CompSci 401: Cloud Computing

Software for the Cloud

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UNIVERSITY

How to build applications for the cloud?

- Software design and architecture
- Distributed and parallel algorithms
- New programming languages and libraries

How to build applications for the cloud?

- Software design and architecture
- Distributed and parallel algorithms
- New programming languages and libraries

- Application development frameworks

Cloud-native applications

- Specifically designed for the cloud
- What can we do better?
  - Improve security
  - Reduce software flaws
  - Enhance performance
  - Increase scalability
  - Improve reliability

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Parallel Computation

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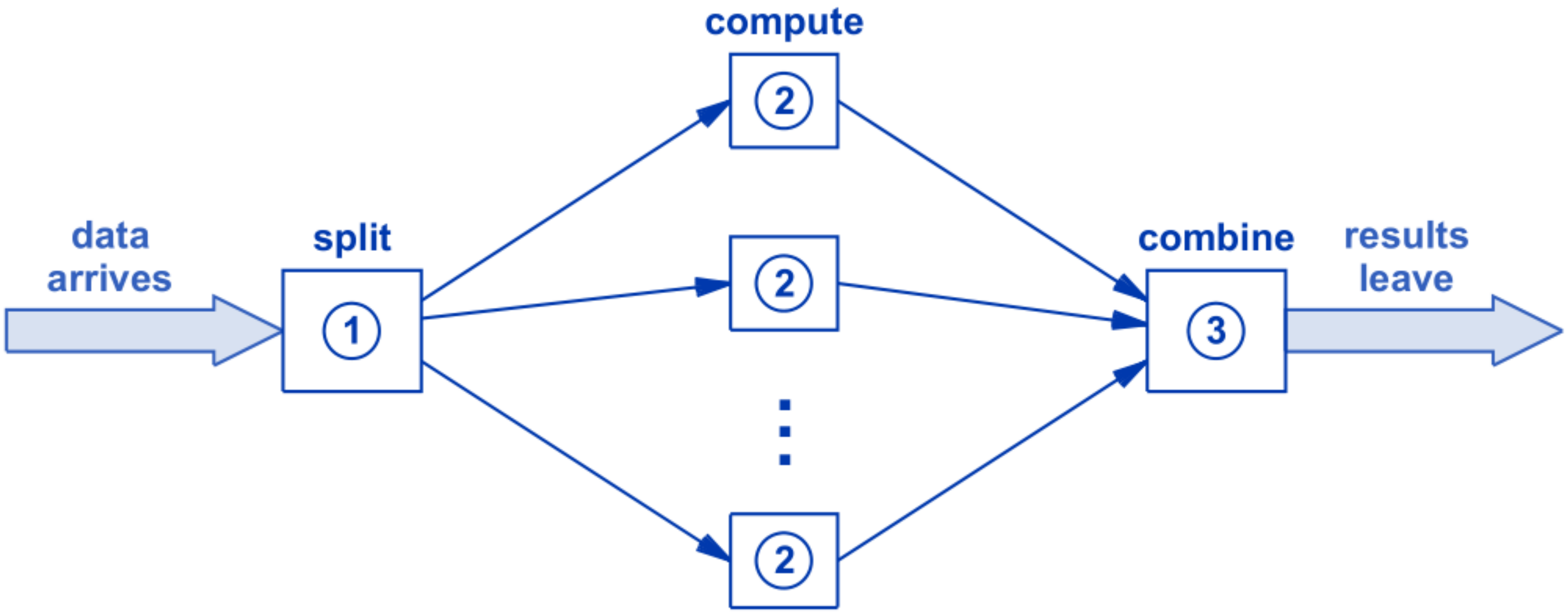
Datacenters have large amounts of resources

- Thousands of cores
- Tebibytes of RAM
- Petabytes of storage
- Need mechanisms to effectively use these resources
  - Efficient use of resources (low overhead)
  - Programmer efficiency (low time to develop applications)

Data parallelism

- Common, widely-applicable approach



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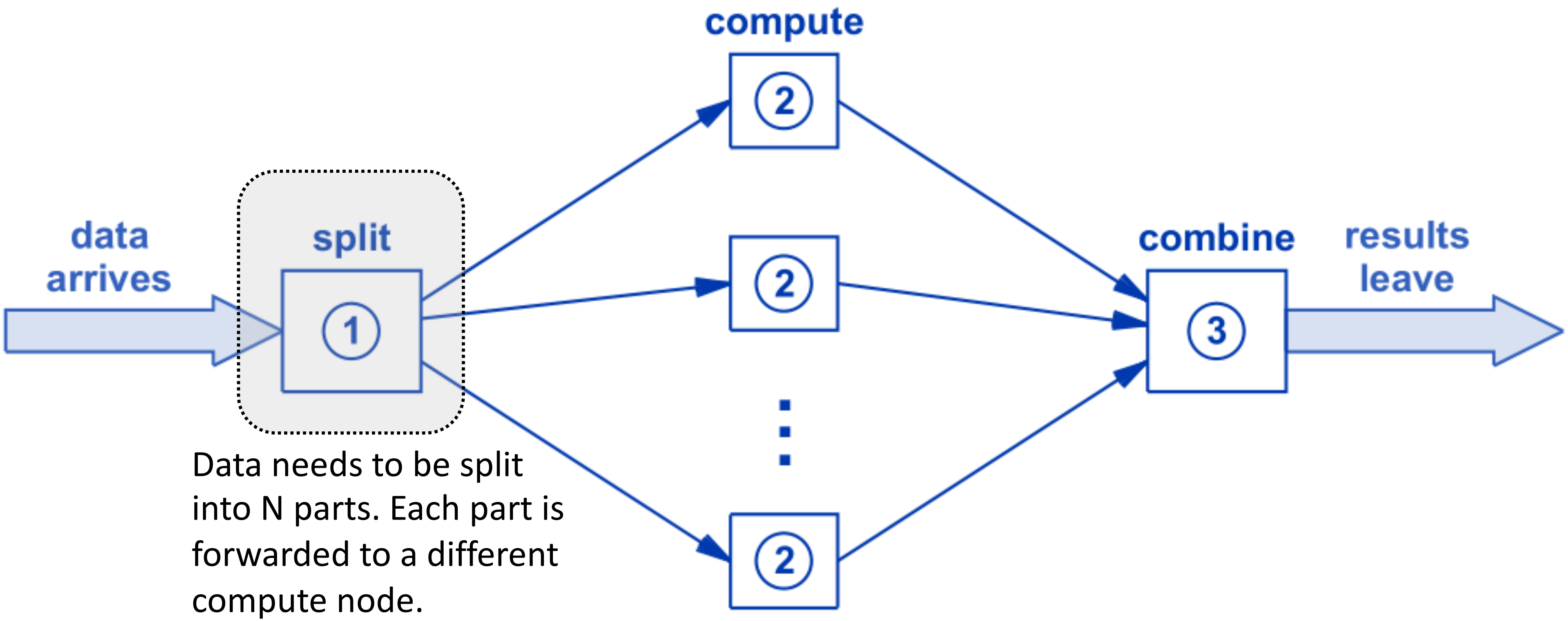
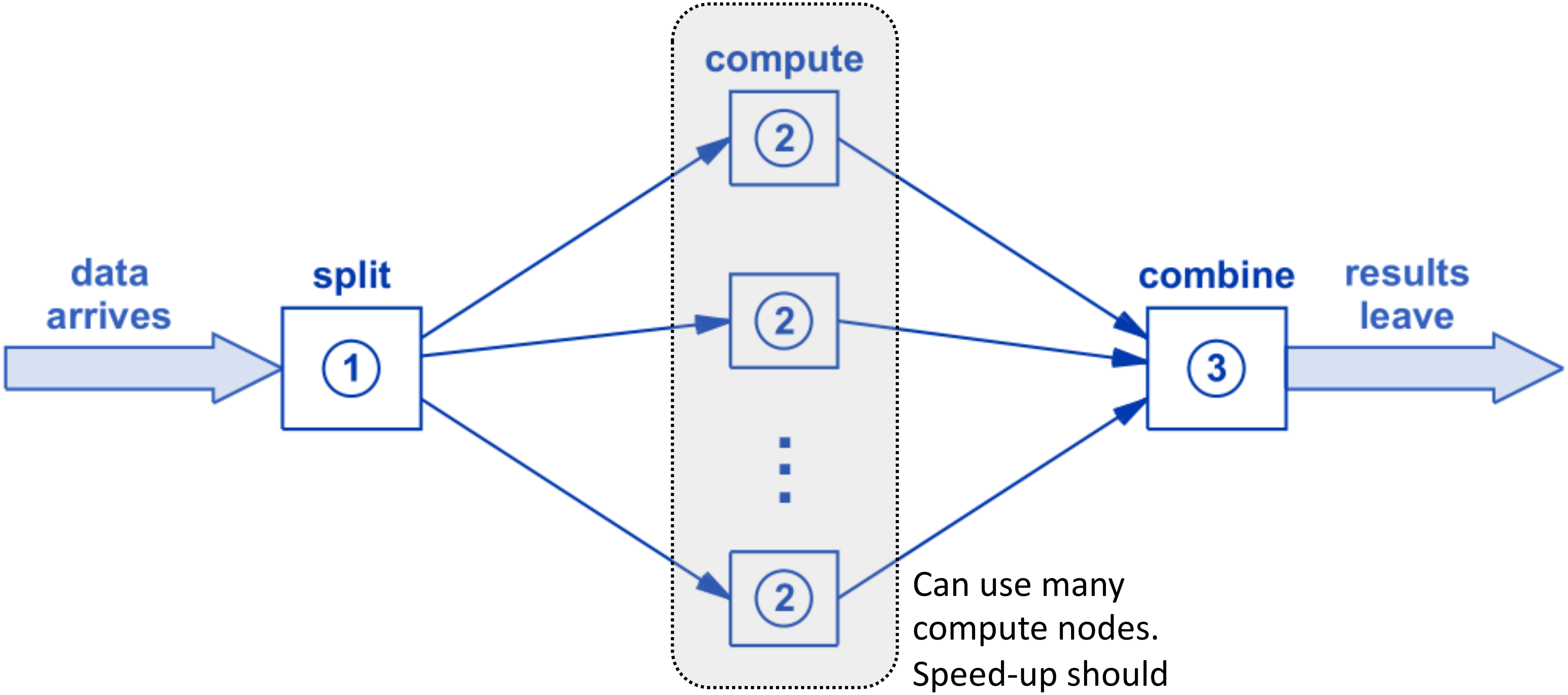


Data needs to be split into N parts. Each part is forwarded to a different compute node.

Data parallelism

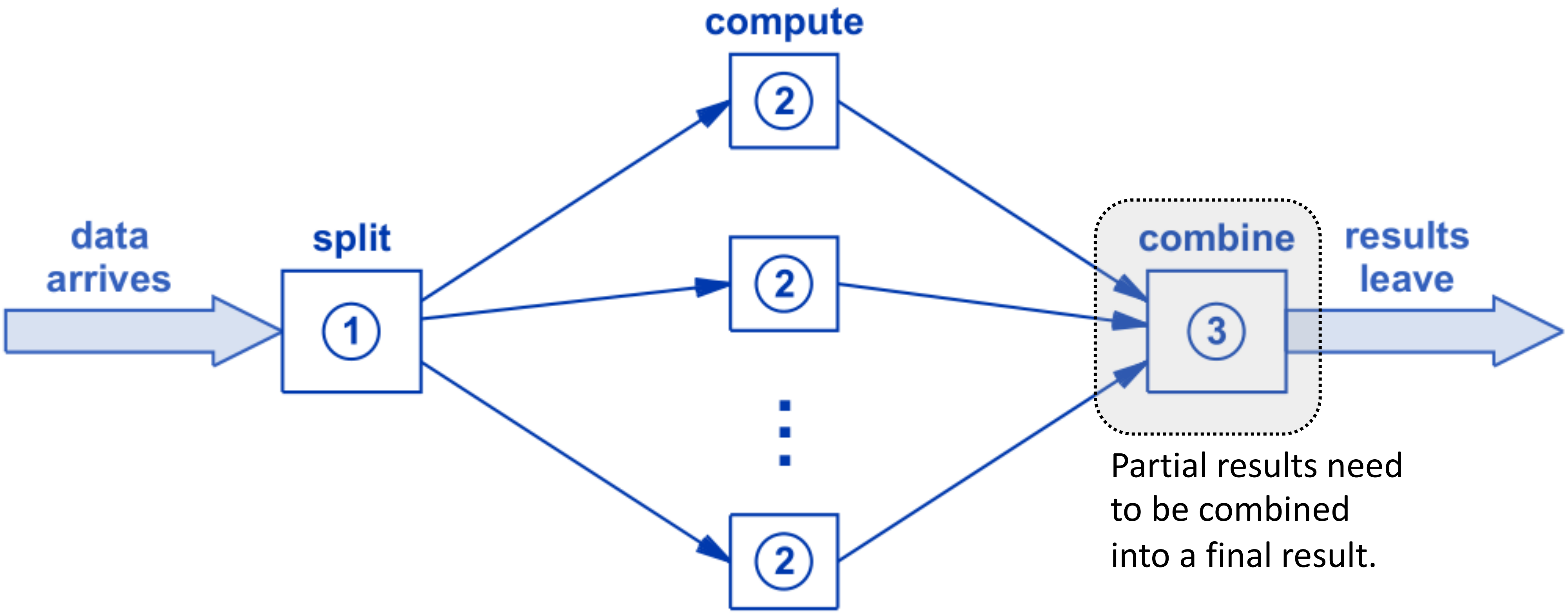
- Common, widely-applicable approach



Can use many compute nodes. Speed-up should be proportional.

Data parallelism

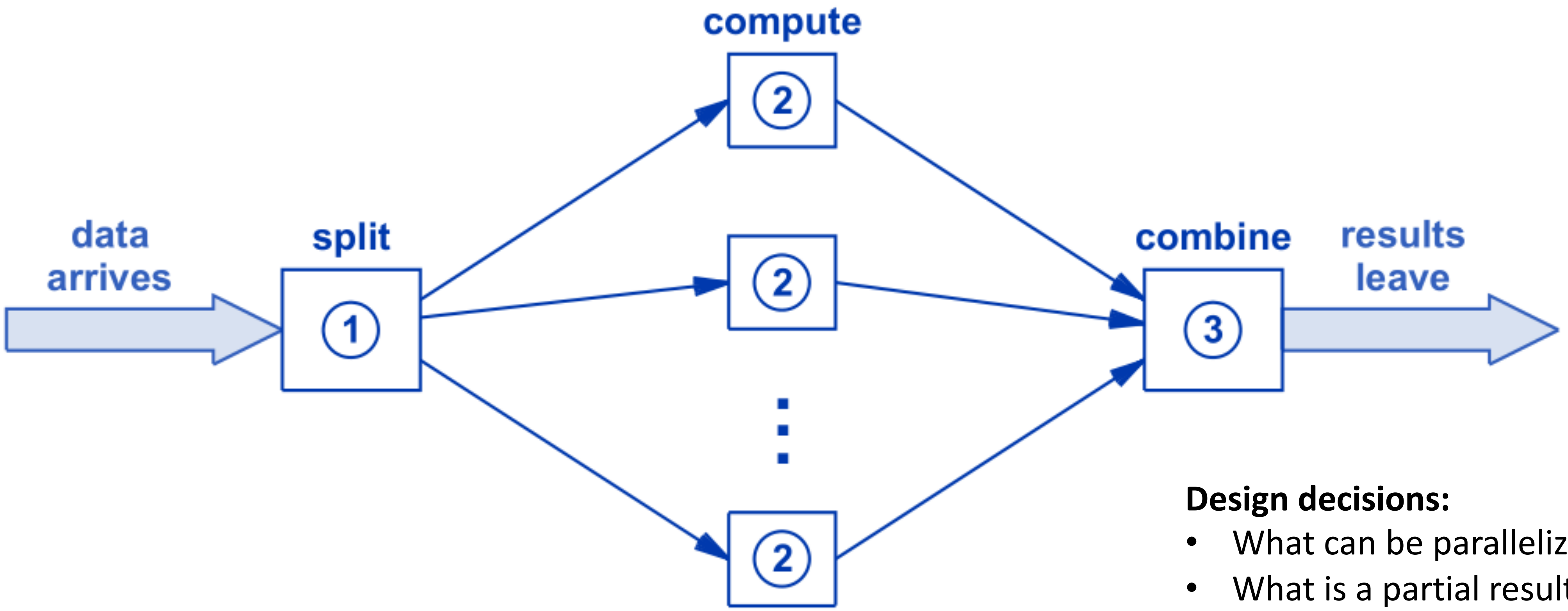
- Common, widely-applicable approach



Partial results need
to be combined
into a final result.

Data parallelism

- Common, widely-applicable approach



Design decisions:
- What can be parallelized?
- What is a partial result?
- How to combine?

Limitations of data parallelism

- Some problems do not allow for data parallelism
  - For example, data may not be splitable

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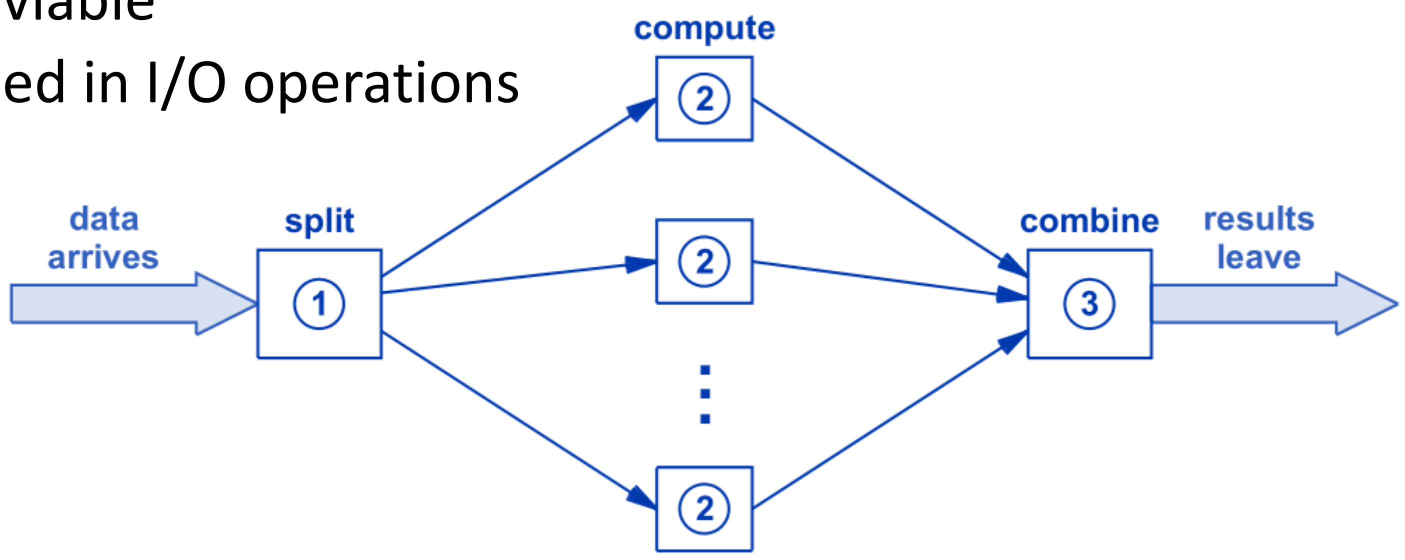
  - Want performance to be proportional to number of compute nodes
  - Too small splits may not be viable
  - Most of the time may be used in I/O operations



Limitations of data parallelism

- Some problems do not allow for data parallelism
  - For example, data may not be splitable
- Limited parallelism
  - Want performance to be proportional to number of compute nodes
  - Too small splits may not be viable
  - Most of the time may be used in I/O operations
- Overheads
  - Splitting data and combining partial results requires CPU time
  - Transmitting data between servers takes up network bandwidth

CompSci 401: Cloud Computing

The MapReduce Paradigm

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DUKE KUNSHAN UNIVERSITY

Counting words in a book

Input text

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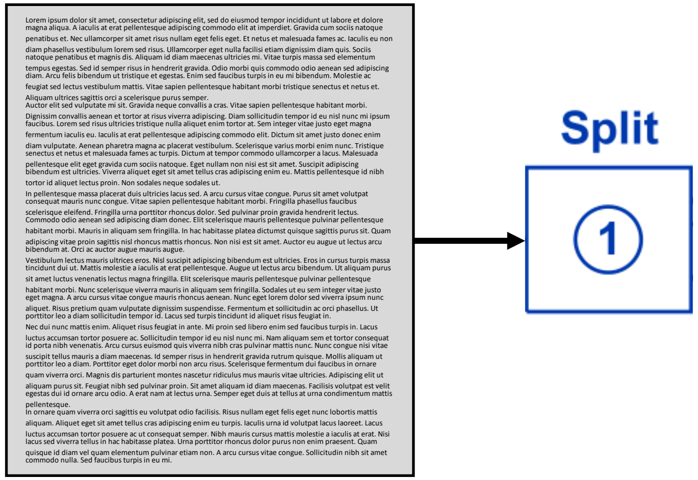
Result

Count	Word
10,500	the
9,968	to
8,553	a
5,972	at
4,851	of
4,269	from
4,055	and
3,448	with

Counting words in a book

Input text



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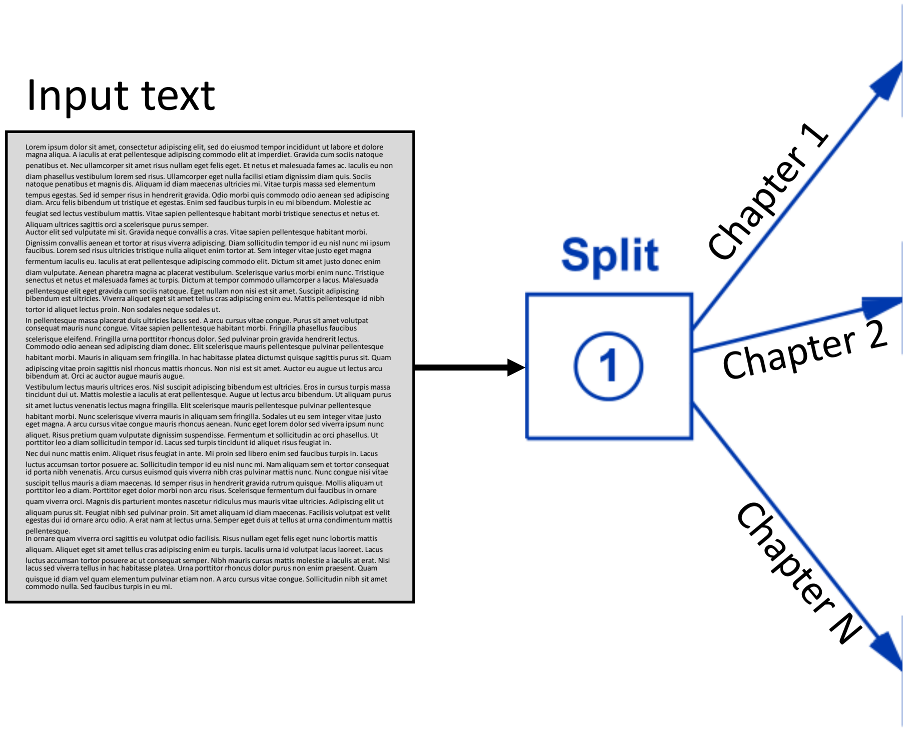

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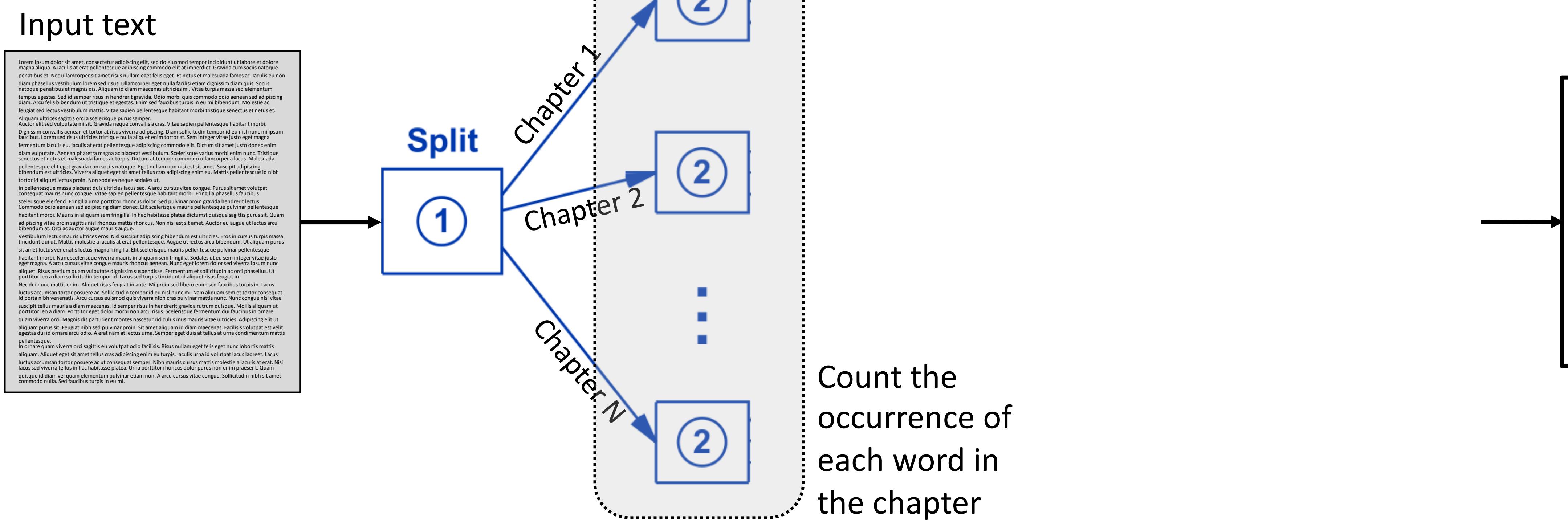

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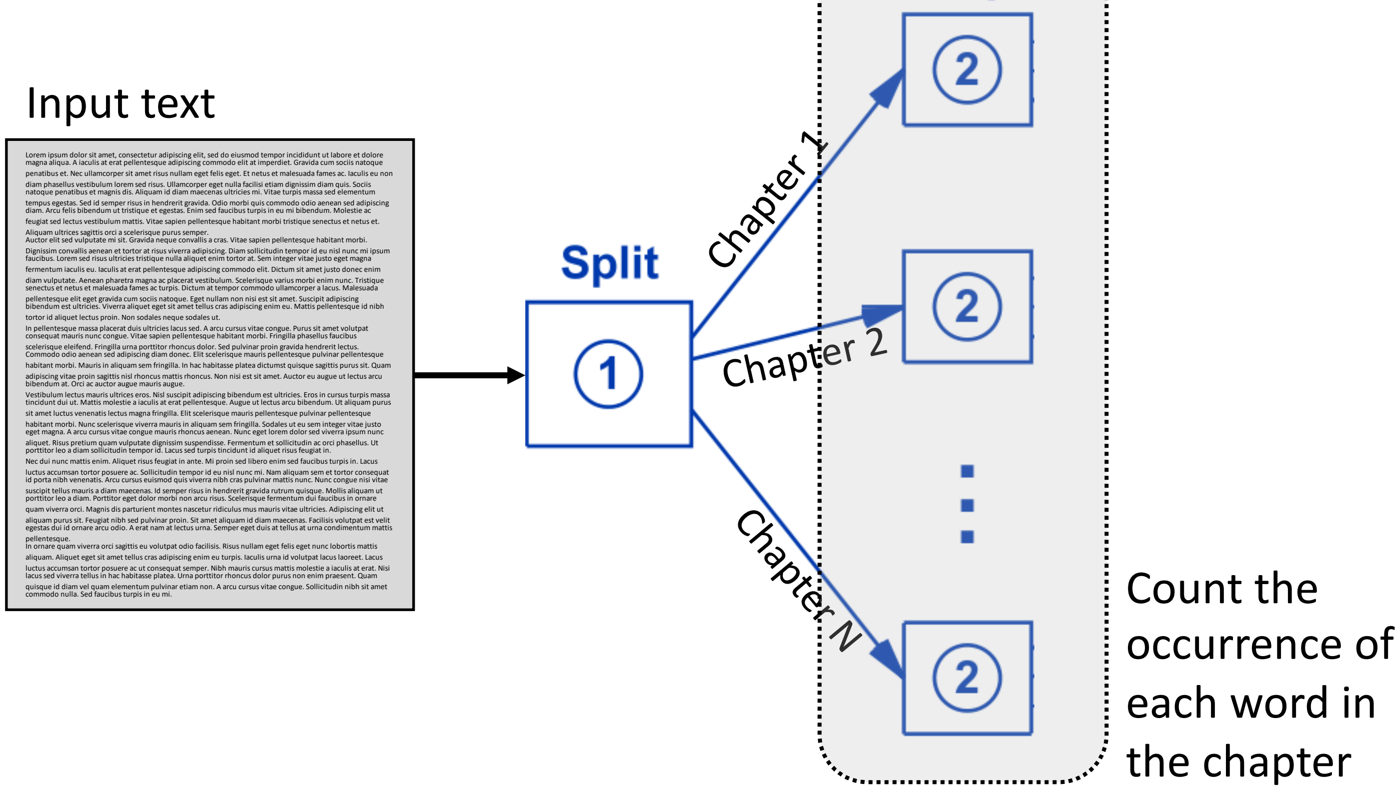

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Partial result after Map

Chapter 1		Chapter 2		Chapter 3	
288	the	166	the	489	the
191	a	62	to	376	a
170	and	61	a	192	to
149	of	59	of	136	of
144	to	57	and	128	and
89	that	36	that	101	is
71	is	34	in	75	that
66	in	18	is	59	an

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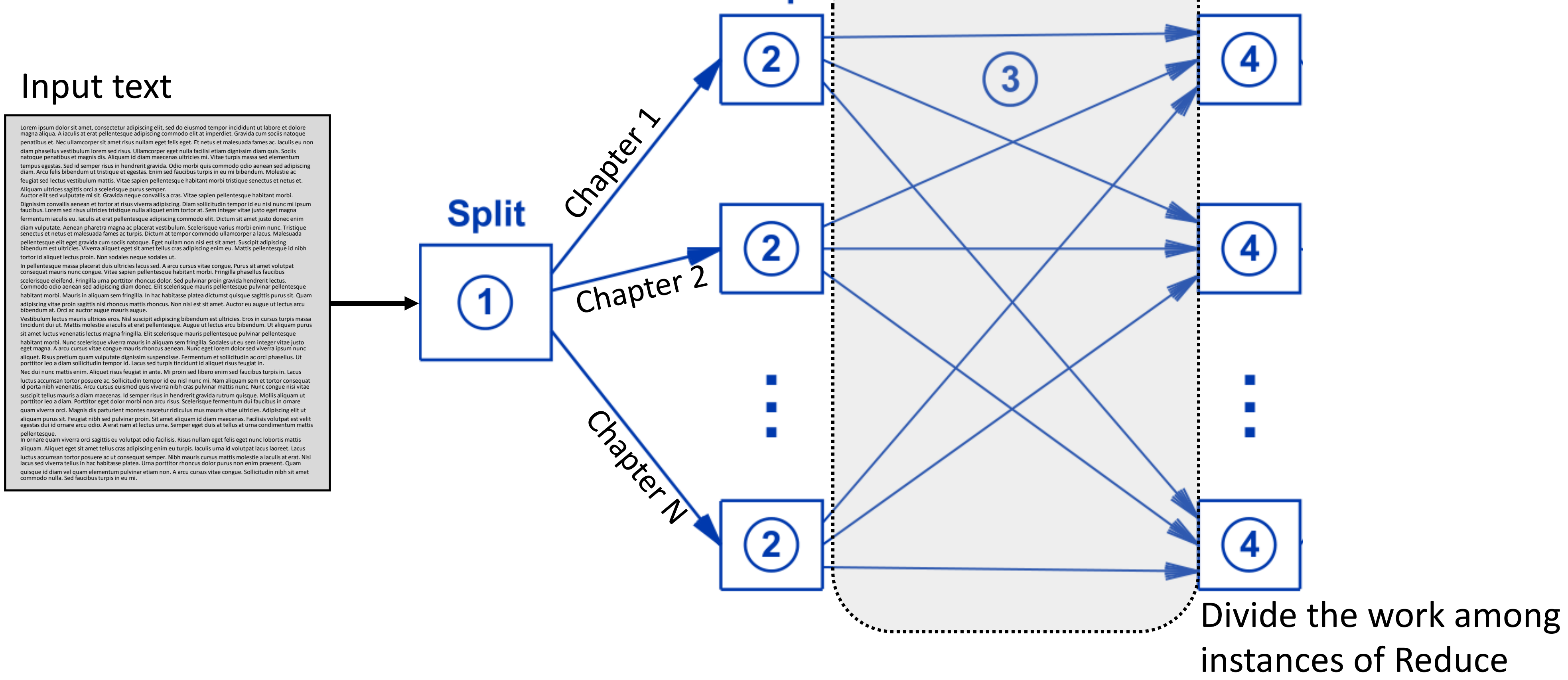

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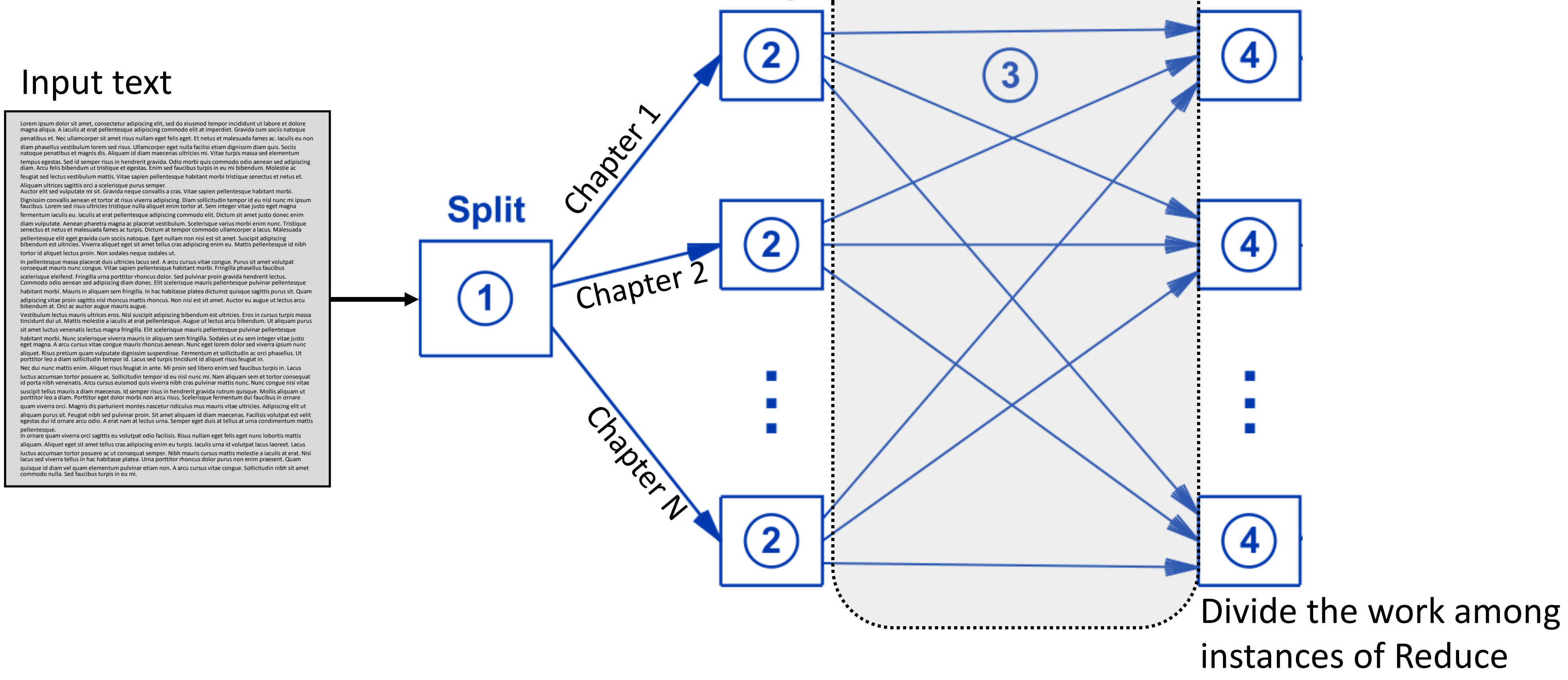

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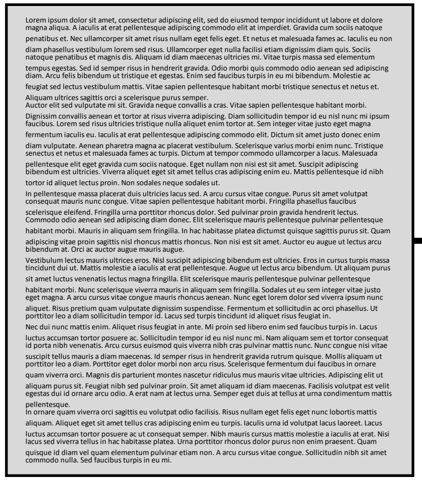
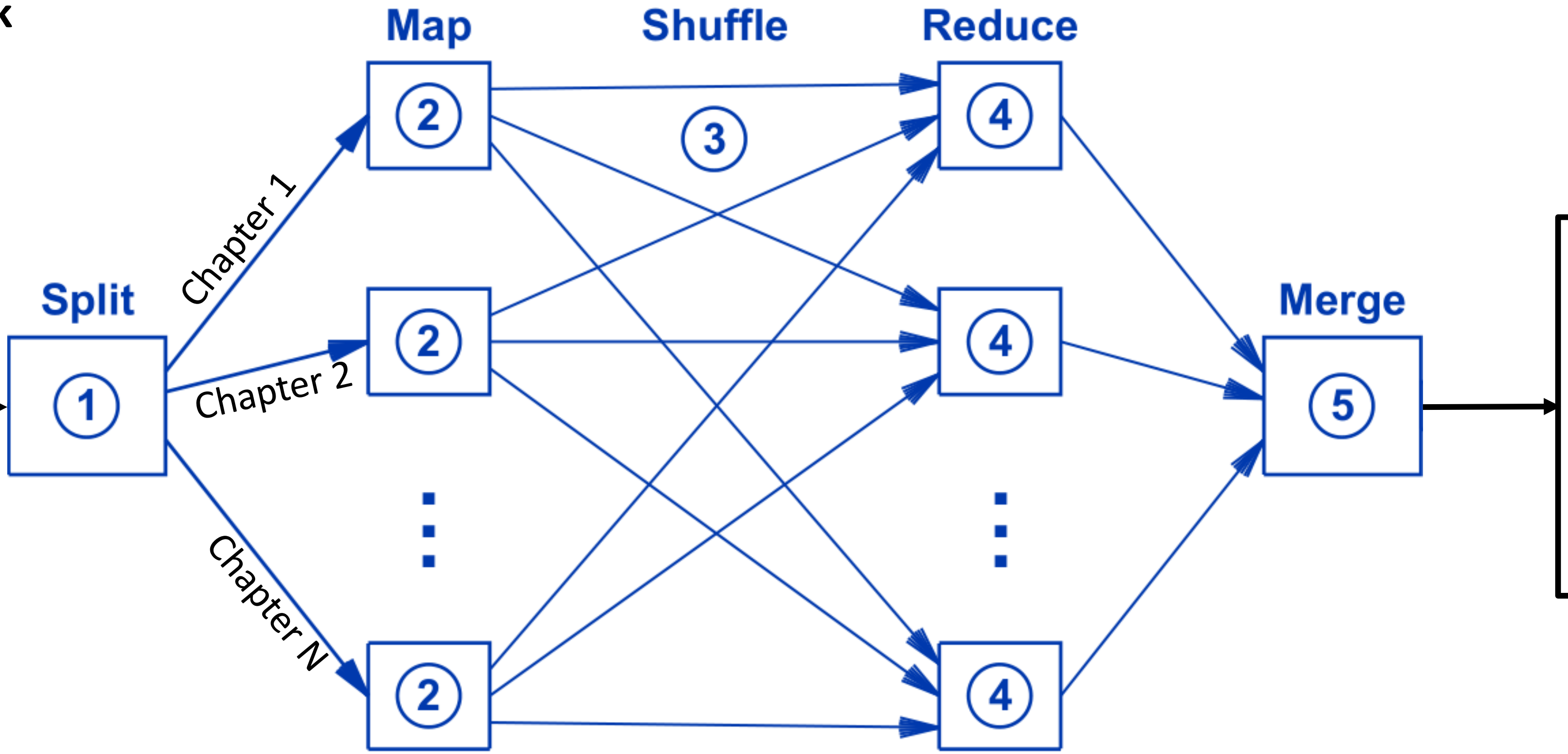
Shuffling of partial results

Reduce Instance	Words Starting With
1	A through E
2	F through J
3	K through O
4	P through T
5	U through Z

Counting words in a book

Input text





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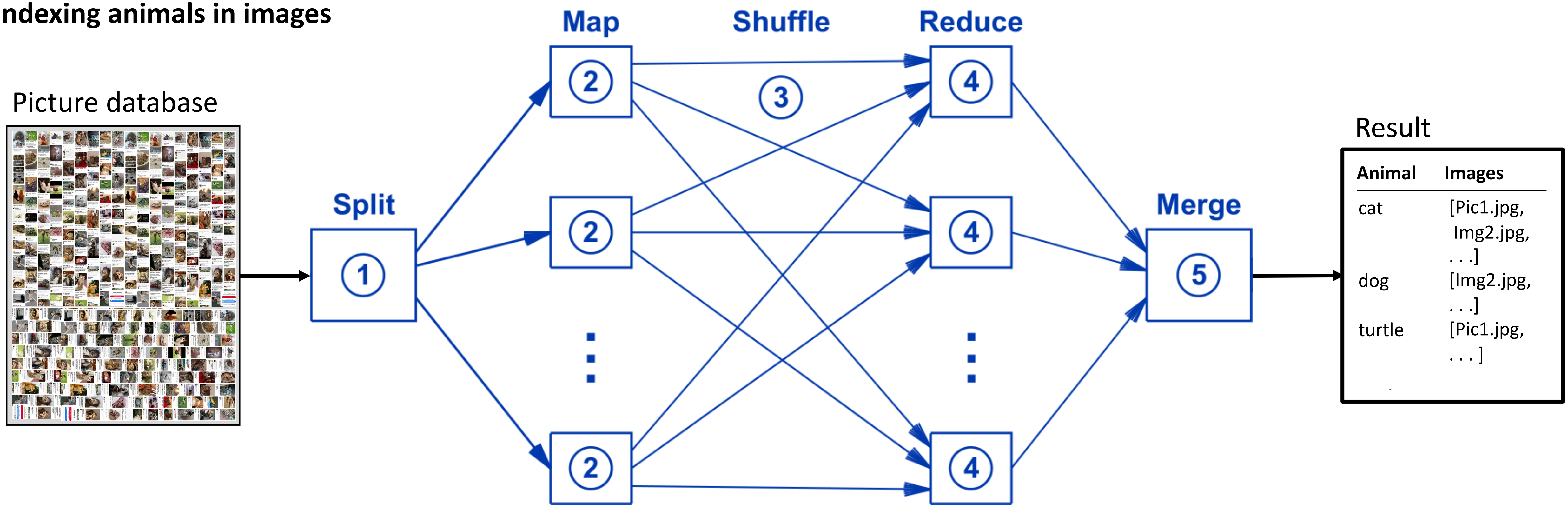
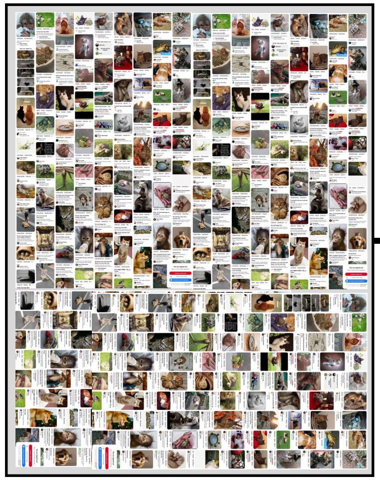
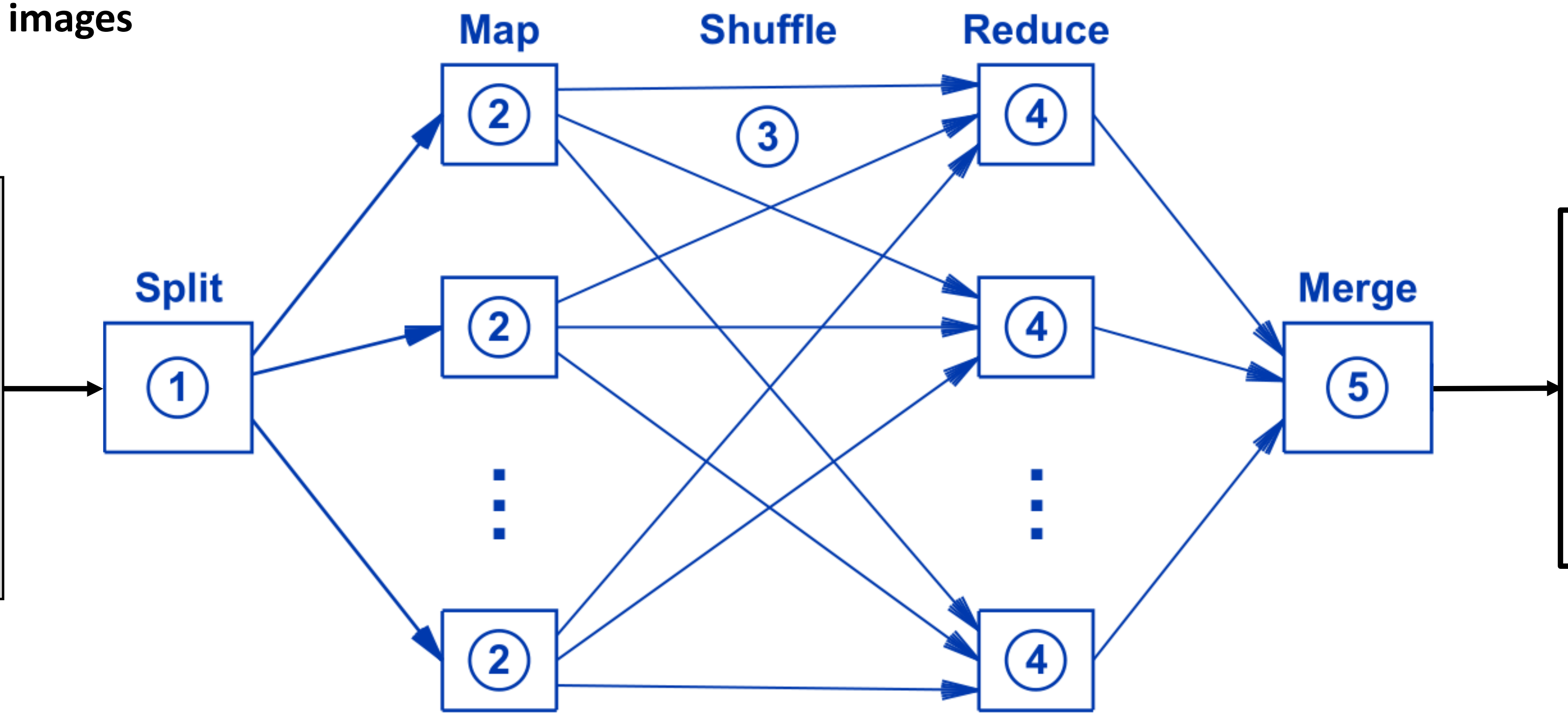
Indexing animals in images



Indexing animals in images

Picture database





Result

Animal	Images
cat	[Pic1.jpg, Img2.jpg, . . .]
dog	[Img2.jpg, . . .]
turtle	[Pic1.jpg, . . .]

Partial result after Map

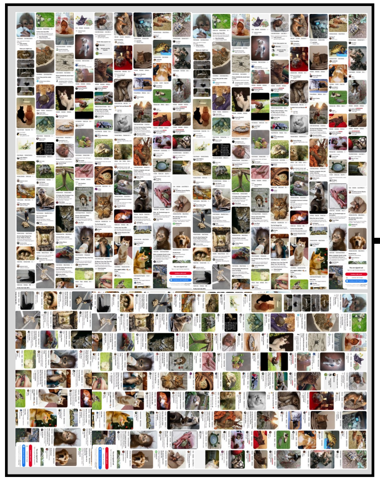
Split 1	Split 2	Split 3
cat Pic1.jpg turtle Pic1.jpg . . .	cat Img2.jpg dog Img2.jpg . . .	. . .

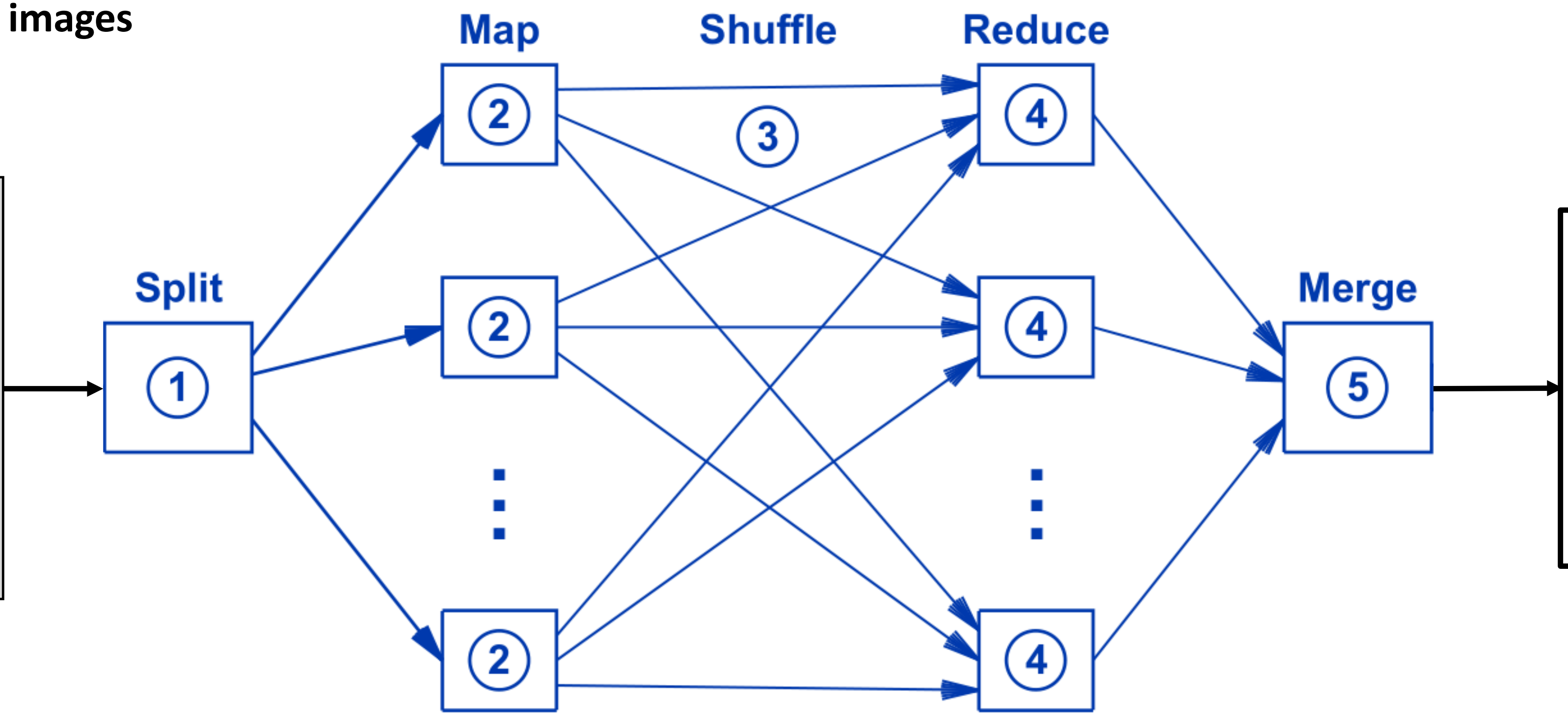
Pic1.jpg in split 1

Img2.jpg in split 2

Indexing animals in images

Picture database





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Partial result after Map

Split 1	Split 2	Split 3
cat Pic1.jpg	cat Img2.jpg	. . .
turtle Pic1.jpg	dog Img2.jpg	
. . .	. . .	

Shuffling of partial results

Reduce Instance	Animals Starting With
1	A through E
2	F through J
3	K through O
4	P through T
5	U through Z

Mathematical formulation of MapReduce

- Split step maps each data item *d* to a Map instance M_i
  - d → M_i
- Map step transforms data into a list *L*
  - Each item *j* is a pair (K_j , V_j)
  - K_j is a key, V_j is a value
- The shuffle step maps each key to a Reduce instance R_k
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In our examples, keys were:

- Word W
- Animal A

And values were:

- Count of occurrences of word W in chapter
- Picture name where animal A appeared

Mathematical formulation of MapReduce

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  - K_j → R_k
  - Shuffle stage merges and sorts values for each key K_j before calling Reduce
    - Reduce gets an iterator

Summary of examples

	Split → Map	Map → Shuffle	Shuffle → Reduce
Book word count	(offset, line of text)	multiple (word, count in line)	(word, list of counts)
Animal identification	(byte offset, figure)	multiple (animal, figure file)	(animal, list of files)

CompSci 401: Cloud Computing

Distributing Load

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Considerations when splitting input

- Load distribution
  - We want compute instances to perform comparable amounts of work
    - The total execution time is determined by the longest-running instance
  - Should send equal amounts of input to each compute instance
    - Complexity of some tasks do not correlate with data size (use a specific mechanism)
- Small but meaningful data pieces
  - Smaller data pieces make it easier to distribute load, but
  - Logical piece of data may be needed in Map and Reduce stages
    - For example, we need a whole picture to detect an animal (Map)
    - Need the complete name of the file where the animal appeared (Reduce)

Distributing load with hash functions

- A hash function maps an input to a random output
  - Hash function has *one* (random) output for each input key
  - One-to-one mapping of inputs to outputs
- Can be used to distribute load when there are many items
  - Many English words start with the letter ‘s’
  - Use whole word as key instead of just the first letter
  - Hash the word, use output to send data to a specific reduce instance

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Why not build a large table with the mapping?

- Do not need for the table and maintaining the mapping
- Do not need to know the words (table rows) in advance

Distributing load incurs overhead

- Splitting and merging data
- Transmitting data over the network
- Simple tasks on small datasets in MapReduce may take longer
- MapReduce is better suited for large datasets and complex tasks

CompSci 401: Cloud Computing

Apache Hadoop

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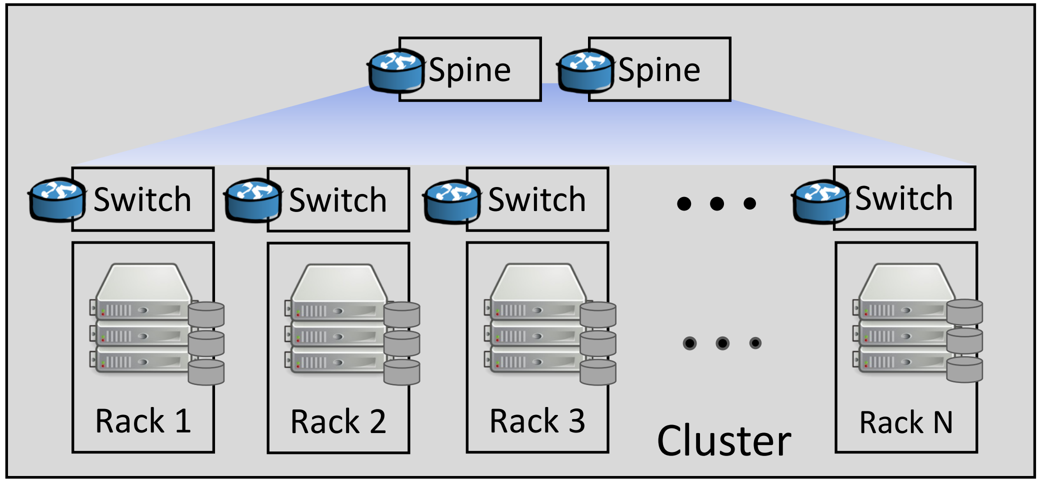
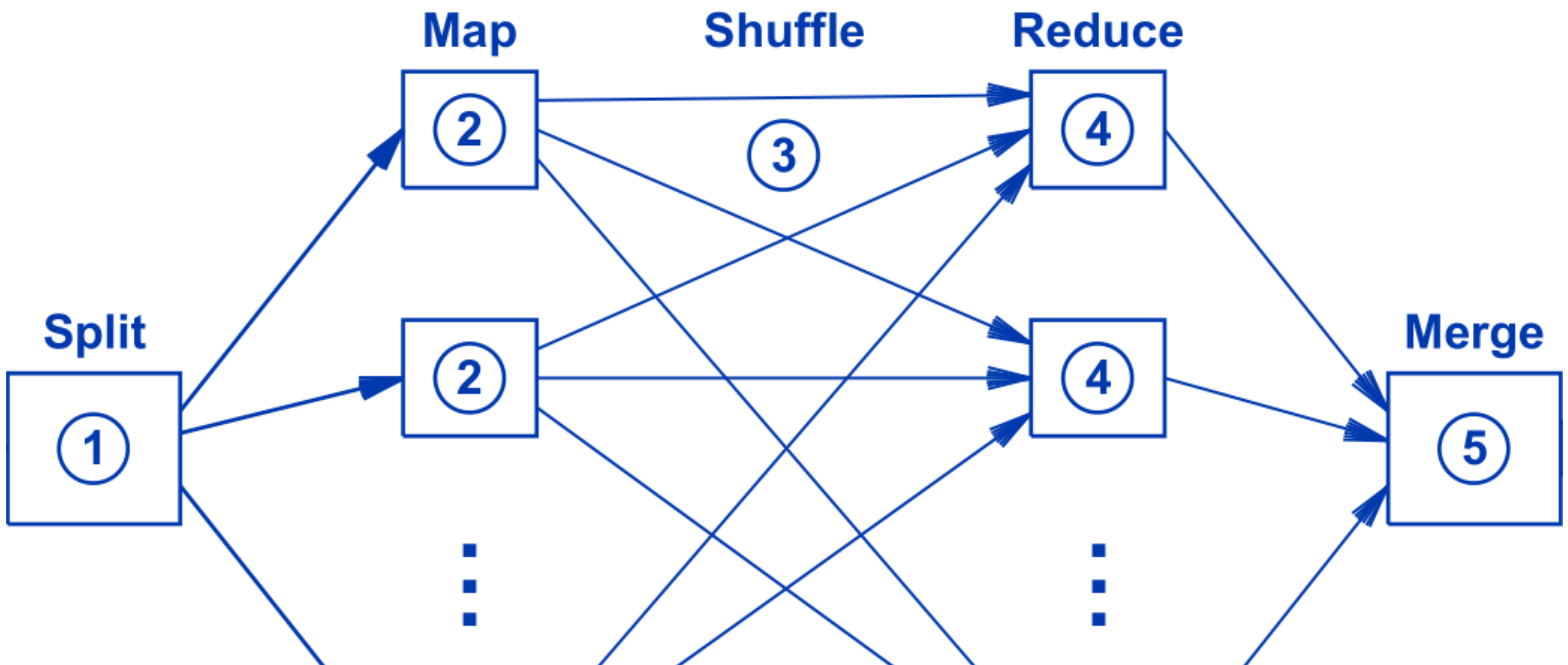
Hadoop hardware cluster model

- Hadoop assumes servers with compute, memory, *and disks*
- Thousands of nodes to handle large volumes of data
- Lots of disk to support large datasets, replication, and I/O



Hadoop processing module

- Hadoop has a “main” node and “worker” nodes
- Worker nodes can run Map and Reduce instances
- Split, shuffle, and merge usually provided by the platform



Hadoop processing component

- Hadoop has a “main” node and “worker” nodes
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  - Reading and writing data, transmitting data over the network
- Instance spawning, monitoring, failure detection, and recovery
  - With thousands of nodes, one might fail during the execution of a task

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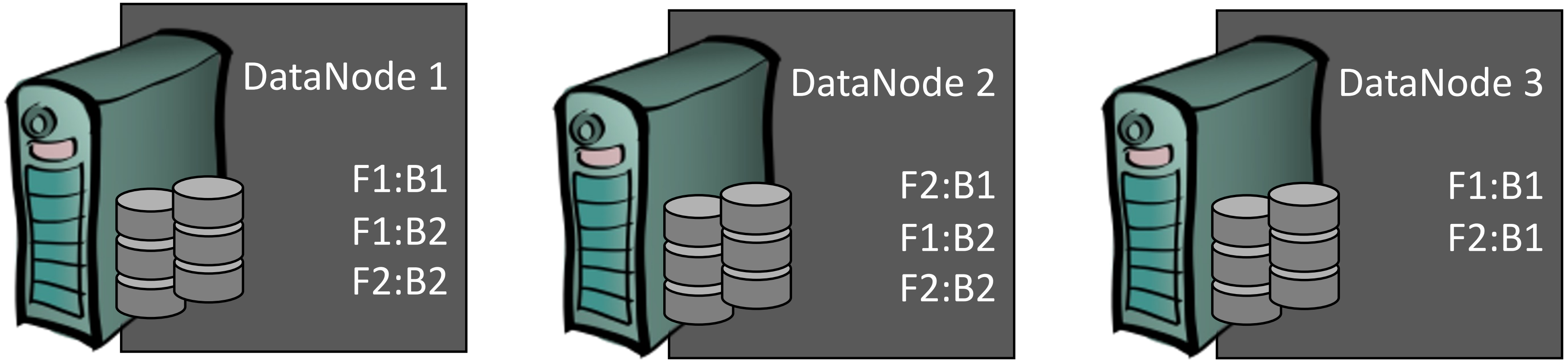
- We only need to write the Map and Reduce classes

HDFS (Hadoop Distributed File System)

- Hadoop handles massive volumes of data
- Data is managed within HDFS
- Specifically tailored to Hadoop’s needs

NameNode and DataNodes

- HDFS splits files into large (128MB) blocks
  - DataNodes store blocks
  - NameNode indexes files → blocks → DataNodes



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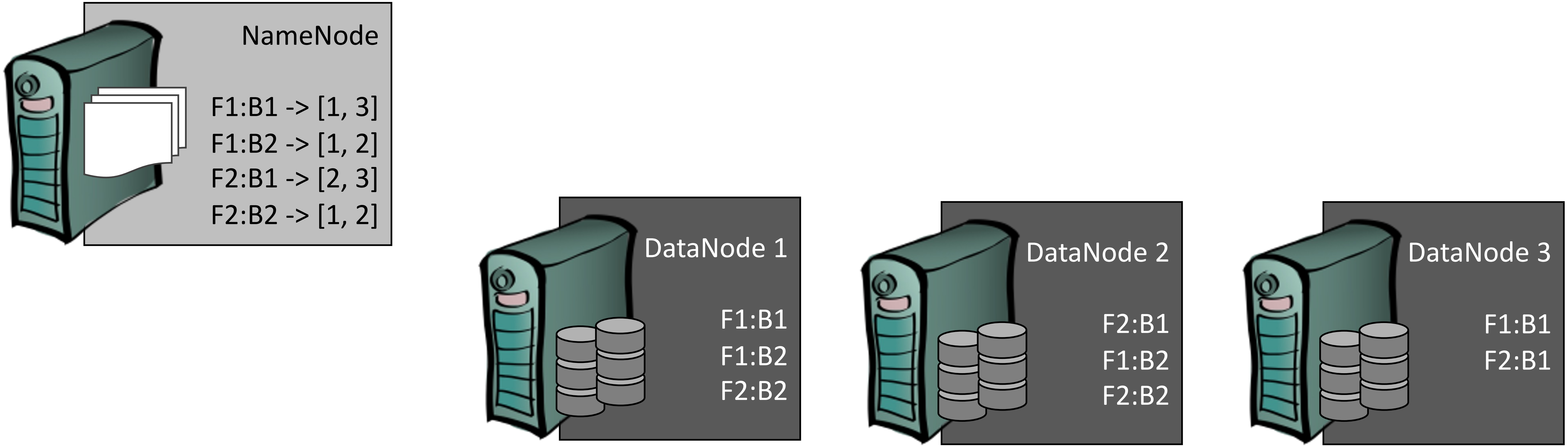
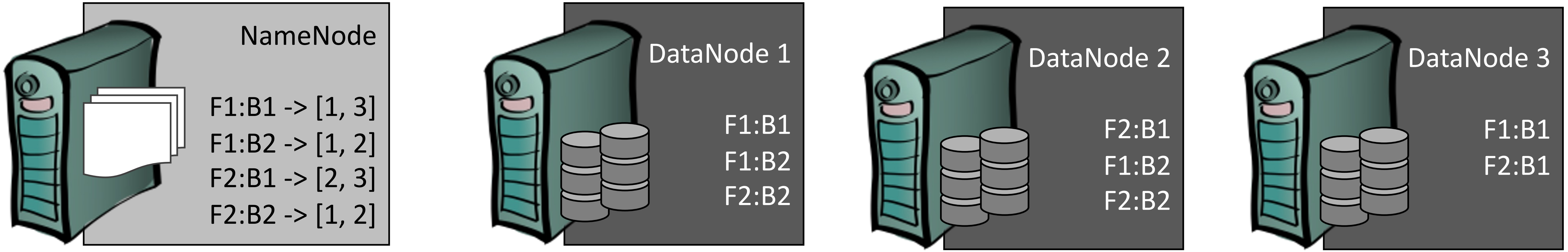


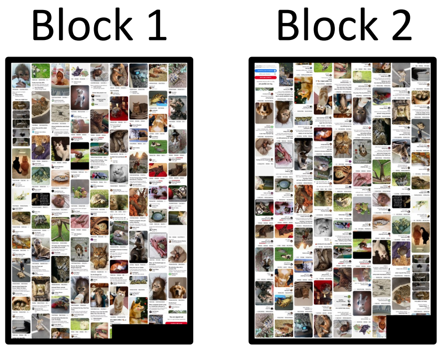
Replication for fault resilience

- Each block is replicated three times by default
  - Allows rebuilding if a disk or server fails
- Hadoop is aware of cluster hierarchy, and distributes blocks across different failure groups
  - For example, servers in a rack share power and the top-of-rack switch, spread blocks across servers in multiple racks



HDFS and MapReduce

- HDFS and MapReduce are tightly linked
- Programmer can split data to fit block size
  - A block is large enough to store many records, allows for improved performance
  - Records may not align with block size, but not a lot of wasted space



Example: Many figure files in a block, will waste some space at the end where we cannot fit a figure

HDFS and MapReduce

- HDFS and MapReduce are tightly linked
- Programmer can split data to fit block size
  - A block is large enough to store many records, allows for improved performance
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- File semantics optimized for MapReduce
  - MapReduce reads data sequentially
  - HDFS only has read and append operations: Cannot modify existing content
- Colocation of computation and data
  - Hadoop tries to spawn Map instances on DataNodes where the data is stored
  - Reduce network overhead

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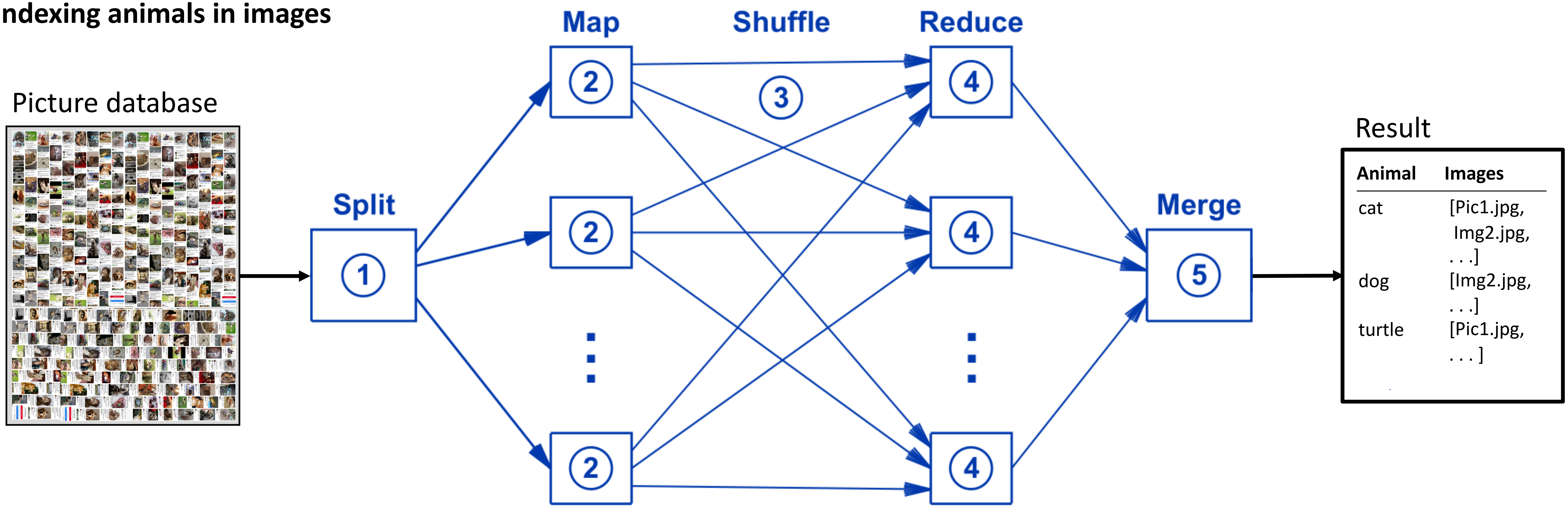
Indexing animals in images



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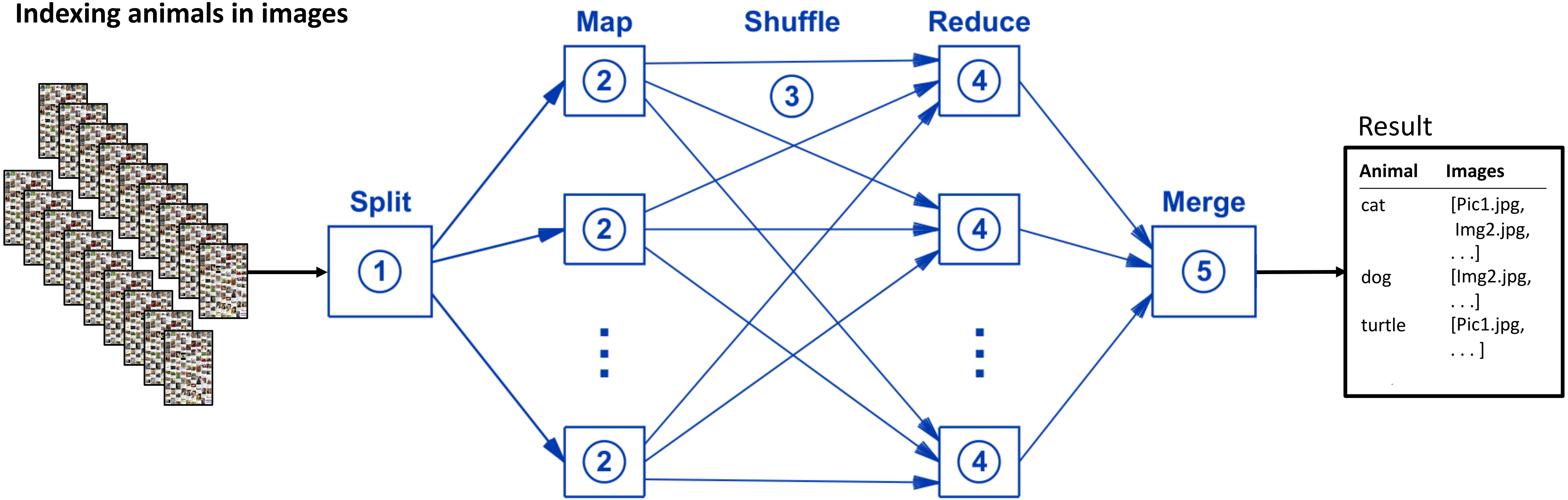

HDFS and MapReduce

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