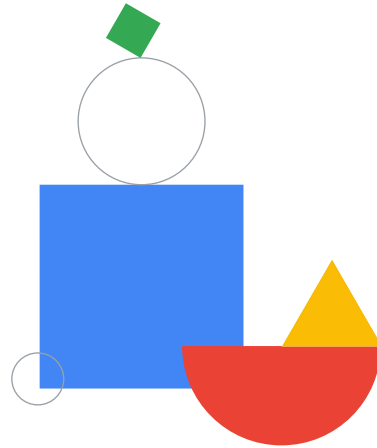


Serverless Data Processing with Dataflow



The canonical way to carry out data processing on Google Cloud is to use Dataflow.

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Dataflow SQL

Dataflow is the execution service for data processing pipelines written using Apache Beam.

Apache Beam is open-source and supported by Java, Python, and Go SDKs. You can also run them using runners like Flink as well. You might use Flink if you want to run a Beam pipeline on-prem or in another cloud.

On Google Cloud, Dataflow is the most effective execution environment within which to run Apache Beam.

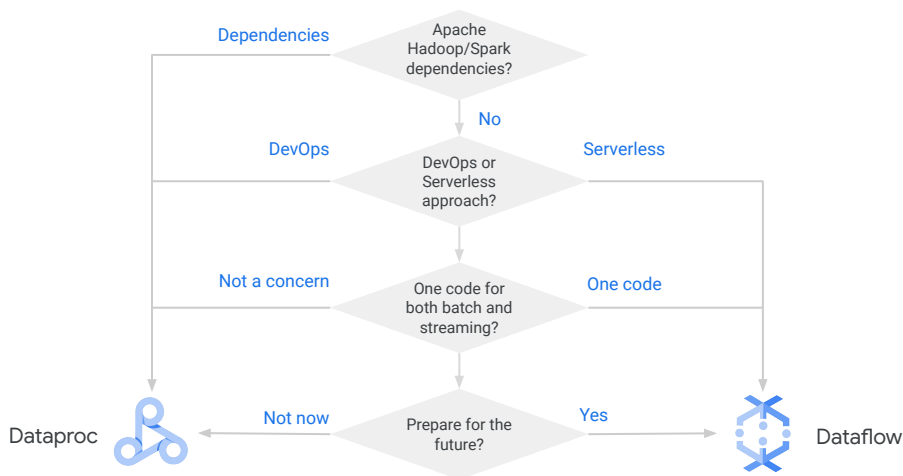
Dataflow versus Dataproc

| |  Dataflow |  Dataproc |
|------------------|--------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------|
| Recommended for: | New data processing pipelines, unified batch and streaming | Existing Hadoop/Spark applications, machine learning/data science ecosystem, large-batch jobs, preemptible VMs |
| Fully-managed: | Yes | No |
| Auto-scaling: | Yes, transform-by-transform (adaptive) | Yes, based on cluster utilization (reactive) |
| Expertise: | Apache Beam | Hadoop, Hive, Pig, Apache Big Data ecosystem, Spark, Flink, Presto, Druid |

The reason Dataflow is the preferred way to do data processing on Google Cloud is that Dataflow is serverless. You don't have to manage clusters at all. Unlike with Dataproc, the autoscaling in Dataflow scales step-by-step. It's very fine-grained. Plus, as we will see in the next course, Dataflow allows you to use the same code for both batch and stream. This is becoming increasingly important.

When building a new data processing pipeline, we recommend that you use Dataflow. If, on the other hand, you have existing pipelines written using Hadoop technologies, it may not be worth it to rewrite everything. Migrate it over to Google Cloud using Dataproc, and then modernize it as necessary.

Choosing between Dataflow and Dataproc



As a Data Engineer, we recommend that you learn both Dataflow and Dataproc and make the choice based on what's best for a specific use case.

If the project has existing Hadoop or Spark dependencies, use Dataproc.

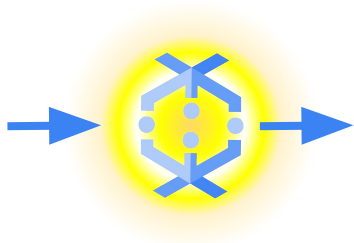
Please keep in mind that there are many subjective issues when making this decision and that no simple guide will fit every use case.

Sometimes, the production team might be much more comfortable with a DevOps approach where they provision machines than with a serverless approach. In that case, too, you might pick Dataproc.

If you don't care about streaming and your primary goal is to move existing workloads, then Dataproc would be fine.

Dataflow, however, is our recommended approach for building pipelines.

Dataflow



Qualities that Dataflow contributes to data engineering solutions:

- ✓ Scalability
- ✓ Low latency



Dataflow

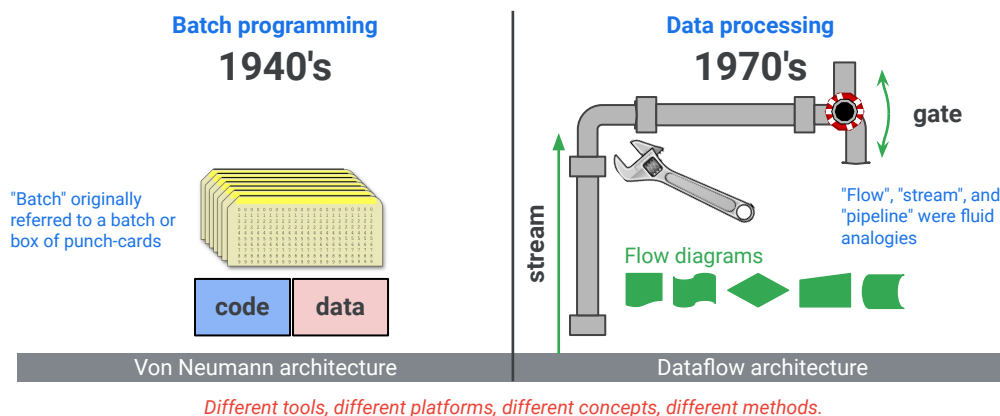
Google Cloud

Dataflow provides a serverless way to execute pipelines on batch and streaming data.

It's scalable -- to process more data, Dataflow will scale out to more machines. It will do this transparently.

The stream processing capability also makes it low latency. You can process the data as it comes in.

Batch programming and data processing used to be two very separate and different things

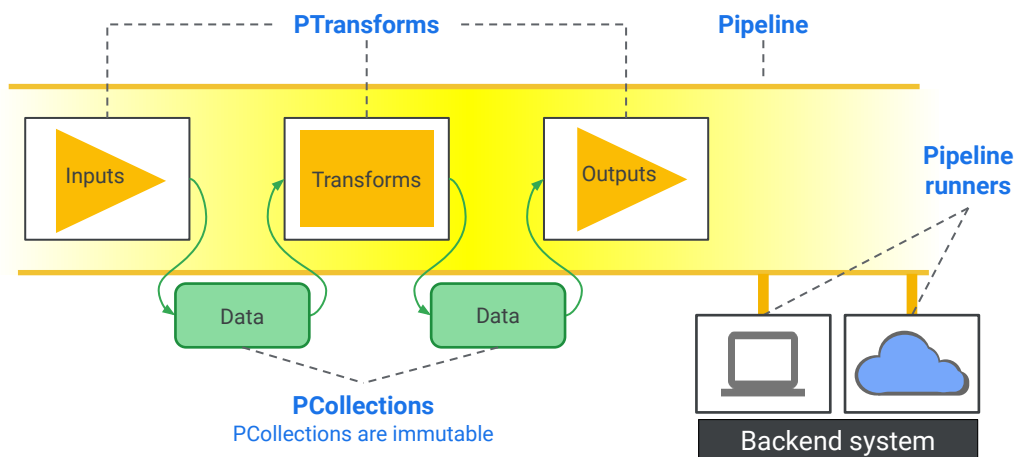


This ability to process batch and stream with the same code is rather unique. For a long time, Batch programming and data processing used to be two very separate and different things

Batch programming dates to the 1940s, and the early days of computing where it was realized that you can think of two separate concepts -- code and data. Use code to process data. Of course, both of these were on punch cards, so that's what you were processing -- a box of punch-cards, called a batch. It was a job that started and ended when the data was fully processed.

Stream processing, on the other hand, is more fluid. It arose in the 1970s with the idea of data processing being something that is ongoing. The idea is that data keeps coming in, and you process the data. The processing itself tended to be done in micro-batches.

Apache BEAM = Batch + strEAM



Google Cloud

The genius of Beam is that it provides abstractions that unify traditional batch programming concepts and traditional data processing concepts. Unifying programming and processing is a big innovation in data engineering.

The four main concepts are PTransforms, PCollections, Pipelines, and Pipeline Runners.

A pipeline identifies the data to be processed and the actions to be taken on the data. The data is held in a distributed data abstraction called a PCollection. The PCollection is immutable. Any change that happens in a pipeline ingests one PCollection and creates a new one. It does not change the incoming PCollection.

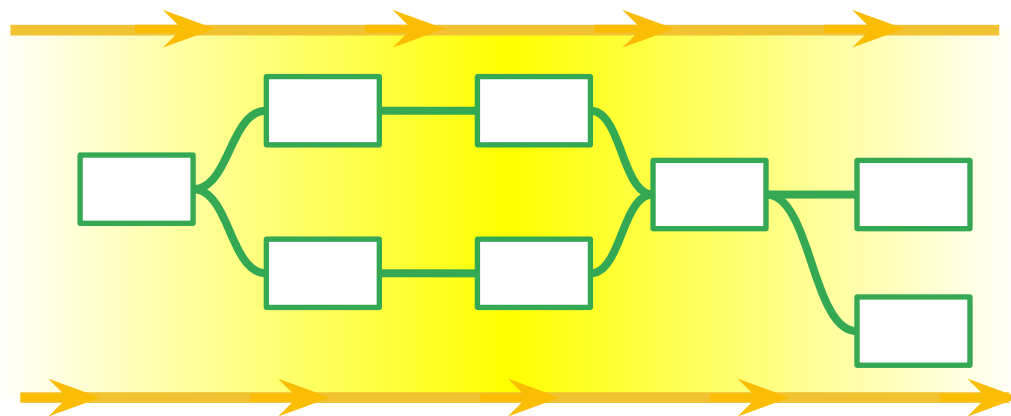
The actions or code is contained in an abstraction called a PTransform. The Ptransform handles input, transformation, and output of the data. The data in a PCollection is passed along a graph from one PTransform to another.

Pipeline runners are analogous to container hosts, such as Google Kubernetes Engine. The identical pipeline can be run on a local computer, Datacenter VM, or on a service such as Dataflow in the cloud. The only difference is scale and access to platform-specific services. The services the runner uses to execute the code is called a back-end system.

Immutable data is one of the key differences between batch programming and data processing. The assumption in the Von Neumann architecture was that data would be

operated on and changed in place, which was very memory efficient. That made sense when memory was very expensive and scarce. Immutable data, where each transform results in a new "copy" means there is no need to coordinate access control or sharing of the original ingest data. So it enables (or at least simplifies) distributed processing.

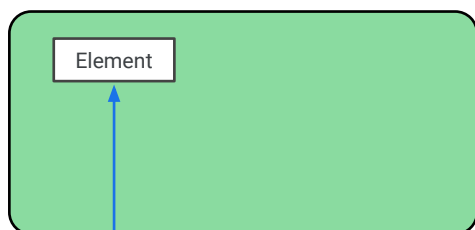
A Dataflow pipeline is a directed graph of steps



The shape of a Pipeline is not actually just a single linear progression, but rather, a directed graph with branches and aggregations. For historical reasons we refer to it as a Pipeline, but a datagraph or dataflow might be a more accurate description.

A PCollection represents batch or stream data

Bounded PCollection



Unbounded PCollection



All data types are stored
as serialized byte strings

Note: Bounded means the data has a fixed size not that the PCollection size is limited. A PCollection can be any size and be distributed across many workers.

A PCollection represents both streaming data and batch data. There is no size limit to a PCollection. Streaming data is an unbounded PCollection that doesn't end.

Each element inside a PCollection can be individually accessed and processed. This is how distributed processing of the PCollection is implemented. So you define the pipeline and the transforms on the PCollection, and the runner handles implementing the transformations on each element, distributing the work as needed for scale and with available resources.

Once an element is created in a PCollection it is immutable. So it can never be changed or deleted. Elements represent different data types.

In traditional programs a data type is stored in memory with a format that favors processing. Integers in memory are different from characters which are different from strings and compound data types. In a PCollection all data types are stored in a serialized state as byte strings. This way there is no need to serialize data prior to network transfer and deserialize it when it is received. Instead, the data moves through the system in a serialized state and is only deserialized when necessary for the actions of a PTransform.

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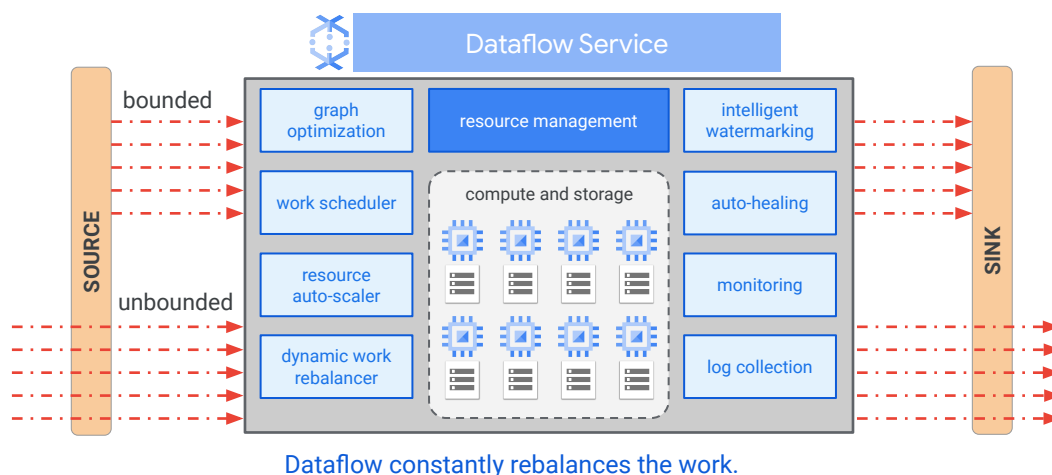
Lab: Serverless Data Analysis with
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Dataflow SQL

That's what Dataflow is. Why do data engineers value Dataflow over other alternatives for data processing?

How does Dataflow work?



Google Cloud

To understand that, it helps to understand a bit about how Dataflow works. Dataflow provides an efficient execution mechanism for Apache Beam.

The Beam pipeline specifies WHAT has to be done. The Dataflow services chooses HOW to run the pipeline.

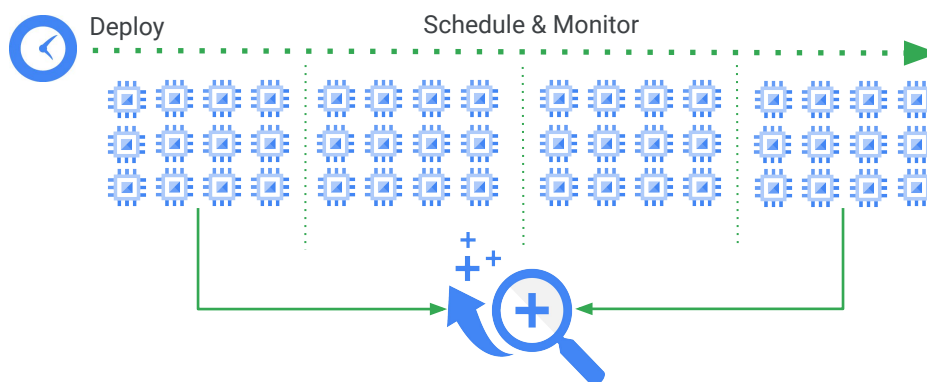
The pipeline typically consists of reading data from one or more sources, applying processing to the data, and writing it to one or more sinks. In order to execute the pipeline, the Dataflow service first optimizes the graph by, for example, fusing transforms together. It then breaks the jobs into units of work and schedules them to various workers.

One of the cool things about Dataflow is that the optimization is always ongoing. Units of work are continually rebalanced.

Resources -- both compute and storage -- are deployed on demand and on a per job basis. Resources are torn down at end of job, stage, or on downscaling. Work scheduled on a resource is guaranteed to be processed. Work can be dynamically rebalanced across resources -- this provides fault-tolerance.

The watermarking handles late arrivals of data, and comes with restarts, monitoring, and logging. No more waiting for other jobs to finish. No more preemptive scheduling. Dataflow provides a reliable, serverless, job-specific way to process your data.

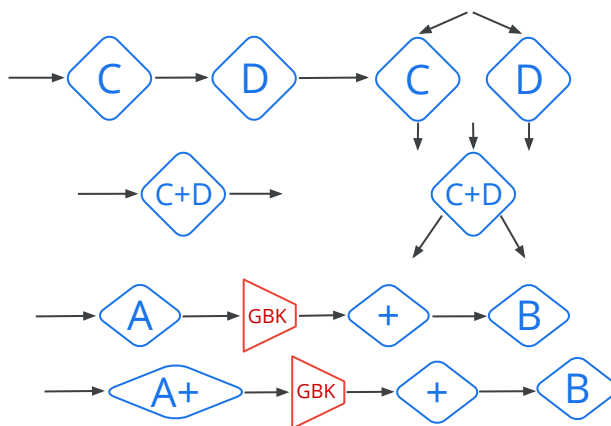
Why customers value Dataflow: Fully-managed and auto-configured



To summarize, the advantages of Dataflow are:

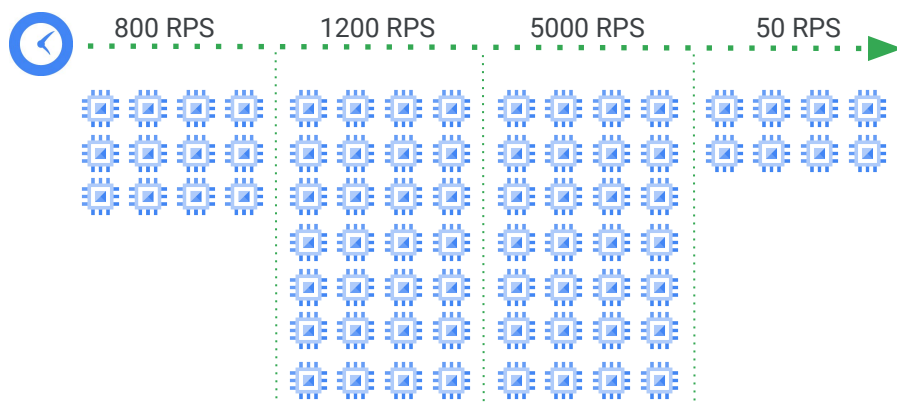
1. Dataflow is fully-managed and auto-configured. Just deploy your pipeline.

Why customers value Dataflow: Graph is optimized for best execution path



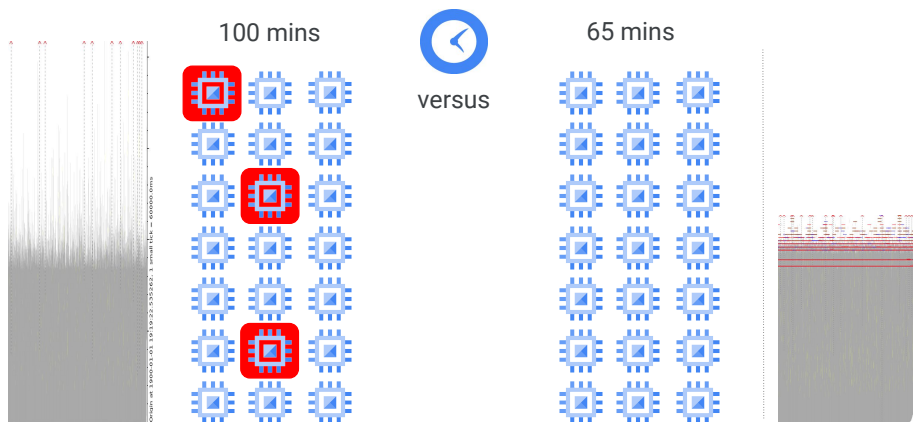
Second, Dataflow doesn't just execute the Apache Beam transforms as-is. It optimizes the graph, fusing operations as we see with C and D. Also, it doesn't wait for a previous step to finish before starting a new step. We see this with A and the Group-by-key.

Why customers value Dataflow: Autoscaling mid-job



Autoscaling happens step-by-step, in the middle of a job. As the jobs needs more resources, it receives more resources. You don't have to manually scale resources to match job needs.

Why customers value Dataflow: Dynamic work rebalancing mid-job



Google Cloud

If some machines have finished their tasks, and others are still going on, the tasks queued up for the busy ones are rebalanced out to the idle machines. This way, the overall job finishes faster.

Dynamic work rebalancing in mid-job removes the need to spend operational or analyst resource time hunting down hotkeys.

Why customers value Dataflow: Strong streaming semantics

- ✓ Exactly once aggregations
- ✓ Rich time tracking
- ✓ Good integration with other Google Cloud services

All this happens while maintaining strong streaming semantics.

Aggregations, like sums and counts, are correct even if the input source sends duplicate records.

Dataflow is able to handle late arriving records.

Finally, Dataflow functions as the glue that ties together many of the services on Google Cloud. Do you need to read from BigQuery and write to Bigtable? Use Dataflow.

Do you need to read from Pub/Sub and write to Cloud SQL? Use Dataflow.

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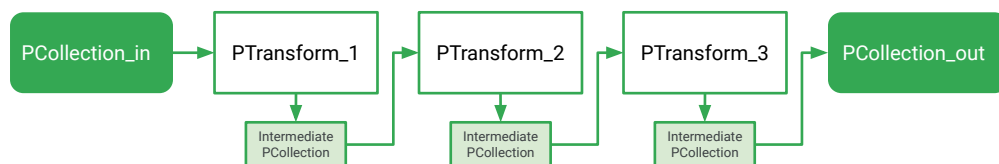
Lab: Serverless Data Analysis with Dataflow: Side Inputs (Python/Java)

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Dataflow SQL

Let's look in greater detail at an example dataflow pipeline.

How to construct a simple pipeline



Python
Python overloads
the pipe operator

```
PCollection_out = (PCollection_in | PTransform_1
                  | PTransform_2
                  | PTransform_3)
```

Java
Java uses the
.apply method

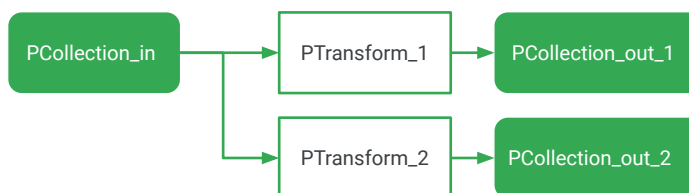
```
PCollection_out = PCollection_in.apply(PTransform_1)
                              .apply(PTransform_2)
                              .apply(PTransform_3)
```

Here's how to construct a simple pipeline where you have an input PCollection and pass it through 3 PTransforms and get an output PCollection.

- The syntax is shown in Python. You have the input, the pipe symbol, the first PTransform, the pipe symbol, the second PTransform, etc.
- The pipe operator essentially applies the transform to the input PCollection and sends out an output PCollection.
- The first three times, we don't give the output a name, simply pass it on the next step.
- The output of PTransform_3, though, we save into a PCollection variable named PCollection_out.

In Java, it is the same thing except that, instead of the pipe symbol, we use the `apply()` method.

How to construct a branching pipeline



Python

```
PCollection_out_1 = PCollection_in | PTransform_1  
PCollection_out_2 = PCollection_in | PTransform_2
```

Java

```
PCollection_out_1 = PCollection_in.apply(PTransform_1)  
PCollection_out_2 = PCollection_in.apply(PTransform_2)
```

If you want to do branching, just send the same PCollection through two different transforms.

Give the output PCollection variable in each case a name. Then, you can use it in the remainder of your program. Here, for example, we take the PCollection_in and pass the collection first through both PTransform_1, then through PTransform_2.

The result in the first case, we store as PCollection_out_1. In the second case, we store it as PCollection_out_2.

A Pipeline is a directed graph of steps

```

import apache_beam as beam

if __name__ == '__main__':
    with beam.Pipeline(argv=sys.argv) as p:
        (p
         | beam.io.ReadFromText('gs://...')
         | beam.FlatMap(count_words)
         | beam.io.WriteToText('gs://...')
        )

# end of with-clause: runs, stops the pipeline

```

Python

Create a pipeline parameterized by command line flags

Read input

Apply transform

Write output

What we showed you so far was the middle part of a pipeline. You already had a PCollection and you applied a bunch of transforms and you end up with a PCollection. But where does the pipeline start? How do you get the first PCollection? You get it from a source. What does a pipeline do with the final PCollection? Typically, it writes out to a sink.

That's what we are showing here. This is Python.

We create a PCollection by taking the pipeline object P and passing it over a text file in Google Cloud Storage. That's the ReadFromText line.

Then, we apply the PTransform called FlatMap to the lines read from the text file. What FlatMap does is that it applies a function to each row of the input and concatenates all the outputs. When the function is applied to a row, it may return zero or more elements that go to the output PCollection.

The function in this case is the function called count_words. It takes a line of text and returns an integer.

The output PCollection then consists of a set of integers. These integers are written to a text file in Google Cloud Storage.

Because the Pipeline was created in a with clause, and because this is not a streaming pipeline, exiting the WITH clause automatically stops the pipeline.

Run a pipeline on Dataflow

```
import apache_beam as beam

options = {'project': <project>,
          'runner': 'DataflowRunner',
          'region': <region>,
          'setup_file': <setup.py file>}
pipeline_options = beam.pipeline.PipelineOptions(flags=[],
**options)
pipeline = beam.Pipeline(options = pipeline_options)
```

Python

Where to run

This creates the pipeline

Once you have written the pipeline, it is time to run it. Executing the Python program on the previous slide will run the program. By default, the program is run using the DefaultRunner, which runs on the same machine that Python program was executed on.

When you create the pipeline, you can pass in a set of options. One of these options is the runner. Specify that as Dataflow to have the pipeline run on Google Cloud.

This example contains hard-coded variables which in most cases is not a preferred practice for programming at scale.

Pipeline Execution using DataflowRunner

Run local

```
python ./grep.py
```

Run on cloud

```
python ./grep.py \  
  --project=$PROJECT \  
  --job_name=myjob \  
  --staging_location=gs://$BUCKET/staging/ \  
  --temp_location=gs://$BUCKET/tmp/ \  
  --runner=DataflowRunner
```

Of course, normally, you will set up command-line parameters to transparently switch.

Simply running `main()` runs pipeline locally. To run on cloud, specify cloud parameters

Read data from local file system, Cloud Storage, Pub/Sub, BigQuery, ...

```
with beam.Pipeline(options=pipeline_options) as p:
```

Read from Cloud Storage (returns a string)

```
lines = p | beam.io.ReadFromText("gs://.../input-*.csv.gz")
```

Read from Pub/Sub (returns a string)

```
lines = p | beam.io.ReadStringsFromPubSub(topic=known_args.input_topic)
```

Read from BigQuery (returns rows)

```
query = "SELECT x, y, z FROM `project.dataset.tablename`"
BQ_source = beam.io.BigQuerySource(query = <query>, use_standard_sql=True)
BQ_data = pipeline | beam.io.Read(BQ_source)
```

Setup
Read

Google Cloud

To design pipelines you need to know how each step works on the individual data elements contained inside of a PCollection. Let's start with the input and outputs of the pipeline.

First, we set up our Beam pipeline with `beam.pipeline` and pass through any options. Here we'll call the pipeline `P`.

Now it's time to get some data as input. If we wanted to read a series of CSV files in Cloud Storage, we could use `beam.io.ReadFromText` and simply parse in the Cloud Storage bucket and filename. Note the use of an asterisk wildcard can handle multiple files.

If we wanted to read instead from a Pub/Sub topic, you would still use `beam.io` but instead it's `ReadStringsFromPubSub` and you'd have to parse in the topic name.

What about if you wanted to read in data that's already in BigQuery? Here's how that would look. You'd prepare your SQL query and specify BigQuery as your input source and then parse in the query and source as a read function to Dataflow. That's just a few of the data sources Dataflow can read from. But now what about writing to sinks?

Write to a BigQuery table

Establish reference to BigQuery table

```
from apache_beam.io.gcp.internal.clients import bigquery

table_spec = bigquery.TableReference(
    projectId='clouddataflow-readonly',
    datasetId='samples',
    tableId='weather_stations')
```

Write to BigQuery table

```
p | beam.io.WriteToBigQuery(
    table_spec,
    schema=table_schema,
    write_disposition=beam.io.BigQueryDisposition.WRITE_TRUNCATE,
    create_disposition=beam.io.BigQueryDisposition.CREATE_IF_NEEDED)
```

Take the BigQuery example but as a data sink this time. With Dataflow you can write to a BigQuery table as you see here. First, you establish the reference to the BigQuery table with what BigQuery expects, your project ID, data set ID and table name.

Then you use `beam.io.WriteToBigQuery` as a sink to your pipeline. Note that we are using the normal BigQuery options here for rate disposition. Here we're truncating the table if it exists, meaning to drop data rows. If the table doesn't exist we can create it if needed. Naturally, this is a batch pipeline if we're truncating the table with each load.

Create a PCollection from in-memory data

```
city_zip_list = [  
    ('Lexington', '40513'),  
    ('Nashville', '37027'),  
    ('Lexington', '40502'),  
    ('Seattle', '98125'),  
    ('Mountain View', '94041'),  
    ('Seattle', '98133'),  
    ('Lexington', '40591'),  
    ('Mountain View', '94085'),  
]  
citycodes = p | 'CreateCityCodes' >> beam.Create(city_zip_list)
```

Python

This is the display name
of the pipeline step



PCollection

You can also create a PCollection in memory without reading from a particular source. Why might you do this? If you have a small data set like a lookup table or a hard-coded list, you could create the PCollection yourself as you see here. Then we can call a pipeline step on this new P collection just as if we sourced it from somewhere else.

Map and FlatMap

Use Map for 1:1 relationship between input and output

```
'WordLengths' >> beam.Map(word, len(word))
```

Map (fn) uses a callable fn to do a one-to-one transformation.

Use FlatMap for non 1:1 relationships, usually with a generator

```
def my_grep(line, term):  
    if term in line:  
        yield line  
  
'Grep' >> beam.FlatMap(my_grep(line, searchTerm))
```

FlatMap is similar to Map, but fn returns an iterable of zero or more elements.
The iterables are flattened into one PCollection.

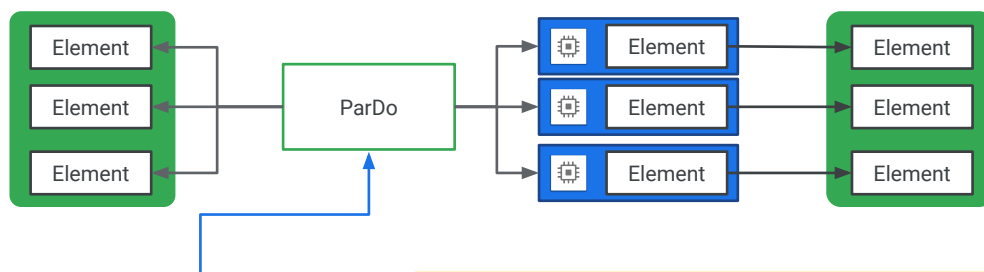
Now that we have looked at how to get the data in, let's look at how we transform each data element in the PCollection with PTransforms. The first step of any map produced process is the map phase where you're doing something in parallel.

In the word length example, there is one length output for each word input. So the word dog would map to three for length. In the bottom graph example the function my_grep returns each instance of the term it's searching for in the line.

There may be multiple instances of the term in a single line a one-to-many relationship. In this case, you may want my-grep to return the next instance each time it's called, which is why the function has been implemented with a generator using yields. The yield commands has the effect of preserving the seed of the function so that the next time it's called, it can continue from where it left off. FlatMap has the effect iterating over one-to-many relationship.

The map example returns a key value pair. In Python, this is simply a two-tuple for each word. The FlatMap example yields the line only for lines that contain the search term.

ParDo implements parallel processing



- ParDo acts on one item at a time in the PCollection
- Multiple instances of class on many machines
- Should not contain any state

Uses:

- Filtering a data set, choosing which elements to output.
- Formatting or type-converting each element in a data set.
- Extracting parts of each element in a data set.
- Performing computations on each element in a data set.

ParDo is a common intermediate step in a pipeline. You might use it to extract certain fields from a set of raw input records, or convert raw input into a different format; you might also use ParDo to convert processed data into an output format, like table rows for BigQuery or strings for printing.

Filtering a data set. You can use ParDo to consider each element in a PCollection and either output that element to a new collection, or discard it.

Formatting or type-converting each element in a data set. If your input PCollection contains elements that are of a different type or format than you want, you can use ParDo to perform a conversion on each element and output the result to a new PCollection.

Extracting parts of each element in a data set. If you have a PCollection of records with multiple fields, for example, you can use a ParDo to parse out just the fields you want to consider into a new PCollection.

Performing computations on each element in a data set. You can use ParDo to perform simple or complex computations on every element, or certain elements, of a PCollection and output the results as a new PCollection.

ParDo requires code passed as a DoFn object

```
words = ...

class ComputeWordLengthFn(beam.DoFn):
    def process(self, element):
        return [len(element)]

word_lengths = words | beam.ParDo(ComputeWordLengthFn())
```

Python

The input is a
PCollection of strings.

The DoFn to perform
on each element in
the input PCollection.

The output is a
PCollection of integers.

Apply a ParDo to the PCollection "words" to compute lengths for each word.

When you apply a ParDo transform, you need to provide user code in the form of a DoFn object. Where do function is a beam SDK class that defines a distributed processing function. Your DoFn code must be fully serializable, item potent, and thread safe. In this example, we're just counting the number of words in a line, and returning the length of the line. Transformations are always going to work on one element at a time here.

ParDo method can emit multiple variables

```
results = (words | beam.ParDo(ProcessWords(),
    cutoff_length=2, marker='x')
    .with_outputs('above_cutoff_lengths',
        'marked strings', main='below_cutoff_strings'))

below = results.below_cutoff_strings
above = results.above_cutoff_lengths
marked = results['marked strings']
```

Here we have an example from Python which can return multiple variables. In this example, we have below and above some cut off in our data elements. And return two different types below and above two different variables by referencing these properties of the results. Please note the formatting of the code block as been optimized for display in this slide.

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Lab Intro

Serverless Data Analysis with
Dataflow: A Simple Dataflow
Pipeline (Python/Java)



The objectives of this lab are to:

- Open Dataflow project,
- Pipeline filtering, and
- Execute the pipeline locally and on the cloud.

The lab can be completed for both Python and Java.

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GroupByKey explicitly shuffles key-values pairs

```
cityAndZipcodes = p | beam.Map(fields[0], fields[1])  
  
grouped = cityAndZipCodes | beam.GroupByKey()
```

The diagram shows the transformation of a PCollection of key-value pairs into a PCollection of key-value groups. On the left, a list of city and zip code pairs is shown. A green arrow points to the right, where the same data is shown but the zip codes are grouped by city.

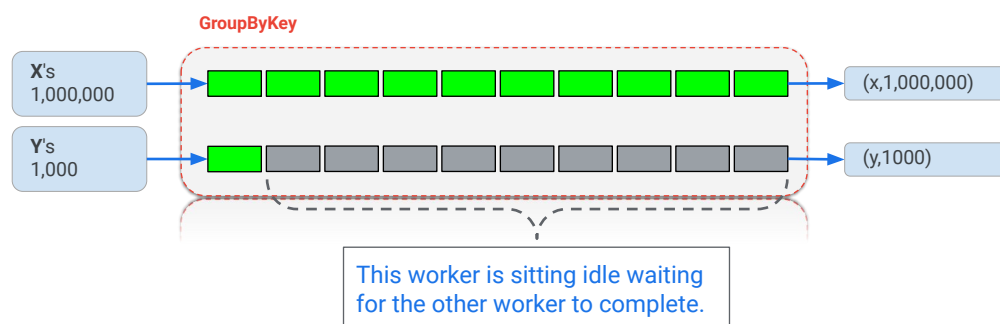
| Input (Key-Value Pairs) | Output (Key-Value Groups) |
|-------------------------|----------------------------------|
| Lexington, 40513 | Lexington, [40513, 40502, 40592] |
| Nashville, 37027 | Nashville, [37027] |
| Lexington, 40502 | |
| Seattle, 98125 | Seattle, [98125, 98133] |
| Mountain View, 94041 | Mountain View, [94041, 94085] |
| Seattle, 98133 | |
| Lexington, 40591 | |
| Mountain View, 94085 | |

Now, let's look at more capabilities of the Dataflow model.

What do you do after the map phase? The unnamed phase is the shuffle phase where you group together like keys. This works on a PCollection of key-value pairs or two elements tuples. Groups by common key and returns a single key-value pair where the value is actually a group of values.

The idea here is that we want to find all the zip codes associated with the city. For example, New York is a city and it may have 10001 and 10002 zip codes. You could first create a key-value pair and a ParDo and then group by the key. The resulting key-value pairs are simply two tuples.

Data skew makes grouping less efficient at scale



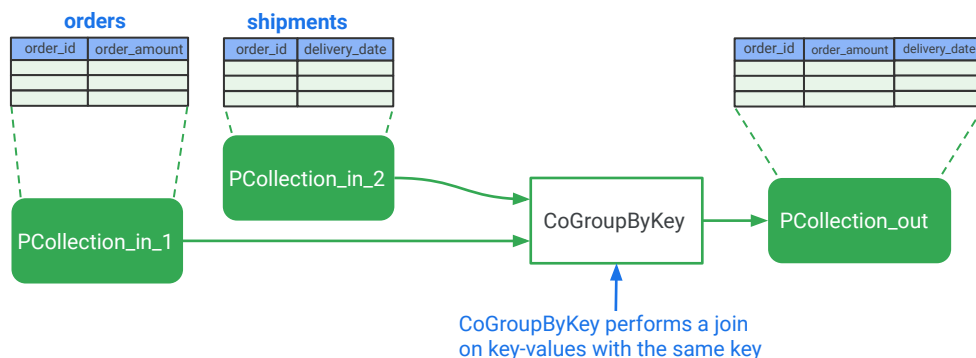
We do have to be aware of data skew on we're doing this. When the same example is scaled up in the presence of skewed data, the situation becomes much worse. Let's say that you're doing your **GroupByKey**, but your group has 1 million items in it. A million is not too big of a deal on modern hardware, but a billion you're forcing all of those elements to go to a single work group to be counted. This could definitely run into some issues on the network. This is the same performance concern when doing high cardinality group by queries on billions of records in BigQuery.

In this example, there are a million X values and only a thousand Y values. **GroupByKey** will group all of the X values on one worker. The worker will take much longer to do its processing on the million values than the other worker, which only has a thousand values to process.

Of course, you're paying for the worker that sits idle waiting for the other worker to complete. Dataflow is designed to avoid an efficiencies by keeping the data balance.

You can help by designing your application to divide work into aggregation steps and subsequent steps and to avoid grouping or to push grouping towards the end of the processing pipeline.

CoGroupByKey joins two or more key-value pairs



```
results = ({'orders': orders, 'shipments': shipments}
           | beam.CoGroupByKey())
```

CoGroupByKey is very similar. It groups results across several **PCollections** by key. For example, input KV ends KW output K with an iteration of V and an iteration of W. **CoGroupByKey** performs a relational join of two or more key value **PCollections** that have the same key type.

Combine (reduce) a PCollection

Applied to a PCollection of values

```
totalAmount = salesAmounts | CombineGlobally(sum)
```

Applied to a grouped Key-Value pair

```
totalSalesPerPerson = salesRecords | CombinePerKey(sum)
```

Each element of salesRecords is a tuple: (salesPerson, salesAmount)

Pre-built combine functions for many common numeric combination operations such as sum, mean, min, and max

Now, we can move to the reduce phase. How do we calculate totals or averages or other aggregations on our PCollections? Combined is used to combine collections of elements or values in your data. Combine has variants that work on entire PCollections and some that combined the values for each key and PCollections of key-value pairs. **CombineGloballyfn** reduces a PCollection to a single value by applying the FN or the function.

CombinePerKey is similar to GroupByKey, but combines the values by a combined function or a callable that takes an iterable such as sum or max.

When you apply a combine transform, you must provide the function that contains the logic for combining the elements or values. There are pre-built combined functions for common numeric combination operations such as sum, min, and max. Simple combine operations such as sums can usually be implemented as a simple function.

More complex combination operations might require you to create a subclass of a combine function that has an accumulation type distinct from the input and or output site.

CombineFn works by overriding existing operations

You must provide
four operations by
overriding the
corresponding
methods

```
class AverageFn(beam.CombineFn):
    def create_accumulator(self):
        return (0.0, 0)
    def add_input(self, sum_count, input):
        (sum, count) = sum_count
        return sum + input, count + 1
    def merge_accumulators(self, accumulators):
        sums, counts = zip(*accumulators)
        return sum(sums), sum(counts)
    def extract_output(self, sum_count):
        (sum, count) = sum_count
        return sum / count if count else float('NaN')

pc = ...
average = pc | beam.CombineGlobally(AverageFn())
```

The combining function should be commutative and associative, as the function is not necessarily invoked exactly once on all values within a given key.

Because the input data including the value collection may be distributed across multiple workers, the combining function might be called multiple times to perform multiple combining on subsets of the value collection.

For more complex combined functions, you can define a subclass of combine function.

You should use the combine function if the combine function requires a more sophisticated accumulator, must perform additional pre or post processing, might change the output type, or takes the key into account.

A general combining operation consists of four operations. When you create a subclass of combine function, you must provide four operations by overriding the corresponding methods. `create_accumulator` creates a new local accumulator. In the example case taking a mean average, a local accumulator tracks the running sum of values. The numerator value for our final average division and the number of values sum so far the denominator value. And may be called any number of times in a distributed fashion.

`add_input` adds an input element to an accumulator returning the accumulator value. In our example, it would update the sum and increment the count, and may also be

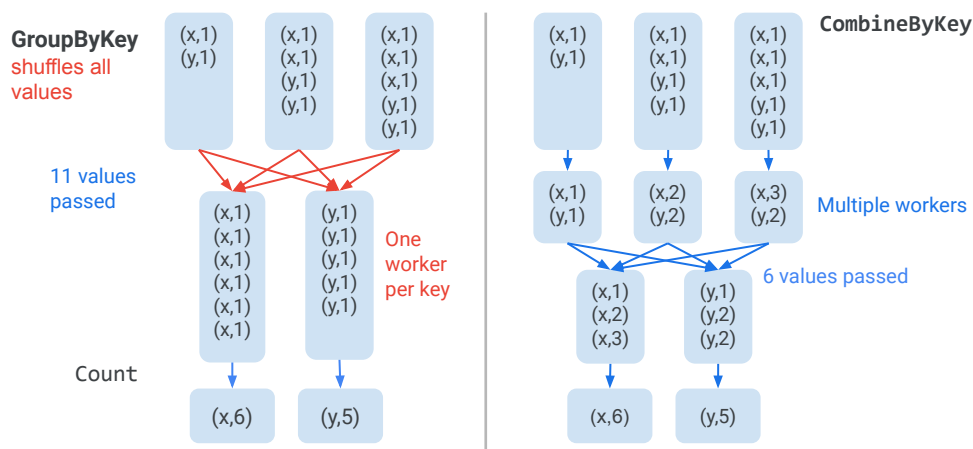
invoked in parallel.

`merge_accumulators` merge several accumulators into a single accumulator. This is how data in multiple accumulators is combined before the final calculation.

In the case of the mean average computation, the accumulators representing each portion of the division are merged together. It may be called again on its output any number of times.

`extract_output` performs the final computation. In the case of computing the mean average, this means dividing the combined sum of all of the values by the number of values summed. It's called once on the final merged accumulator.

Combine is more efficient than GroupByKey



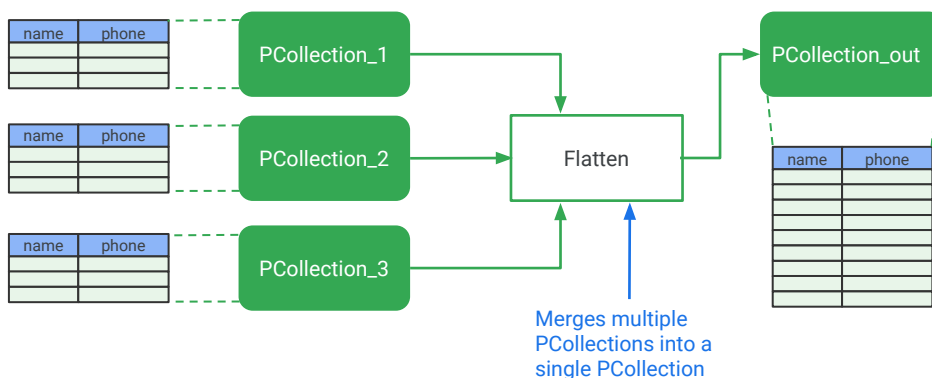
Combine is orders of magnitude faster than GroupByKey because Dataflow knows how to parallelize a combine step.

The way that **GroupByKey** works, Dataflow can use no more than one worker per key. In this example, **GroupByKey** causes all the values to be shuffled so they are all transmitted over the network. And then there is one worker for the 'x' key and one worker for the 'y' key.

Combine allows Dataflow to distribute a key to multiple workers and process it in parallel. In this example, **CombineByKey** first aggregates values and then processes the aggregates with multiple workers. Also, only 6 aggregate values need to be passed over the network.

Combine is a Java interface that tells Dataflow that the combine operation (like Count) is both commutative and associative. This allows Dataflow to shard within a key vs. having to group each key first. As a developer, you can create your own custom **Combine** class for any operation that has commutative and associative properties.

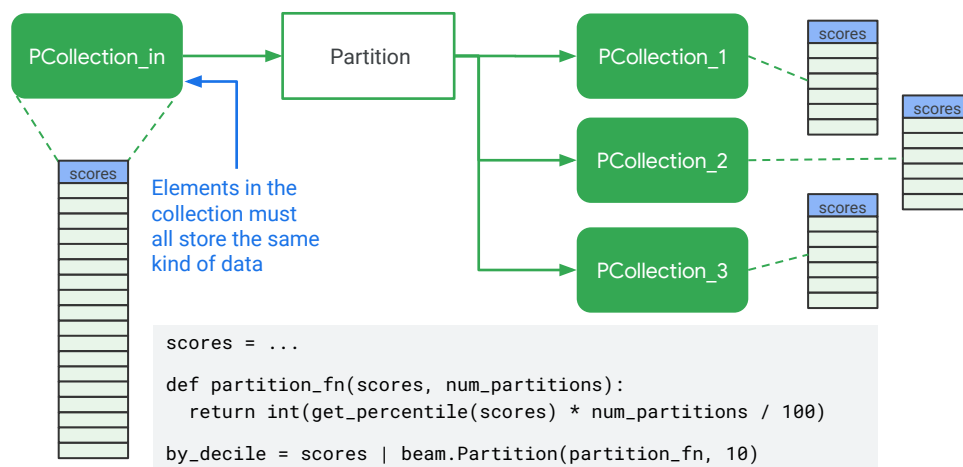
Flatten merges identical PCollections



```
merged = ((pcoll1, pcoll2, pcoll3) | beam.Flatten())
```

Flatten works a lot like a SQL UNION. It's a beam transform for PCollection objects that store the same data type. Flatten merges multiple PCollection objects into a single logical PCollection. Partition is also a beam transform for PCollection objects that store the same data type.

Partition splits PCollections into smaller PCollections



Partition splits a single PCollection into a fixed number of smaller collections. You might use partition if, for example, you wanted to calculate percentages or quartiles and the top quartile has different processing than all the others.

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Lab: Serverless Data Analysis with
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Aggregating with GroupByKey and
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Side Inputs and Windows

Lab: Serverless Data Analysis with
Dataflow: Side Inputs (Python/Java)

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Dataflow SQL

Lab Intro

Serverless Data Analysis with
Dataflow: MapReduce in Dataflow
(Python/Java)



The objectives of this lab are to:

- Identify Map and Reduce operations,
- Execute the pipeline, and
- Use command line parameters.

Agenda

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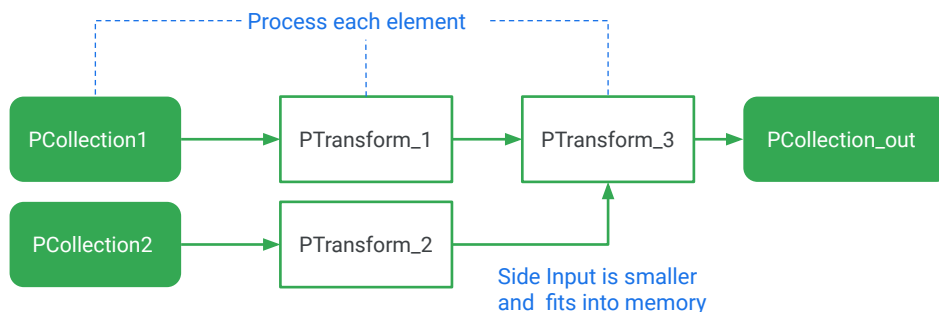
[Side Inputs and Windows](#)

Lab: Serverless Data Analysis with
Dataflow: Side Inputs (Python/Java)

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Use side inputs to inject additional runtime data



In addition to the main input PCollection, you can provide additional inputs to a ParDo transform in the form of side inputs. A side input is an additional input that your DoFn can access each time it processes an element in the input PCollection. When you specify a side input, you create a view of some other data that can be read from within the ParDo transform's DoFn while processing each element.

Side inputs are useful if your ParDo needs to inject additional data when processing each element in the input PCollection, but the additional data needs to be determined at runtime (and not hard-coded). Such values might be determined by the input data, or depend on a different branch of your pipeline.

How side inputs work

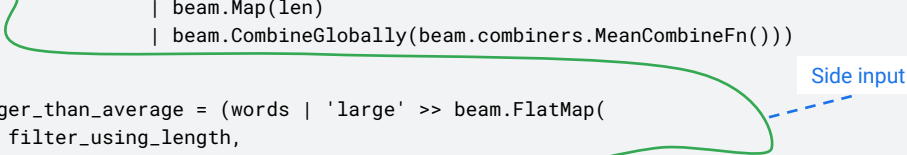
```
words = ...

def filter_using_length(word, lower_bound, upper_bound=float('inf')):
    if lower_bound <= len(word) <= upper_bound:
        yield word

small_words = words | 'small' >> beam.FlatMap(filter_using_length, 0, 3)

avg_word_len = (words
                | beam.Map(len)
                | beam.CombineGlobally(beam.combiners.MeanCombineFn()))

larger_than_average = (words | 'large' >> beam.FlatMap(
    filter_using_length,
    lower_bound=pvalue.AsSingleton(avg_word_len)))
```



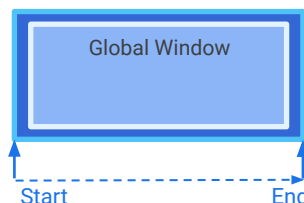
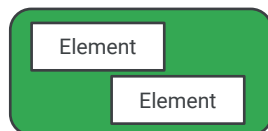
Here's how side inputs work. And here's how it looks in Python.

This set of steps is actually a subgraph of our overall graph. It begins with words that run through the map function to get the length and then combine globally to compute the total lengths across the whole data set.

So if we were trying to figure out if any given word is shorter or longer than the average word length, first we need to compute the average word length using these steps. But then this whole branch can be fed into this method. That's what creates the view which is static and then becomes available to all the worker nodes for later use. That is a side input you see here.

Every PCollection is processed within a Window

Bounded PCollection

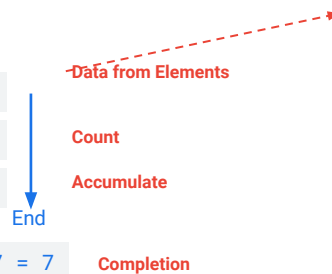


- 1 The default window is called the global window, it starts when the data is input and ends when the last element in the collection is processed.

- 2 In Bounded PCollections, commonly the Elements are all marked as occurring at the same time. (Example: TextIO does this.) So the global window basically ignores the timing information.

- 3

| | | | | | | |
|---|---|----|----|----|----|----|
| 1 | 5 | 13 | 2 | 8 | 9 | 11 |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 1 | 6 | 19 | 21 | 29 | 38 | 49 |



Before we go to the next lab a few notes about additional capabilities. Many transforms have two parts, one occurs item-at-a-time until all items are processed, and another occurs after the last item is processed. One of the easiest analogies is the arithmetic mean. You add up the value of each element and keep count. This is the accumulation step. After you have processed all the elements, you have a total of all the values read and a count of the number of values read. The last thing to do is divide the total by the count. This is fine so long as you know you have read the last item. But if you have an unbounded data set, there is no pre-determined end. So you just keep adding and never break out of the loop and perform the division.

The global window is not very useful for an unbounded PCollection

Unbounded PCollection



- 1 The timing associated with the elements in an Unbounded PCollection is usually important to processing the data.
- 3 The discussion about Unbounded PCollections and Windows will be continued in the course on Processing Streaming Data.



- 2 An Unbounded PCollection has no defined end or last element. So it can never perform the completion step.

This is particularly important for **GroupByKey** and **Combine**, which perform the shuffle after 'end'.

The global window is not very useful for an unbounded PCollection, meaning streaming data. The timing associated with the elements and an unbounded PCollection is usually important to processing the data. An unbounded PCollection has no defined end or last element, so it can never perform the completion step. This is particularly important for group by key and combined, which perform the shuffle after end. The discussion about unbounded PCollections and Windows will be continued in the course on processing streaming data.

Setting a single global window for a PCollection

Single global window

```
from apache_beam import window
session_windowed_items = (
    items | 'window' >> beam.WindowInto(window.GlobalWindows()))
```

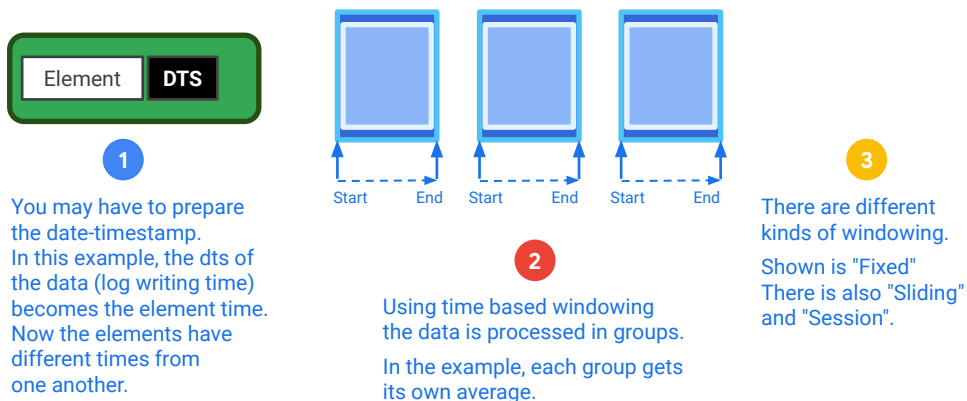
Python

This is the default.

This code illustrates how you could explicitly set it.

The global window is a default and here you see how you can set it with `beam.WindowInto(window.GlobalWindows)`.

Time-based Windows can be useful for processing time-series data



So we're streaming pipelines out of luck if they can't use the global window?

No, you can use time-based Windows, which can be useful for processing data that comes in streaming at different times. We'll cover this in detail in the streaming course.

Using Windowing with Batch (group by time)

```
lines = p | 'Create' >> beam.io.ReadFromText('access.log')
windowed_counts = (
    lines
    | 'Timestamp' >> beam.Map(beam.window.TimestampedValue(x, extract_timestamp(x)))
    | 'Window' >> beam.WindowInto(beam.window.SlidingWindows(60, 30))
    | 'Count' >>
    (beam.CombineGlobally(beam.combiners.CountCombineFn()).without_defaults())
)
windowed_counts = windowed_counts | beam.ParDo(PrintWindowFn())
```

Python

access.log (example)

```
131.108.5.17 - - [29/Apr/2019:04:53:15 -0800] "GET /view HTTP/1.1" 200 7352
131.108.5.17 - - [29/Apr/2019:05:21:35 -0800] "GET /view HTTP/1.1" 200 5253
```

Date Time Stamp

Google Cloud

For batch inputs, you can Group by time as well. You can explicitly admit a timestamp in your pipeline instead of standard output. In this example, an offline access log is being read, and the date time stamp is extracted and used for windowing. Here we're using Windows to aggregate our batch data by time.

Subsequent groups, aggregations, and so forth are computed only within the time Window.

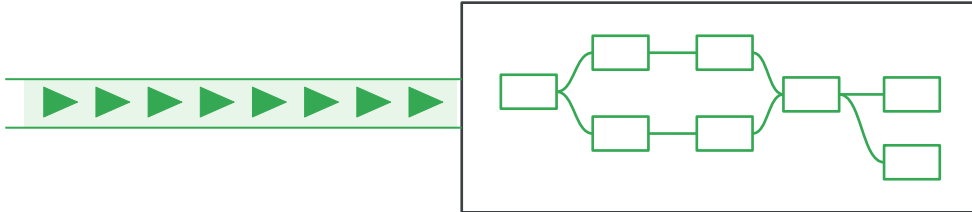
This example here uses a sliding window, as you can see with `beam.WindowInto(beam.window.SlidingWindows(60, 30))`, which means capture 60 seconds worth of data, but start a new window every 30 seconds.

So for example, say you had all of your sales records and you wanted to compute sales by day. You'd just extract that timestamp field that represents the timestamp. Then you would create fixed windows with a one-day duration and data flow automatically will compute the sum over each window to compute those totals. The main thing to remember here is that you can do this in batch.

A Streaming Wordcount example in Python is available here:

https://github.com/apache/beam/blob/master/sdks/python/apache_beam/examples/streaming_wordcount.py

Streaming data processing with Dataflow



Discussion of streaming continues in the
Streaming Data Processing course.

Discussion of streaming continues in the Streaming Data Processing course.

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Side Inputs and Windows

[Lab: Serverless Data Analysis with
Dataflow: Side Inputs \(Python/Java\)](#)

Dataflow Templates

Dataflow SQL

Lab Intro

Serverless Data Analysis with
Dataflow: Side Inputs
(Python/Java)



The objectives of this lab are to:

- Try out a BigQuery query,
- Explore the pipeline code, and
- Execute the pipeline.

Agenda

Dataflow

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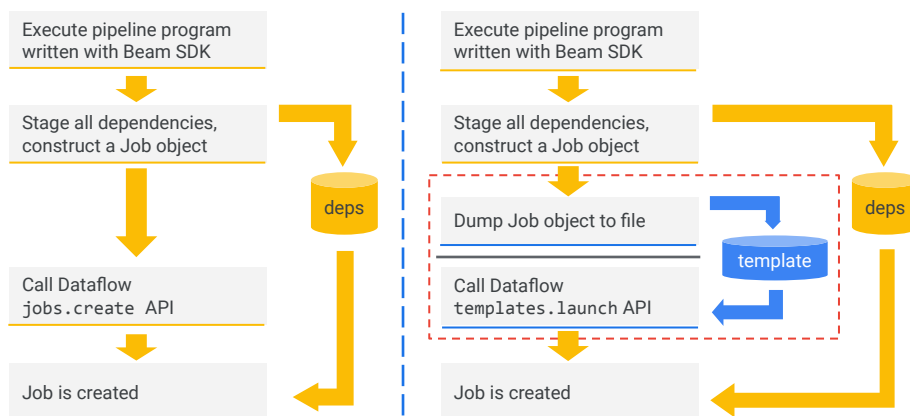
Lab: Serverless Data Analysis with
Dataflow: Side Inputs (Python/Java)

[Dataflow Templates](#)

Dataflow SQL

Next, we'll look at Dataflow Templates where you as a data engineer can create new templates for your team to leverage. You can also start from some of Google's preexisting templates which we'll cover as well.

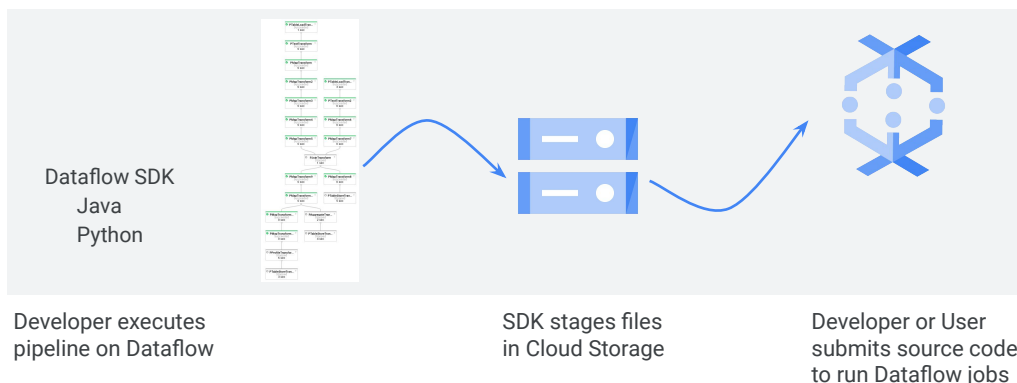
Dataflow templates enable the rapid deployment of standard job types



Dataflow templates allow users who don't have any coding capability to execute their Dataflow job. It enables the rapid deployment of standard types of data transformation jobs, removing the need to develop the pipeline code, and removing the need to consider the management of components dependencies in the pipeline code.

Traditional workflow all happens in one environment

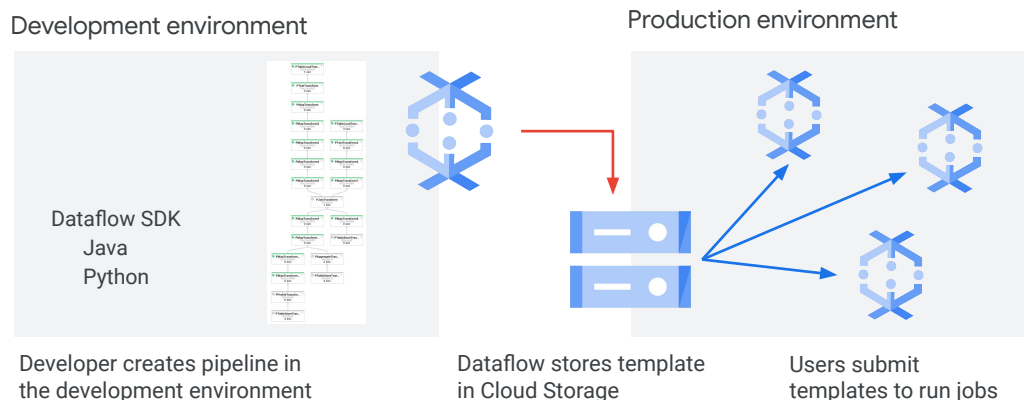
Development environment



Google Cloud

In the traditional workflow the Developer creates the pipeline in the development environment using the Dataflow SDK in Java or Python. And there are dependencies to the original language and SDK files. Whenever a job is submitted it is re-processed entirely or re-compiled. There is no separation of developers from users. So the users basically have to be developers or have the same access and resources as developers.

Template workflow supports non-developer users

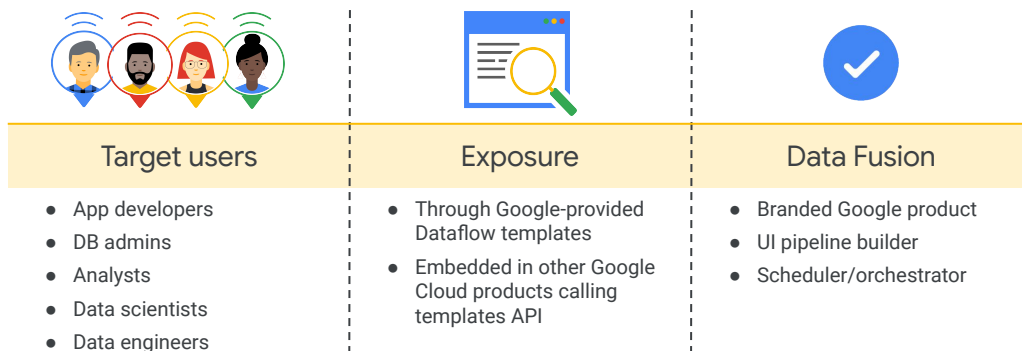


Dataflow Templates enable a new development and execution workflow. The templates help separate the development activities and the developers from the execution activities and the users. The user environment no longer has dependencies back to the development environment. The need for recompilation to run a job is limited. The new approach facilitates the scheduling of batch jobs and opens up more ways for users to submit jobs, and more opportunities for automation.

<https://cloud.google.com/dataflow/docs/templates/overview>

Get started with Google-provided templates

Pre-written Dataflow pipelines for common data tasks that can be triggered with a single command or UI form.



App developers, DB admins, Analysts, and Data scientists will use templates as a solution. Data engineers: Getting started with Beam (productive and then learn).

<https://cloud.google.com/dataflow/docs/templates/provided-templates>

All open source: <https://github.com/GoogleCloudPlatform/DataflowTemplates>

Execute templates with the Cloud Console, gcloud command-line tool, or the REST API

Google Cloud Platform My Project 28557

Dataflow Create job from template

Job name
Must be unique among running jobs. Use lowercase letters, numbers, and hyphens (-).
my-job-name

Cloud Dataflow template ⓘ
Select a template

Run job Cancel




```
gcloud dataflow jobs run \
--gcs-location=gs://df-ts/latest/PubsubToBigQuery \
--parameters inputTopic=X outputTable=Y
```

| |
|----------------------------------------------------------------|
| Get Started |
| Word Count |
| Process Data Continuously (stream) |
| Cloud Pub/Sub Subscription to BigQuery |
| Cloud Pub/Sub Topic to BigQuery |
| Cloud Pub/Sub to Text Files on Cloud Storage |
| Cloud Pub/Sub to Avro Files on Cloud Storage |
| Cloud Pub/Sub to Cloud Pub/Sub |
| Text Files on Cloud Storage to Cloud Pub/Sub |
| Text Files on Cloud Storage to BigQuery |
| Data Masking/Tokenization using Cloud DLP from GCS to BigQuery |
| Process Data in Bulk (batch) |
| Text Files on Cloud Storage to Cloud Pub/Sub |
| Text Files on Cloud Storage to BigQuery |
| Cloud Datastore to Text Files on Cloud Storage |
| Text Files on Cloud Storage to Cloud Datastore |
| Cloud Spanner to Text Files on Cloud Storage |
| Cloud Spanner to Avro Files on Cloud Storage |
| Avro Files on Cloud Storage to Cloud Spanner |
| Cloud BigTable to SequenceFile Files on Cloud Storage |
| SequenceFile Files on Cloud Storage to Cloud BigTable |
| Cloud Bigtable to Avro Files on Cloud Storage |
| Avro Files on Cloud Storage to Cloud Bigtable |
| Jdbc to BigQuery |

You can also run them using the command-line tool, or REST API as you see here. Simply specify the Cloud Storage location of your template that you already have.

Google-provided templates documentation

How-to guides

- All how-to guides
- Installing the SDK
- Creating a pipeline
- Specifying execution parameters
- Deploying a pipeline
- Using the monitoring UI
- Using the command-line interface
- Using Stackdriver Monitoring 
- Logging pipeline messages
- Troubleshooting your pipeline
- Updating an existing pipeline
- Stopping a running pipeline
- Creating and executing templates
- Overview
- Google-provided templates
 - Get started
 - Streaming templates
 - Batch templates
 - Utility templates
 - Creating templates
 - Executing templates
 - Migrating from MapReduce
 - Migrating from SDK 1.x for Java
 - Configuring networking
 - Using Cloud Pub/Sub Sink
 - Using Flexible Resource Scheduling 
 - Creating Cloud Dataflow SQL jobs 

Cloud Dataflow > Documentation

Get started with Google-provided templates

☆☆☆☆☆ [Contents](#)
[SEND FEEDBACK](#) [WordCount](#)

Google provides a set of [open-source](#) Cloud Dataflow templates. For general information about templates, see the [Overview](#) page. To get started, use the [WordCount](#) template documented in the section below. See other Google-provided templates:

Streaming templates - Templates for processing data continuously:

- Cloud Pub/Sub Subscription to BigQuery
- Cloud Pub/Sub Topic to BigQuery
- Cloud Pub/Sub to Cloud Pub/Sub
- Cloud Pub/Sub to Cloud Storage Avro
- Cloud Pub/Sub to Cloud Storage Text
- Cloud Storage Text to BigQuery (Stream)
- Cloud Storage Text to Cloud Pub/Sub (Stream)
- Data Masking/Tokenization using Cloud DLP from Cloud Storage to BigQuery (Stream)

Batch templates - Templates for processing data in bulk:

- Cloud Bigtable to Cloud Storage Avro
- Cloud Bigtable to Cloud Storage SequenceFiles
- Cloud Datastore to Cloud Storage Text
- Cloud Spanner to Cloud Storage Avro
- Cloud Spanner to Cloud Storage Text
- Cloud Storage Avro to Cloud Bigtable

Alternatively, you can use the Google-provided templates.

Use cases of Google-provided templates

- Code-free routine job launcher for data engineers.
- Building block for import/export feature of other services on Google Cloud.
- OSS code base works as good knowledge base.



Pub/Sub



Cloud Spanner



Cloud Bigtable

Which means now you can...

- Launch Dataflow jobs programmatically (via API).
- Launch Dataflow jobs instantaneously.
- Re-use Dataflow jobs.
- Letting you customize the execution of your pipeline.

After you create and stage your Dataflow template, execute the template with the Cloud Console, REST API, or gcloud command-line tool. You can deploy Dataflow template jobs from many environments, including App Engine standard environment, Cloud Functions, and other constrained environments.

The standard way of launching Dataflow jobs sometimes doesn't work in

- AppEngine Standard (Cannot stage libraries due to thread model limitations)
- Non Java/Python environment (SDK is not available)
 - E.g., a job launcher interface written in PHP.
 - Command line tools.
- Environments where writing to Cloud Storage is not possible.

What if you want to create your own template?

1. Modify pipeline options with ValueProviders.
2. Generate template file.

```
mvn compile exec:java \
-Dexec.mainClass=com.example.myclass \
-Dexec.args="--runner=DataflowRunner \
--project=[YOUR_PROJECT_ID] \
--stagingLocation=gs://[YOUR_BUCKET_NAME]/staging \
--output=gs://[YOUR_BUCKET_NAME]/output \
--templateLocation=gs://[YOUR_BUCKET_NAME]/templates/MyTemplate"
```

3. Call it from an API.

```
POST https://dataflow.googleapis.com/v1b3/projects/[YOUR_PROJECT_ID]/templates:launch?gcsPath=gs://[
{
  "jobName": "[JOB_NAME]",
  "parameters": {
    "inputFile": "gs://[YOUR_BUCKET_NAME]/input/my_input.txt",
    "outputFile": "gs://[YOUR_BUCKET_NAME]/output/my_output"
  },
  "environment": {
    "tempLocation": "gs://[YOUR_BUCKET_NAME]/temp",
    "zone": "us-central1-f"
  }
}
```

What if you wanted to create your own template? To create your own template, you'll add your own Value Providers. This is what parses the command line or optional arguments to your template, and that is how users can specify optional arguments. Once a template file is created, you call it from an API.

For more information refer to the documentation at <https://cloud.google.com/dataflow/docs/templates/overview>

Templates require modifying parameters for runtime

```

class WordcountOptions(PipelineOptions):
    @classmethod
    def _add_argparse_args(cls, parser):
        parser.add_value_provider_argument(
            '--input',
            default='gs://dataflow-samples/shakespeare/kinglear.txt',
            help='Path of the file to read from')
        parser.add_argument(
            '--output',
            required=True,
            help='Output file to write results to.')
        pipeline_options = PipelineOptions(['--output', 'some/output_path'])
        p = beam.Pipeline(options=pipeline_options)

        wordcount_options = pipeline_options.view_as(WordcountOptions)
        lines = p | 'read' >> ReadFromText(wordcount_options.input)

```

Python

Run-time
parametersNon run-time
parameters can stayRuntime parameters
must be modified

You might not have considered this before, but values like "user options" and "input file" that are compiled into your job. They aren't just parameters, they are compile-time parameters. To make these values available to non-developer users, they have to be converted to runtime parameters. These work through the ValueProvider interface so that your users can set these values when the template is submitted. ValueProvider can be used in I/O, transformations, and DoFn (your functions). And there are Static and Nested versions of ValueProvider for more complex cases.

Creating a template

- ValueProviders are passed down throughout the whole pipeline construction phase
- ValueProvider.get() only available in processElement()
 - Because it is fulfilled via API call

```
public interface SumIntOptions extends PipelineOptions {
    // New runtime parameter, specified by the --int
    // option at runtime.
    ValueProvider<Integer> getInt();
    void setInt(ValueProvider<Integer> value);
}

class MySumFn extends DoFn<Integer, Integer> {
    ValueProvider<Integer> mySumInteger;

    MySumFn(ValueProvider<Integer> sumInt) {
        // Store the value provider
        this.mySumInteger = sumInt;
    }

    @ProcessElement
    public void processElement(ProcessContext c) {
        // Get the value of the value provider and add it to
        // the element's value.
        c.output(c.element() + mySumInteger.get());
    }
}

public static void main(String[] args) {
    SumIntOptions options =
        PipelineOptionsFactory.fromArgs(args).withValidation()
            .as(SumIntOptions.class);
}
```

This is a Java example for creating your own template. Note that Value Providers are passed down throughout the whole pipeline construction phase.

Nested Value Providers

```
public static void main(String[] args) {  
    pipeline  
    .apply(Create.of(1, 2, 3).withCoder(BigEndianIntegerCoder.of()));  
    // Write to the computed complete file path.  
    .apply("OutputNums". TextIO.write().to(NestedValueProvider.of(  
        options.getFileName().  
        new SerializableFunction<String, String>() {  
            @Override  
            public String apply(String file) {  
                return "gs://bucket/" + file;  
            }  
        }  
    ))));  
    pipeline.run();  
}
```

Sometimes we need to transform a value from what the user passes at runtime, to what a source or sink expects to consume. Nested Value Providers meet this need.

Template metadata

Located at the same directory, named <template_name>_metadata

```
{
  "name": "WordCount",
  "description": "An example pipeline that counts words in the input file.",
  "parameters": [{
    "name": "inputFile",
    "label": "Input Cloud Storage File(s)",
    "help_text": "Path of the file pattern glob to read from.",
    "regexes": ["^gs:\\/\\/[^\\n\\r]+$"],
    "is_optional": true
  }],
  {
    "name": "output",
    "label": "Output Cloud Storage File Prefix",
    "help_text": "Path and filename prefix for writing output files. ex: gs://MyBucket/counts",
    "regexes": ["^gs:\\/\\/[^\\n\\r]+$"]
  }]
}
```

Each template has associated metadata with it upon creation. This will help your downstream users know what your template is doing and what parameters it expects. The metadata file is located in the same directory as your template and simply has the underscore metadata suffix to the name.

Agenda

Dataflow

Why Customers Value Dataflow

Dataflow Pipelines

Lab: Serverless Data Analysis with
Dataflow: A Simple Dataflow
Pipeline (Python/Java)

Aggregating with GroupByKey and
Combine

Lab: Serverless Data Analysis with
Dataflow: MapReduce in Dataflow
(Python/Java)

Side Inputs and Windows

Lab: Serverless Data Analysis with
Dataflow: Side Inputs (Python/Java)

Dataflow Templates

[Dataflow SQL](#)

Now let's talk about Dataflow SQL.

Dataflow SQL lets you use SQL queries to develop and run Dataflow jobs from the BigQuery web UI



Dataflow SQL integrates with Apache Beam SQL and supports a variant of the ZetaSQL query syntax. You can use ZetaSQL's streaming extensions to define your streaming data parallel-processing pipelines.

Use your existing SQL skills to develop and run streaming pipelines from the BigQuery web UI. You do not need to set up an SDK development environment or know how to program in Java or Python.

Join streams (such as Pub/Sub) with snapshotted datasets (such as BigQuery tables).

Query your streams or static datasets with SQL by associating schemas with objects, such as tables, files, and Pub/Sub topics.

Write your results into a BigQuery table for analysis and dashboarding.

Selecting Dataflow as the execution engine for SQL statements using the BigQuery web UI is currently available only as an alpha release and you should not use it in production.

Summary

- Dataflow versus Dataproc
- Building Dataflow pipelines in code
- Key considerations with designing pipelines
- Transforming data with PTransforms
- Aggregating with GroupByKey and Combine
- Side inputs
- Windows of data
- Creating and reusing Pipeline Templates
- Dataflow SQL pipelines

Earlier in the course, you learned how to do batch processing of your Hadoop and Spark jobs using Dataproc. This is an ideal first step to the Cloud for existing jobs, simply run them on Dataproc and they just work. You learned that Dataflow takes a lot of the cluster resizing and other management tasks and automates them for you as a true serverless product. Use Dataflow if you're writing new pipelines or if you're ready to rewrite and migrate your Hadoop jobs to faster processing with Apache Beam on Dataflow.

You then saw how to build pipelines using Apache Beam which is open source. For the pipelines to work, we created inputs with a beam.io syntax and walked through how you can read CSV files from Cloud Storage, streaming message queues from Pub/Sub, and structure data already living in BigQuery.

We then looked at some key considerations when designing your pipeline. Recall that you should consider using Combine when you can instead of GroupByKey especially if your data is heavily skewed. This will prevent a single worker from being a bottleneck if you have a high cardinality dataset.

To do the actual transformations, you practice writing PTransforms in your labs. Remember that the P in PTransforms and PCollection means parallel. Recall that the PCollection itself is immutable. Data is never processed in place, a new PCollection is always created and that the individual elements of a PCollection are massively distributed over many workers to perform the parallel transform. This is a whole map part of MapReduce.

For the reduced part of MapReduce, we looked at aggregation functions like GroupByKey and Combine. Keep in mind you can have multiple parallel parts of your pipeline Combine into a single PTransform like an aggregation. The pipeline does not have to execute in serial unless you've set it up that way with dependencies.

After that you practiced with side inputs in your lab and how to create windows of data even for batch datasets.

Lastly, you saw how to create and save new Dataflow templates for your team to use and where you can see Google's pre-made templates in our public GitHub.

We ended our discussion with Dataflow's ability to run SQL on your pipelines.