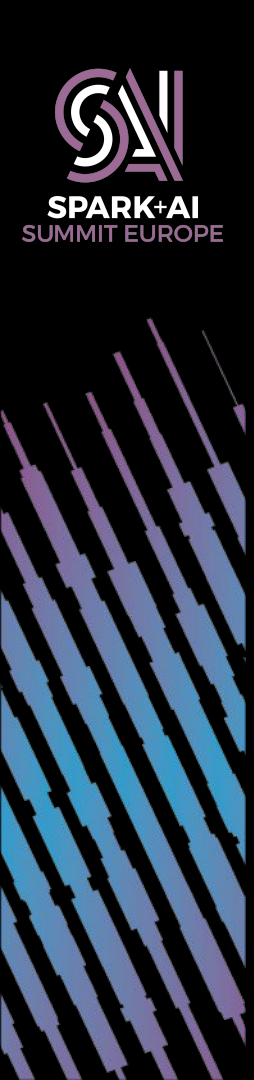


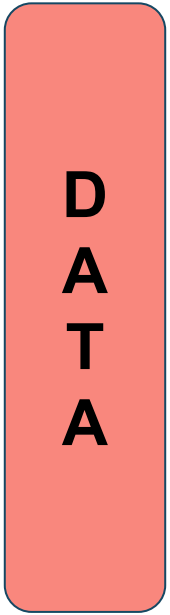
Extending Structured Streaming Made Easy with Algebra

Erik Erlandson
Red Hat, Inc.

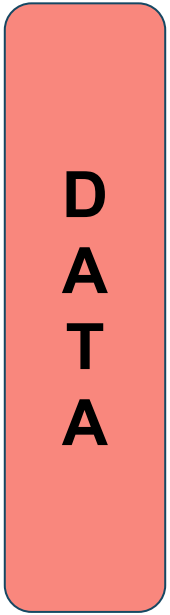
eje@redhat.com
@manyangled

#SAISDev2

In The Beginning



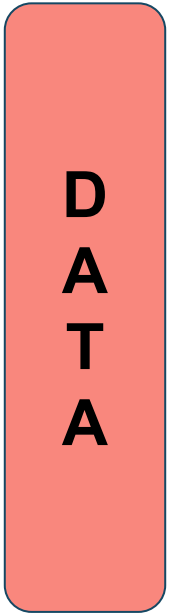
In The Beginning



1 Data Set

In The Beginning

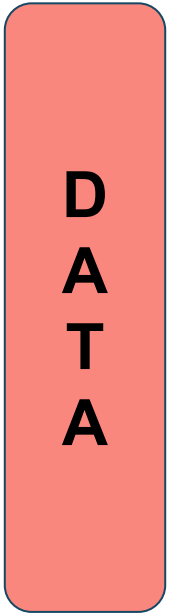
1 File



1 Data Set

In The Beginning

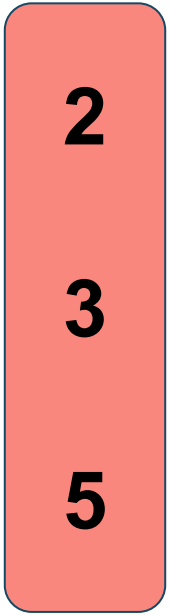
1 File



1 Data Set

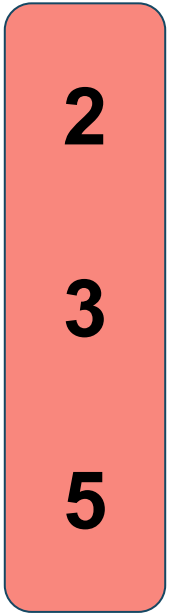
1 Machine

Sum

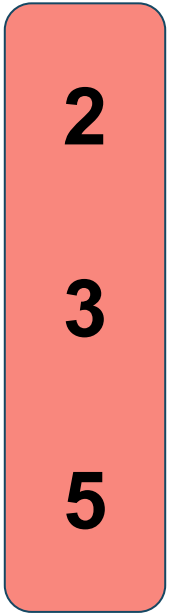


Sum

s = 0

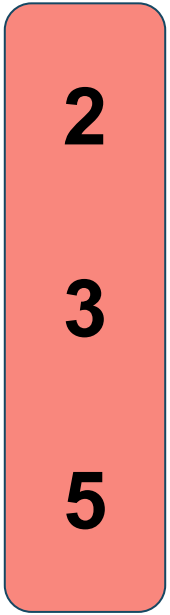


Sum



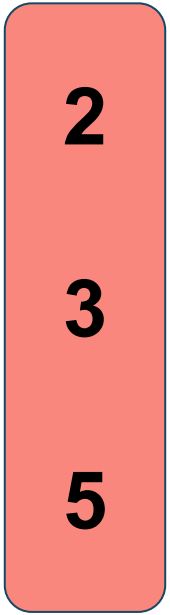
$s = s + 2 \quad (2)$

Sum



s = s + 3 (5)

Sum



s = s + 5 (10)

Commodity Scale-Out

2003 Google FS

2004 MapReduce

Commodity Scale-Out

2003	Google FS
2004	MapReduce
2006	Hadoop & HDFS

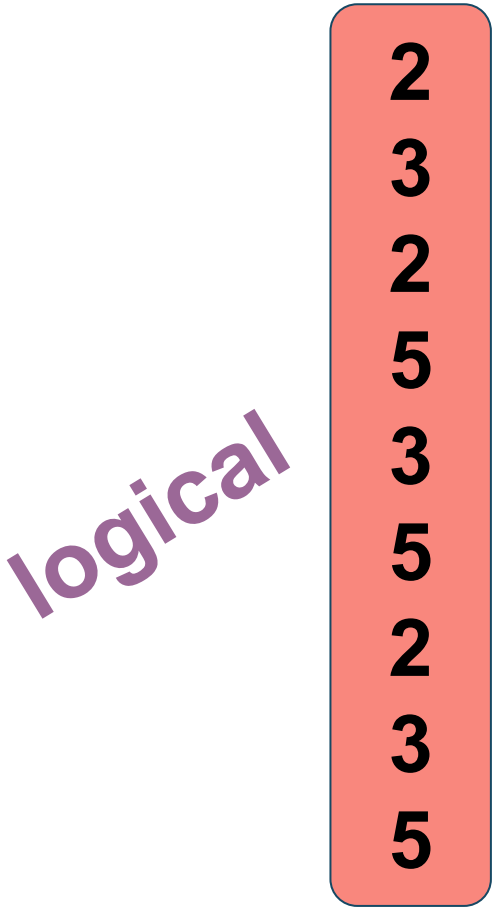
Commodity Scale-Out

2003	Google FS
2004	MapReduce
2006	Hadoop & HDFS
2009	Spark & RDD

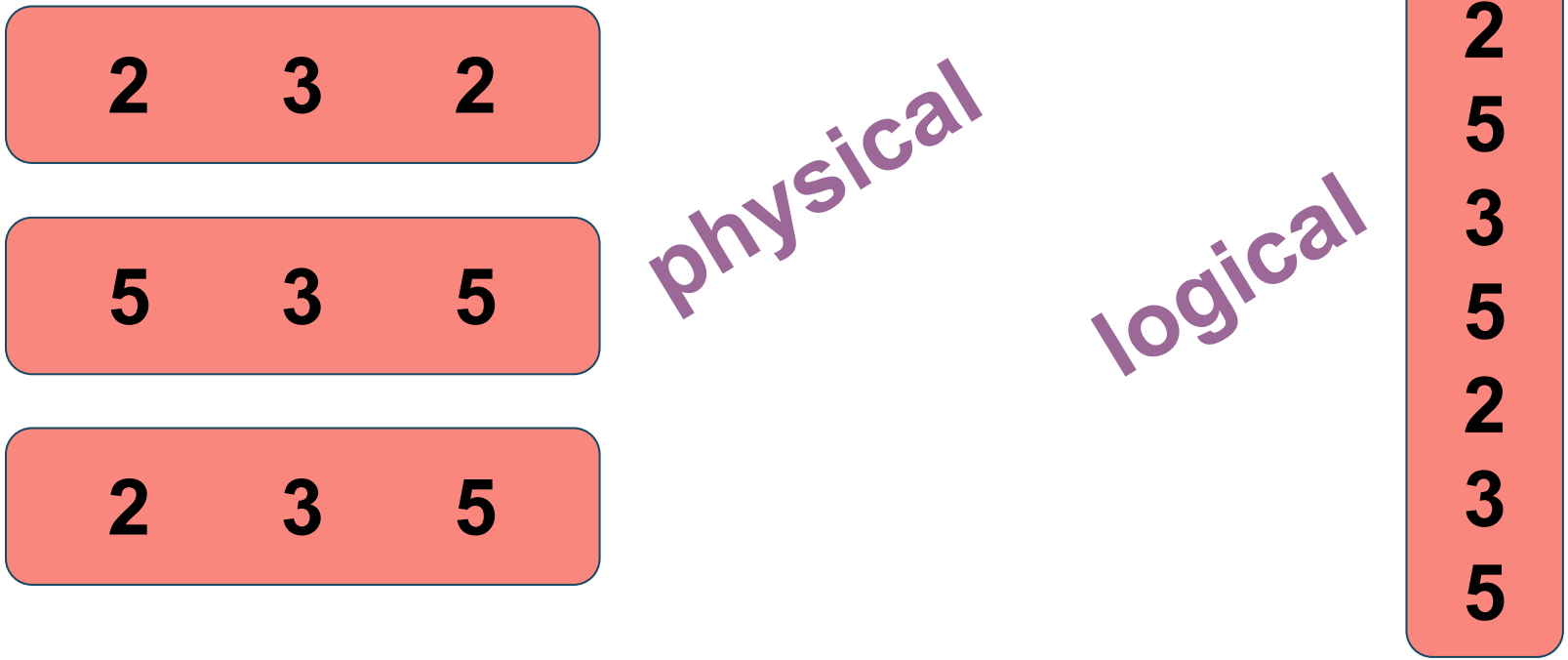
Commodity Scale-Out

2003	Google FS
2004	MapReduce
2006	Hadoop & HDFS
2009	Spark & RDD
2015	DataFrame
2016	Structured Streaming

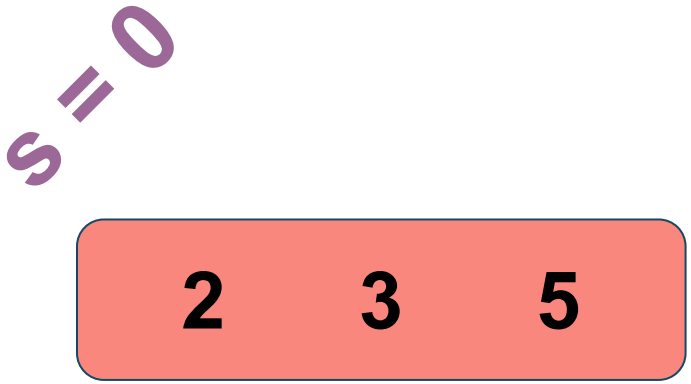
Our Scale-Out World



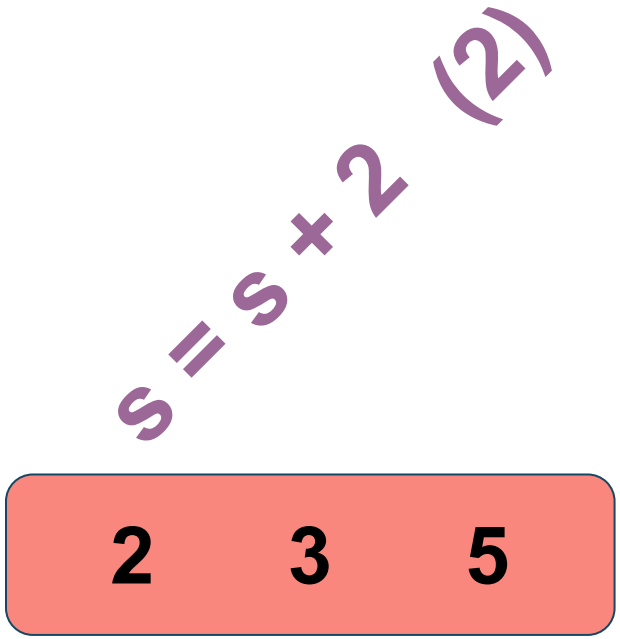
Our Scale-Out World



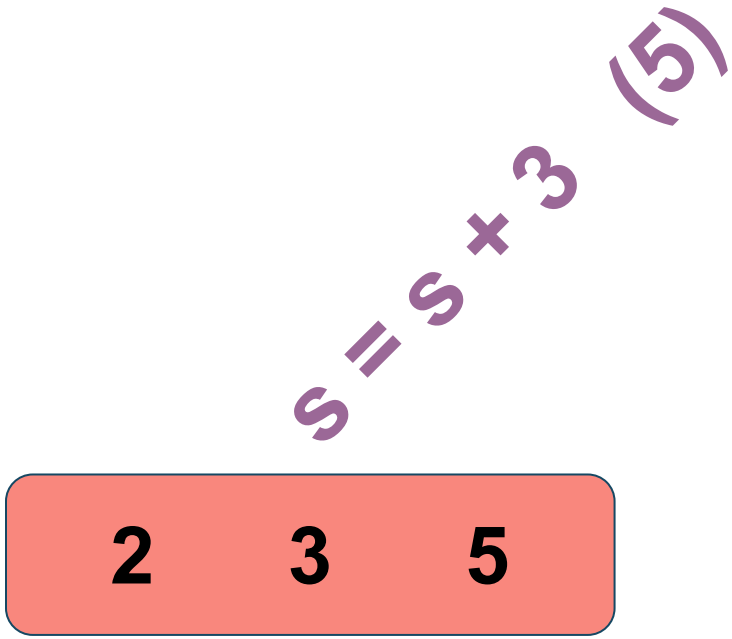
Scale-Out Sum



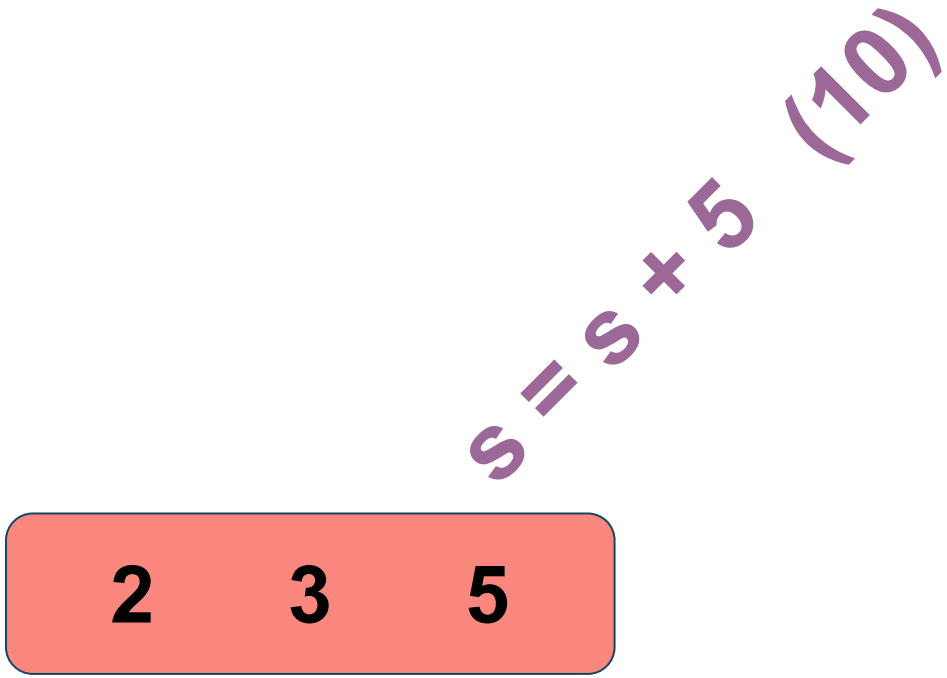
Scale-Out Sum



Scale-Out Sum



Scale-Out Sum



Scale-Out Sum

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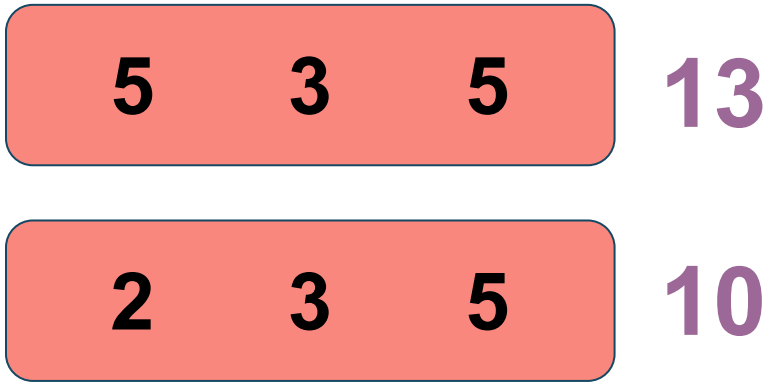
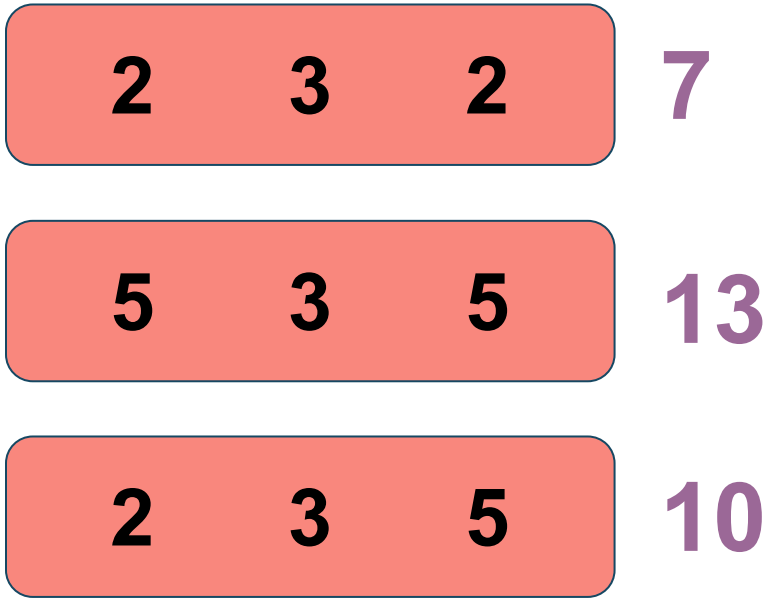
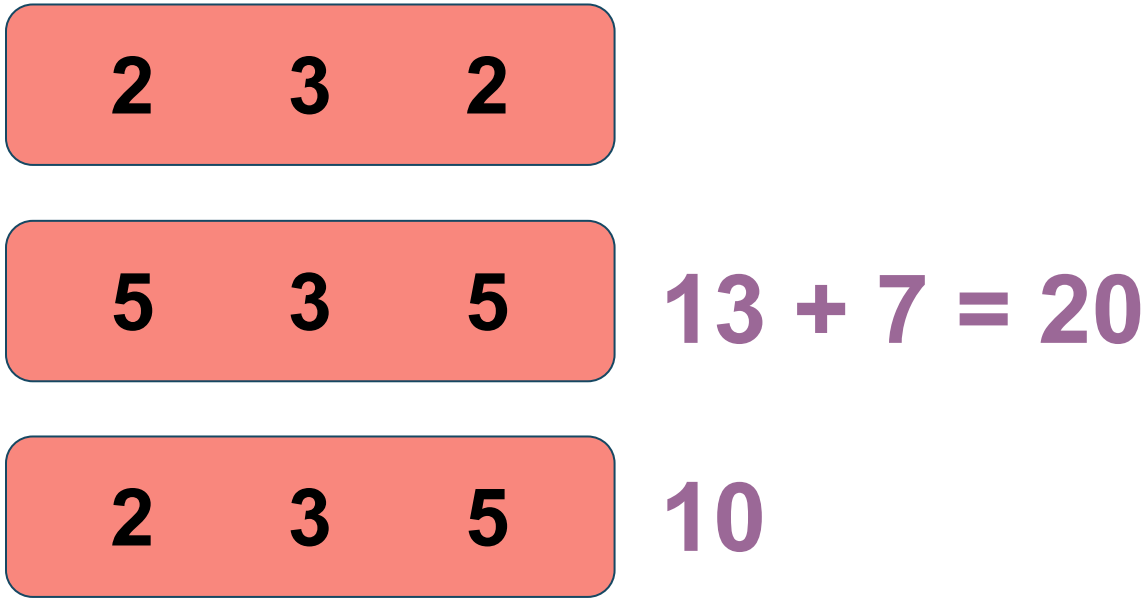


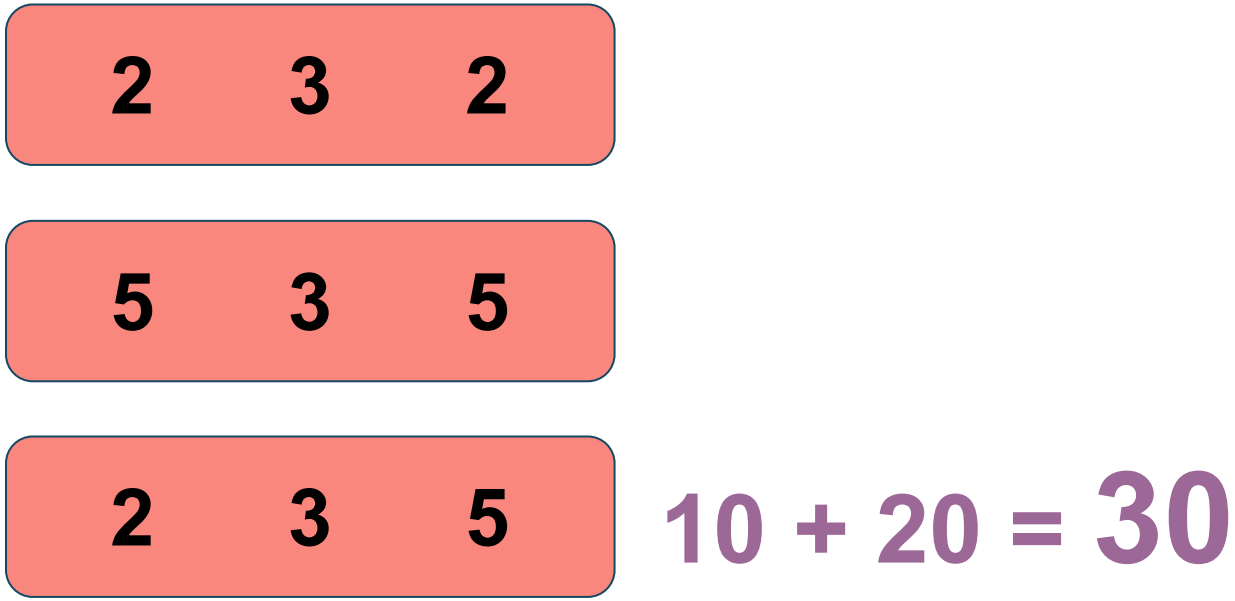
Scale-Out Sum



Scale-Out Sum

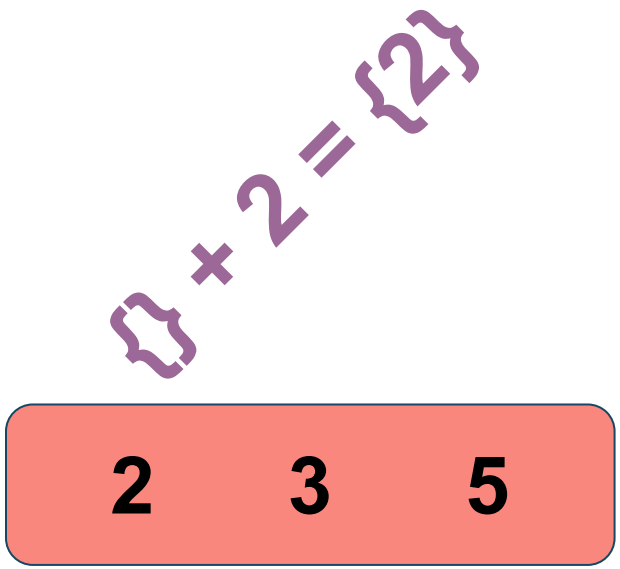


Scale-Out Sum



Unique

Unique



Unique

{2} + 3 = {2, 3}

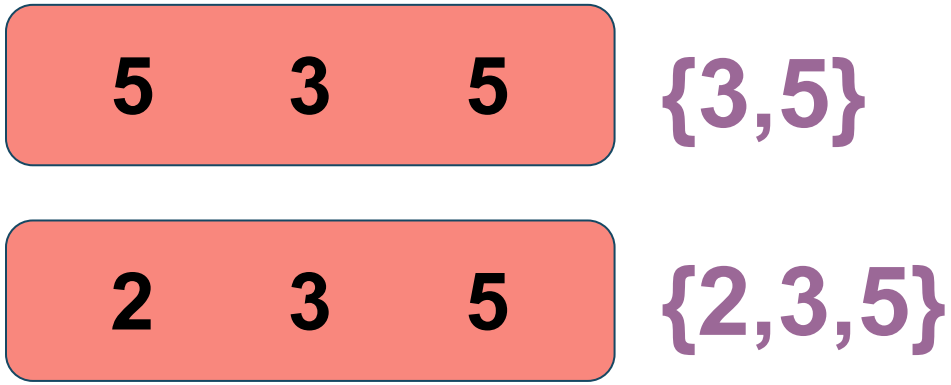
Unique

{2,3} + 5 = {2,3,5}

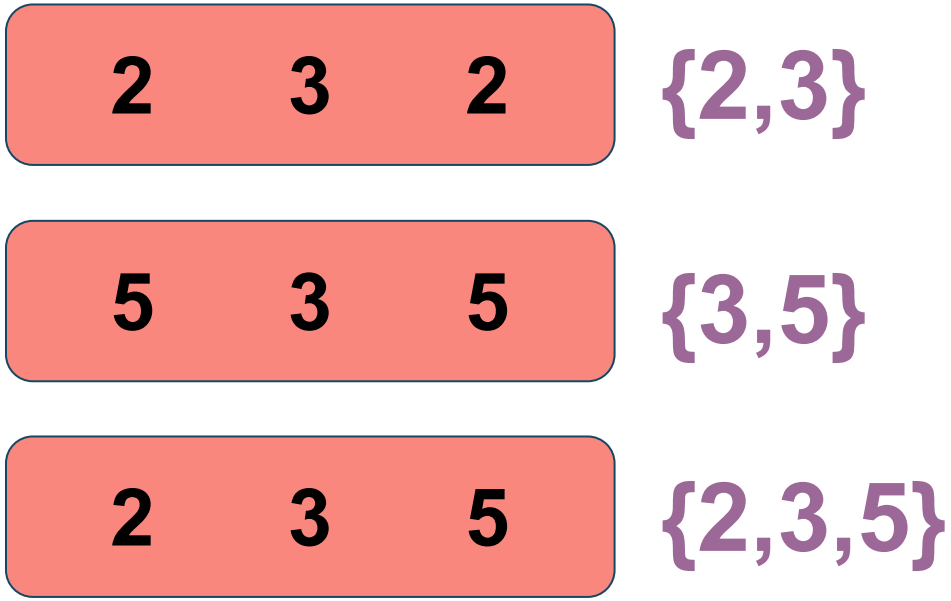
Unique

{2,3,5}

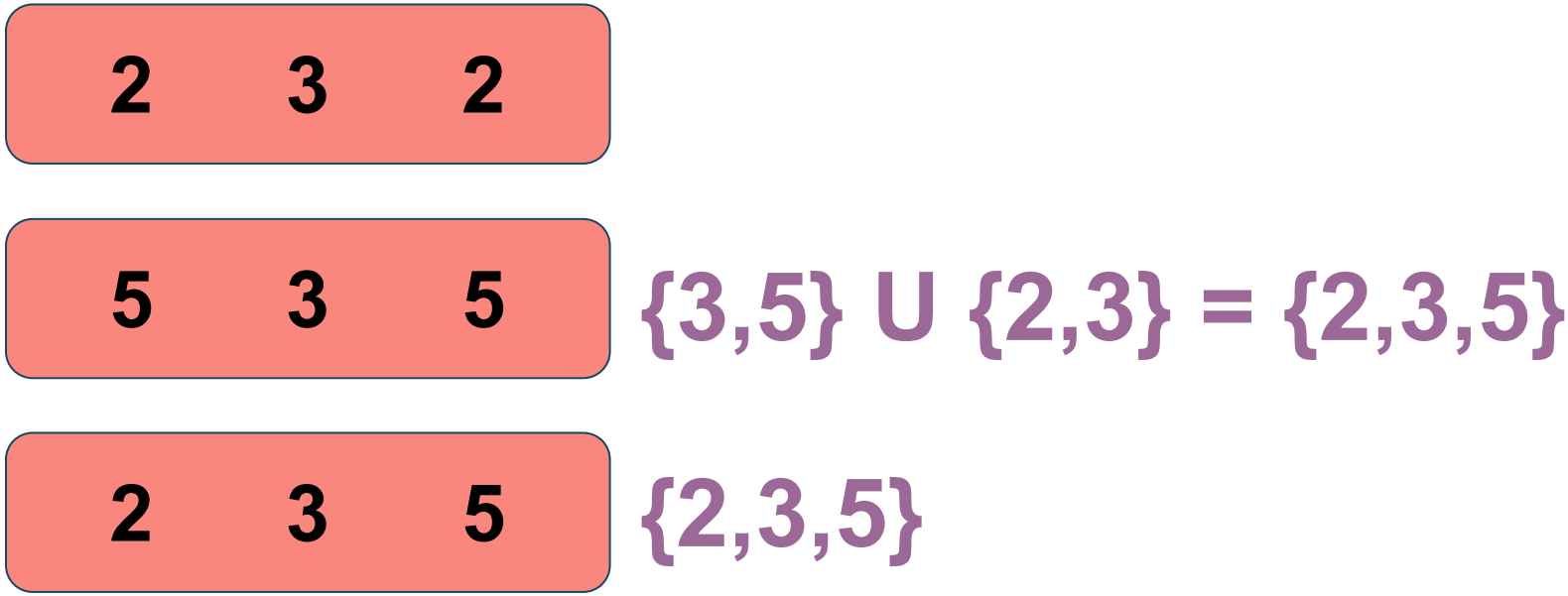
Unique



Unique



Unique



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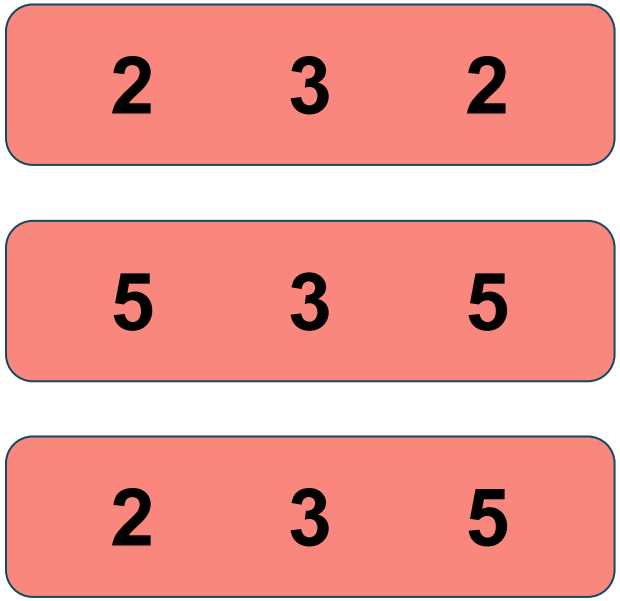

{2,3,5} U {2,3,5} = {2,3,5}

Patterns

Examples	Sum	Unique	Pattern
`s = 0` `s = {}`	0	{}	zero (aka identity)

Patterns

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`2 + 3 = 5` `{2} + 3 = {2, 3}`	addition	set insertion	update (aka reduce)

Patterns

Examples	Sum	Unique	Pattern
`s = 0` `s = {}`	0	{ }	zero (aka identity)
`2 + 3 = 5` `{2} + 3 = {2, 3}`	addition	set insertion	update (aka reduce)
`13 + 7 = 20` `{3,5} U {2,3} = {2,3,5}`	addition	set union	merge (aka combine)

Spark Operators

Operation	Data	Accumulator	Zero	Update	Merge
Sum	Numbers	Number	0	a + x	a1 + a2

Spark Operators

Operation	Data	Accumulator	Zero	Update	Merge
Sum	Numbers	Number	0	a + x	a1 + a2
Max	Numbers	Number	-∞	max(a, x)	max(a1, a2)

Spark Operators

Operation	Data	Accumulator	Zero	Update	Merge
Sum	Numbers	Number	0	a + x	a1 + a2
Max	Numbers	Number	-∞	max(a, x)	max(a1, a2)
Average	Numbers	(sum, count)	(0, 0)	(sum + x, count + 1)	(s1 + s2, c1 + c2)

Present
sum / count

Shhhhh...

Operation	Data	Accumulator	Zero	Update	Merge
Sum	Numbers	Number	0	a + x	a1 + a2
Max	Numbers	Number	-∞	max(a, x)	max(a1, a2)
Average	Numbers	(sum, count)	(0, 0)	(sum + x, count + 1)	(s1 + s2, c1 + c2)

We're secretly algebras!

Algebras are Pattern Checklists

Object Sets
(data types)

Algebras are Pattern Checklists

Object Sets
(data types) ✔

Operations ✔

Algebras are Pattern Checklists

Object Sets (data types) ✔

Operations ✔

Properties ✔

DataFrame Aggregations...

```
records.show(5)
```

```
+----------+---------+
|   user_id|wordcount|
+----------+---------+
|6458791872|       12|
|7699035787|        5|
|2509155359|        9|
|9914782373|       18|
|7816616846|       12|
+----------+---------+
```

```
records.groupBy($"user_id")
  .agg(avg($"wordcount").alias("avg"))
  .orderBy($"avg".desc)
  .show(5)
```

```
+----------+----+
|   user_id| avg|
+----------+----+
|9438801796|42.0|
|0837938601|41.0|
|0004926696|40.0|
|7439949213|39.0|
|2505585758|39.0|
+----------+----+
```

DataFrame Aggregations...

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+----------+---------+
```

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|0004926696|40.0|
|7439949213|39.0|
|2505585758|39.0|
+----------+----+
```
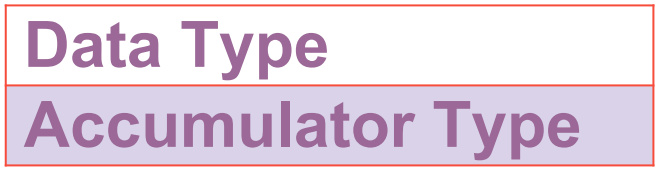

Are Algebras!

Aggregator Algebra

Data Type

Aggregator Algebra



Aggregator Algebra

Data Type
Accumulator Type
Zero

Aggregator Algebra

Data Type
Accumulator Type
Zero
Update

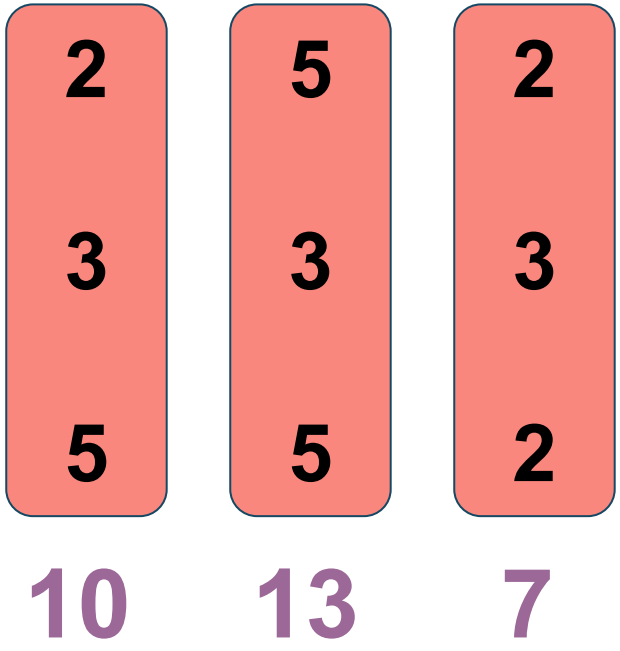
Aggregator Algebra

Data Type
Accumulator Type
Zero
Update
Merge

Aggregator Algebra

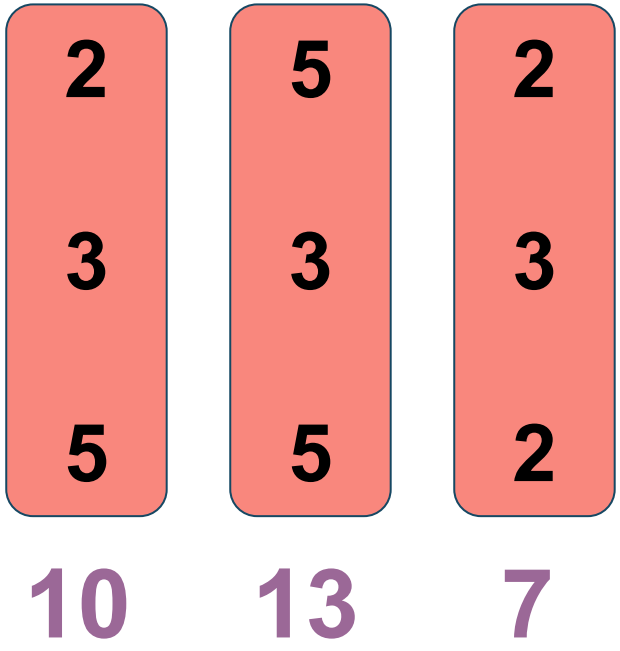
Data Type
Accumulator Type
Zero
Update
Merge
Present

Merge Is Associative



(10 + 13) + 7 = 30

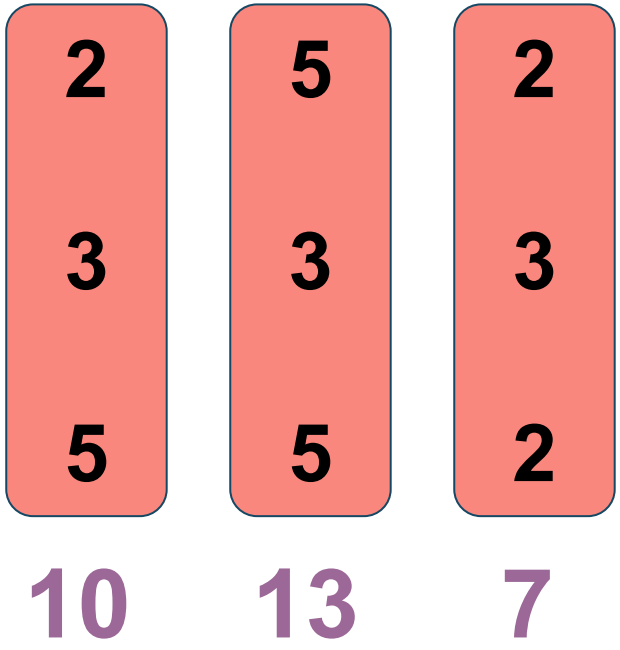
Merge Is Associative



(10 + 13) + 7 = 30

10 + (13 + 7) = 30

Merge Is (usually) Commutative



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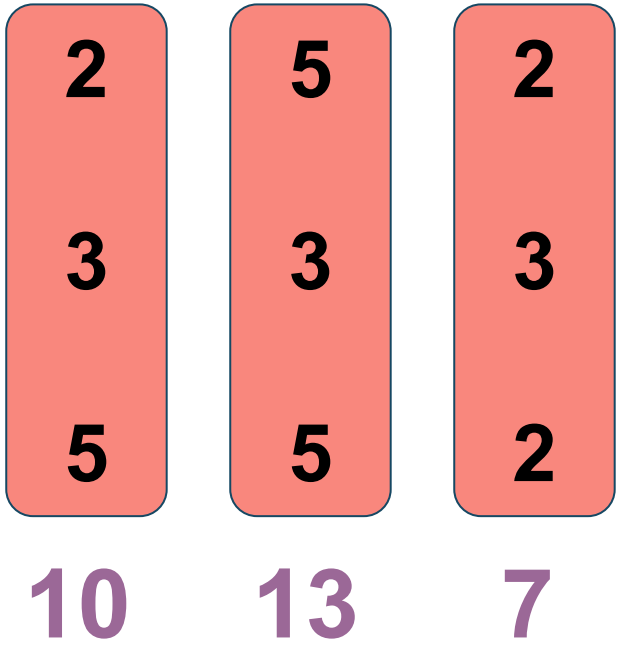
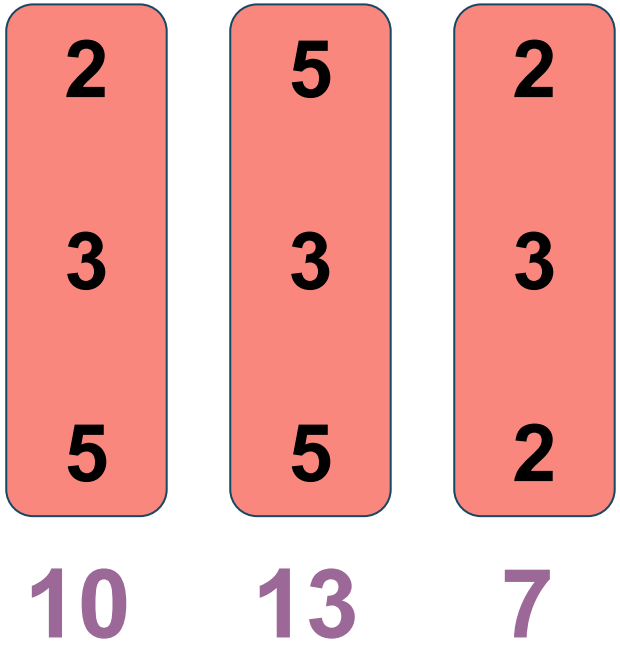
Merge Is (usually) Commutative



10 + 13 + 7 = 30

13 + 7 + 10 = 30

Merge Is (usually) Commutative



sum	a1 + a2 = a2 + a1
max	max(a1, a2) = max(a2, a1)
avg	(s1+s2, n1+n2) = (s2+s1, n2+n1)

Structured Streaming

user	wordcount
a	5
c	7

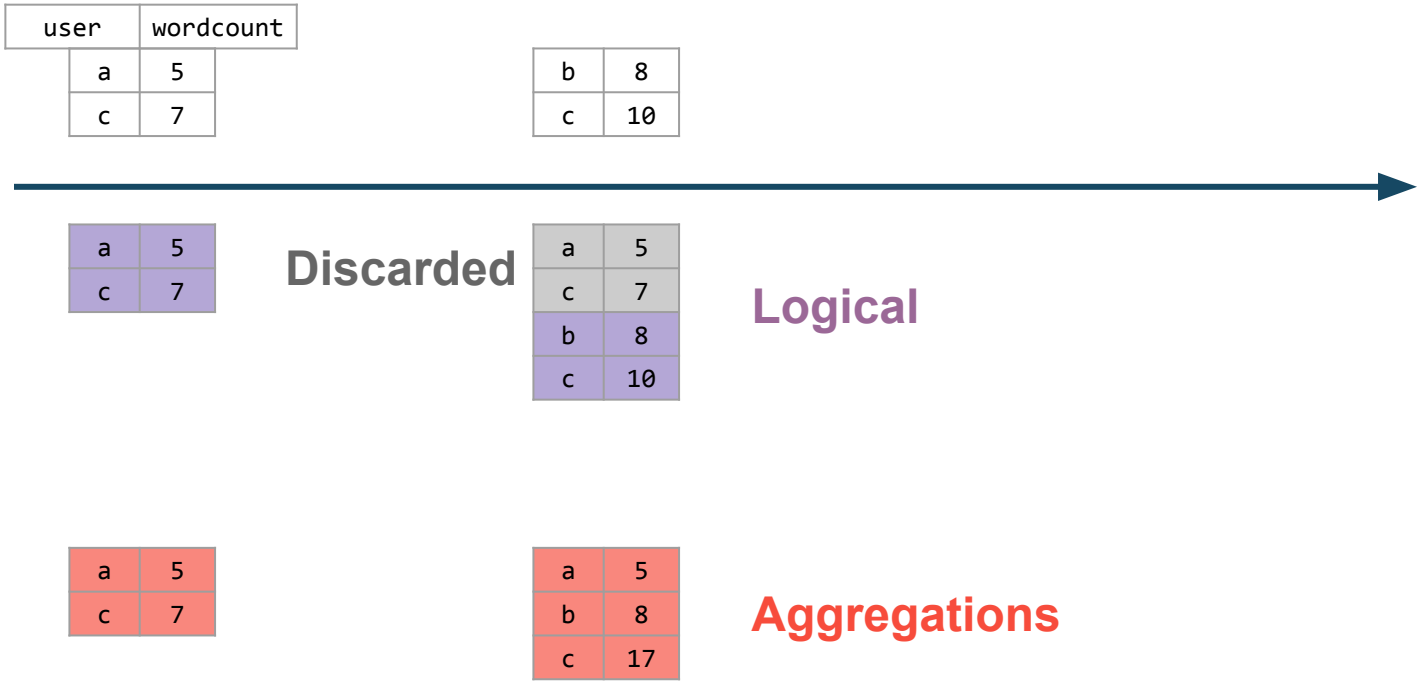
a	5
c	7

Logical

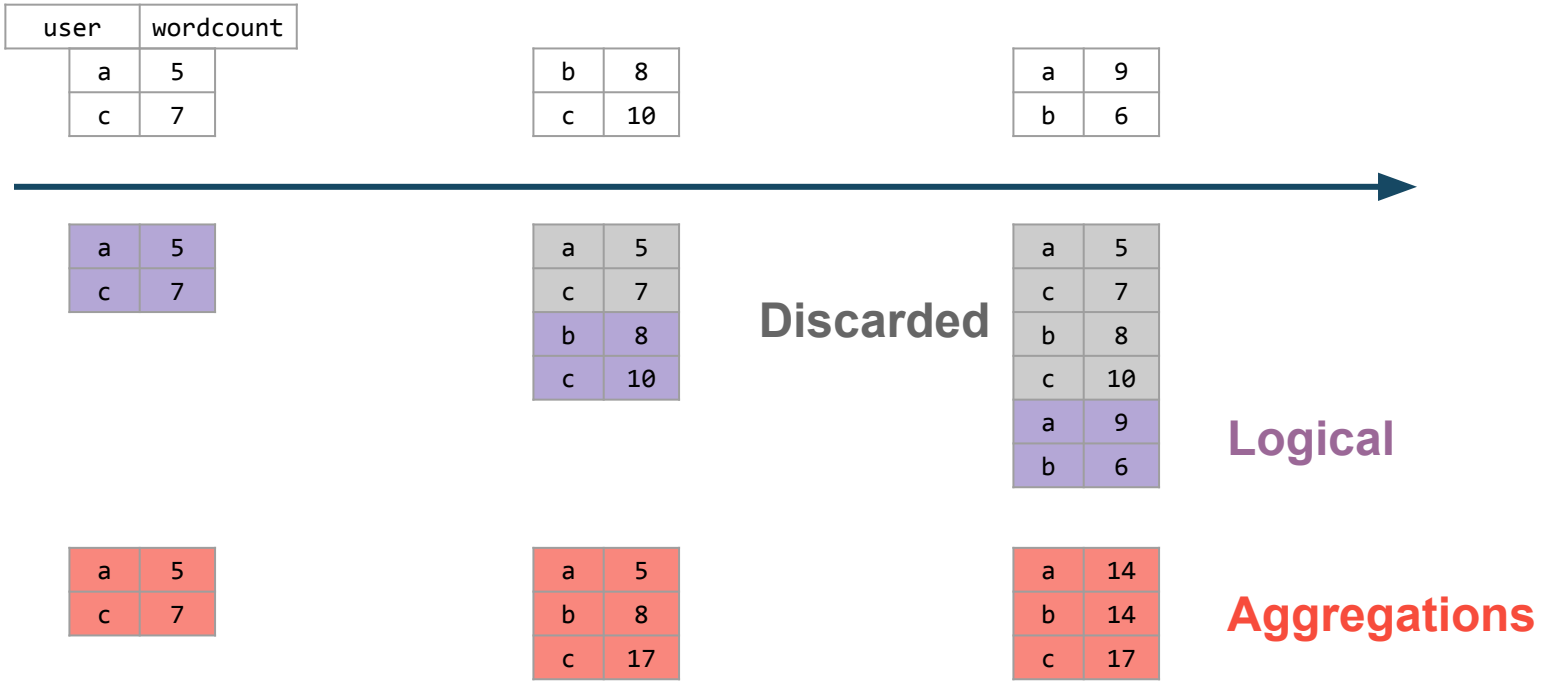
a	5
c	7

Aggregations

Structured Streaming



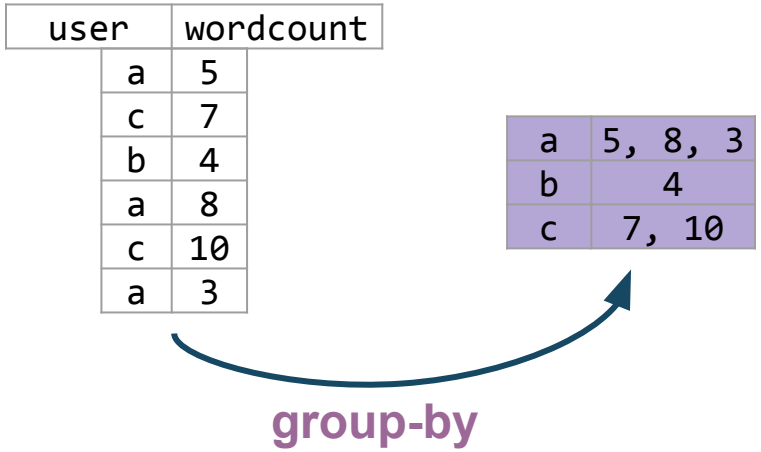
Structured Streaming



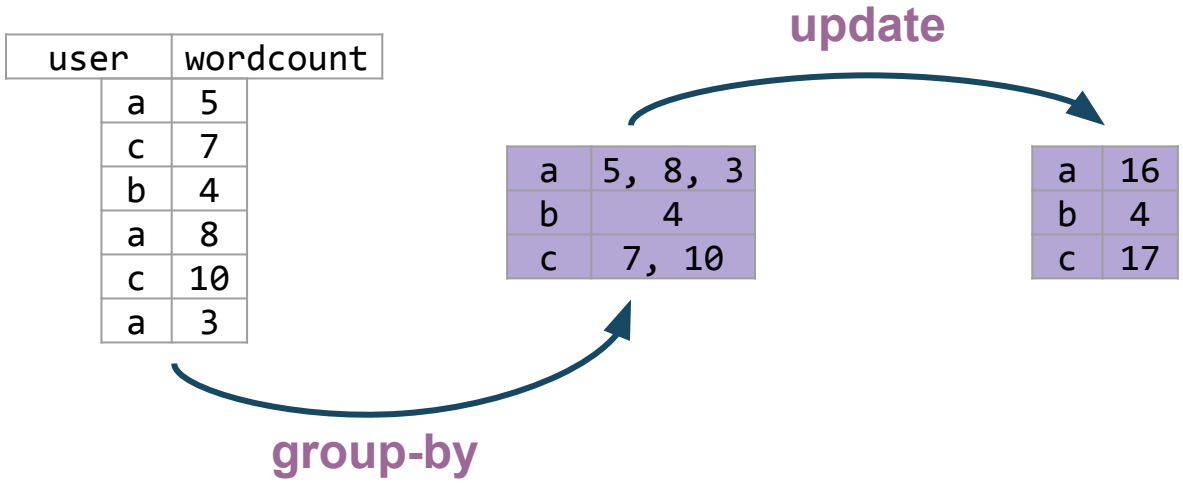
Structured Streaming

user	wordcount
a	5
c	7
b	4
a	8
c	10
a	3

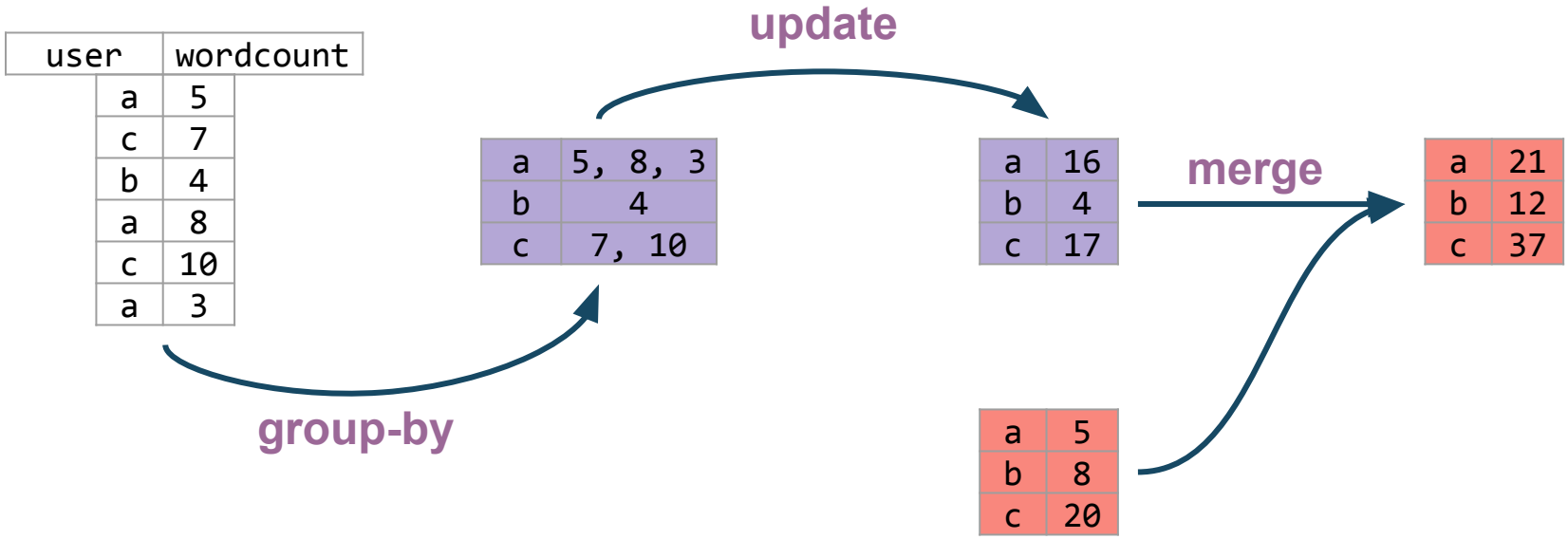
Structured Streaming



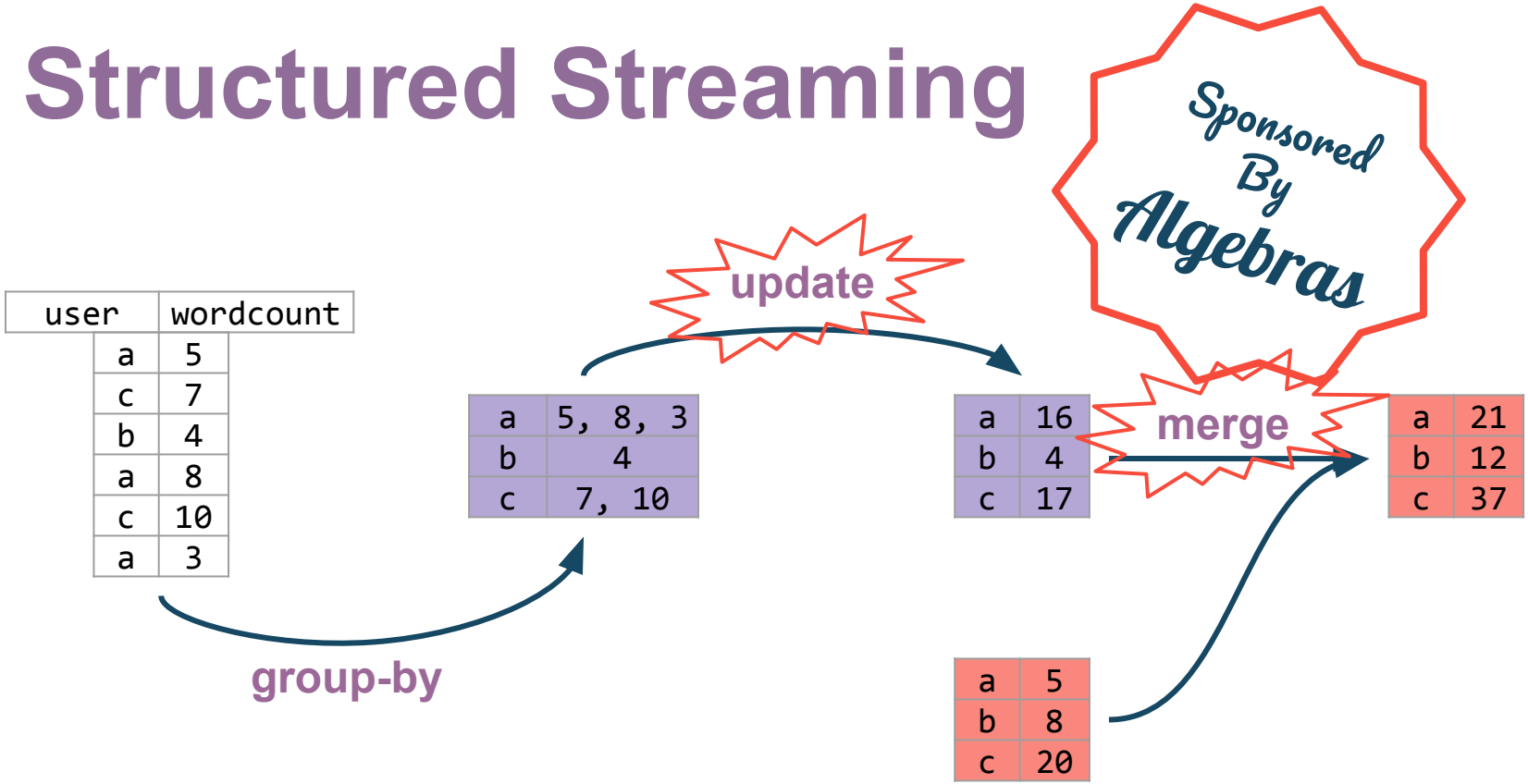
Structured Streaming



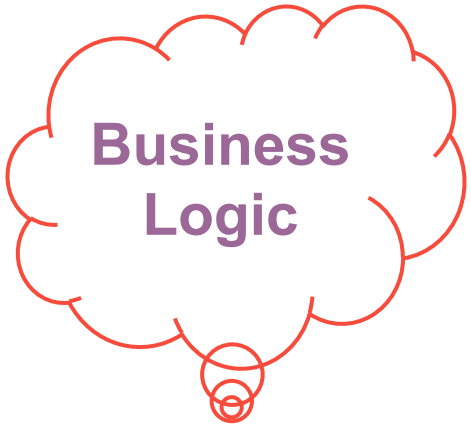
Structured Streaming



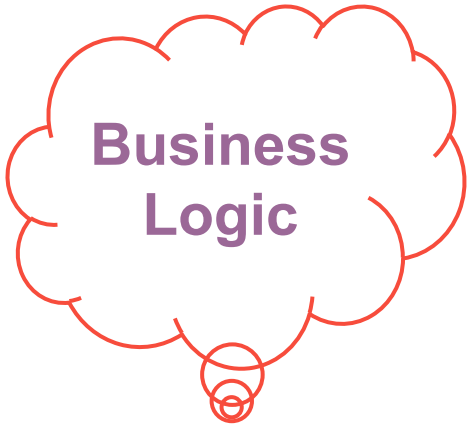
Structured Streaming



Algebras Around Us

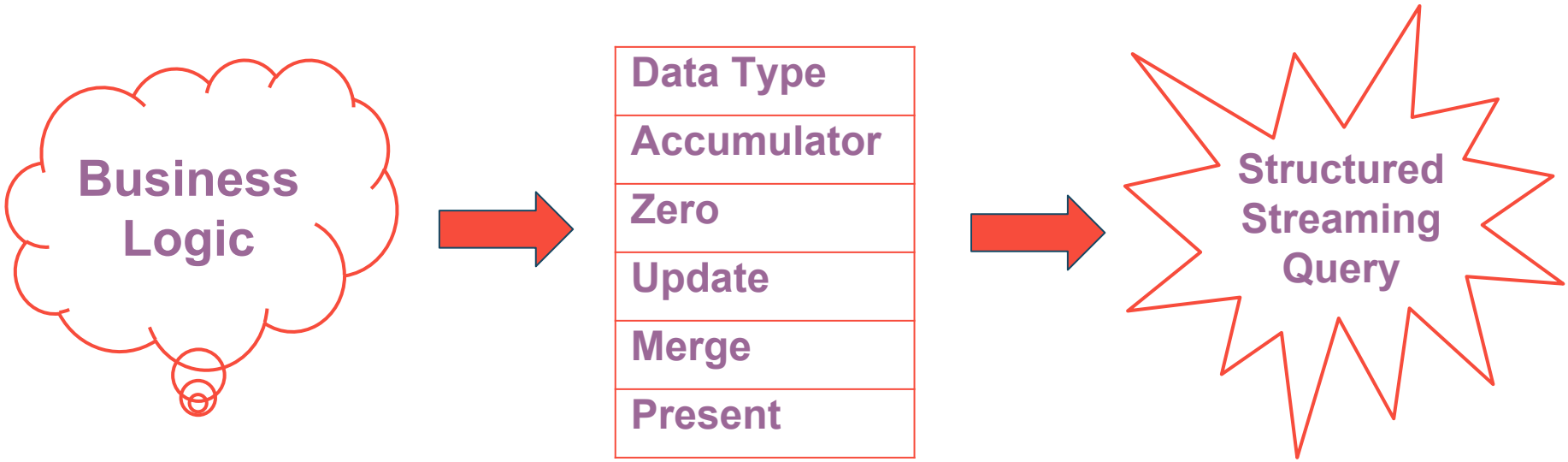


Algebras Around Us

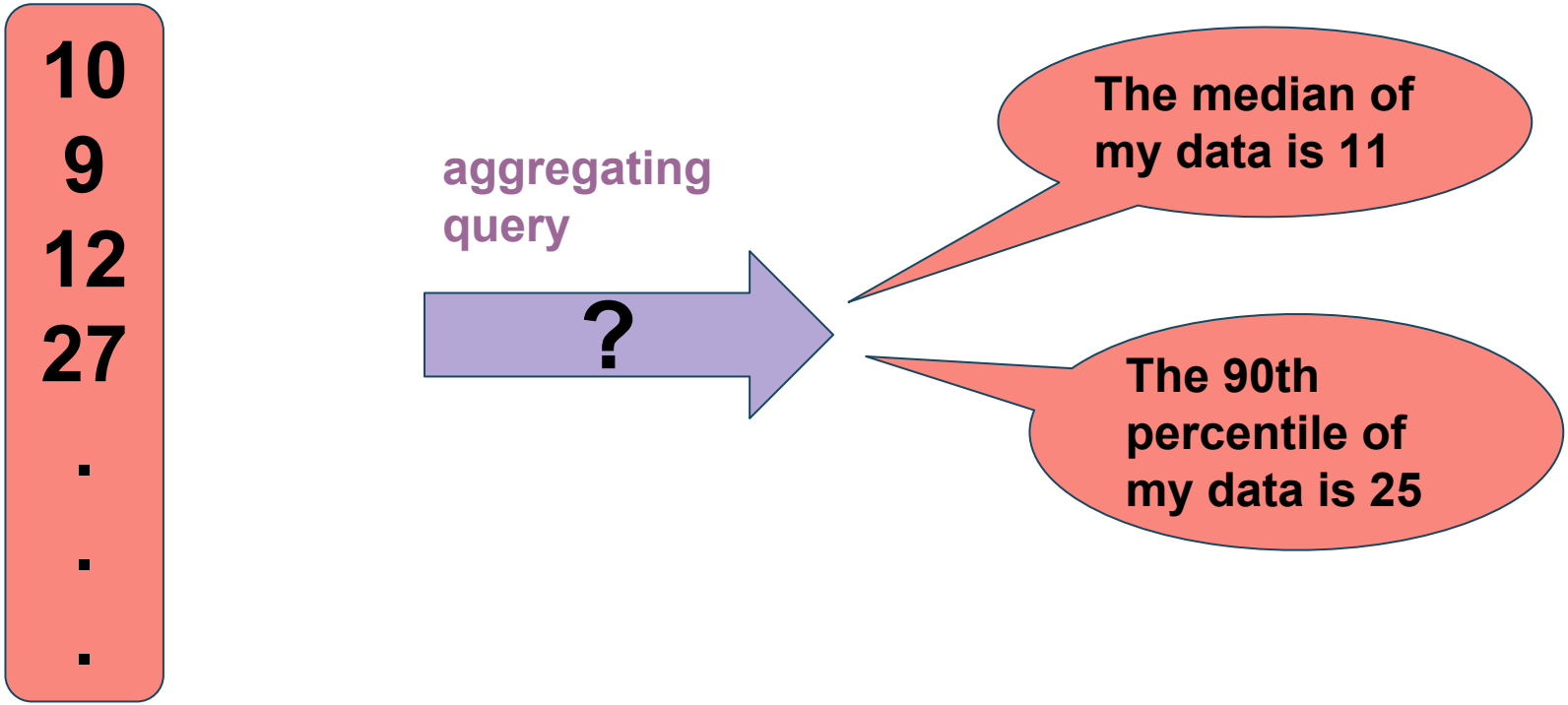


Data Type
Accumulator
Zero
Update
Merge
Present

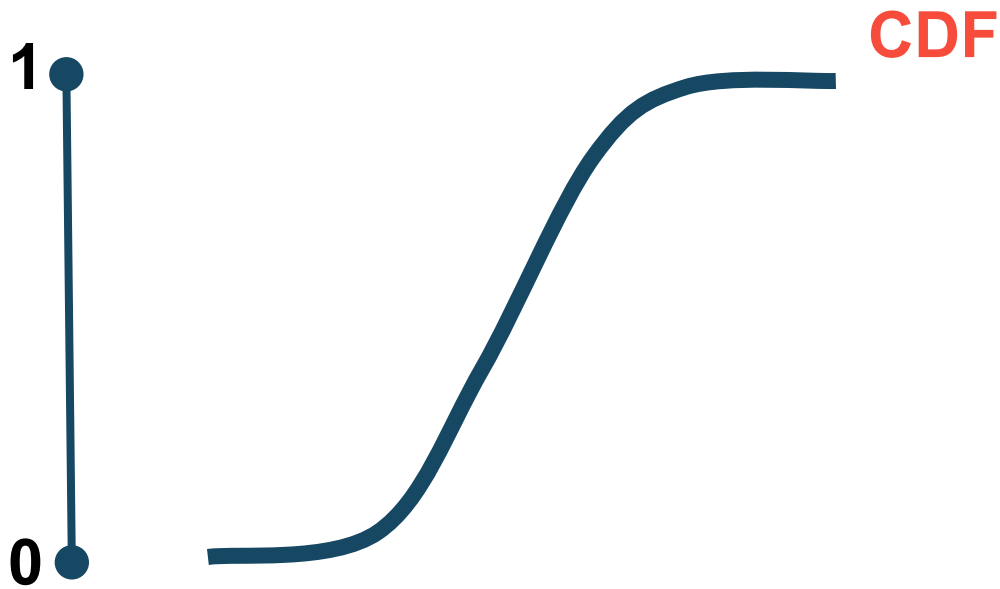
Algebras Around Us



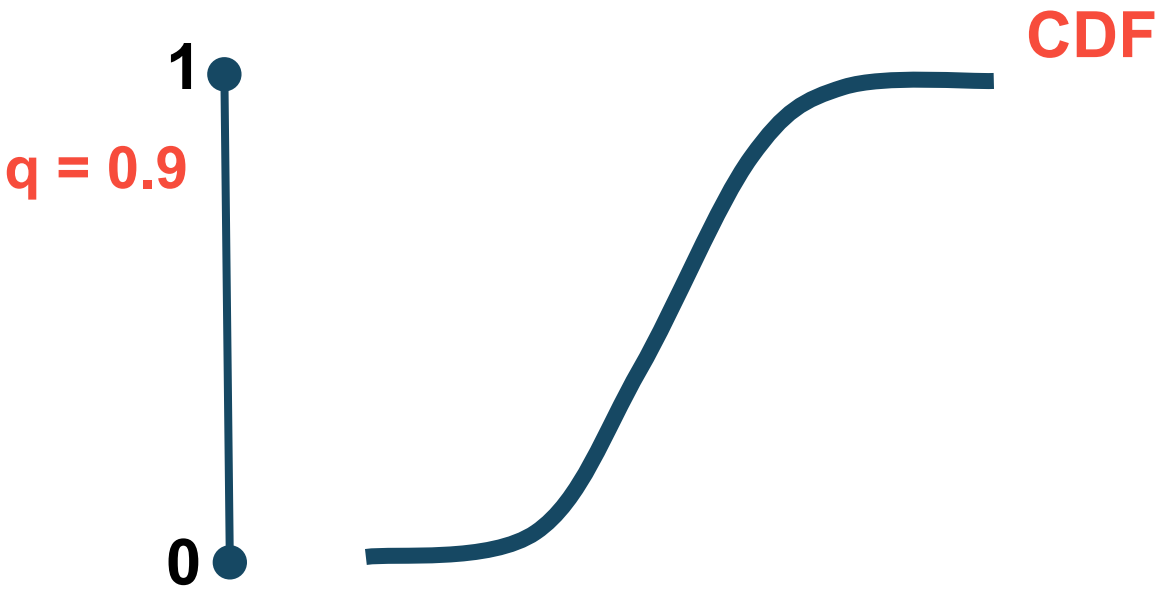
Aggregating Quantiles



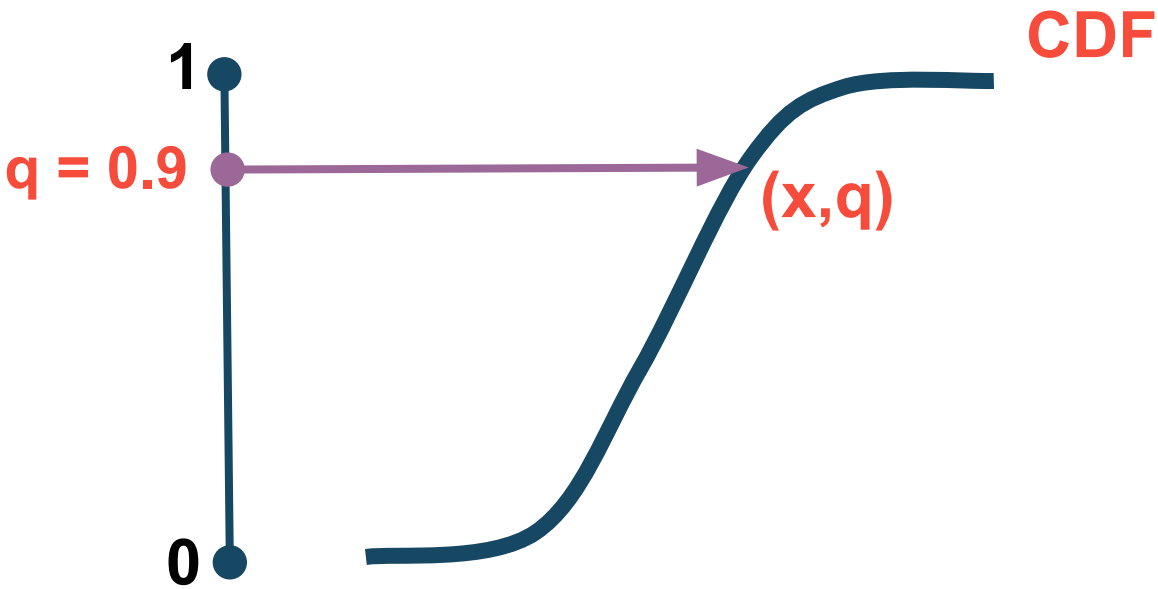
Distribution Sketch: T-Digest



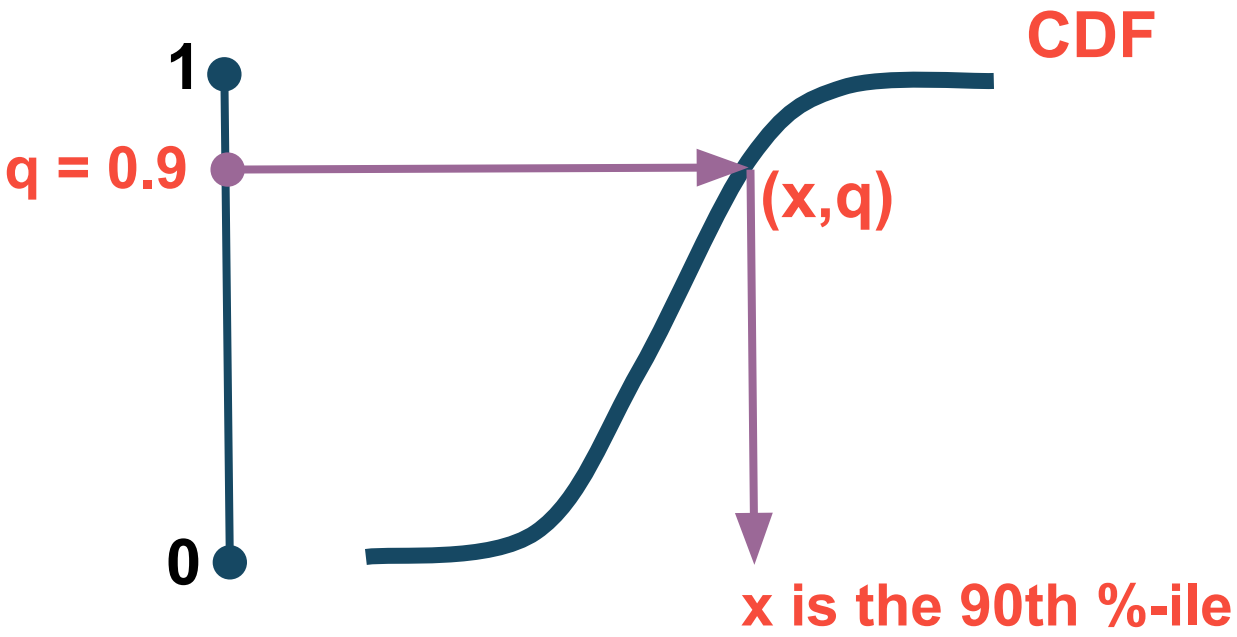
Distribution Sketch: T-Digest



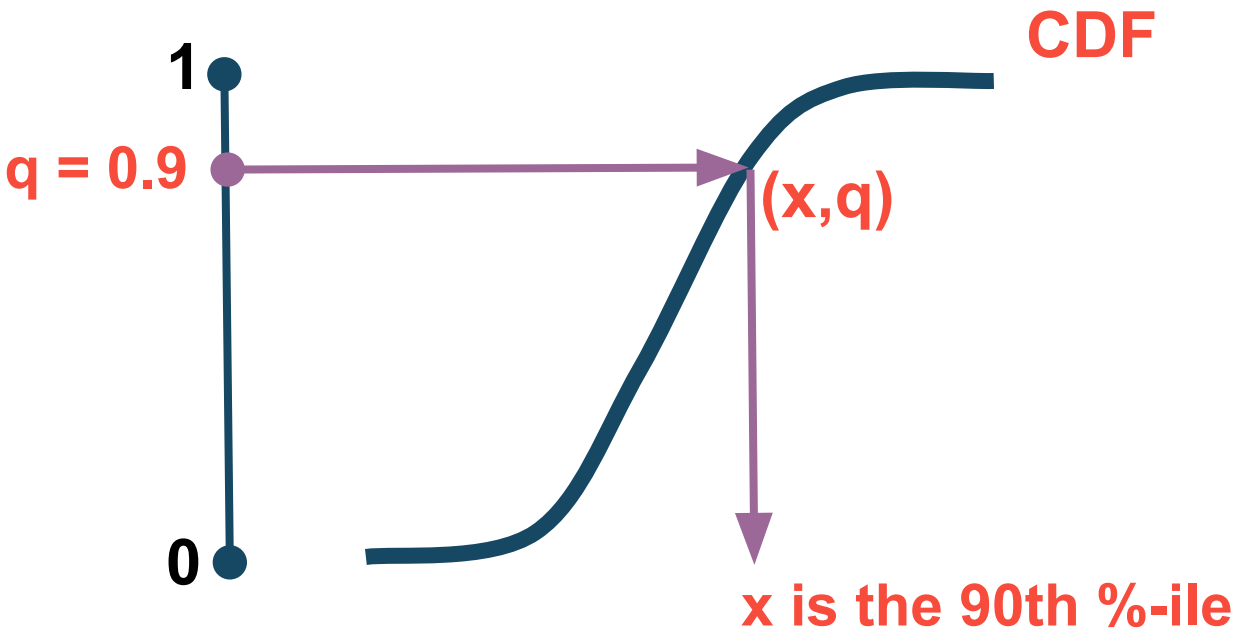
Distribution Sketch: T-Digest



Distribution Sketch: T-Digest



Distribution Sketch: T-Digest



Is T-Digest an Algebra?

Data Type	Numeric

Is T-Digest an Algebra?

Data Type	Numeric
Accumulator Type	T-Digest Sketch

Is T-Digest an Algebra?

Data Type	Numeric
Accumulator Type	T-Digest Sketch
Zero	Empty T-Digest

Is T-Digest an Algebra?

Data Type	Numeric
Accumulator Type	T-Digest Sketch
Zero	Empty T-Digest
Update	tdigest + x

Is T-Digest an Algebra?

Data Type	Numeric
Accumulator Type	T-Digest Sketch
Zero	Empty T-Digest
Update	tdigest + x
Merge	tdigest1 + tdigest2

Is T-Digest an Algebra?

Data Type	Numeric
Accumulator Type	T-Digest Sketch
Zero	Empty T-Digest
Update	tdigest + x
Merge	tdigest1 + tdigest2
Present	tdigest.cdfInverse(quantile)

Is T-Digest an Algebra?

Data Type	Numeric
Accumulator Type	T-Digest Sketch
Zero	Empty T-Digest
Update	tdigest + x
Merge	tdigest1 + tdigest2
Present	tdigest.cdfInverse(quantile)

User Defined Aggregator Function

```
val sketchCDF = tdigestUDAF[Double]


spark.udf.register("p50",
  (c:Any)=>c.asInstanceOf[TDigestSQL].tdigest.cdfInverse(0.5))


spark.udf.register("p90",
  (c:Any)=>c.asInstanceOf[TDigestSQL].tdigest.cdfInverse(0.9))
```

User Defined Aggregator Function

```
val sketchCDF = tdigestUDAF[Double]


spark.udf.register("p50",
  (c:Any)=>c.asInstanceOf[TDigestSQL].tdigest.cdfInverse(0.5))


spark.udf.register("p90",
  (c:Any)=>c.asInstanceOf[TDigestSQL].tdigest.cdfInverse(0.9))
```

Streaming Percentiles

```
val query = records
  .writeStream //...
```

```
+---------+
|wordcount|
+---------+
|       12|
|        5|
|        9|
|       18|
|       12|
+---------+
```

```
val r = records.withColumn("time", current_timestamp())
  .groupBy(window($"time", "30 seconds"))
  .agg(sketchCDF($"wordcount").alias("CDF"))
  .select(callUDF("p50", $"CDF").alias("p50"),
          callUDF("p90", $"CDF").alias("p90"))
val query = r.writeStream //...
```

```
+----+----+
| p50| p90|
+----+----+
|15.6|31.0|
|16.0|30.8|
|15.8|30.0|
|15.7|31.0|
|16.0|31.0|
+----+----+
```

Streaming Percentiles

```
val query = records
  .writeStream //...
```

```
+---------+
|wordcount|
+---------+
|       12|
|        5|
|        9|
|       18|
|       12|
+---------+
```

```
val r = records.withColumn("time", current_timestamp())
  .groupBy(window($"time", "30 seconds"))
  .agg(sketchCDF($"wordcount").alias("CDF"))
  .select(callUDF("p50", $"CDF").alias("p50"),
          callUDF("p90", $"CDF").alias("p90"))
val query = r.writeStream //...
```

```
+----+----+
| p50| p90|
+----+----+
|15.6|31.0|
|16.0|30.8|
|15.8|30.0|
|15.7|31.0|
|16.0|31.0|
+----+----+
```

Most-Frequent Items

#DogRates

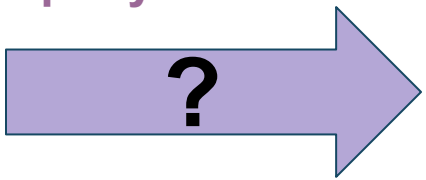
#YOLO

#SAIRocks

#TruthBomb

#Mondays

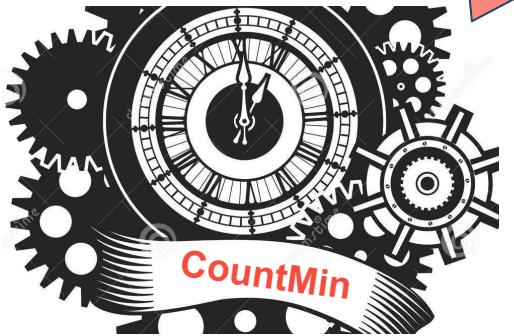
aggregating query



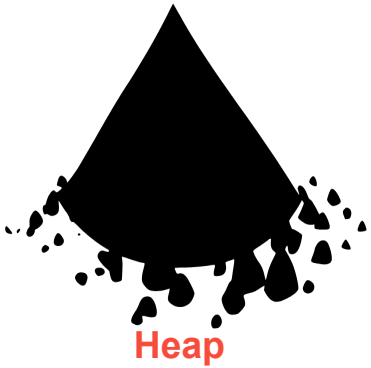
#tag	frequency
#DogRates	1000000000
#Blockchain	780000
#TaylorSwift	650000

Heavy-Hitter Sketch

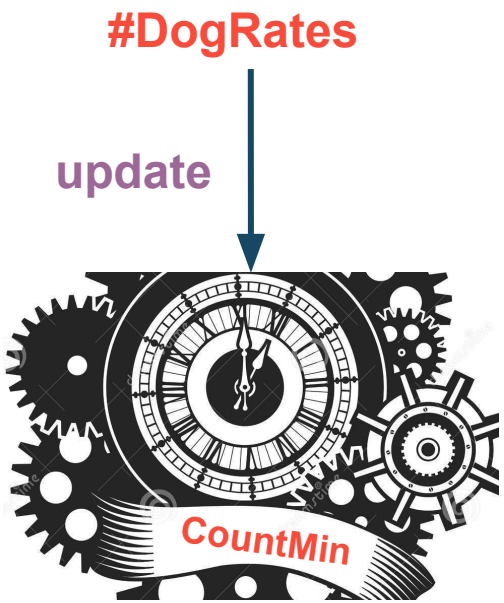
I estimate frequencies of objects!

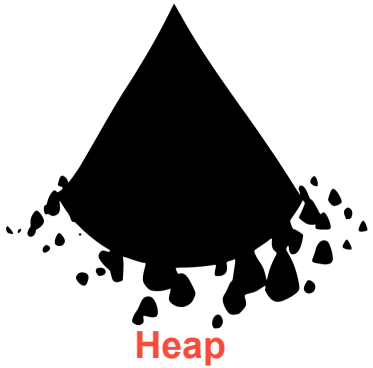


I store objects in sorted order!

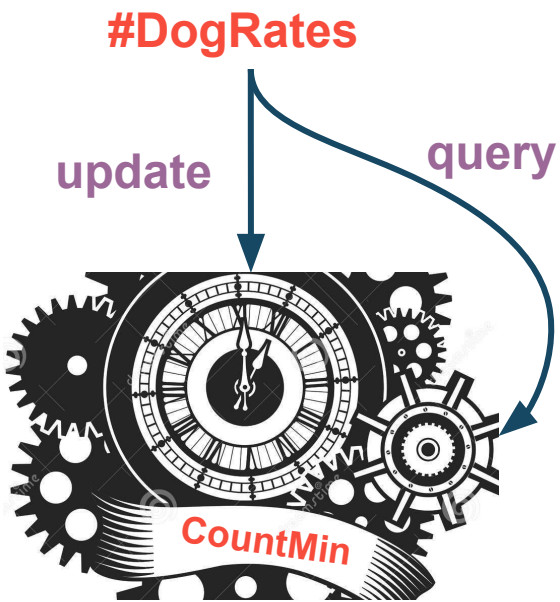


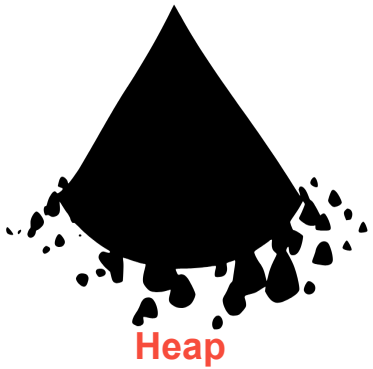
Heavy-Hitter Sketch



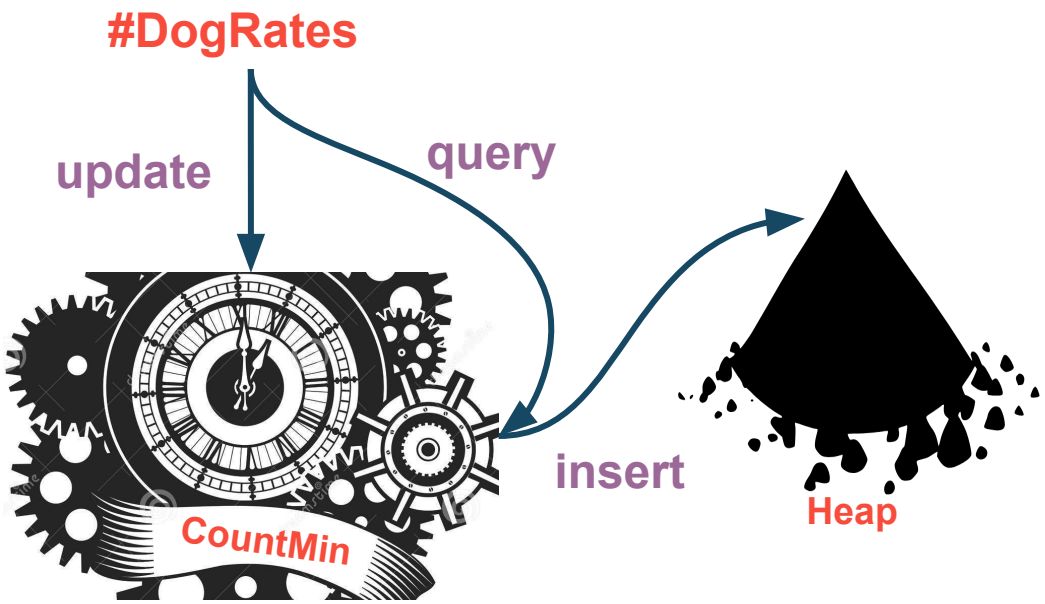


Heavy-Hitter Sketch

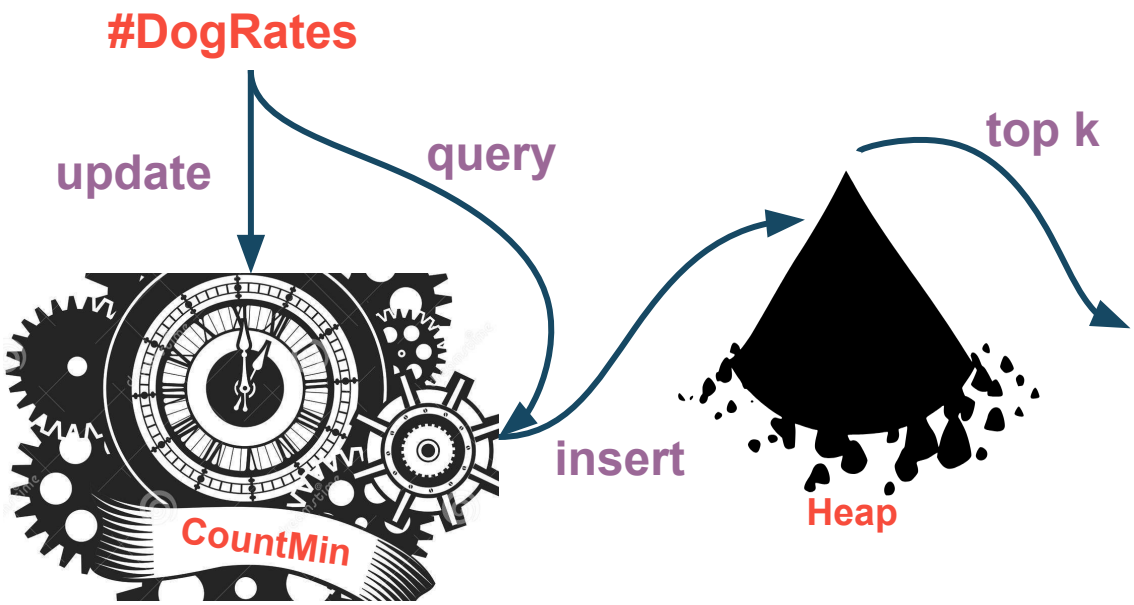




Heavy-Hitter Sketch

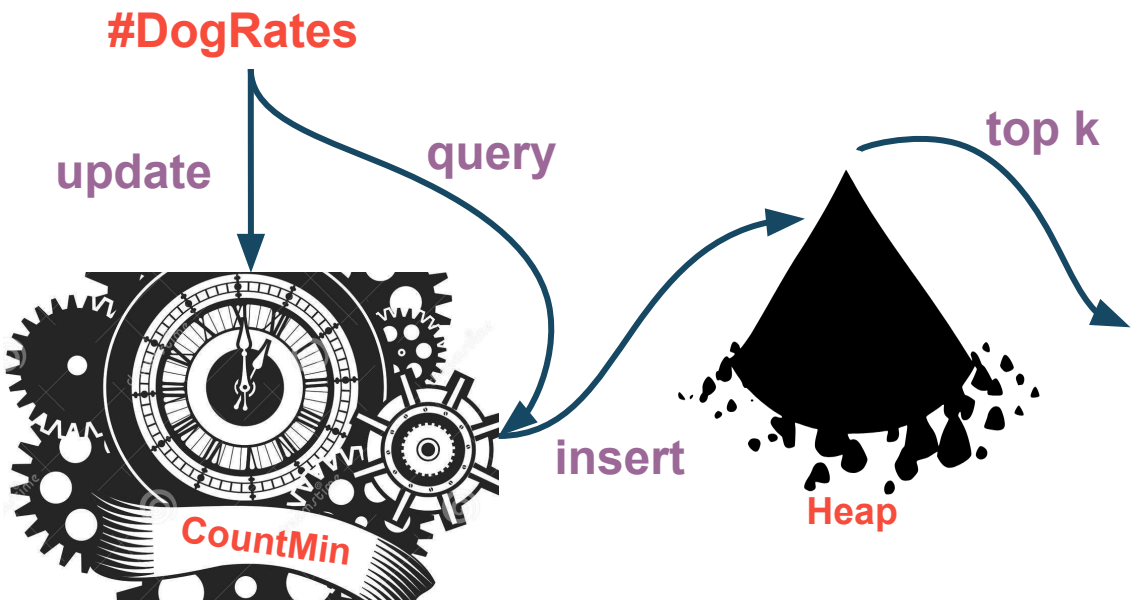


Heavy-Hitter Sketch



#tag	frequency
#DogRates	1000000000
#Blockchain	780000
#TaylorSwift	650000

Heavy-Hitter Sketch



#tag	frequency
#DogRates	1000000000
#Blockchain	780000
#TaylorSwift	650000

Is Heavy-Hitter an Algebra?

Data Type	Items

Is Heavy-Hitter an Algebra?

Data Type	Items
Accumulator Type	countmin sketch heap

Is Heavy-Hitter an Algebra?

Data Type	Items
Accumulator Type	countmin sketch heap
Zero	empty countmin empty heap

Is Heavy-Hitter an Algebra?

Data Type	Items
Accumulator Type	countmin sketch heap
Zero	empty countmin empty heap
Update	countmin.update(x) heap.insert(x, frequency)

Is Heavy-Hitter an Algebra?

Data Type	Items
Accumulator Type	countmin sketch heap
Zero	empty countmin empty heap
Update	countmin.update(x) heap.insert(x, frequency)
Merge	countmin1 + countmin2 update(heap1 + heap2)

Is Heavy-Hitter an Algebra?

Data Type	Items
Accumulator Type	countmin sketch heap
Zero	empty countmin empty heap
Update	countmin.update(x) heap.insert(x, frequency)
Merge	countmin1 + countmin2 update(heap1 + heap2)
Present	heap.top(k)

Is Heavy-Hitter an Algebra?

Data Type	Items
Accumulator Type	countmin sketch heap
Zero	empty countmin empty heap
Update	countmin.update(x) heap.insert(x, frequency)
Merge	countmin1 + countmin2 update(heap1 + heap2)
Present	heap.top(k)

Streaming Most-Frequent Items

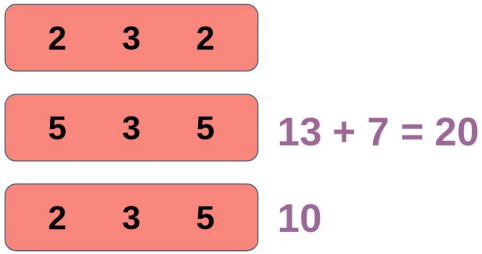
```
val query = records
  .writeStream //...
```

```
+----------+
|   hashtag|
+----------+
| #DogRates|
|     #YOLO|
| #SAIRocks|
|#TruthBomb|
|  #Mondays|
+----------+
```

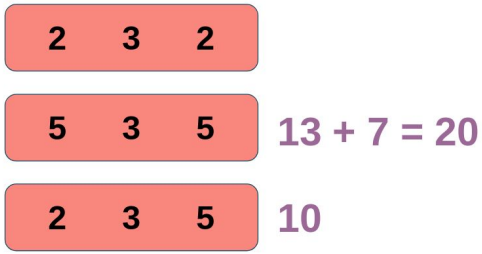
```
val windowBy60 =
  windowing.windowBy[(Timestamp, String)](_._1, 60)
val top3 = new TopKAgg[(Timestamp, String)](_._2)
val r = records.withColumn("time", current_timestamp())
  .as[(Timestamp, String)]
  .groupByKey(windowBy60).agg(top3.toColumn)
  .map { case (_, tk) => tk.toList.toString }
val query = r.writeStream //...
```

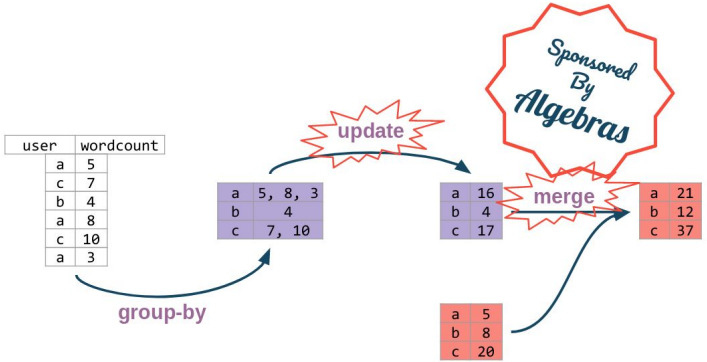
```
+-----------------------------------------------------+
+ value                                               |
+-----------------------------------------------------+
|List((#Iddesleigh,3), (#Gardiner,2), (#Willoughby,2)) |
|List((#Elizabeth,3), (#HERPRESENT,1), (#upforhours,1))|
|List((#PETE,4), (#Nutiva,1), (#Fairfax,1))            |
+-----------------------------------------------------+
```

Review

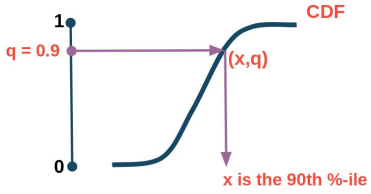


Review


2 3 2
5 3 5
13 + 7 = 20
2 3 5
10


Sponsored By Algebras
update
merge
group-by
user wordcount
a 5
c 7
b 4
a 8
c 10
a 3
a 5, 8, 3
b 4
c 7, 10
a 16
b 4
c 17
a 21
b 12
c 37
a 5
b 8
c 20

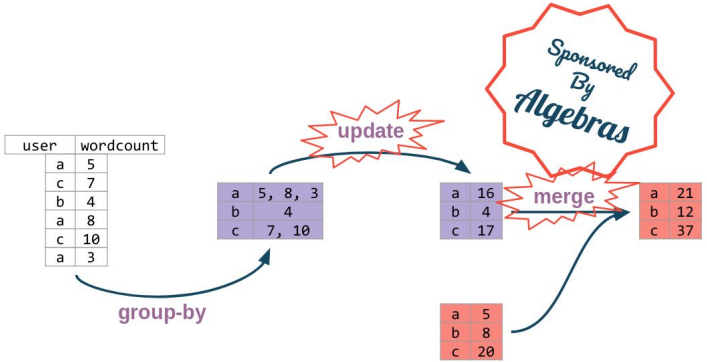
Review



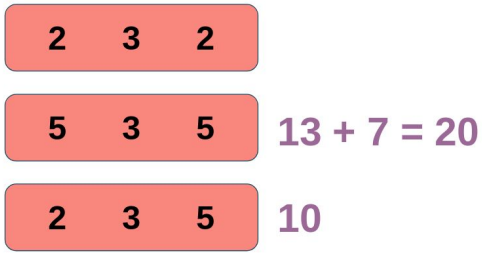
2	3	2
5	3	5
2	3	5

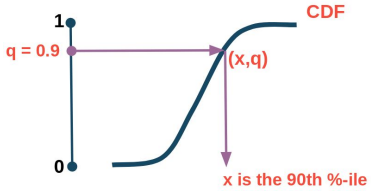
13 + 7 = 20

10



Review





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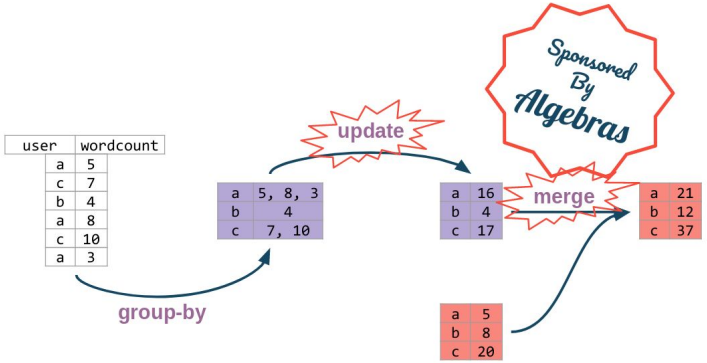
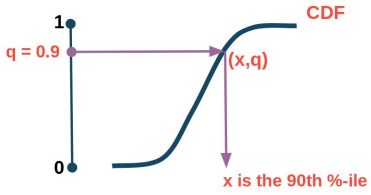
val windowBy60 =
  windowing.windowBy[(Timestamp, String)](_._1, 60)
val top3 = new TopKAgg[(Timestamp, String)](_._2)
val r = records.withColumn("time", current_timestamp())
  .as[(Timestamp, String)]
  .groupByKey(windowBy60).agg(top3.toColumn)
  .map { case (_, tk) => tk.toList.toString }
val query = r.writeStream //...
```

```
+--------------------------------------------------------+
+ value                                                  |
+--------------------------------------------------------+
|List((#Iddesleigh,3), (#Gardiner,2), (#Willoughby,2)) |
|List((#Elizabeth,3), (#HERPRESENT,1), (#upforhours,1))|
|List((#PETE,4), (#Nutiva,1), (#Fairfax,1))            |
+--------------------------------------------------------+
```



Review

2	3	2	
5	3	5	13 + 7 = 20
2	3	5	10



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val top3 = new TopKAgg[(Timestamp, String)](_._2)
val r = records.withColumn("time", current_timestamp())
  .as[(Timestamp, String)]
  .groupByKey(windowBy60).agg(top3.toColumn)
  .map { case (_, tk) => tk.toList.toString }
val query = r.writeStream //...
```
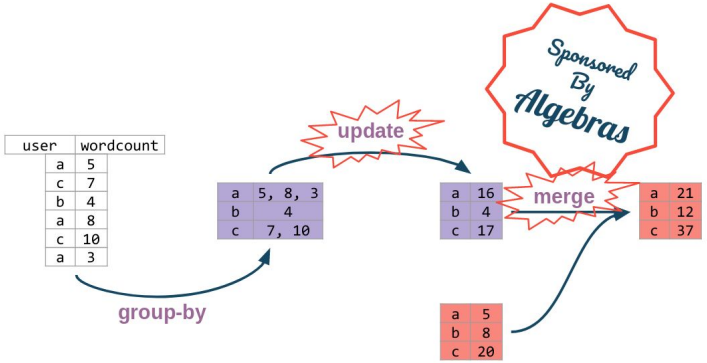

```
+--------------------------------------------------------+
+ value                                                  |
+--------------------------------------------------------+
|List((#Iddesleigh,3), (#Gardiner,2), (#Willoughby,2)) |
|List((#Elizabeth,3), (#HERPRESENT,1), (#upforhours,1))|
|List((#PETE,4), (#Nutiva,1), (#Fairfax,1))             |
+--------------------------------------------------------+
```



eje@redhat.com
@manyangled