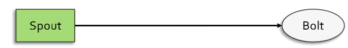
Developing Storm Applications

A trivial running example topology



This spout emits a stream of random integer numbers between 0 and 99.
It emits one number every 100ms.

This bolt multiplies each element of the input stream by 2 and prints the result on the standard output

(.., 74, 10, 5, ..) → (.., 148, 20, 10, ..)

Developing a Storm application

- You must implement
  - One class for each spout of your topology
    - However, in real applications, you typically use an existing spout (Kafka spout, Redis spout, etc)
  - One class for each bolt of your topology
  - One class, with the main method, to define and submit the topology

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Implementing Spouts

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Implementing Spouts

- For each spout you must specify
  - The format of the emitted tuples
    - The names of the fields
  - How tuples are generated

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Implementing Spouts

- Spouts implement the BaseRichSpout abstract class
  - BaseRichSpout implements the following interfaces
    - Serializable, ISpout, IComponent, IRichSpout
- The methods to be implemented are
  - public void open(Map conf, TopologyContext context, SpoutOutputCollector collector)
  - public void declareOutputFields(OutputFieldsDeclarer declarer)
  - public void nextTuple()

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Implementing Spouts

- public void open(Map conf, TopologyContext context, SpoutOutputCollector collector)
  - It is called when a task for this component is initialized within a worker on the cluster
  - It provides the spout with the environment in which it executes
  - Parameters
    - conf
      - The Storm configuration for this spout
    - context
      - It can be used to get information about this task's place within the topology, including the task id and component id of this task
    - collector:
      - The collector is used to emit tuples from this spout
      - Tuples can be emitted at any time, including the open and close methods
      - The collector is thread-safe and should be saved as an instance variable of this spout object

Implementing Spouts

- public void declareOutputFields(OutputFieldsDeclarer declarer)
  - Declares the output schema for all the streams of this spout
    - An spout can emit more than one stream
  - Parameter
    - declarer
      - It is used to declare output stream ids, output fields, and whether or not each output stream is a direct stream

Implementing Spouts

- public void nextTuple()
  - It is used to emit the next tuple(s) of the stream(s) generated by this spout by calling the emit method on the output collector
  - When this method is called, Storm is requesting that the Spout emits tuples to the output collector
  - This method should be non-blocking
    - So if the Spout has no tuples to emit, this method should return

Running example Spout

```
package ...
import ...

@SuppressWarnings("serial")
public class EmitRandomIntSpout extends BaseRichSpout {
    private SpoutOutputCollector collector;
    private Random rand;

    @Override
    public void open(Map conf, TopologyContext context, SpoutOutputCollector
    collector) {
        this.collector = collector;
        this.rand = new Random();
    }

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


Running example Spout

```
package ...
import ...

@SuppressWarnings("serial")
public class EmitRandomIntSpout extends BaseRichSpout {
    private SpoutOutputCollector collector;
    private Random rand;

    @Override
    public void open(Map conf, TopologyContext context, SpoutOutputCollector
    collector) {
        this.collector = collector;
        this.rand = new Random();
    }

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


Store the output collector in an instance variable

Running example Spout

```
package ...
import ...

@SuppressWarnings("serial")
public class EmitRandomIntSpout extends BaseRichSpout {
    private SpoutOutputCollector collector;
    private Random rand;

    @Override
    public void open(Map conf, TopologyContext context, SpoutOutputCollector
    collector) {
        this.collector = collector;
        this.rand = new Random();
    }

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


Declare the schema of the emitted tuples

Running example Spout

```
    @Override
    public void nextTuple() {
        Utils.sleep(100);
        collector.emit(new Values(rand.nextInt(100)));
    }
}
```


Running example Spout

```
    @Override
    public void nextTuple() {
        Utils.sleep(100);
        collector.emit(new Values(rand.nextInt(100)));
    }
}
```

Emit a new tuple by using the emit method and the Values class

Implementing Bolts

Implementing Bolts

- For each bolt you must specify
  - How the input tuples are processed
  - The format of the emitted tuples
    - The final bolt of a path of the topology does not emit a new stream of tuples
    - For the final bolts the tuple format is not specified

Implementing Bolts

- Bolts implement the BaseRichBolt abstract class
  - BaseRichBolt implements the following interfaces
    - Serializable, IBolt, IComponent, IRichBolt
- The methods to be implemented are
  - public void prepare(Map conf, TopologyContext context, OutputCollector collector)
  - public void declareOutputFields(OutputFieldsDeclarer declarer)
  - public void execute(Tuple tuple)

Implementing Bolts

- public void prepare(Map conf, TopologyContext context, OutputCollector collector)
  - It is called when a task for this component is initialized within a worker on the cluster
  - It provides the bolt with the environment in which it executes
  - Parameters
    - conf
      - The Storm configuration for this spout
    - context
      - It can be used to get information about this task's place within the topology, including the task id and component id of this task
    - collector:
      - The collector is used to emit tuples from this bolt
      - Tuples can be emitted at any time, including the prepare and cleanup methods
      - The collector is thread-safe and should be saved as an instance variable of this bolt object

Implementing Bolts

- public void declareOutputFields(OutputFieldsDeclarer declarer)
  - Declares the output schema for all the streams of this bolt
    - A bolt can emit zero or many streams
  - Parameter
    - declarer
      - It is used to declare output stream ids, output fields, and whether or not each output stream is a direct stream

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Implementing Bolts

- public void execute(Tuple tuple)
  - It is used to process a single tuple of input
  - The Tuple object contains metadata on it about which component/stream/task it came from
  - The values of the Tuple can be accessed using the getValue* methods
  - The Bolt does not have to process the Tuple immediately
    - It is perfectly fine to hang onto a tuple and process it later (for instance, to do an aggregation or a join)

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Running example Bolt

```
package ...
Import ...

@SuppressWarnings("serial")
public class MultiplyBy2Bolt extends BaseRichBolt {

    private OutputCollector collector;

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

    @Override
    public void declareOutputFields(OutputFieldsDeclarer declarer) {
    }
```

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Running example Bolt

```
package ...
Import ...

@SuppressWarnings("serial")
public class MultiplyBy2Bolt extends BaseRichBolt {

    private OutputCollector collector;

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

    @Override
    public void declareOutputFields(OutputFieldsDeclarer declarer) {
    }
```

Store the output collector in an instance variable

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Running example Bolt

```
package ...
Import ...

@SuppressWarnings("serial")
public class MultiplyBy2Bolt extends BaseRichBolt {

    private OutputCollector collector;

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

    @Override
    public void declareOutputFields(OutputFieldsDeclarer declarer) {
    }
```

The schema of the output tuples is not defined because this bolt does not emit a new stream

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Running example Bolt

```
    @Override
    public void execute(Tuple tuple) {
        // Print the computed value on the standard output
        System.out.println(tuple.getIntegerByField("intValue") * 2);

    }

}
```

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Running example Bolt

```
@Override
public void execute(Tuple tuple) {
        // Print the computed value on the standard output
        System.out.println(tuple.getIntegerByField("intValue") * 2);

}
}
```

Process the current tuple

Implementing Topologies

Implementing Topologies

- For each topology you must specify
  - Which spouts and bolts are part of the topology
  - How spouts and bolts are connected
  - Which stream grouping is used for each stream
    - It depends on the pair (emitter spout/bolt, consumer bolt) and the performed stream transformation/processing
  - You must specify the initial parallelism of the topology
    - Pay attention: The maximum number of tasks cannot be changed at runtime

Implementing Topologies

- Topologies are created and configured by means of the TopologyBuilder class
- The main methods to be used are
  - public SpoutDeclarer setSpout(String id, IRichSpout spout)
  - public BoltDeclarer setBolt(String id, IRichBolt bolt)
  - public StormTopology createTopology()

Implementing Topologies

- public SpoutDeclarer setSpout(String id, IRichSpout spout, Number parallelism_hint)
  - It is used to add a spout to the topology
  - Parameters
    - id
      - The id of this component
        - Usually it is the "name" of the spout
      - This id is referenced by other components that want to consume this spout's outputs
    - spout
      - An instance of the class implementing this spout
    - parallelism_hint
      - Number of executors that should be assigned to execute this spout

Implementing Topologies

- public BoltDeclarer setBolt(String id, IRichBolt bolt, Number parallelism_hint)
  - It is used to add a bolt to the topology
  - Parameters
    - id
      - The id of this component
        - Usually it is the "name" of the bolt
      - This id is referenced by other components that want to consume this bolt's outputs
    - bolt
      - An instance of the class implementing this bolt
    - parallelism_hint
      - Number of executors that should be assigned to execute this bolt

Implementing Topologies

- Use the object returned by setBolt to declare the inputs of the bolt
  - Specify the input streams and the stream grouping technique
- Use one of the following methods of the BoltDeclarer class
  - shuffleGrouping(..), localOrShuffleGrouping(..), fieldsGrouping(..), partialKeyGrouping(..) , allGrouping(..), globalGrouping(..), noneGrouping(..), directGrouping(..), customGrouping(..)

Implementing Topologies

- public StormTopology createTopology()
  - It is used to create an instance of the defined topology

Implementing Topologies

- public static void submitTopology(String name, Map stormConf, StormTopology topology) of StormSubmitter is used to submit the topology
  - Submits a topology to run on the cluster
    - A topology runs forever or until explicitly killed.
  - Parameters
    - name
      - name of the topology
    - stormConf
      - the topology-specific configuration
    - Topology
      - An instance of the topology to execute

Running example Topology

```
package ...
import ...

public class MultiplyBy2Topology {

    public static void main(String[] args) throws Exception {

        TopologyBuilder builder = new TopologyBuilder();

        builder.setSpout("streamIntegers", new EmitRandomIntSpout(), 1);
        builder.setBolt("multiply", new MultiplyBy2Bolt(), 2)
                .shuffleGrouping("streamIntegers");


        Config conf = new Config();
        conf.setDebug(false);
        conf.setNumWorkers(3);
```


Running example Topology

```
package ...
import ...

public class MultiplyBy2Topology {

    public static void main(String[] args) throws Exception {

        TopologyBuilder builder = new TopologyBuilder();

        builder.setSpout("streamIntegers", new EmitRandomIntSpout(), 1);
        builder.setBolt("multiply", new MultiplyBy2Bolt(), 2)
                .shuffleGrouping("streamIntegers");


        Config conf = new Config();
        conf.setDebug(false);
        conf.setNumWorkers(3);
```

Create a topology builder

Running example Topology

```
package ...
import ...

public class MultiplyBy2Topology {

    public static void main(String[] args) throws Exception {

        TopologyBuilder builder = new TopologyBuilder();

        builder.setSpout("streamIntegers", new EmitRandomIntSpout(), 1);
        builder.setBolt("multiply", new MultiplyBy2Bolt(), 2)
                .shuffleGrouping("streamIntegers");


        Config conf = new Config();
        conf.setDebug(false);
        conf.setNumWorkers(3);
```

Set the spout
Specify:
- Name
- Instance of the spout
- Number of executors

Running example Topology

```
package ...
import ...

public class MultiplyBy2Topology {

    public static void main(String[] args) throws Exception {

        TopologyBuilder builder = new TopologyBuilder();

        builder.setSpout("streamIntegers", new EmitRandomIntSpout(), 1);
        builder.setBolt("multiply", new MultiplyBy2Bolt(), 2)
              .shuffleGrouping("streamIntegers");

        Config conf = new Config();
        conf.setDebug(false);
        conf.setNumWorkers(3);
```

Set the bolt
Specify:
- Name
- Instance of the bolt
- Number of executors

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Running example Topology

```
package ...
import ...

public class MultiplyBy2Topology {

    public static void main(String[] args) throws Exception {

        TopologyBuilder builder = new TopologyBuilder();

        builder.setSpout("streamIntegers", new EmitRandomIntSpout(), 1);
        builder.setBolt("multiply", new MultiplyBy2Bolt(), 2)
              .shuffleGrouping("streamIntegers");

        Config conf = new Config();
        conf.setDebug(false);
        conf.setNumWorkers(3);
```

Subscribe the bolt to the streamInteger spout
- Use the Shuffle Grouping technique

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Running example Topology

```
package ...
import ...

public class MultiplyBy2Topology {

    public static void main(String[] args) throws Exception {

        TopologyBuilder builder = new TopologyBuilder();

        builder.setSpout("streamIntegers", new EmitRandomIntSpout(), 1);
        builder.setBolt("multiply", new MultiplyBy2Bolt(), 2)
              .shuffleGrouping("streamIntegers");

        Config conf = new Config();
        conf.setDebug(false);
        conf.setNumWorkers(3);
```

Specify the number of workers used to deploy the topology

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Running example Topology

```
        if (args != null && args.length > 0) {
            String topologyName = args[0];

            StormSubmitter.submitTopology(topologyName, conf,
                                          builder.createTopology());
        } else {
            System.out.println("storm jar example-1.0.0.jar
                    storm_example.multiplyby2 <topology name>");
        }

    }
}
```

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Running example Topology

```
        if (args != null && args.length > 0) {
            String topologyName = args[0];

            StormSubmitter.submitTopology(topologyName, conf,
                                          builder.createTopology());
        } else {
            System.out.println("storm jar example-1.0.0.jar
                    storm_example.multiplyby2 <topology name>");
        }

    }
}
```

Submit the topology
Specify:
- Name
- Environment Configuration
- An instance of the topology

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Reliable vs unreliable spouts

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Reliable vs unreliable spouts

- Spouts can be reliable or unreliable
- A reliable spout is capable of replaying a tuple if it failed to be processed by Storm
- An unreliable spout forgets about the tuple as soon as it is emitted
  - It does not reemit the tuple if it processing fails
- Unreliable spouts are faster
  - Use them if you need high-performance and you can "lose" some tuples

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Reliable vs unreliable spouts

- Each reliable spout maintains a queue with the emitted tuples
- The ack() and fail() methods of BaseRichSpout are used to update the content of the queue
  - ack is used to remove from the queue a tuple that has been fully processed
  - fail is usually used to resend a tuple that has not been properly processed

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Ack and Fail methods

- BaseRichSpout has also the following methods
  - void ack(Object msgId)
    - This method of the spout is invoked when the tuple emitted by this spout with the msgId identifier has been fully processed
  - void fail(Object msgId)
    - This method of the spout is invoked when the tuple emitted by this spout with the msgId identifier has failed to be fully processed

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Reliable implementation of the running example topology: Spout

```
package ...
import ....

/**
 * Emits a random integer every 100 ms.
 */
@SuppressWarnings("serial")
public class EmitRandomIntSpoutReliable extends BaseRichSpout{

	private SpoutOutputCollector collector;
	private Random rand;
	private Integer msgId;
	HashMap<Integer, Integer> sentTuples;

	@Override
	public void open(Map conf, TopologyContext context, SpoutOutputCollector collector) {
		this.collector = collector;
		this.msgId = 0;
		this.rand = new Random();
		this.sentTuples = new HashMap<Integer, Integer>();
	}

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

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Reliable implementation of the running example topology: Spout

```
	@Override
	public void nextTuple() {
		Utils.sleep(100);
		Integer val = rand.nextInt(100);
		msgId++;
		collector.emit(new Values(val), msgId);
		// Store the sent tuple until the ack is received
		sentTuples.put(msgId, val);
	}

	@Override
	public void ack(Object id) {
		sentTuples.remove(msgId);
	}

	@Override
	public void fail(Object id) {
		// Send again the number associated with this msgId
		Integer val = sentTuples.get(id);
		collector.emit(new Values(val), msgId);
	}


}
```

Store the sent tuples

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Reliable implementation of the running example topology: Spout

```
	@Override
	public void nextTuple() {
		Utils.sleep(100);
		Integer val = rand.nextInt(100);
		msgId++;
		collector.emit(new Values(val), msgId);
		// Store the sent tuple until the ack is received
		sentTuples.put(msgId, val);
	}

	@Override
	public void ack(Object id) {
		sentTuples.remove(msgId);
	}

	@Override
	public void fail(Object id) {
		// Send again the number associated with this msgId
		Integer val = sentTuples.get(id);
		collector.emit(new Values(val), msgId);
	}


}
```

Remove the tuple when the ack is received

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Reliable implementation of the running example topology: Spout

```
@Override
public void nextTuple() {
        Utils.sleep(100);
        Integer val = rand.nextInt(100);
        msgId++;
        collector.emit(new Values(val), msgId);
        // Store the sent tuple until the ack is received
        sentTuples.put(msgId, val);
}

@Override
public void ack(Object id) {
        sentTuples.remove(msgId);
}

@Override
public void fail(Object id) {
        // Send again the number associated with this msgId
        Integer val = sentTuples.get(id);
        collector.emit(new Values(val), msgId);
}

}
```

Send again the tuple if a fail is received

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Reliable implementation of the running example topology: Bolt

```
package ...
import ....

@SuppressWarnings("serial")
public class MultiplyBy2BoltReliable extends BaseRichBolt {

    private OutputCollector collector;

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

    @Override
    public void declareOutputFields(OutputFieldsDeclarer declarer) {
    }

    @Override
    public void execute(Tuple tuple) {
            // Print the computed value on the standard output
            System.out.println(tuple.getIntegerByField("intValue") * 2);
            collector.ack(tuple);
    }

}
```

Ack the processing of the tuple

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Reliable implementation of the running example topology: Topology

```
package ...
import ....

public class MultiplyBy2TopologyReliable {

    public static void main(String[] args) throws Exception {

            TopologyBuilder builder = new TopologyBuilder();

            builder.setSpout("streamIntegers", new EmitRandomIntSpoutReliable(), 1);
            builder.setBolt("multiply", new MultiplyBy2BoltReliable(), 2).shuffleGrouping("streamIntegers");

            Config conf = new Config();
            conf.setDebug(false);
            conf.setNumWorkers(3);

            if (args != null && args.length > 0) {
                        String topologyName = args[0];

                        StormSubmitter.submitTopology(topologyName, conf, builder.createTopology());
            } else {
                        System.out.println("storm jar example-1.0.0.jar storm_example.multiplyby2Reliable
    <topology name>");
            }

    }
}
```

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Examples

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Bolts emitting tuples: Example

- Run a topology with one spout and two bolts
- The spout emits random integer numbers
- The first bolt reads the stream emitted by the spout and multiplies each number by 2
  - It emits the output as a new stream
- The second bolt reads the stream emitted by the first bolt and sums 1 to each number
  - It prints the output on the standard output

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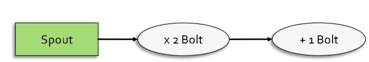
Bolts emitting tuples: Example



This spout emits random integer numbers between 0 and 99. → - x 2 Bolt multiplies by 2
- + 1 Bolt sums 1

(.., 1, 10, 5, ..) → (.., 2, 20, 10, ..) → (.., 3, 21, 11, ..)

Bolts emitting tuples: Example - Topology

```
package ....
import ......

public class BoltEmitStreamTopology {

    public static void main(String[] args) throws Exception {

        TopologyBuilder builder = new TopologyBuilder();

        builder.setSpout("spout", new EmitRandomIntSpout(), 1);
        builder.setBolt("multiplyBy2", new MultiplyBy2Bolt(), 2).shuffleGrouping("spout");
        builder.setBolt("sum1", new Sum1Bolt(), 2).shuffleGrouping("multiplyBy2");

        Config conf = new Config();
        conf.setDebug(false);
        conf.setNumWorkers(3);
```

sum1 processes the data emitted by multiplyBy2

Bolts emitting tuples: Example - Topology

```
        if (args != null && args.length > 0) {
            String topologyName = args[0];

            StormSubmitter.submitTopology(topologyName, conf,
    builder.createTopology());
        } else {
            System.out.println("storm jar target/example-1.0.0.jar
    storm_example.bolt_emitting_stream.BoltEmitStreamTopology <topology name>");
        }

    }
}
```


Bolts emitting tuples: Example - Spout

```
package ....
import ......

@SuppressWarnings("serial")
public class EmitRandomIntSpout extends BaseRichSpout {

    private SpoutOutputCollector collector;
    private Random rand;
    private Integer msgId;
    HashMap<Integer, Integer> sentTuples;

    @Override
    public void open(Map conf, TopologyContext context, SpoutOutputCollector collector) {
        this.collector = collector;
        this.msgId = 0;
        this.rand = new Random();
        this.sentTuples = new HashMap<Integer, Integer>();
    }
```


Bolts emitting tuples: Example - Spout

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

    @Override
    public void nextTuple() {
        Utils.sleep(100);
        Integer val = rand.nextInt(100);
        msgId++;
        collector.emit(new Values(val), msgId);
        // Store the sent tuple until the ack is received
        sentTuples.put(msgId, val);
    }
```


Bolts emitting tuples: Example - Spout

```
    @Override
    public void ack(Object id) {
        sentTuples.remove(msgId);
    }

    @Override
    public void fail(Object id) {
        // Send again the number associated with this msgId
        Integer val = sentTuples.get(id);

        collector.emit(new Values(val), msgId);
    }
}
```


Bolts emitting tuples: Example – x2Bolt

```
package ....
import ......

@SuppressWarnings("serial")
public class MultiplyBy2Bolt extends BaseRichBolt {

    private OutputCollector collector;

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

Bolts emitting tuples: Example – x2Bolt

```
@Override
public void declareOutputFields(OutputFieldsDeclarer declarer) {
        declarer.declare(new Fields("time2Value"));
}

@Override
public void execute(Tuple tuple) {
        // Print the computed value on the standard output
        // Multiply by 2 the value of the tuple and emit it on the output stream
        collector.emit(tuple, new Values(tuple.getIntegerByField("intValue")* 2));
        collector.ack(tuple);
}

}
```

Declare the schema of the emitted tuples

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Bolts emitting tuples: Example – x2Bolt

```
@Override
public void declareOutputFields(OutputFieldsDeclarer declarer) {
        declarer.declare(new Fields("time2Value"));
}

@Override
public void execute(Tuple tuple) {
        // Print the computed value on the standard output
        // Multiply by 2 the value of the tuple and emit it on the output stream
        collector.emit(tuple, new Values(tuple.getIntegerByField("intValue")* 2));
        collector.ack(tuple);
}

}
```

Emit a new tuple on the ouput stream.
- The first parameter is the original tuple
-The second one is the new tuple

The first tuple is used to create a link between the original tuple and the generated ones for managing reliability

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Bolts emitting tuples: Example – +1Bolt

```
package ….
import ……

@SuppressWarnings("serial")
public class Sum1Bolt extends BaseRichBolt {

    private OutputCollector collector;

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

    @Override
    public void declareOutputFields(OutputFieldsDeclarer declarer) {
    }
```

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Bolts emitting tuples: Example – +1Bolt

```
@Override
public void execute(Tuple tuple) {
        // Print the computed value on the standard output
        // Sum 1 to the value of the tuple
        System.out.println((tuple.getInteger(0) + 1));
        collector.ack(tuple);
}

}
```

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Spouts and Bolt: other methods

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Spouts: other methods

- BaseRichSpout has also the following methods
  - void close()
    - Called when a spout is going to be shutdown
      - There is no guarantee that cleanup will be called
  - void activate()
    - Called when a spout has been activated out of a deactivated mode
  - void deactivate()
    - Called when a spout has been deactivated

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Bolts: other methods

- BaseRichBolt has also the following methods
  - void cleanup()
    - It is called when a Bolt is going to be shutdown
      - There is no guarantee that cleanup will be called

Multiple input and output streams

Multiple input streams

- Each bolt can subscribe multiple input streams/the output of multiple components to
  - Implement join operations
  - Receive data and signals
  - ...
- For each stream, the most appropriate stream grouping technique is specified
- In the nextTuple(..) method a different operation is executed depending on the origin of the tuple (i.e., the input stream)

Multiple input streams

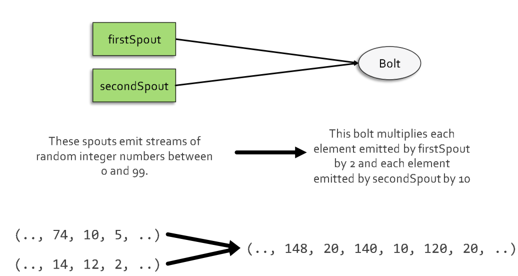
- A bolt can subscribe the streams of multiple components by means of a chain of calls to the stream grouping methods
  - One call for each subscribed component
- Example

```
builder.setBolt("merge",
   new ProcessMultipleStreamsBolt(), 2)
   .shuffleGrouping("firstSpout")
   .shuffleGrouping("secondSpout");
```


Multiple input streams: Example

- Run a topology with two spouts and one bolt
- The two spouts emit random integer numbers
- The bolt multiply by 2 the numbers emitted by the first spout and by 10 the numbers emitted by the second spout
  - Print the results computed by the bolt on the standard output

Multiple input streams: Example



Multiple input streams: Example - Topology

```
package ....
import ......

public class MultipleInputStreamsTopology {

    public static void main(String[] args) throws Exception {

        TopologyBuilder builder = new TopologyBuilder();

        builder.setSpout("firstSpout", new EmitRandomIntSpout(), 1);
        builder.setSpout("secondSpout", new EmitRandomIntSpout(), 1);
        builder.setBolt("merge", new ProcessMultipleStreamsBolt(), 2)
        .shuffleGrouping("firstSpout")
        .shuffleGrouping("secondSpout");

        Config conf = new Config();
        conf.setDebug(false);
        conf.setNumWorkers(3);
```

merge subscribes the streams emitted by firstSpout and secondSpout

Multiple input streams: Example - Topology

```
        if (args != null && args.length > 0) {
            String topologyName = args[0];

            StormSubmitter.submitTopology(topologyName, conf, builder.createTopology());
        } else {
            System.out.println("storm jar target/example-1.0.0.jar
    storm_example.multiple_input_streams.MultipleInputStreamsTopology <topology name>");
        }

    }
}
```


Multiple input streams: Example - Spout

```
package ...
Import ...
@SuppressWarnings("serial")
public class EmitRandomIntSpout extends BaseRichSpout {

    private SpoutOutputCollector collector;
    private Random rand;
    private Integer msgId;
    HashMap<Integer, Integer> sentTuples;

    @Override
    public void open(Map conf, TopologyContext context, SpoutOutputCollector collector) {
        this.collector = collector;
        this.msgId = 0;
        this.rand = new Random();
        this.sentTuples = new HashMap<Integer, Integer>();
    }

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


Multiple input streams: Example - Spout

```
    @Override
    public void nextTuple() {
        Utils.sleep(100);
        Integer val = rand.nextInt(100);
        msgId++;
        collector.emit(new Values(val), msgId);
        // Store the sent tuple until the ack is received
        sentTuples.put(msgId, val);
    }

    @Override
    public void ack(Object id) {
        sentTuples.remove(msgId);
    }

    @Override
    public void fail(Object id) {
        // Send again the number associated with this msgId
        Integer val = sentTuples.get(id);
        collector.emit(new Values(val), msgId);
    }
}
```


Multiple input streams: Example - Bolt

```
package ....
import ......

@SuppressWarnings("serial")
public class ProcessMultipleStreamsBolt extends BaseRichBolt {

    private OutputCollector collector;

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

    @Override
    public void declareOutputFields(OutputFieldsDeclarer declarer) {
    }
```


Multiple input streams: Example - Bolt

Check which spout (component) emitted the tuple

```
    @Override
    public void execute(Tuple tuple) {
        // Print the computed value on the standard output
        // Multiply by 2 the numbers of the stream collected from the firstSpout
        // and by 10 the numbers of the stream of the secondSpout
        if (tuple.getSourceComponent().equals("firstSpout")) {
            System.out.println("firstSpout:" + tuple.getIntegerByField("intValue") + "->"
                        + tuple.getIntegerByField("intValue") * 2);
        } else {
            System.out.println("secondSpout:" + tuple.getIntegerByField("intValue") + "->"
                        + tuple.getIntegerByField("intValue") * 10);
        }

        collector.ack(tuple);
    }

}
```

Multiple output streams

- Each spout can emit multiple output streams
  - The emitted streams are usually used by different paths of the topology to perform different analysis in parallel
- Each output stream must be associated with a unique name
- The emit(..) method must be called specifying the name of the emitting stream for every emitted tuple

Multiple output streams

- Names and schemas of the emitted streams are defined in the declareOutputFields(...) method of the spout by using the declareStream(name, schema) method
- Example

```
public void declareOutputFields(OutputFieldsDeclarer declarer){
    declarer.declareStream("firstStream",
            new Fields("firstAttr", "secondAttr"));
    declarer.declareStream("secondStream",
            new Fields("attr1"));
}
```


Multiple output streams

- In the nextTuple(..) method the emit(..) method must be called by specifying the stream name
- Example

```
public void nextTuple() {
    ...
    if (test) {
            collector.emit("firstStream", new Values(val1, val2), msgId);
    } else {
            collector.emit("secondStream", new Values(val1), msgId);
    }
    // Store the sent tuple until the ack is received
    sentTuples.put(msgId, val);
}
```


Multiple output streams

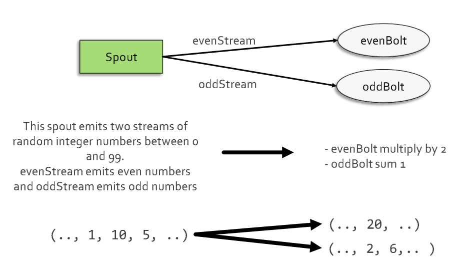
- Bolts must specify which emitted stream want to subscribe by specifying the name of the spout and the name of the stream
  - Each bolt can subscribe multiple streams of the same spout by means of multiple calls to the grouping methods
    - One different call for each subscribed stream
- Example

```
builder.setBolt("myBolt", new MyBolt(),2)
  .shuffleGrouping("spout","firstStream");
```


Multiple output streams: Example

- Run a topology with one spout and two bolts
- The spout emits two streams of random integer numbers
  - The first stream (called evenStream) contains even numbers
  - The second stream (called oddStream) contains odd numbers
- One bolt subscribes the evenStream and multiplies each value by 2
- The other bolt subscribes the oddStream and sums 1 to each value
  - Print the results computed by the two bolts on the standard output

Multiple output streams: Example



Multiple output streams: Example - Topology

```
package ....
import ......

public class MultipleOuputStreamsTopology {

    public static void main(String[] args) throws Exception {

        TopologyBuilder builder = new TopologyBuilder();

        builder.setSpout("spout", new EmitMultipleRandomIntSpout(), 1);
        builder.setBolt("processEven", new MultiplyBy2Bolt(), 2)
                .shuffleGrouping("spout","evenStream");
        builder.setBolt("processOdd", new Sum1Bolt(), 2)
                .shuffleGrouping("spout","oddStream");

        Config conf = new Config();
        conf.setDebug(false);
        conf.setNumWorkers(3);
```

Specify component and stream

Multiple output streams: Example - Topology

```
        if (args != null && args.length > 0) {
                String topologyName = args[0];

                StormSubmitter.submitTopology(topologyName, conf,
    builder.createTopology());
        } else {
                System.out.println("storm jar target/example-1.0.0.jar
    storm_example.multiple_output_streams.MultipleOuputStreamsTopology <topology
    name>");
        }

    }
}
```


Multiple output streams: Example - Spout

```
package ....
import ......

@SuppressWarnings("serial")
public class EmitMultipleRandomIntSpout extends BaseRichSpout {

    private SpoutOutputCollector collector;
    private Random rand;
    private Integer msgId;
    HashMap<Integer, Integer> sentTuples;

    @Override
    public void open(Map conf, TopologyContext context, SpoutOutputCollector collector) {
        this.collector = collector;
        this.msgId = 0;
        this.rand = new Random();
        this.sentTuples = new HashMap<Integer, Integer>();
    }
```


Multiple output streams: Example - Spout

```
@Override
public void declareOutputFields(OutputFieldsDeclarer declarer) {
        declarer.declareStream("oddStream", new Fields("intValue"));
        declarer.declareStream("evenStream", new Fields("intValue"));
}

@Override
public void nextTuple() {
        Utils.sleep(100);
        Integer val = rand.nextInt(100);
        msgId++;
        if (val % 2 == 0) {
                collector.emit("evenStream", new Values(val), msgId);
        } else {
                collector.emit("oddStream", new Values(val), msgId);
        }
        // Store the sent tuple until the ack is received
        sentTuples.put(msgId, val);
}
```

Declare the output streams:
-Name
- Schema

Multiple output streams: Example - Spout

```
    @Override
    public void declareOutputFields(OutputFieldsDeclarer declarer) {
        declarer.declareStream("oddStream", new Fields("intValue"));
        declarer.declareStream("evenStream", new Fields("intValue"));
    }

    @Override
    public void nextTuple() {
        Utils.sleep(100);
        Integer val = rand.nextInt(100);
        msgId++;
        if (val % 2 == 0) {
                collector.emit("evenStream", new Values(val), msgId);
        } else {
                collector.emit("oddStream", new Values(val), msgId);
        }
        // Store the sent tuple until the ack is received
        sentTuples.put(msgId, val);
    }
```

Specify the name of the output stream

Multiple output streams: Example - Spout

```
@Override
public void ack(Object id) {
        sentTuples.remove(msgId);
}

@Override
public void fail(Object id) {
        // Send again the number associated with this msgId
        Integer val = sentTuples.get(id);

        if (val % 2 == 0) {
                collector.emit("evenStream", new Values(val), msgId);
        } else {
                collector.emit("oddStream", new Values(val), msgId);
        }
    }
}
```

Remove the tuple from the queue when received an ack

Multiple output streams: Example - Spout

```
    @Override
    public void ack(Object id) {
        sentTuples.remove(msgId);
    }

    @Override
    public void fail(Object id) {
        //Send again the number associated with this msgId
        Integer val = sentTuples.get(id);

        if (val % 2 == 0) {
                collector.emit("evenStream", new Values(val), msgId);
        } else {
                collector.emit("oddStream", new Values(val), msgId);
        }
    }
}
```

Send again the tuple in case of failure

Multiple output streams: Example – MultiplyBy2Bolt

```
package ...
import ...
@SuppressWarnings("serial")
public class MultiplyBy2Bolt extends BaseRichBolt {

    private OutputCollector collector;

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

    @Override
    public void declareOutputFields(OutputFieldsDeclarer declarer) {
    }
```


Multiple output streams: Example – MultiplyBy2Bolt

```
    @Override
    public void execute(Tuple tuple) {
        // Print the computed value on the standard output
        // Multiply by 2 the value of the tuple
        System.out.println(tuple.getSourceStreamId());
        System.out.println("Even"+tuple.getIntegerByField("intValue") + "->" +
    (tuple.getIntegerByField("intValue") * 2));
        collector.ack(tuple);
    }

}
```


Multiple output streams: Example – Sum1Bolt

```
package ...
import ...
@SuppressWarnings("serial")
public class Sum1Bolt extends BaseRichBolt {

    private OutputCollector collector;

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

    @Override
    public void declareOutputFields(OutputFieldsDeclarer declarer) {
    }
```


Multiple output streams: Example – Sum1Bolt

```
    @Override
    public void execute(Tuple tuple) {
        // Print the computed value on the standard output
        // Sum 1 to the value of the tuple
        System.out.println(tuple.getSourceStreamId());
        System.out.println("Odd"+tuple.getIntegerByField("intValue") + "->" +
    (tuple.getIntegerByField("intValue") + 1));
        collector.ack(tuple);
    }

}
```


Multiple output streams

- Also bolts can emit multiple streams
- The approach is the same used for spouts

Reliability with complex tolopologies

Reliable Topologies

- Storm offers several different levels of guaranteed message (tuple) processing
  - Best effort
    - No reliable spouts
      - Acks and fails are not managed
  - At least once
    - Reliable spouts
      - Acks an fails are managed and non-processed tuples are sent again in order to be processed
  - Exactly once through Trident
    - We will see it later

Reliable Topologies

- At least once
  - We already discuss how to implement simple reliable topologies
    - A topology with one spout and one bolt
    - A topology with a single path
  - The next slides discuss how to manage reliability with more complex topologies

Tuple trees

- A tuple coming off a spout can trigger thousands of tuples to be created based on it
- For each tuple emitted by a spout, storm can build a tuple tree
  - It represents the dependencies among the original tuples and its "descendants"
- Storm considers a tuple coming off a spout "**fully processed**" when the tuple tree has been exhausted and every message in the tree has been processed
- A tuple is considered "**failed**" when its tree of messages fails to be fully processed within a specified timeout or when at least one failure appends

Storm's reliability

- To benefit from Storm's reliability capabilities you must
  - Tell Storm whenever you're creating a new link in the tree of tuples
    - Anchoring the new tuples to the original ones
  - Tell Storm when you have finished processing an individual tuple
    - By call the ack method on the processed tuples
- By doing both these things, Storm can detect when the tree of tuples is fully processed and can ack or fail the spout tuple appropriately

Anchoring

- Specifying a link in the tuple tree is called anchoring
- Anchoring is done at the same time you emit a new tuple by specifying also the original tuple in the emit(..) method
  - collector.emit(tuple, emitted tuple)

Multiple-Anchoring

- An output tuple can be anchored to more than one input tuple
  - This is useful when doing streaming joins or aggregations
- A multi-anchored tuple failing to be processed will cause multiple tuples to be replayed from the spouts

Multiple-Anchoring

- Multi-anchoring is done by specifying a list of tuples rather than just a single tuple when calling the emit() method
- Example

```
List<Tuple> anchors = new ArrayList<Tuple>();
anchors.add(tuple1);
anchors.add(tuple2);
collector.emit(anchors, new Values(1, 2, 3));
```


Aggregations and joins

- Bolts that do aggregations or joins may delay acking a tuple until after it has computed a result based on a bunch of tuples
- Aggregations and joins will commonly multi-anchor their output tuples as well
- We will see an example later

Common Topology Patterns

Streaming joins

Streaming joins

- A streaming join combines two or more data streams together based on some common fields
- There are several definitions/types of "streaming join"
  - Some applications join all tuples for two streams over a finite window of time
  - Other applications expect exactly one tuple for each stream involved in the join
  - ..
- The join type is usually application-dependent

Streaming joins

- The common pattern among all these join types consists of the following steps
  - Send the tuples of the multiple input streams with the same values of the join fields to the same task of the joining bolt
    - This is accomplished by using a fields grouping on the join fields for the input streams to the join bolt
  - Temporarily store the tuples in an instance variable of the task
  - Perform the join operation inside the task
  - Remove the tuples from the instance variable as soon as they are not more needed

In-memory caching + fields grouping combo

In-memory caching + fields grouping combo

- It is common to keep caches in-memory in Storm bolts
  - For example to avoid invoking multiple times an external service through http requests
- Caching becomes particularly powerful when you combine it with a fields grouping
  - Each task keeps only the subset of cache used to process the values sent to it
    - No useless overlapping among the caches of the bolt's tasks

In-memory caching + fields grouping combo

- Suppose you have a bolt that expands short URLs into long URLs
  - Given a short URL, an HTTP request to an external service is invoked to obtain the long URL
- Keep an LRU cache of short URL to long URL to avoid doing the same HTTP requests multiple times
- To improve the efficiency and reduce multiple requests for the same short URL, fields grouping on the short URL field must be specified
  - Each task of the bolt manages a subset mapping short URL -> long URL

BasicBolt

BasicBolt

- Many bolts follow a similar pattern of
  - Reading an input tuple
  - Emitting zero or more tuples based on that input tuple
  - And then acking that input tuple immediately at the end of the execute method
- Bolts that match this pattern are things like functions and filters

BasicBolt

- This is such a common pattern that Storm exposes an abtract class called BaseBasicBolt that automates this pattern for you
  - All acking is managed for you
  - Throw a FailedException if you want to fail the tuple

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Periodic statistics/output

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Periodic statistics/output

- Many applications emit a statistic of interest, based on the analysis of the input stream, every ***t*** seconds
- For example, suppose you have a bolt that every ***t*** seconds emits the number of analyzed input tuples

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Periodic statistics/output: Sol #1

- This problem can be solved by using a spout generating a "signal" every ***t*** seconds
  - The bolt emits the current value of the statistic every time it receives the "signal" tuple
  - The bolt subscribes both the signal stream and the stream of data to analyze

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Periodic statistics/output: Sol #2

- Storm provides a special type of tuples called Tick tuples
- They are configured per-component, i.e. per bolt
  - One Tick tuple is sent to each component every Config.TOPOLOGY_TICK_TUPLE_FREQ_SECS seconds
- We can use this special type of tuples to decide when to emit the statistic of interest

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Tick tuples

- The frequency of the tick tuples for each bolt is set in the getComponentConfiguration method of the bolt

```
@Override
public Map<String, Object> getComponentConfiguration() {
  Map<String, Object> conf = new HashMap<String,
  Object>();
  conf.put(Config.TOPOLOGY_TICK_TUPLE_FREQ_SECS,
  emitFrequencyInSeconds);
  return conf;
}
```

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Tick tuples

- The method TupleUtils.isTick(tuple) can be used in the execute(..) method of a bolt to check if the current tuple is a Tick tuple

Tick tuples

- Tick tuples are not 100% guaranteed to arrive in time
  - They are sent to a bolt just like any other tuples, and will enter the same queues and buffers
    - Congestion, for example, may cause tick tuples to arrive too late.
  - Across different bolts, tick tuples are not guaranteed to arrive at the same time
    - Even if the bolts are configured to use the same tick tuple frequency
  - Currently, tick tuples for the same bolt will arrive at the same time at the bolt's various task instances
    - However, this property is not guaranteed for the future
- Tick tuples must be acked like any other tuple

Periodic statistics/output: Exmple

- Run a topology that every ***t*** seconds emits the number of tuples emitted by a spout that emits a stream of random integers

Streaming top N

Streaming top N

- A common continuous computation done on Storm is "**streaming/selecting top N**" elements
- For example, suppose you have a spout that emits tuples of the form ["value", "count"] and you want a bolt that emits, every ***t*** seconds, the top N tuples based on count

Streaming top N: Solution #1

- The simplest way to implement streaming top N is based on one single bolt
- The bolt
  - Does a global grouping on the stream
    - i.e., all tuples are sent to one single task of the bolt
  - Maintains a list in memory of the top N items
    - In the only task executing the bolt
  - Emits the top-N list every ***t*** seconds
- This approach does not scale to large streams since the entire stream has to go through one single task

Streaming top N: Solution #2

- A more scalable solution is based on two bolts
- The first bolt computes local top-N lists in parallel on the input stream
  - One top-N list in each task of the first bolt
  - Each task emits its local top-N list every ***t*** seconds
- The second bolt computes the global top-N list merging the local ones
  - This bolt does a global grouping on the output of the first bolt and emits the global top-N list every ***t*** seconds

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Streaming top N

- The differences between Solution #1 and Solution #2 is highly related to ***t*** (the frequency of emission of the global top-N list)
  - The higher ***t***, the higher the difference between Sol. #1 and Sol. #2

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Batching

Batching

- Some applications need to process a group of tuples in batch rather than individually
  - You may want to batch updates to a database for efficiency reasons
  - You may need to do a streaming aggregation

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Batching

- If you want reliability in your batching data processing
  - You must hold on the tuples in an instance variable while the bolt waits to do the batching
  - Once you complete the batch operation, ack all the tuples you were holding
  - If the bolt emits tuples, then you may want to use multi-anchoring to ensure reliability

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Batching

- This pattern can be implemented by using
  - The standard classes
  - Or transactional topologies
    - There are specifically designed for processing batch of tuples

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