Single-pass Graph Stream Analytics with Apache Flink

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Outline

- Why Graph Streaming?
- Single-Pass Algorithms Examples
- Apache Flink Streaming API
- The GellyStream API

Real Graphs are *dynamic*

Graphs are created from **events** happening in real-time

@GraphDevroom

Vasia Kalavri @vkalavri · 9 Dec 2015
Just submitted a talk w/ @SenorCarbone at the FOSDEM @GraphDevroom! Have you submitted yours? CfP closes Dec 14 graphdevroom.github.io

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Christophe Willemsen @ikwattro · 9 Dec 2015
@vkalavri @SenorCarbone @GraphDevroom looking forward to your talk !!

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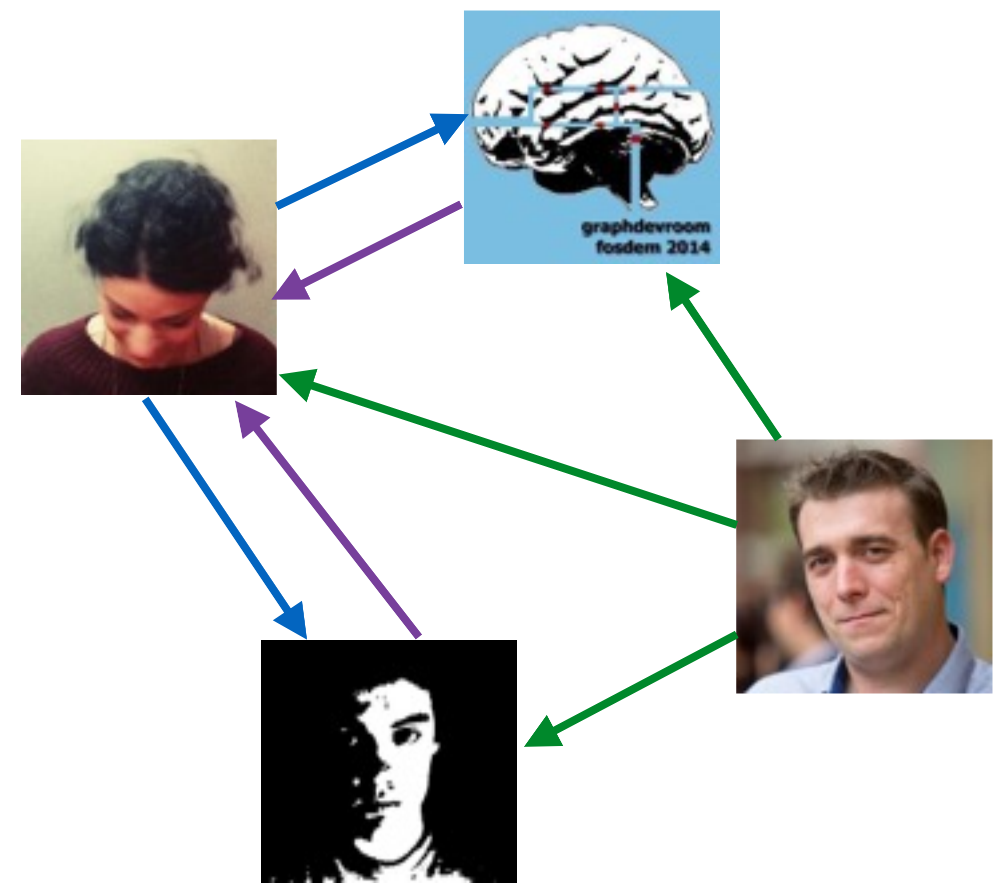


Batch Graph Processing

We create and analyze a **snapshot** of the real graph

- the Facebook social network on January 30 2016
- user web logs gathered between March 1st 12:00 and 16:00
- retweets and replies for 24h after the announcement of the death of David Bowie

Streaming Graph Processing

We consume events in **real-time**

- Get results *faster*
  - No need to wait for the job to finish
  - Sometimes, early approximations are better than late exact answers
- Get results *continuously*
  - Process *unbounded* number of events

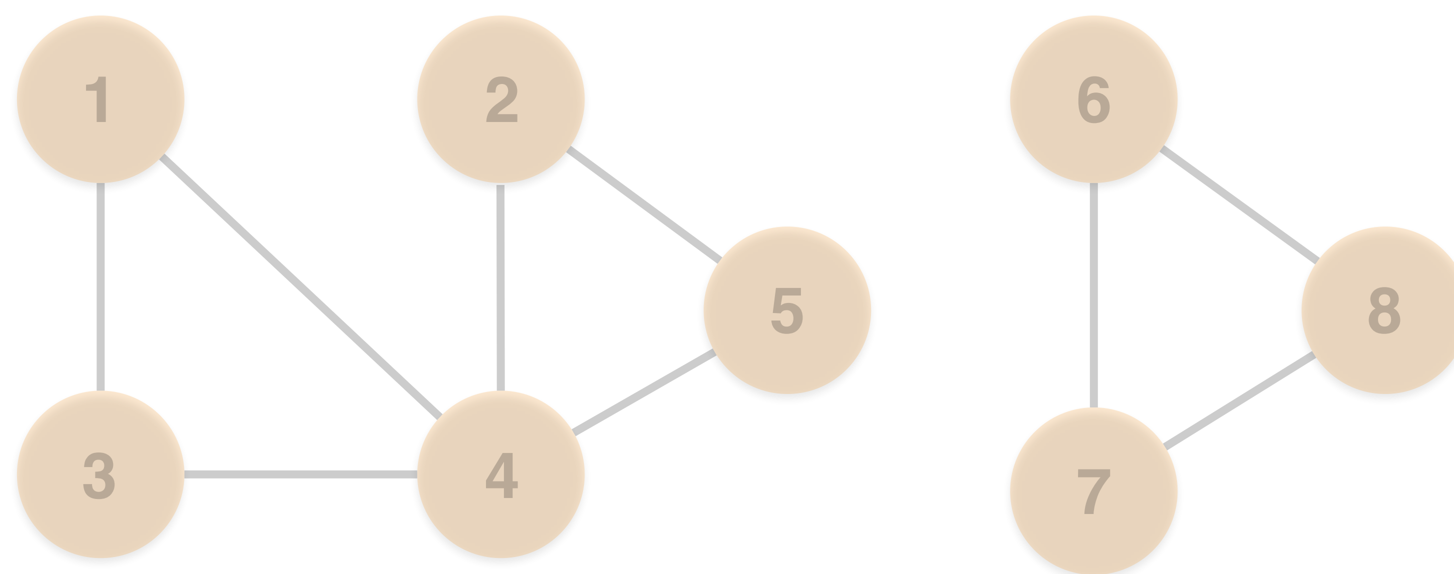
Challenges

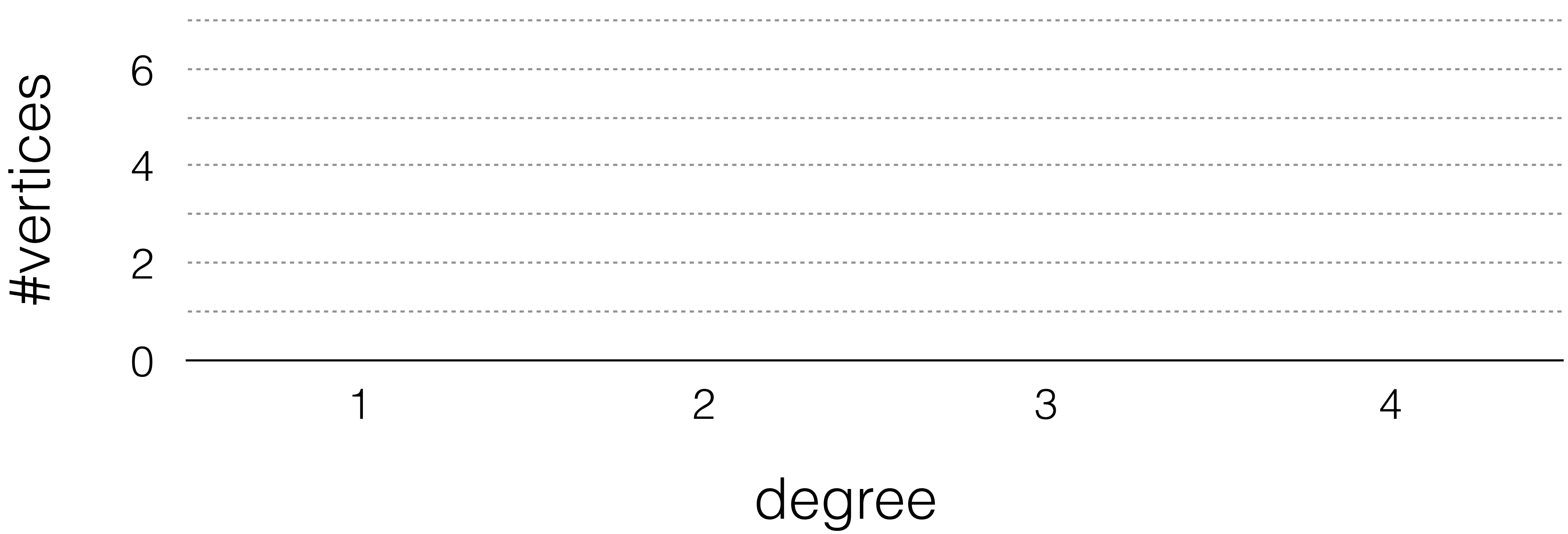
- Maintain the graph structure
  - How to apply state updates efficiently?
- Result updates
  - Re-run the analysis for each event?
  - Design an incremental algorithm?
  - Run separate instances on multiple snapshots?
- Computation on most recent events only

Single-Pass Graph Streaming

- Each event is an edge addition
- Maintains only a graph *summary*
- Recent events are grouped in graph *windows*

Streaming Degrees Distribution





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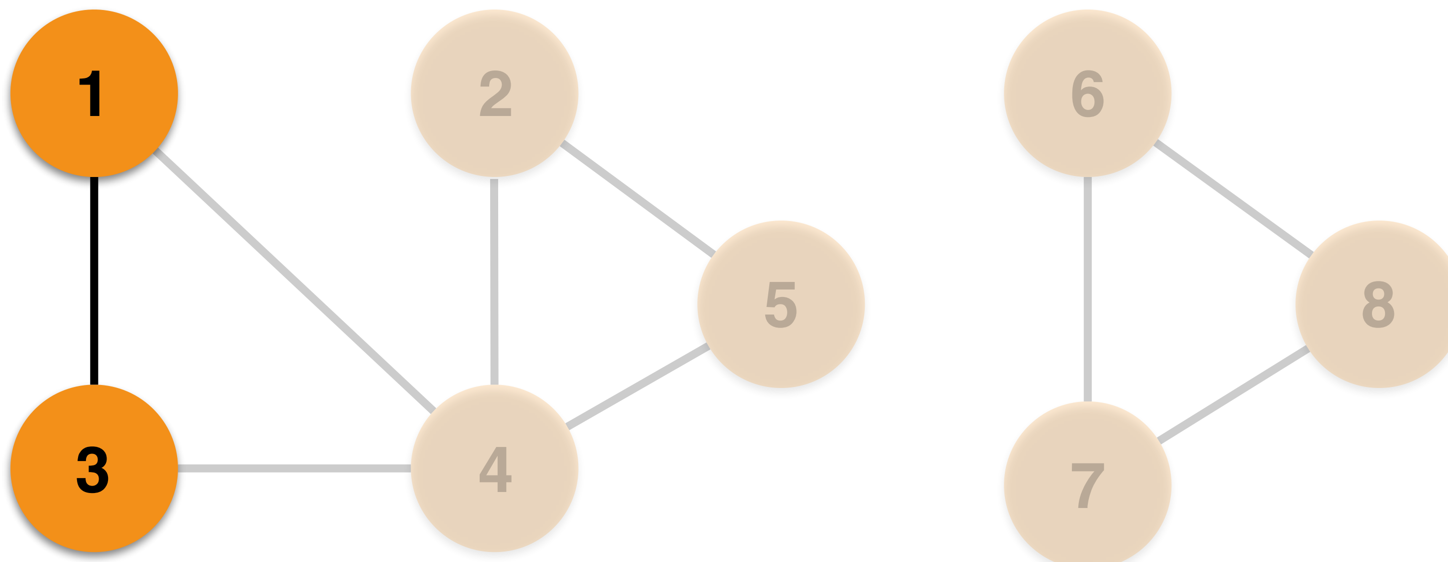

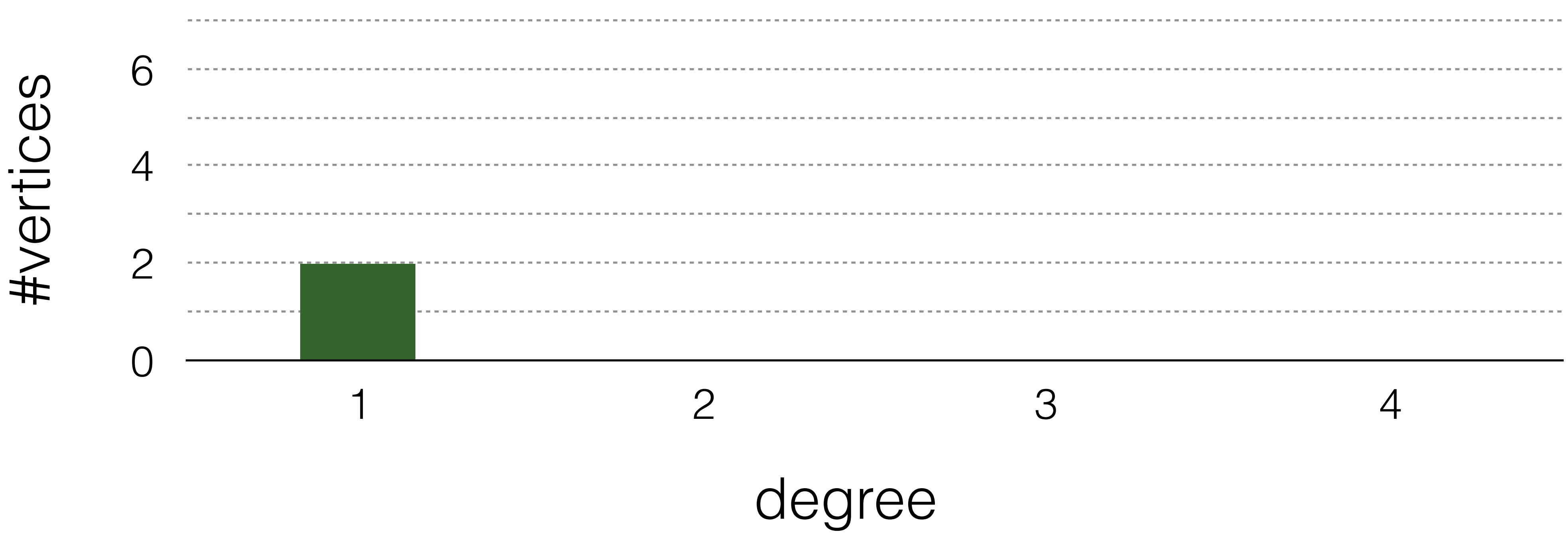

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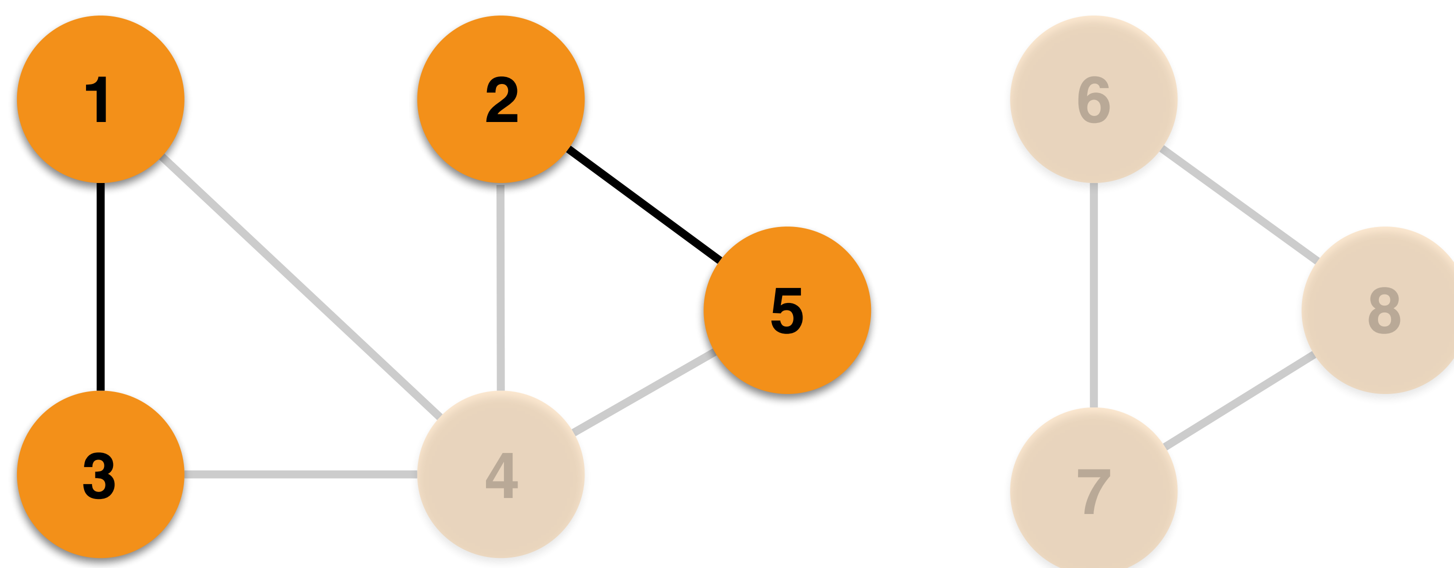

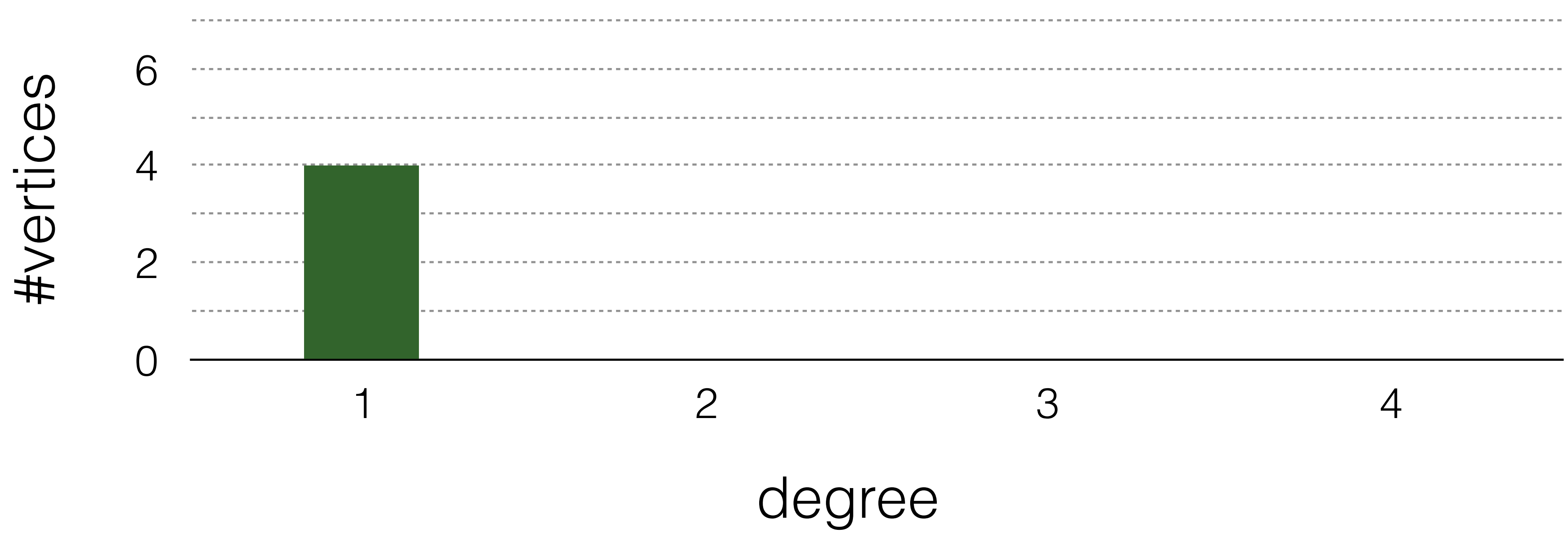

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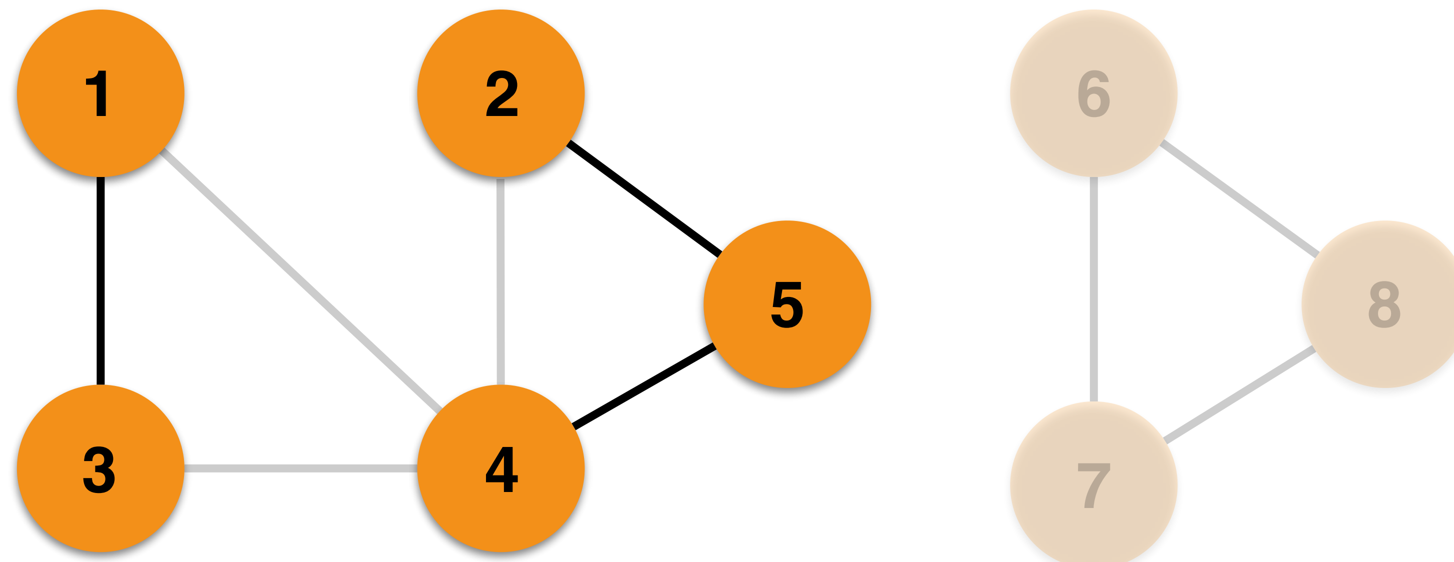

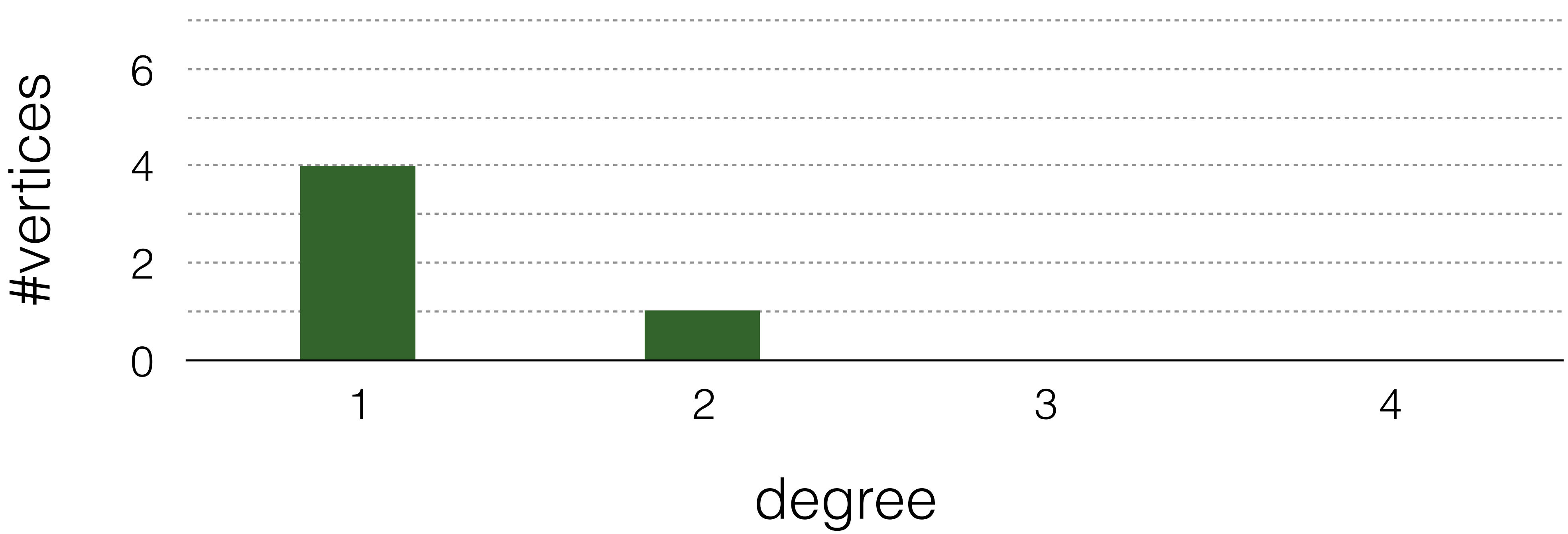

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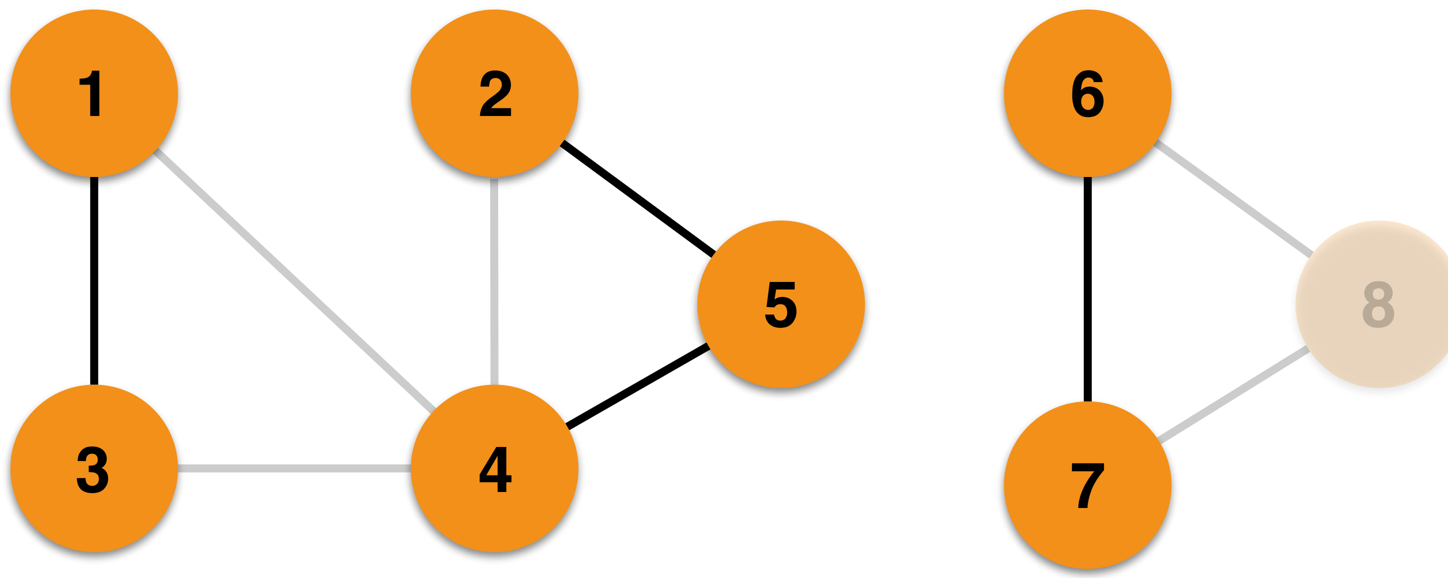

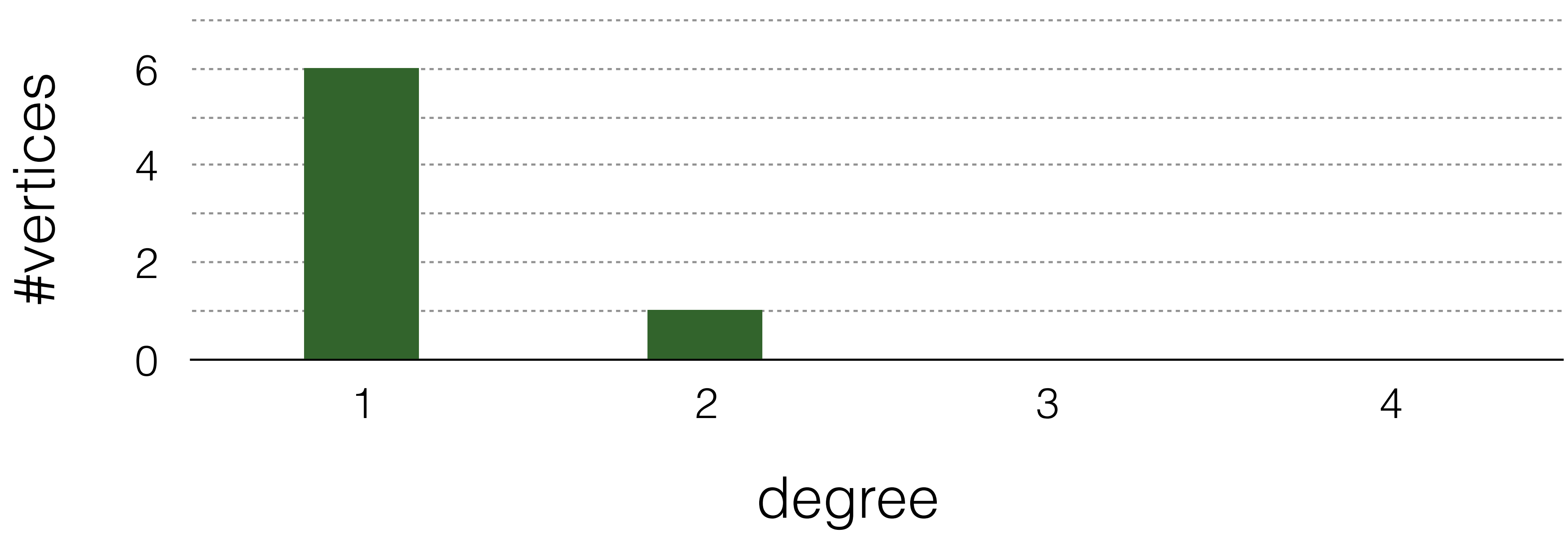

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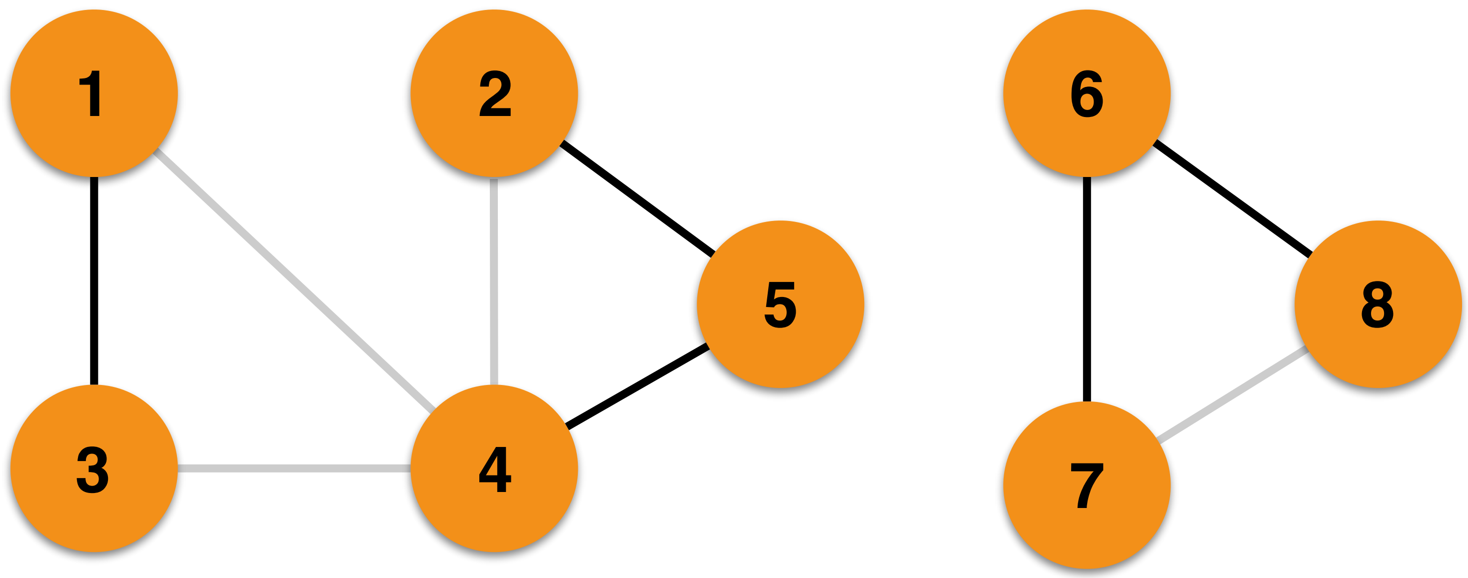

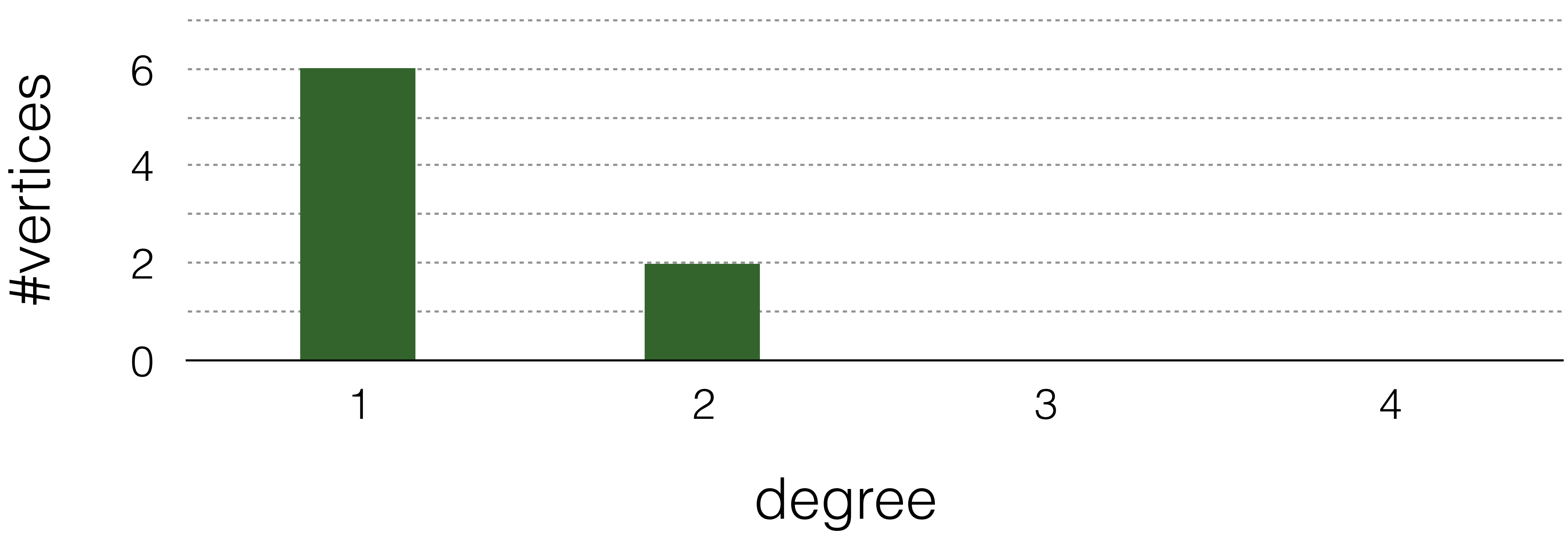

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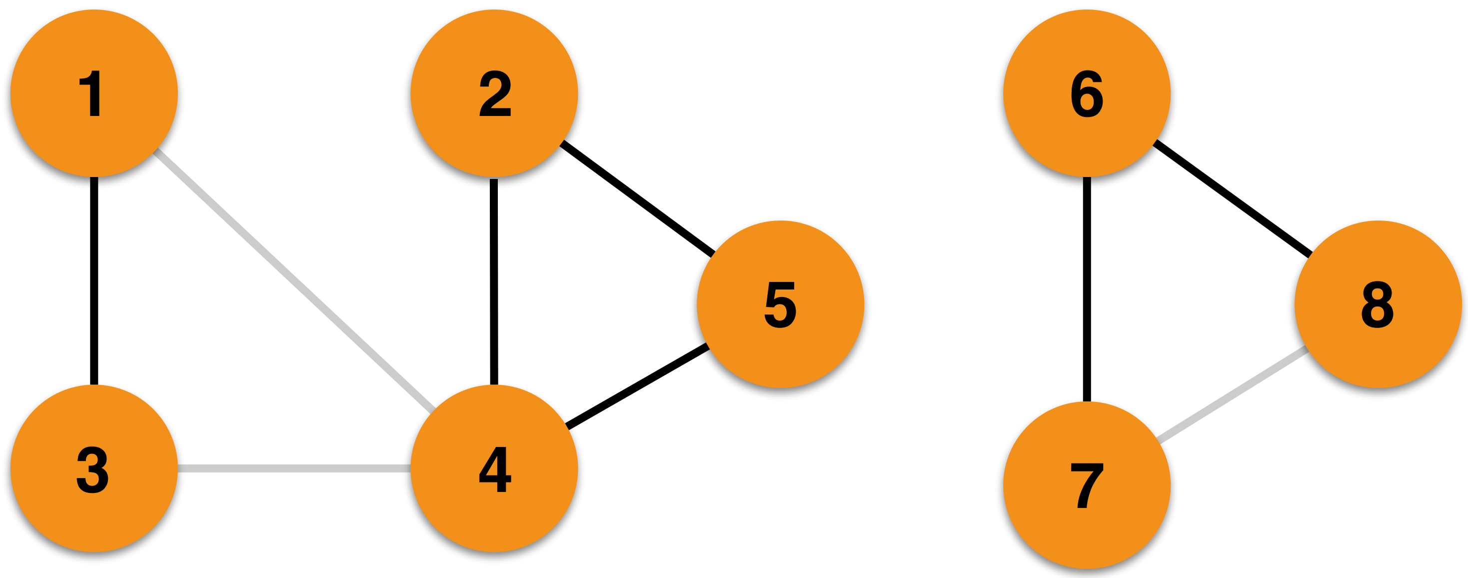
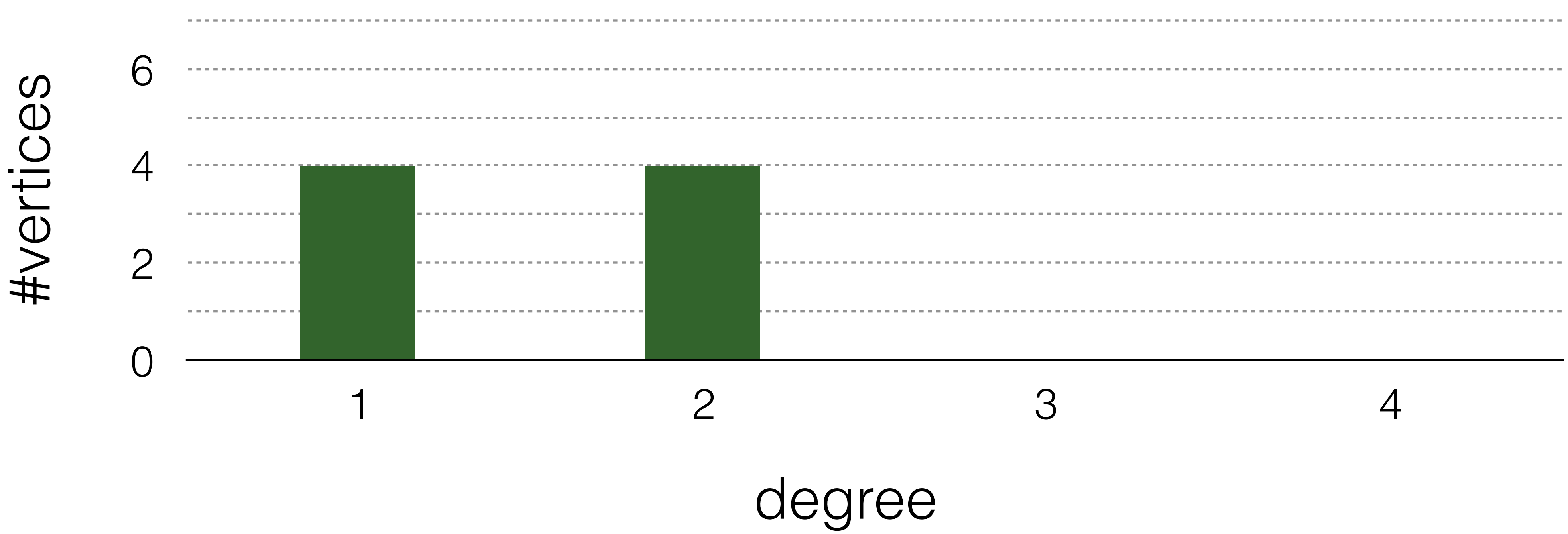
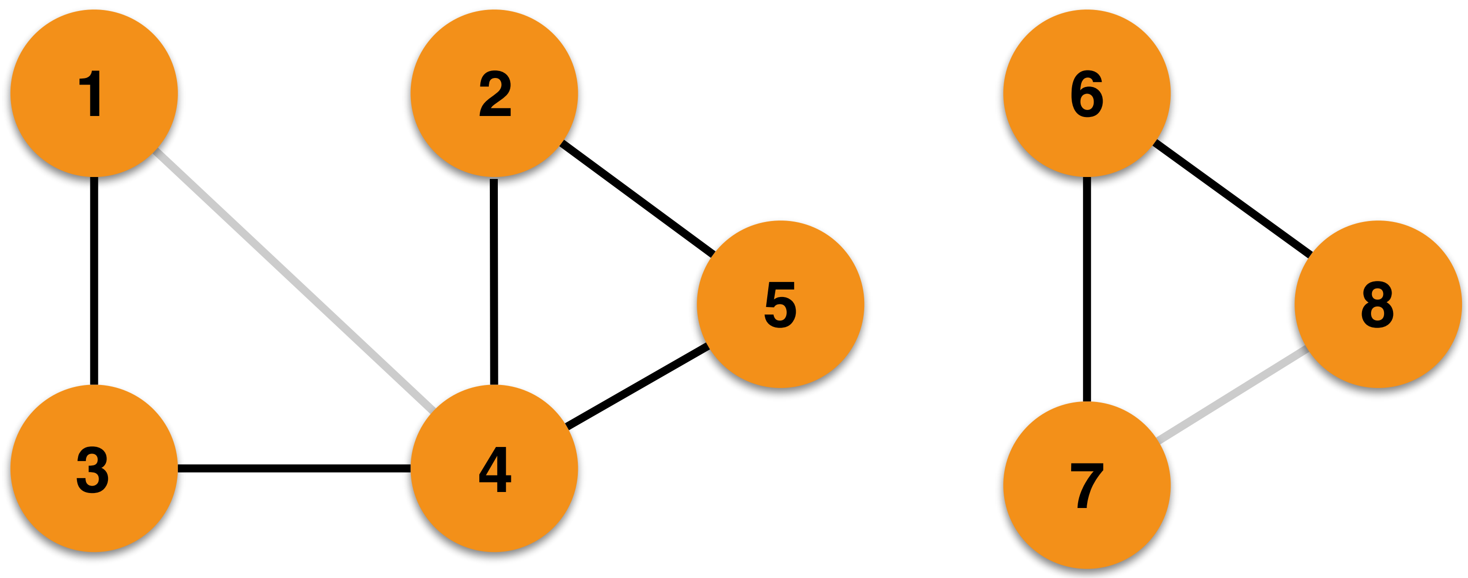
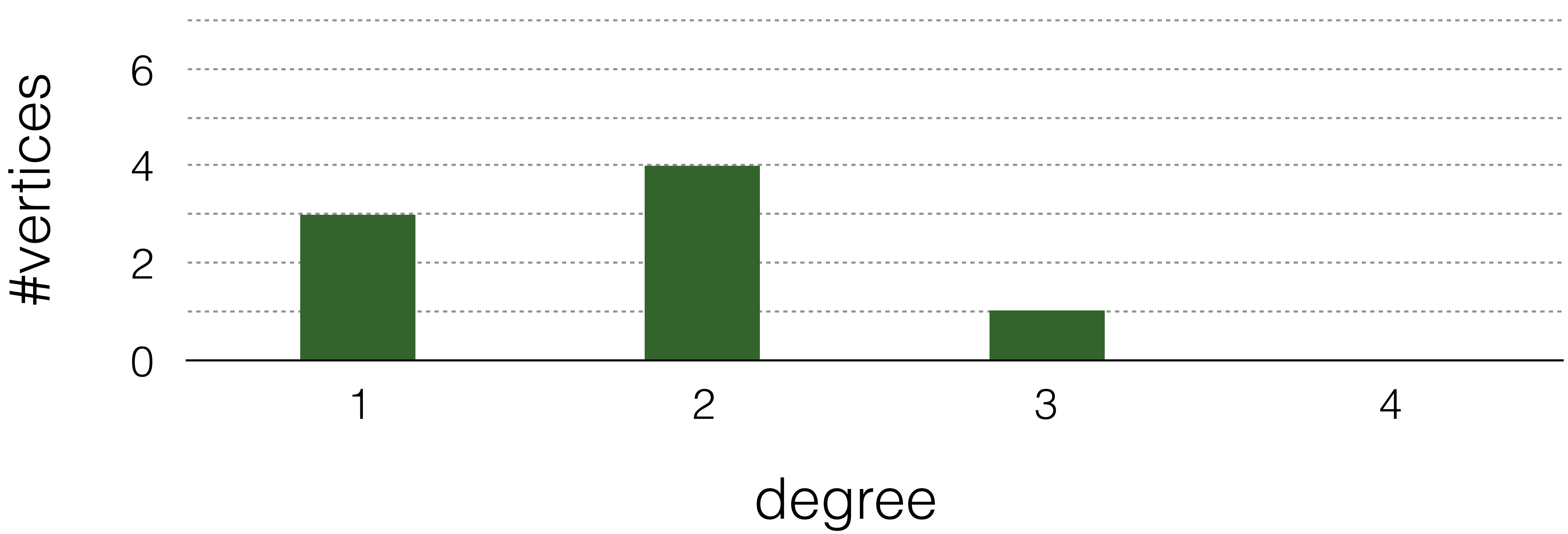


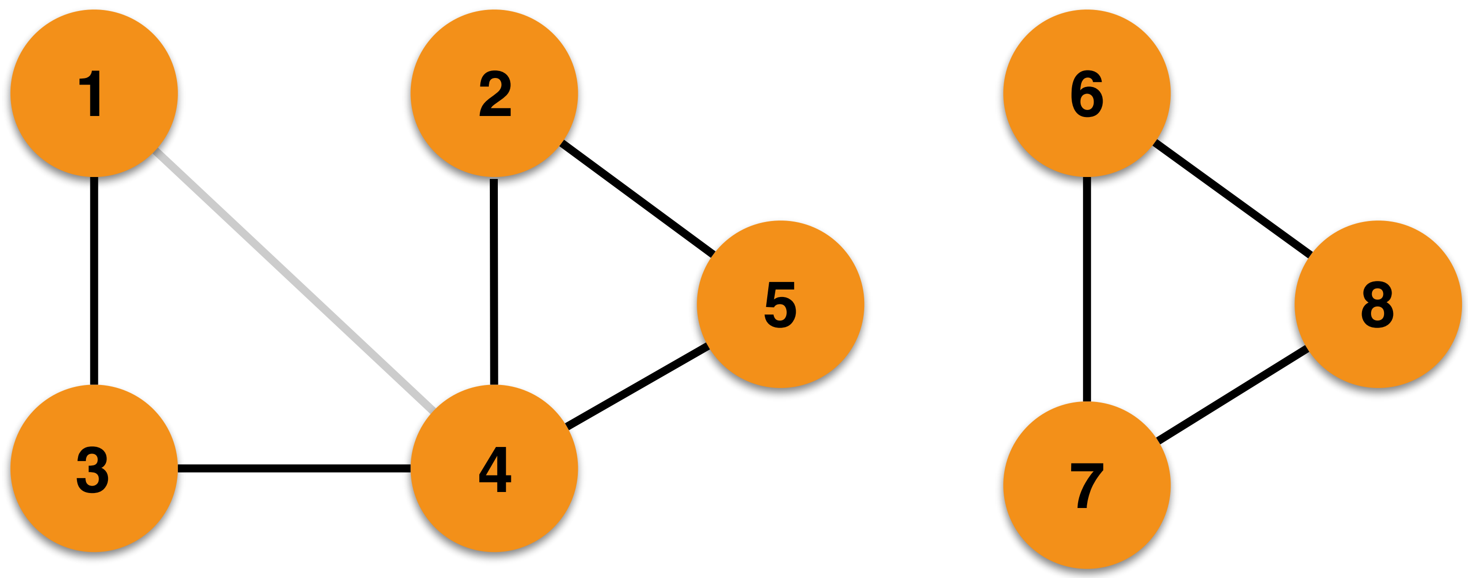


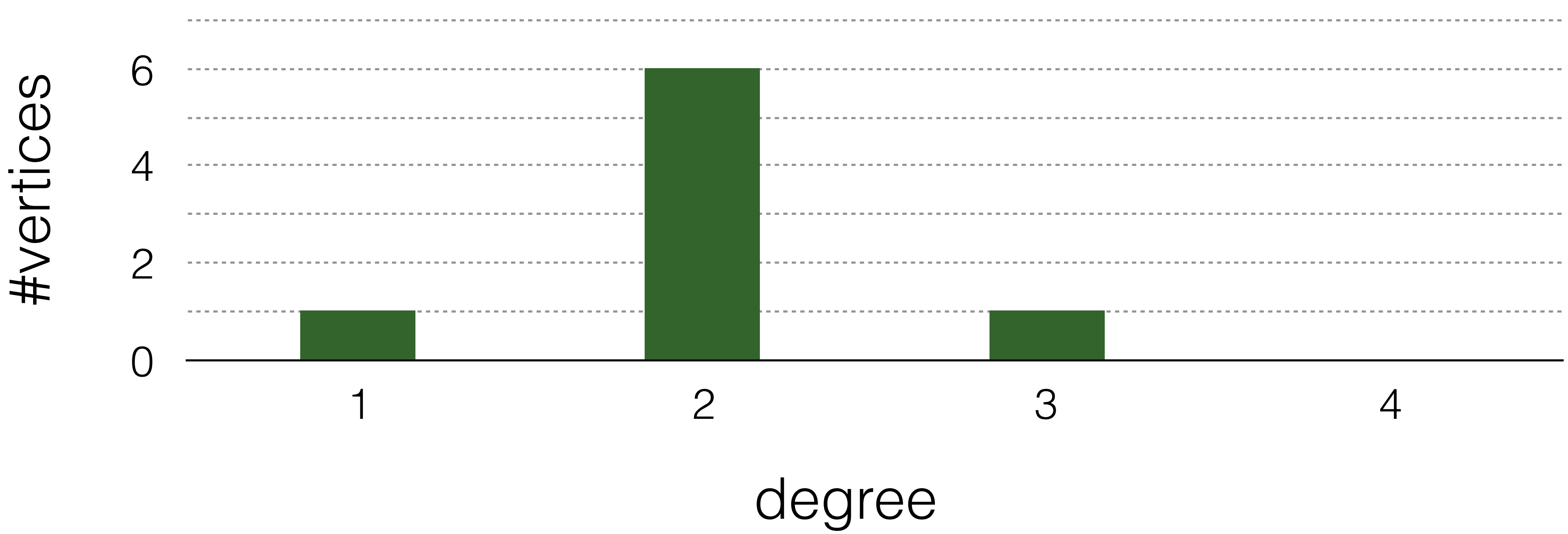
Streaming Degrees Distribution





Streaming Degrees Distribution





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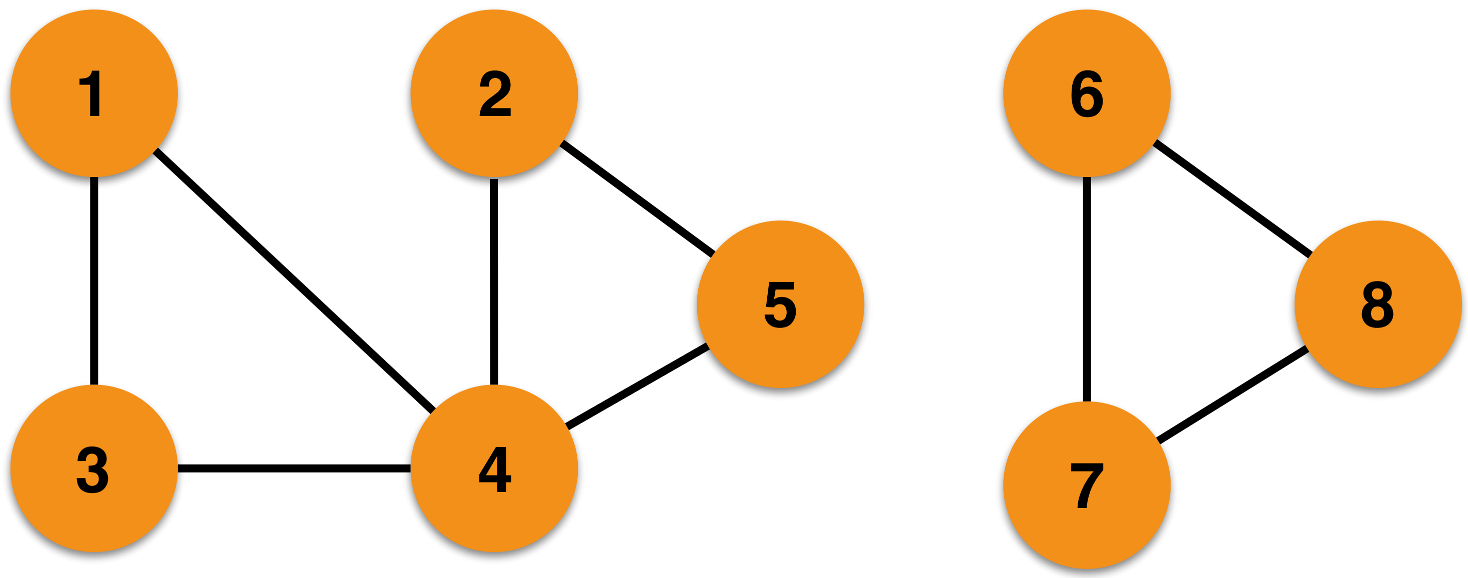
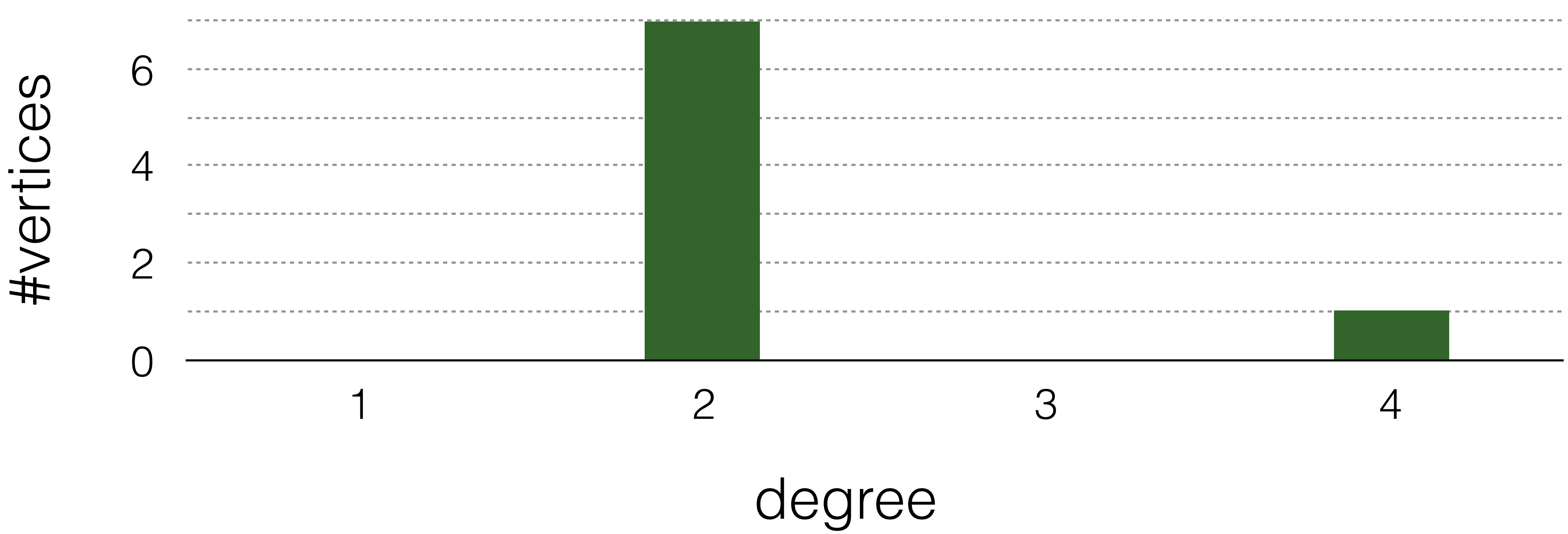
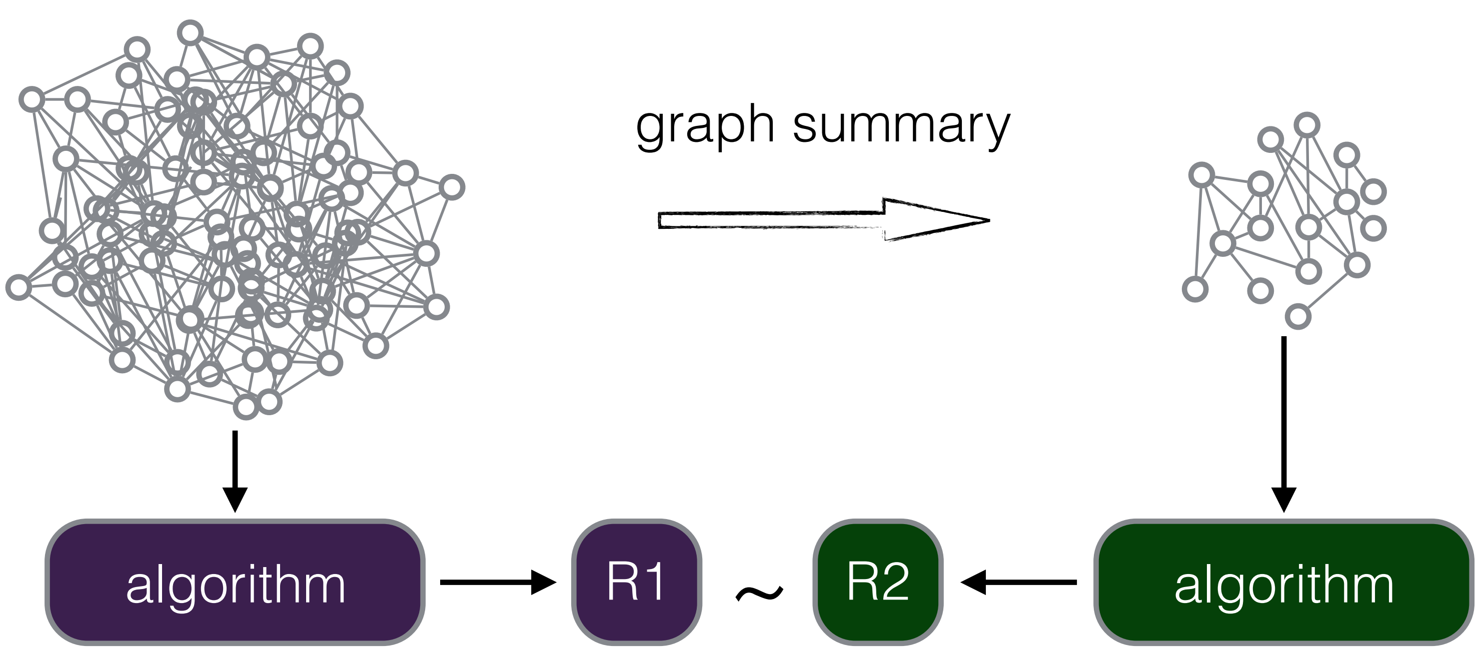




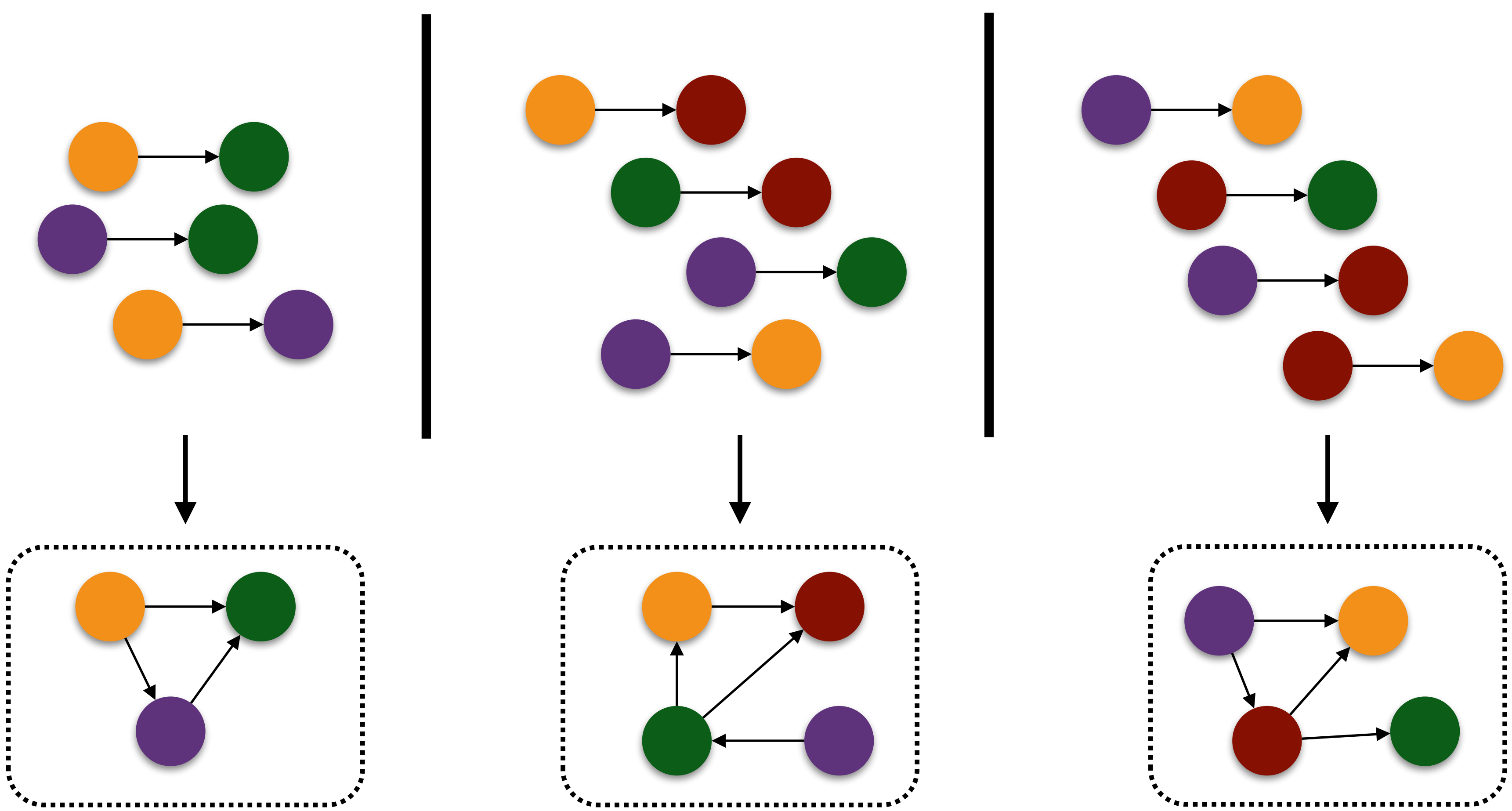
Graph Summaries

- **spanners** for distance estimation
- **sparsifiers** for cut estimation
- **sketches** for homomorphic properties



Window Aggregations

Neighborhood aggregations on windows



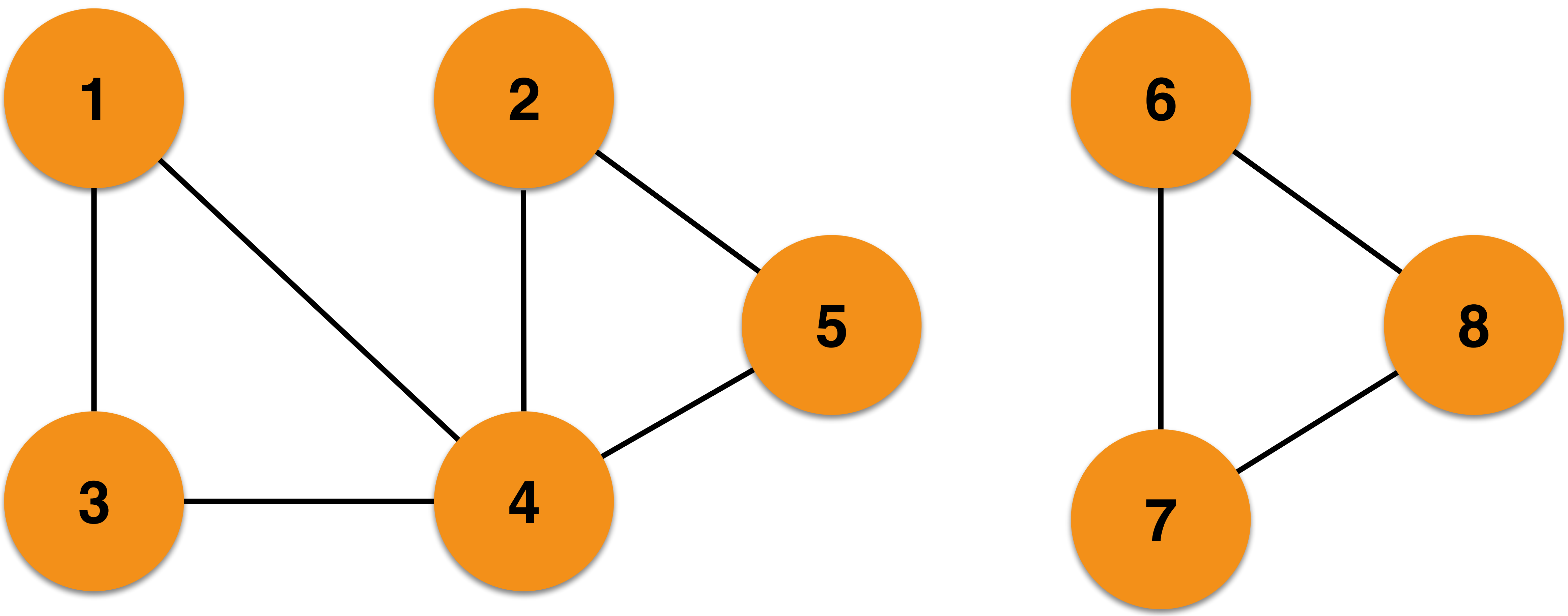
Examples

Batch Connected Components

- **State:** the graph and a component ID per vertex (initially equal to vertex ID)
- Iterative **Computation:** For each vertex:
    - choose the min of neighbors' component IDs and own component ID as new ID
    - if component ID changed since last iteration, notify neighbors

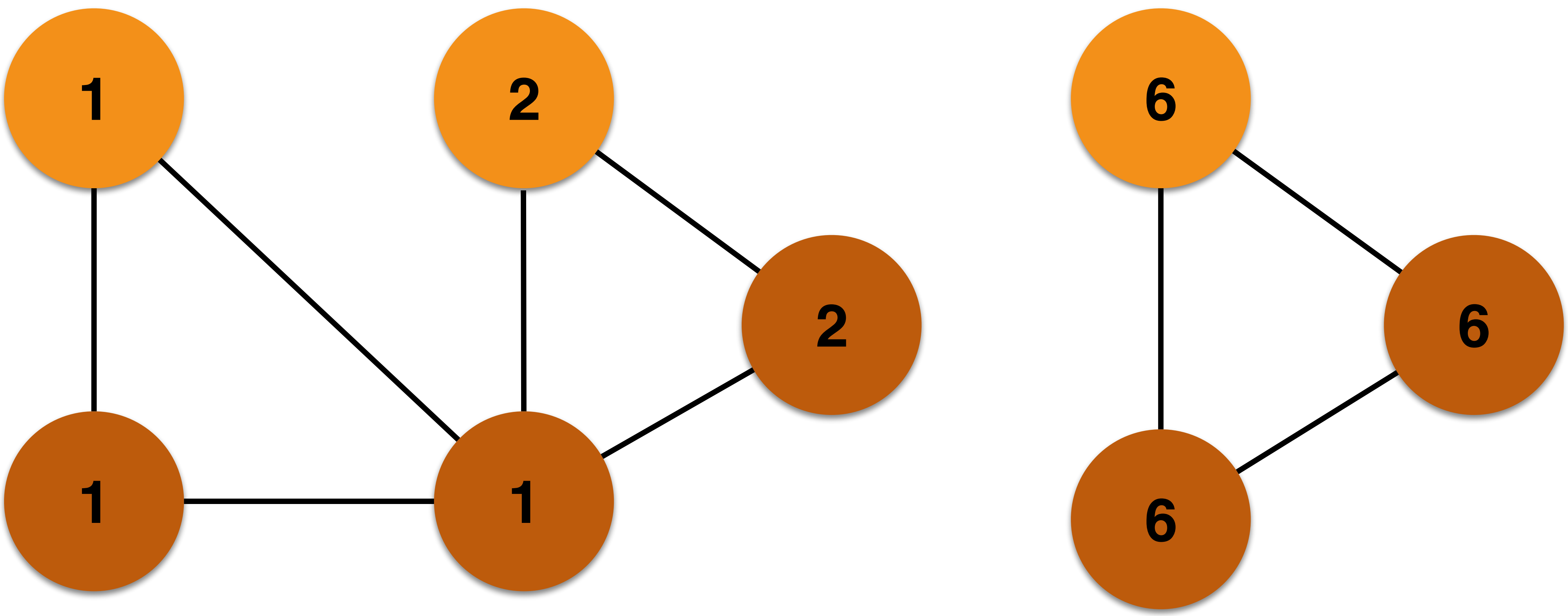
Batch Connected Components

i=0



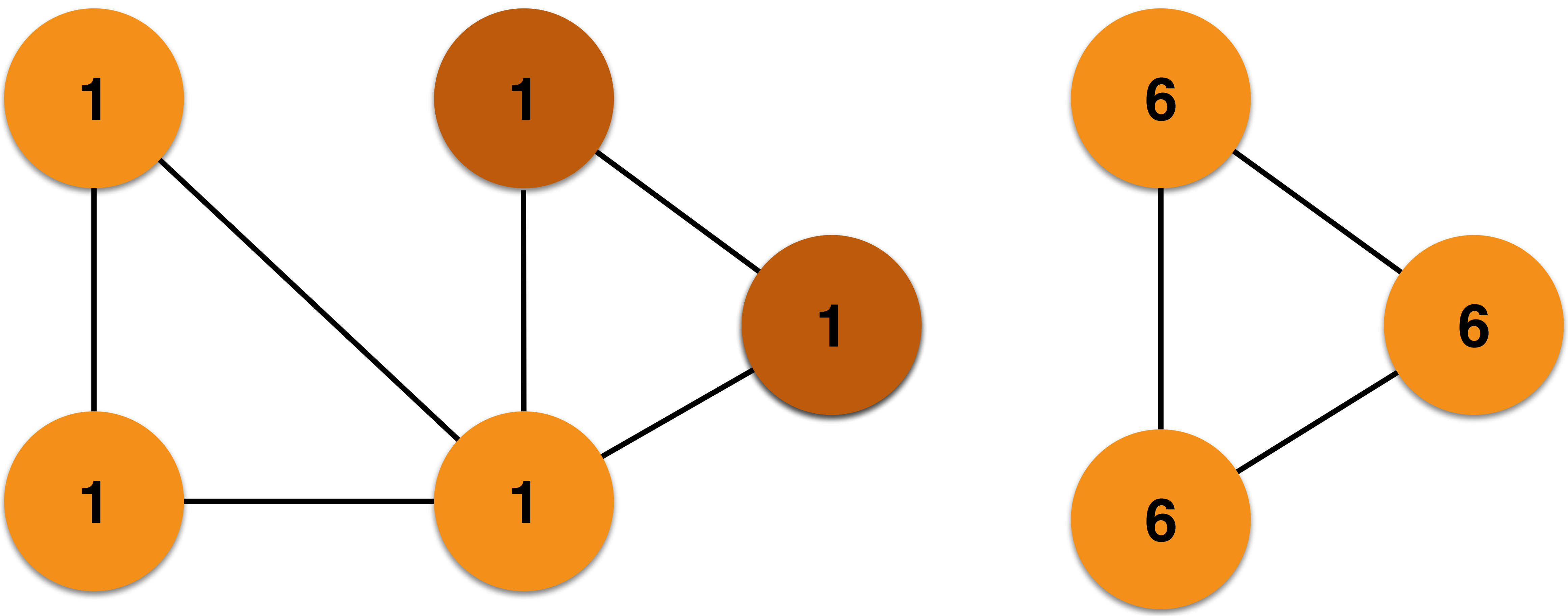
Batch Connected Components

i=1



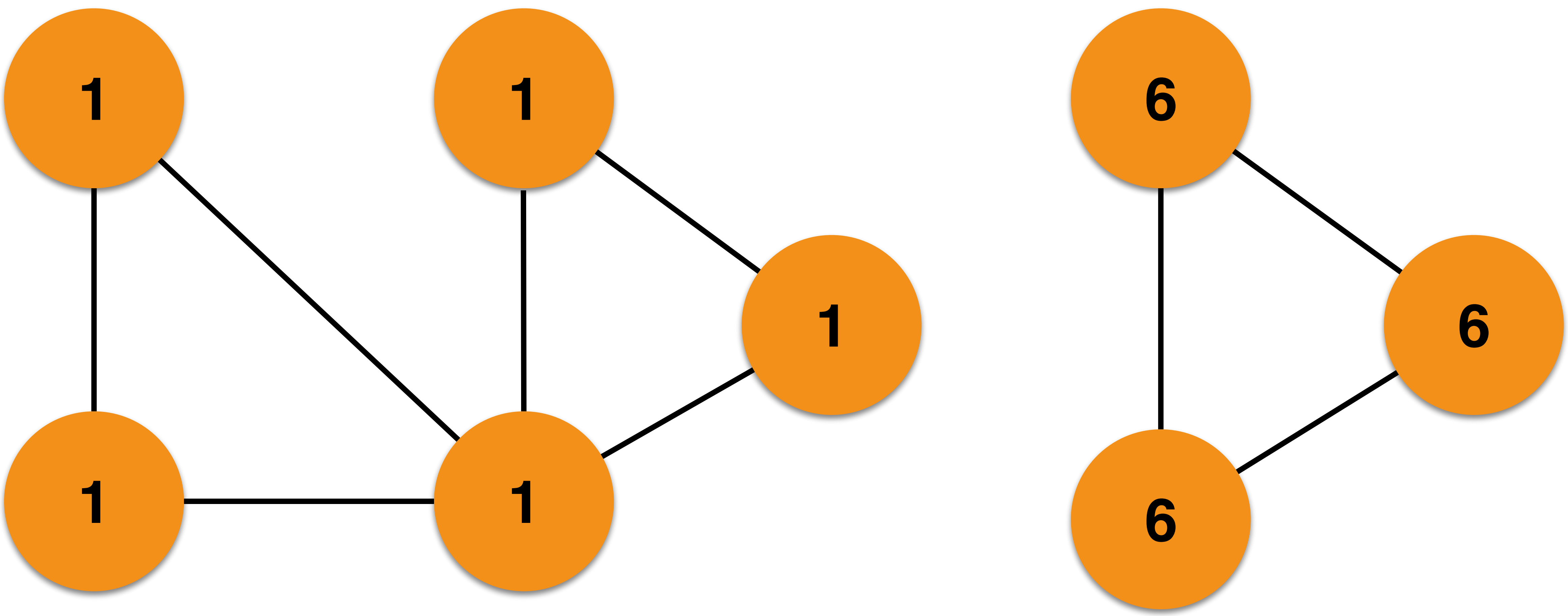
Batch Connected Components

i=2



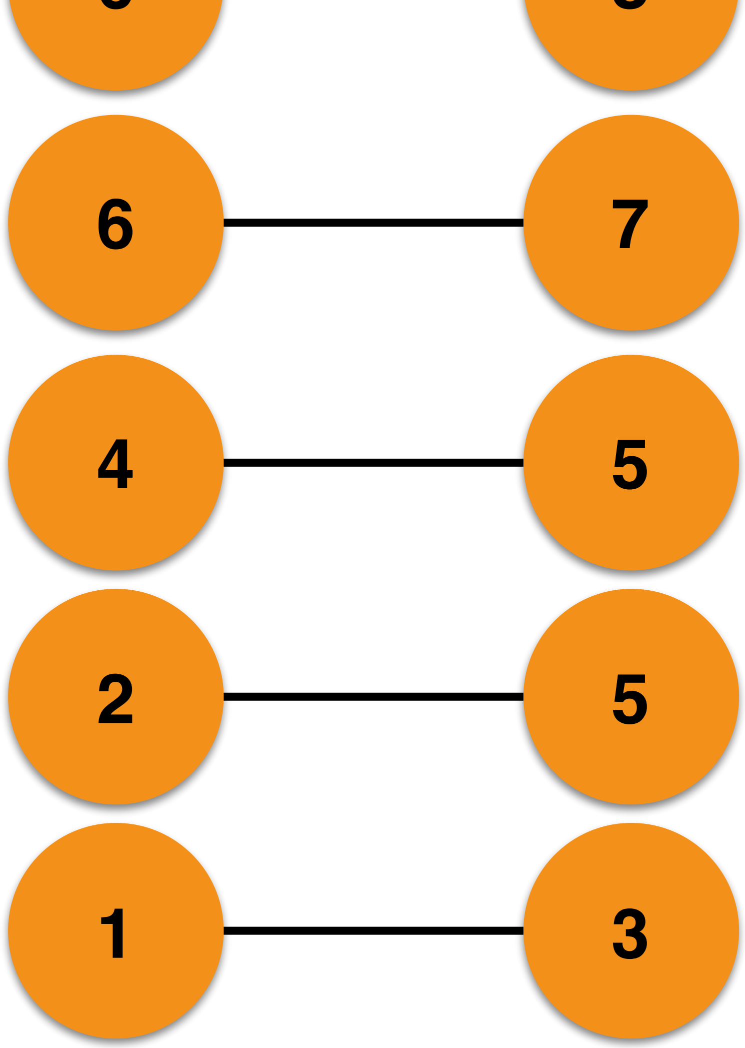
Batch Connected Components

i=3

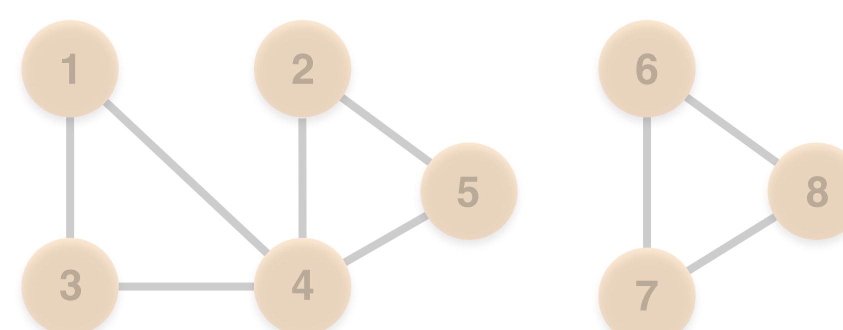


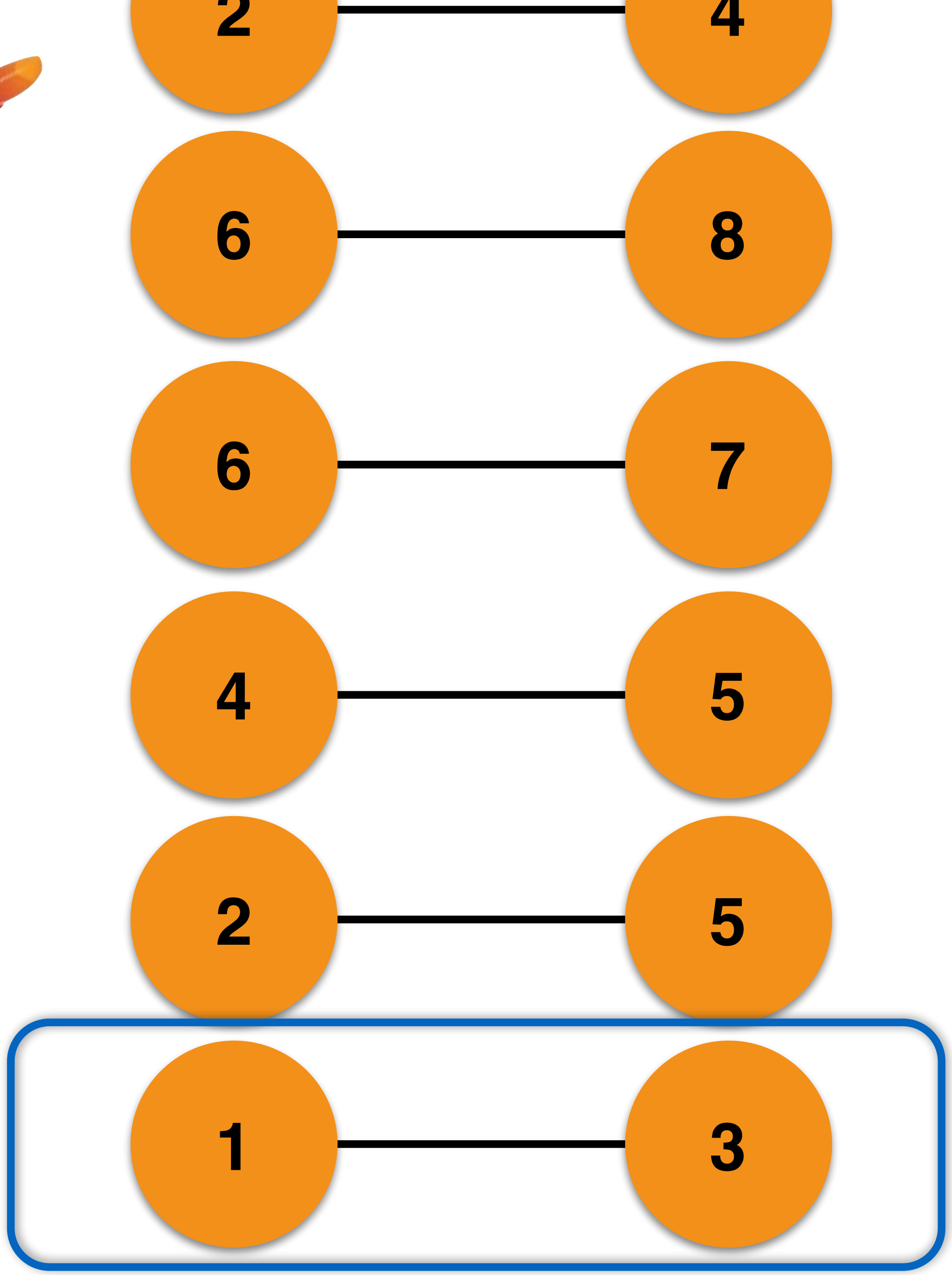
Stream Connected Components

- **State:** a *disjoint set* data structure for the components
- **Computation:** For each edge
    - if seen for the 1st time, create a component with ID the min of the vertex IDs
    - if in different components, *merge* them and update the component ID to the min of the component IDs
    - if only one of the endpoints belongs to a component, add the other one to the same component

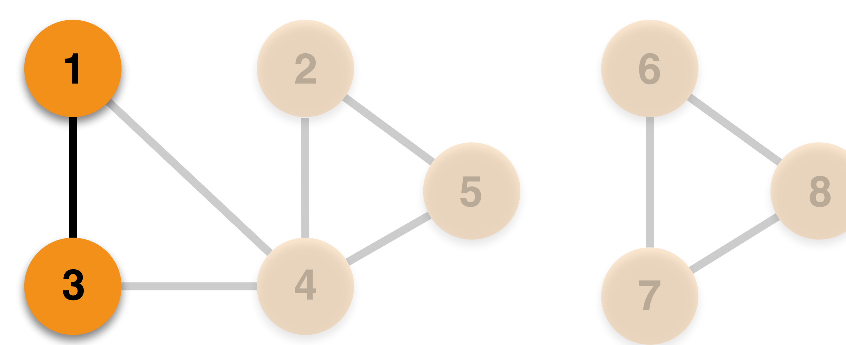


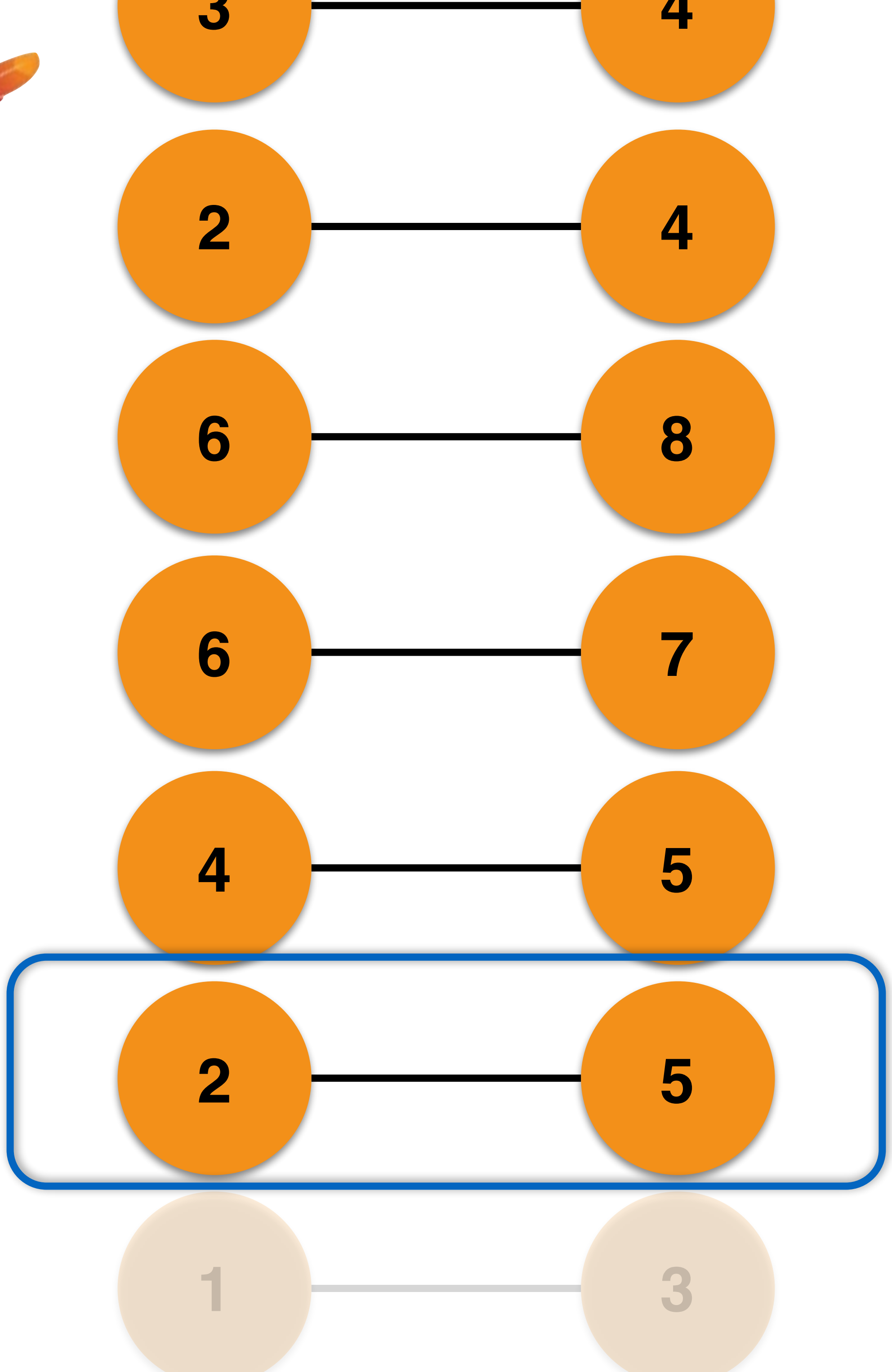
ComponentID	Vertices



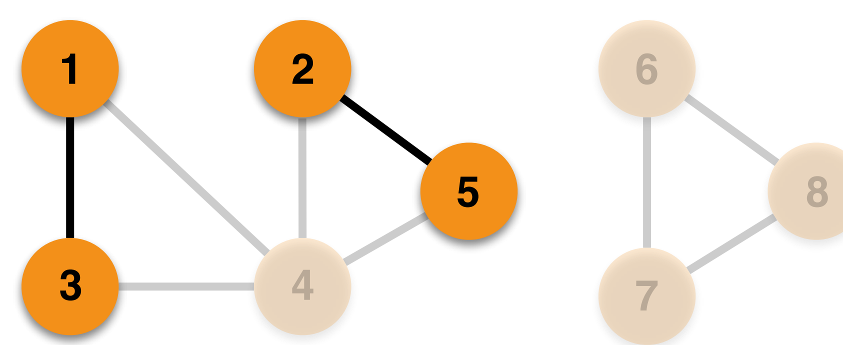


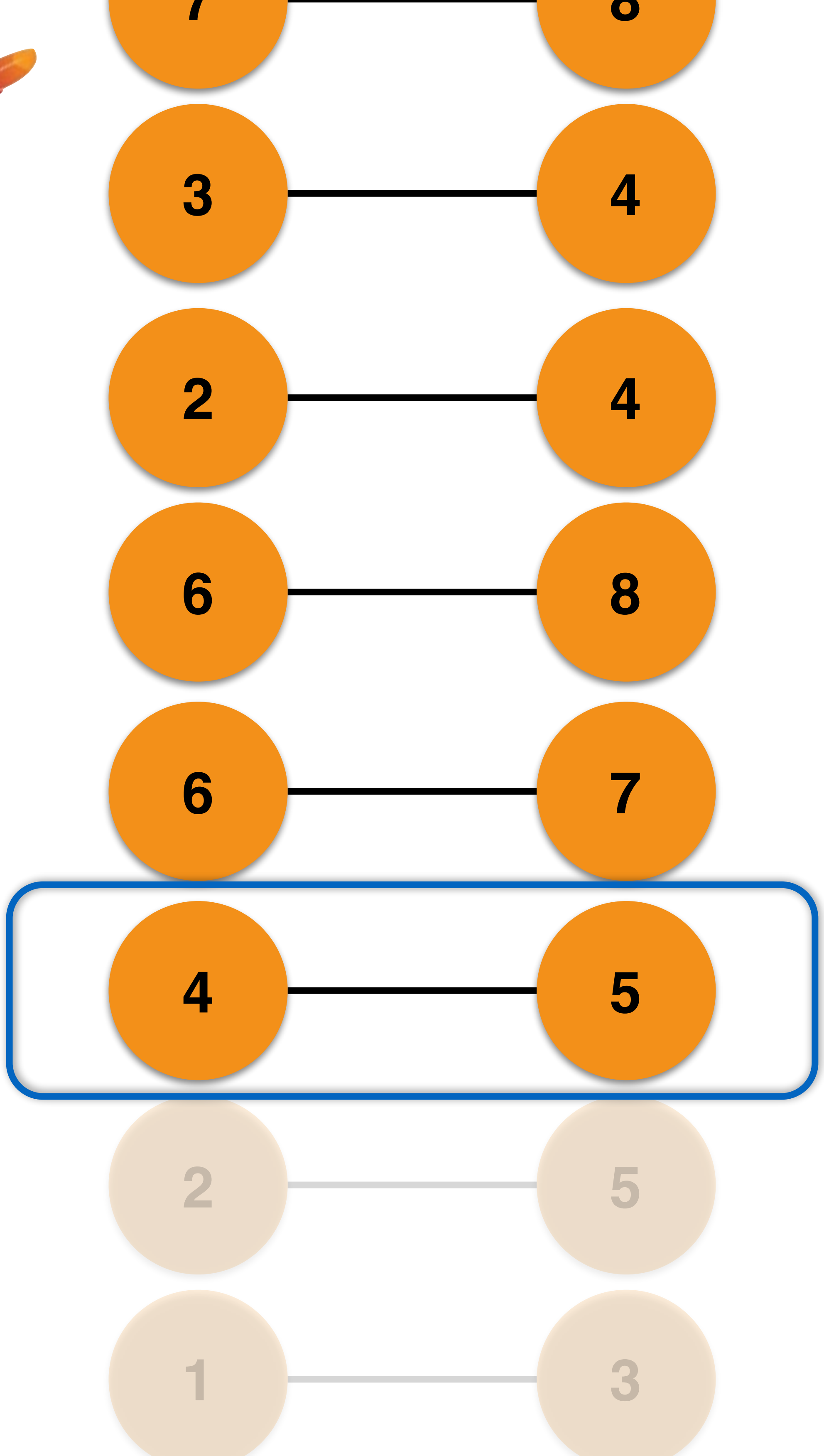
ComponentID	Vertices
1	1, 3



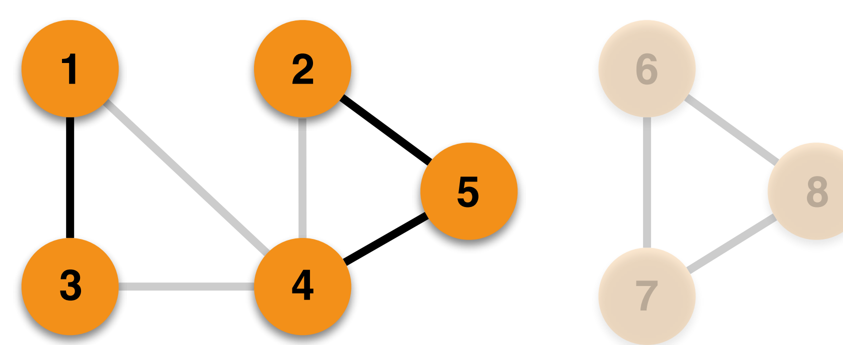


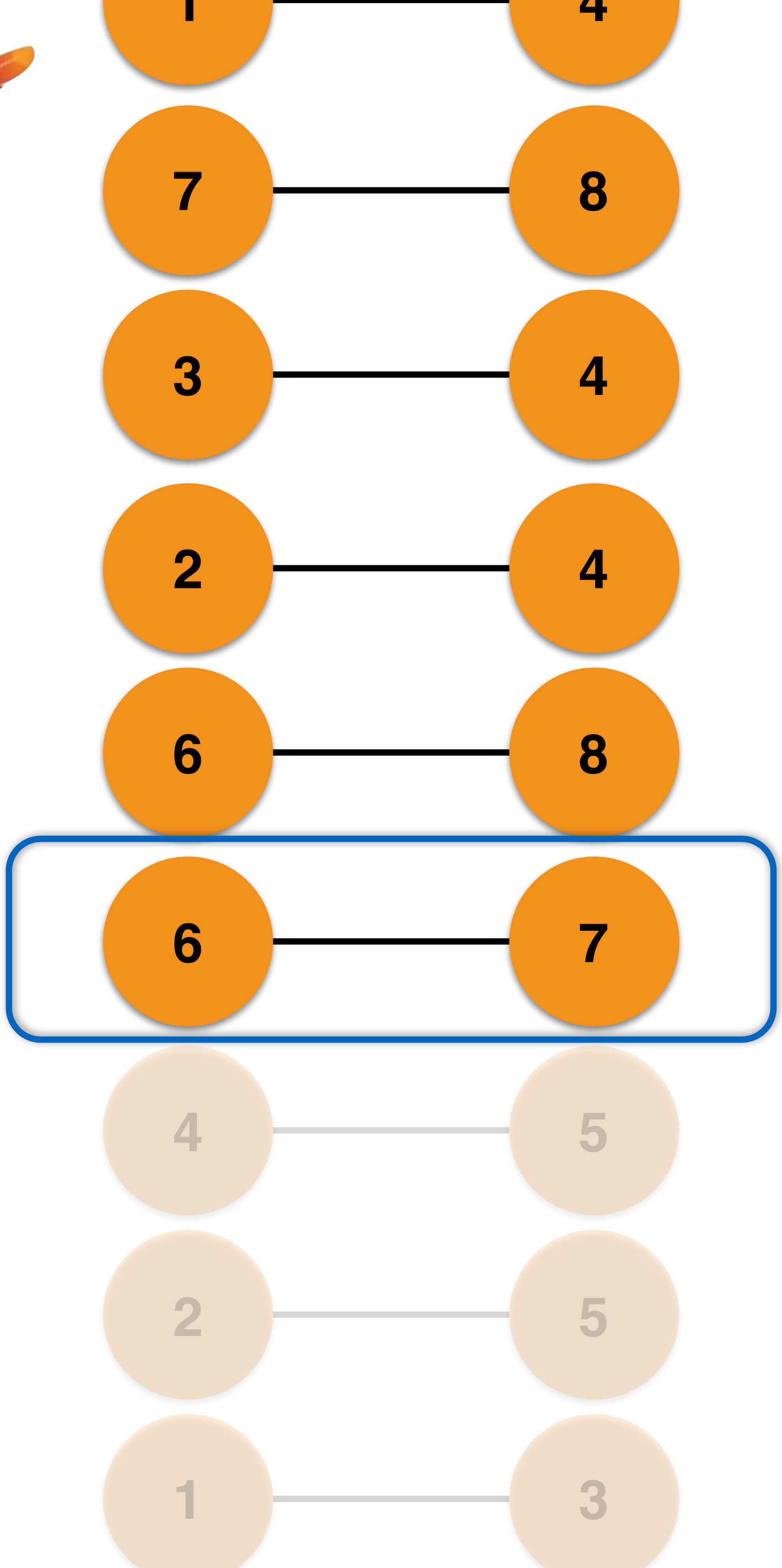
ComponentID	Vertices
1	1, 3
2	2, 5



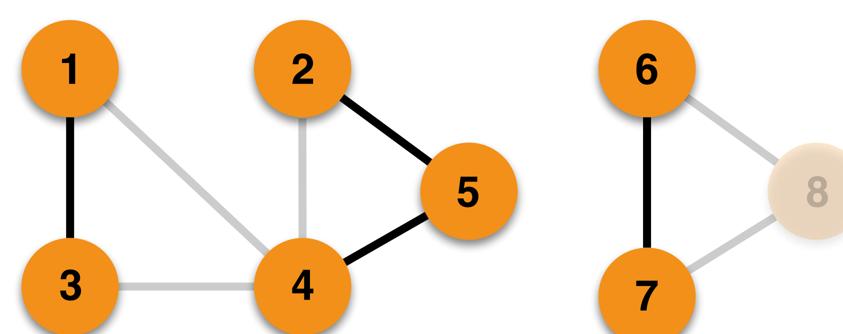


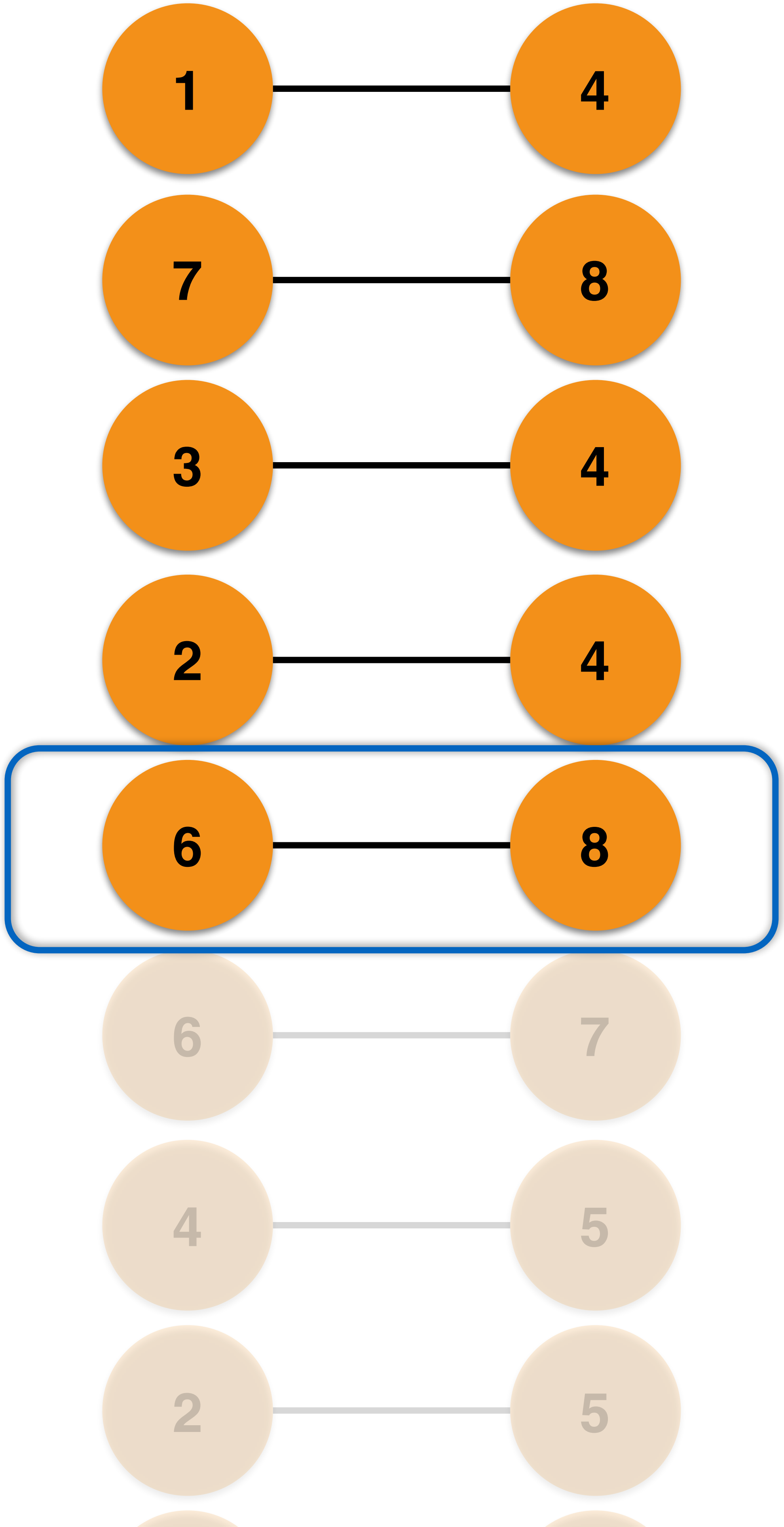
ComponentID	Vertices
1	1, 3
2	2, 4, 5



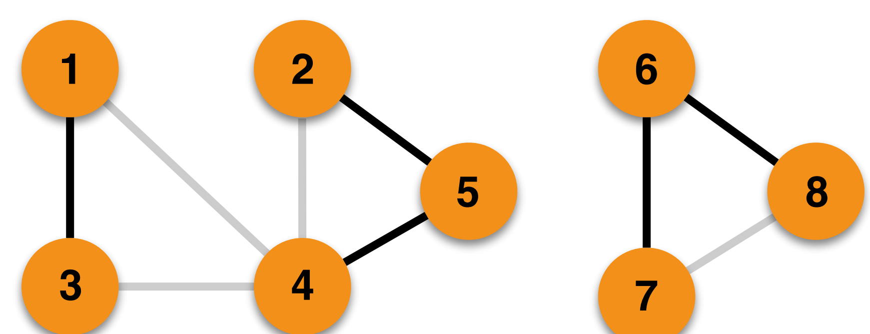


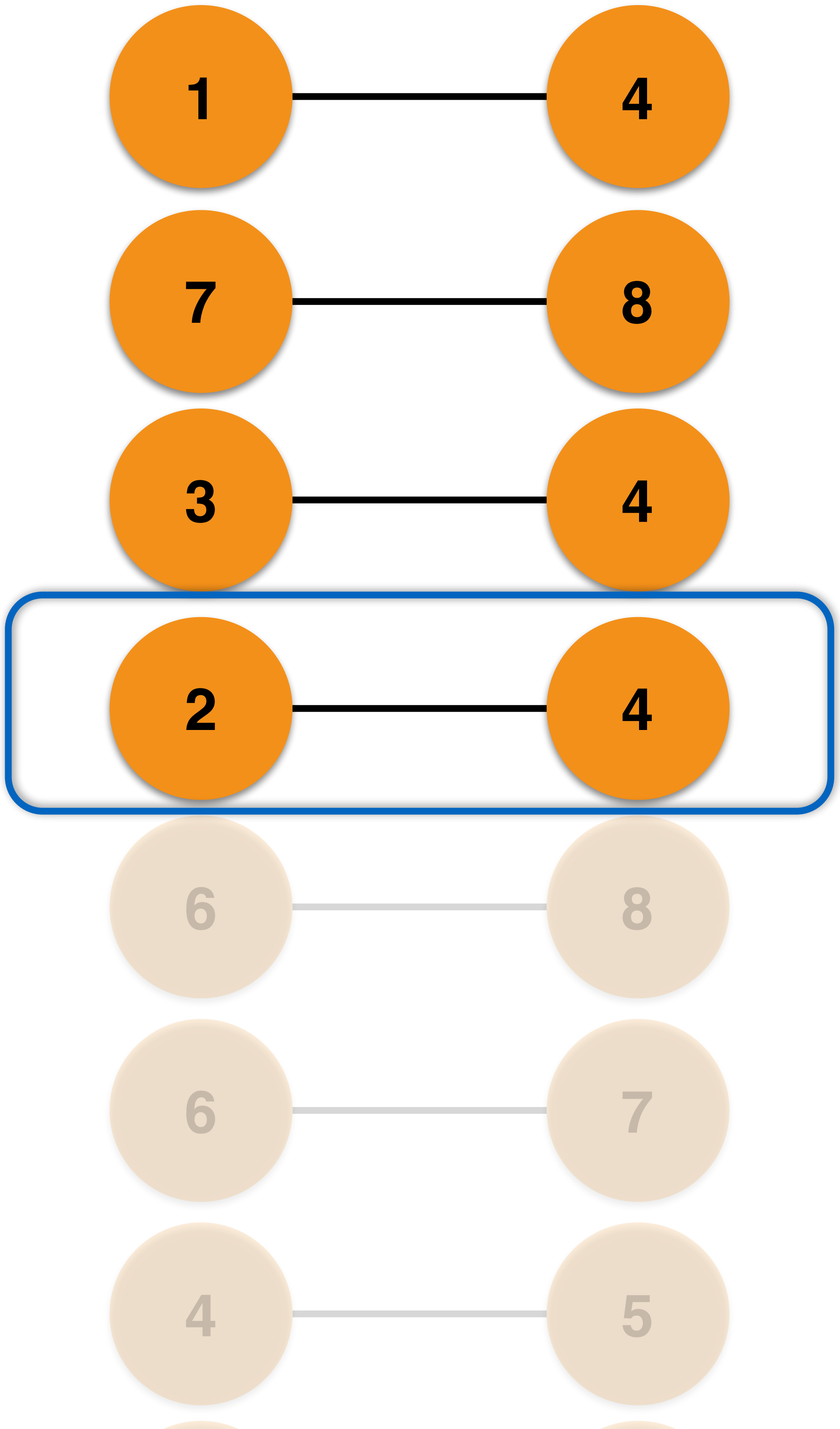
ComponentID	Vertices
1	1, 3
2	2, 4, 5
6	6, 7



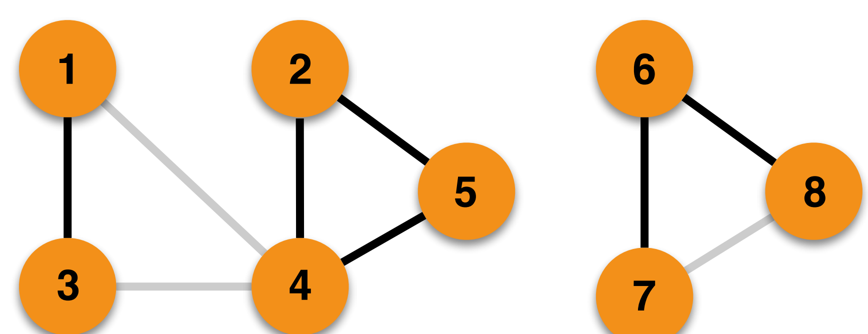


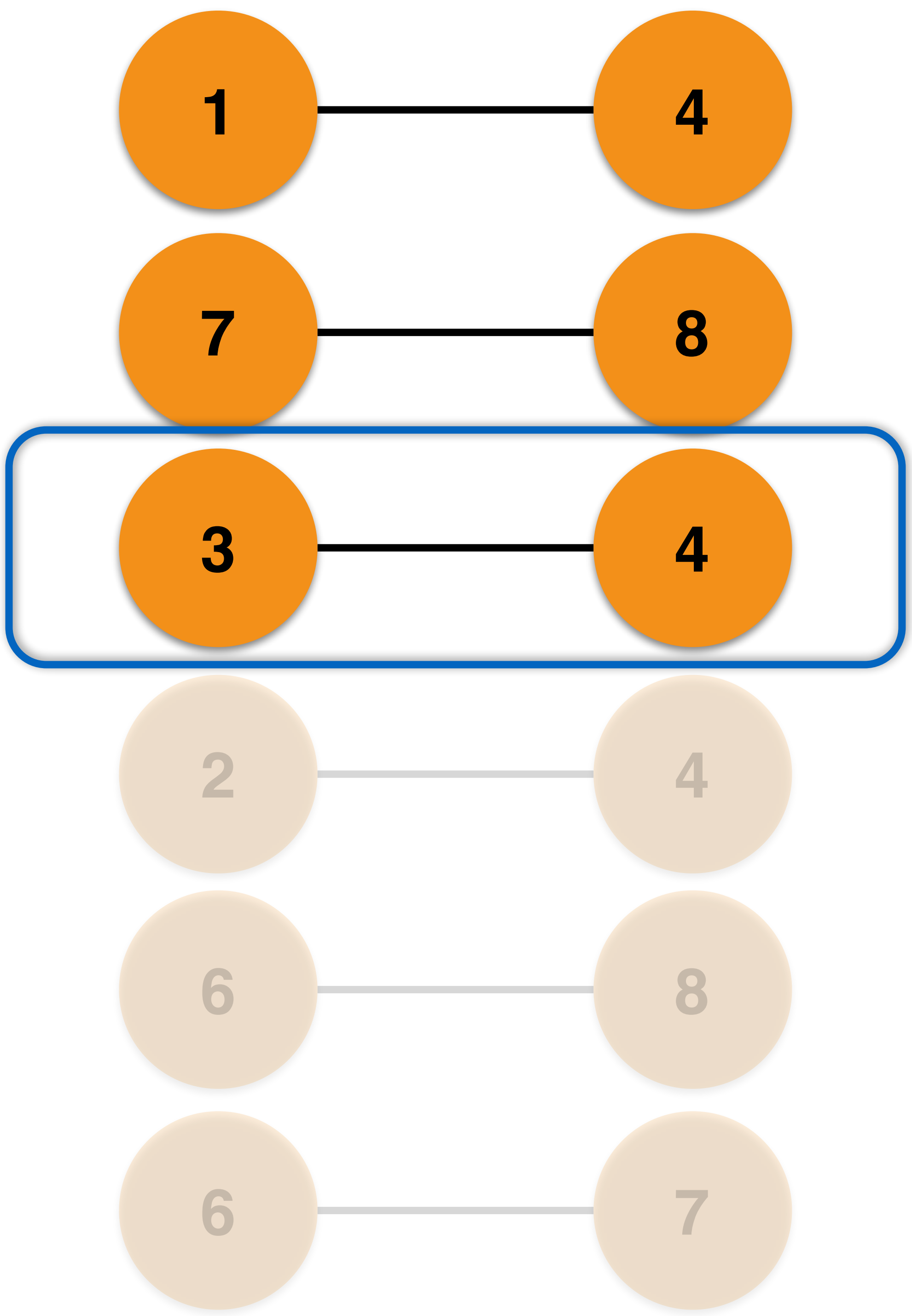
ComponentID	Vertices
1	1, 3
2	2, 4, 5
6	6, 7, 8



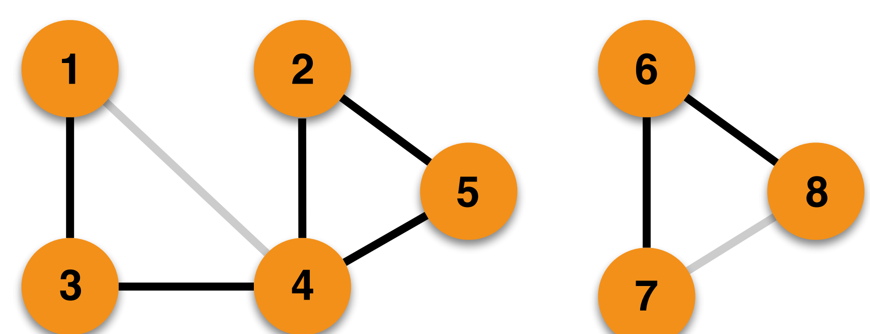


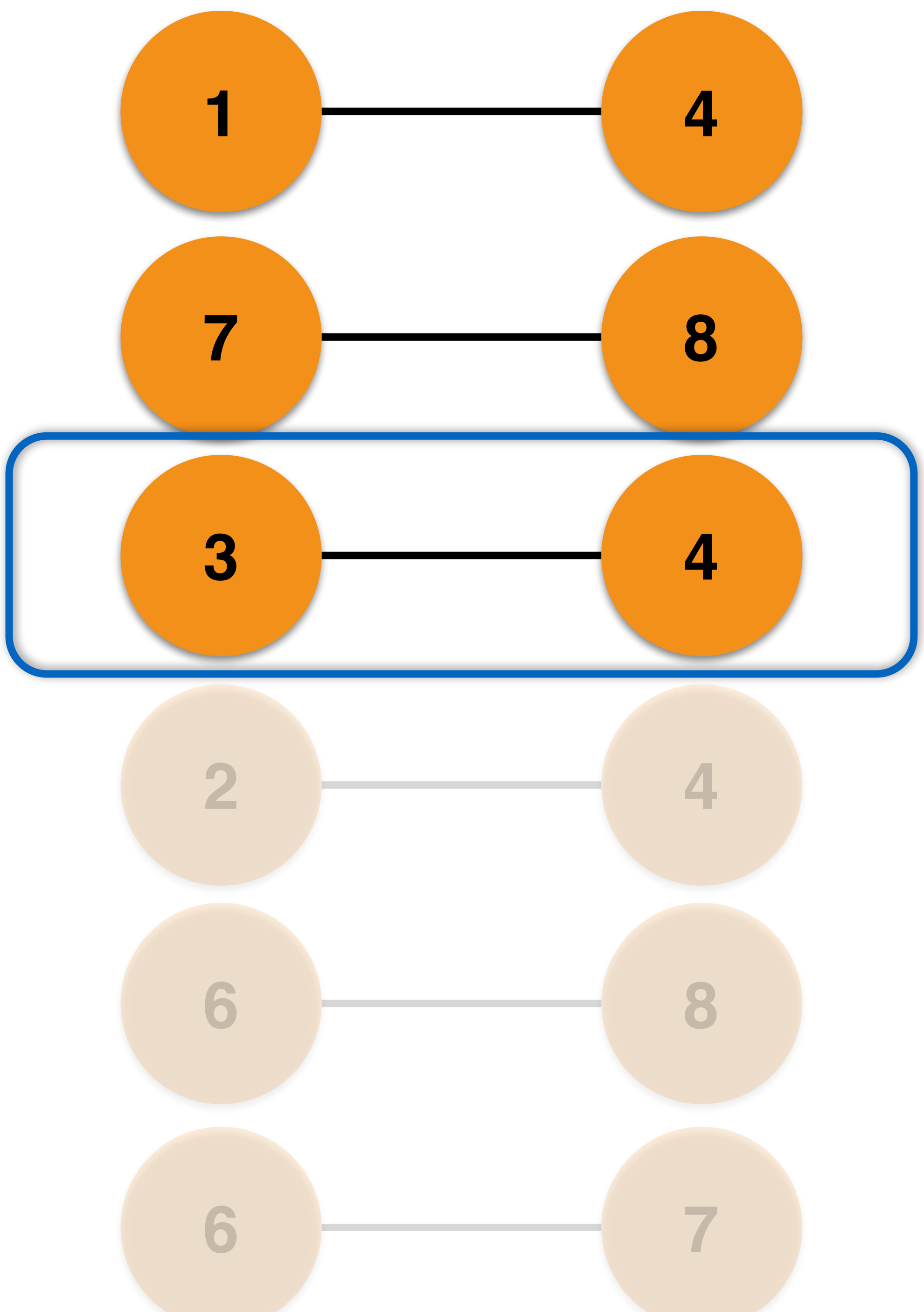
ComponentID	Vertices
1	1, 3
2	2, 4, 5
6	6, 7, 8



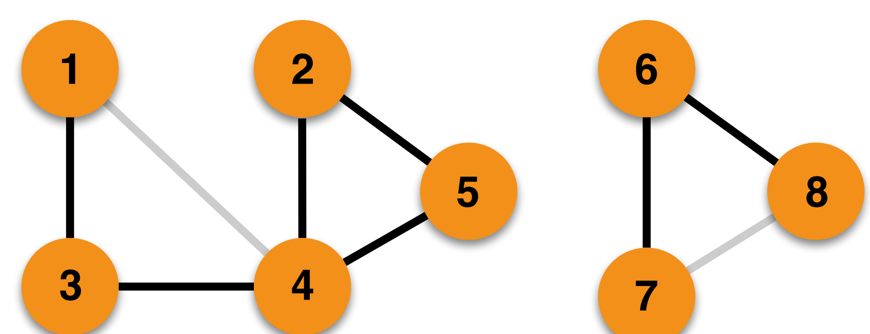


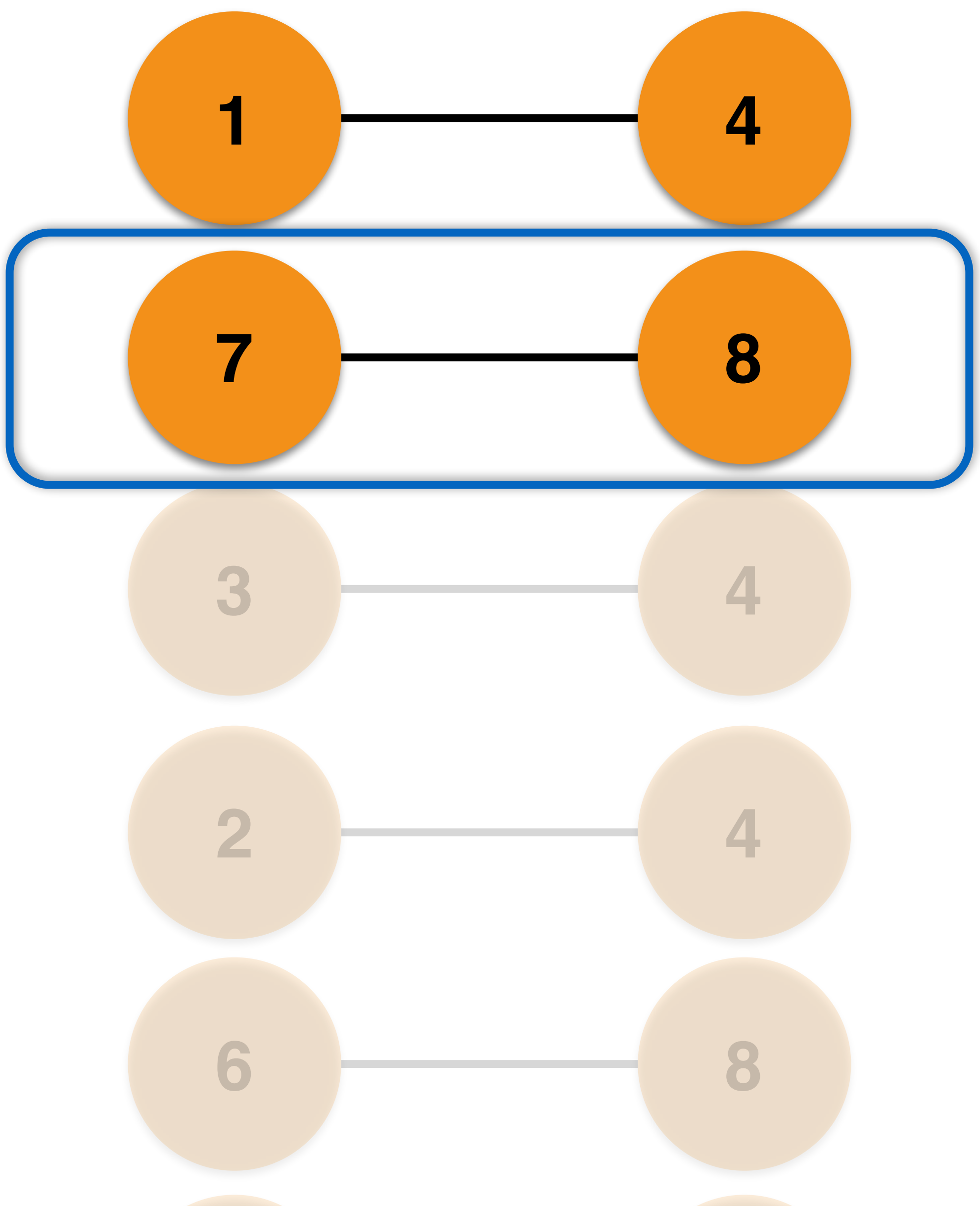
ComponentID	Vertices
1	1, **3**
2	2, **4**, 5
6	6, 7, 8





ComponentID	Vertices
1	1, 2, 3, 4, 5
6	6, 7, 8





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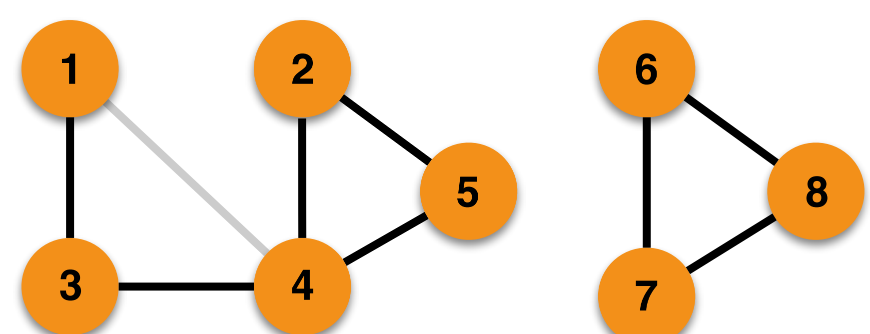

ComponentID	Vertices
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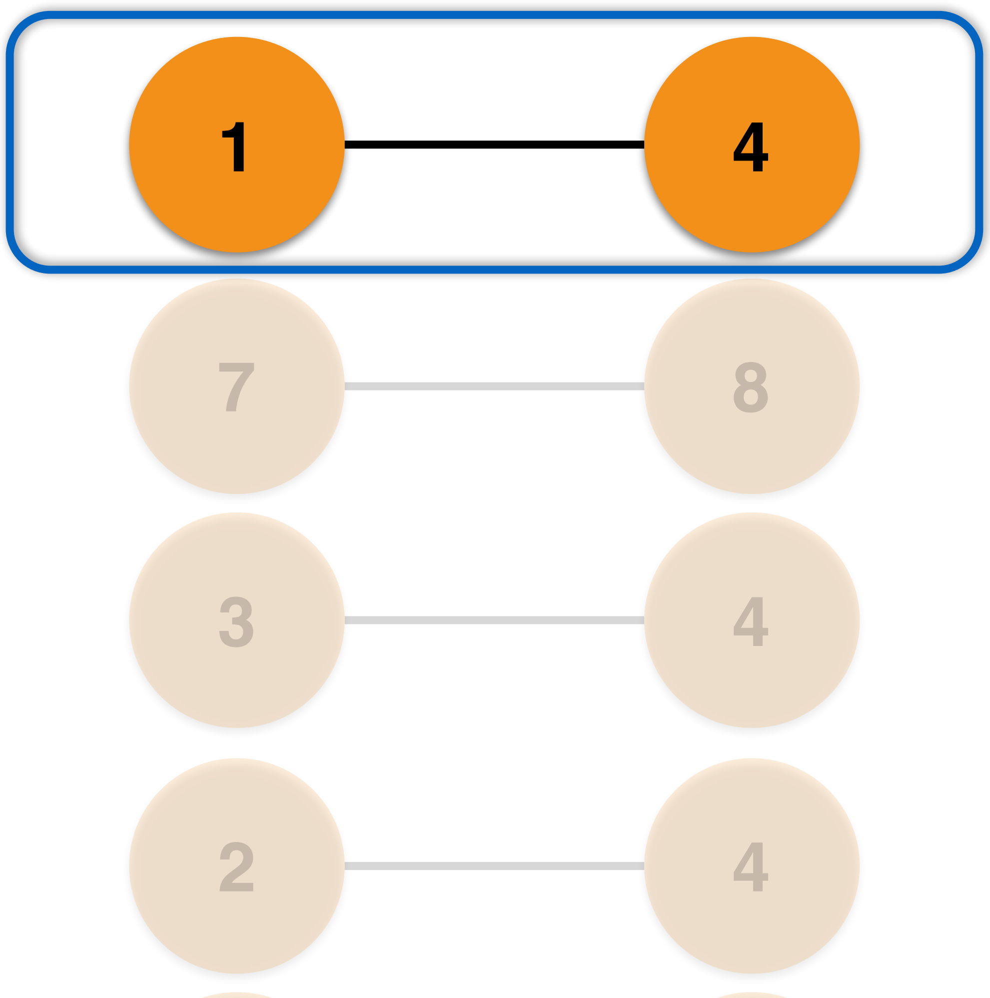
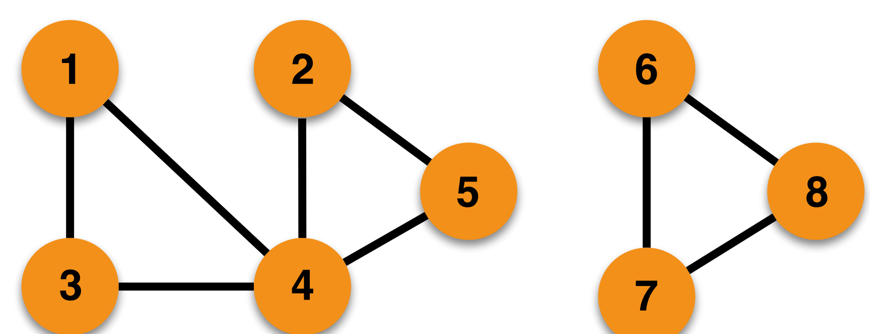
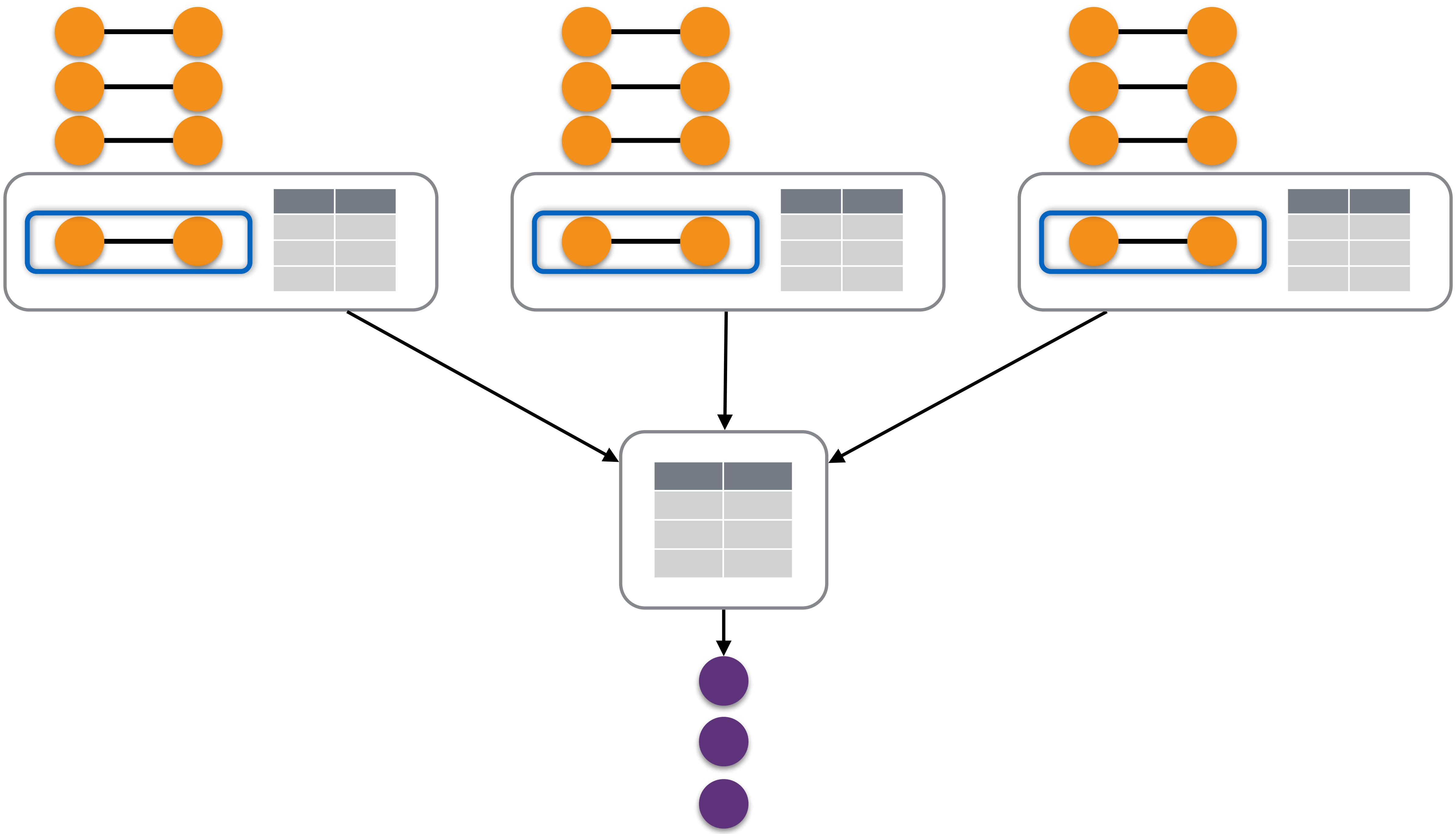




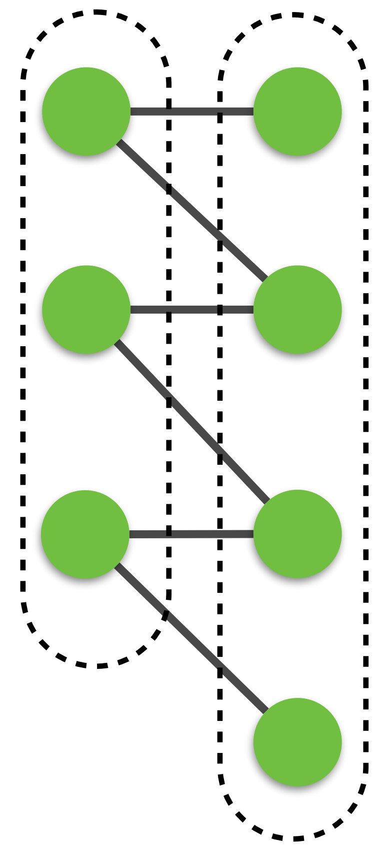
Distributed Stream Connected Components



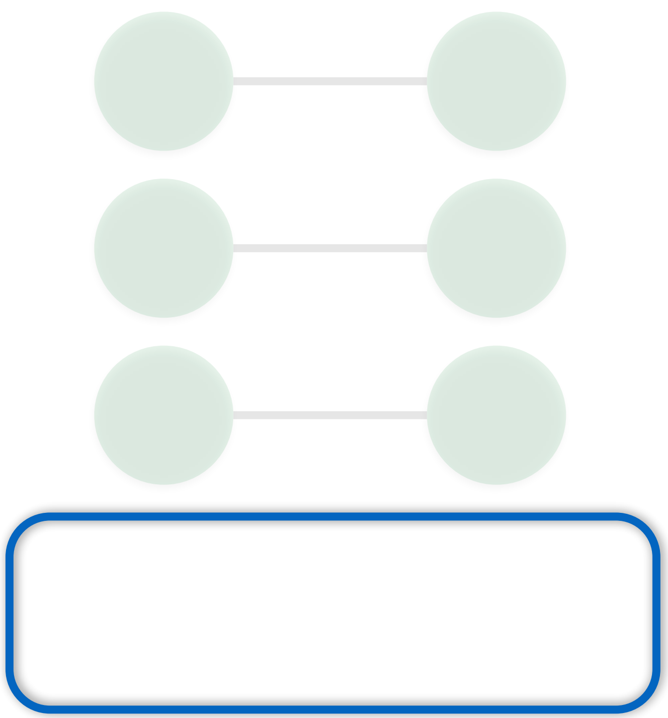
Stream Bipartite Detection

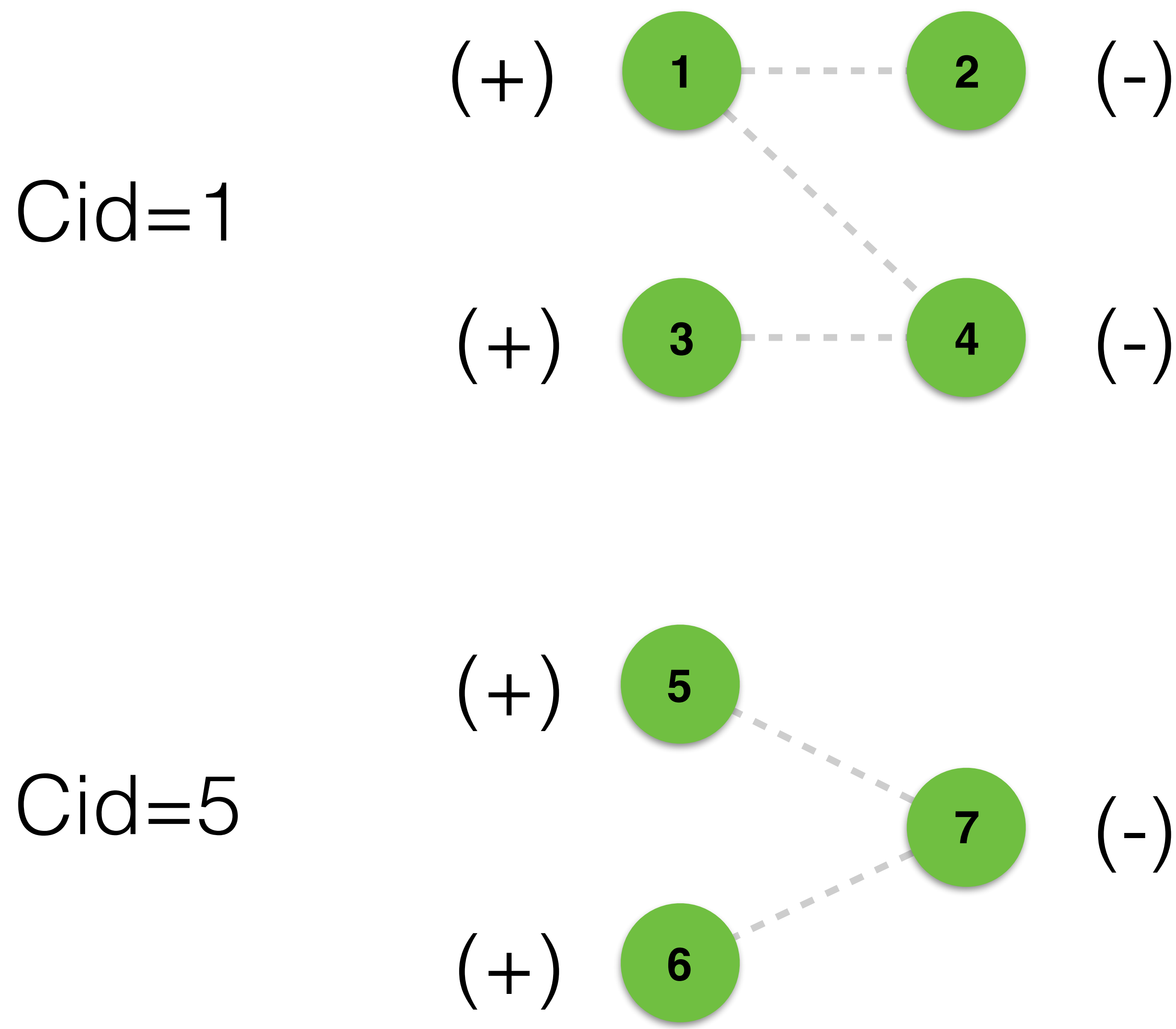
Similar to connected components, but

- Each vertex is also assigned a sign, (+) or (-)
- Edge endpoints must have different signs
- When merging components, if flipping all signs doesn't work => the graph is not bipartite

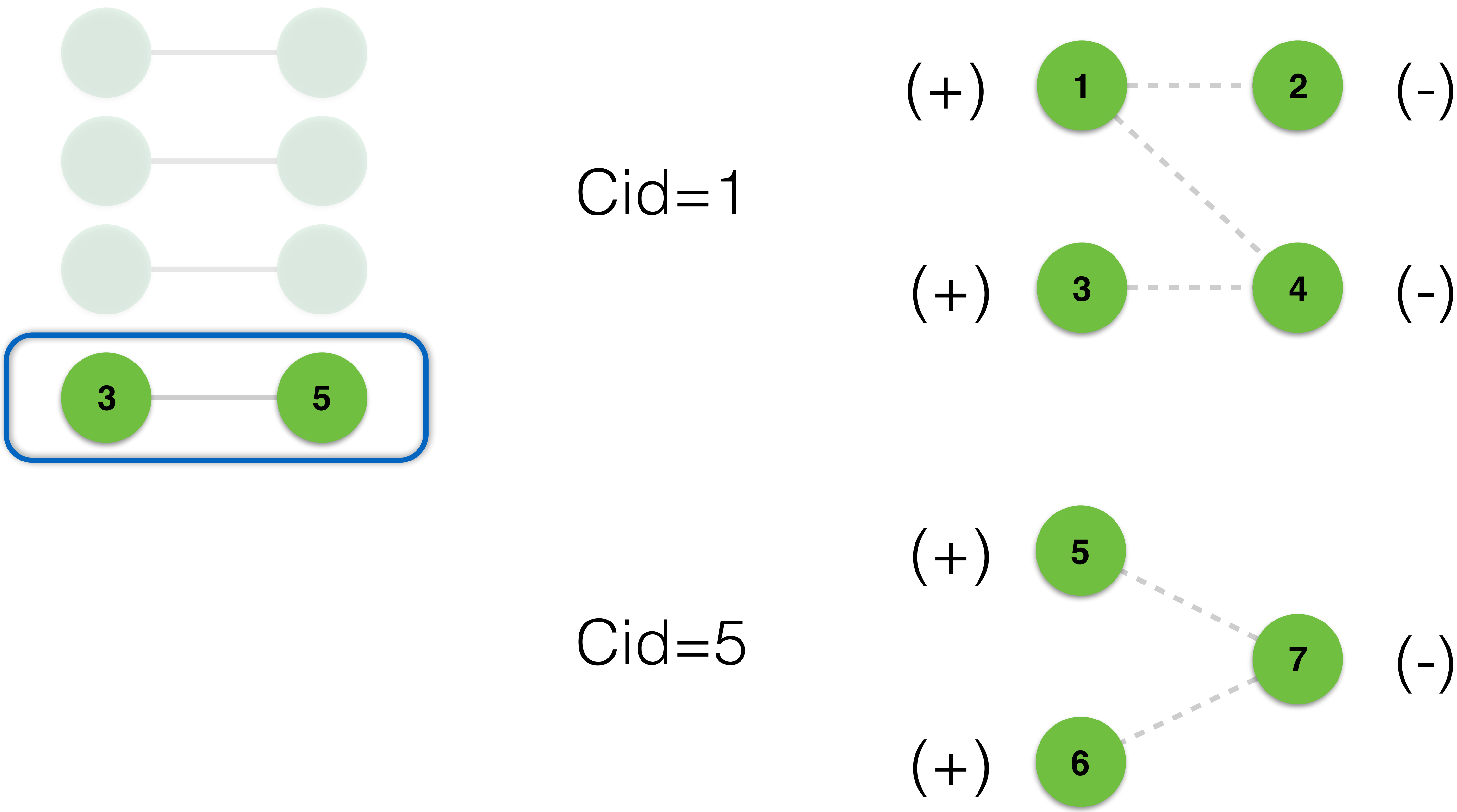


Stream Bipartite Detection

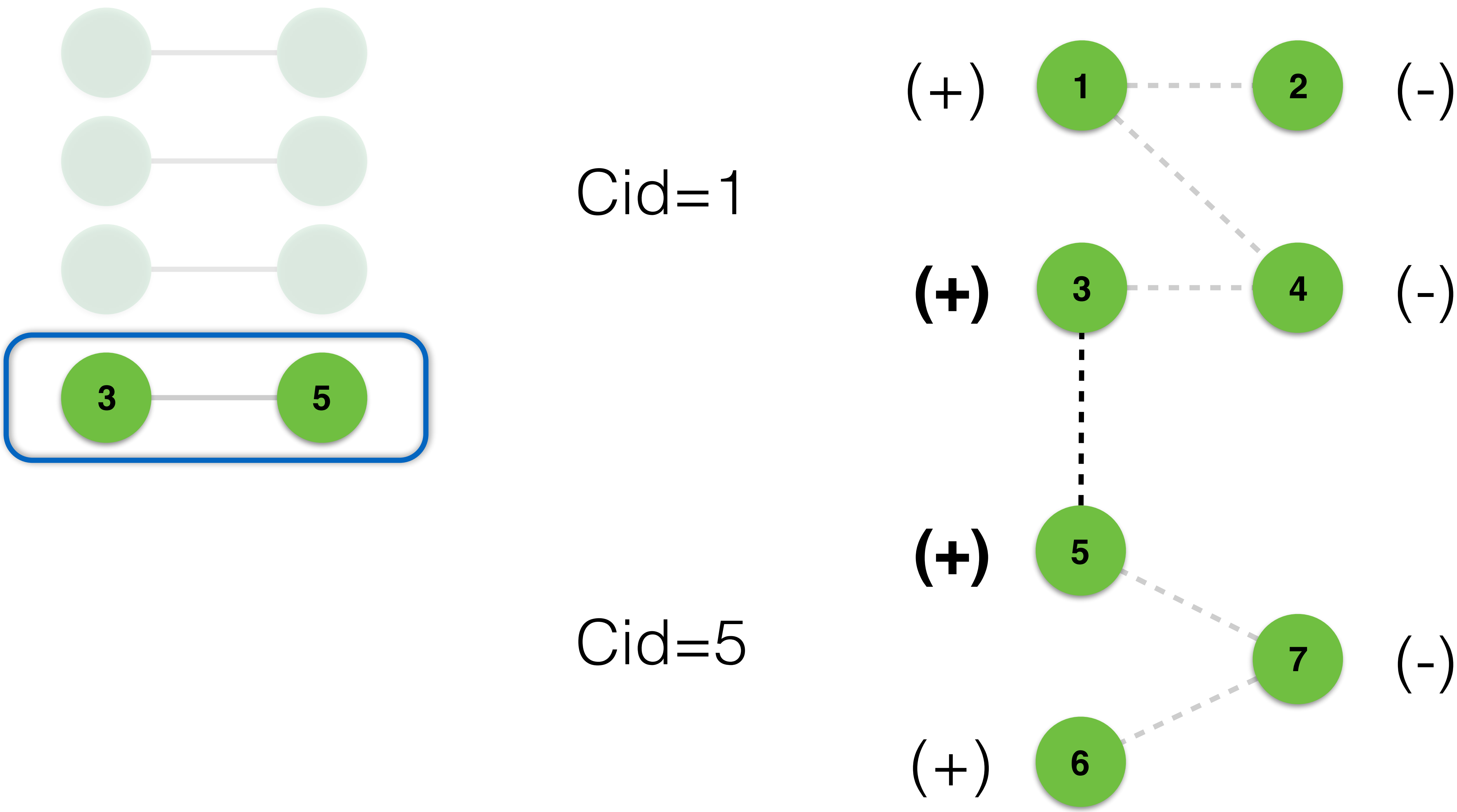




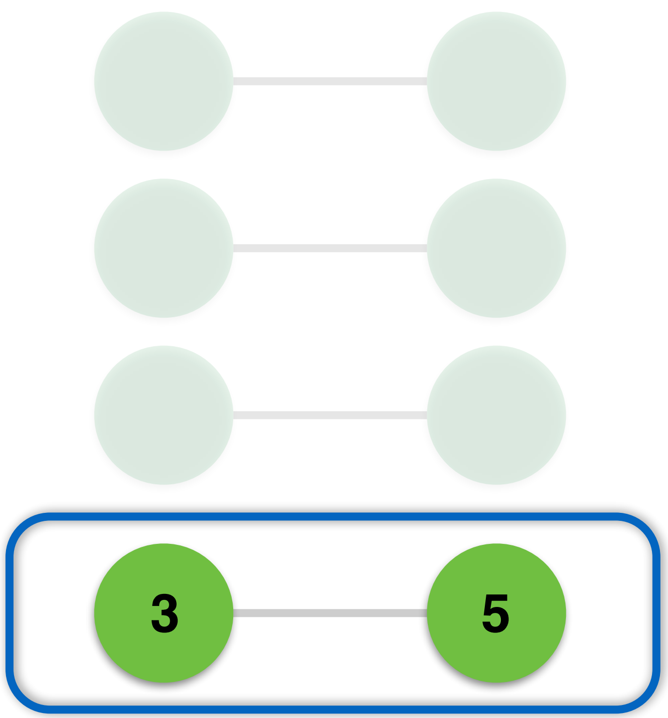
Stream Bipartite Detection



Stream Bipartite Detection



Stream Bipartite Detection



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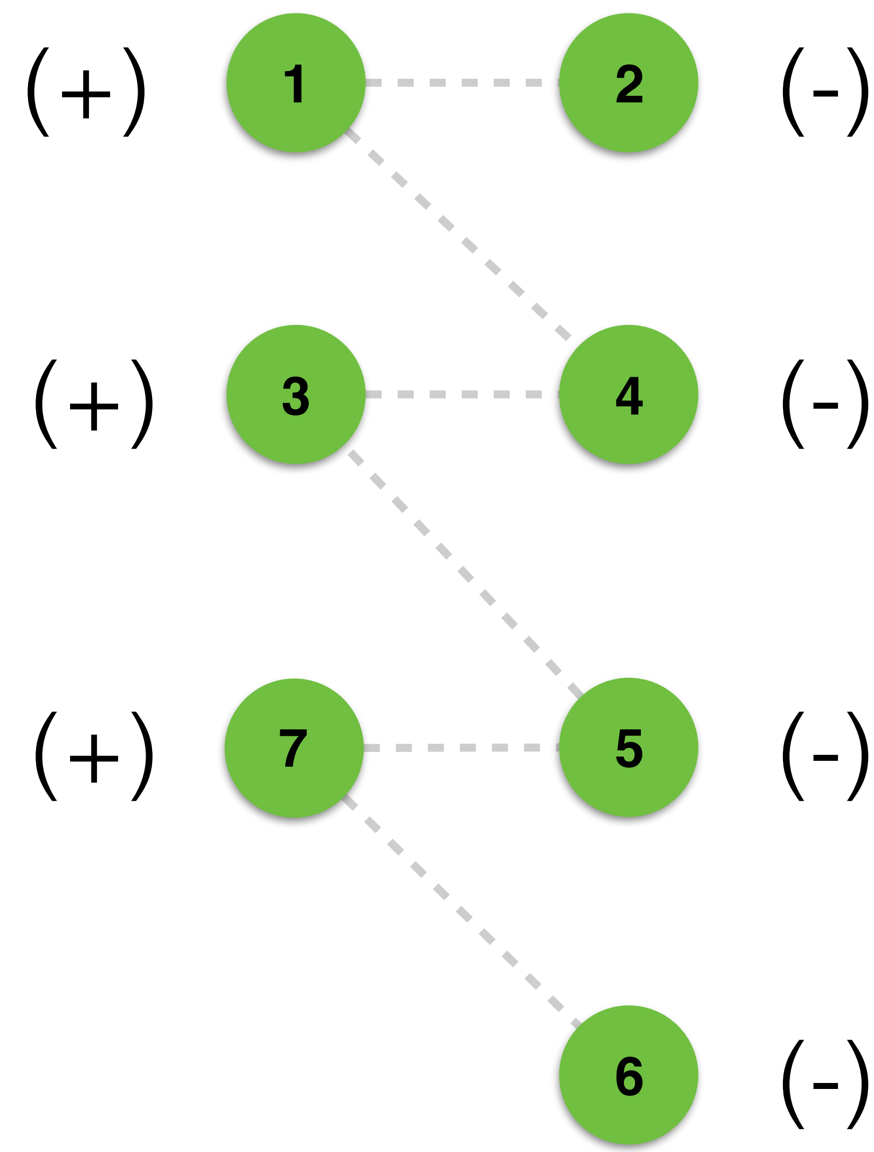
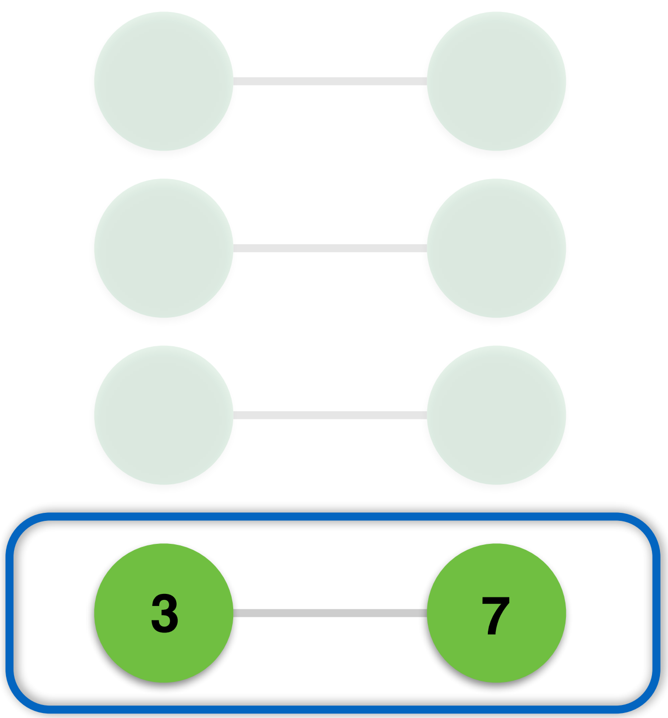


Stream Bipartite Detection



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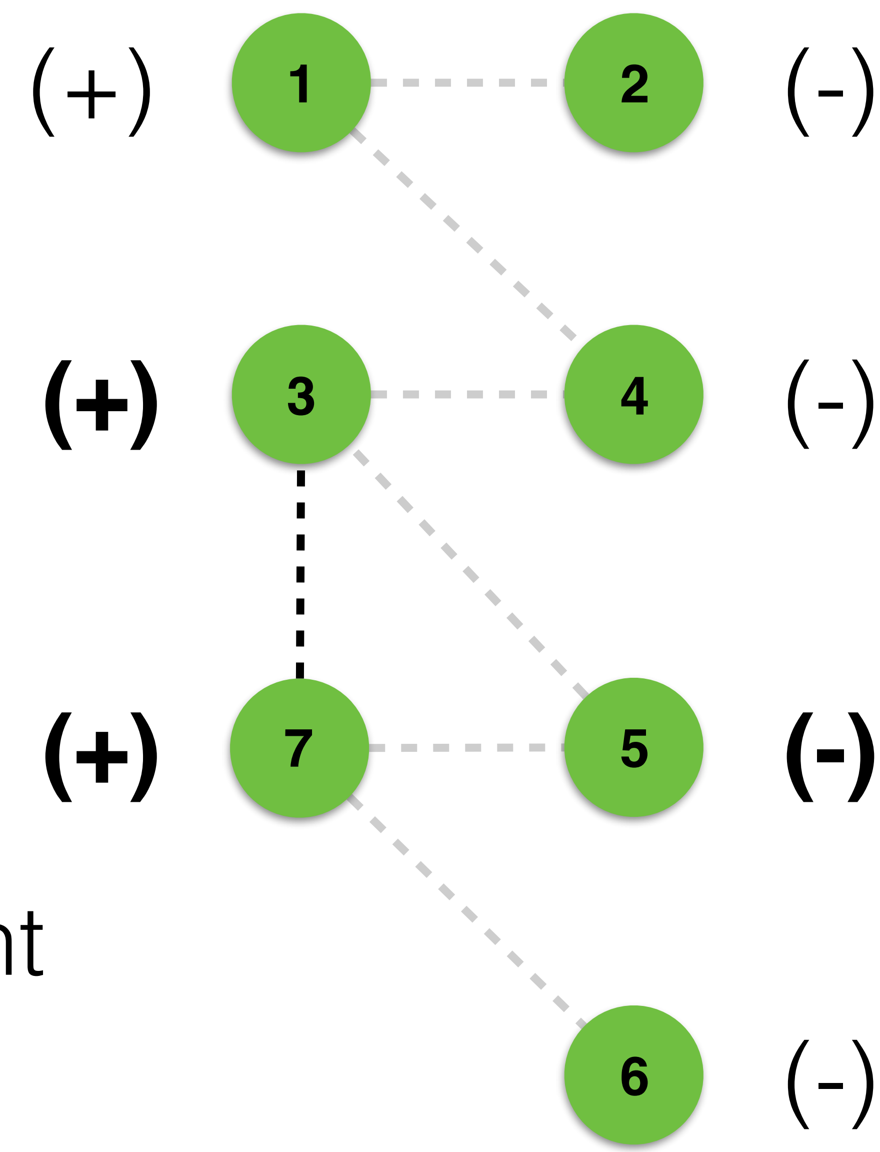


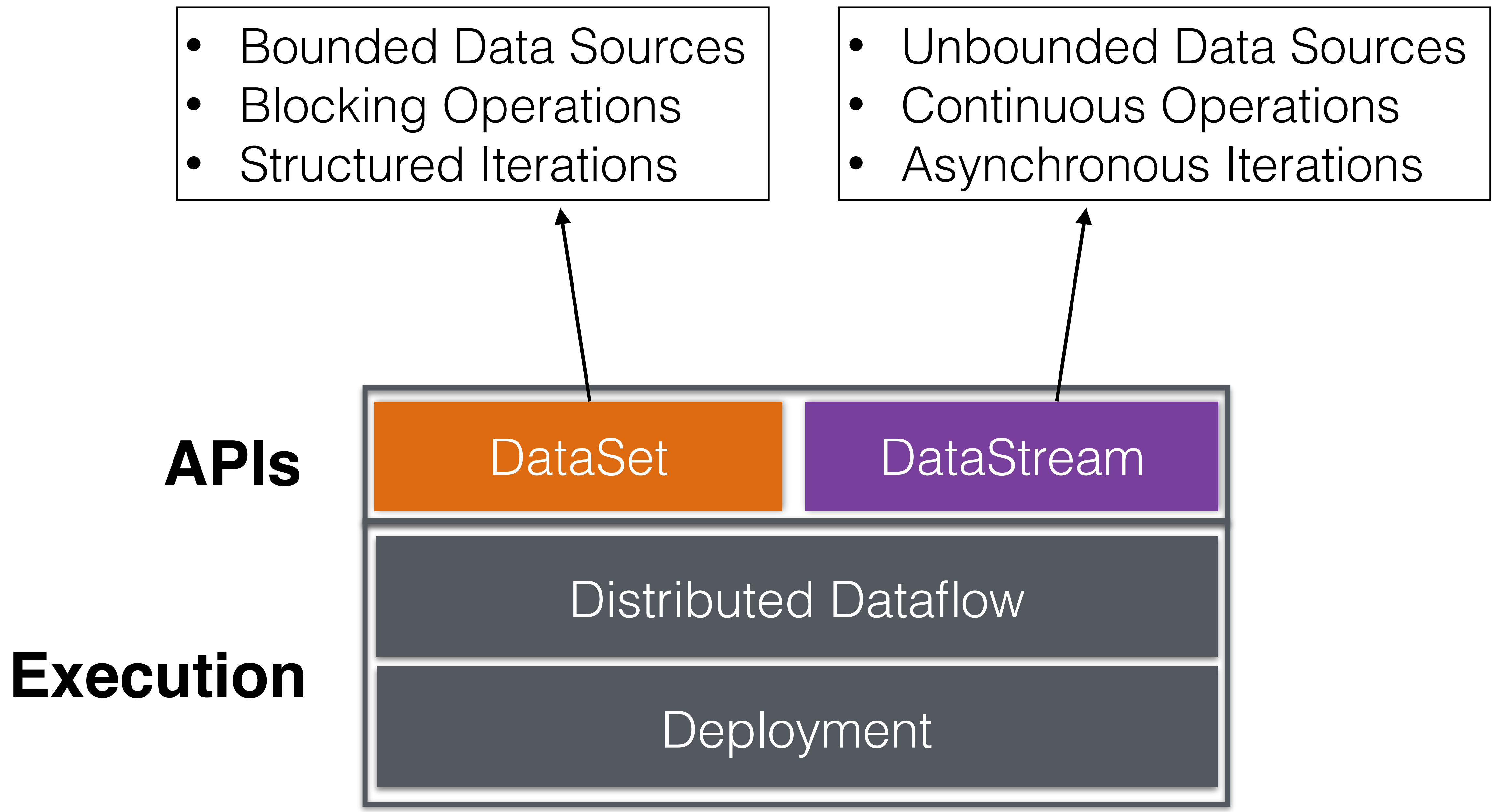
Can't flip signs and stay consistent
=> not bipartite!

API Requirements

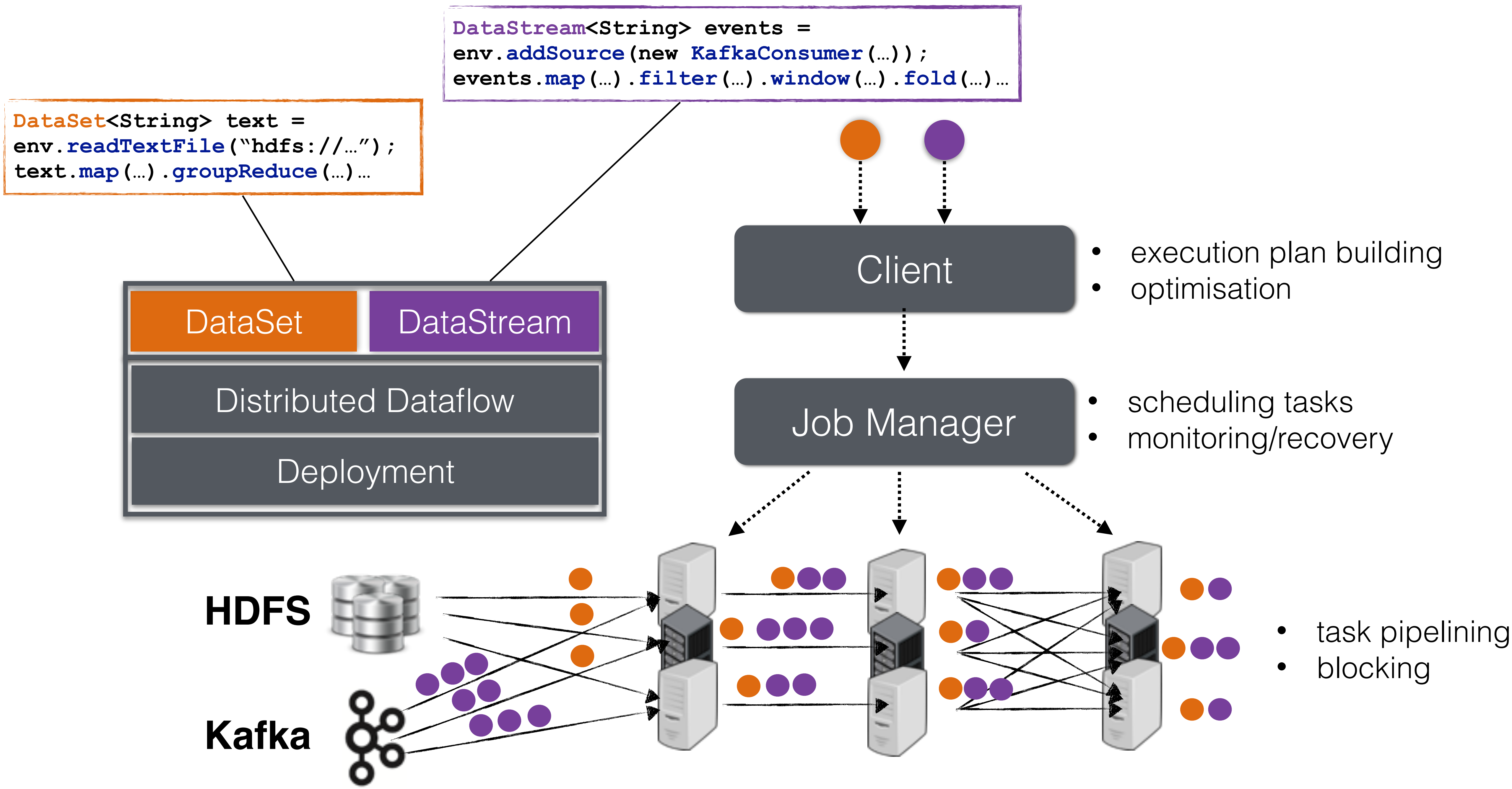
- Continuous aggregations on edge streams
- Global graph aggregations
- Support for windowing

@GraphDevroom

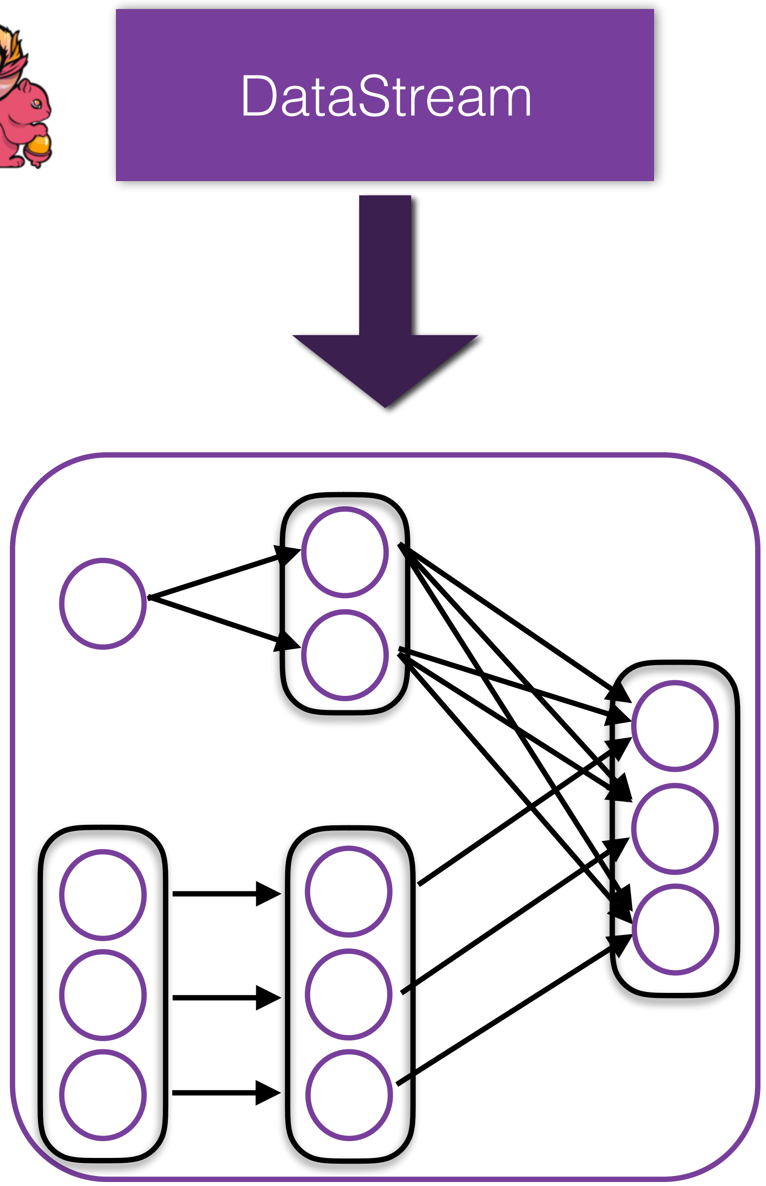
The Apache Flink Stack



Unifying Data Processing



Data Streams as ADTs

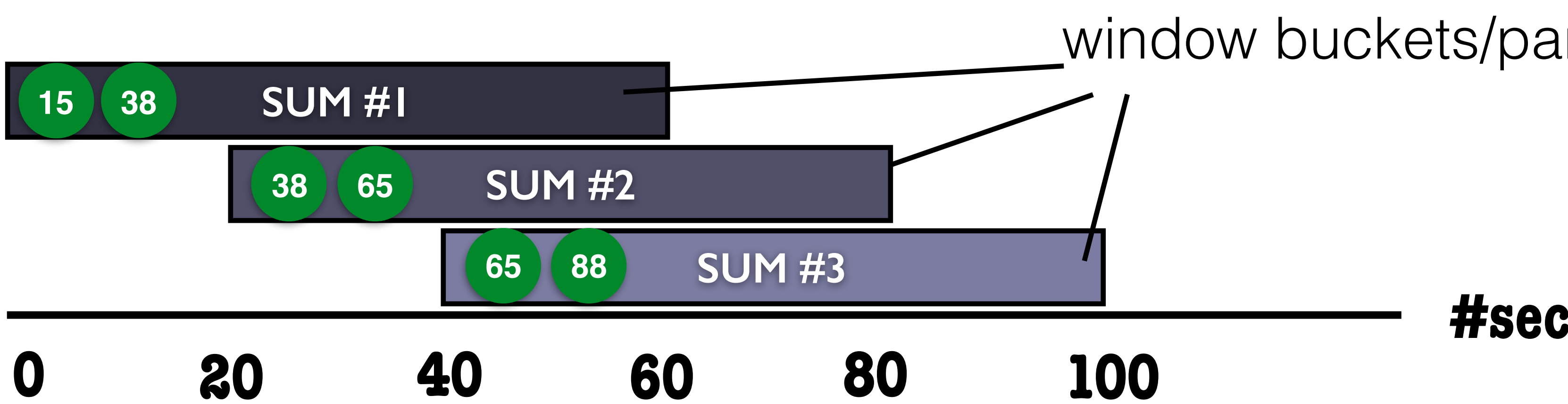


- **Transformations:** map, flatmap, filter, union…
- **Aggregations:** reduce, fold, sum
- **Partitioning:** forward, broadcast, shuffle, keyBy
- **Sources/Sinks:** custom or Kafka, Twitter, Collections…

- **Tasks** are long running in a pipelined execution.
- **State** is kept within tasks.
- **Transformations** are applied per-record or window.

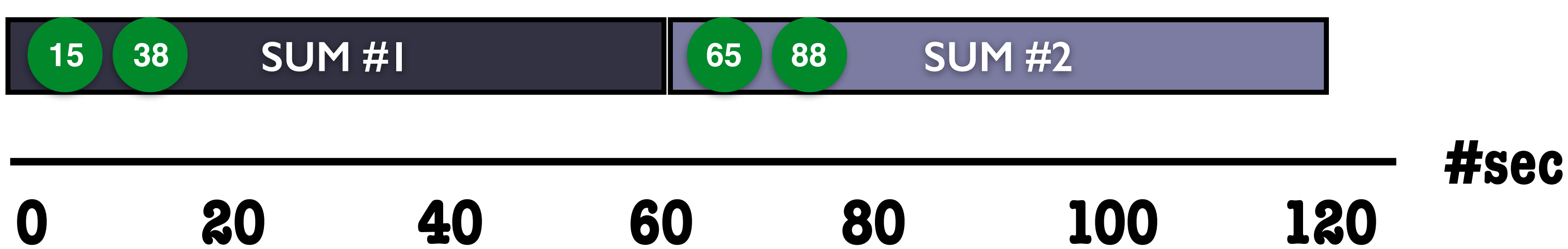
Working with Windows

Why windows?
We are often interested in *fresh* data!



1) Sliding windows

```
myKeyStream.timeWindow(
    Time.of(60, TimeUnit.SECONDS),
    Time.of(20, TimeUnit.SECONDS));
```



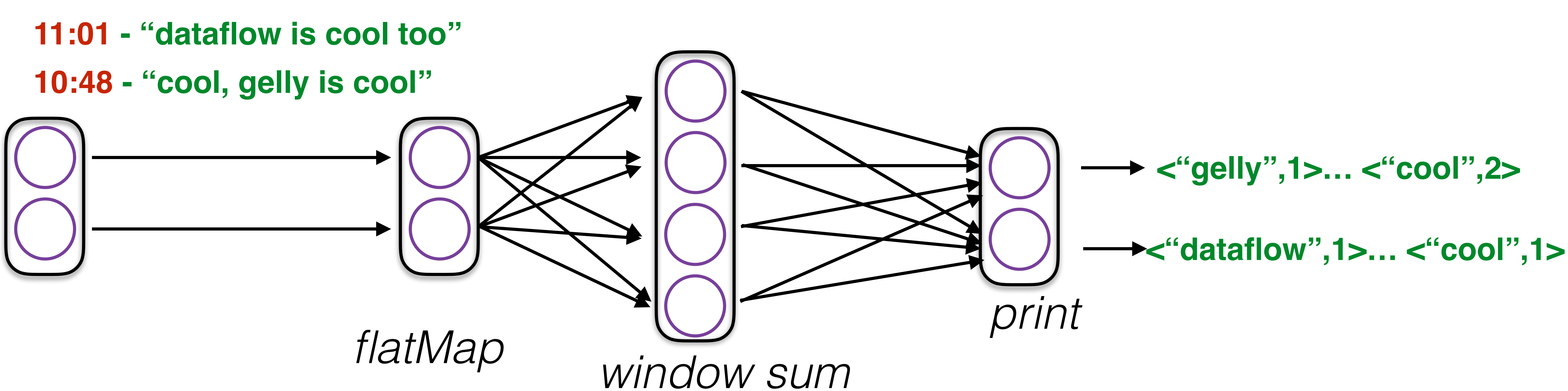
2) Tumbling windows

```
myKeyStream.timeWindow(
    Time.of(60, TimeUnit.SECONDS));
```

Highlight: Flink can form and trigger windows consistently under different notions of **time** and deal with late events!

Example

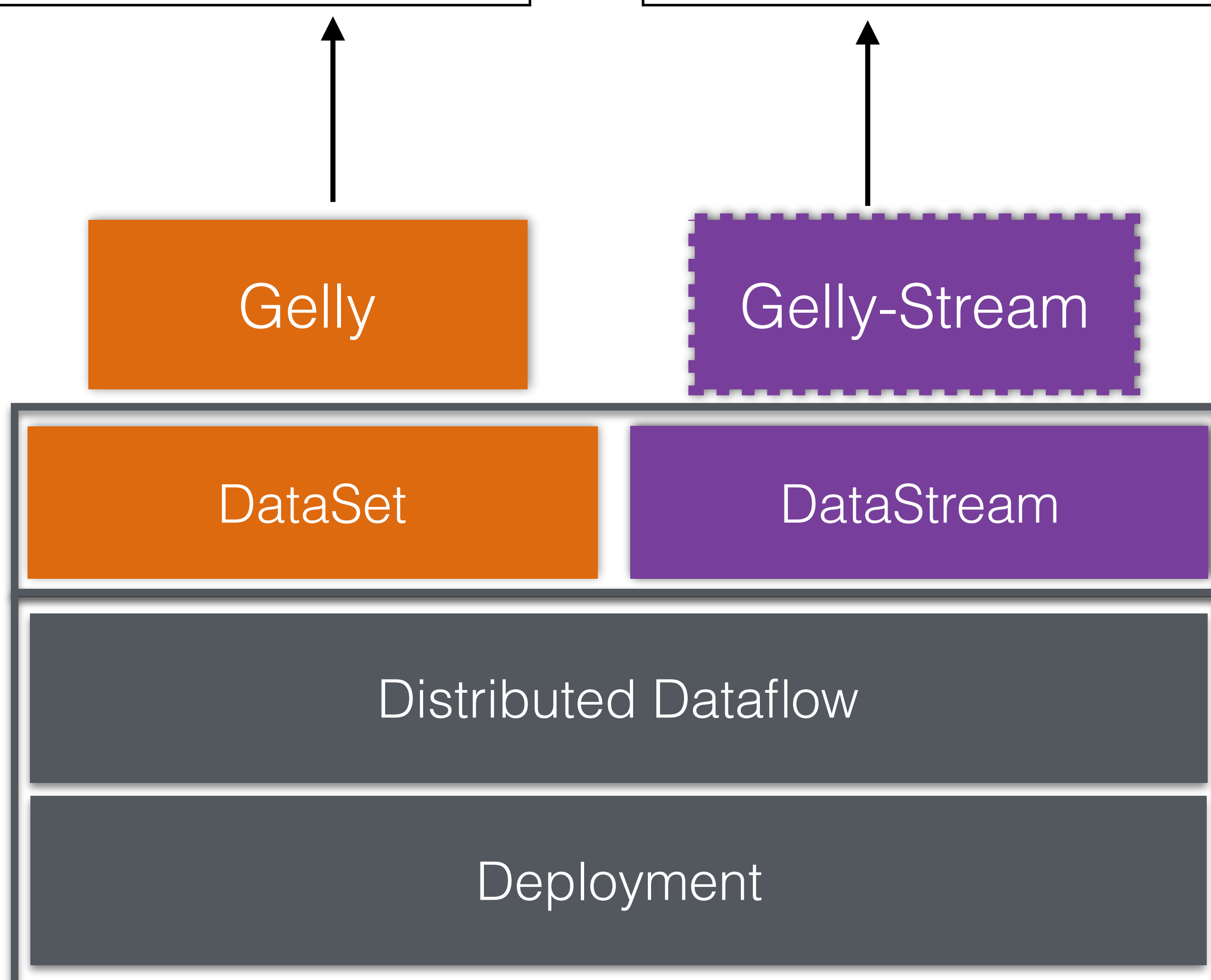
```
myTextStream
    .flatMap(new Splitter()) //transformation
    .keyBy(0) //partitioning
    .window(Time.of(5, TimeUnit.MINUTES))
    .sum(1) //rolling aggregation
    .setParallelism(4);
counts.print();
```



Gelly on Streams

- Static Graphs
- Multi-Pass Algorithms
- Full Computations

- Dynamic Graphs
- Single-Pass Algorithms
- Approximate Computations



Introducing Gelly-Stream

Gelly-Stream enriches the DataStream API with two new additional ADTs:

- GraphStream:
  - A representation of a data **stream of edges**.
  - Edges can have **state** (e.g. weights).
  - Supports **property** streams, **transformations** and **aggregations.**
- GraphWindow:
  - A “time-slice” of a graph stream.
  - It enables neighbourhood aggregations

GraphStream Operations

Property Streams

GraphStream -> DataStream

```
.getEdges()
.getVertices()
.numberOfVertices()
.numberOfEdges()
.getDegrees()
.inDegrees()
.outDegrees()
```

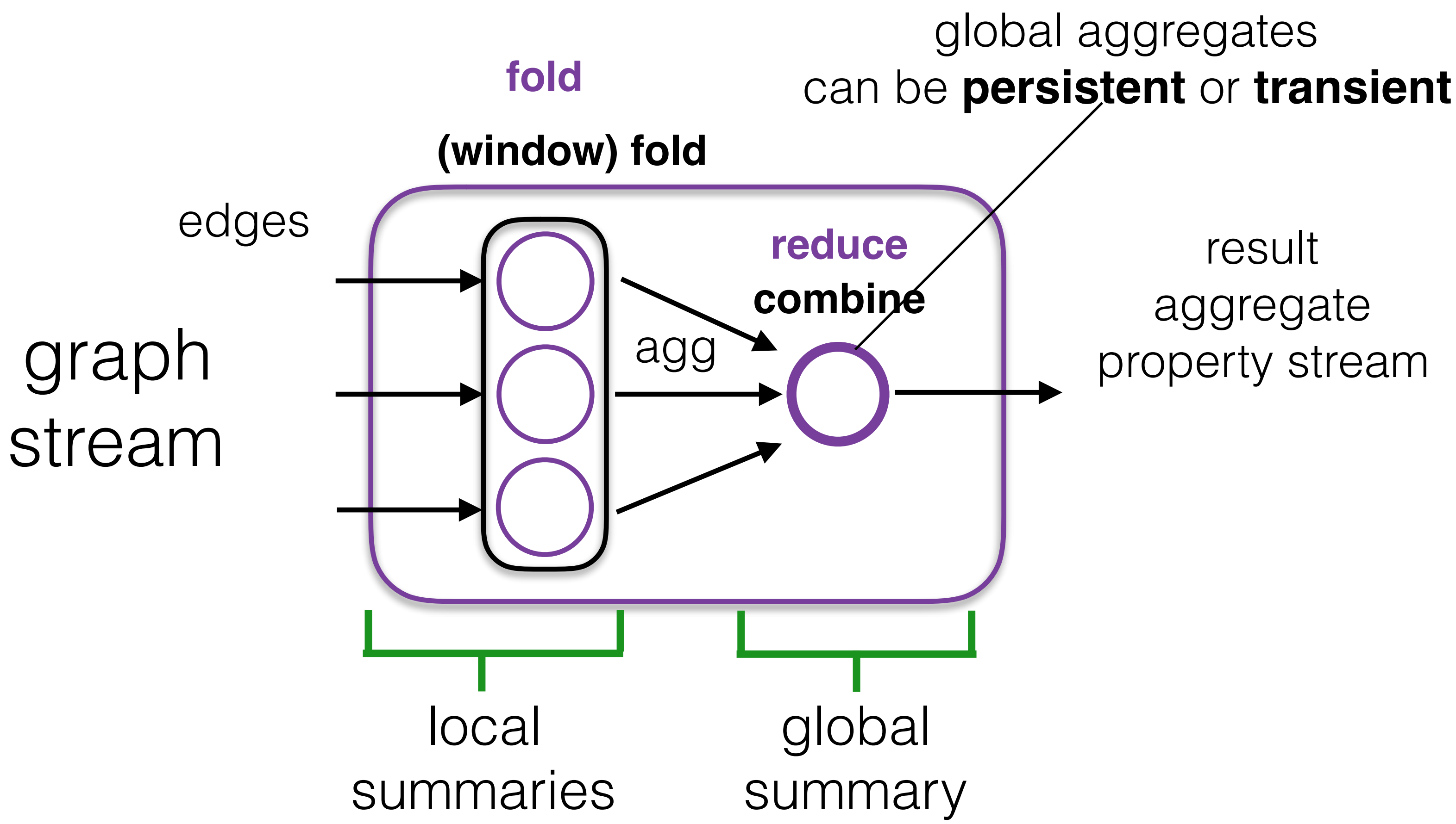
Transformations

GraphStream -> GraphStream

```
.mapEdges();
.distinct();
.filterVertices();
.filterEdges();
.reverse();
.undirected();
.union();
```

Graph Stream Aggregations

```
graphStream.aggregate(
    new MyGraphAggregation(window, fold, combine, transform))
```



Graph Stream Aggregations

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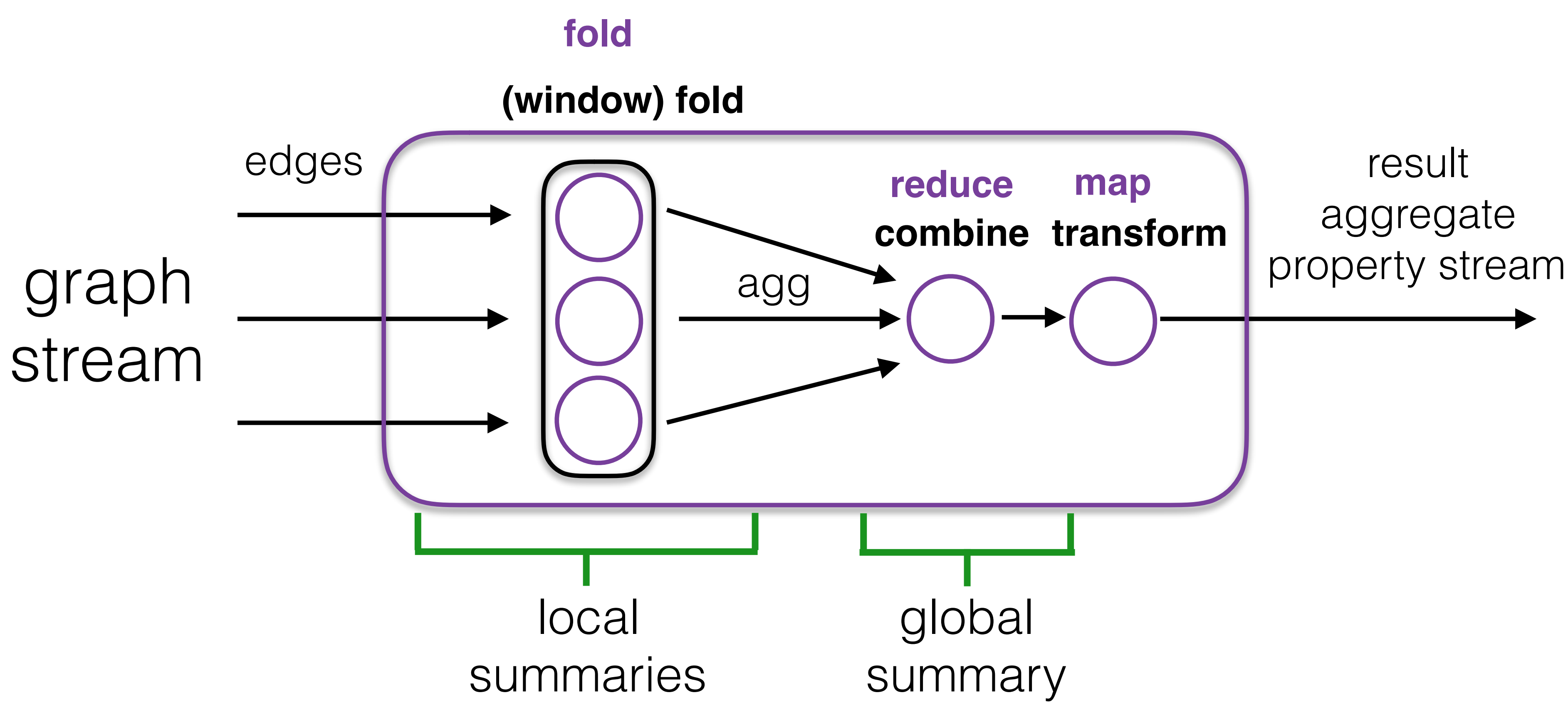
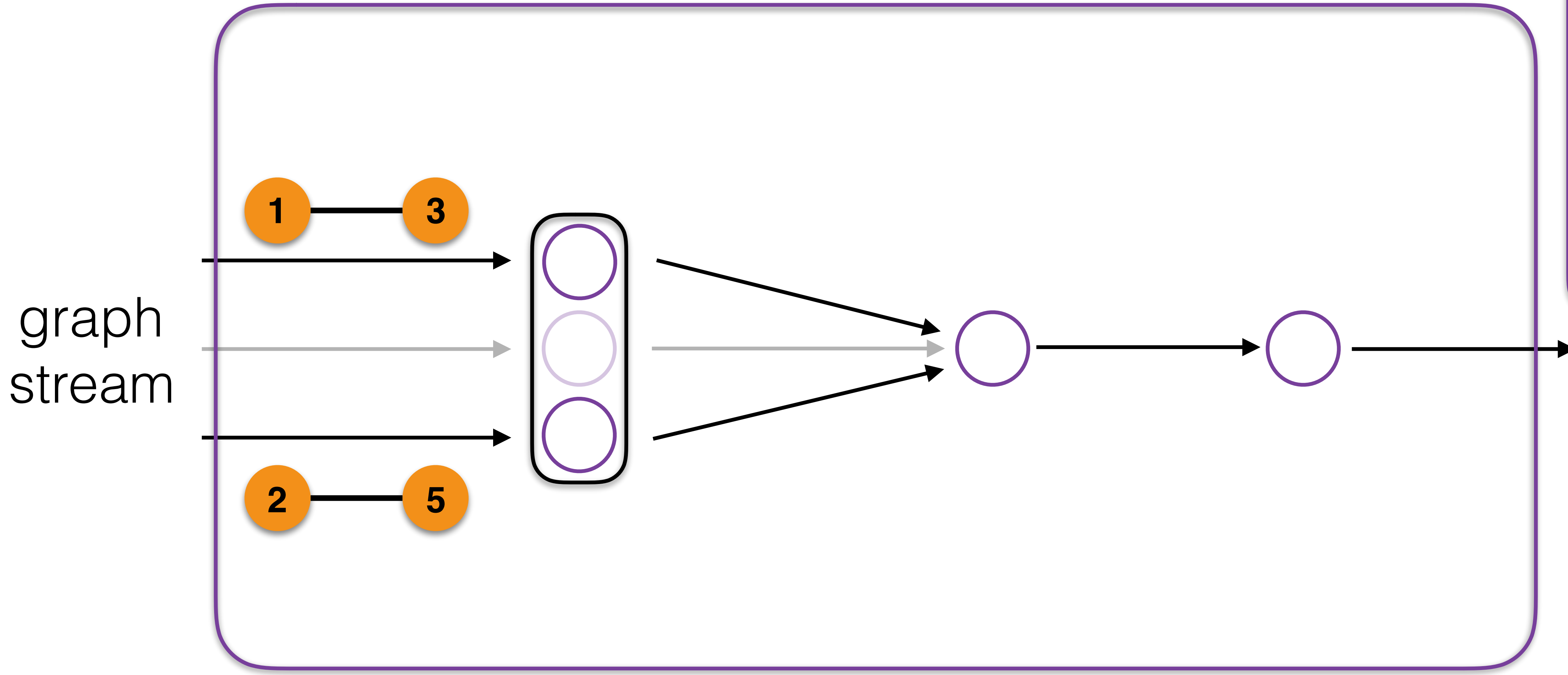
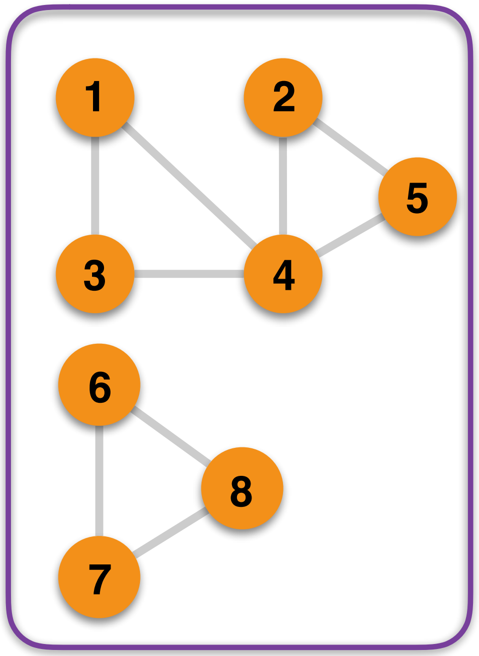


Connected Components

```
graphStream.aggregate(
new ConnectedComponents(window,fold,combine,transform))
```





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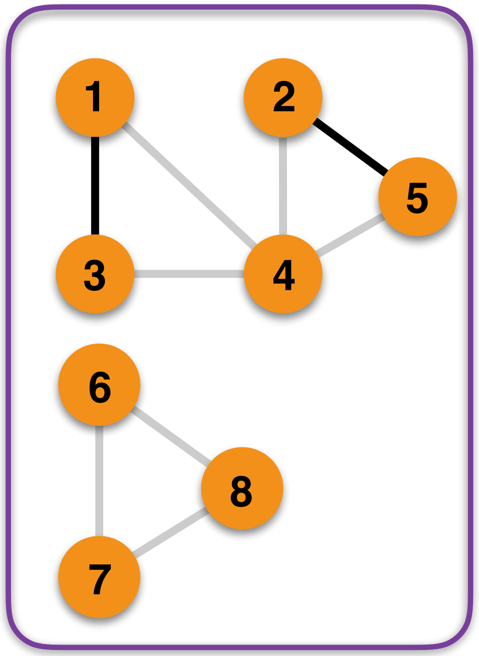
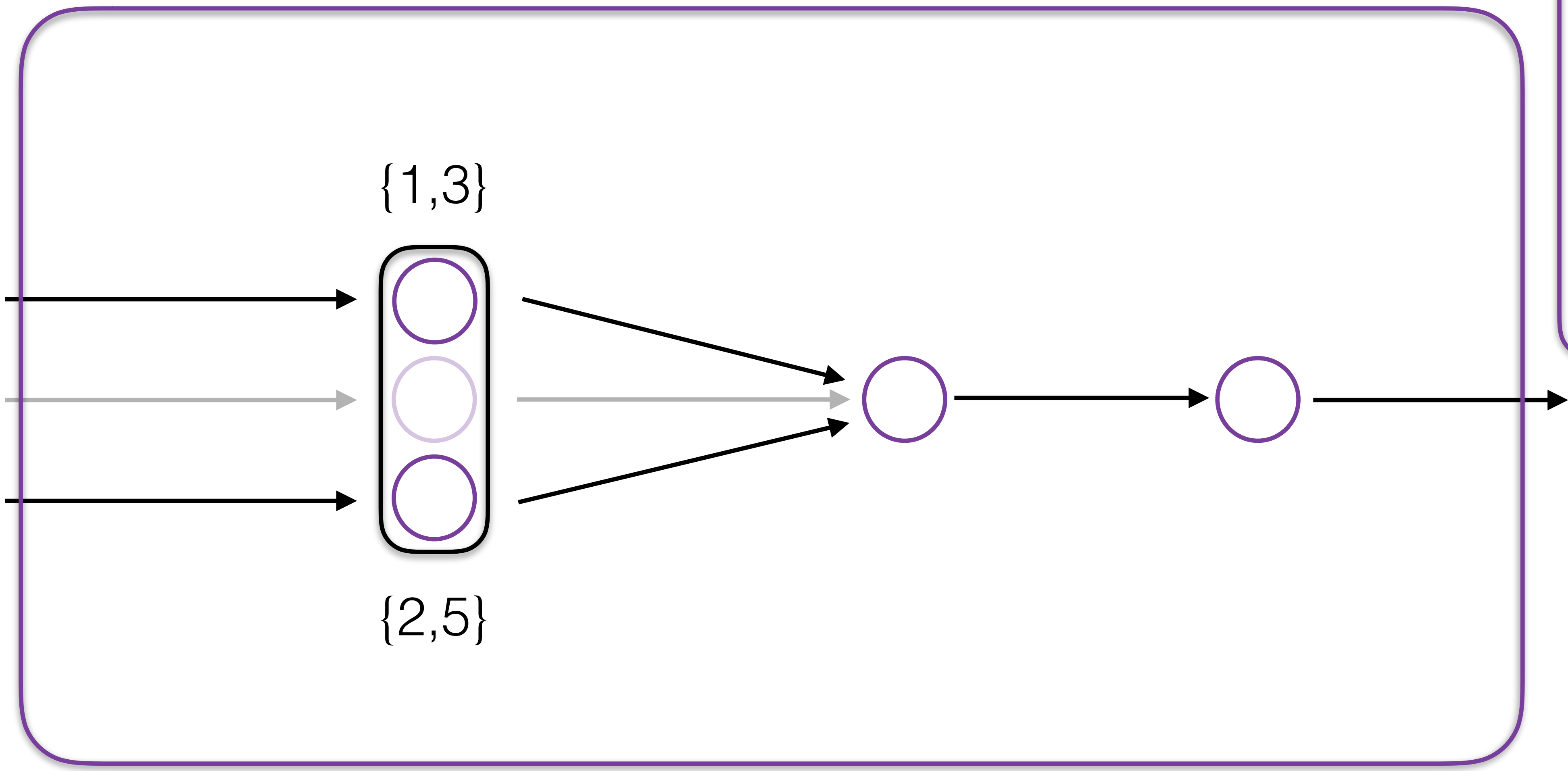


graph stream



#components

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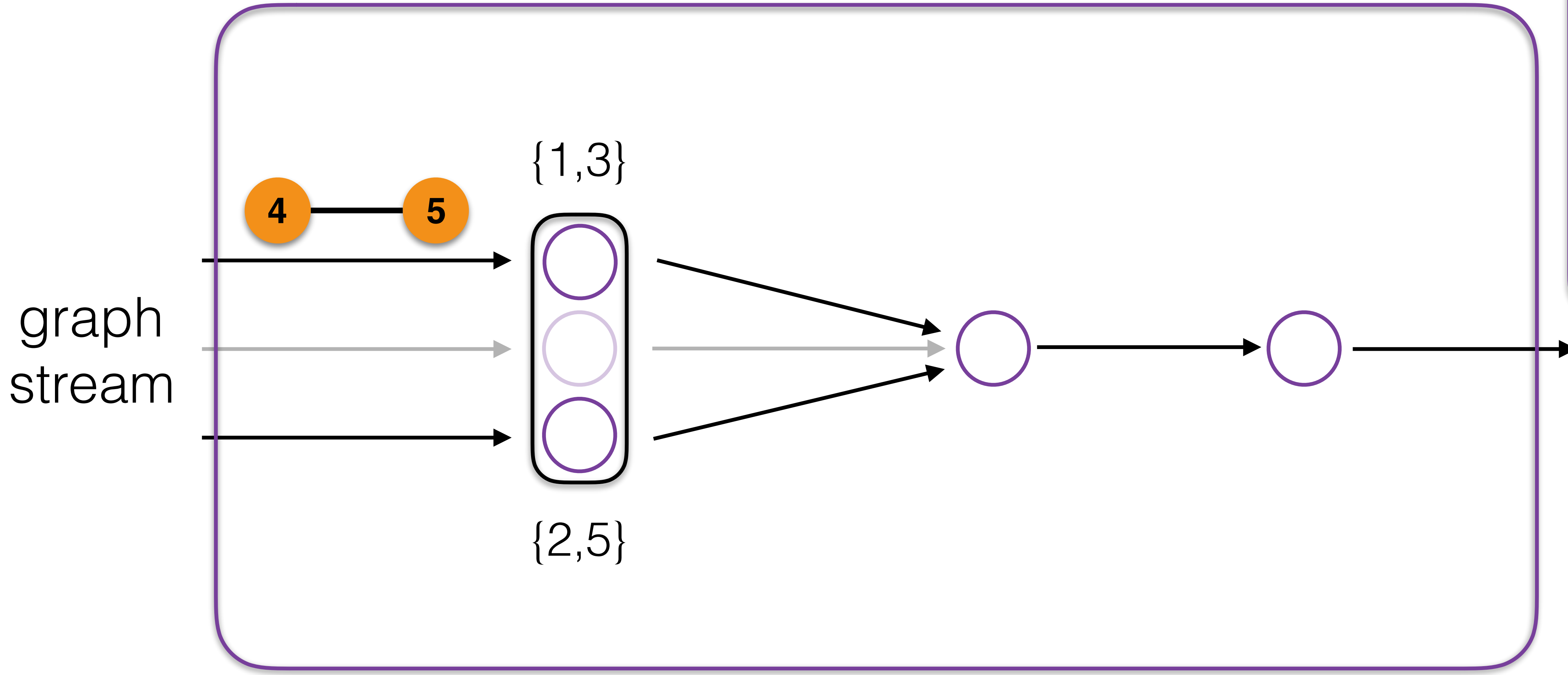

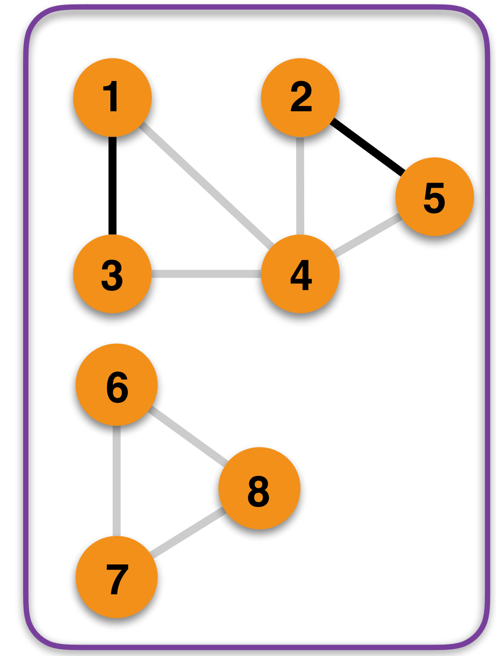

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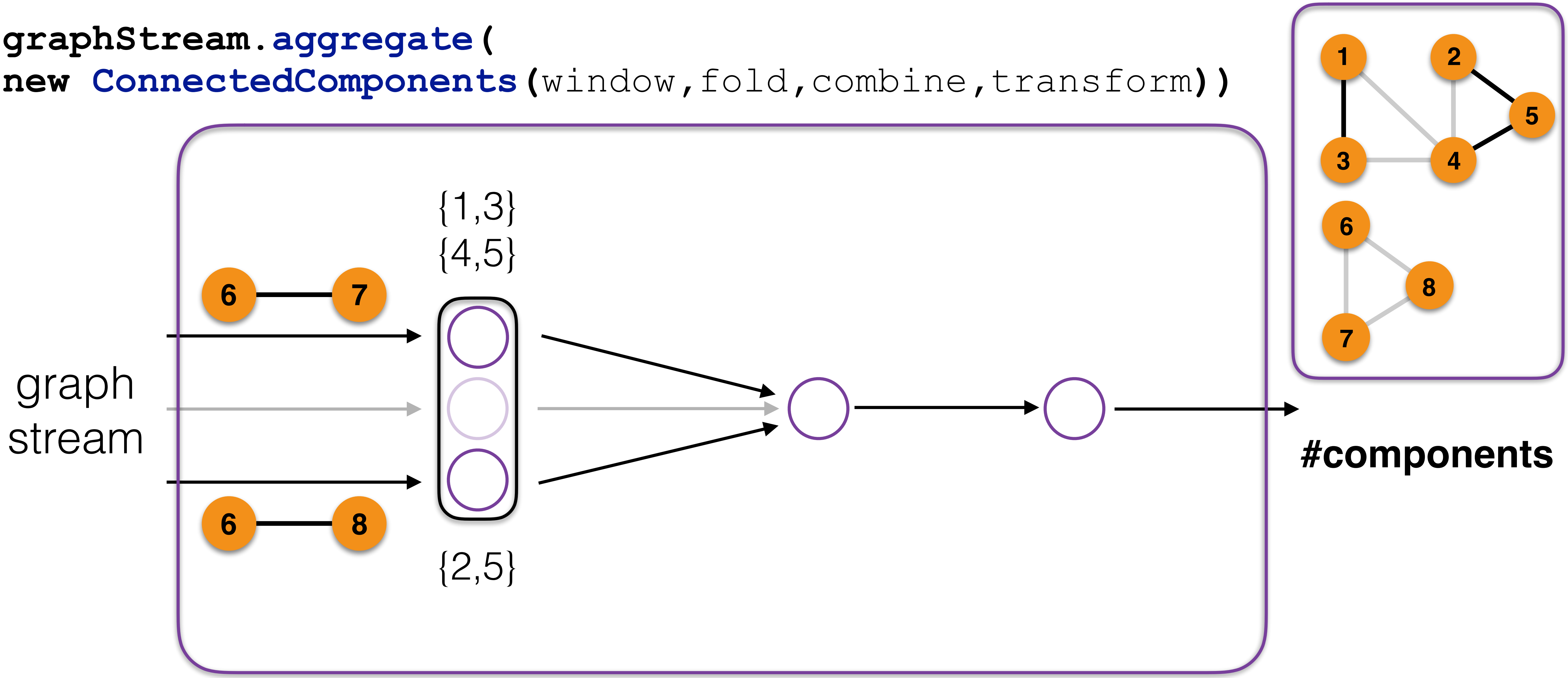

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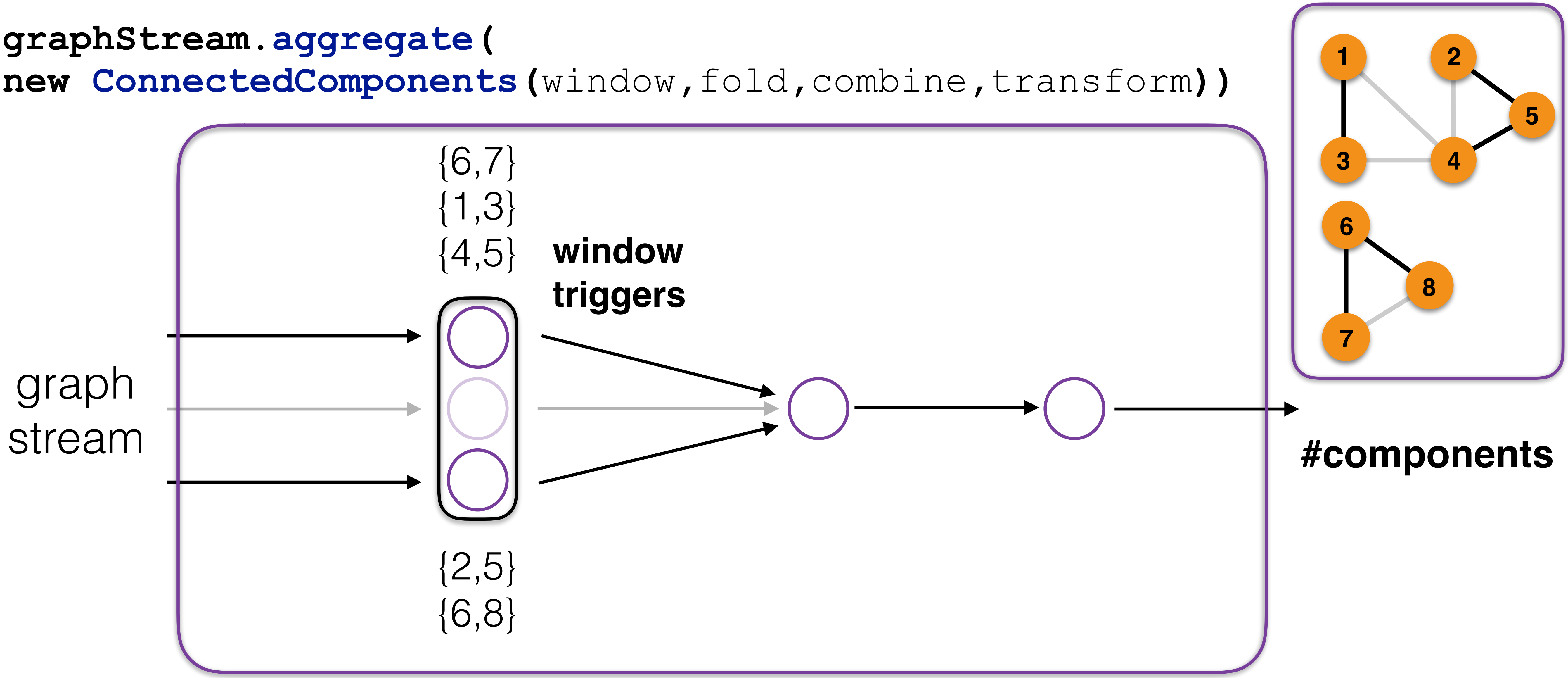

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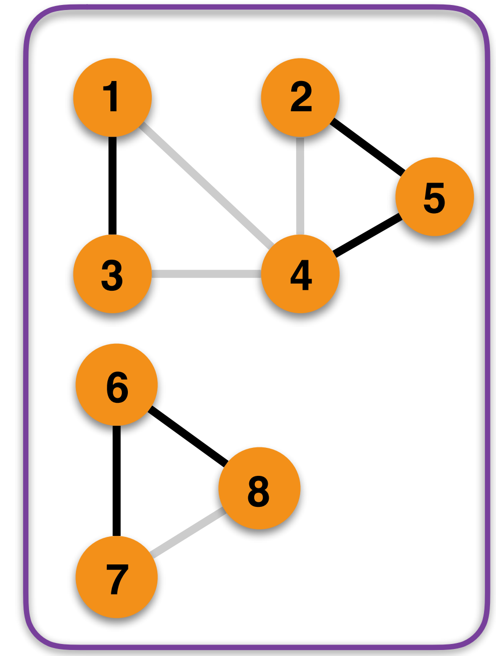

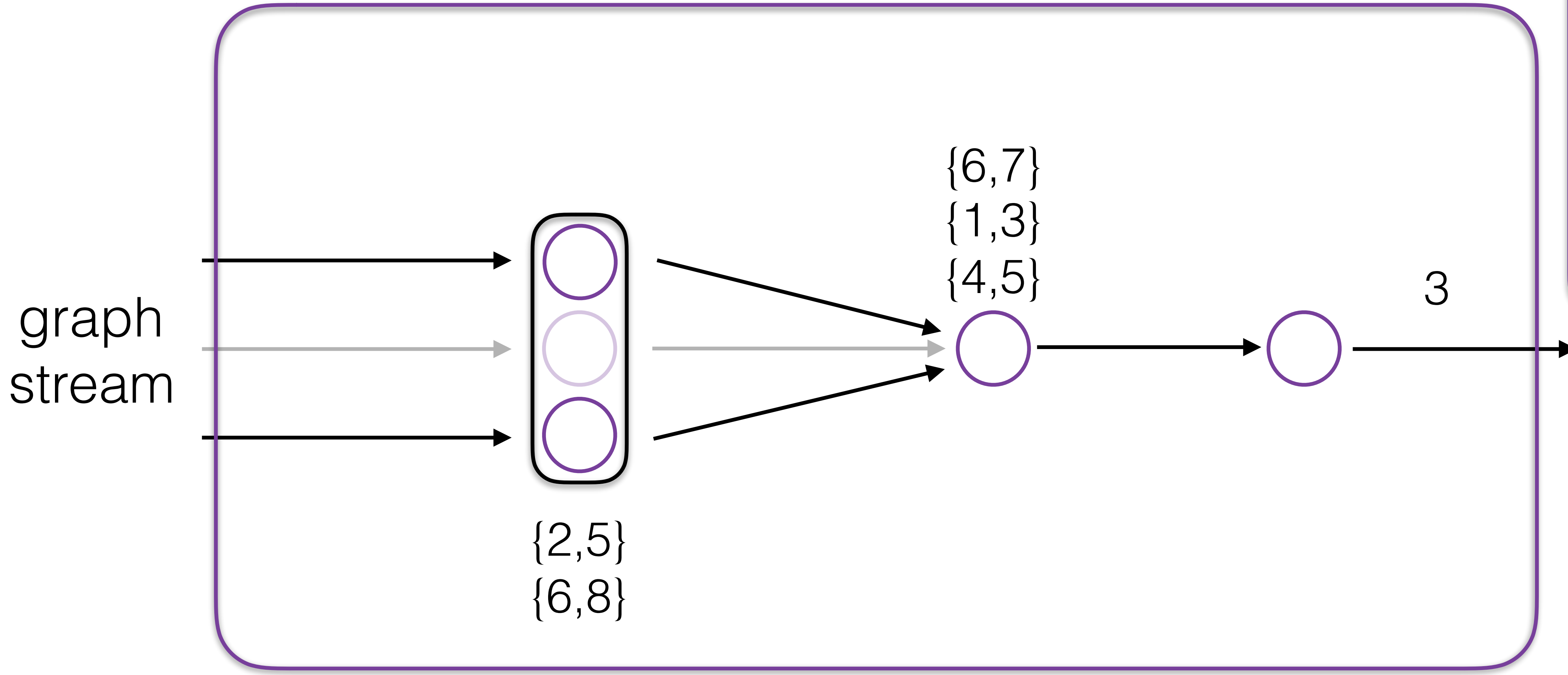

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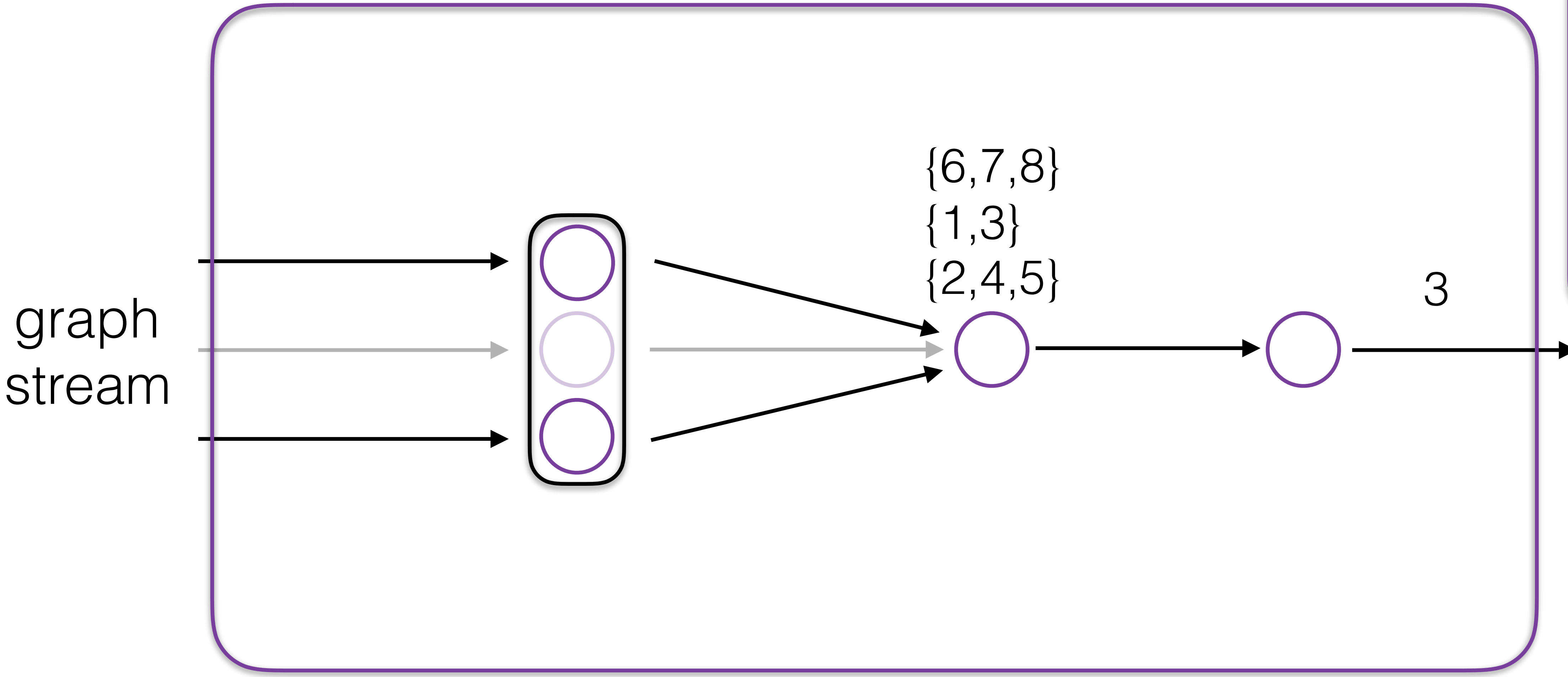

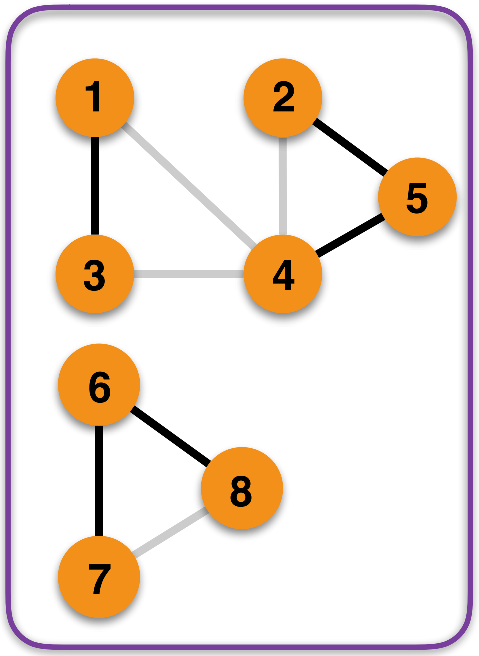

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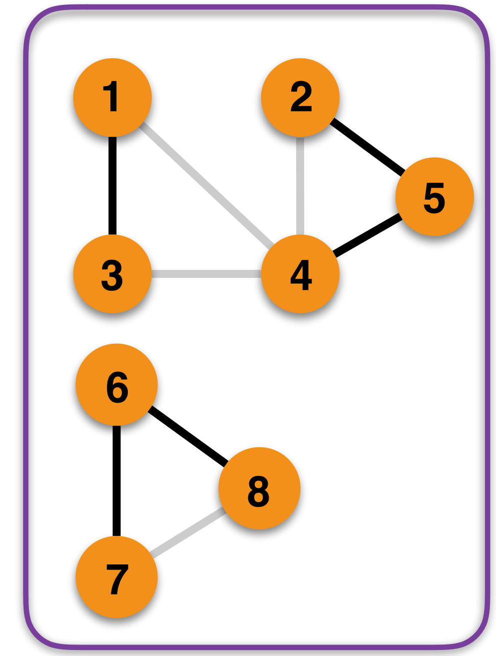

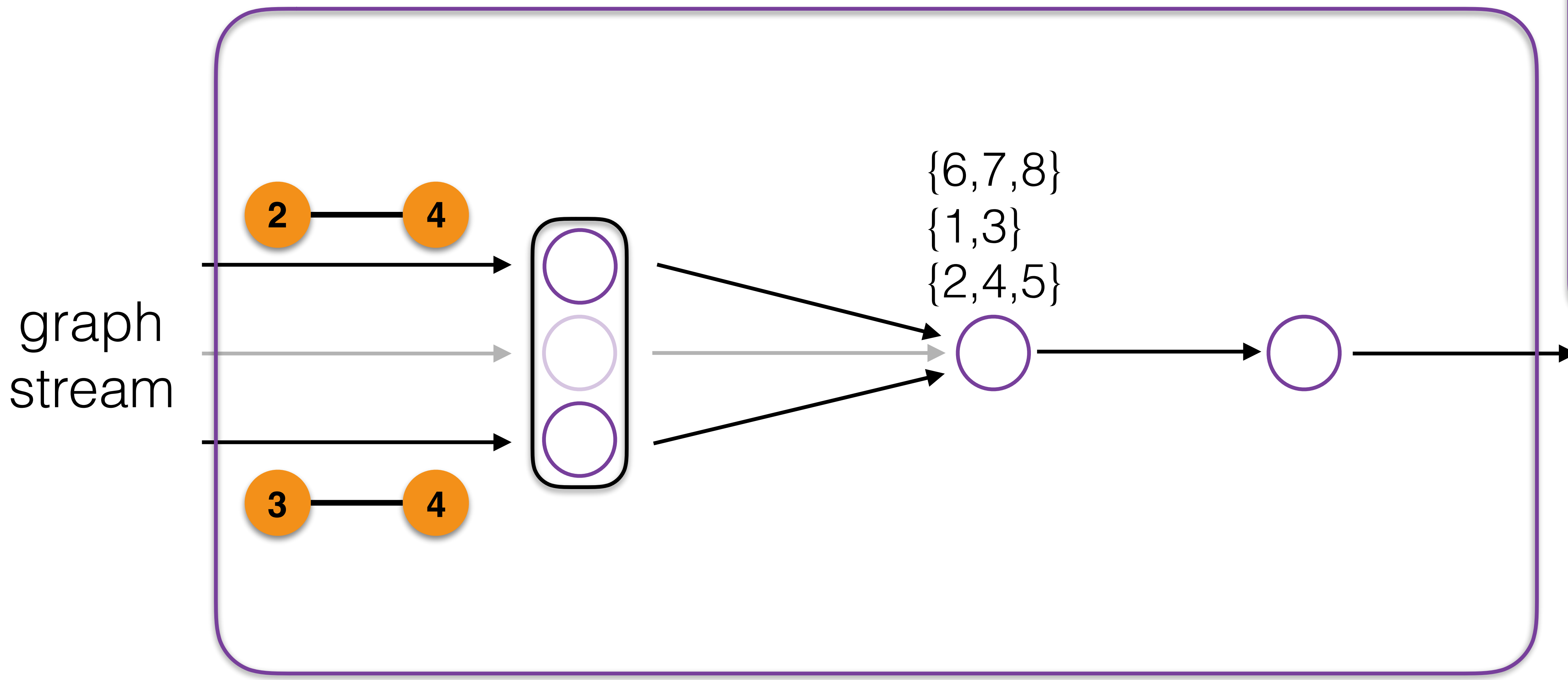

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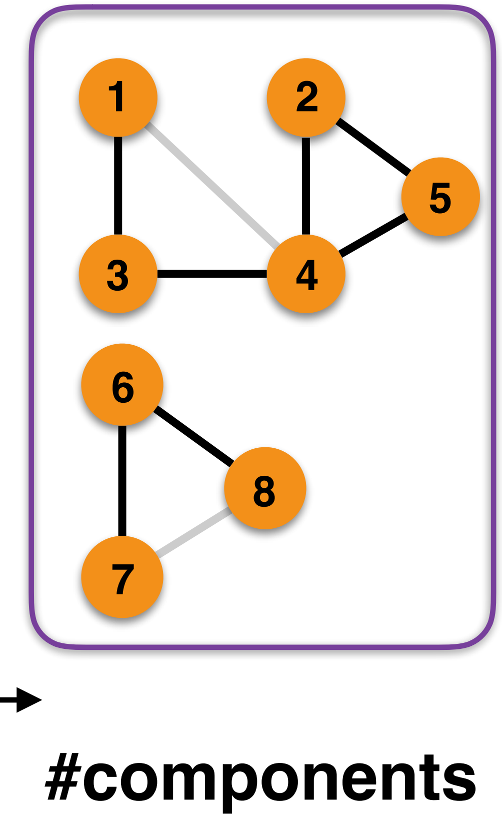

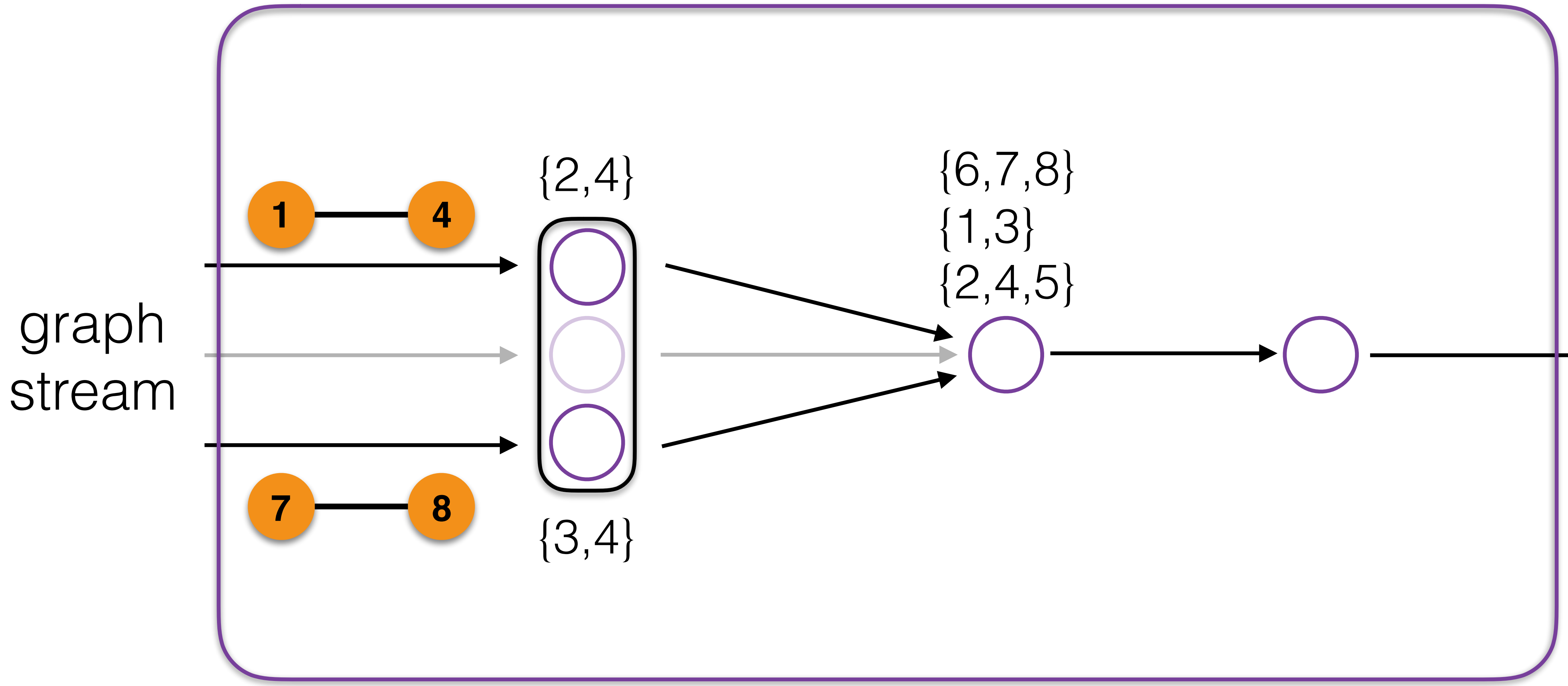

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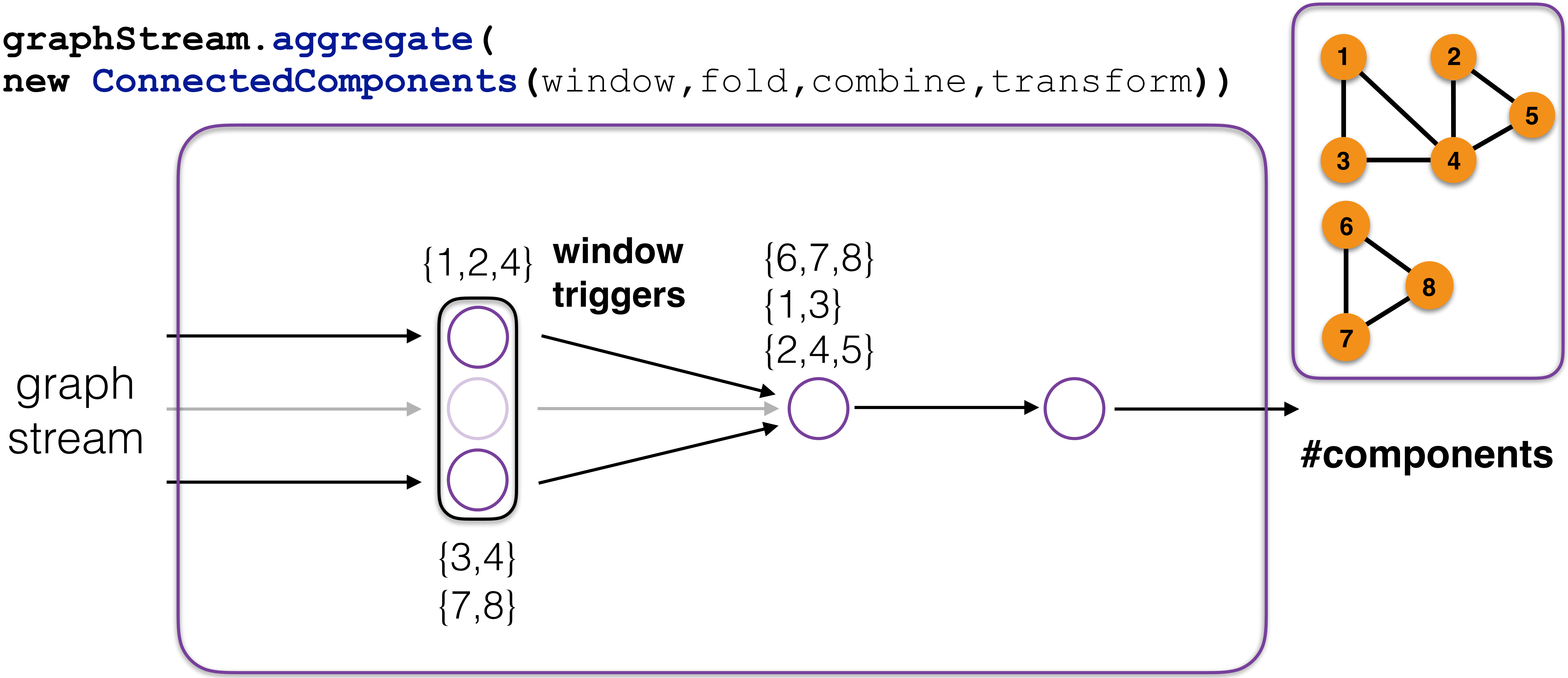

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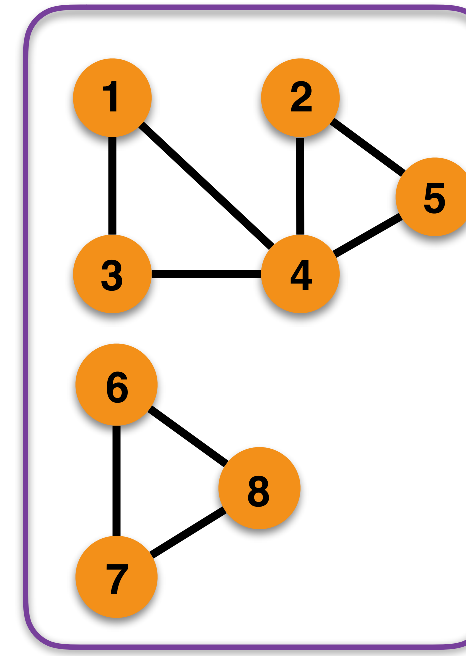

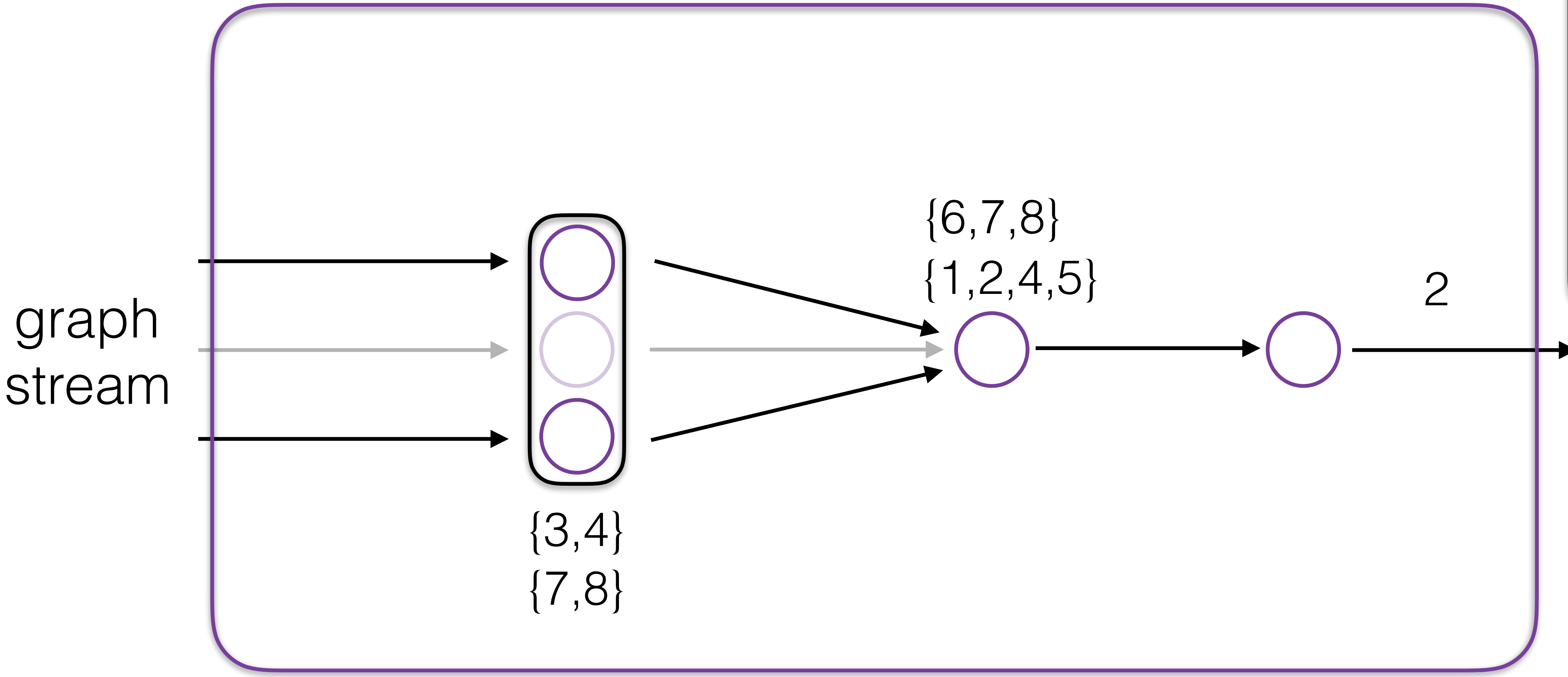

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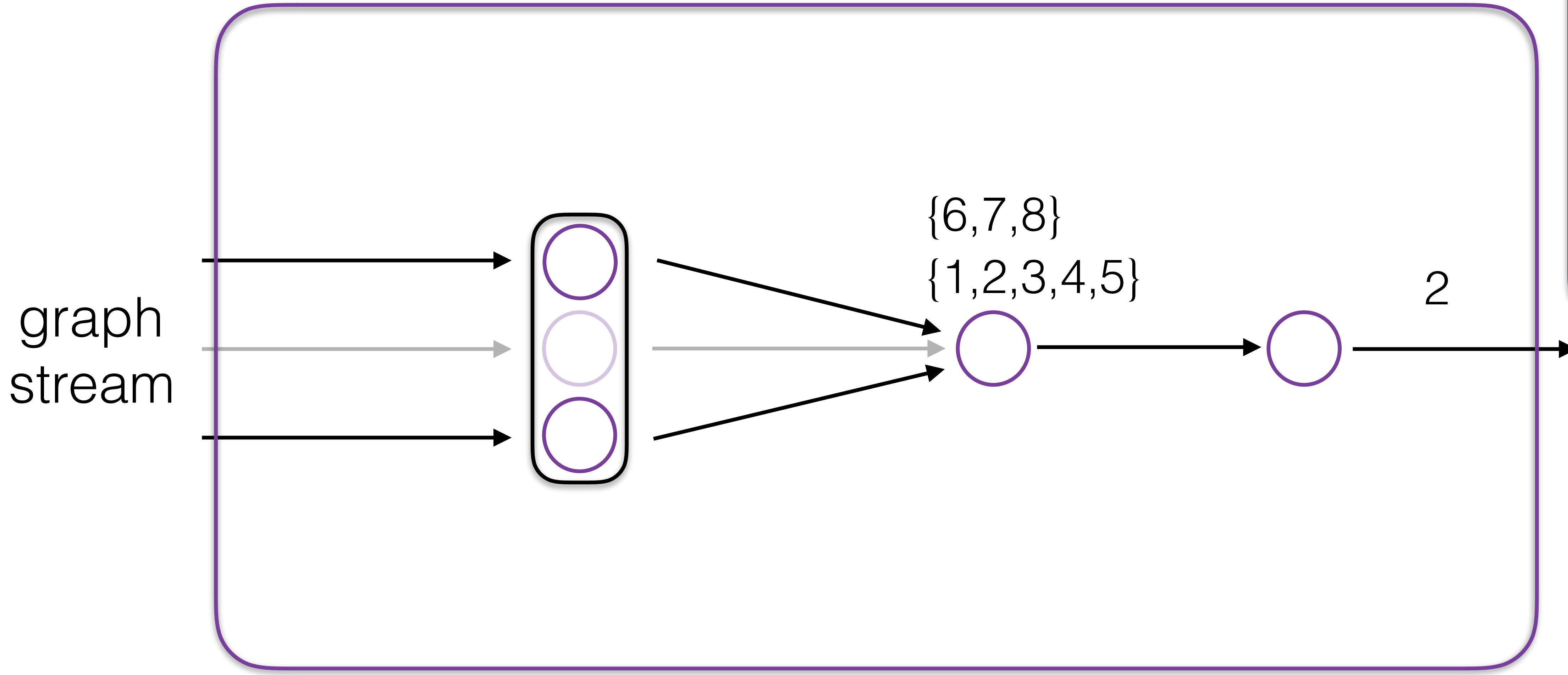
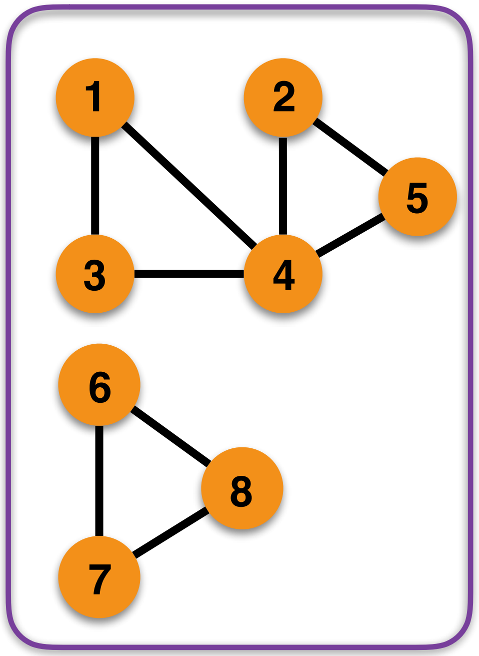
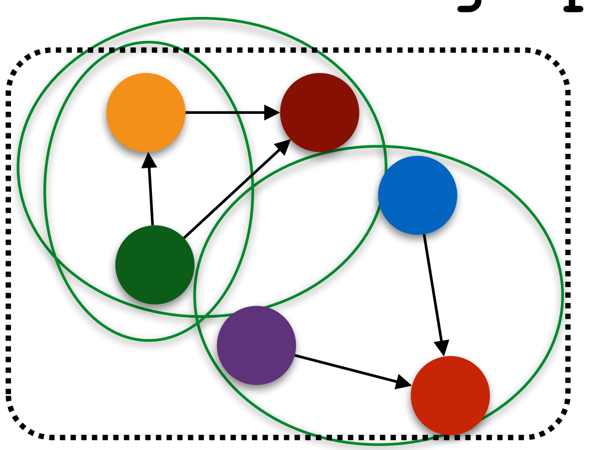




Aggregating Slices

```
graphStream.slice(Time.of(1, MINUTE), direction)
```

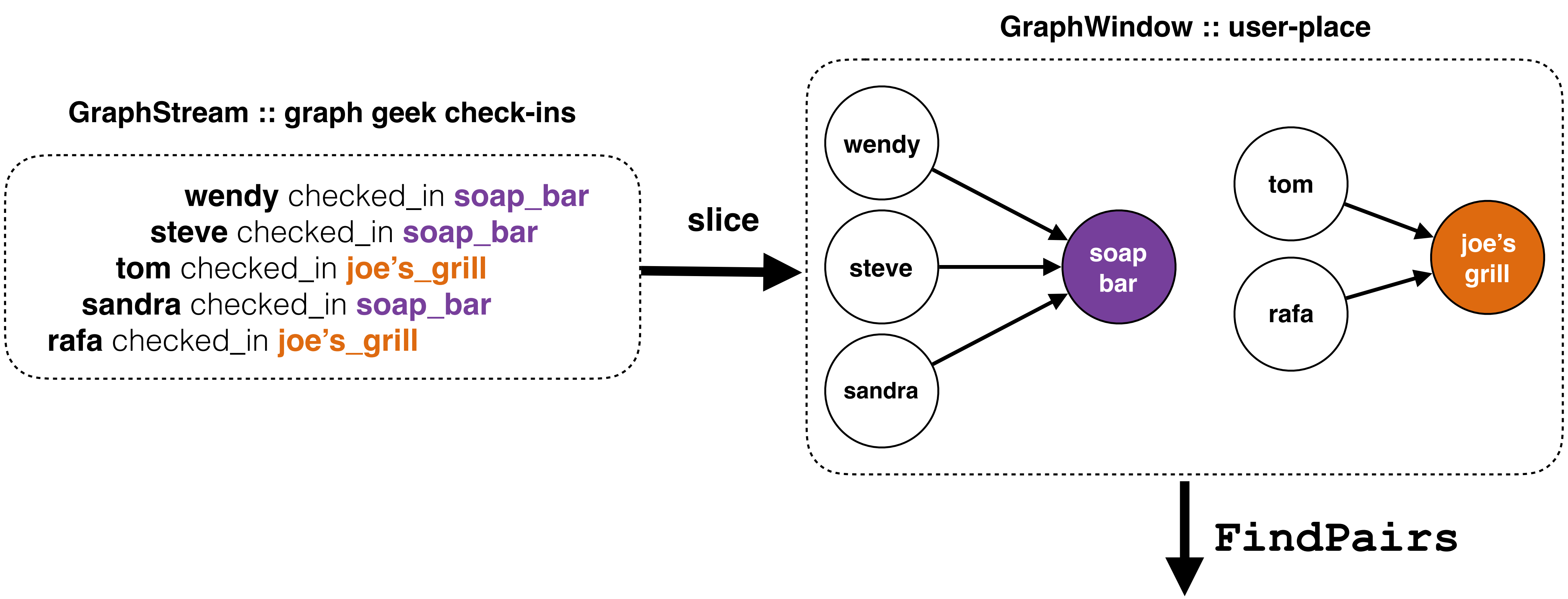
<u>Aggregations</u>

```
.reduceOnEdges();
.foldNeighbors();
.applyOnNeighbors();
```

- Slicing collocates edges by vertex information
- Neighbourhood aggregations are now enabled on sliced graphs

Finding Matches Nearby

```
graphStream.filterVertices(GraphGeeks())
    .slice(Time.of(15, MINUTE), EdgeDirection.IN)
    .applyOnNeighbors(FindPairs())
```




```
{wendy, steve}
{steve, sandra}
{wendy, sandra}
{tom, rafa}
```

Feeling Gelly?

- **Gelly-Stream**: https://github.com/vasia/gelly-streaming
- **Apache Flink**: https://github.com/apache/flink
- **An interesting read**: http://users.dcc.uchile.cl/~pbarcelo/mcg.pdf
- **A cool thesis**: http://urn.kb.se/resolve?urn=urn:nbn:se:kth:diva-170425
- **Twitter:** @vkalavri , @senorcarbone