

# Online Clustering & Semantic Enrichment of Textual Data with Apache Beam

By Konstantin Buschmeier  
Machine Learning Engineer @ ML6

# ML6

Machine Learning services company.

We help our clients build  
machine learning applications using  
technologies such as Apache Beam.

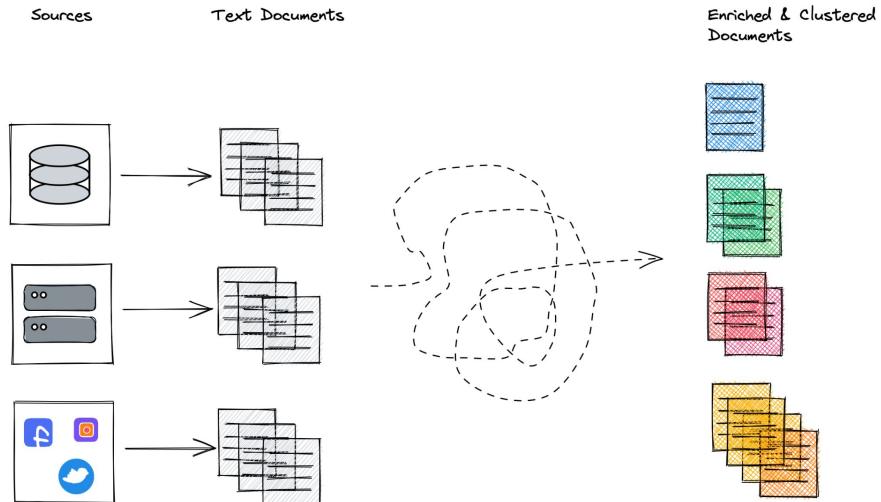
# Motivation

## Semantic Enrichment

Add semantic information to text documents.

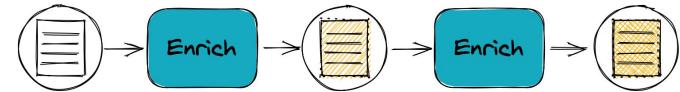
## Online Clustering

Arrange documents into not yet defined groups as they come in.



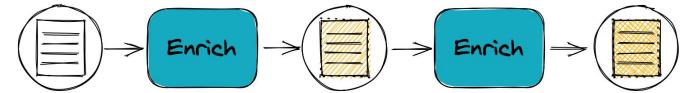
# Semantic Enrichment

- Count word occurrences
- Add geo location
- Categorise: Add predefined labels
- Sentiment Analysis
- Filter profanity
- Extract keywords
- Named-Entity Recognition/Linking
- Summarize
- Word/sentence/document embeddings
- OCR correction
- Translation
- Coreference Resolution



# Semantic Enrichment

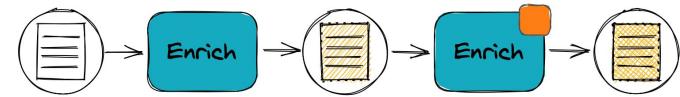
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```
class CountWords(beam.DoFn):
    def process(self, element, *args, **kwargs):
        text = element.get('text', "")
        words = text.split(' ')
        yield {
            **element,
            'word_count': len(words)
        }
```

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```
class TextEmbedding(beam.DoFn):
    """Get the text embedding using the Universal Sentence Encoder."""

    def embed(self, texts):
        module_url = "https://tfhub.dev/google/universal-sentence-encoder/4"
        model = hub.load(module_url)

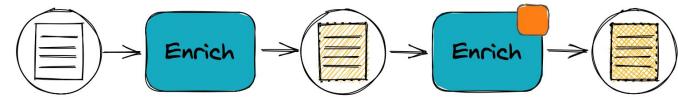
        if isinstance(texts, list):
            return np.array(model(texts))
        else:
            return np.array(model([texts]))

    def process(self, element, *args, **kwargs):
        text = element.get('text', "")

        if text:
            yield {
                **copy.deepcopy(element),
                'text_embedding': np.squeeze(self.embed(text))
            }
```

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class TextEmbedding(beam.DoFn):
    """Get the text embedding using the Universal Sentence Encoder."""

    module_url = "https://tfhub.dev/google/universal-sentence-encoder/4"

    def setup(self):
        self.model = hub.load(self.module_url)

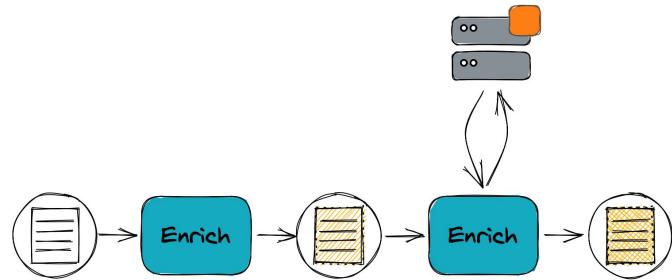
    def embed(self, texts):
        if isinstance(texts, list):
            return np.array(self.model(texts))
        else:
            return np.array(self.model([texts]))

    def process(self, element, *args, **kwargs):
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```
class TextEmbedding(beam.DoFn):
    """Get the text embedding using the Universal Sentence Encoder."""

    model_url = "https://example.com/models/universal-sentence-encoder/4"
    headers = {"Content-Type": "application/json"}

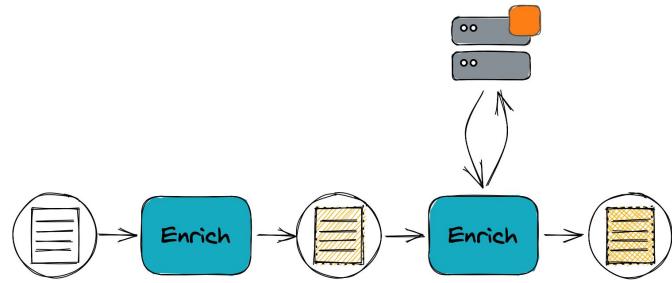
    def embed(self, texts):
        payload = {'text': texts}
        response = requests.post(model_url, json=payload, headers=headers)
        return response['embedding']

    def process(self, element, *args, **kwargs):
        text = element.get('text', "")

        if text:
            yield {
                **element,
                'text_embedding': self.embed(text)
            }
```

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    """Get the text embedding using the Universal Sentence Encoder."""

    model_url = "https://example.com/models/universal-sentence-encoder/4"
    headers = {"Content-Type": "application/json"}

    def setup(self):
        self.session = requests.Session()

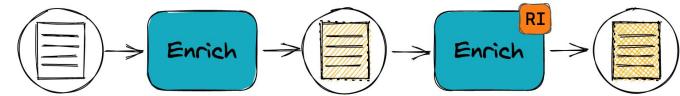
    def embed(self, texts):
        payload = {'text': texts}
        response = self.session.post(model_url, json=payload, headers=headers)
        return response['embedding']

    def process(self, element, *args, **kwargs):
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```
from apache_beam.ml.inference.base import RunInference
from apache_beam.ml.inference.base import PytorchModelHandlerKeyedTensor
[...]

model_config=AutoConfig.from_pretrained(
    'sentence-transformers/paraphrase-MiniLM-L6-v2', return_dict=True)
model_handler = PytorchNobatchModelHandler(
    state_dict_path='sentence_transformer.pth', model_class=BertModel,
    model_params = {'config': model_config})

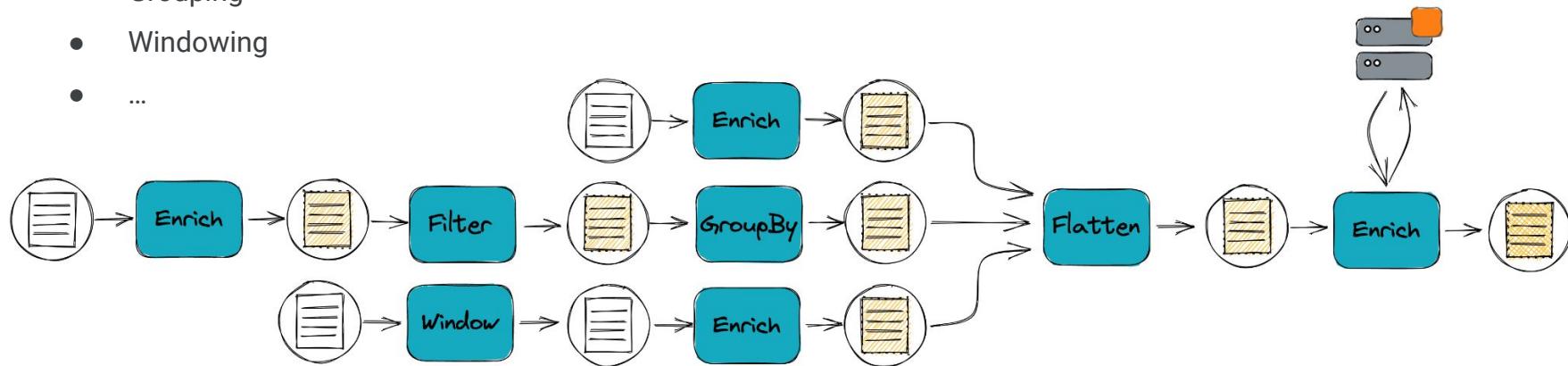
with pipeline as p:
    text = (p | 'Create Examples' >> beam.Create([example_docs]))

    text_and_tokenized_text_tuple = (
        text
        | 'Tokenize Sentence' >> beam.Map(tokenize_with_sentence_transformer)
    )
    embedding = (
        text_and_tokenized_text_tuple
        | 'Run Inference' >> RunInference(KeyedModelHandler(model_handler))
        | 'Postprocess' >> beam.ParDo(SentenceBertPostProcessor())
    )
```

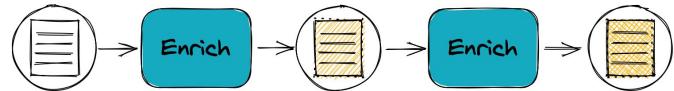
# Semantic Enrichment

→ Beam provides great tools:

- Batch/Streaming
- Filtering
- Grouping
- Windowing
- ...



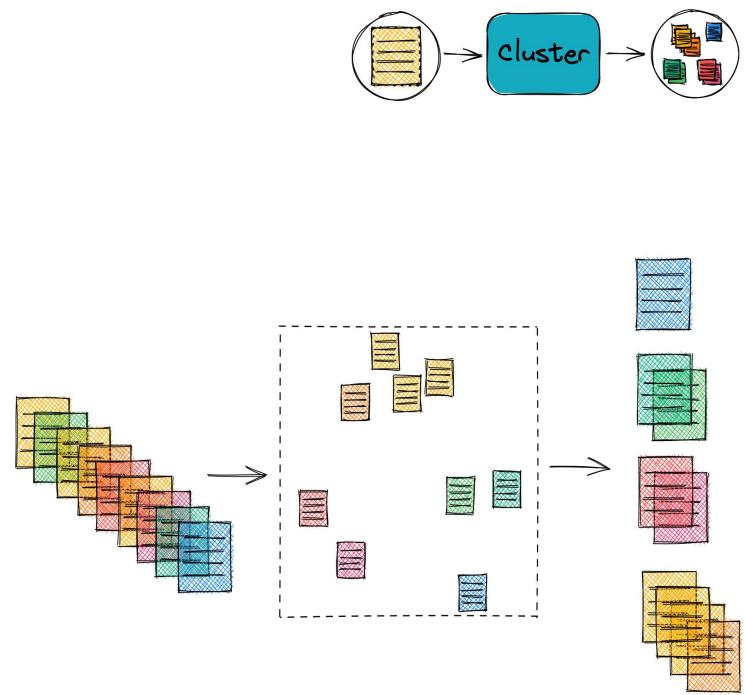
# Examples



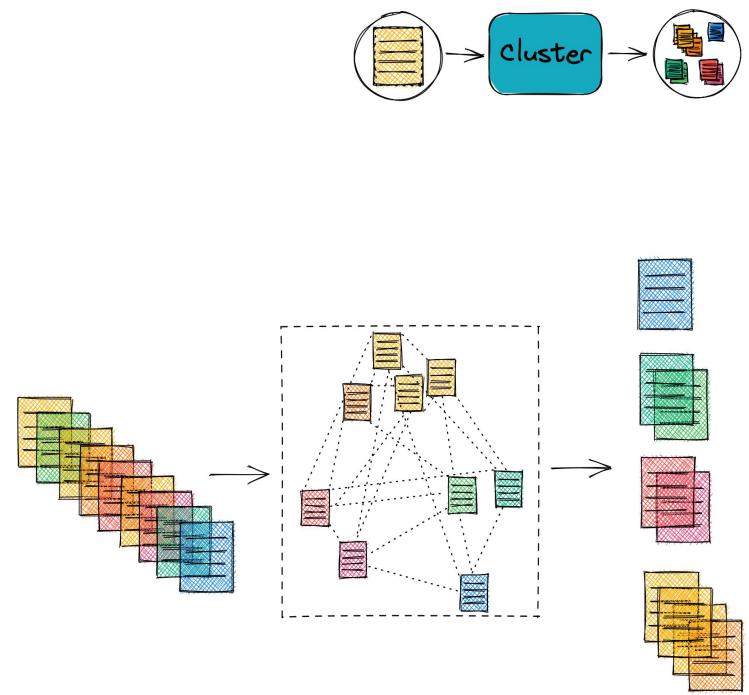
# Online Clustering

Arrange documents into not yet defined groups as they come in.

# Online Clustering



# Online Clustering

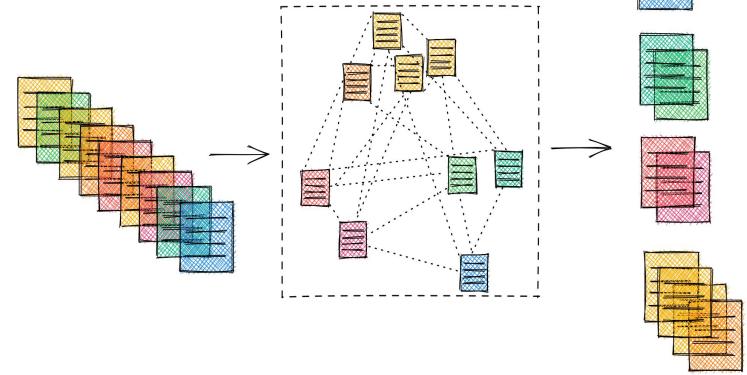


# Online Clustering



Distance Matrix

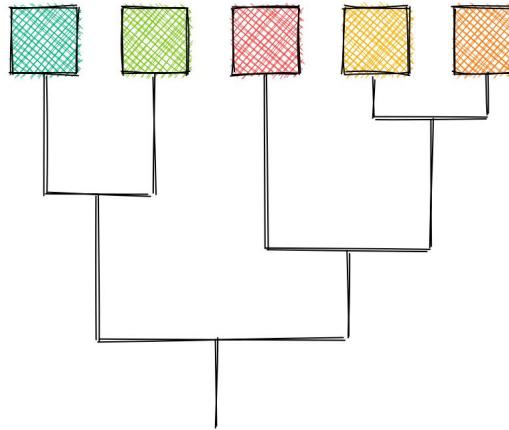
	■	■	■	■	■
■		○	○	○	○
■	○		○	○	○
■	○	○		○	○
■	○	○	○		○



# Online Clustering

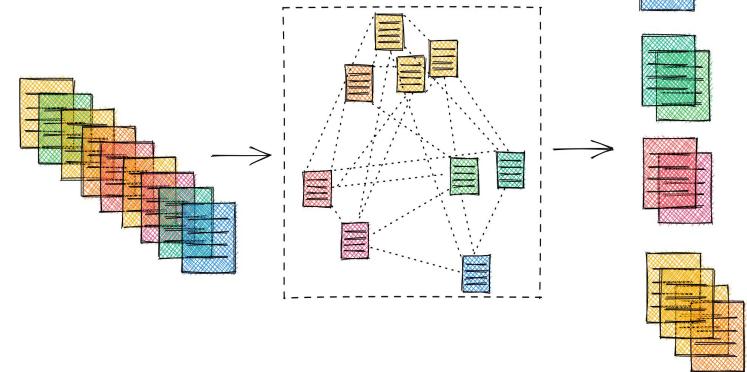


Agglomerative Clustering



Distance Matrix

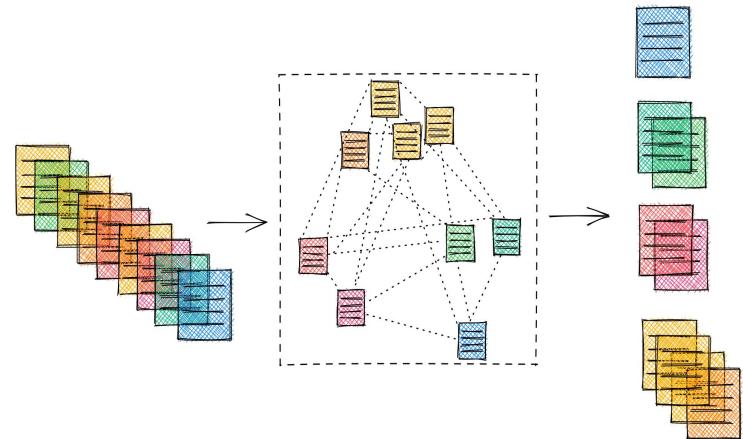
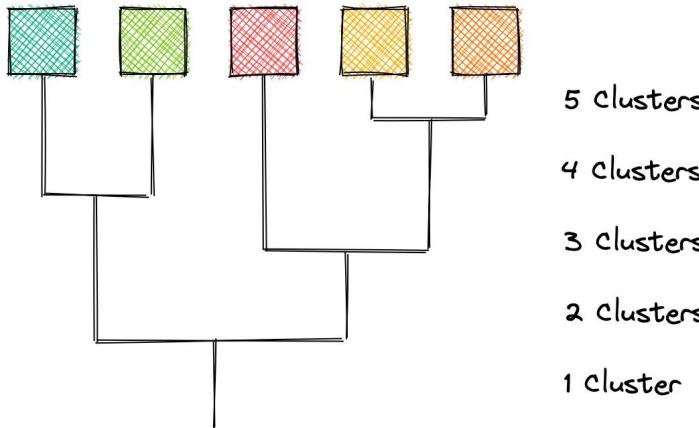
[green square]	•	•	•	•
[yellow square]	•	•	•	•
[red square]	•	•	•	•
[blue square]	•	•	•	•
[orange square]	•	•	•	•



# Online Clustering



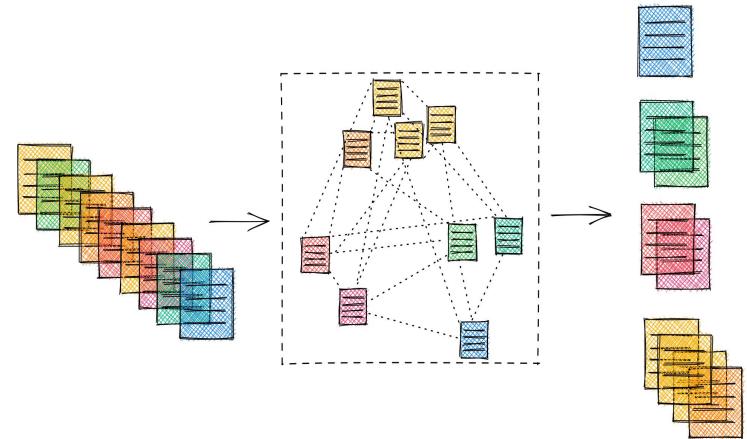
Agglomerative clustering



# Online Clustering



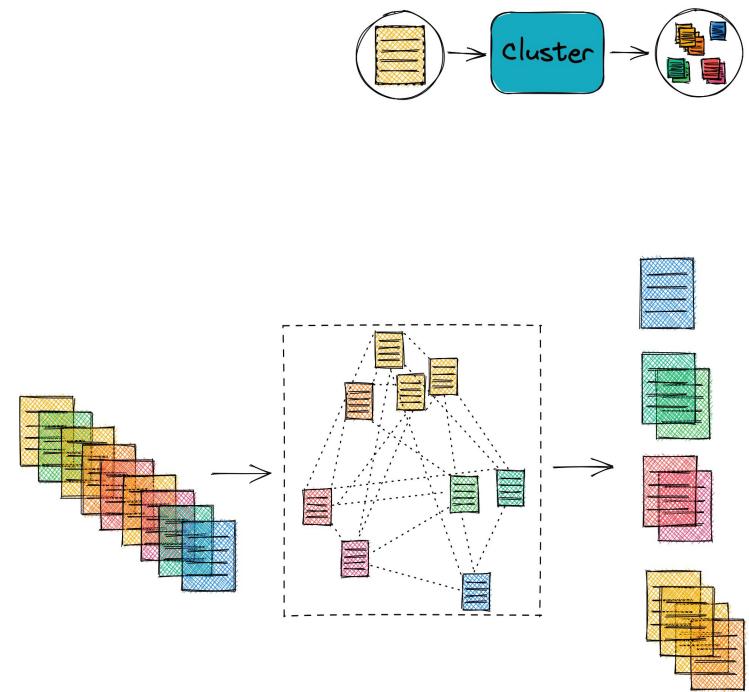
Clustering is usually a **batch operation**.



# Online Clustering

Clustering is usually a **batch operation**.

What do we need?



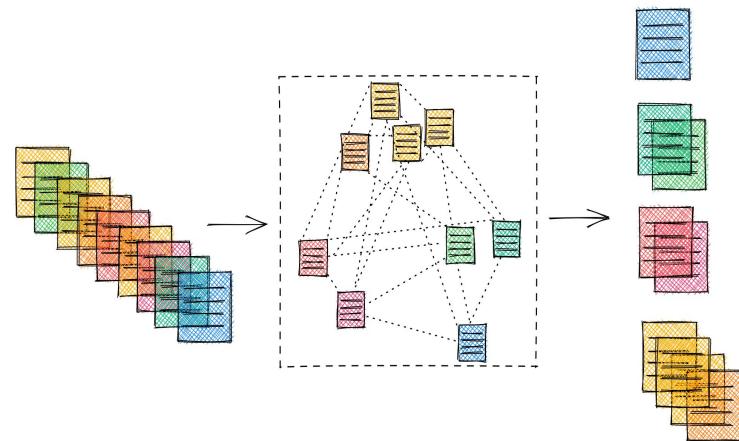
# Online Clustering



Clustering is usually a **batch operation**.

What do we need?

A **clustering algorithm** that works **iteratively**.



# Online Clustering

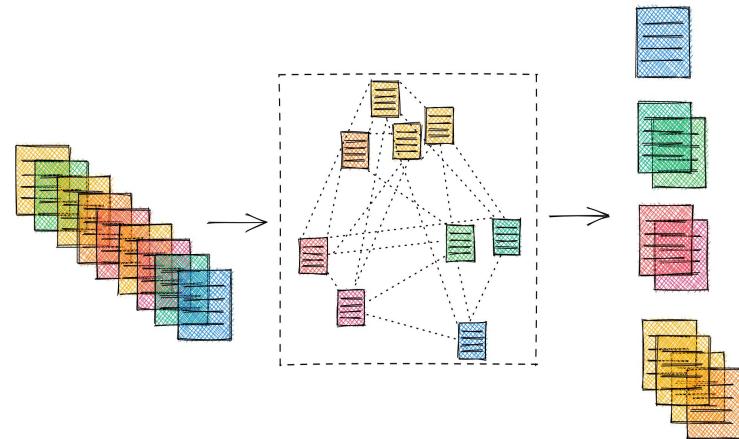


Clustering is usually a **batch operation**.

What do we need?

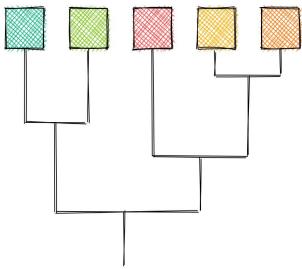
A **clustering algorithm** that works **iteratively**.

A mechanism to access the **previous state**.

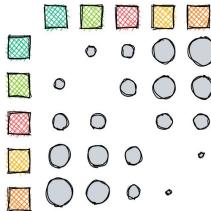


# BIRCH

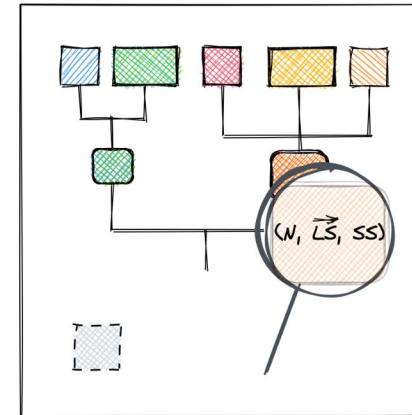
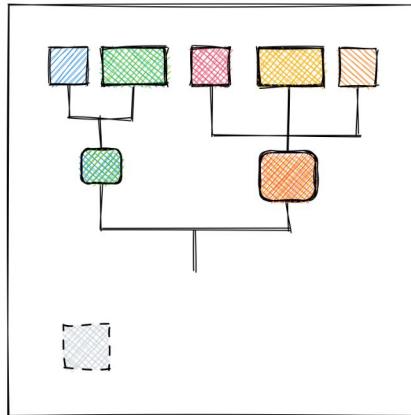
Agglomerative Clustering



Distance Matrix



Birch



Centroid  
Radius  
Diameter



$D_0, D_1, D_2, D_3, D_4$

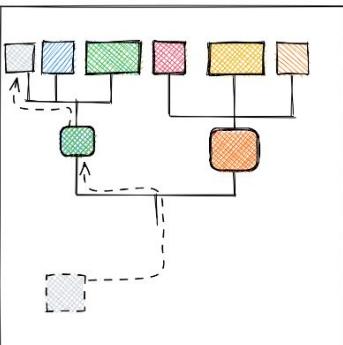
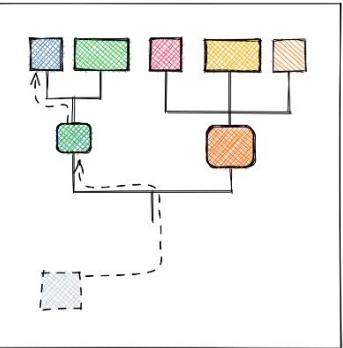
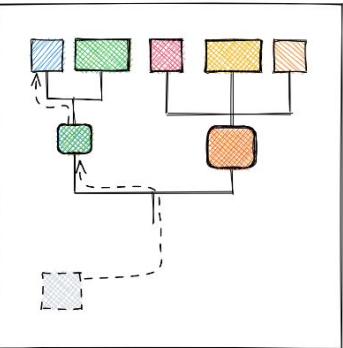
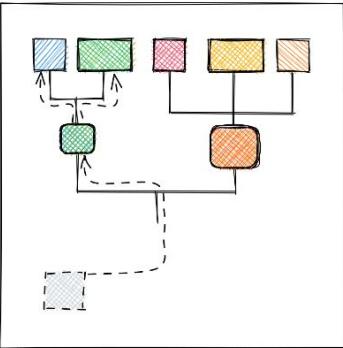
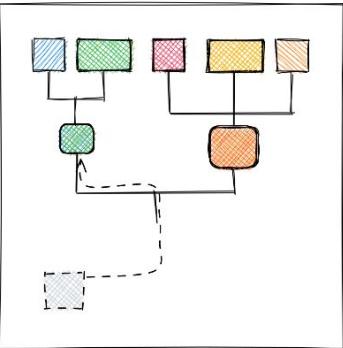
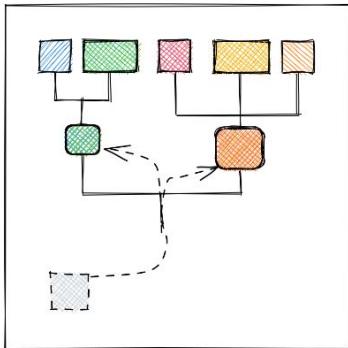


Additive Theorem:

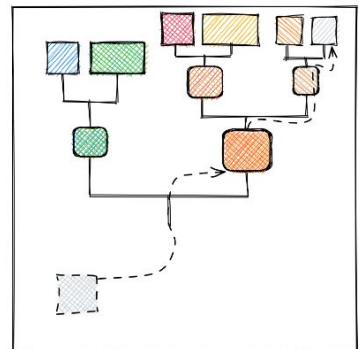
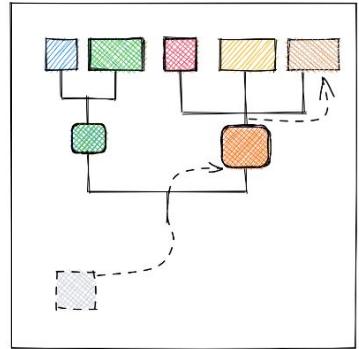
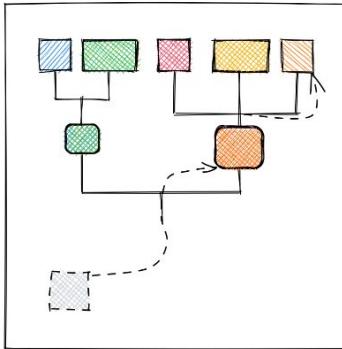
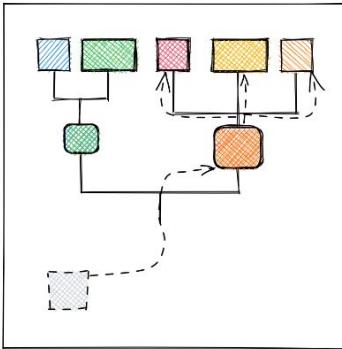
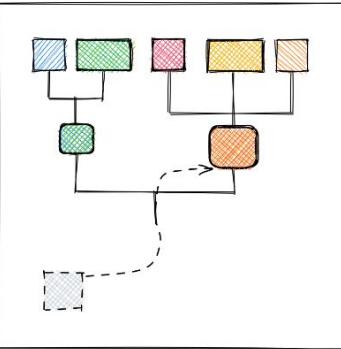
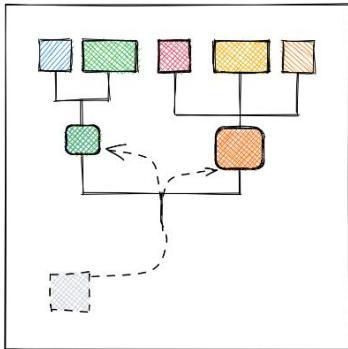


$N_1 + N_2, \vec{LS}_1 + \vec{LS}_2, SS + SS$

# BIRCH



# BIRCH



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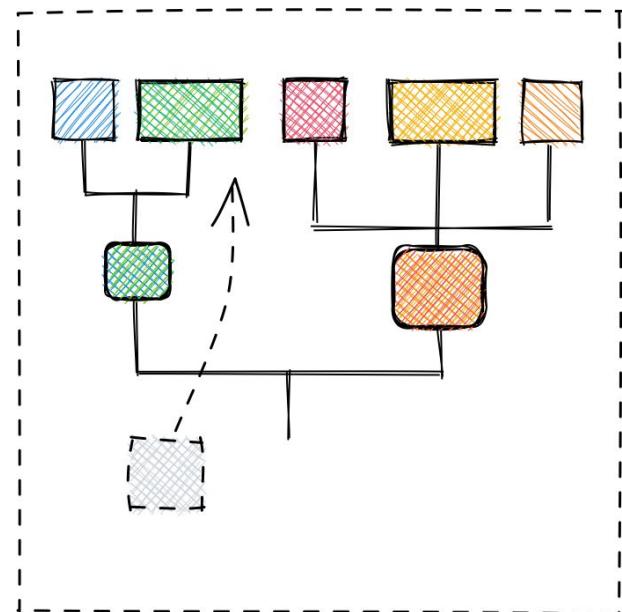
Add documents **iteratively**.

Build a **tree** structure that contains **summaries of subclusters** that are **sufficient** for cluster decisions.

**Tight, local subclusters** are summarised.

Very **fast**, input **data** only needs to be **read once**,  $O(n)$ .

Resulting summaries can be used as input to other clustering algorithms.

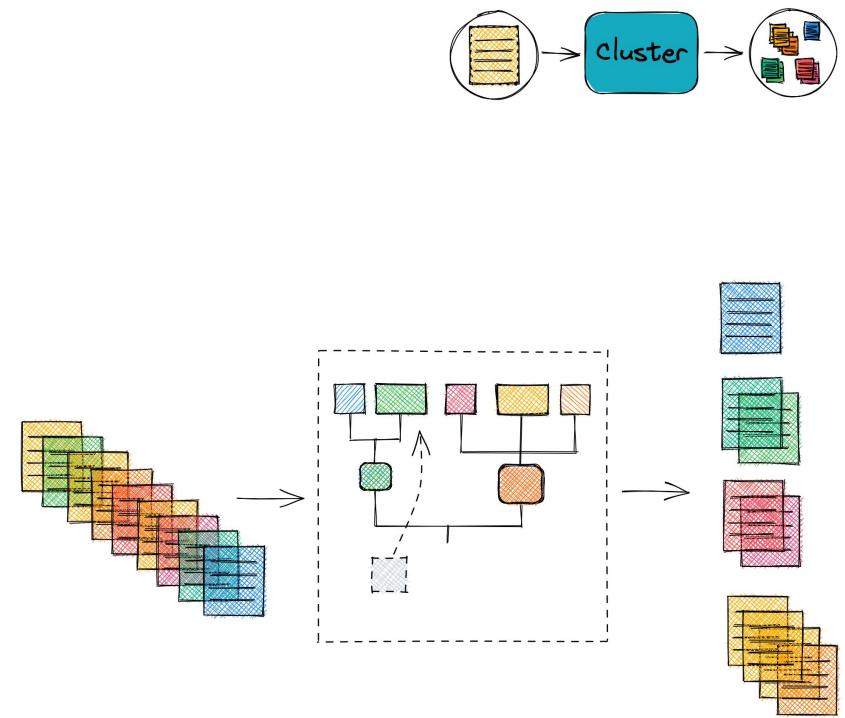


# Online Clustering

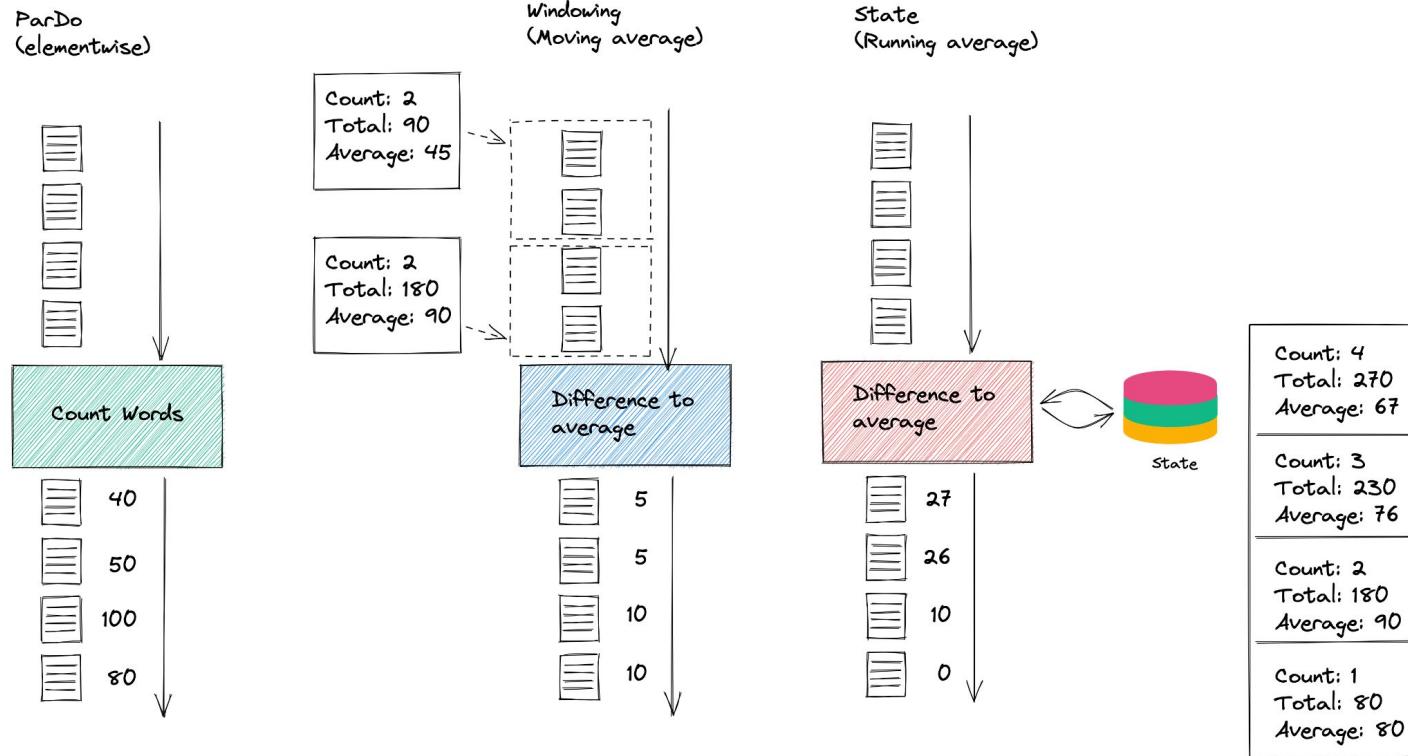
What do we need?

A **clustering algorithm** that works **iteratively**.

A mechanism to access the **previous state**.



# Stateful Processing



# Stateful Processing

```
def run():
    """Main function that defines the pipeline and runs it."""
    pipeline = beam.Pipeline()

    # Input text documents
    docs = (
        pipeline
        | "Load documents" >> beam.Create(example_docs)
    )

    # Enrichment
    enriched_docs = (
        docs
        | "Count words" >> beam.ParDo(CountWords())
    )

    # Difference to running average
    differences = (
        enriched_docs
        # The state is partitioned by key: Use a single key
        | "Make key-value pair" >> beam.Map(lambda e: (1, e))
        | "Difference to Running Average" >> beam.ParDo(StatefulAverageDifference())
    )

    # Print
    _ = (
        differences
        | "Print" >> beam.Map(pprint)
    )

    pipeline.run().wait_until_finish()
```

```
class CountWords(beam.DoFn):
    def process(self, element, *args, **kwargs):
        text = element.get('text', '')
        words = text.split(' ')
        yield {
            **copy.deepcopy(element),
            'word_count': len(words)
        }

class StatefulAverageDifference(beam.DoFn):
    DOCUMENT_COUNT_SPEC = ReadModifyWriteStateSpec('document_count', PickleCoder())
    WORD_TOTAL_SPEC = ReadModifyWriteStateSpec('word_total', PickleCoder())

    def process(self, element,
                document_count_state=beam.DoFn.StateParam(DOCUMENT_COUNT_SPEC),
                word_total_state=beam.DoFn.StateParam(WORD_TOTAL_SPEC),
                *args, **kwargs):
        # 1. Initialise or load states
        document_count = document_count_state.read() or int()
        word_total = word_total_state.read() or int()

        # 2. Extract document, update state, and calculate average
        _, doc = element # The state is partitioned by key
        document_count = document_count + 1
        word_total = word_total + doc['word_count']
        average = word_total / document_count
        difference = abs(doc['word_count'] - average)

        # 3. Write states
        document_count_state.write(document_count)
        word_total_state.write(word_total)

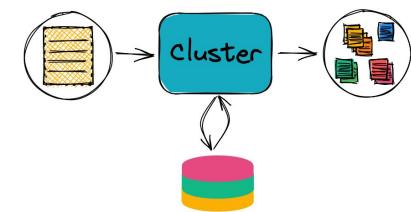
        # 4. Yield element
        yield {
            'uuid': doc['uuid'],
            'word_count': doc['word_count'],
            'difference': difference,
        }
```

```

1  class StatefulOnlineClustering(beam.DoFn):
2      """Group documents using online clustering of embeddings."""
3
4      DOCS_SPEC = ReadModifyWriteStateSpec('documents', PickleCoder())
5      EMBEDDINGS_SPEC = ReadModifyWriteStateSpec('embeddings', PickleCoder())
6
7      BIRCH_MODEL_SPEC = ReadModifyWriteStateSpec('clustering_model', PickleCoder())
8
9      LABEL_MAP_SPEC = ReadModifyWriteStateSpec('label_map', PickleCoder())
10     PREVIOUS_ASSIGNMENT_SPEC = ReadModifyWriteStateSpec('previous_cluster_assignment', PickleCoder())
11     UPDATE_COUNTER_SPEC = ReadModifyWriteStateSpec('update_counter', PickleCoder())
12
13     def process(
14         self,
15         element,
16         model_state=beam.DoFn.StateParam(BIRCH_MODEL_SPEC),
17         label_map_state=beam.DoFn.StateParam(LABEL_MAP_SPEC),
18         collected_docs_state=beam.DoFn.StateParam(DOCS_SPEC),
19         collected_embeddings_state=beam.DoFn.StateParam(EMBEDDINGS_SPEC),
20         previous_assignments_state=beam.DoFn.StateParam(PREVIOUS_ASSIGNMENT_SPEC),
21         update_counter_state=beam.DoFn.StateParam(UPDATE_COUNTER_SPEC),
22         *args,
23         **kwargs,
24     ):
25
26         # 1. Initialise or load states
27         clustering = model_state.read() or Birch(n_clusters=None, threshold=0.7)
28         label_map = label_map_state.read() or dict()
29         collected_documents = collected_docs_state.read() or dict()
30         collected_embeddings = collected_embeddings_state.read() or dict()
31         previous_assignments = previous_assignments_state.read() or dict()
32         update_counter = update_counter_state.read() or Counter()
33
34         # 2. Process document
35         doc_uuid = element['uuid']
36         embedding_vector = element['embedding']
37         doc_embedding = np.array([embedding_vector])
38         clustering.fit(doc_embedding)
39         cluster_id = clustering.predict(doc_embedding)[0]
40
41         # 3. Update state
42         label_map[doc_uuid] = cluster_id
43         collected_documents[doc_uuid] = element
44         previous_assignments[doc_uuid] = cluster_id
45         update_counter[cluster_id] += 1
46
47         # 4. Write state
48         label_map_state.write(label_map)
49         collected_docs_state.write(collected_documents)
50         collected_embeddings_state.write(collected_embeddings)
51         previous_assignments_state.write(previous_assignments)
52         update_counter_state.write(update_counter)
53
54         # 5. Yield updated clusters
55         yield {
56             'cluster_id': cluster_id,
57             'updates': update_counter[cluster_id],
58             'documents': collected_documents[doc_uuid],
59         }
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# Online Clustering

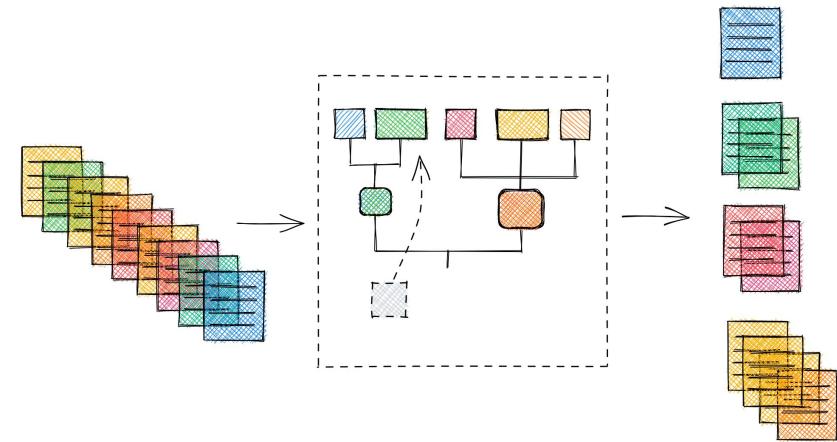


**BIRCH:**

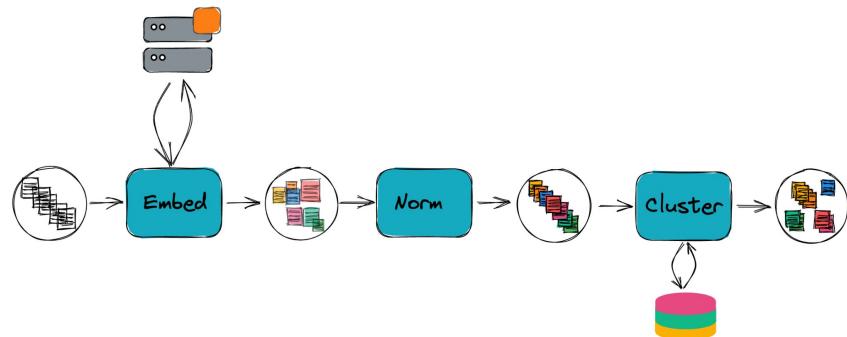
A **clustering** algorithm that works **iteratively**.

**Stateful processing:**

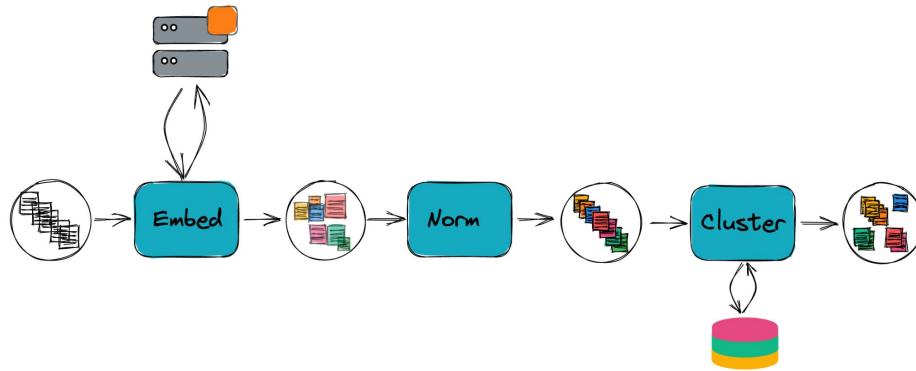
A mechanism to access the **previous state**.



# Example



Semantic Enrichment &  
Online Clustering  
of textual data using Apache Beam





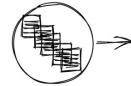
"Star Wars is my favourite movie!"



"I reject the later edits. Clearly, Han Solo shot first!"



"I like turtles."



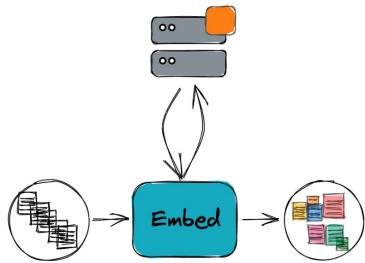
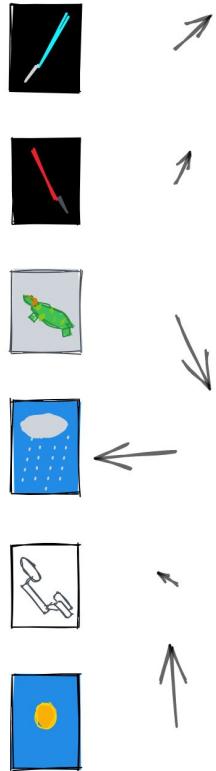
"July could be the first month with no measurable rain in Austin since 2015."

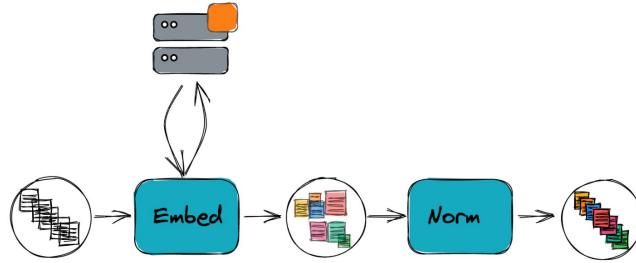
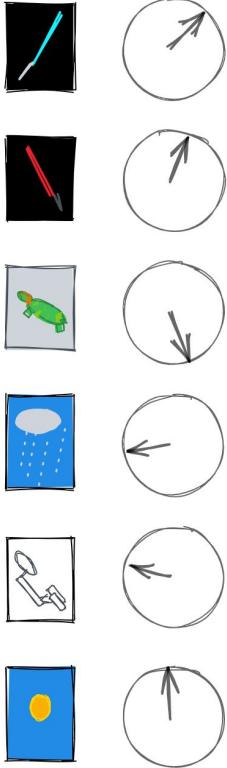


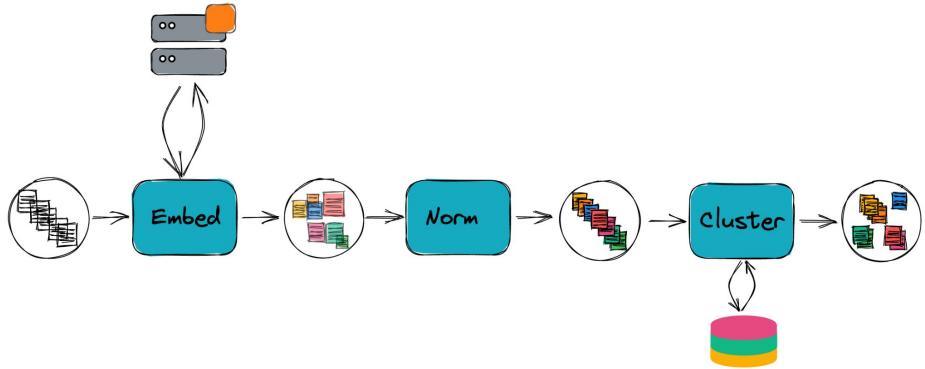
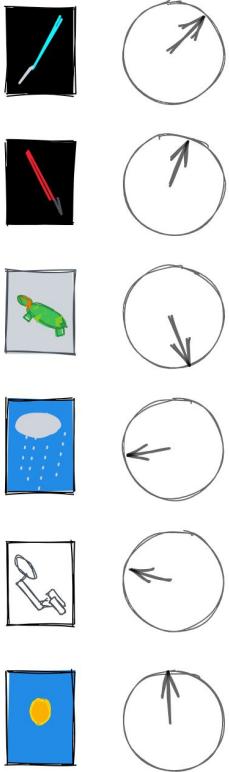
"Star Trek is an awesome series."



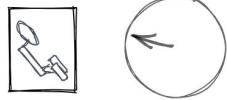
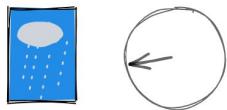
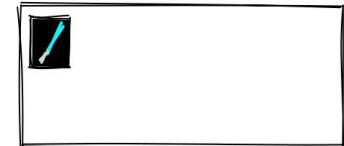
"Dry conditions, low humidity, and breezy winds will allow any fires to spread rapidly."

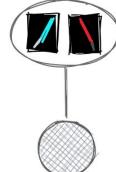
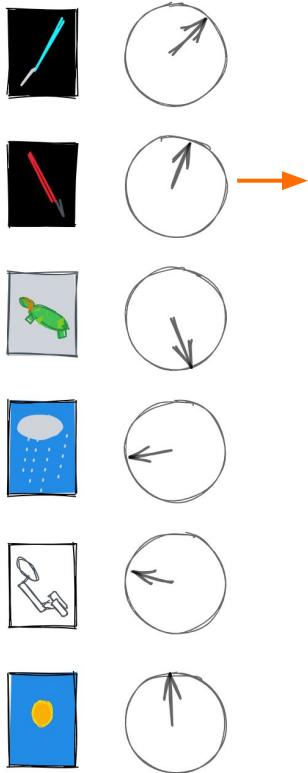






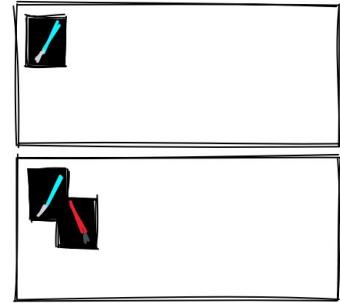
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Documents:  
Movies (Star Wars 1)

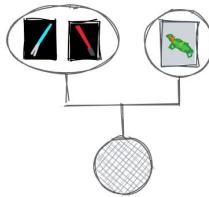
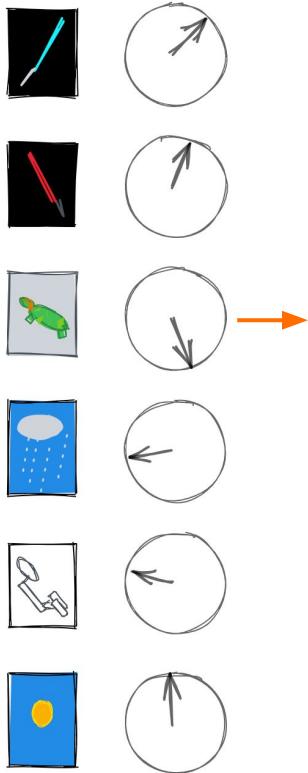




New cluster: 10940495-f79e-436a  
 Documents:  
 Movies (Star Wars 1)

Update: 10940495-f79e-436a  
 Documents:  
 Movies (Star Wars 1)  
 Movies (Star Wars 2)

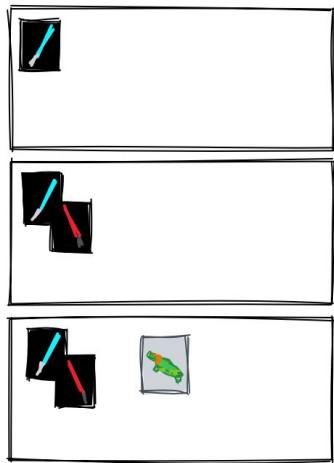


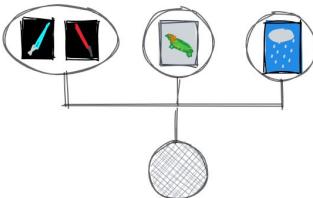
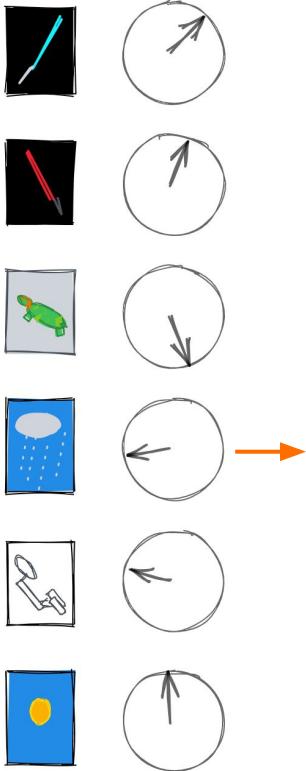


New cluster: 10940495-f79e-436a  
Documents:  
Movies (Star Wars 1)

Update: 10940495-f79e-436a  
Documents:  
Movies (Star Wars 1)  
Movies (Star Wars 2)

New cluster: 072a9e0d-4763-4afa  
Documents:  
Turtles



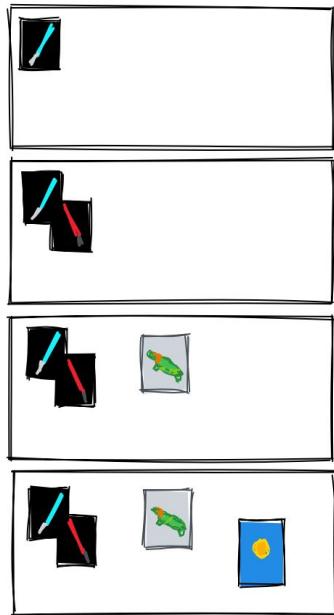


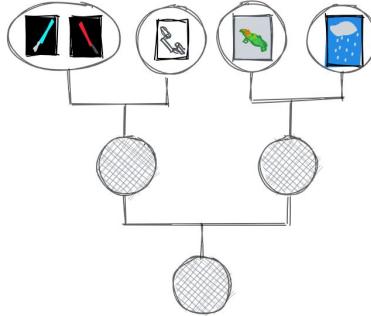
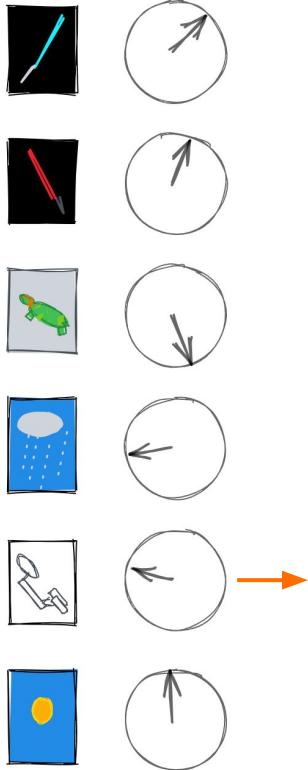
New cluster: 10940495-f79e-436a  
Documents:  
Movies (Star Wars 1)

Update: 10940495-f79e-436a  
Documents:  
Movies (Star Wars 1)  
Movies (Star Wars 2)

New cluster: 072a9e0d-4763-4afa  
Documents:  
Turtles

New cluster: fbdae2ec-9cc6-48b3  
Documents:  
Weather 1





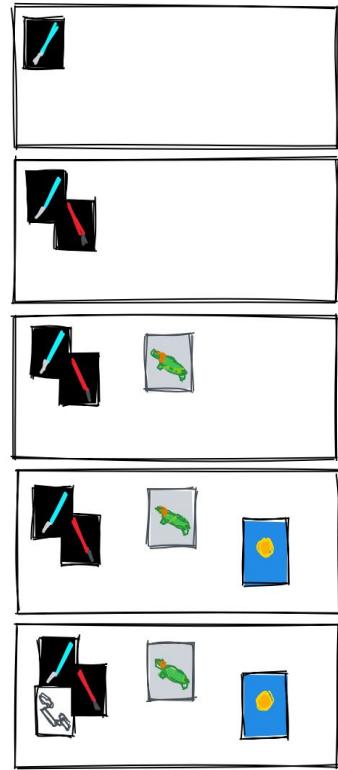
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Documents:  
Movies (Star Wars 1)

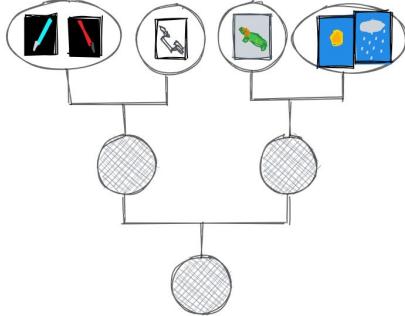
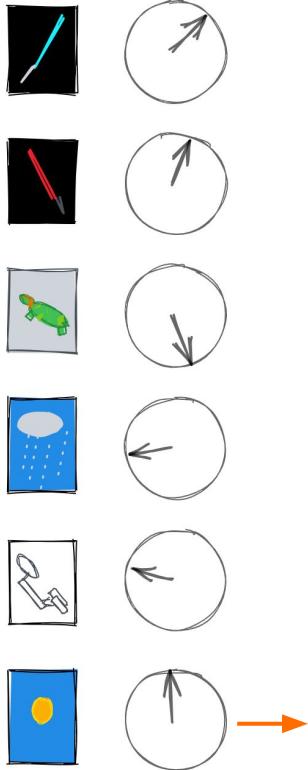
Update: 10940495-f79e-436a  
Documents:  
Movies (Star Wars 1)  
Movies (Star Wars 2)

New cluster: 072a9e0d-4763-4afa  
Documents:  
Turtles

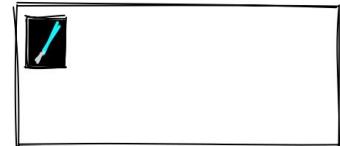
New cluster: fbdae2ec-9cc6-48b3  
Documents:  
Weather 1

Update: 10940495-f79e-436a  
Documents:  
Movies (Star Wars 1)  
Movies (Star Wars 2)  
Movies (Star Trek)

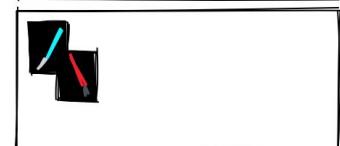




New cluster: 10940495-f79e-436a  
 Documents:  
 Movies (Star Wars 1)



Update: 10940495-f79e-436a  
 Documents:  
 Movies (Star Wars 1)  
 Movies (Star Wars 2)



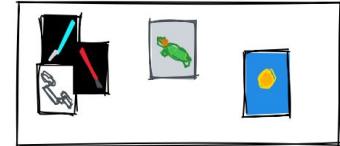
New cluster: 072a9e0d-4763-4afa  
 Documents:  
 Turtles



New cluster: fbdae2ec-9cc6-48b3  
 Documents:  
 Weather 1



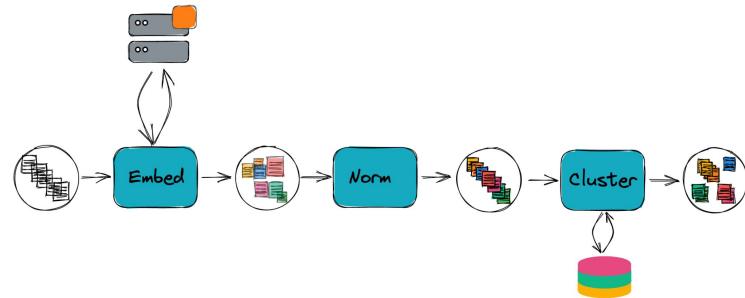
Update: 10940495-f79e-436a  
 Documents:  
 Movies (Star Wars 1)  
 Movies (Star Wars 2)  
 Movies (Star Trek)



Update: fbdae2ec-9cc6-48b3  
 Documents:  
 Weather 1  
 Weather 2



# Summary



**Semantic enrichment** adds information from the content to the documents. This often involves **machine learning** which are **expensive operations**.

**Online clustering** allows the grouping of text documents into groups that are unknown up-front in real-time. **Stateful processing** enables **iterative cluster model building**.

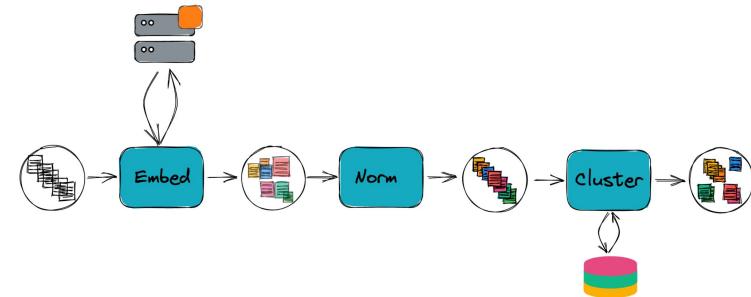
**BIRCH** is an **iterative** clustering algorithm that can handle very **large amounts of data**.

# Summary

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**Online clustering** allows the grouping of text documents into groups that are unknown up-front in real-time. **Stateful processing** enables **iterative cluster model building**.

**BIRCH** is an **iterative** clustering algorithm that can handle very **large amounts of data**.



**Real-time Productionizing: Streaming pipeline**

## Enrichment

Serve ML models using **microservices** or [RunInference](#). Initialise connection in the **setup** of the DoFn & use [time-batched](#) requests.

**Clustering:** Tidy up the **state** once in a while by pruning outdated elements.

# Q & A

@ml6team  
[linkedin.com/company/ml6team](https://www.linkedin.com/company/ml6team)

ML6 is hiring  
👉 <https://www.ml6.eu/join-us>



# Further Reading

- [Stateful Processing with Apache Beam](#)
- [Timely \(and Stateful\) Processing with Apache Beam](#)
- [BIRCH: An Efficient Data Clustering Method for Very Large Databases](#)  
(paper)
- [RunInference examples](#), [RunInference \(Beam Summit 2022\)](#) by Andy Ye