Distributed Systems

CS422/522 Lecture17

17 November 2014

Lecture Outline

- Introduction
- Hadoop
- Chord

What’s a distributed system?

What's a distributed system?

A distributed system is a collection of loosely coupled nodes interconnected by a communication network.

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A distributed system is a collection of loosely coupled nodes interconnected by a communication network.

In a distributed system, users access remote resources in the same way they access local resources.

Why distributed systems?

Scalability

PC

Scalability

PC

- What if one computer is not enough?

Scalability

PC

Server

- What if one computer is not enough?
  - Buy a bigger (server-class) computer

Scalability

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- What if one computer is not enough?
  - Buy a bigger (server-class) computer
- What if the biggest computer is not enough?

Scalability

PC

Server

Cluster

- What if one computer is not enough?
  - Buy a bigger (server-class) computer
- What if the biggest computer is not enough?
  - Buy many computers

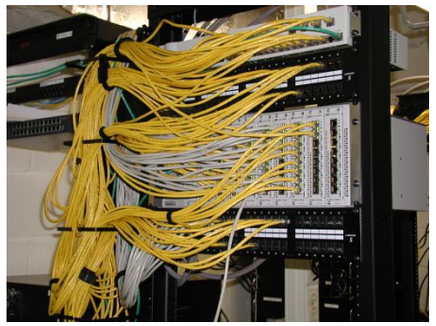
Scalability

Scalability

Rack

Scalability

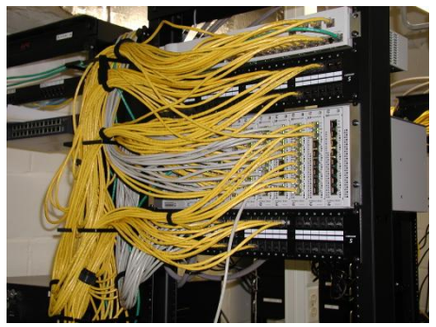
Rack



Network switches
(connects nodes with each other and with other racks)

Scalability

Rack



Network switches
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Many nodes/blades
(often identical)

Scalability

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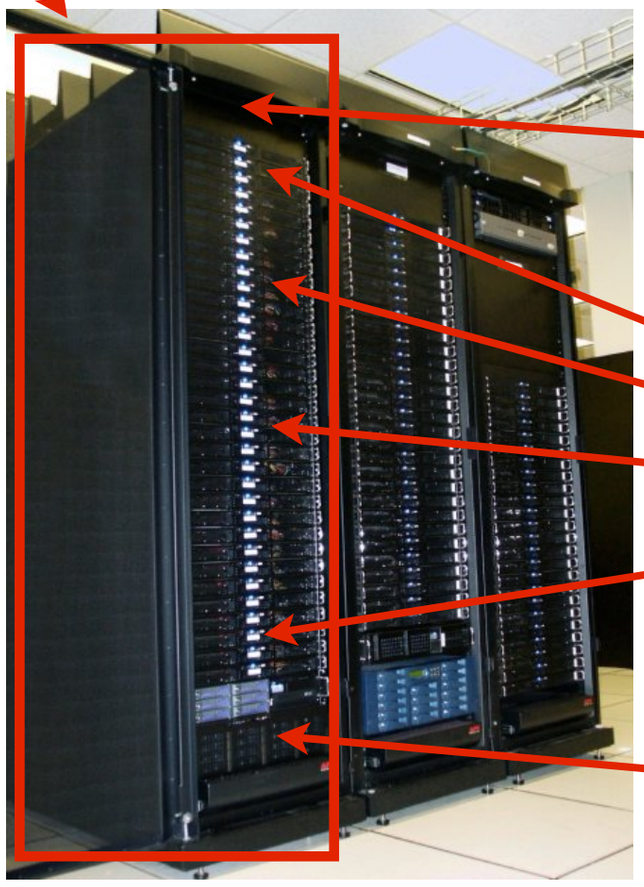

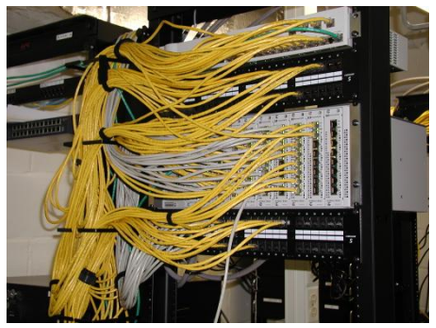

Network switches
(connects nodes with each other and with other racks)

Many nodes/blades
(often identical)

Storage device(s)

Scalability

PC

Server

Cluster

- What if cluster is too big to fit into machine room?

Scalability

PC

Server

Cluster

- What if cluster is too big to fit into machine room?
  - Build a separate building for the cluster
  - Building can have lots of cooling and power

Scalability

PC

Server

Cluster

Data center

- What if cluster is too big to fit into machine room?
  - Build a separate building for the cluster
  - Building can have lots of cooling and power
  - Result: Data center

Google Data Center in Oregon

Google Data Center in Oregon

Data centers (size of a football field)

Google Data Center in Oregon

Data centers (size of a football field)

- A warehouse-sized computer
  - A single data center can easily contain 10,000 racks with 100 cores in each rack (1,000,000 cores total)

Google Data Centers World Wide

Why distributed systems?

- Resource sharing
  - E.g., Napster

Why distributed systems?

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  - E.g., Napster
- Computation speedup
  - E.g., Hadoop

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Why distributed systems?

- Resource sharing
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Issues?

Lecture Outline

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What's the Hadoop

- A project based on GFS and MapReduce
  - Distribute data across machines
  - Try to achieve the reliability and scalability

The Google File System

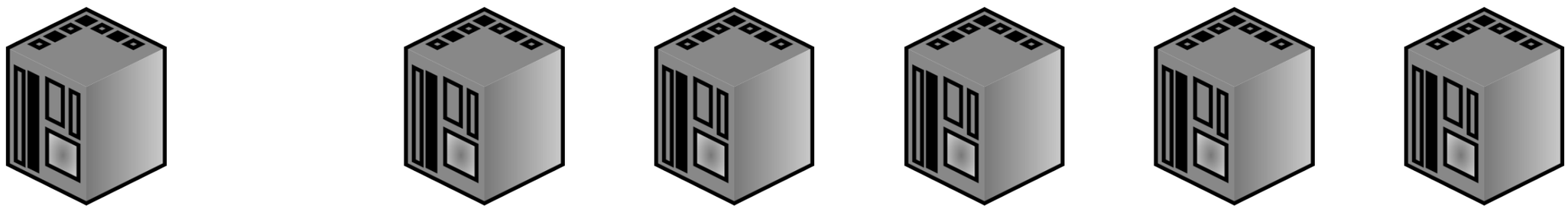
What's the Hadoop

- A project based on GFS and MapReduce
  - Distribute data across machines
  - Try to achieve the reliability and scalability

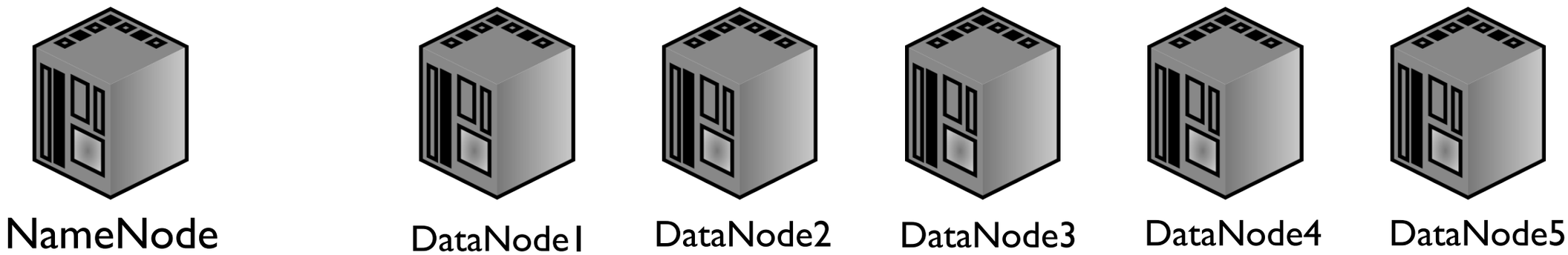
- An open-source software framework for big data
  - Distributed storage
  - Distributed processing

Why Hadoop?

Hadoop Components

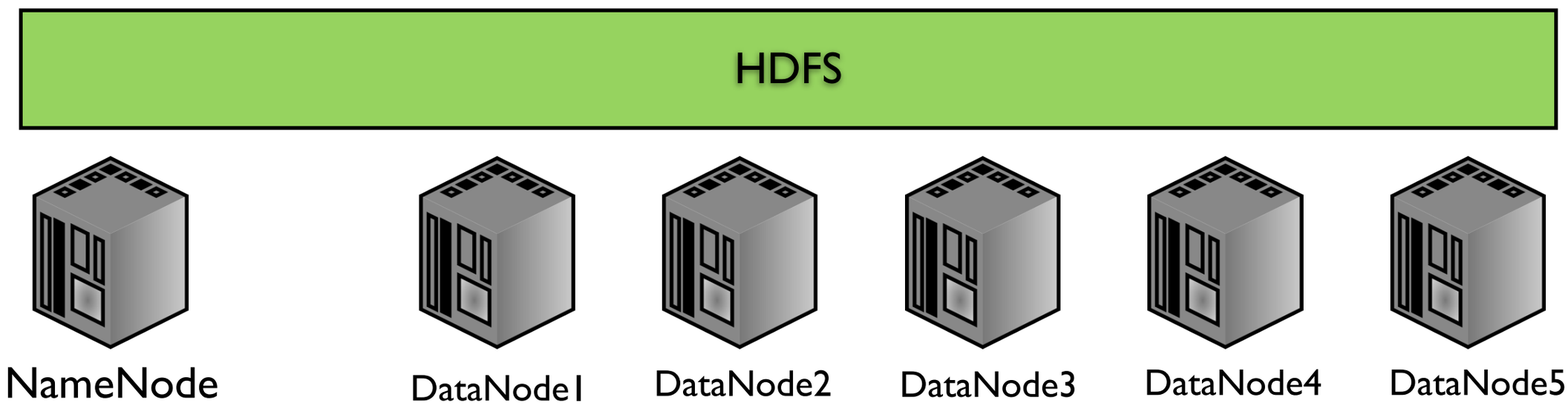


Hadoop Components



Hadoop Components

- Two core components
  - The Hadoop distributed file system (HDFS)



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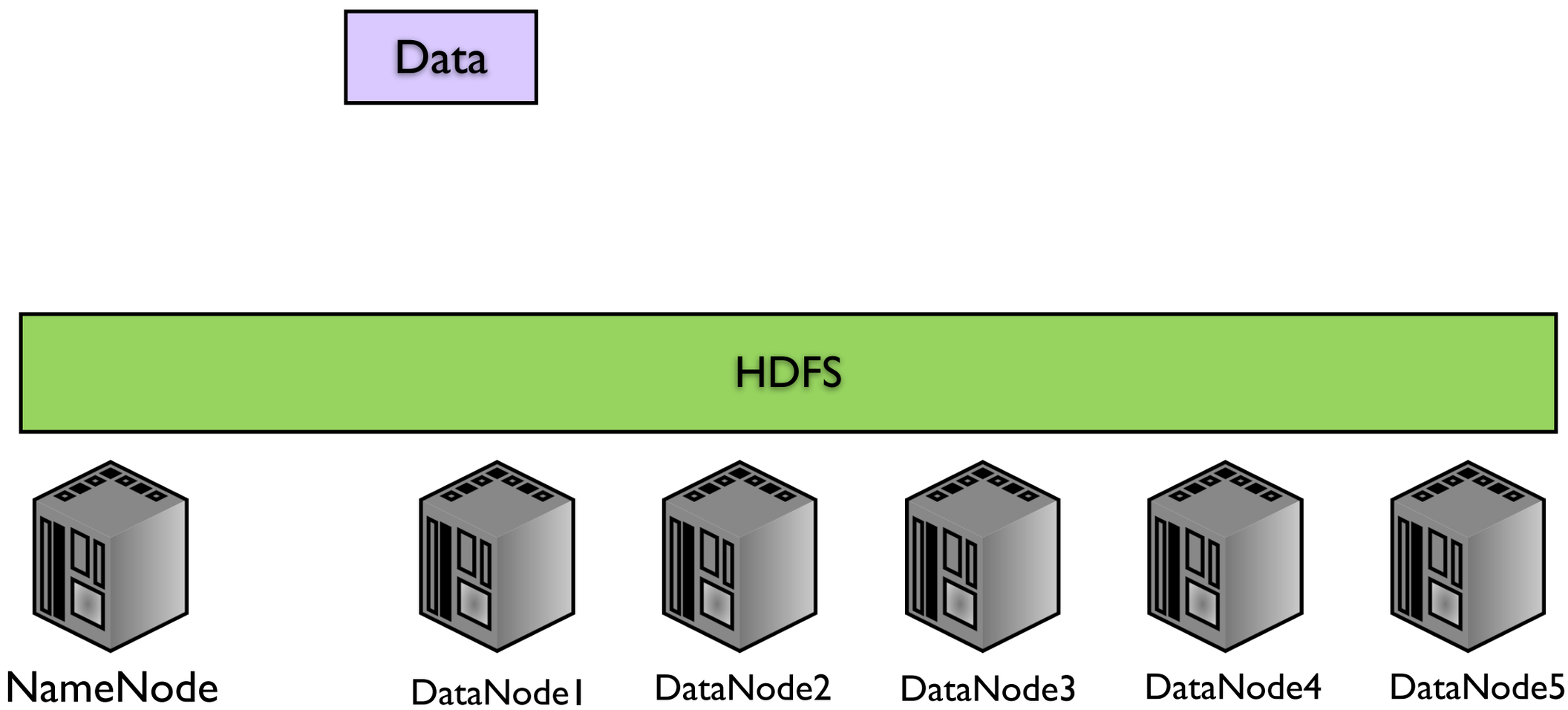

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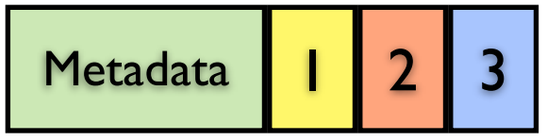

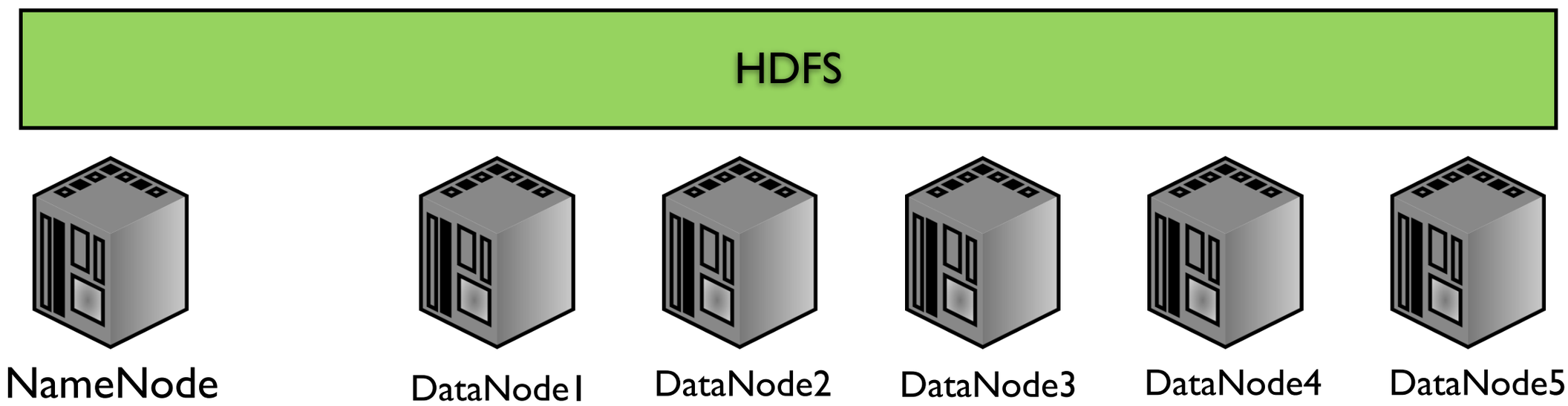

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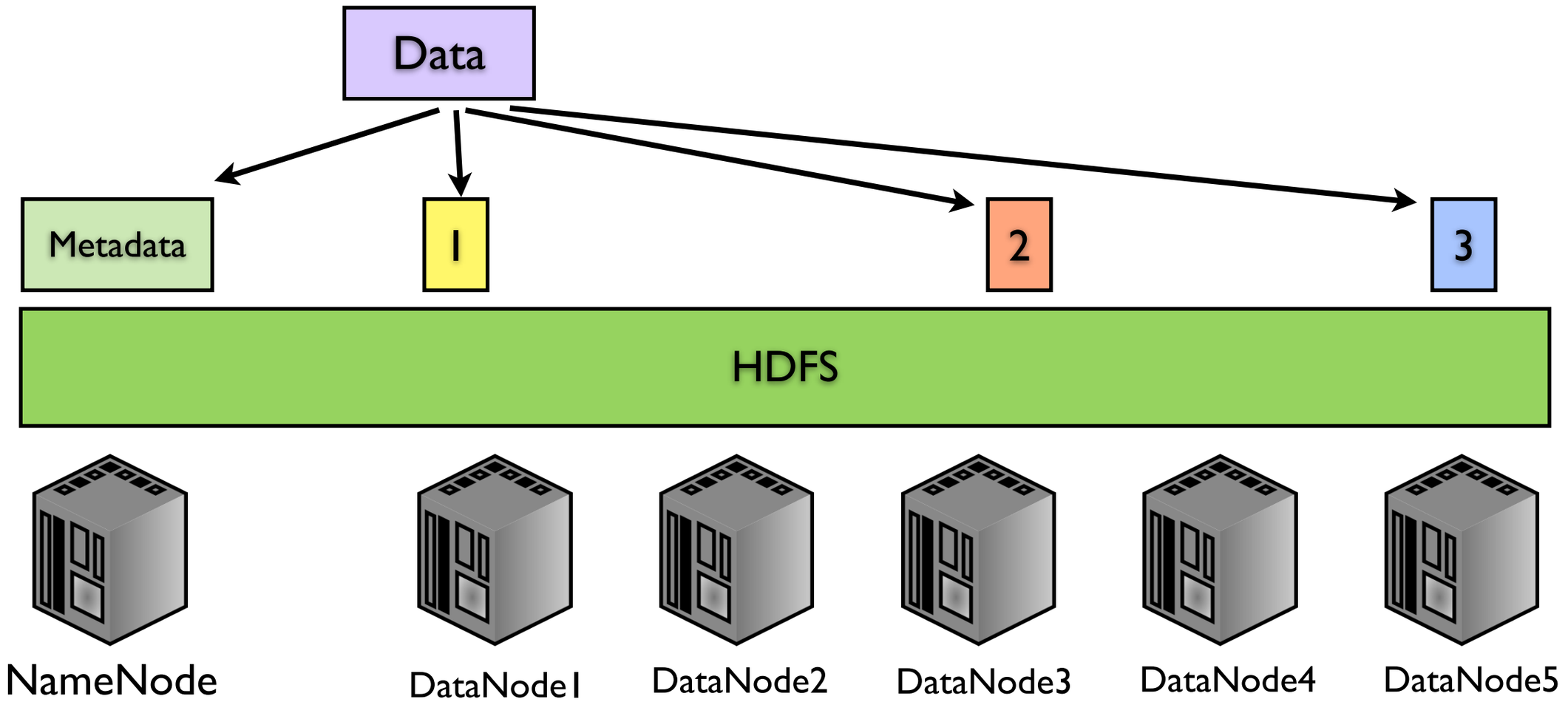

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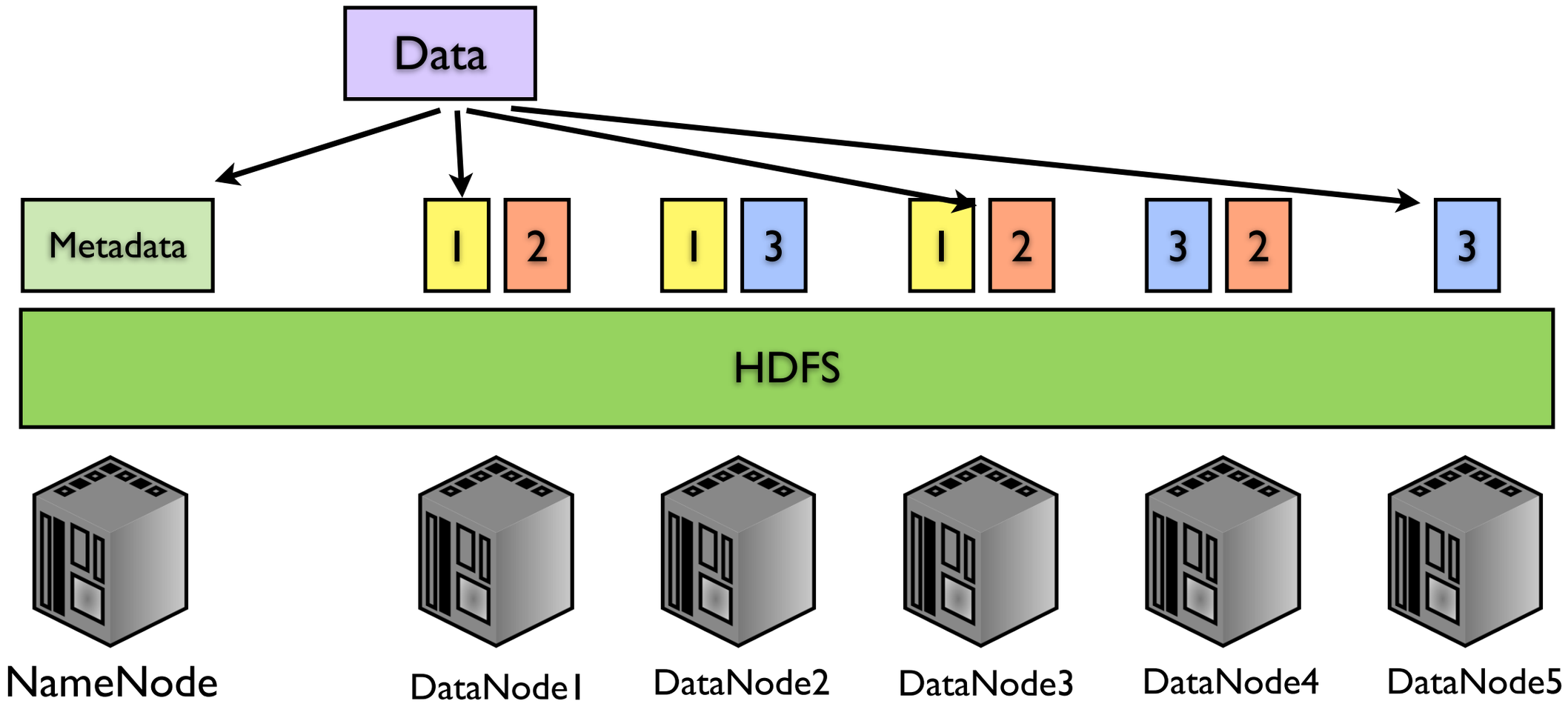

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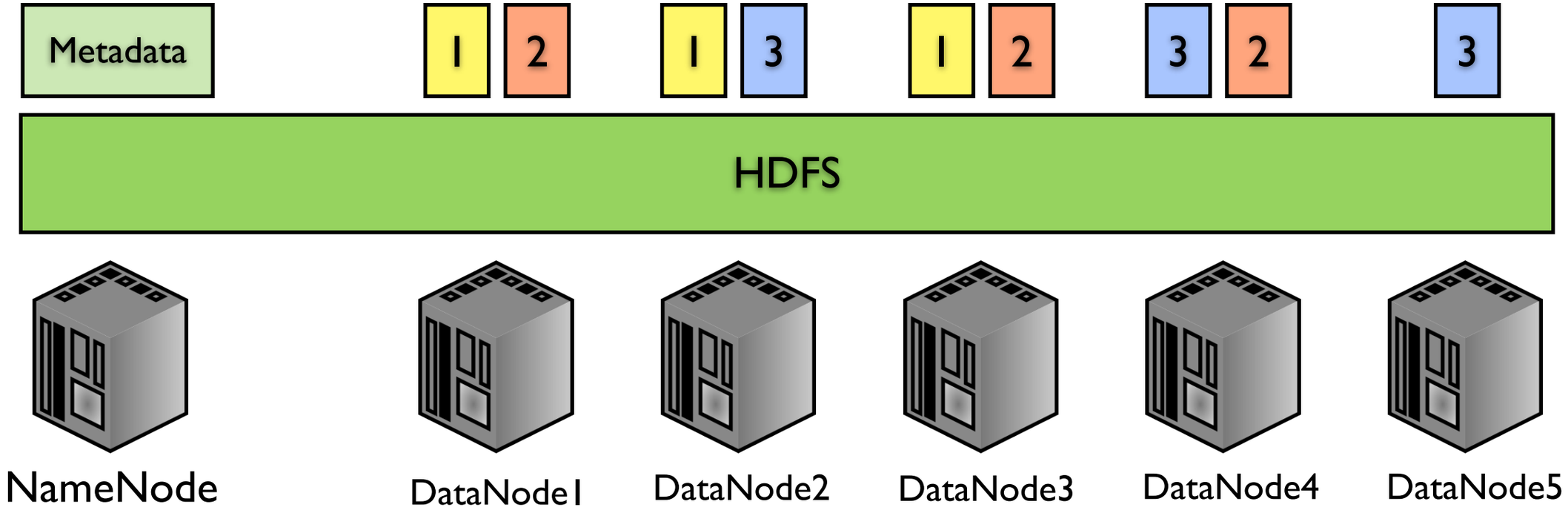

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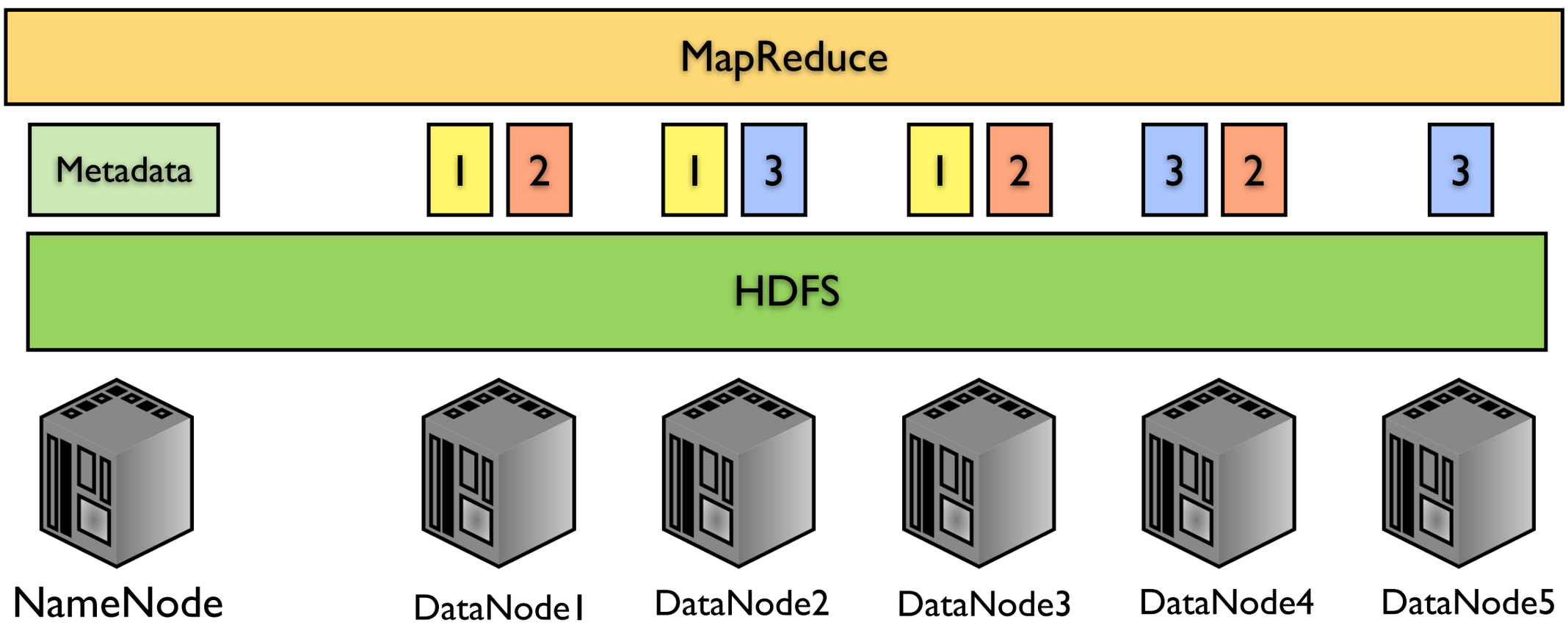

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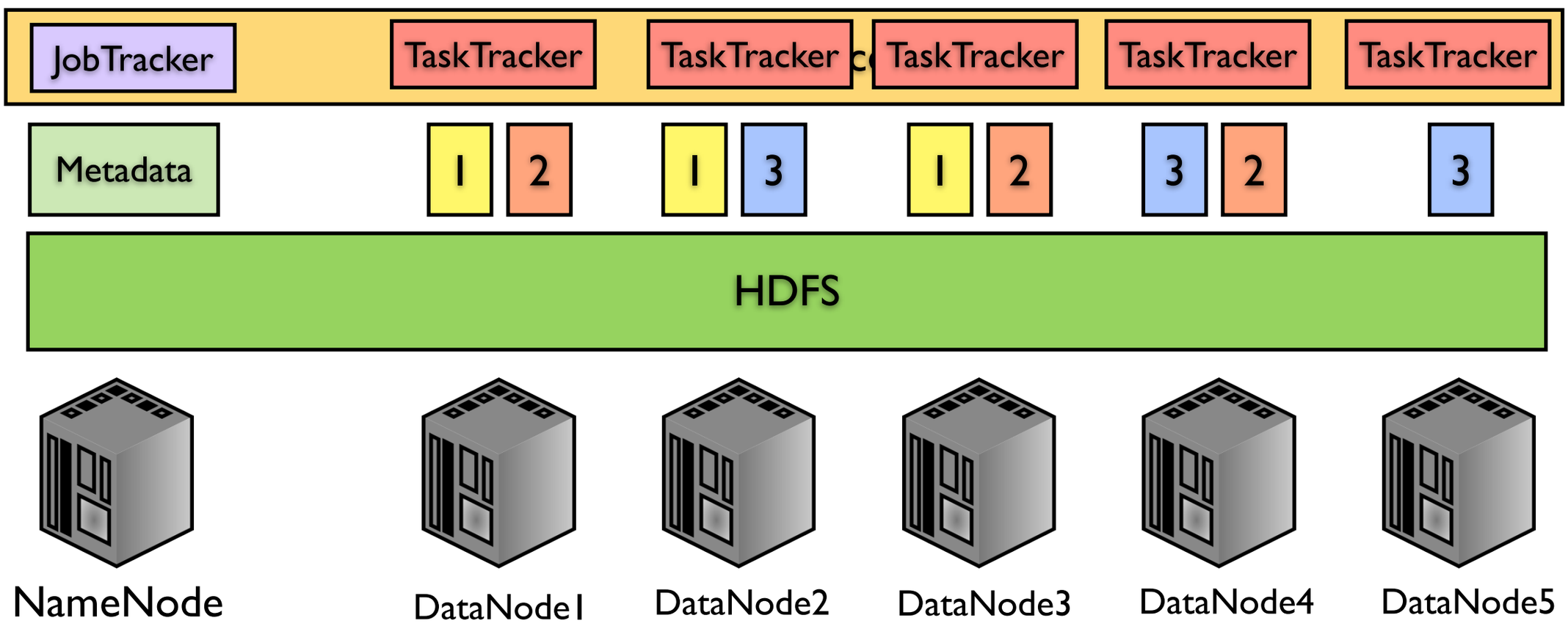

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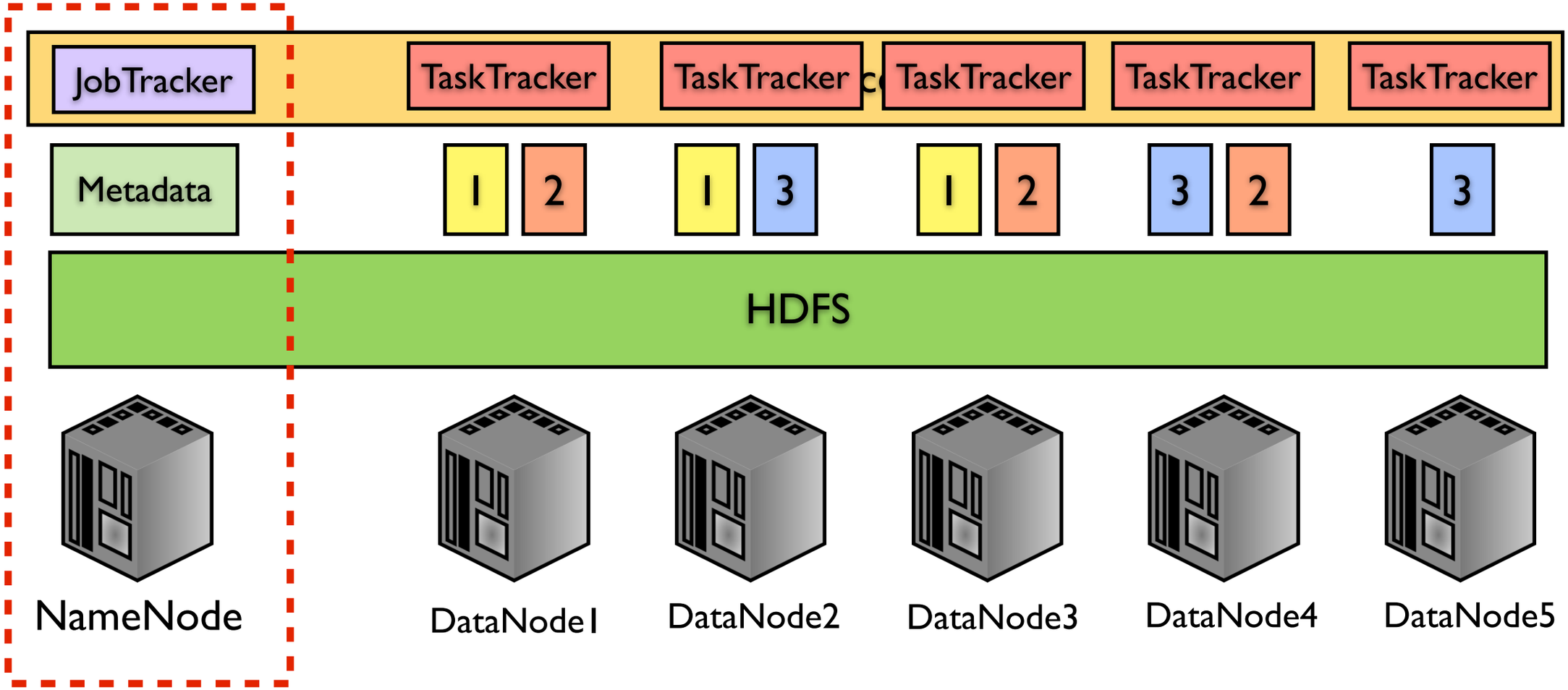

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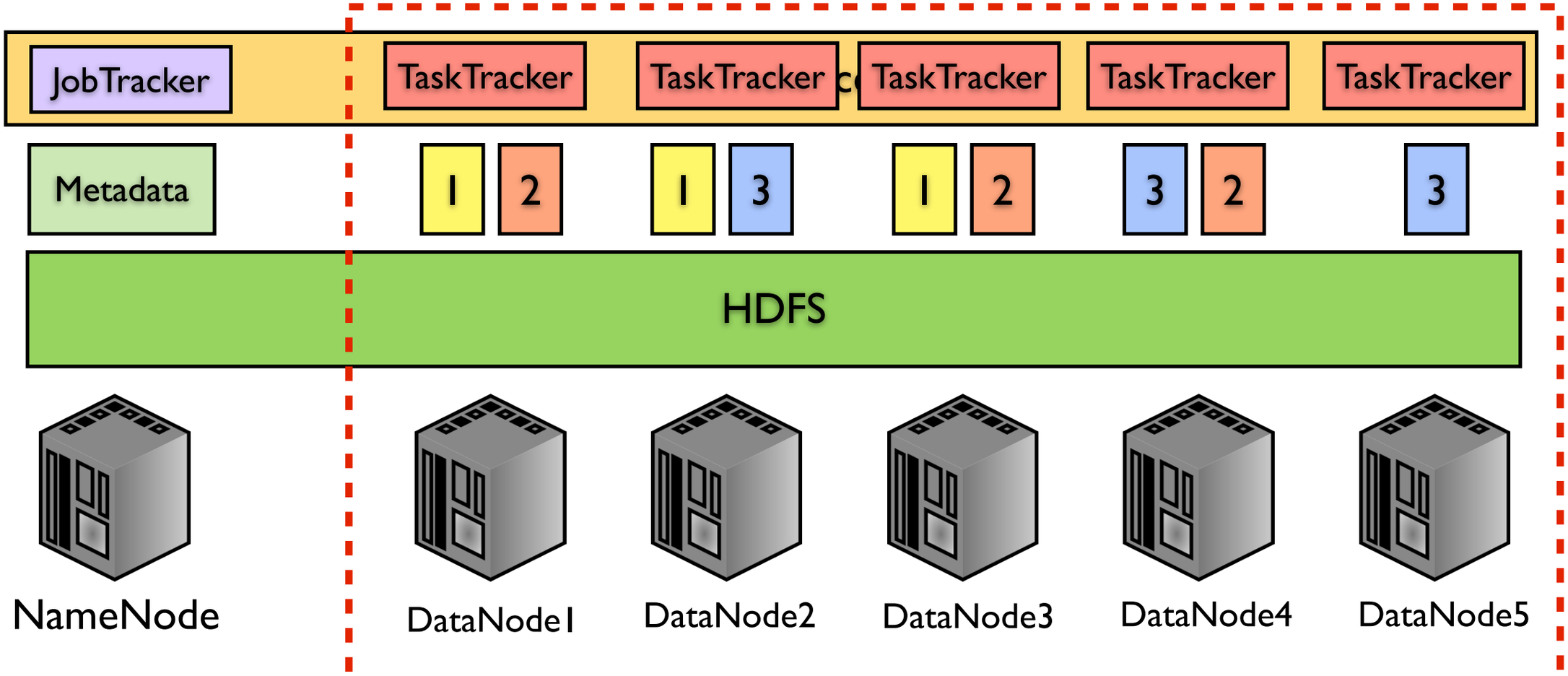


HDFS

- HDFS is responsible for storing data
  - Data is split into blocks and distributed across nodes
  - Each block is replicated

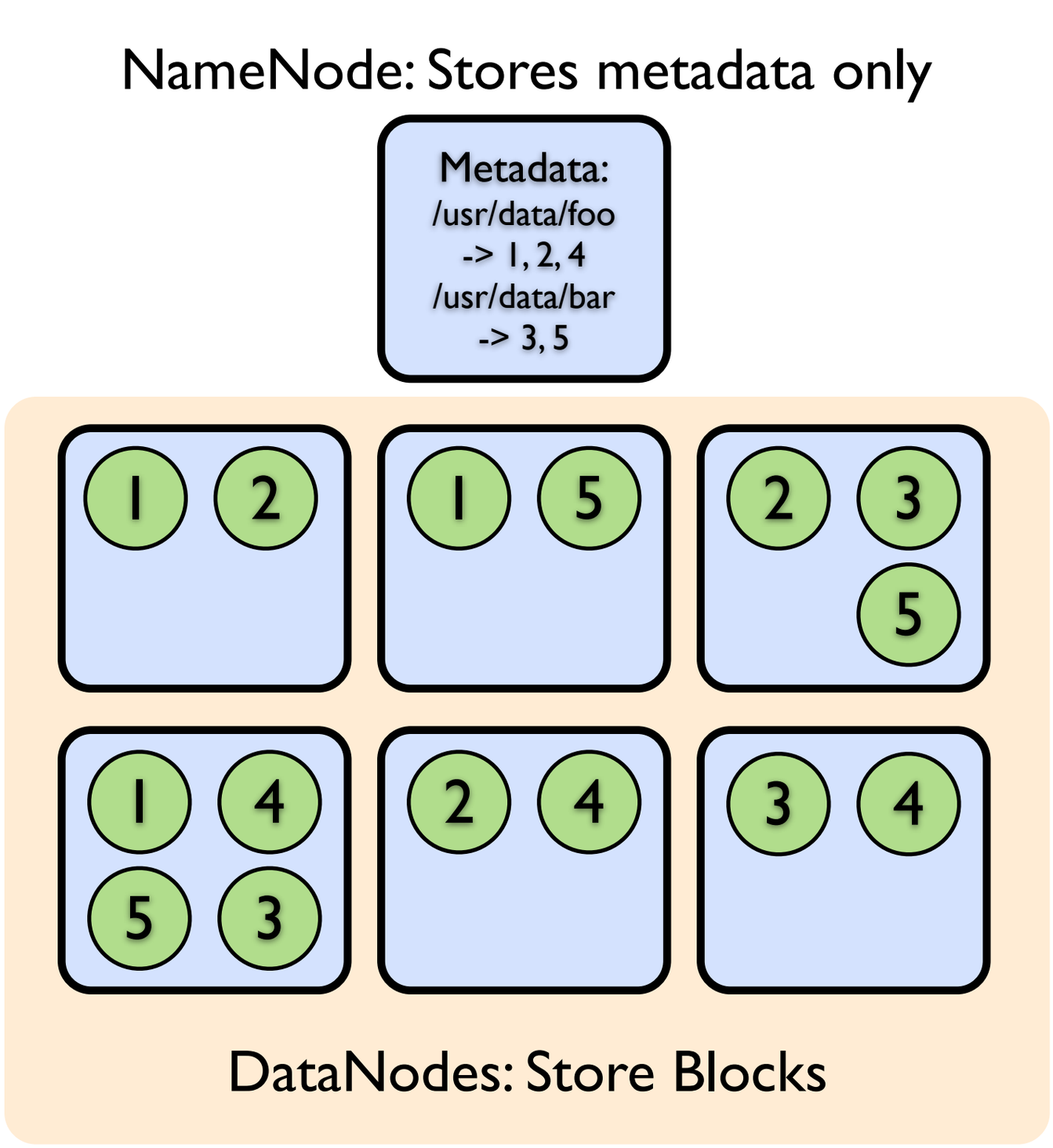
- Implementation of HDFS:
  - Based on Google's GFS
  - Offers redundant storage for massive amounts of data

Getting Data in/out of HDFS

- Hadoop API:
  - Use `hadoop fs` to work with data in HDFS

```
- hadoop fs -copyFromLocal local_dir /hdfs_dir
- hadoop fs -copyToLocal /hdfs_dir local_dir
```

HDFS Example



- NameNode holds metadata for the data files
- DataNodes hold the actual blocks
  - Each block is replicated three times

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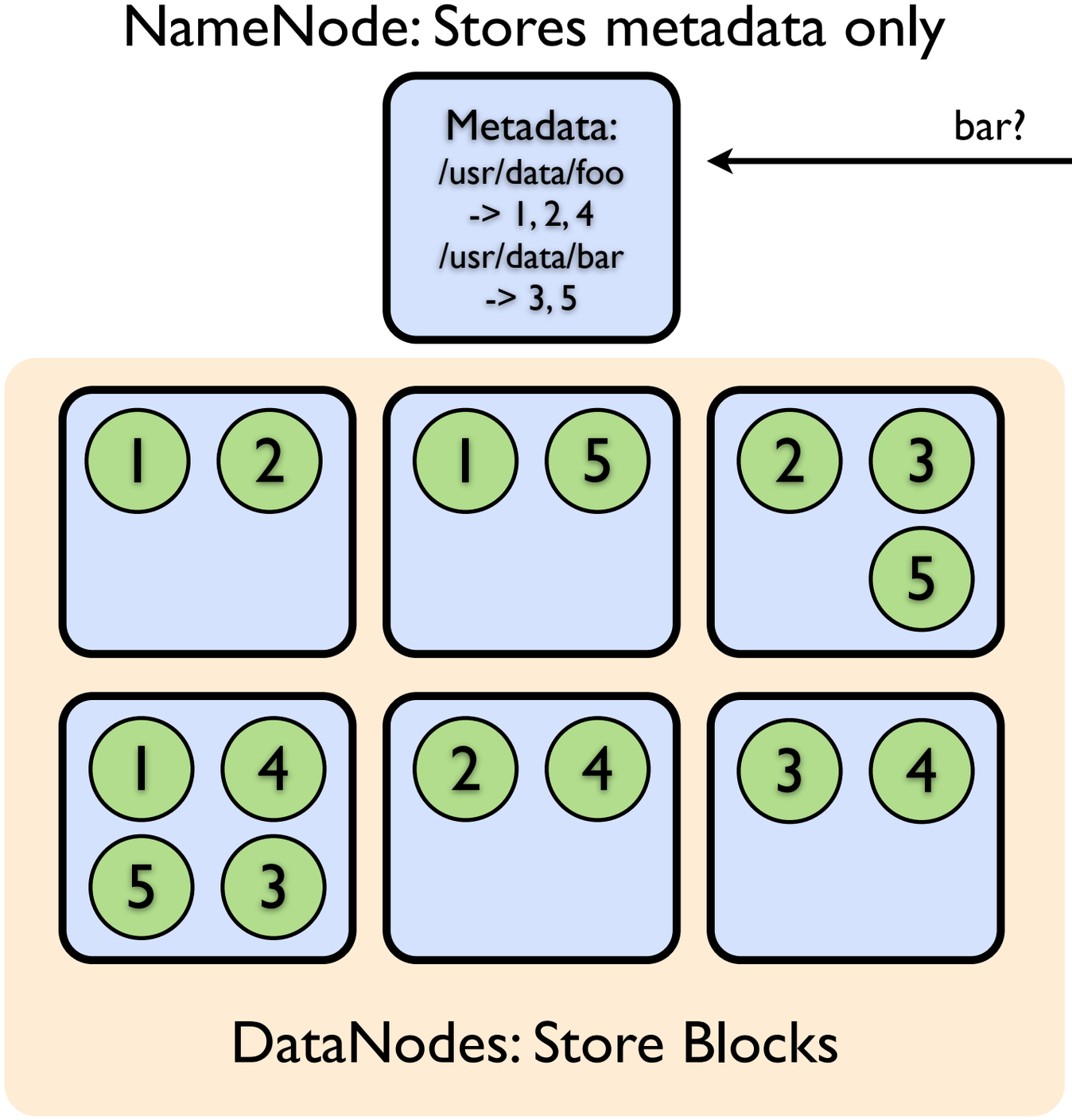

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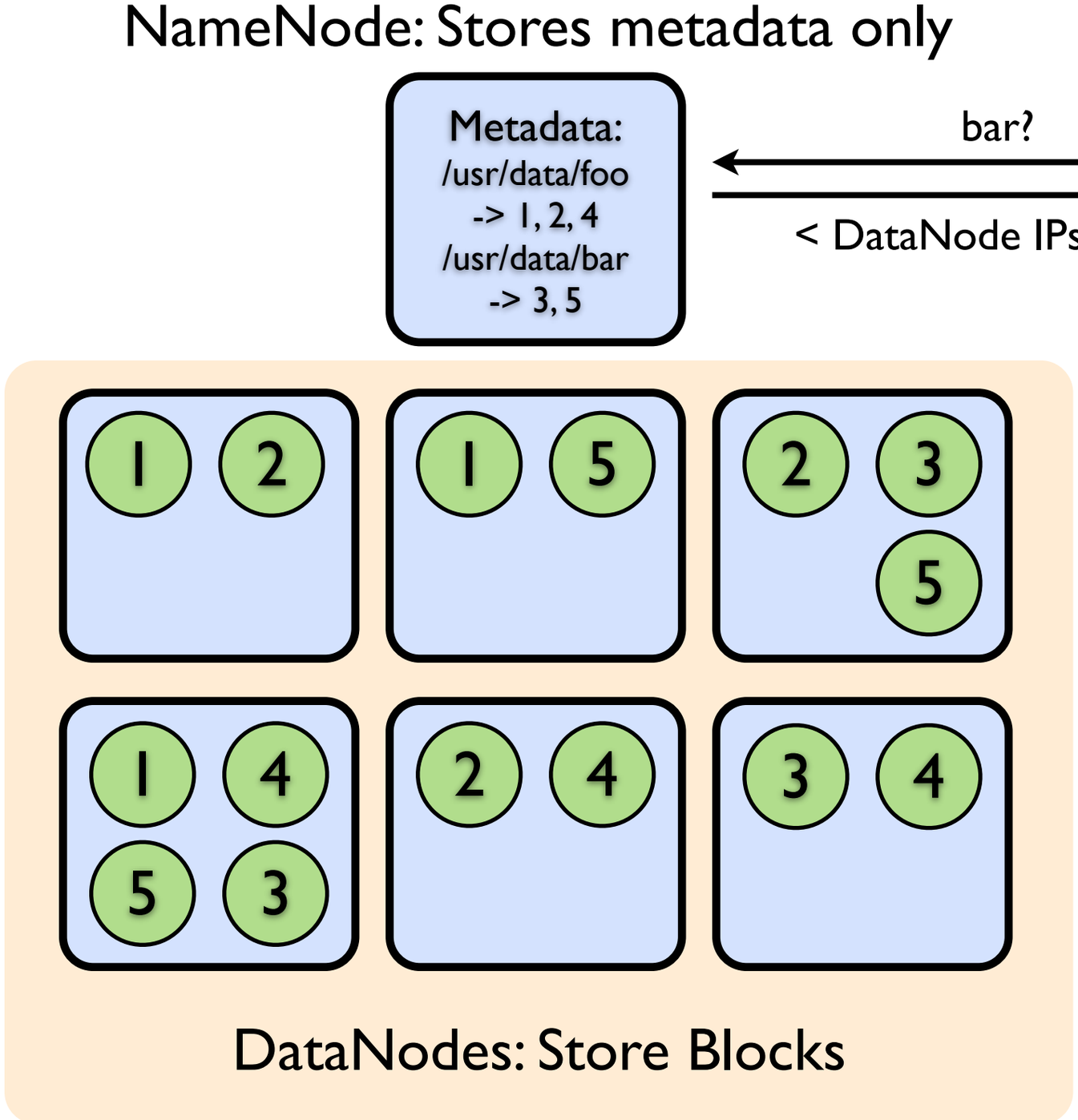

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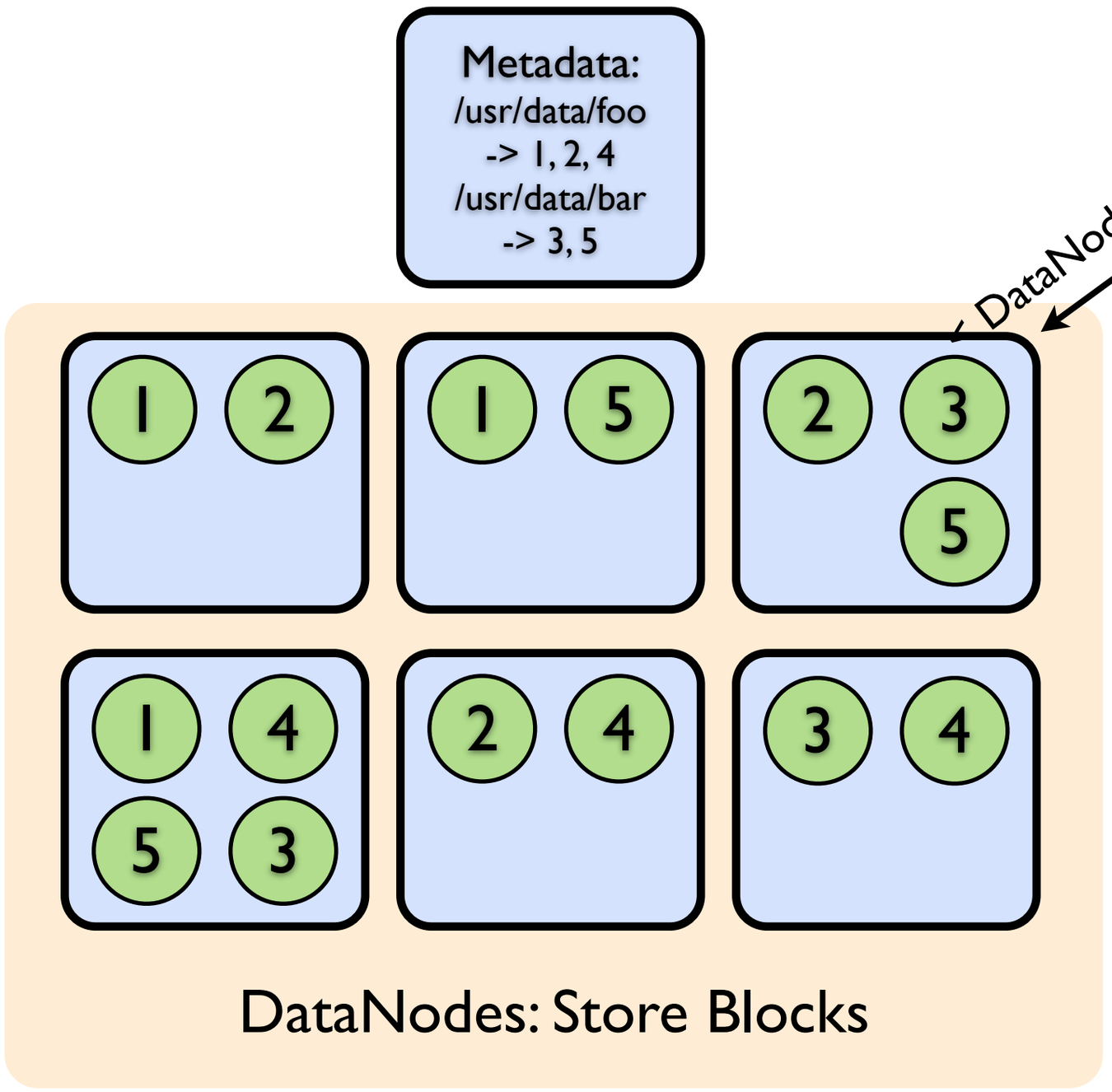

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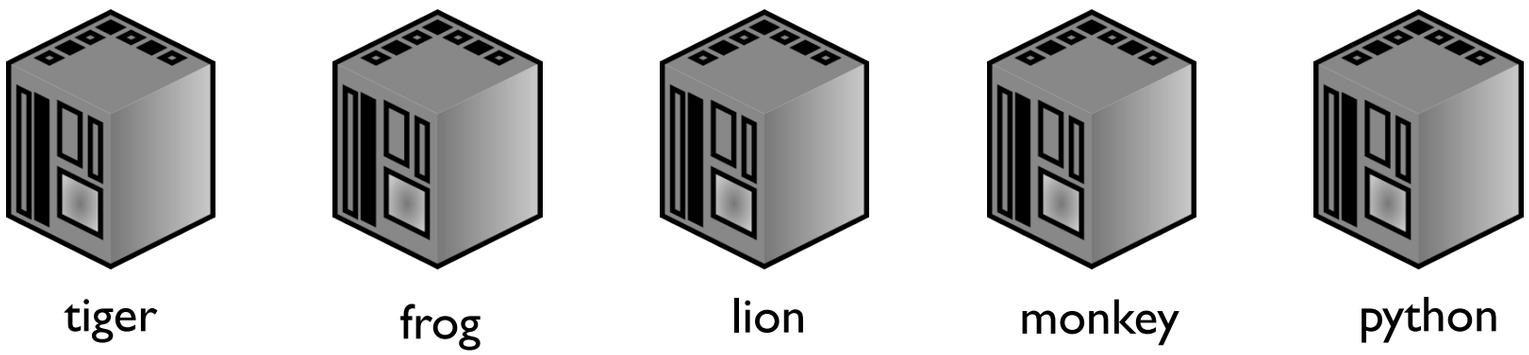
Case Study

- Policy: Assigning blocks based on disk space



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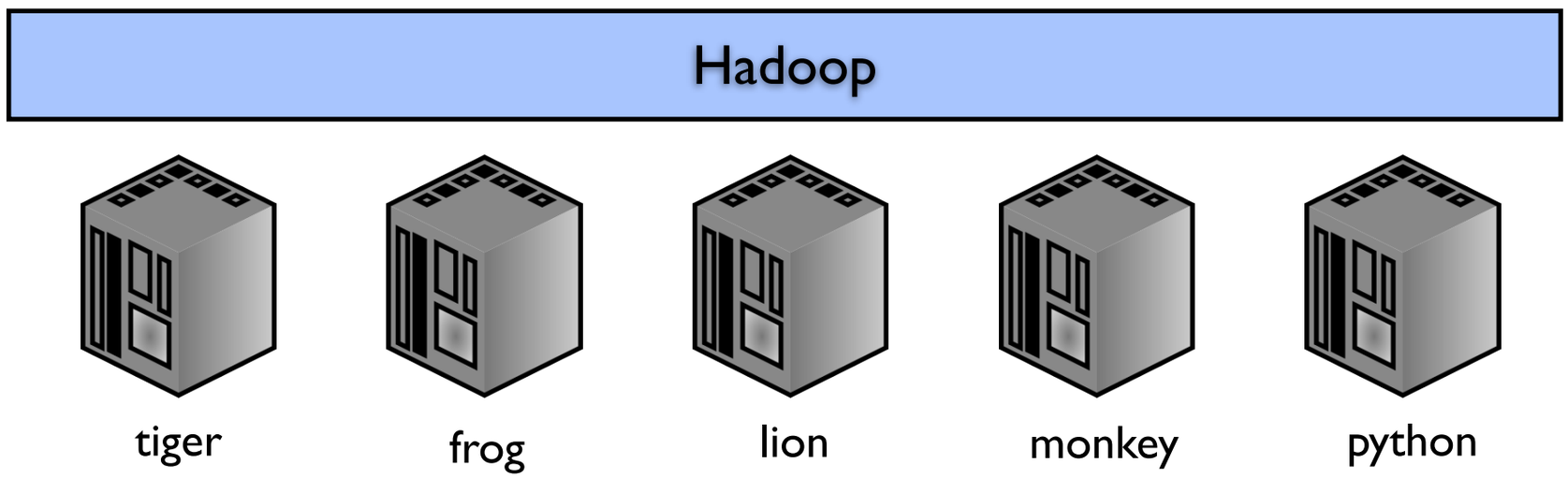

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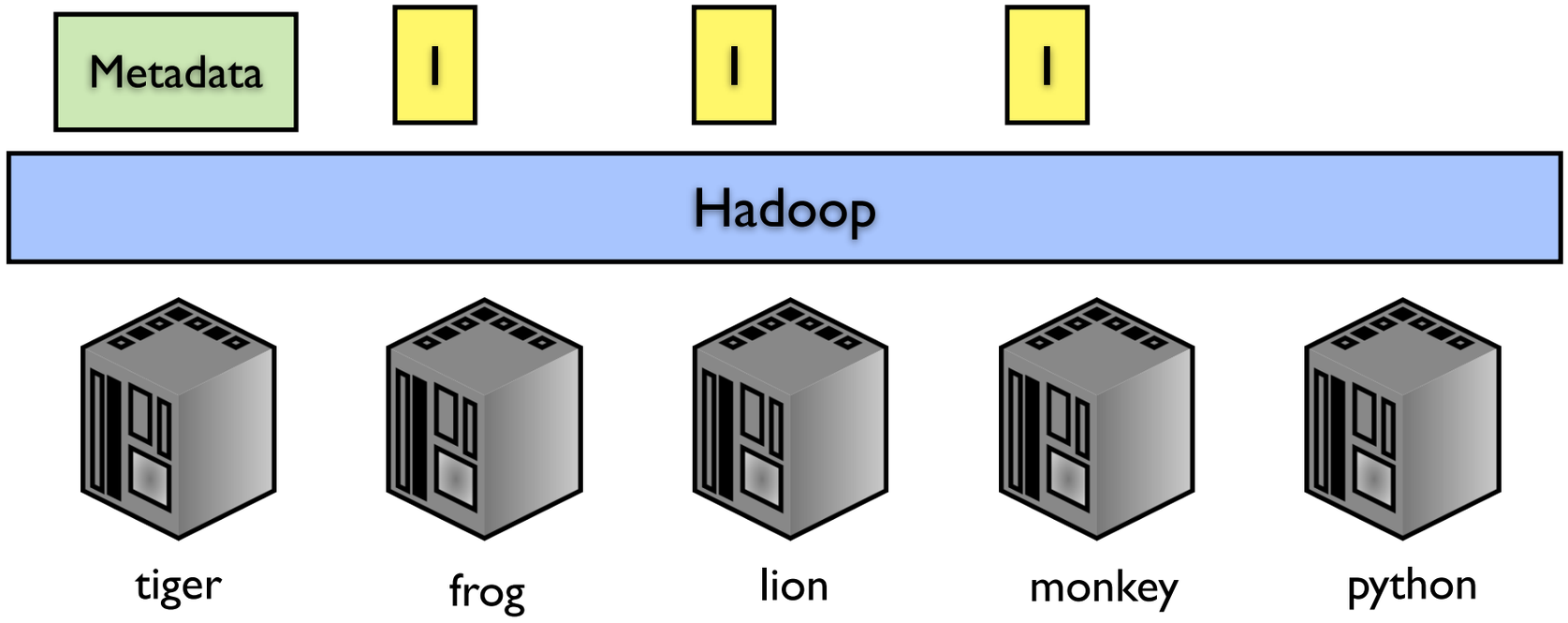

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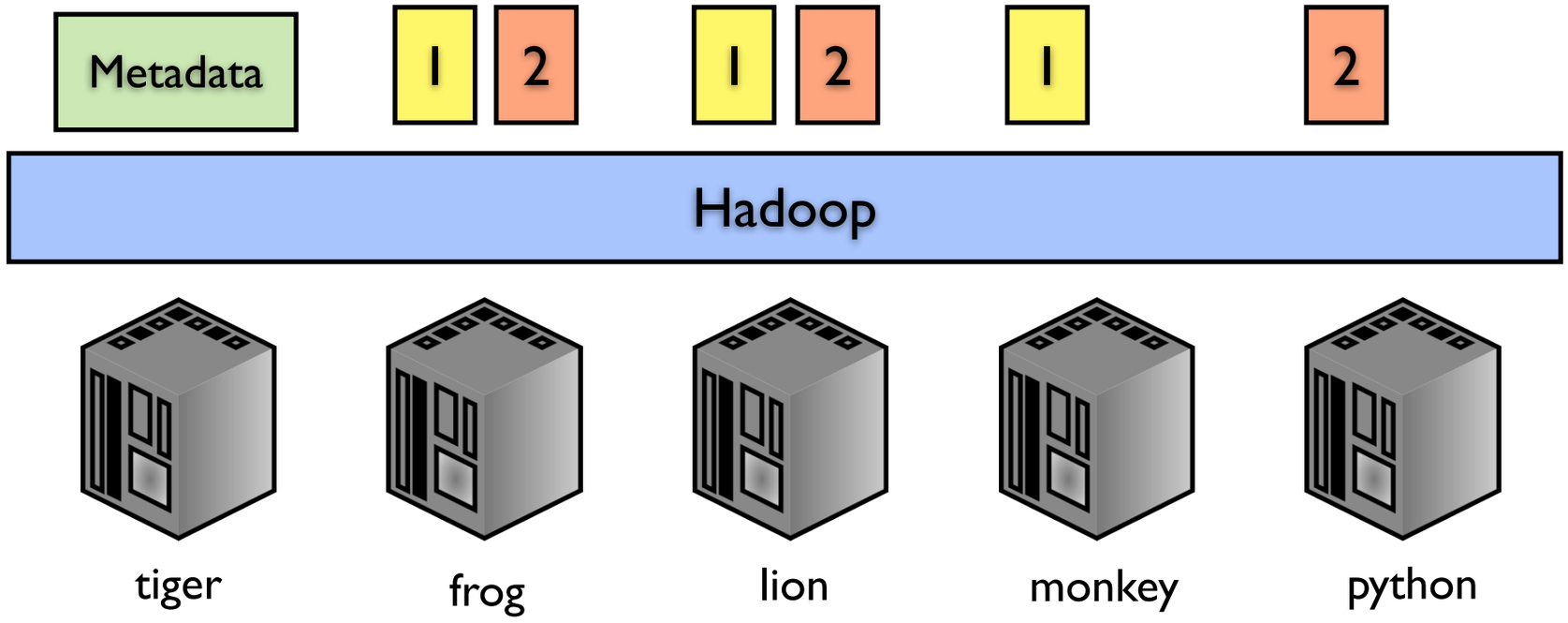

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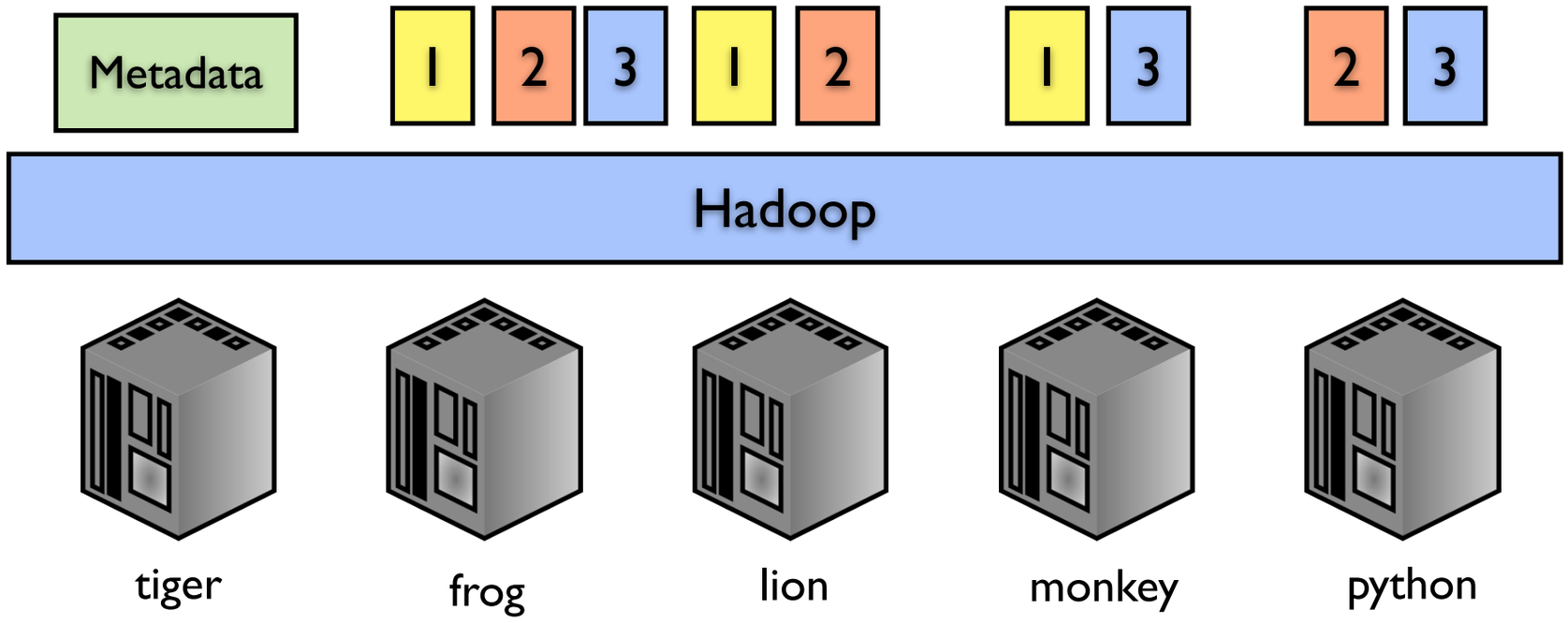

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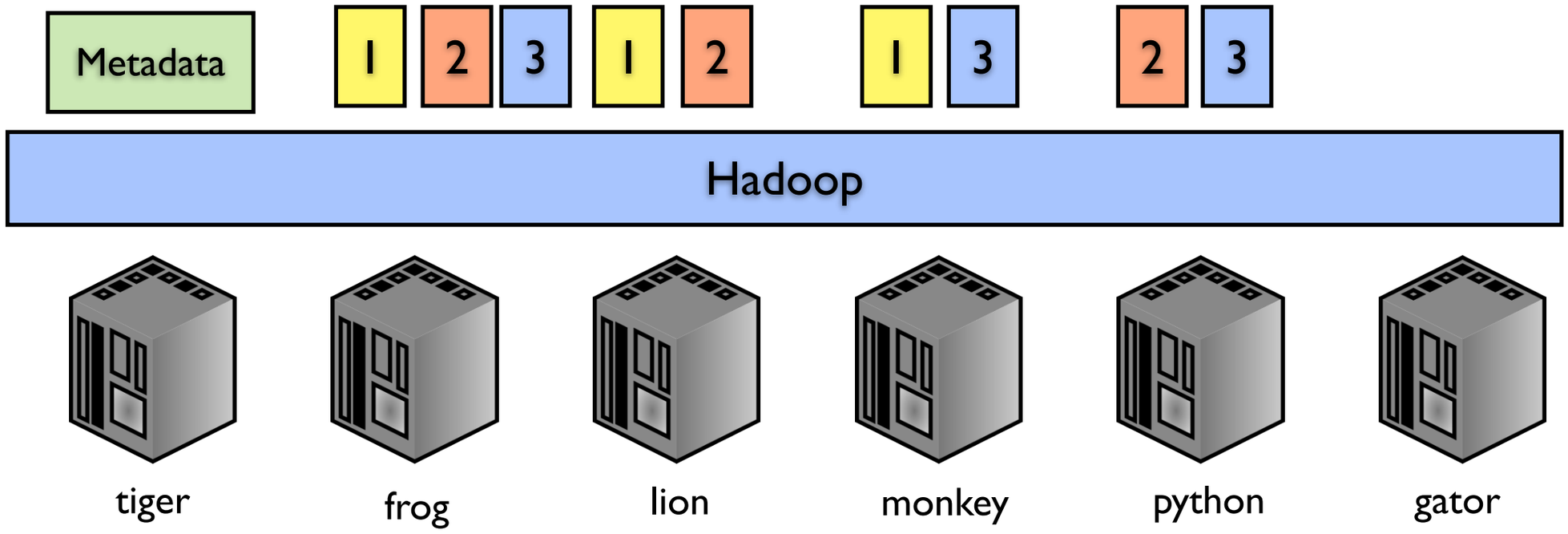
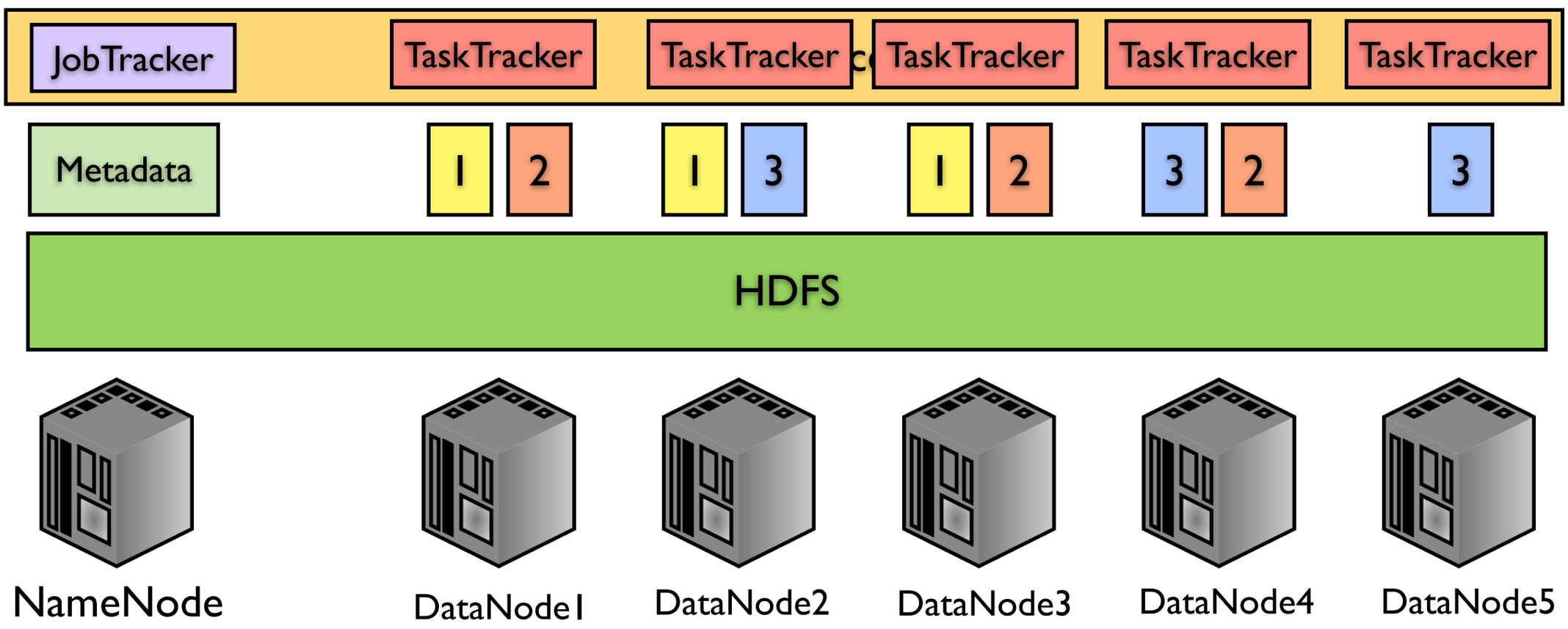


Recall: Hadoop Components

- Two core components
  - The Hadoop distributed file system (HDFS)
  - MapReduce software framework



MapReduce

- A method distributing a task across nodes:
  - Each node processes data stored on that node

- Consists of two phases:
  - Map
  - Reduce

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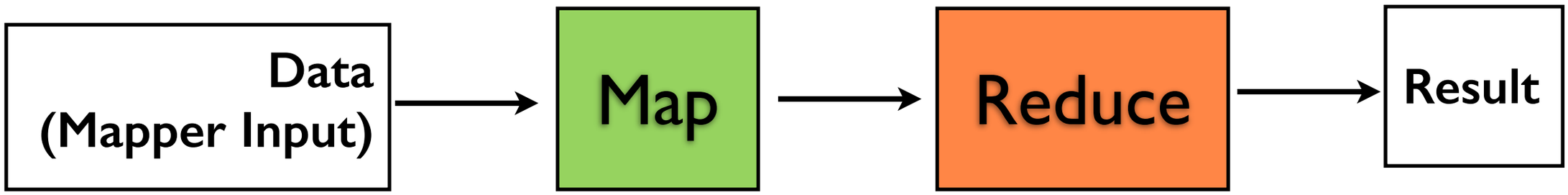

Features of MapReduce

- Automatic parallelization and distribution
- A clean abstraction for programmers
  - MapReduce programs are usually written in Java
- MapReduce abstracts all the housekeeping away from the developer:
  - Developers concentrate on Map and Reduce functions

MapReduce Example: Word Count

Count the # of occurrences of each word in a large amount of input data

```
Map(input_key, input_value) {
  foreach word w in input_value:
    emit(w, 1);
}
```

MapReduce Example: Word Count

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- Input to the Mapper

```
(3414, ‘the cat sat on the mat’)
(3437, ‘the aardvark sat on the sofa’)
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- Output from the Mapper

```
(‘the’, 1), (‘cat’, 1), (‘sat’, 1), (‘on’, 1),
(‘the’, 1), (‘mat’, 1), (‘the’, 1), (‘aardvark’, 1),
(‘sat’, 1), (‘on’, 1), (‘the’, 1), (‘sofa’, 1)
```

Map Phase

Mapper Input

```
the cat sat on the mat
the aardvark sat on the sofa
```

Map Phase

Mapper Input

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the cat sat on the mat
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Mapper Output

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('the', 1),
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Reducer

- After the Map, all the intermediate values for a given intermediate key are combined together into a list

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Mapper Output

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('the', 1),
('aardvark', 1),
('sat', 1),
('on', 1),
('the', 1),
('sofa', 1)
```

Reducer Input

```
aardvark, 1
cat, 1
mat, 1
on [1, 1]
sat [1, 1]
sofa, 1
the [1, 1, 1, 1]
```

Reducer

Add up all the values associated with each intermediate key:

```
Reduce(output_key, intermediate_vals) {
  set count = 0;
  foreach v in intermediate_vals:
    count += v;
  emit(output_key, count);
}
```

Reducer

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  set count = 0;
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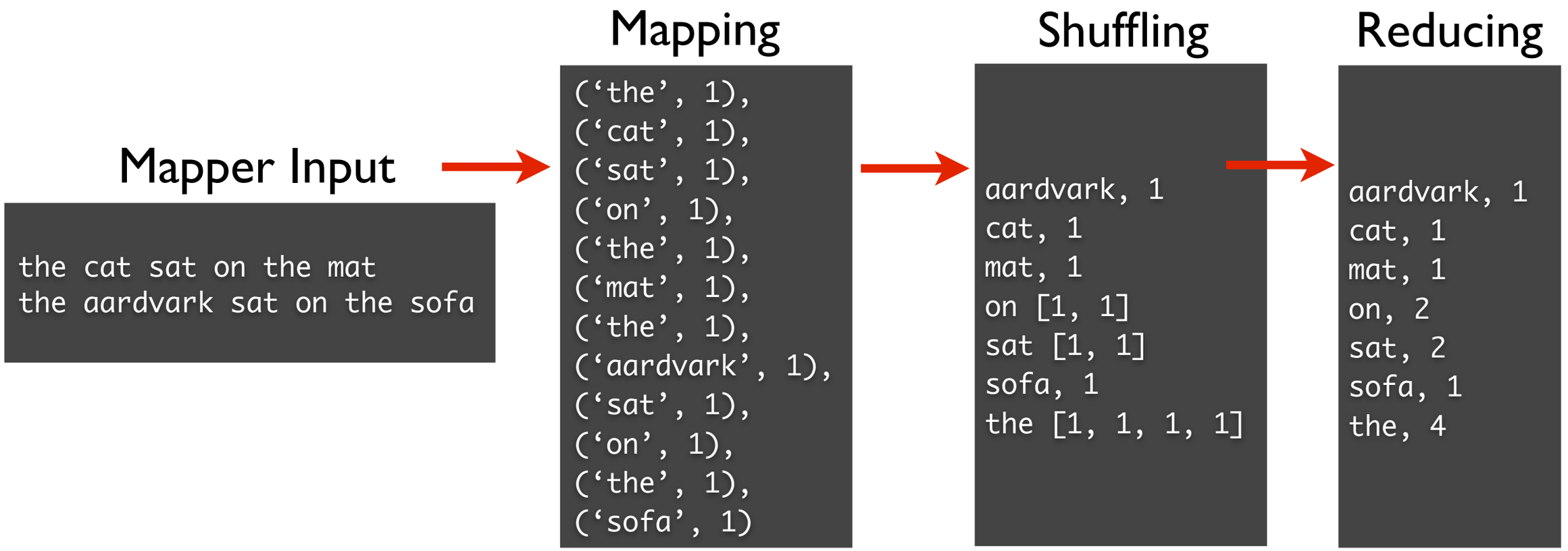
}
```

- Output from the Reducer

```
('the', 4), ('sat', 2), ('on', 2), ('sofa', 1),
('mat', 1), ('cat', 1), ('aardvark', 1)
```

Map + Reduce


Mapper Input
the cat sat on the mat
the aardvark sat on the sofa
Mapping
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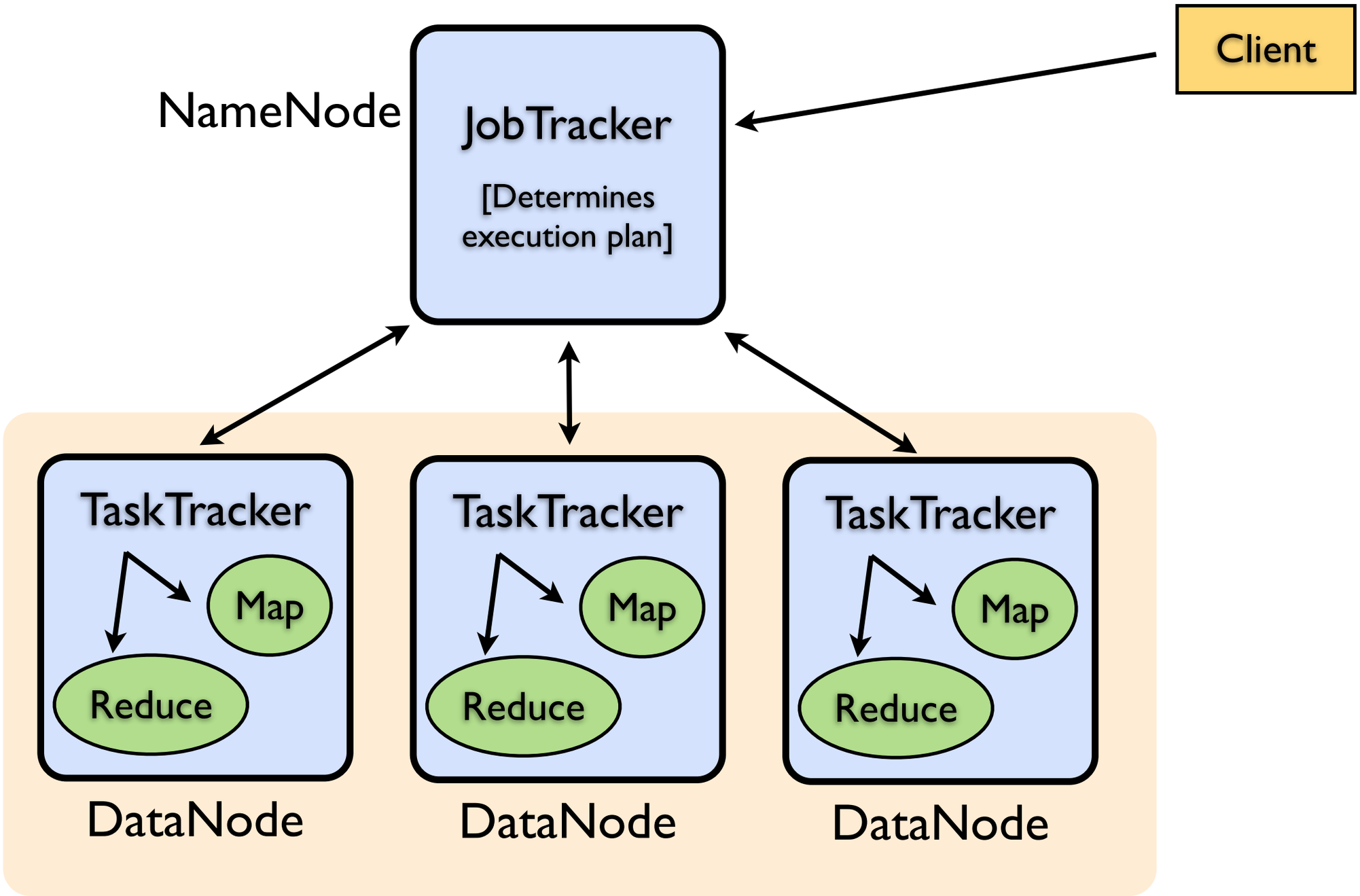
('cat', 1),
('sat', 1),
('on', 1),
('the', 1),
('mat', 1),
('the', 1),
('aardvark', 1),
('sat', 1),
('on', 1),
('the', 1),
('sofa', 1)
Shuffling
aardvark, 1
cat, 1
mat, 1
on [1, 1]
sat [1, 1]
sofa, 1
the [1, 1, 1, 1]
Reducing
aardvark, 1
cat, 1
mat, 1
on, 2
sat, 2
sofa, 1
the, 4

Why we care about counting words

- Word count is challenging over massive amounts of data
- Fundamentals of statistics often are aggregate functions
- Most aggregation functions have distributive nature
- MapReduce breaks complex tasks into smaller pieces which can be executed in parallel

Deployment


NameNode
JobTracker
[Determines execution plan]
Client
TaskTracker
Map
Reduce
DataNode
TaskTracker
Map
Reduce
DataNode
TaskTracker
Map
Reduce
DataNode

Discussions

Lecture Outline

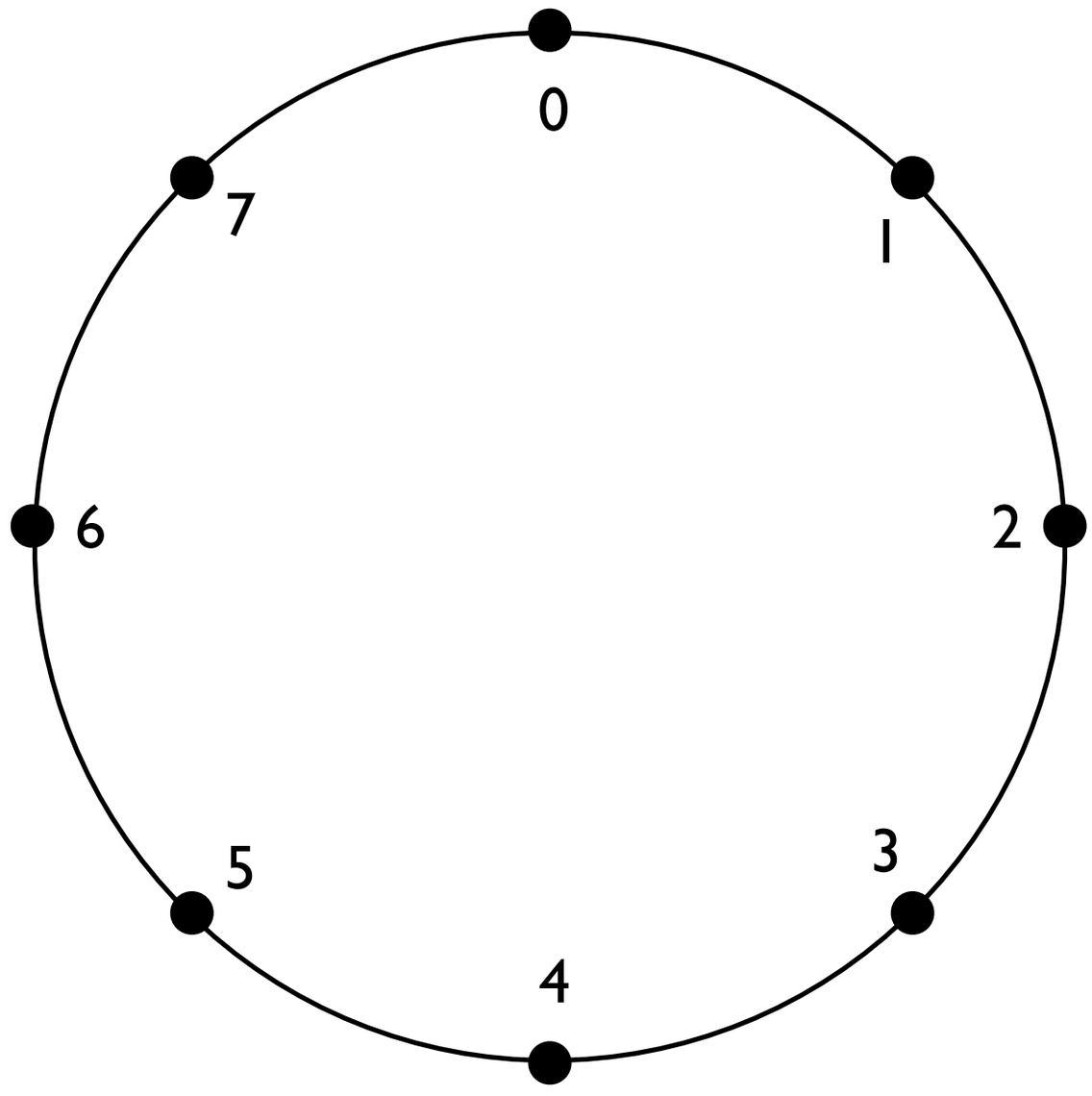
- Introduction
- Hadoop
- Chord

Lecture Outline

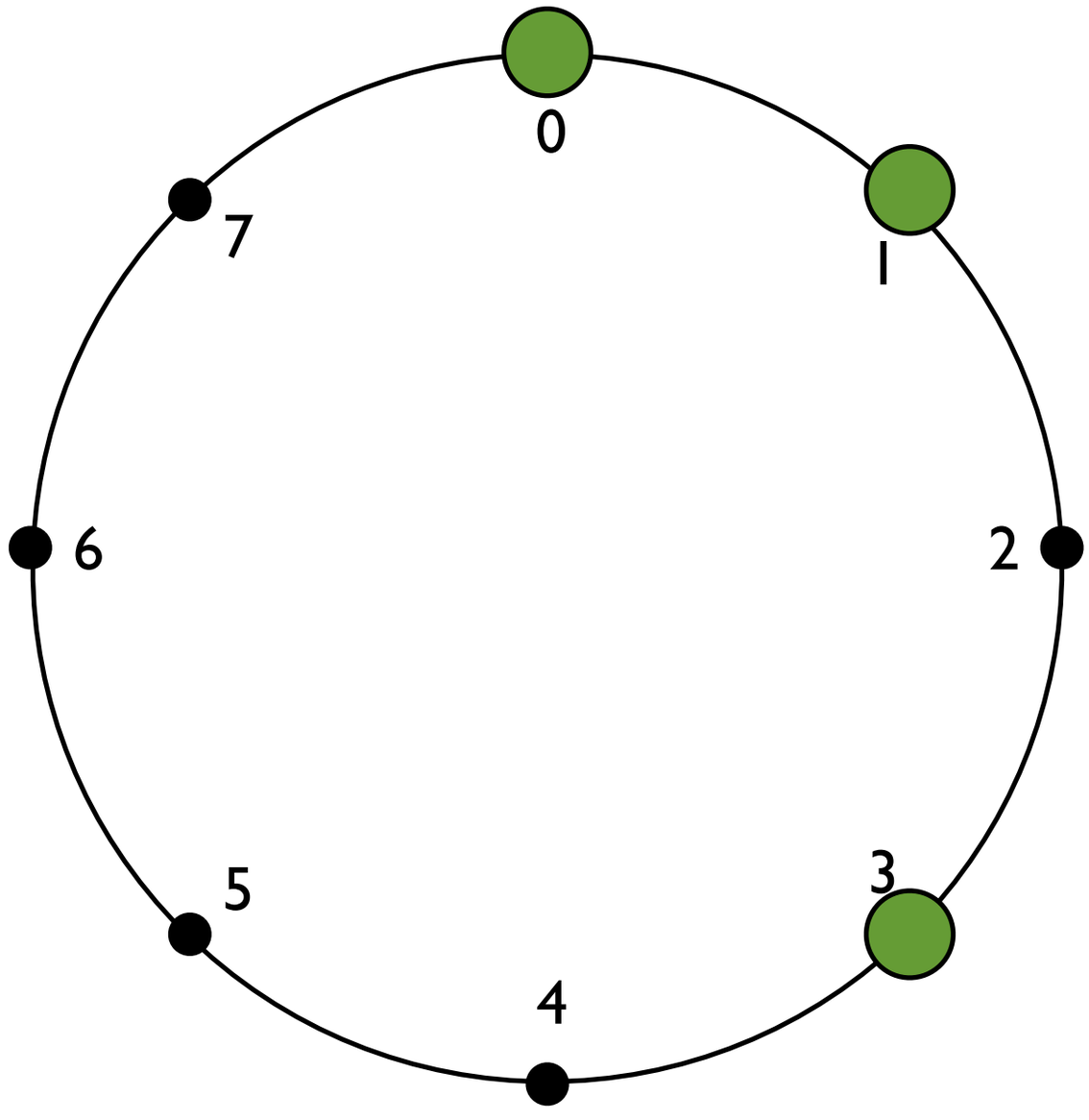
- Introduction
- Hadoop
- Chord

Why Chord?

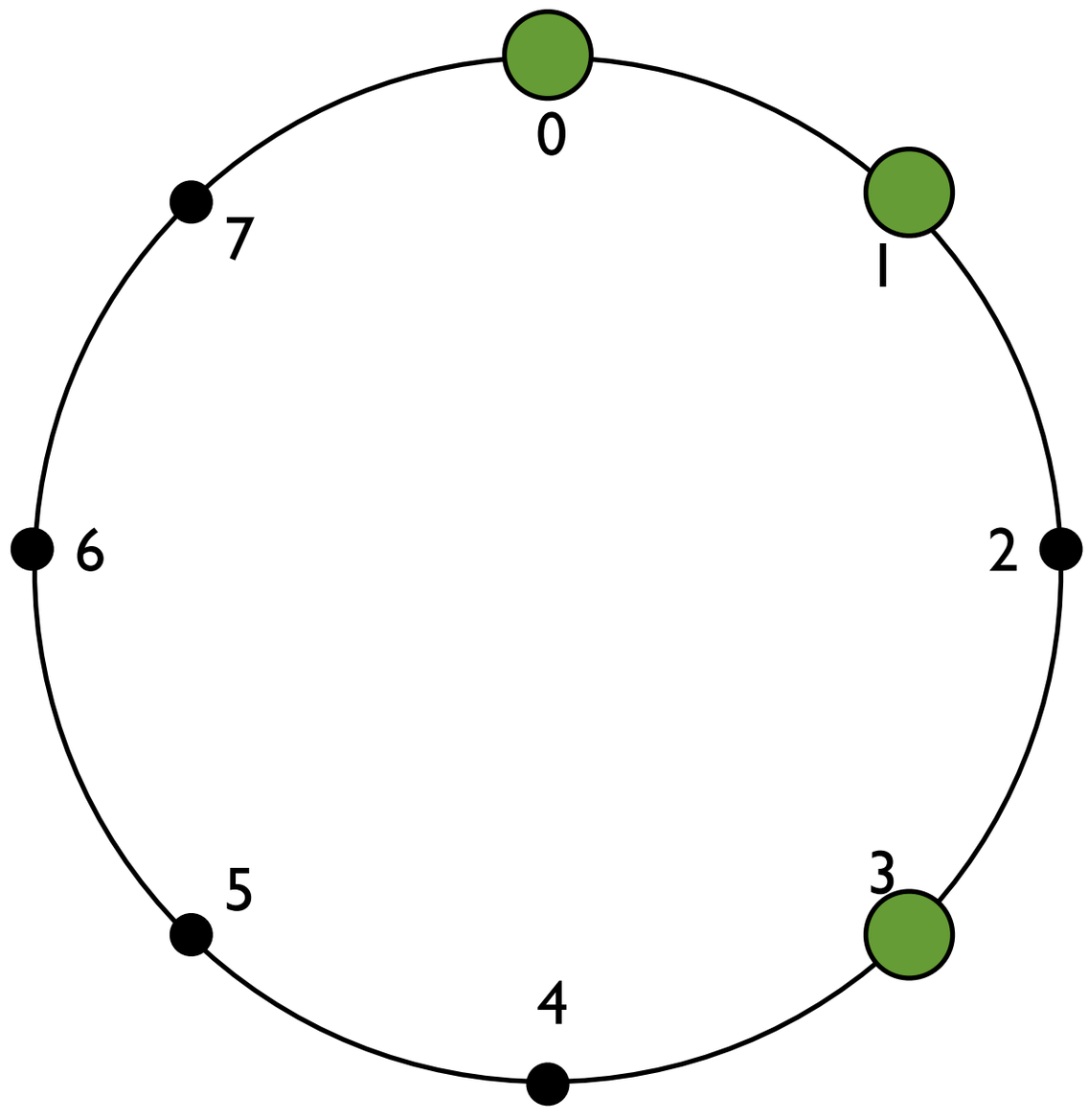
Chord



Chord



Chord

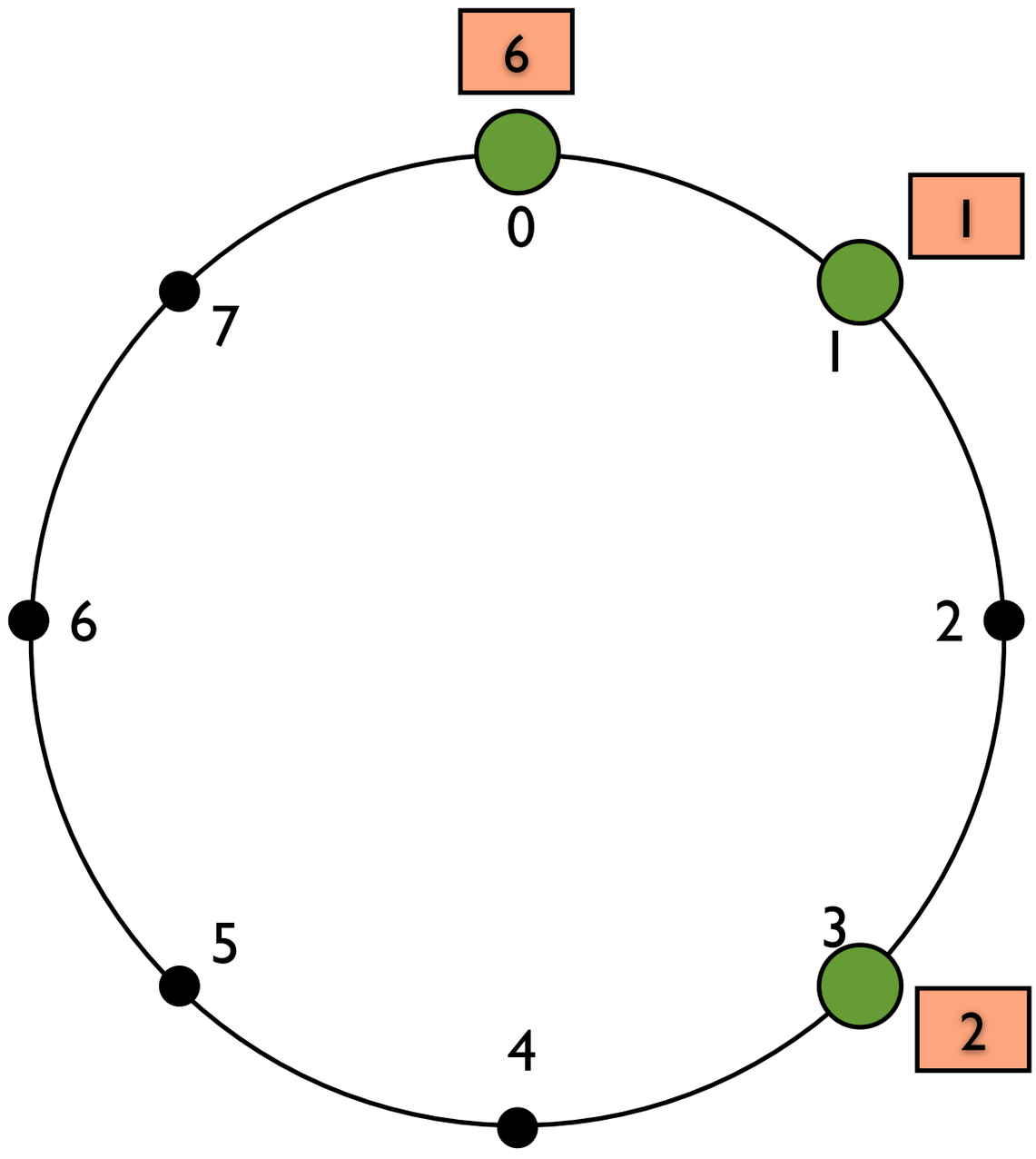


1

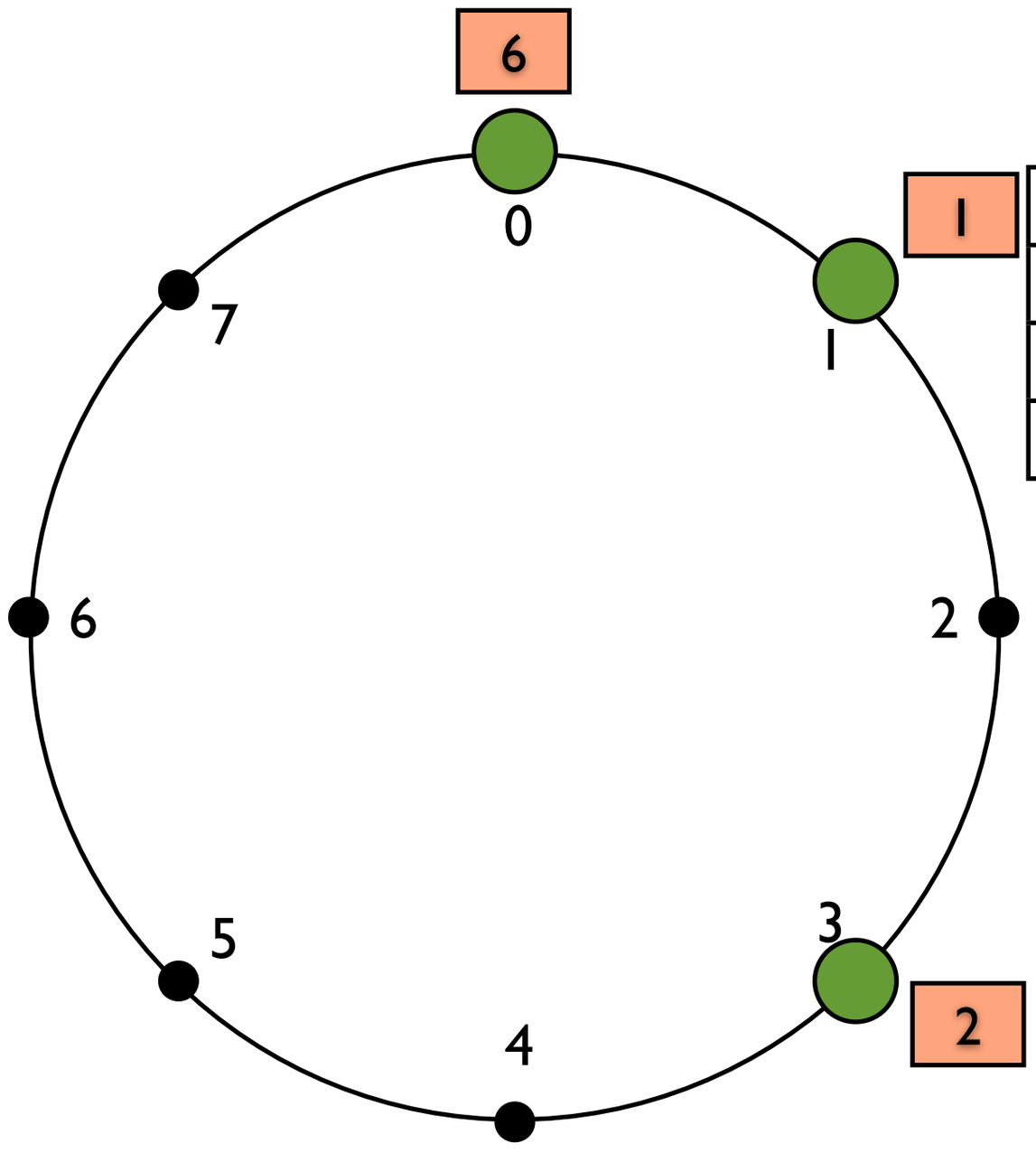
2

6

Chord

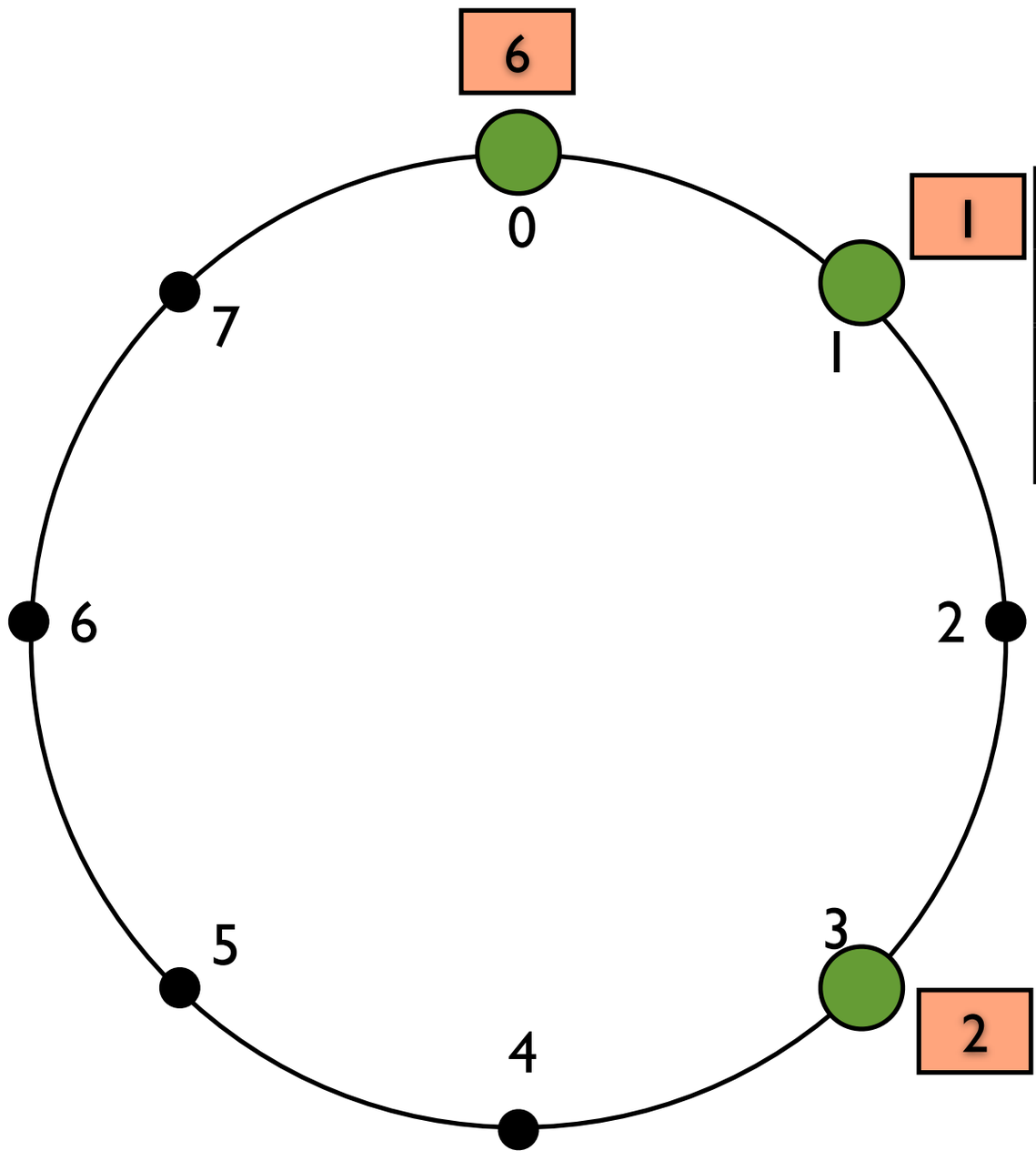


Chord



start	int.	succ.
2	[2,3)	3
3	[3,5)	3
5	[5,1)	0

Chord

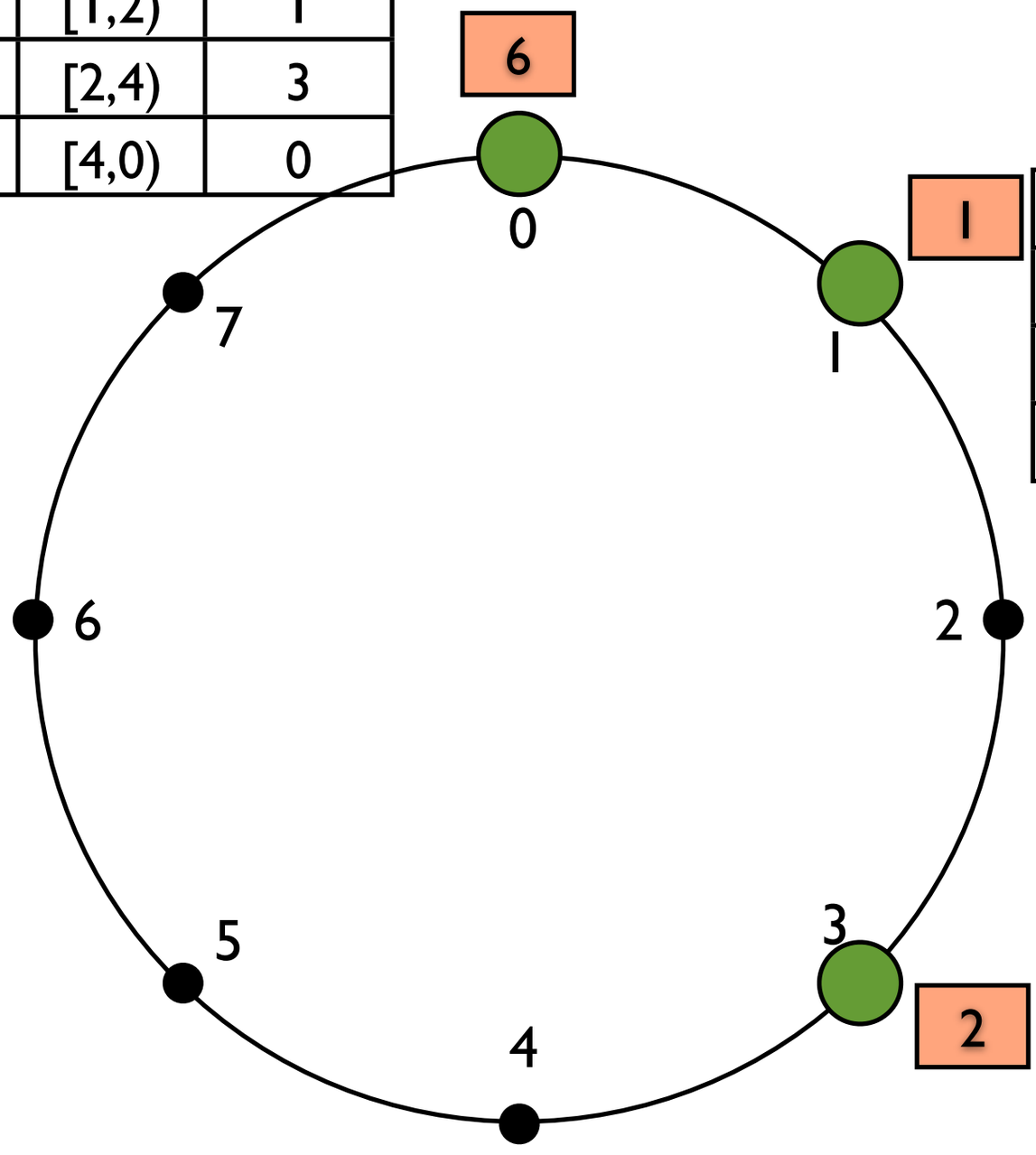


start	int.	succ.
2	[2,3)	3
3	[3,5)	3
5	[5,1)	0

start	int.	succ.
4	[4,5)	0
5	[5,7)	0
7	[7,3)	0

Chord

start	int.	succ.
1	[1,2)	1
2	[2,4)	3
4	[4,0)	0



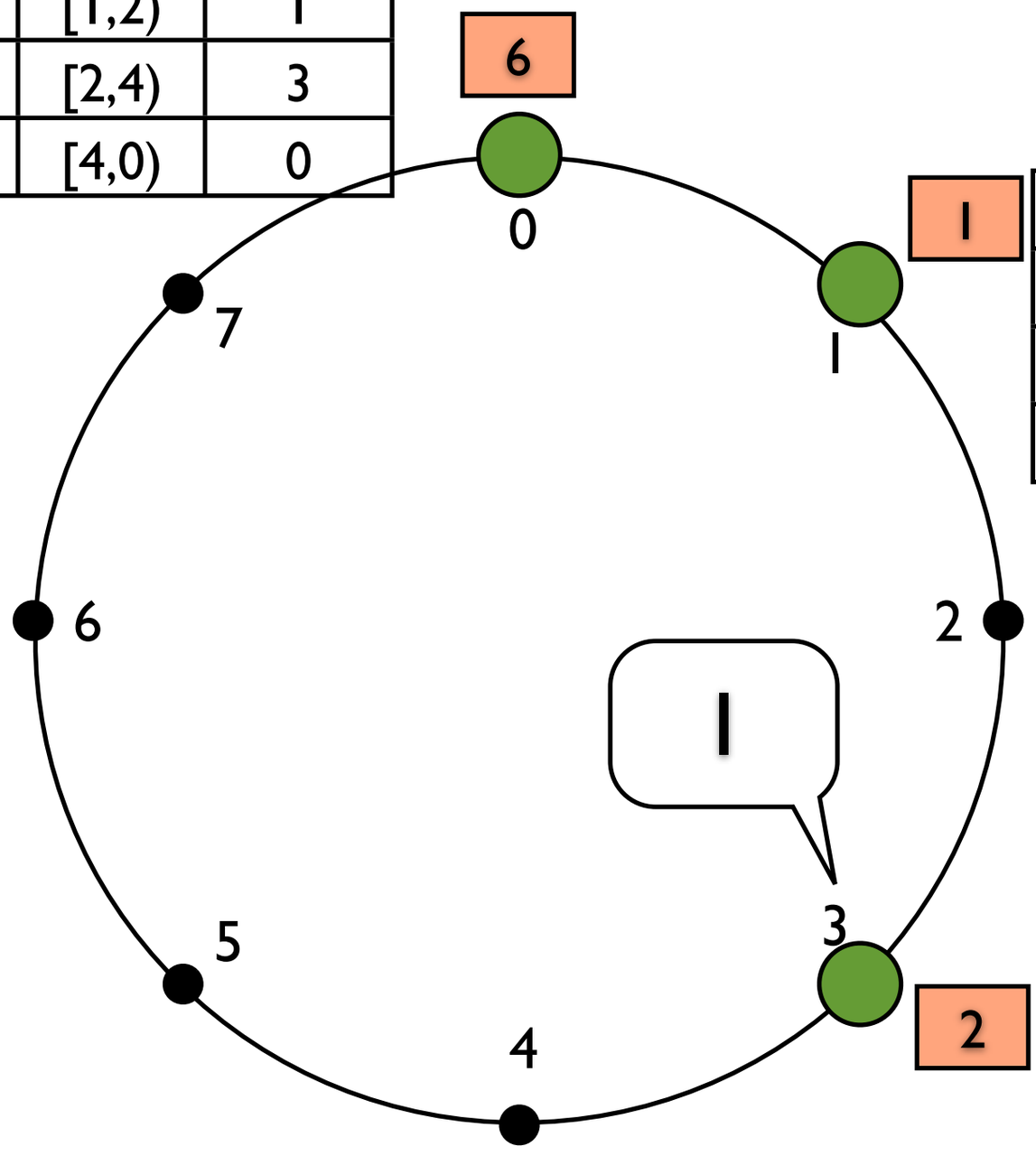
1

start	int.	succ.
2	[2,3)	3
3	[3,5)	3
5	[5,1)	0

start	int.	succ.
4	[4,5)	0
5	[5,7)	0
7	[7,3)	0

Chord

start	int.	succ.
1	[1,2)	1
2	[2,4)	3
4	[4,0)	0

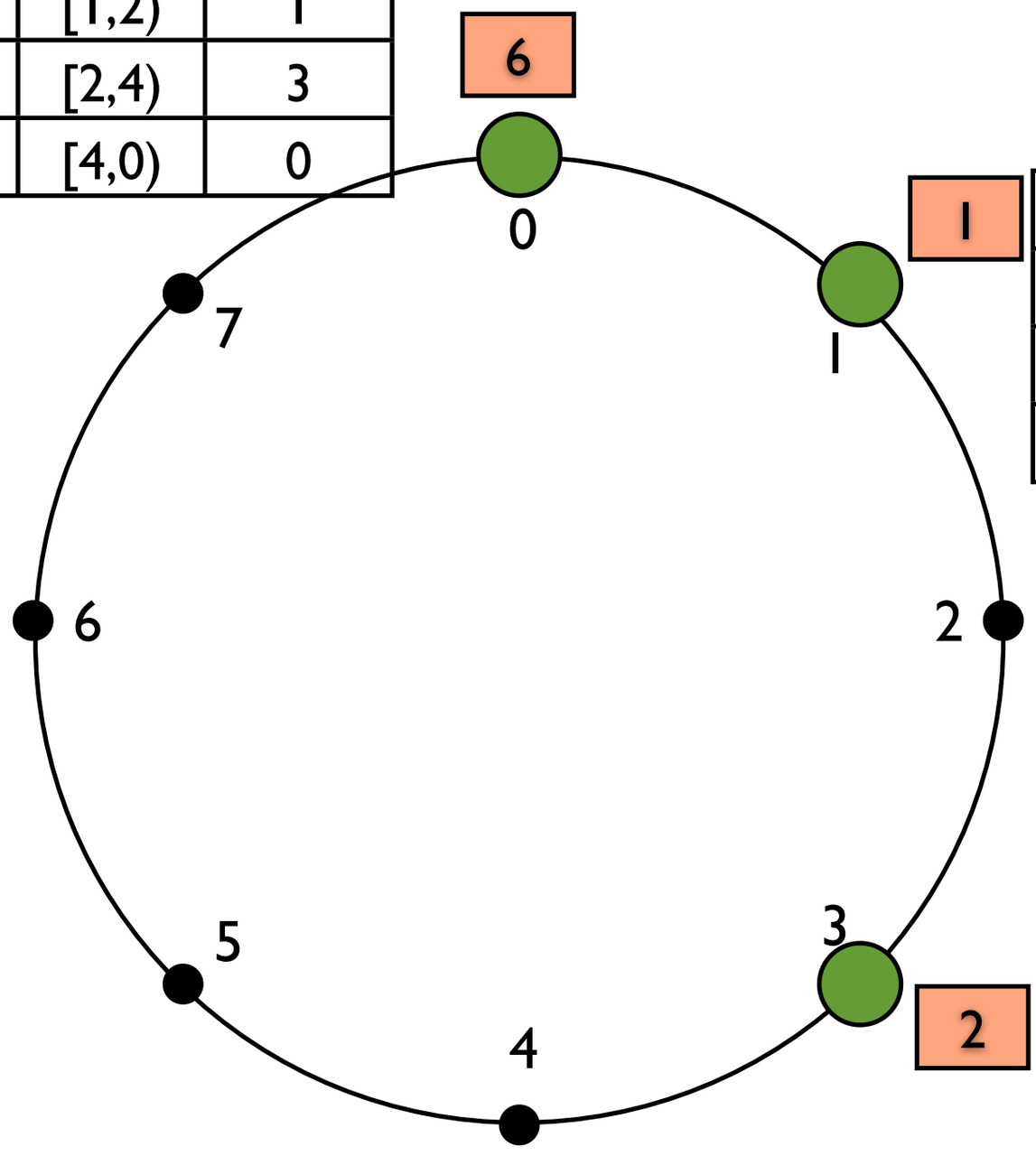


start	int.	succ.
2	[2,3)	3
3	[3,5)	3
5	[5,1)	0

start	int.	succ.
4	[4,5)	0
5	[5,7)	0
7	[7,3)	0

Importance: Complexity!

start	int.	succ.
1	[1,2)	1
2	[2,4)	3
4	[4,0)	0

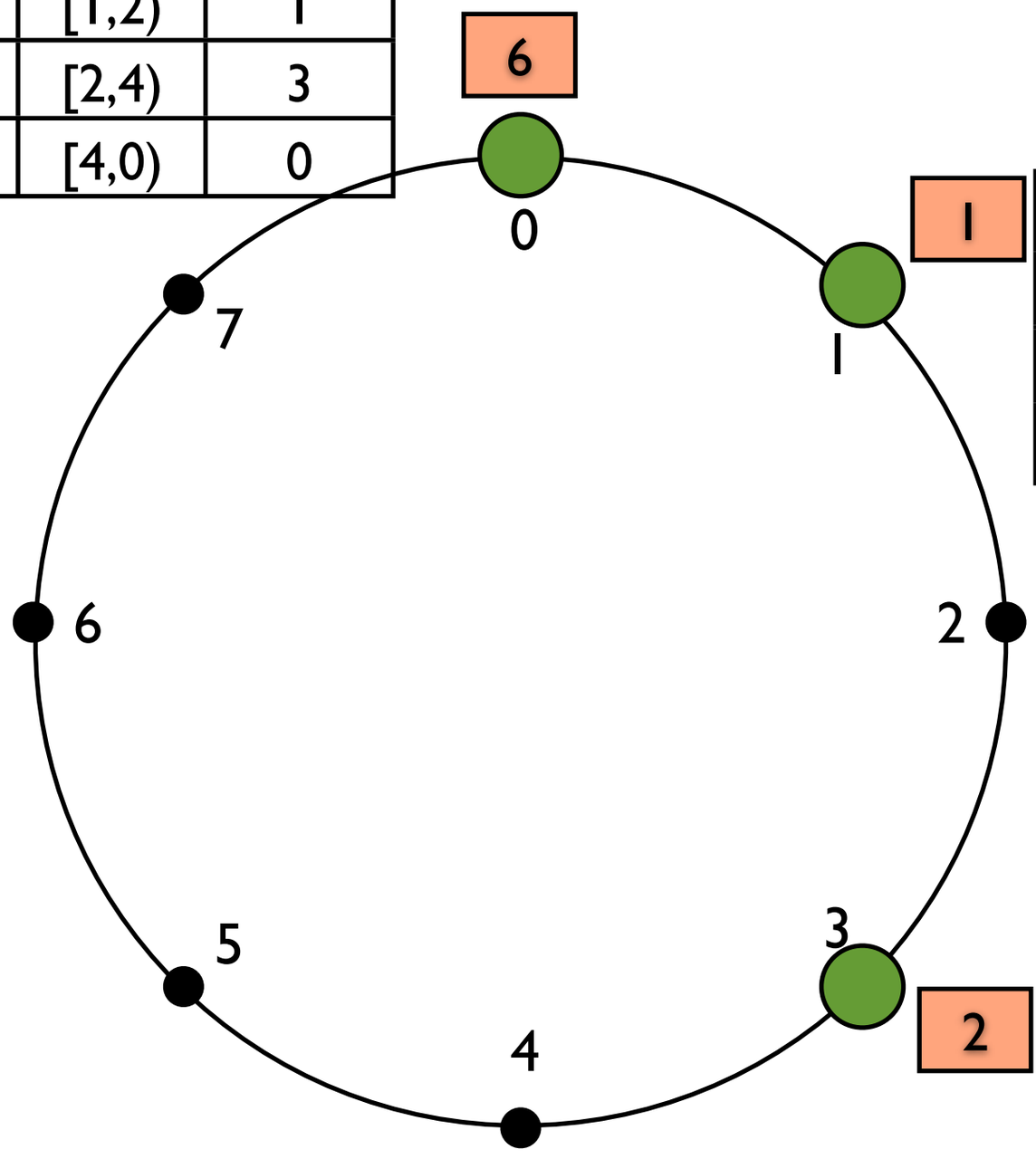


1	start	int.	succ.
	2	[2,3)	3
	3	[3,5)	3
	5	[5,1)	0

2	start	int.	succ.
	4	[4,5)	0
	5	[5,7)	0
	7	[7,3)	0

Node Joins

start	int.	succ.
1	[1,2)	1
2	[2,4)	3
4	[4,0)	0



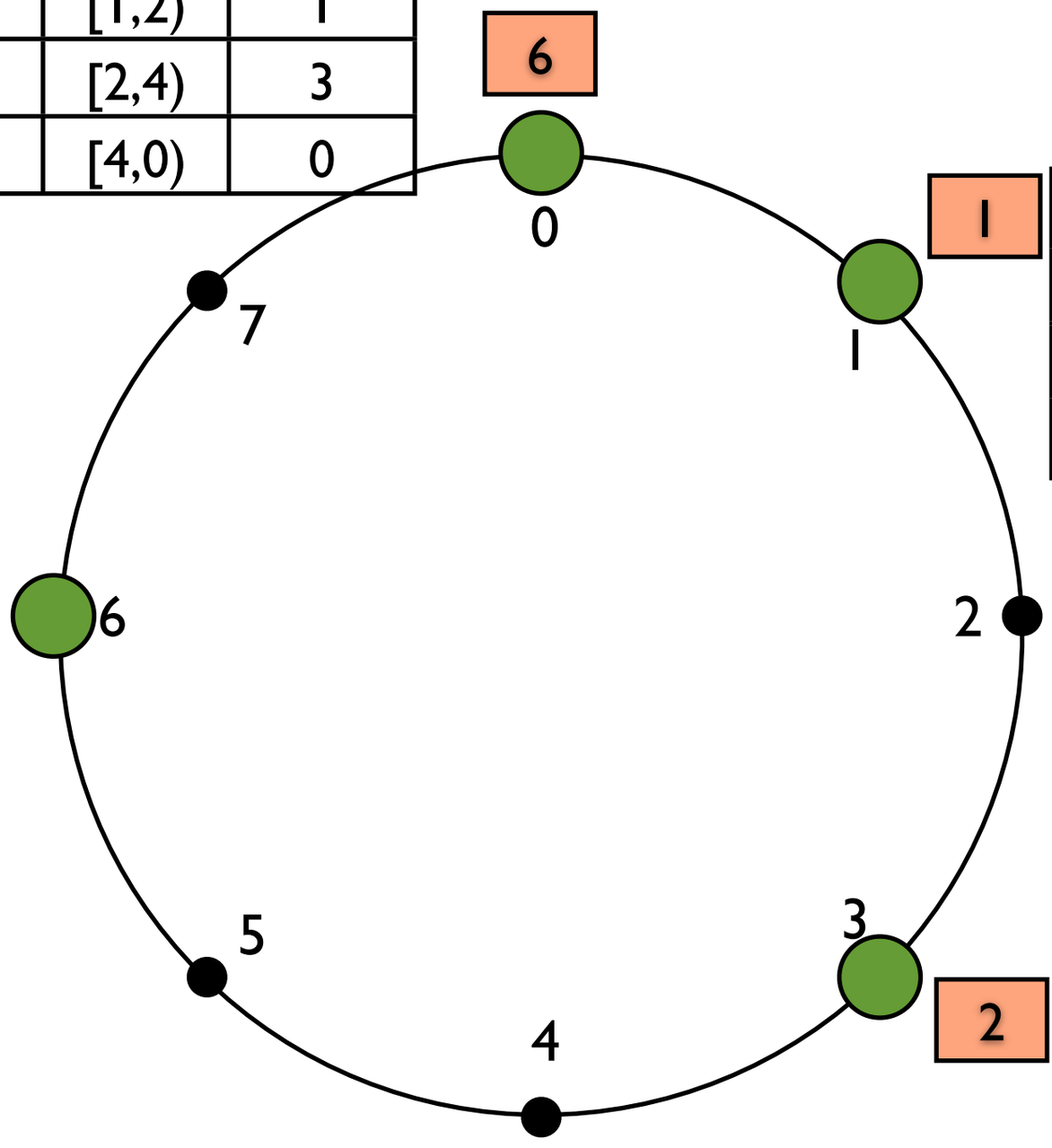
1

start	int.	succ.
2	[2,3)	3
3	[3,5)	3
5	[5,1)	0

start	int.	succ.
4	[4,5)	0
5	[5,7)	0
7	[7,3)	0

Node Joins

start	int.	succ.
1	[1,2)	1
2	[2,4)	3
4	[4,0)	0

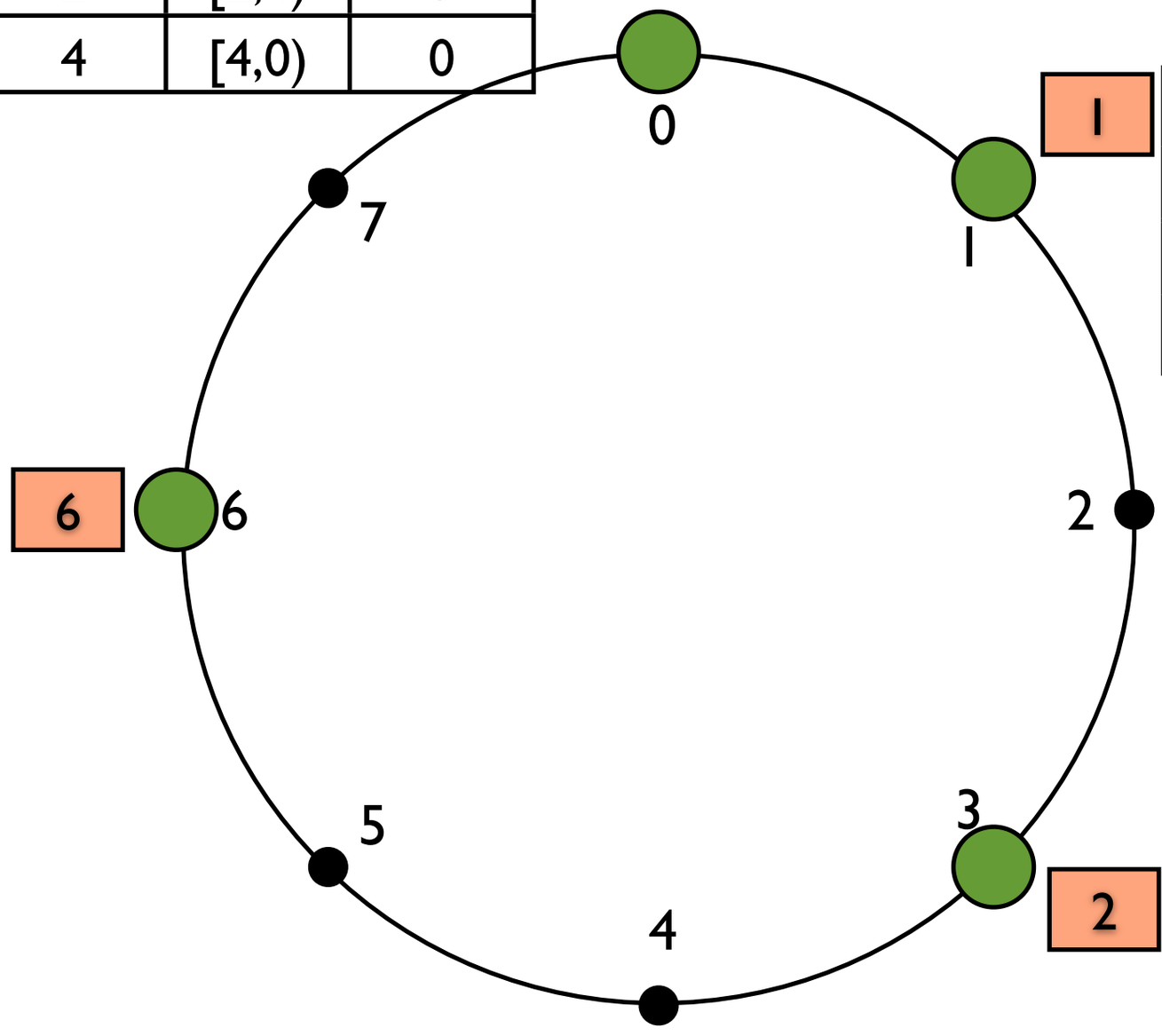


start	int.	succ.
2	[2,3)	3
3	[3,5)	3
5	[5,1)	0

start	int.	succ.
4	[4,5)	0
5	[5,7)	0
7	[7,3)	0

Node Joins

start	int.	succ.
1	[1,2)	1
2	[2,4)	3
4	[4,0)	0



1

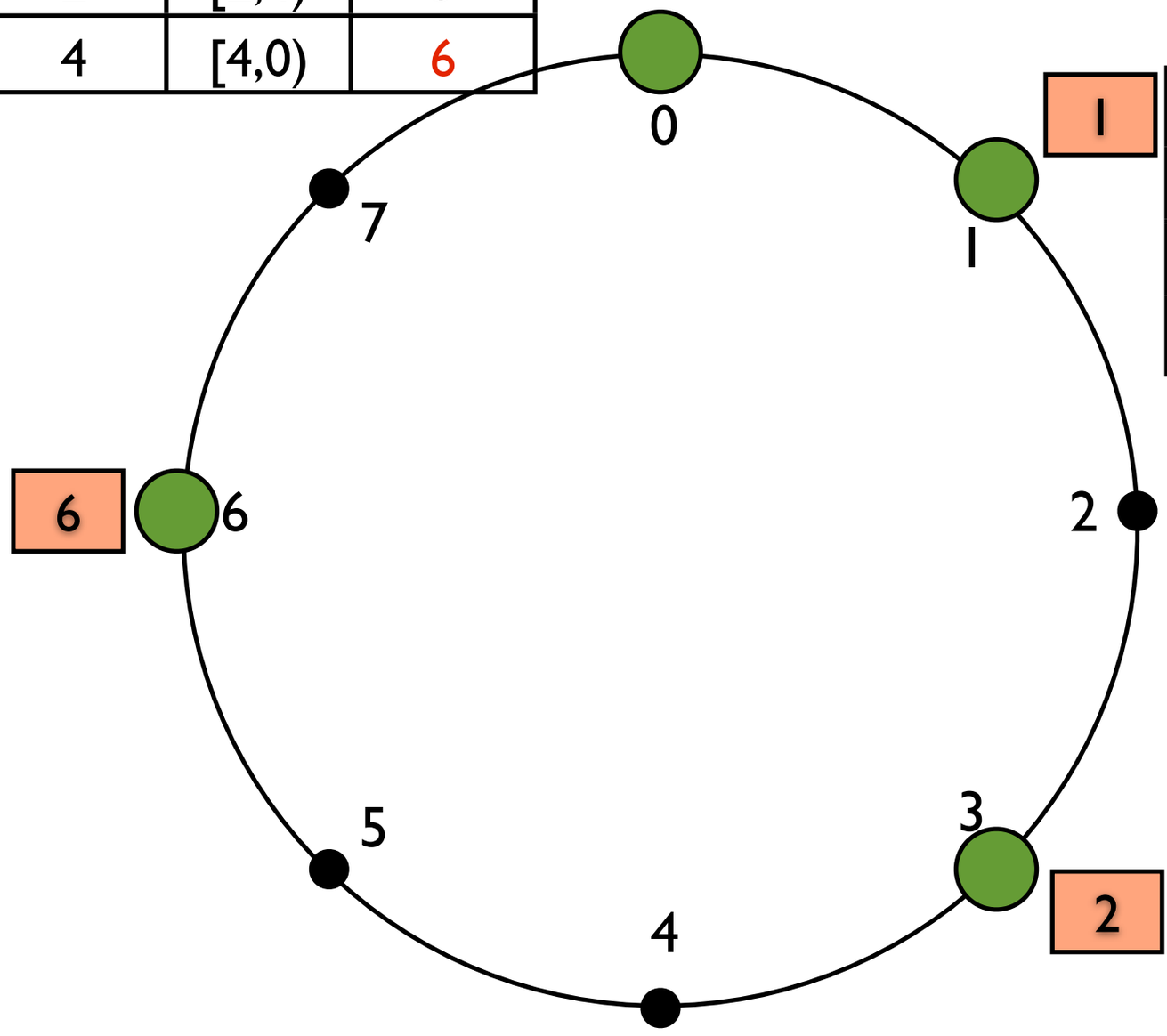
start	int.	succ.
2	[2,3)	3
3	[3,5)	3
5	[5,1)	0

2

start	int.	succ.
4	[4,5)	0
5	[5,7)	0
7	[7,3)	0

Node Joins

start	int.	succ.
1	[1,2)	1
2	[2,4)	3
4	[4,0)	6

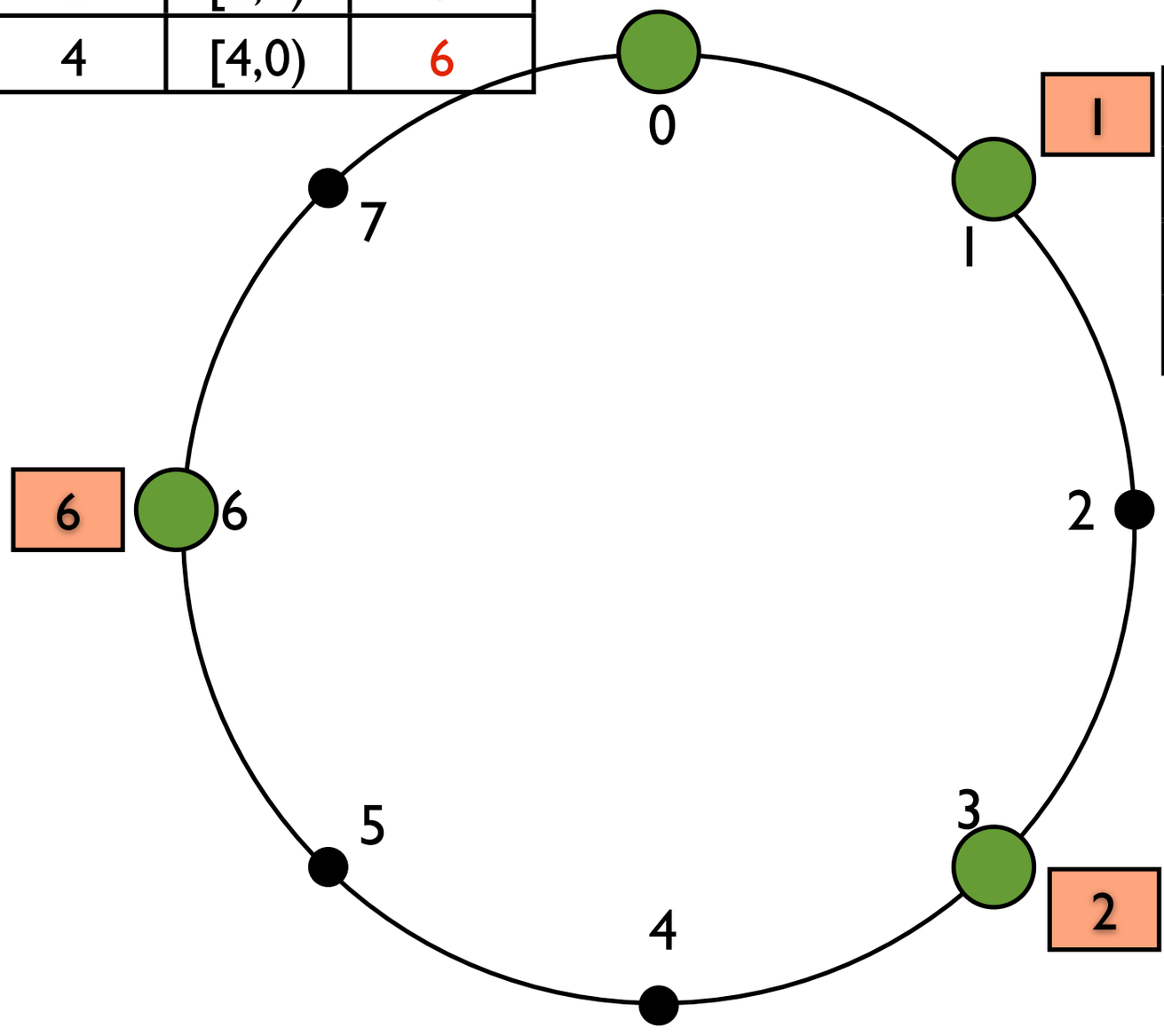


start	int.	succ.
2	[2,3)	3
3	[3,5)	3
5	[5,1)	0

start	int.	succ.
4	[4,5)	0
5	[5,7)	0
7	[7,3)	0

Node Joins

start	int.	succ.
1	[1,2)	1
2	[2,4)	3
4	[4,0)	6



1

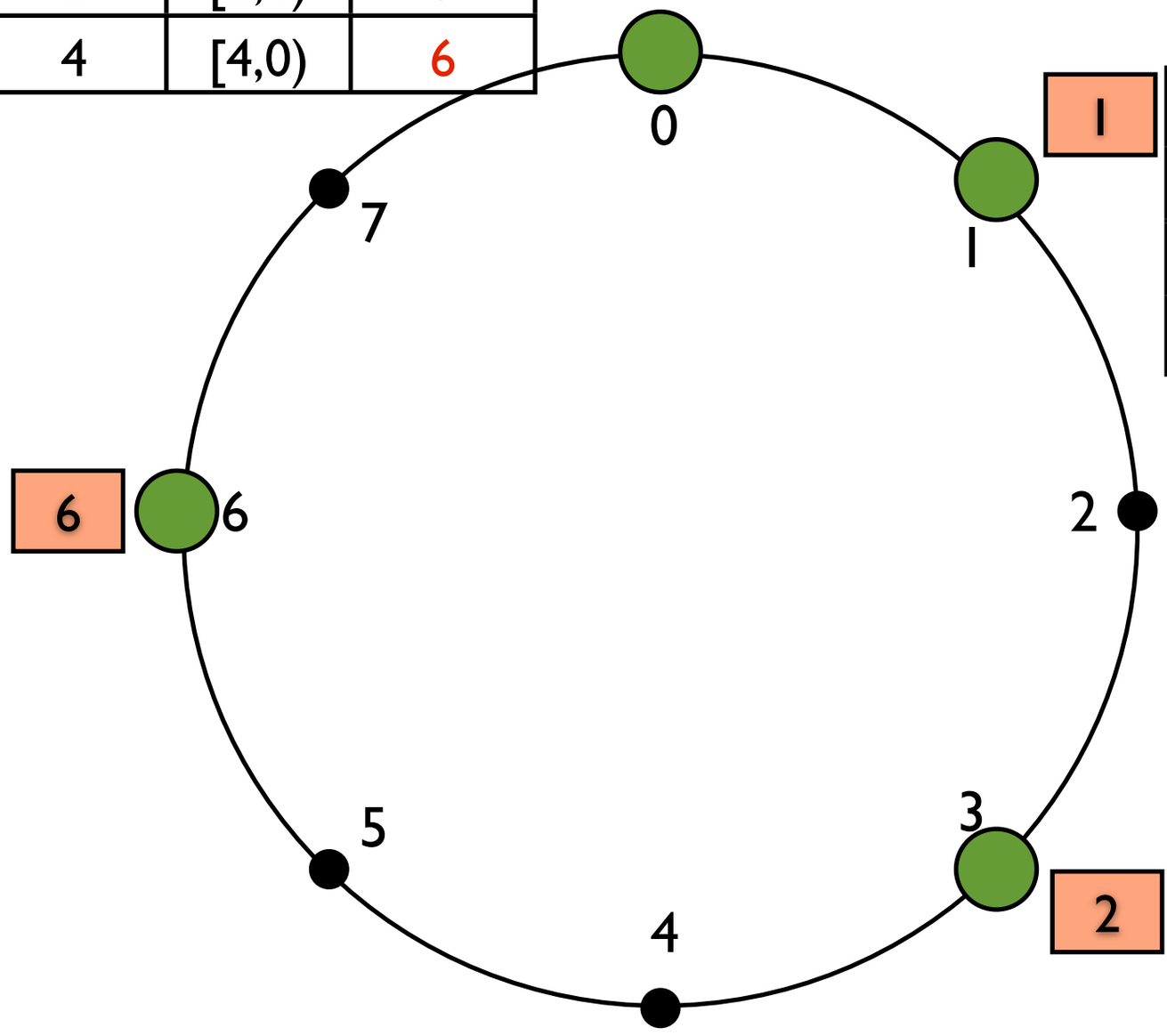
start	int.	succ.
2	[2,3)	3
3	[3,5)	3
5	[5,1)	6

2

start	int.	succ.
4	[4,5)	0
5	[5,7)	0
7	[7,3)	0

Node Joins

start	int.	succ.
1	[1,2)	1
2	[2,4)	3
4	[4,0)	6



1

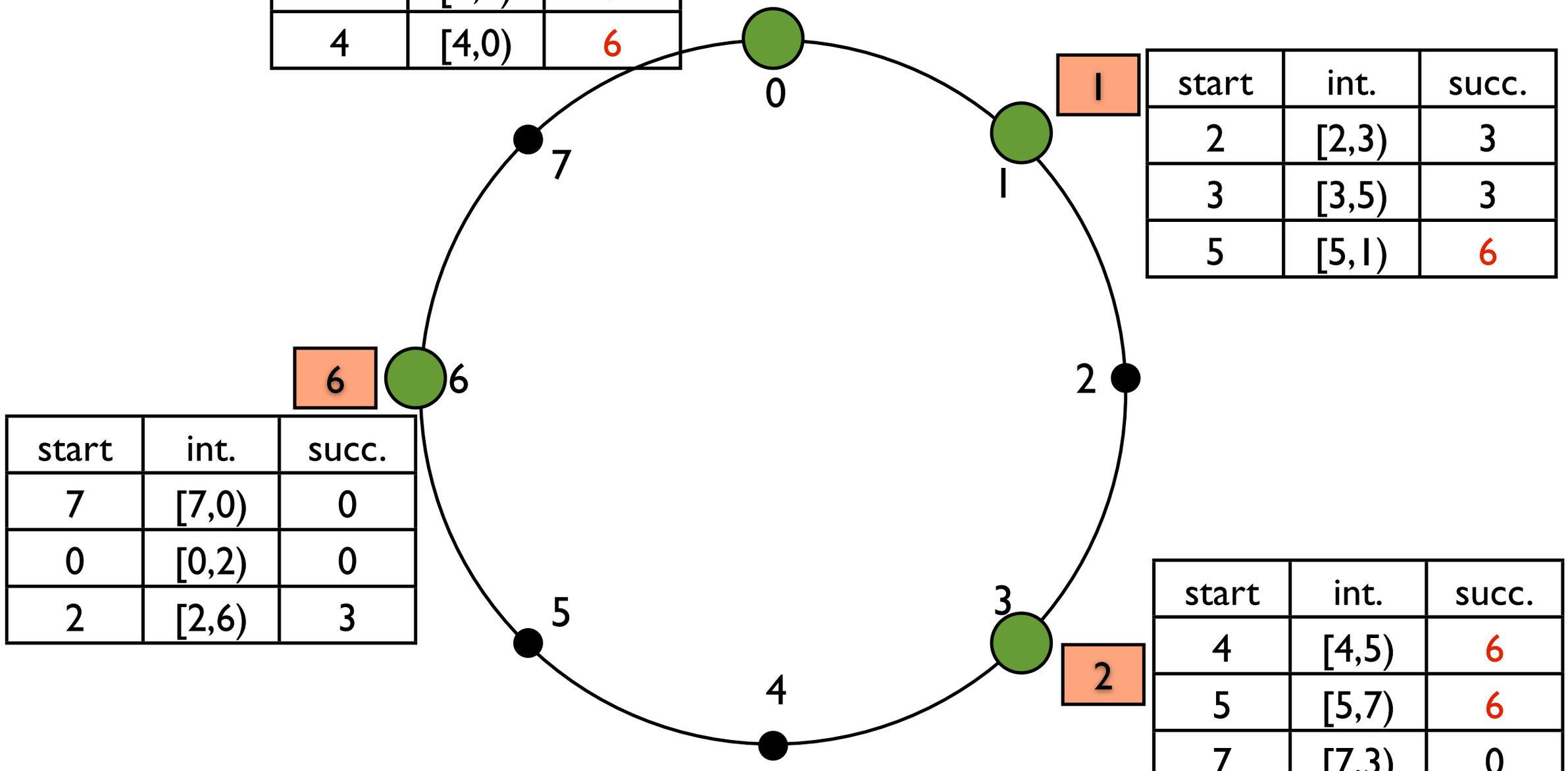
start	int.	succ.
2	[2,3)	3
3	[3,5)	3
5	[5,1)	6

2

start	int.	succ.
4	[4,5)	6
5	[5,7)	6
7	[7,3)	0

Node Joins

start	int.	succ.
1	[1,2)	1
2	[2,4)	3
4	[4,0)	6



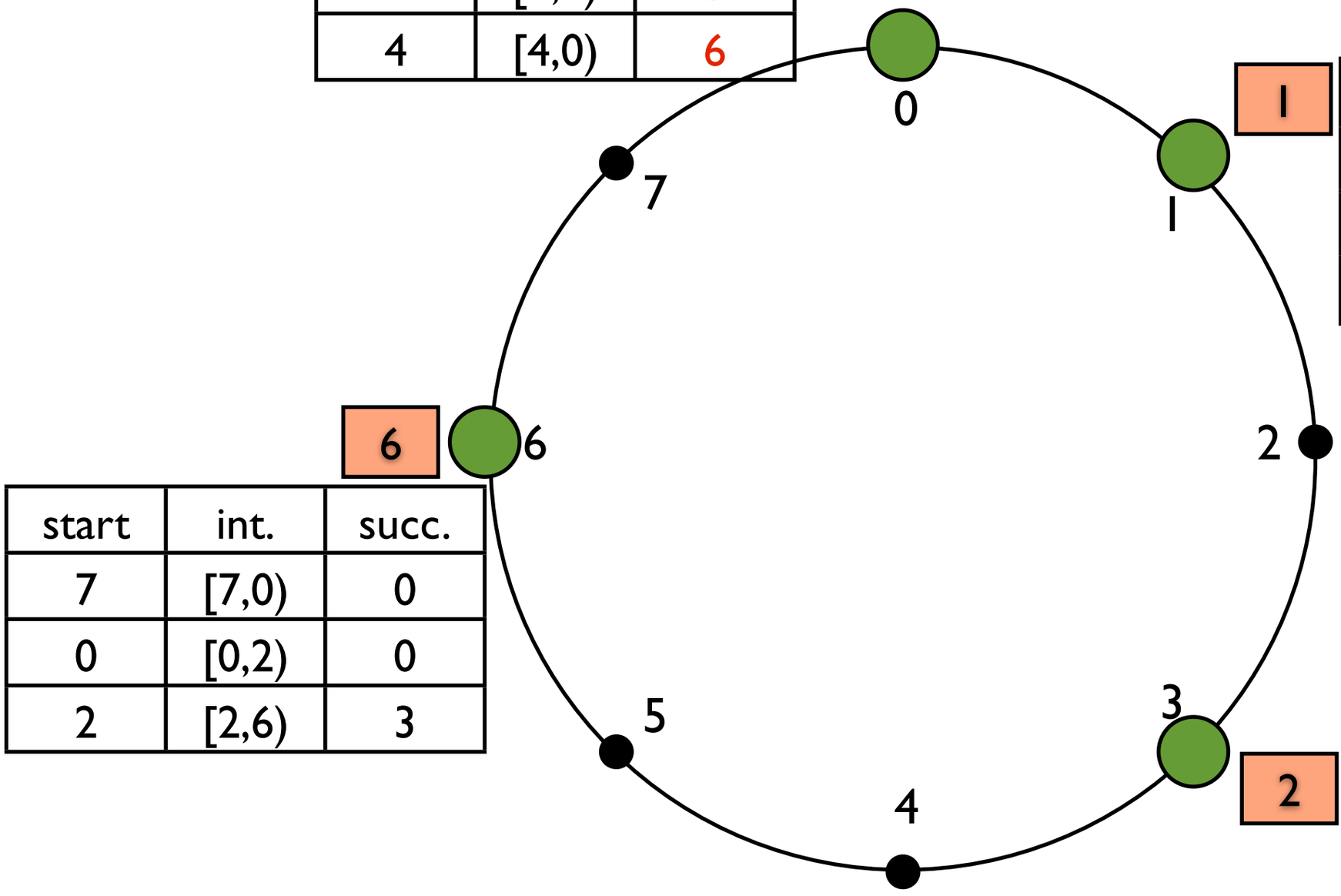
start	int.	succ.
2	[2,3)	3
3	[3,5)	3
5	[5,1)	6

start	int.	succ.
7	[7,0)	0
0	[0,2)	0
2	[2,6)	3

start	int.	succ.
4	[4,5)	6
5	[5,7)	6
7	[7,3)	0

Case Study: Node Leaves

start	int.	succ.
1	[1,2)	1
2	[2,4)	3
4	[4,0)	6



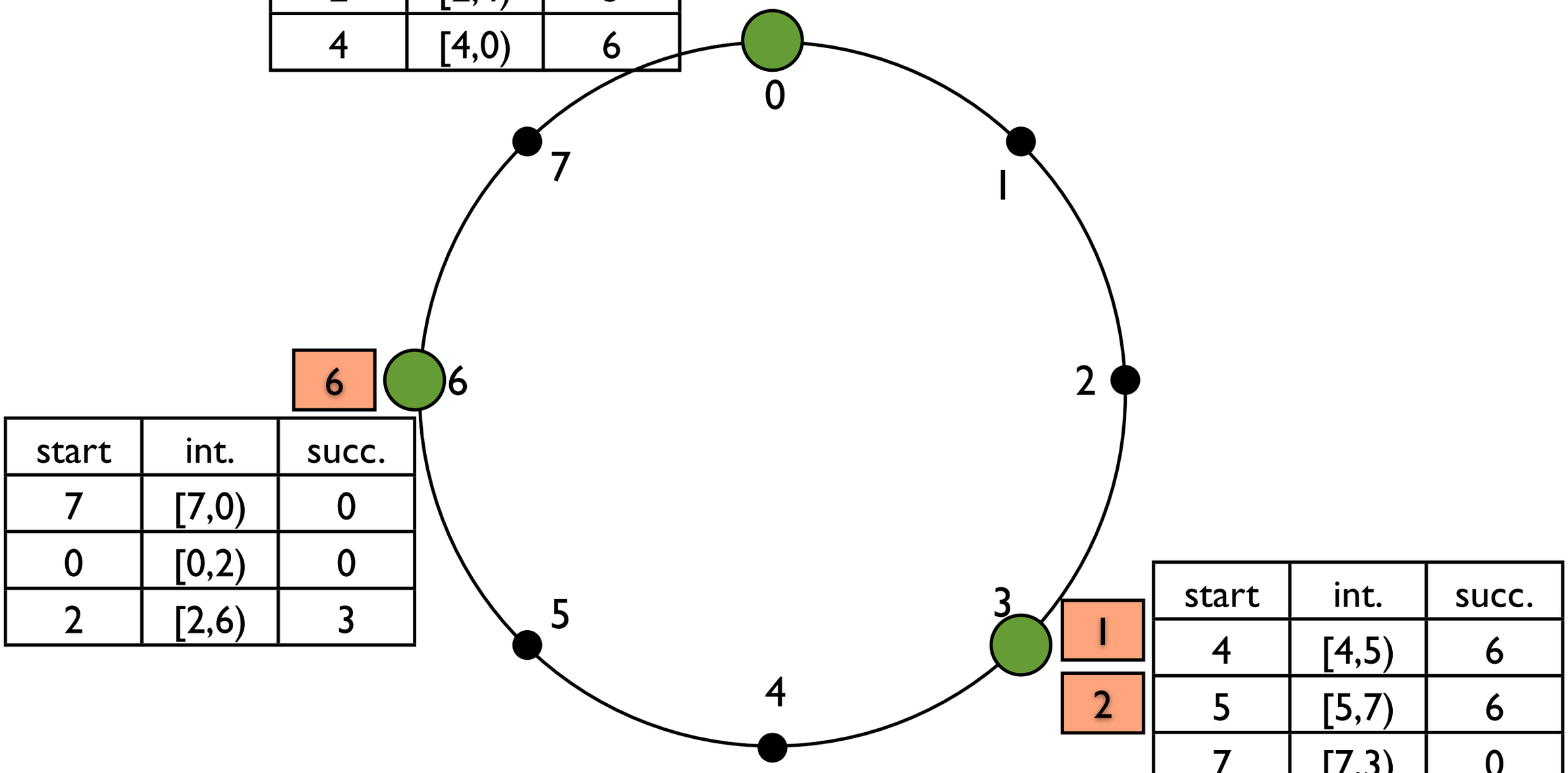
start	int.	succ.
2	[2,3)	3
3	[3,5)	3
5	[5,1)	6

start	int.	succ.
7	[7,0)	0
0	[0,2)	0
2	[2,6)	3

start	int.	succ.
4	[4,5)	6
5	[5,7)	6
7	[7,3)	0

Case Study: Node Leaves

start	int.	succ.
1	[1,2)	3
2	[2,4)	3
4	[4,0)	6



start	int.	succ.
7	[7,0)	0
0	[0,2)	0
2	[2,6)	3

1
2

start	int.	succ.
4	[4,5)	6
5	[5,7)	6
7	[7,3)	0

Chord Issues?