Agenda

Joining Iterators To One Iterator

```java
public class JoiningIterators {

    public static void main(String[] args) {

        Iterator<String> iterator1 = Arrays.asList("a", "b", "c").iterator();
        Iterator<String> iterator2 = Collections.<String>emptyList().iterator();
        Iterator<String> iterator3 = Arrays.asList("x").iterator();

        Iterator<String> joinedIterators = new JoinedIterators<String>(
                iterator1,
                iterator2,
                iterator3
        );

        while (joinedIterators.hasNext()) {
            String next = joinedIterators.next();
            System.out.println(next);
        }
    }

}
```

Joining Iterators To One Iterator - A Traditional Approach

```java
public class JoinedIterators<T> implements Iterator<T> {
    private final Iterator<Iterator<T>> iteratorIterator;
    private Iterator<T> currentIterator;

    public JoinedIterators(Iterator<T>... iterators) {
        iteratorIterator = Arrays.asList(iterators).iterator();
    }

    public boolean hasNext() {
        if (currentIterator == null) {
            if (!iteratorIterator.hasNext()) {
                return false;
            } else {
                currentIterator = iteratorIterator.next();
            }
        }
        while (!currentIterator.hasNext()) {
            if (iteratorIterator.hasNext()) {
                currentIterator = iteratorIterator.next();
            } else {
                currentIterator = null;
                return false;
            }
        }
        return true;
    }

    public T next() {
        if (!hasNext()) {
            throw new NoSuchElementException();
        }
        return currentIterator.next();
    }
```

Joining Iterators To One Iterator - A Pipe

```java
public class PipeJoinedIterators<T> implements Iterator<T>, Runnable {
    private final Iterator<T>[] iterators;
    private final ArrayBlockingQueue<Object> pipe = new ArrayBlockingQueue<Object>(1);
    private static final Object STOP = new Object();

    public PipeJoinedIterators(Iterator<T>... iterators) {
        this.iterators = iterators;
        new Thread(this).start();
    }

    private void run_() throws InterruptedException {
        for (Iterator<T> iterator : iterators) {
            while (iterator.hasNext()) {
                T next = iterator.next();
                pipe.put(next);
            }
        }
        pipe.offer(STOP);
    }

    public boolean hasNext() {
        Object e;
        while ((e = pipe.peek()) == null);
        return e != STOP;
    }

    public T next() {
        if (!hasNext()) {
            throw new NoSuchElementException();
        }
        try {
            return (T)pipe.take();
        } catch (InterruptedException e) {
            throw new IllegalStateException(e);
        }
    }
```

```java
public class CoJoinedIterators<T> extends CoIterator<T> {
    private final Iterator<T>[] iterators;

    public CoJoinedIterators(Iterator<T>... iterators) {
        this.iterators = iterators;
    }

    protected void run() throws SuspendExecution {
        for (Iterator<T> iterator : iterators) {
            while (iterator.hasNext()) {
                T next = iterator.next();
                produce(next);
            }
        }
    }
}
```

- A generalization of subroutines
- *AKA green threads, co-expressions, fibers, generators*
- Some may remember the old windows event loop
- Behavior similar to that of subroutines
- Coroutines can call other coroutines
- Execution can later return to the point of invocation
- Often demonstrated on Produce/Consumer scenario

Coroutines Conceptual Example - Producer/Consumer (http://en.wikipedia.org/wiki/Coroutines)

```
var q := new queue

coroutine produce
    loop
        while q is not full
            create some new items
            add the items to q
        yield to consume

coroutine consume
    loop
        while q is not empty
            remove some items from q
            use the items
        yield to produce
```

- None of the top TIOBE languages (Java, C, C++, PHP, Basic)
- Go, Icon, Lua, Perl, Prolog, Ruby, Tcl, Simula, Python, Modula-2 …

- Emulations by threads - bad
- Byte-code manipulation - better
- A need for JVM support, some future JSR?
- For some implementations see the references
- In this presentation I use Continuations library developed by Matthias Mann (http://www.matthiasmann.de/content/view/24/26/)

- Iterators
- Producer/Consumer chains
- State machines
- Visitors with loops instead of callbacks
- Pull parsers
- Loggers
- Observers, listeners, notifications
- Generally capable of converting PUSH algorithms to PULL

MapReduce And Coroutines

- PULL, batch processing, offline
- Two-phase computational mode: Map and Reduce
- Map - filters, cleans or parses the input records
- Reduce - aggregates the records obtained from Map
- Easily distributable
- Inspired by functional programming
- Benefits - scalable, thread-safe (no race conditions), simple computational model
- Rich libraries of algorithms - e.g. machine learning (Mahout)

Map-Reduce Overview - Word Count example (http://en.wikipedia.org/wiki/MapReduce)

```
function map(String name, String document):
  // name: document name
  // document: document contents
  for each word w in document:
    emit (w, 1)

function reduce(String word, Iterator partialCounts):
  // word: a word
  // partialCounts: a list of aggregated partial counts
  sum = 0
  for each pc in partialCounts:
    sum += ParseInt(pc)
  emit (word, sum)
```

- Could we write the same code for data streams?
- We could keep thinking in MR paradigm
- Perhaps, it would inherit the nice MR properties
- Sadly, streaming algorithms are inherently PUSH,

incremental or event-driven, i.e. callbacks instead of loops

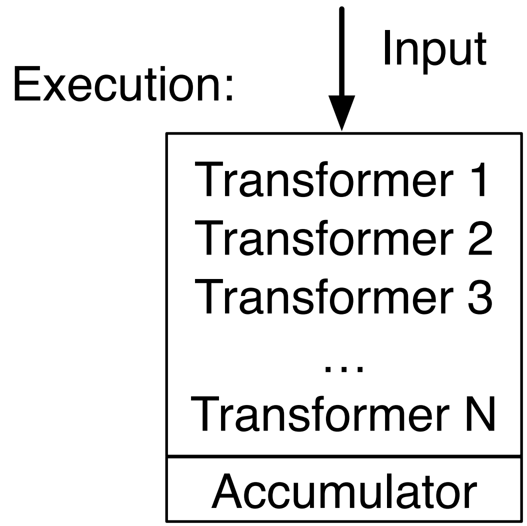
- WordCount MR solution has 2 simple loops
- It is a typical Producer/Consumer problem
- Coroutines should help us!

Clockwork

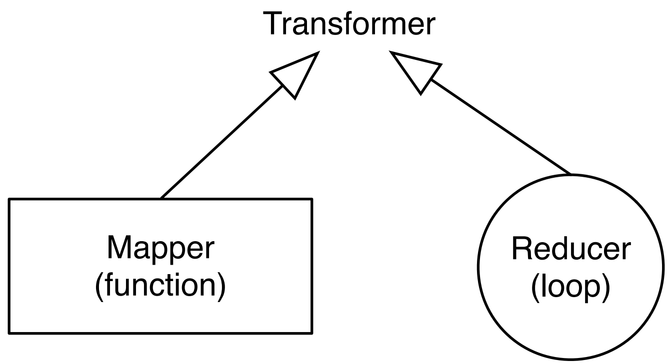
Adoption of MR to stream data processing

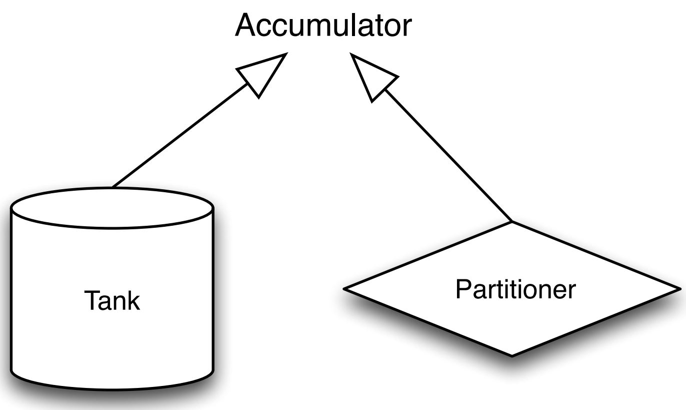
- Adoption of MR paradigm to data stream processing
- Built on top of coroutines (Producer/Consumer)
- Goes further than the original MR concepts
- Easy for anyone familiar with Hadoop (or other)
- Open-sourced recently by AVAST
- The core is practically production-ready (RC)
- A lot of work to be done (networking, RPC)

Clockwork Execution Model

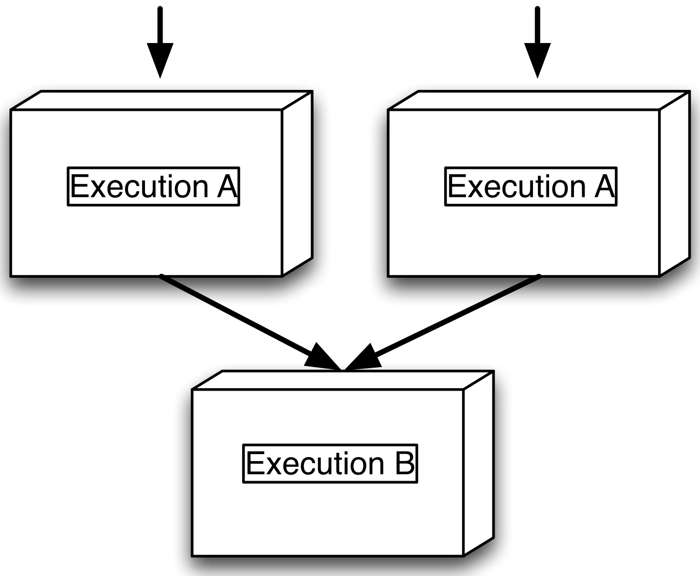


Clockwork Execution Model - Transformers and Accumuators

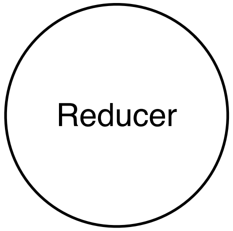




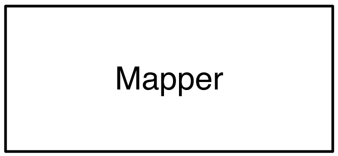
Clockwork Distributed Execution



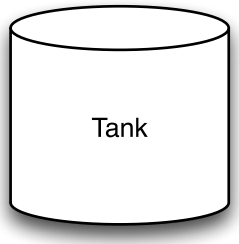
Clockwork Components



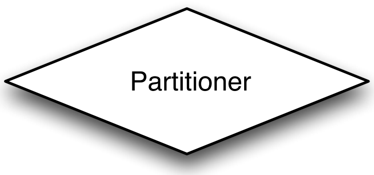
- aggregations
- a coroutine component (loop)



- filtering
- transforming
- expanding

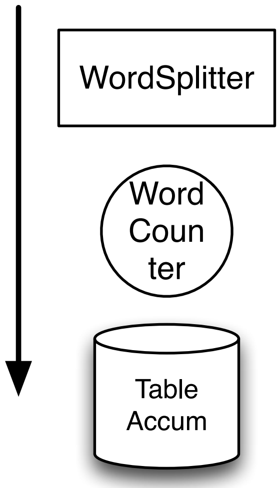


- key-value storage
- key-values storage
- flushing buffer



- routing output to another nodes
- partitioning
- broadcasting

Word Counter in Clockwork



Construction:

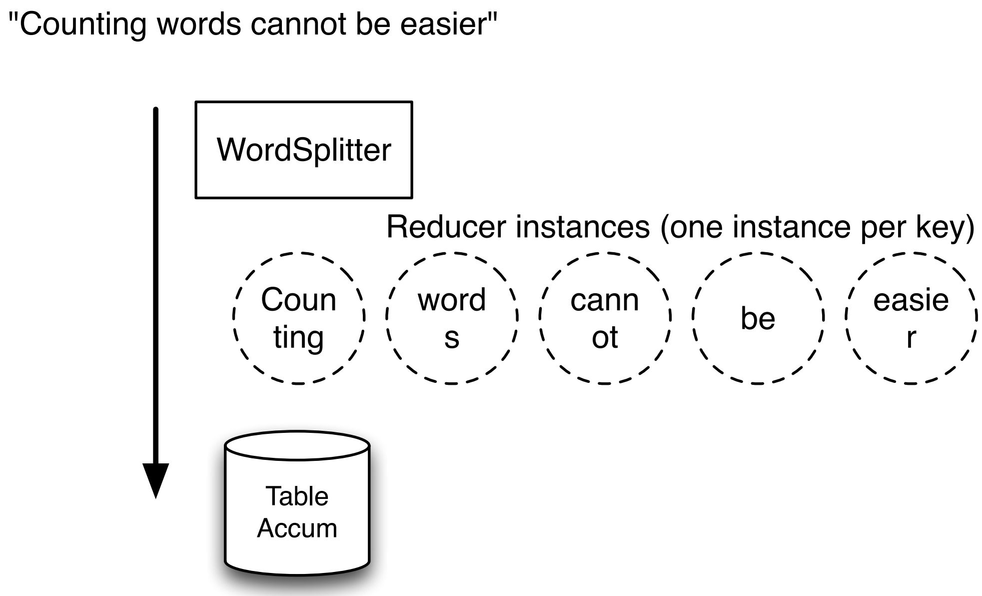
```
Execution<Long, String, String, Long> execution = Execution.newBuilder()
        .mapper(new WordSplitter())
        .reducer(new WordCounter())
        .accumulator(new TableAccumulator<String, Long>()).build();
```

Feeding:

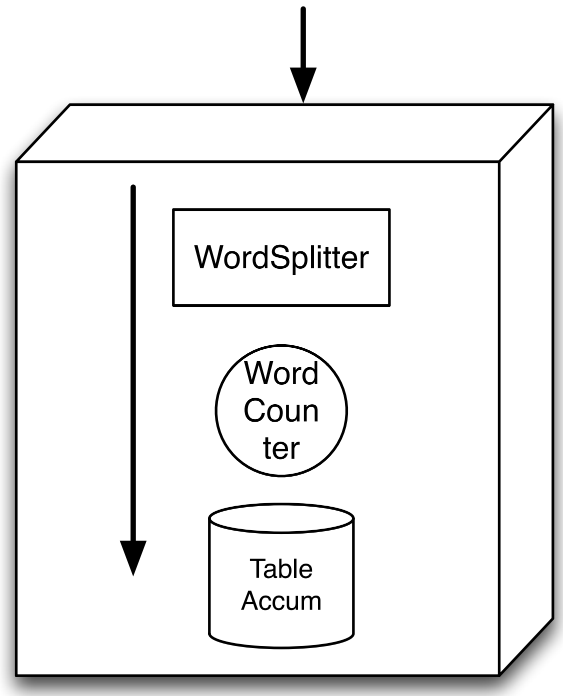
```
long counter = 0;
BufferedReader reader =
        new BufferedReader(new FileReader(fileName));
String line;
while ((line = reader.readLine()) != null) {
    execution.emit(counter++, line);
}
```

```java
public class WordSplitter extends Mapper<Long, String, String, Long> {
    @Override
    protected void map(Long inputKey, String inputValue, Context context) throws Exception {
        Iterable<String> splits = Splitter.on(" ").trimResults().split(inputValue);
        for (String split : splits) {
            emit(split, 1L);
        }
    }
}
```

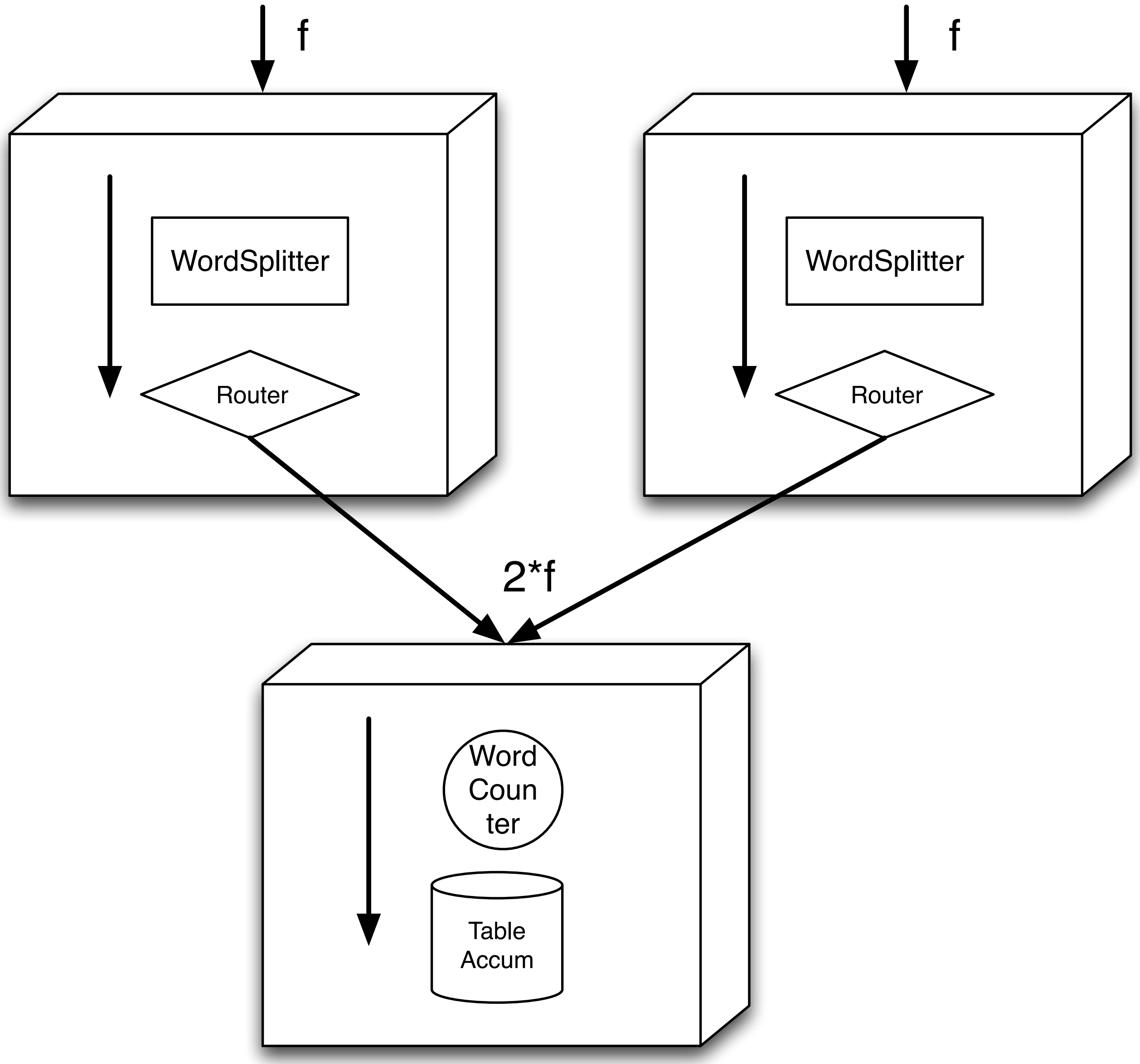
```java
public class WordCounter extends Reducer<String, Long, String, Long> {
    @Override
    protected void reduce(String inputKey, SuspendableIterator<Long> inputValues, Context context)
            throws SuspendExecution, Exception {
        long counter = 0;
        while (inputValues.hasNext()) {
            counter += inputValues.next();
        }
        emit(inputKey, counter);
    }
}
```


"Counting words cannot be easier"
WordSplitter
Reducer instances (one instance per key)
Coun ting
word s
cann ot
be
easie r
Table Accum

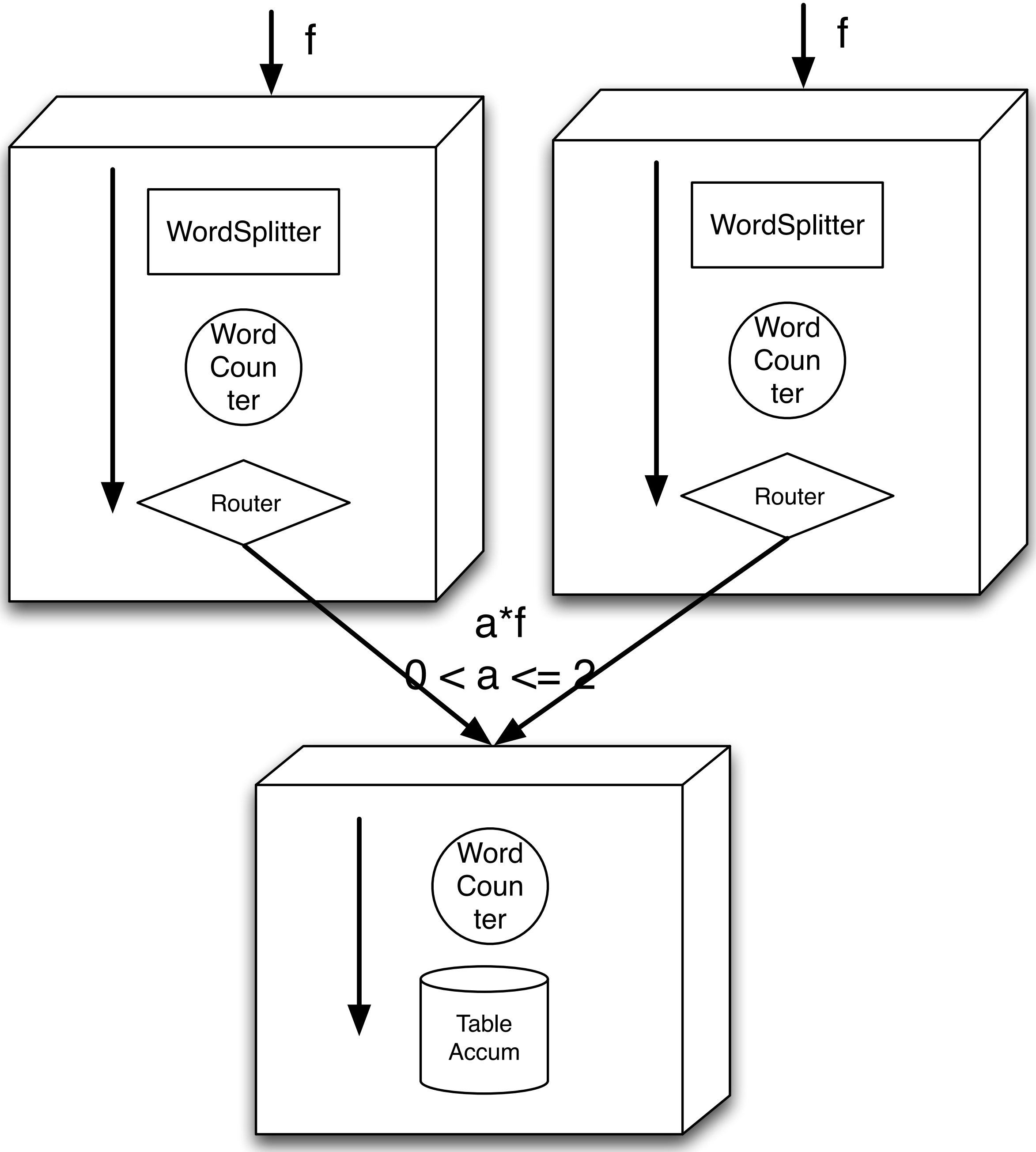
Word Counter in Clockwork



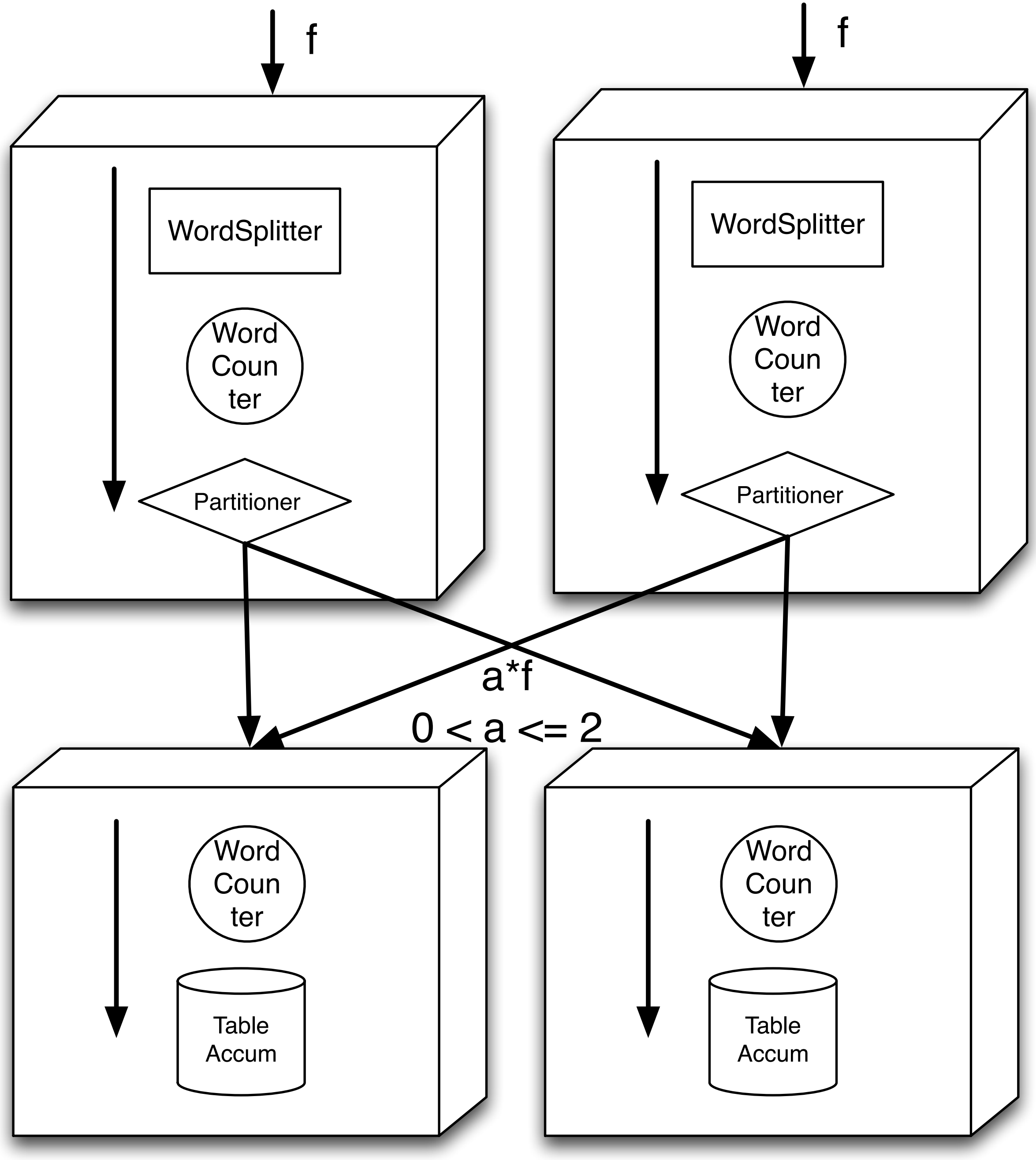
Word Counter in Clockwork



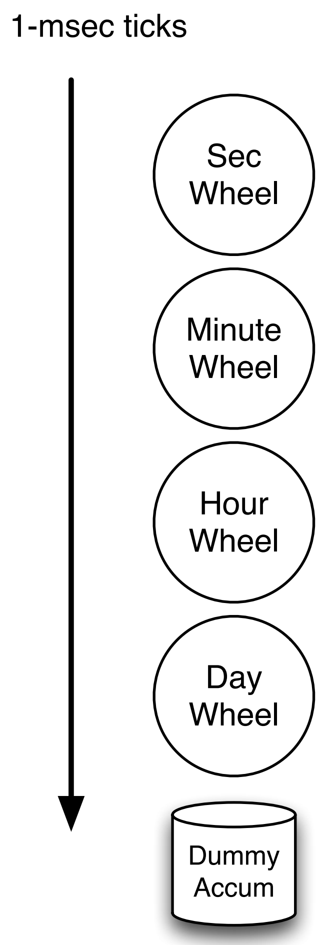
Word Counter in Clockwork



Word Counter in Clockwork



Reduce-only Setup - The "Nerdiest" clock in the world



Construction:

```
Clock clock = new Clock();
Execution<Long, Long, Long, Long> clockWork = Execution.newBuilder()
        .reducer(new Wheel(ClockPart.SEC, clock))
        .reducer(new Wheel(ClockPart.MIN, clock))
        .reducer(new Wheel(ClockPart.HOUR, clock))
        .reducer(new Wheel(ClockPart.DAY, clock))
        .accumulator(new DummyAccumulator<Long, Long>())
        .build();
```

Feeding:

```
for (; ; ) {
    clockWork.emit(0L, 0L);
    Thread.sleep(1000);
    System.out.println(clock);
}
```

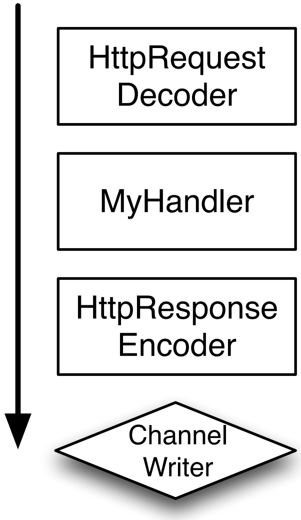
```java
public static class Wheel extends Reducer<Long, Long, Long, Long> {

    final ClockPart clockPart;
    final Clock clock;

    public Wheel(ClockPart clockPart, Clock clock) {
        this.clockPart = clockPart;
        this.clock = clock;
    }

    @Override
    protected void reduce(Long inputKey, SuspendableIterator<Long> inputValues, Context context)
            throws SuspendExecution, Exception {
        long counter = 0;
        long timeHand = 0;
        while (inputValues.hasNext()) {
            inputValues.next();
            counter++;
            if (counter % clockPart.period == 0) {
                clockPart.inc(clock);
                emit(0L, timeHand++);
            }
        }
    }
}
```

Map-only Setup - HTTP pipeline



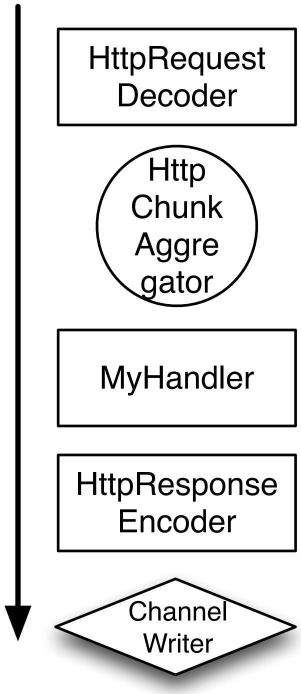
Construction:

```
Execution<Long, ByteBuffer, Long, ByteBuffer> pipeline =
        Execution.newBuilder()
                .mapper(new HttpRequestDecoder())
                .mapper(new MyHandler()) // custom business logic
                .mapper(new HttpResponseEncoder())
                .accumulator(new ChannelWriter<Long>())
                .build();
```

Feeding:

```
WritableChannelContext channelContext = createContext(socket);
pipeline.emit(rqCnt, inputBuffer, channelContext);
```

Many-Maps-One-Reduce Setup - HTTP pipeline



Construction:

```
int maxContentLength = 10000;
Execution<Long,ByteBuffer, Long, ByteBuffer> pipeline =
        Execution.newBuilder()
        .mapper(new HttpRequestDecoder())
        .reducer(new HttpChunkAggregator(maxContentLength))
        .mapper(new MyHandler())
        .mapper(new HttpResponseEncoder())
        .accumulator(new ChannelWriter<Long>())
        .build();
```

```
int maxContentLength = 10000;
Execution<Long, ByteBuffer, Long, ByteBuffer> pipeline =
        Execution.newBuilder()
                .mapper(new HttpMessageDecoder())
                .reducer(new HttpChunkAggregator(maxContentLength))
                .mapper(new MyHandler())
                .mapper(new HttpResponseEncoder())
                .accumulator(new ChannelWriter<Long>())
                .build();
```

Feeding:

```
WritableChannelContext channelContext = createContext(socket);
pipeline.emit(rqCnt, inputBuffer, channelContext);
```

Naive Bayes Classification Map Reduce Job (http://nickjenkin.com/blog/?p=85)

```
def map(key, instance):
    i = 0
    for attribute in instance.attributes:
        collect(instance.class + "_" + i, attribute)
        i++

    collect("target_" + instance.class, 1) # class distribution

def reduce(key, values):
    if key.startsWith("target_"): # reduce class dist keys
        sum = 0
        for v in values:
            sum += v
                collect(key,sum)

    else: # reduce attribute/class keys
        sum=0
        sumSq = 0
        count = 0
        for v in values:
            sum += v
            sumSq += v*v
            count++

        mean = sum/count
        collect(key + "_mean", mean)
        collect(key + "_stddev", sqrt(abs(sumSq - mean * sum) / count))
```

```java
public class InstanceMapper extends Mapper<Long, String, String, Double> {

    private final Splitter splitter = Splitter.on(CharMatcher.WHITESPACE).omitEmptyStrings().trimResults();

    @Override
    protected void map(Long rowNumber, String instanceRow, Context context) throws Exception {
        int attrCnt = 0;
        String target = null;
        for (String cell: splitter.split(instanceRow)) {
            if (target == null) {
                target = cell;
                emit("target_" + target, 1d);
            } else {
                double attr = Double.parseDouble(cell);
                emit(target + "_" + attrCnt, attr);
                attrCnt++;
            }
        }
    }
}
```

```java
public class InstanceReducer extends Reducer<String, Double, String, BaseStat> {

    @Override
    protected void reduce(String inputKey, SuspendableIterator<Double> inputValues, Context context)
            throws SuspendExecution, Exception {
        if (inputKey.startsWith("target_")) {
            int targetTotal = 0;
            while (inputValues.hasNext()) {
                Double value = inputValues.next();
                int targetCounter = value.intValue();
                targetTotal += targetCounter;
            }
            emit(inputKey, new BaseStat(targetTotal));

        } else {
            float sum = 0;
            float sumSq = 0;
            int count = 0;
            while (inputValues.hasNext()) {
                double attr = inputValues.next();
                sum += attr;
                sumSq += attr * attr;
                count++;
            }

            emit(inputKey, new AttrStat(sum, sumSq, count));

        }
    }
}
```

Conclusion

- Distributed stream processing easier
- Some techniques known from offline MR can be adopted more or less directly
- Requires incremental algorithms and models
- Many deployment options, flushing strategies
- A lot of work to be done: communication protocol, machine learning and statistics algorithms, management tools, documentation ...

Thanks for your attention!

Q&A

References