epsilon) {
  val clusters = (for (p <- points) yield {
    val c = ctrds.minBy(distanceTo(p)).get
    Solution(c.id, p.p)
  }).groupBy(_.cid)
  // compute new centroids
  val newCtrds = for (clr <- clusters) yield {
    val sum = clr.values.map(_.p.pos).sum()
    val cnt = clr.values.map(_.p.pos).cnt()
    Point(c.key, sum / cnt)
  }
  // compute the total change in all centroids
  change = {
    val distances = for (
      x <- ctrds;
      y <- newCtrds; if x.id == y.id) yield dist(x, y)
    distances.sum()
  }
  // use the new centroids in the next iteration
  ctrds = newCtrds
}
```

Implicit pipelining

```
while (change < epsilon) {
  val clusters = (for (p <- points) yield {
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}
```

clusters only used once

distances only used once

Aggregations

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Aggregations not spread in UDFs

Comprehension syntax

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```
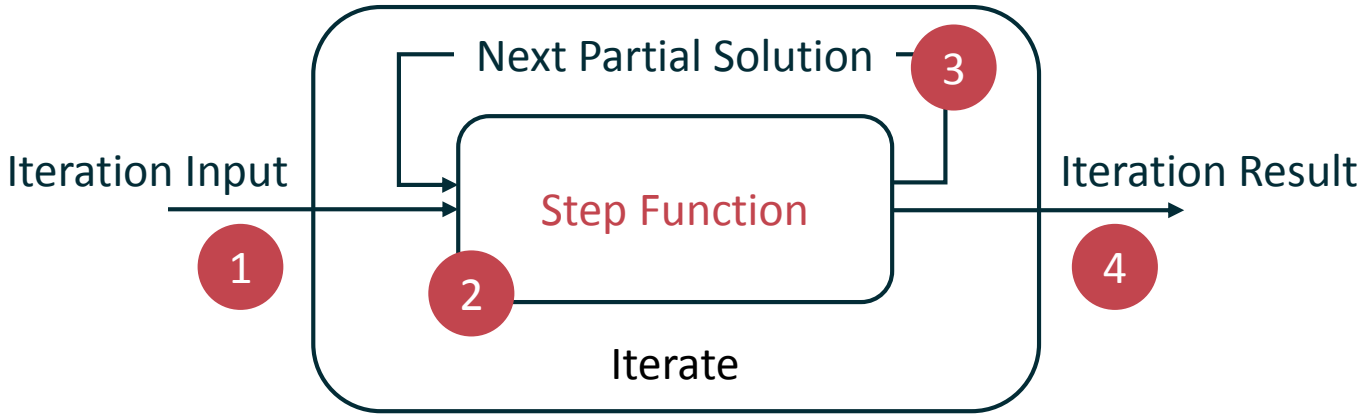

Comprehension syntax hides map

Comprehension syntax hides join

Backup slides

Flink Bulk Iteration



1. Initial input for first iteration from data source / previous operators
2. Arbitrary data flow that is executed in each iteration
3. Output of step function is fed back into next iteration
4. Output of last iteration is written to data sink / following operators

PageRank

```
DataSet<Edge<Long, Double>> links = getLinksDataSet(env);
Graph<Long, Double, Double> network = Graph.fromDataSet(links, new MapFunction<Long, Double>() {
 public Double map(Long value) throws Exception {
  return 1.0;
 }
}, env);


DataSet<Tuple2<Long, Long>> vertexOutDegrees = network.outDegrees();
Graph<Long, Double, Double> networkWithWeights = network.joinWithEdgesOnSource(vertexOutDegrees,
 new MapFunction<Tuple2<Double, Long>, Double>() {
  public Double map(Tuple2<Double, Long> value) {
   return value.f0 / value.f1;
  }
});


DataSet<Vertex<Long, Double>> pageRanks = networkWithWeights.run(
 new PageRankAlgorithm<Long>(DAMPENING_FACTOR, maxIterations)
).getVertices();
```

PageRank

```
public Graph<K, Double, Double> run(Graph<K, Double, Double> network) throws Exception {
  final long numberOfVertices = network.numberOfVertices();
  return network.runVertexCentricIteration(new VertexRankUpdater<K>(beta, numberOfVertices),
  new RankMessenger<K>(numberOfVertices), maxIterations);
}
```

```
public void updateVertex(Vertex<K, Double> vertex, MessageIterator<Double> inMessages) {
  double rankSum = 0.0;
  for (double msg : inMessages) {
    rankSum += msg;
  }
  double newRank = (beta * rankSum) + (1 - beta) / numVertices;
  setNewVertexValue(newRank);
}
```

```
public void sendMessages(Vertex<K, Double> vertex) {
  if (getSuperstepNumber() == 1) {
    vertex.setValue(new Double(1.0 / numVertices));
  }
  for (Edge<K, Double> edge : getEdges()) {
    sendMessageTo(edge.getTarget(), vertex.getValue() * edge.getValue());
  }
}
```