# Parallel Processing in Python

*DS 5110: Big Data Systems (Spring 2023)*

Lecture 5

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Some material taken/derived from:

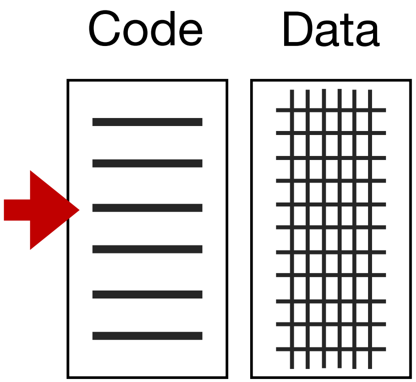
- Wisconsin CS301 by Tyler Harter and UC San Diego DSC102 by Arun Kumar.

# Parallelism: Doing multiple things at once

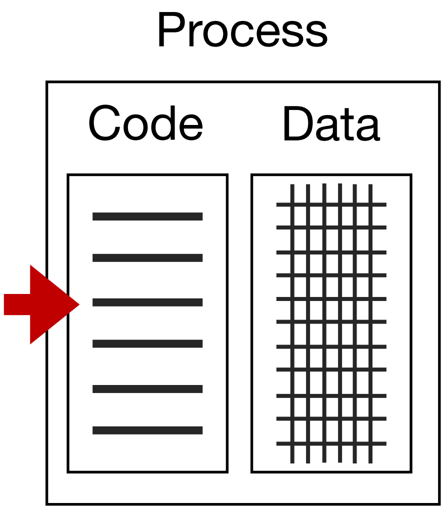
- Mental models

- Two problems

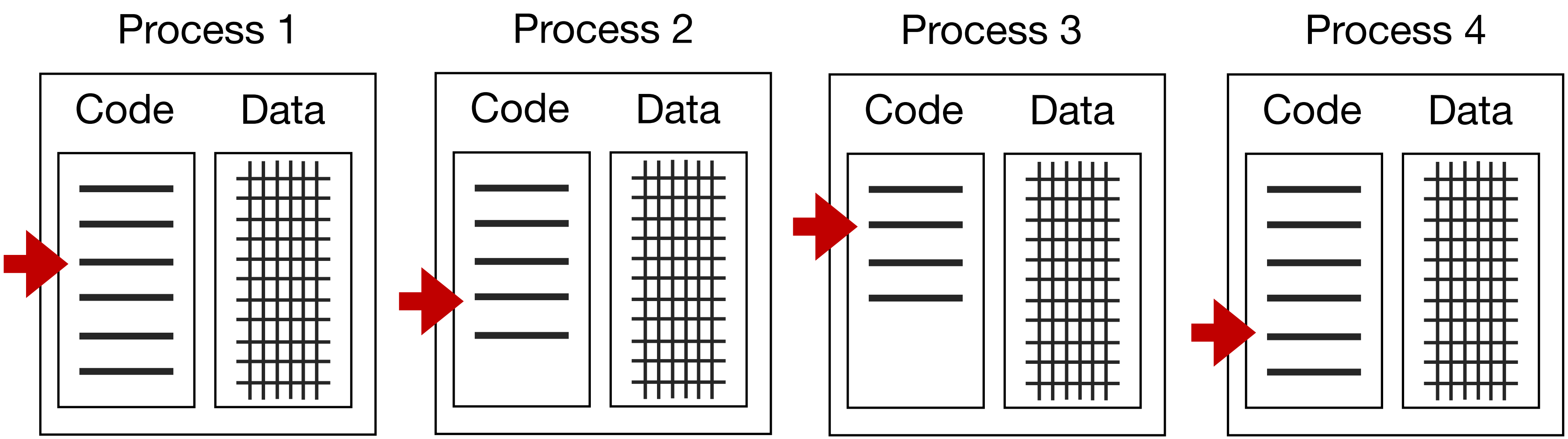
- Parallelism
  - Thread
  - Process
  - Task

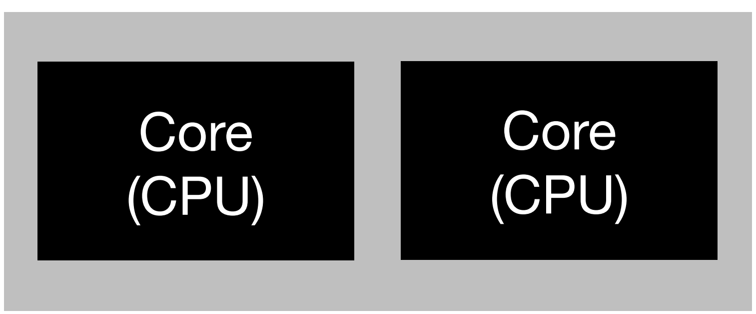


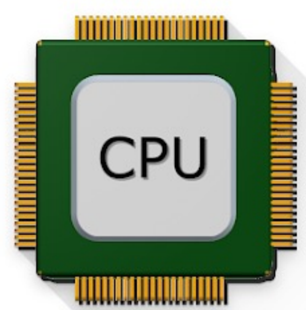

Instruction pointer
(also called “program counter”)



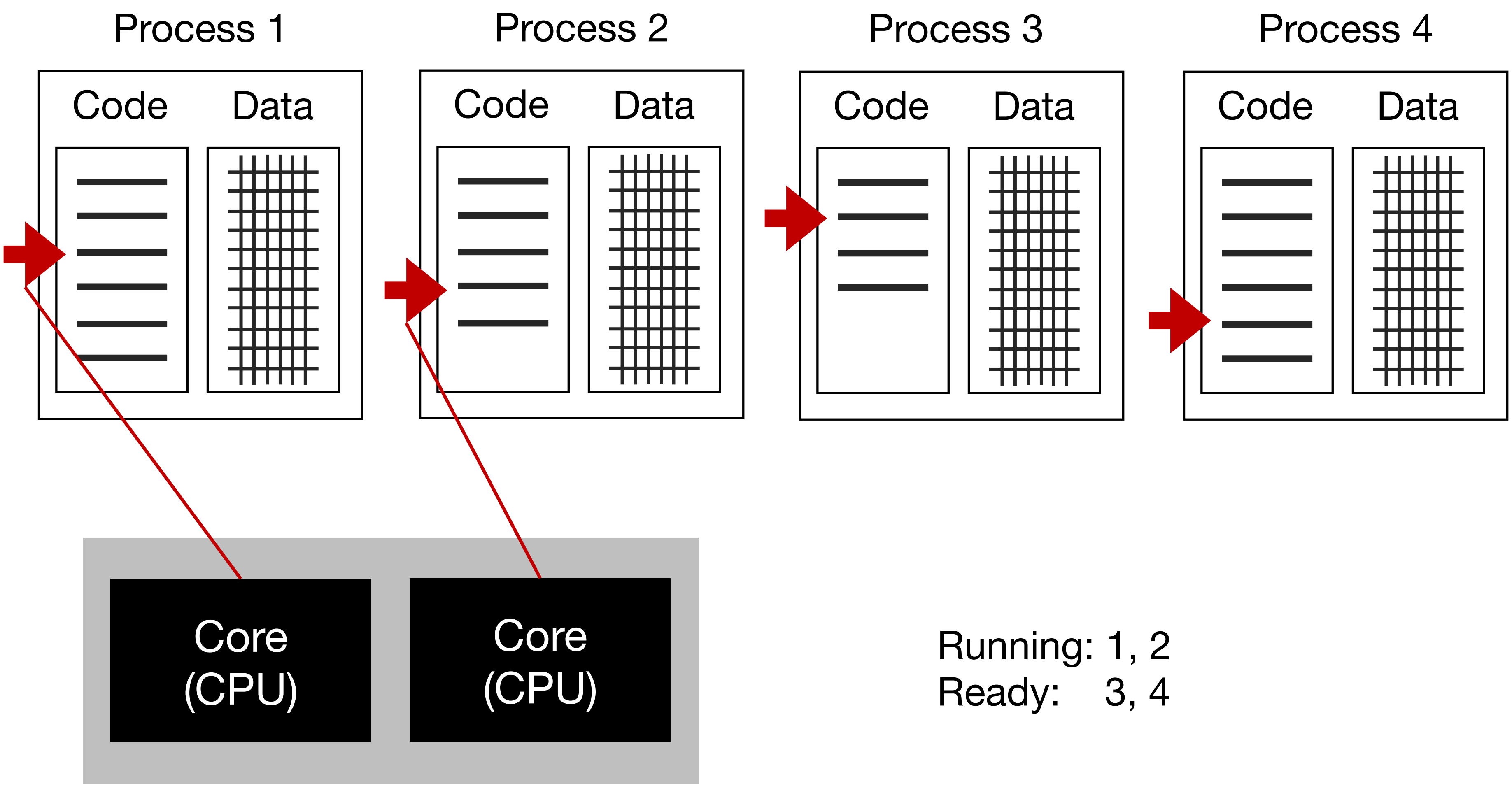

Instruction pointer belongs to a thread within the process



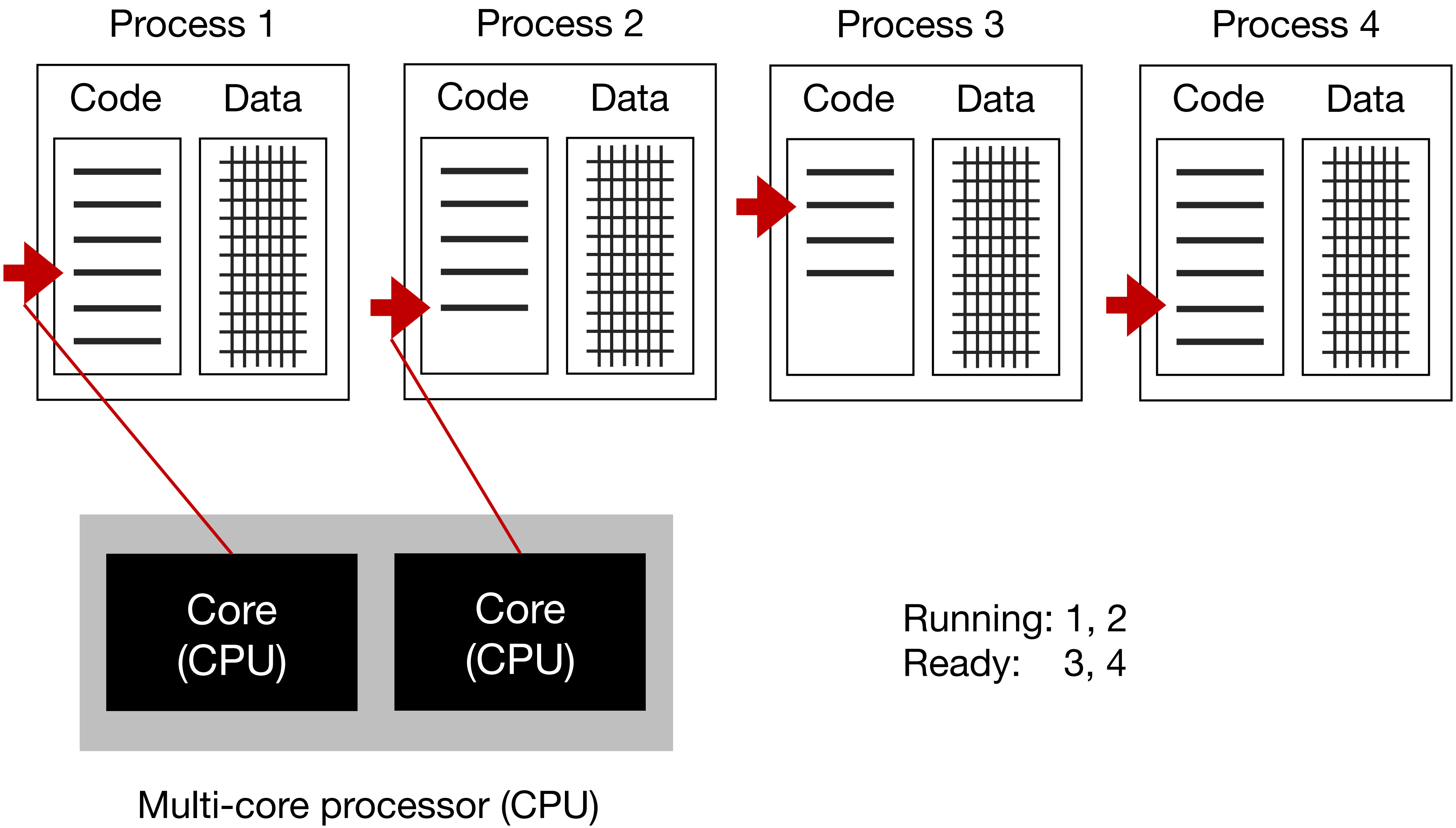




Multi-core processor (CPU)




Multi-core processor (CPU)

Running: 1, 2
Ready: 3, 4

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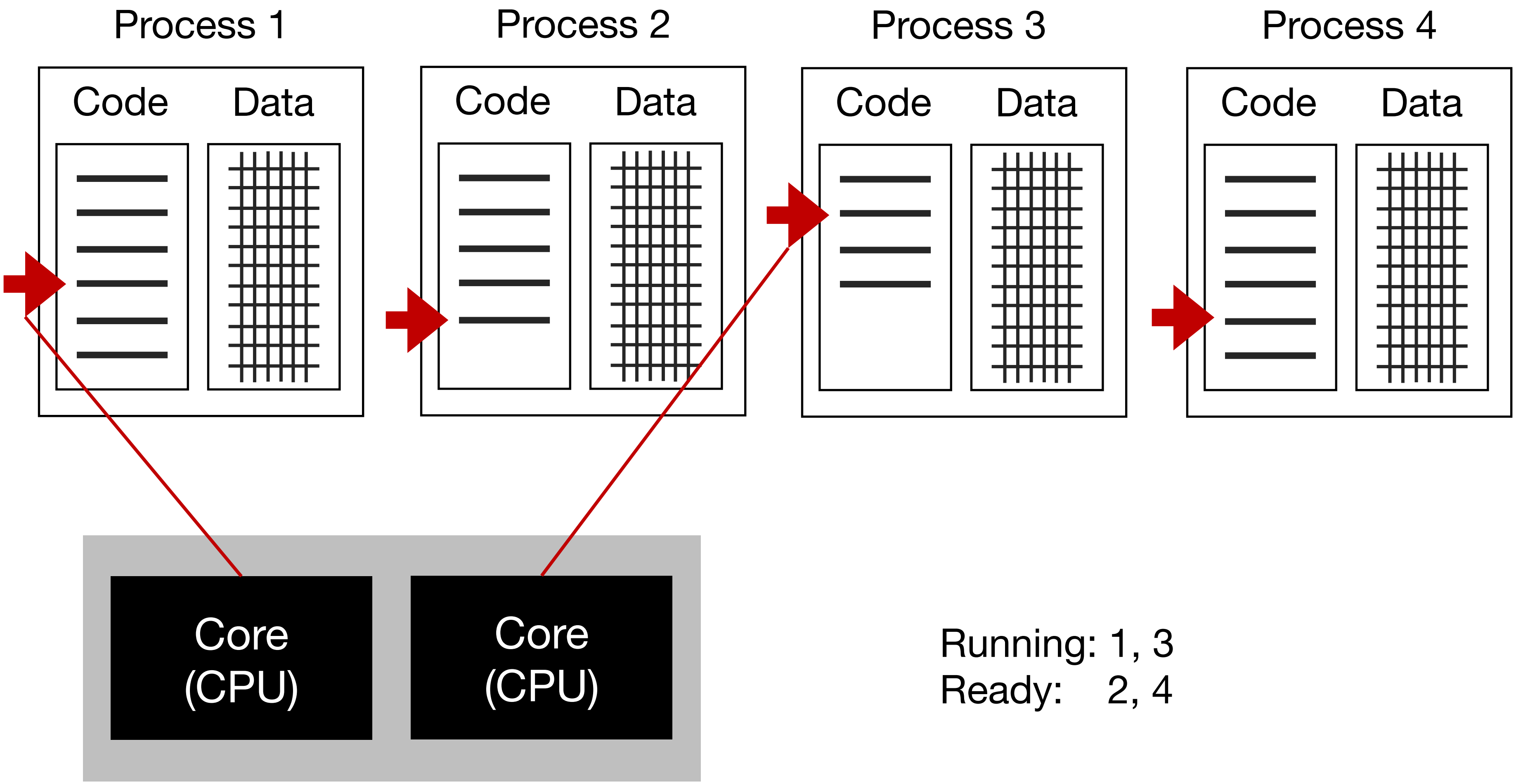
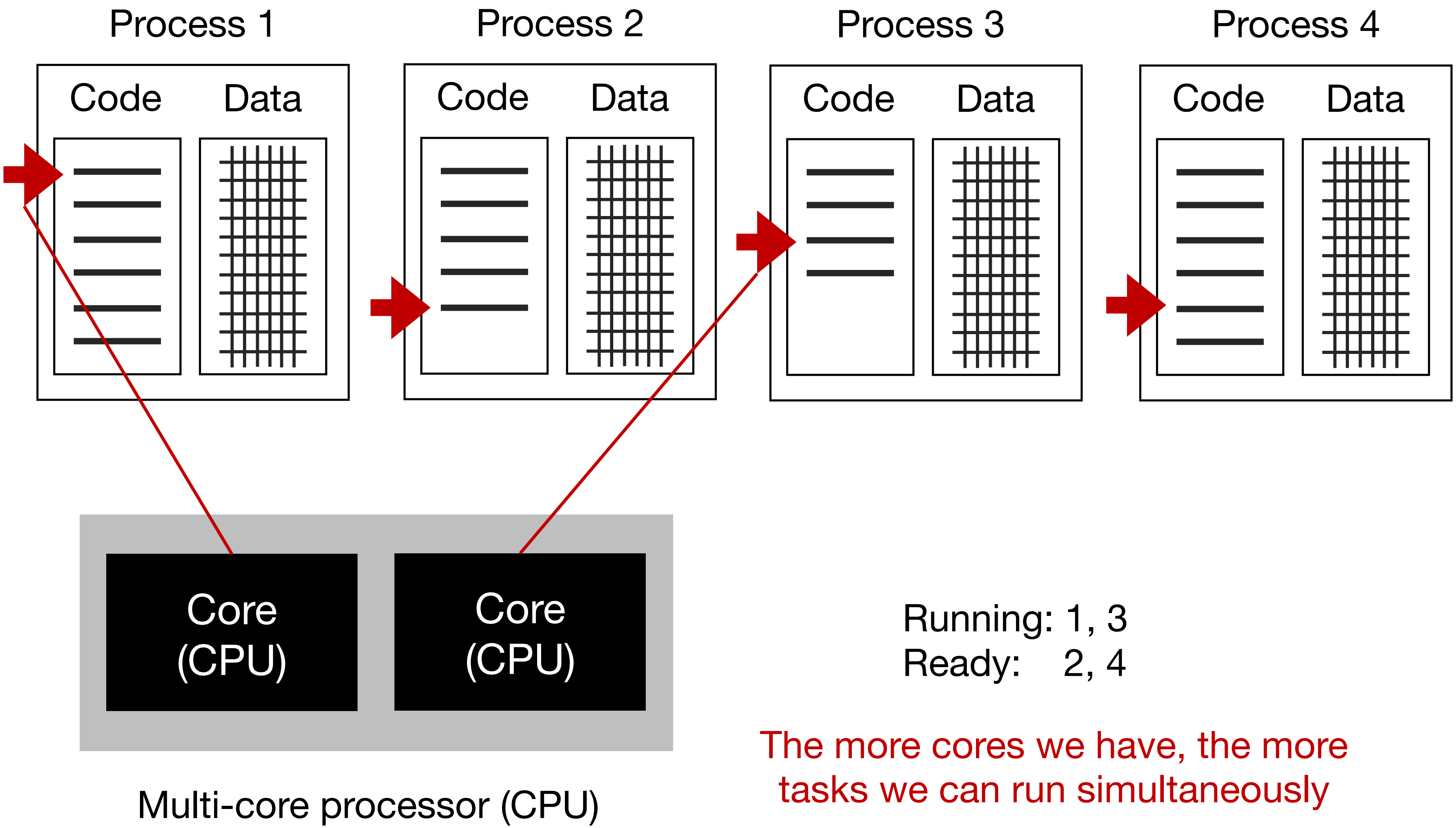



Multi-core processor (CPU)

Running: 1, 3
Ready: 2, 4




Running: 1, 3
Ready: 2, 4

The more cores we have, the more tasks we can run simultaneously

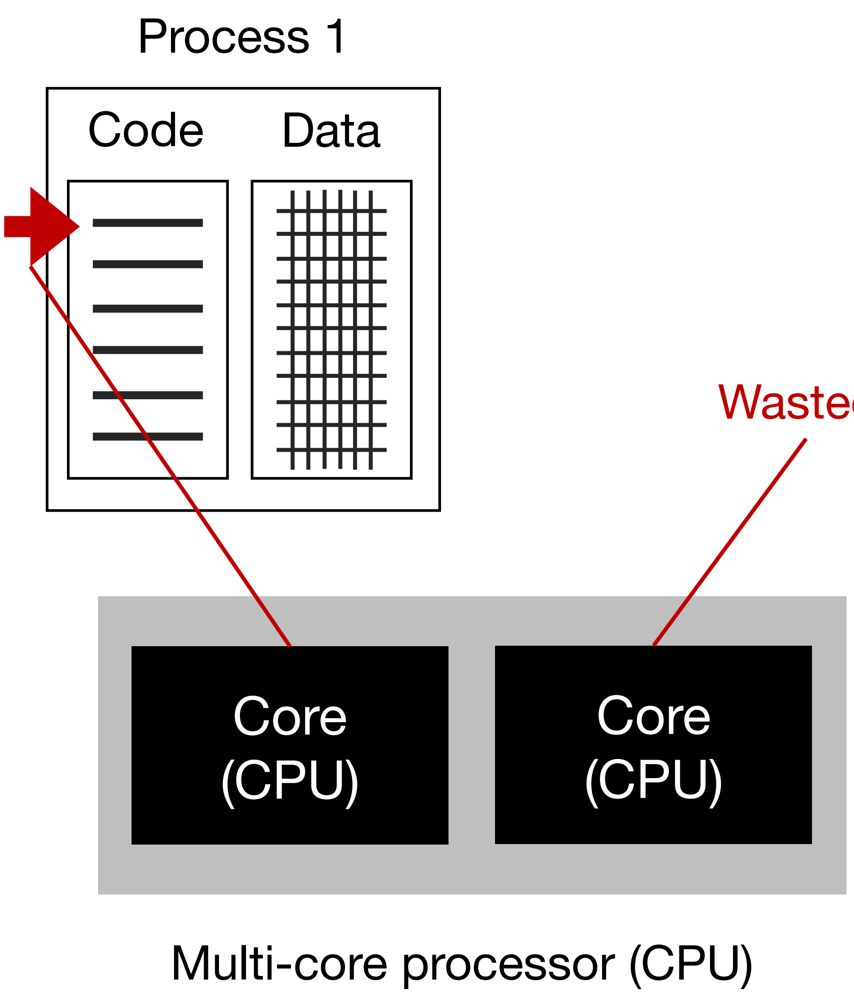
# Wasted compute resources

Two problems

- Not enough distinct (parallelizable) tasks to utilize all cores
- Some operations require waiting (task is “blocked”)

# Problem 1

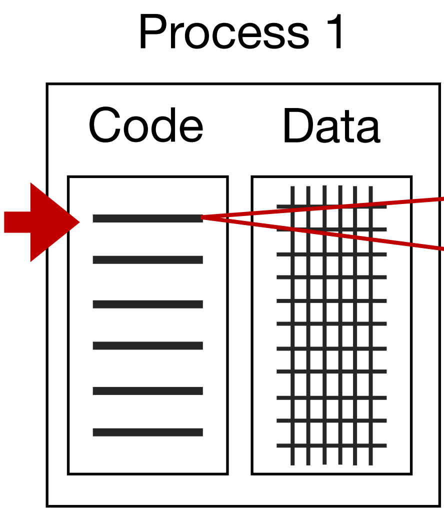
Not enough distinct (parallelizable) tasks to utilize all cores




Running: 1
Ready:

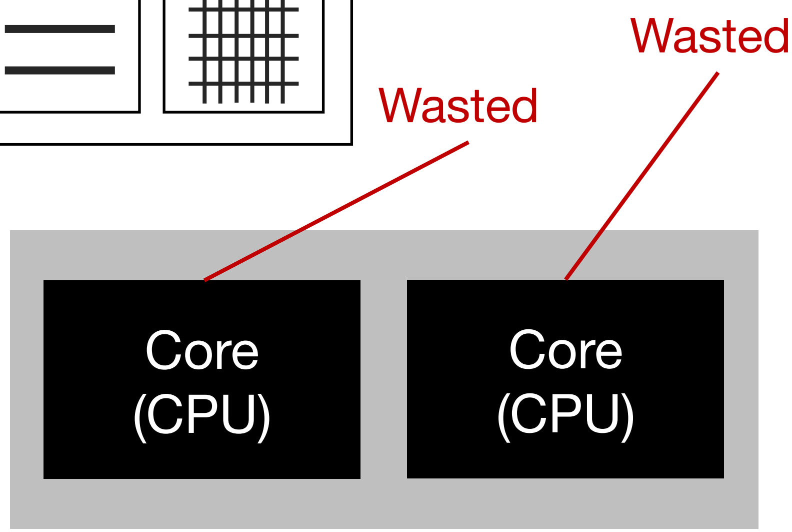
# Problem 2

Some operations require waiting (task is “blocked”)




Operations may require to wait on external resources

- `f.read()`
- `requests.get(URL)`
- `time.sleep(SECONDS)`




Multi-core processor (CPU)

Running:
Ready:
Blocked: 1

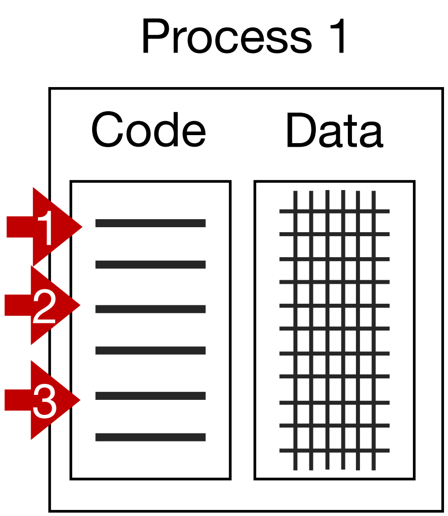
# Solution

- Thread-level parallelism
- Process-level parallelism
- Task-level parallelism

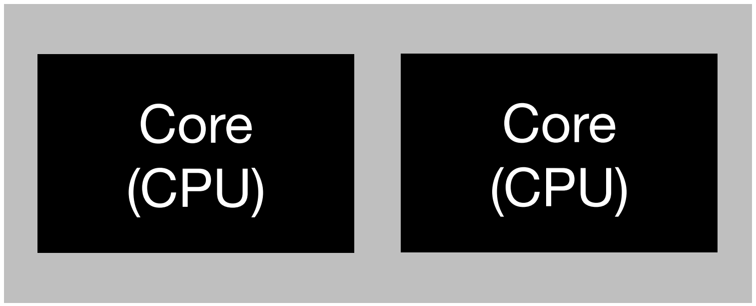
# Solution

- **Thread-level parallelism**
- Process-level parallelism
- Task-level parallelism

# Thread-level parallelism

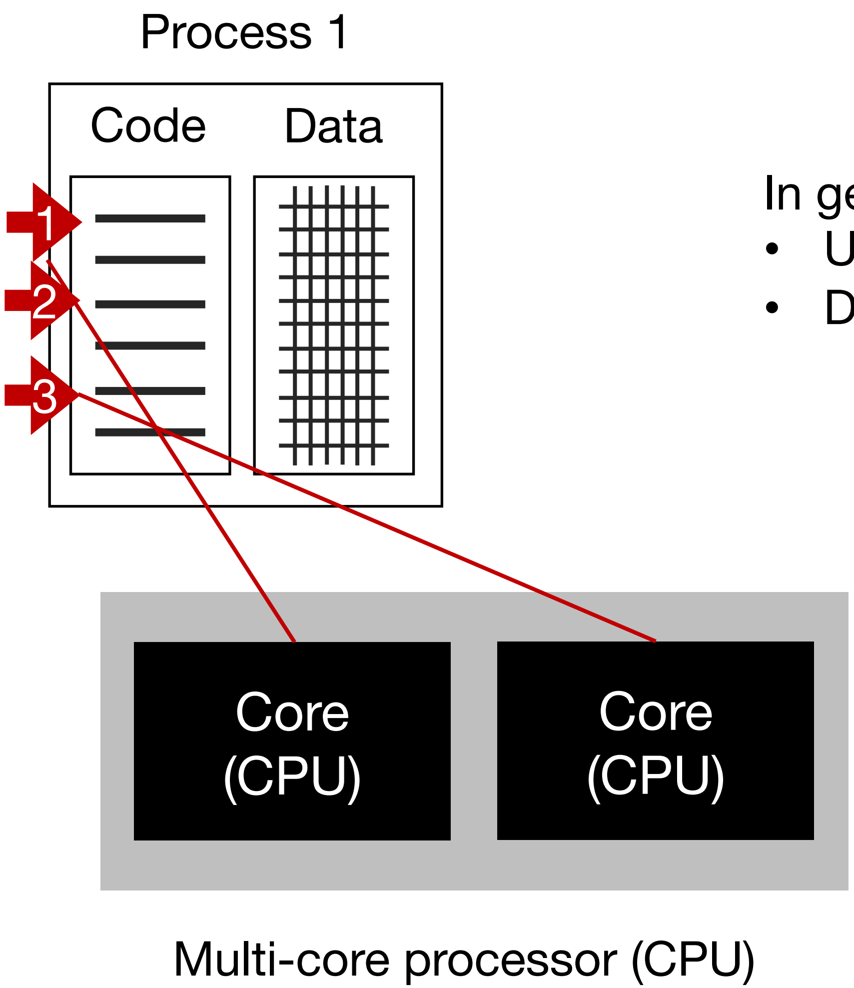



Threads give us multiple instruction pointers in a process, allowing us to execute multiple parts of the code at the same time!




Multi-core processor (CPU)

# Thread-level parallelism

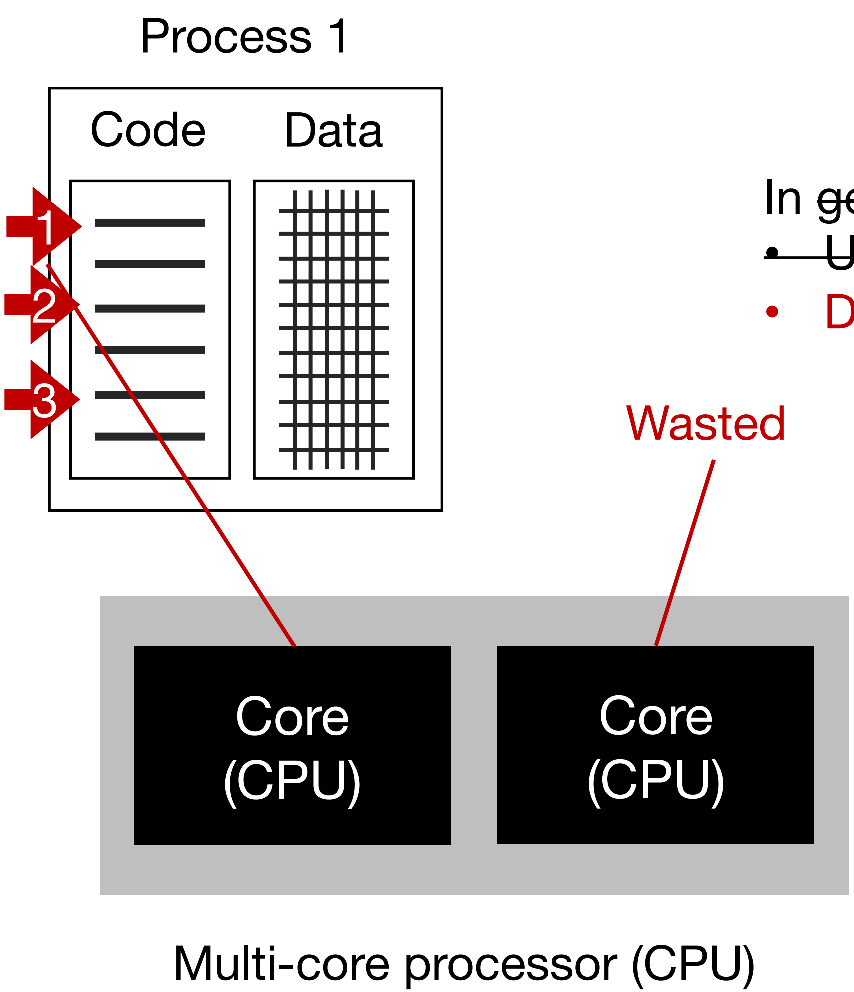



In general, threads help:

- Use multiple cores
- Do useful work when threads are blocking

Running: 1, 3
Ready: 2

# Thread-level parallelism in Python




In ~~general~~ Python, threads help:

- ~~Use multiple cores~~ (b/c of the GIL)
- Do useful work when threads are blocking

https://wiki.python.org/moin/GlobalInterpreterLock

Running: 1
Ready: 3
Blocked: 2

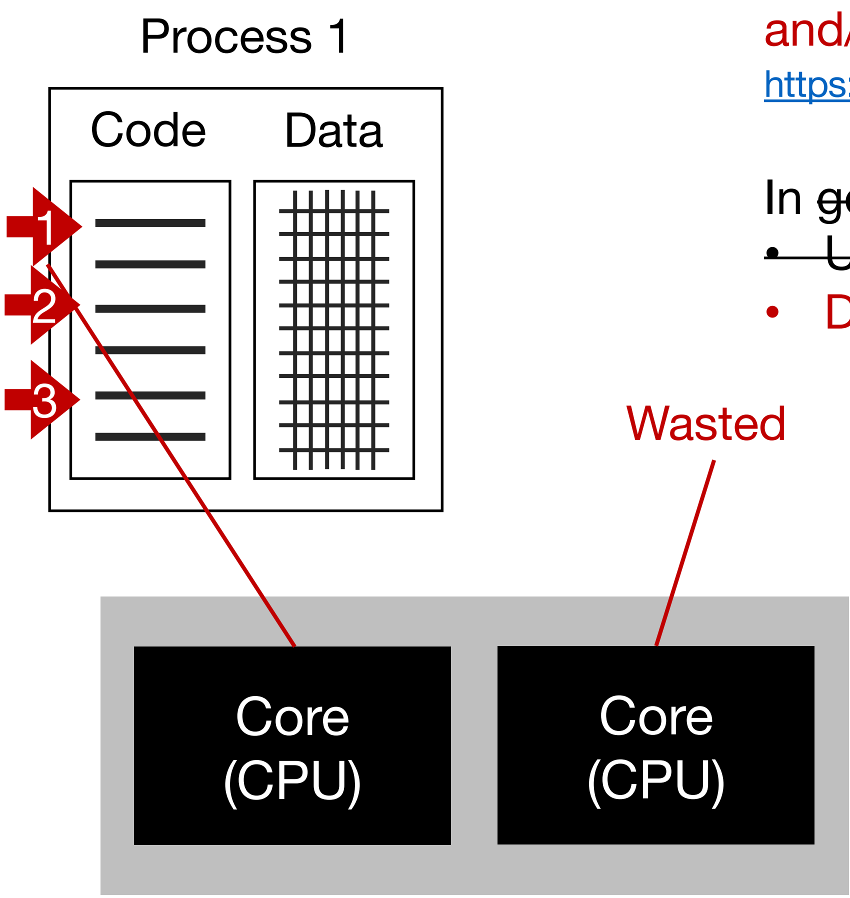
# Thread-level parallelism in Python

**Recommendation:** Don't use threads unless you learn a lot on asynchronous processing and/or coroutines
https://docs.python.org/3/library/asyncio-task.html

In ~~general~~ Python, threads help:

- ~~Use multiple cores~~ (b/c of the GIL)
- Do useful work when threads are blocking

https://wiki.python.org/moin/GlobalInterpreterLock



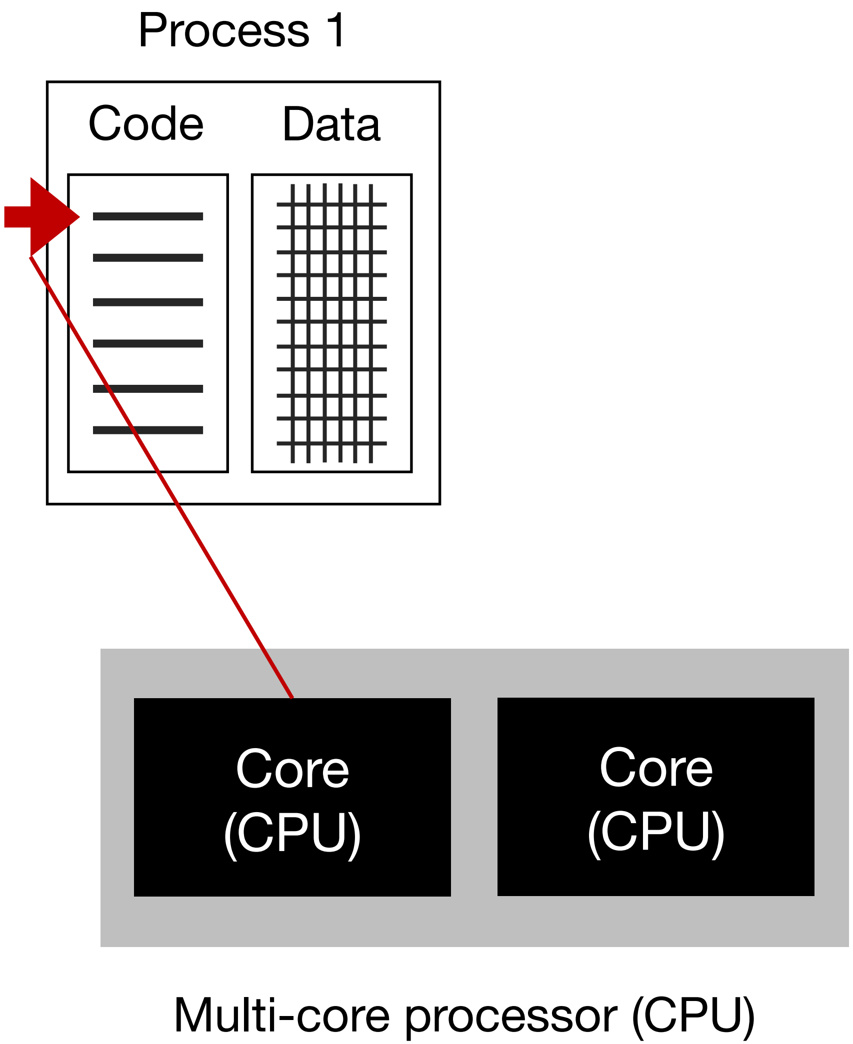

Multi-core processor (CPU)

Running: 1
Ready: 3
Blocked: 2

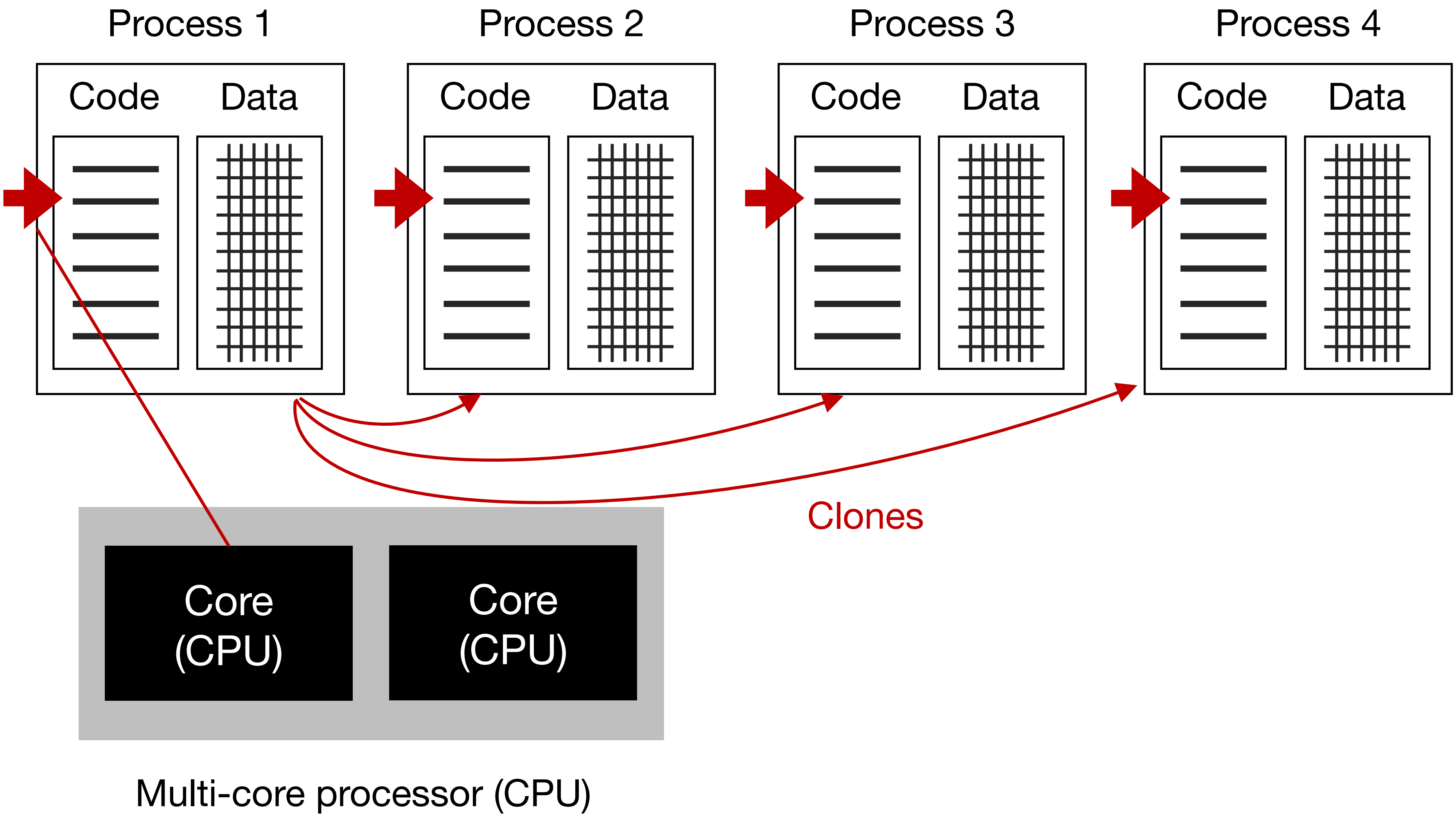
# Solution

- Thread-level parallelism
- **Process-level parallelism**
- Task-level parallelism

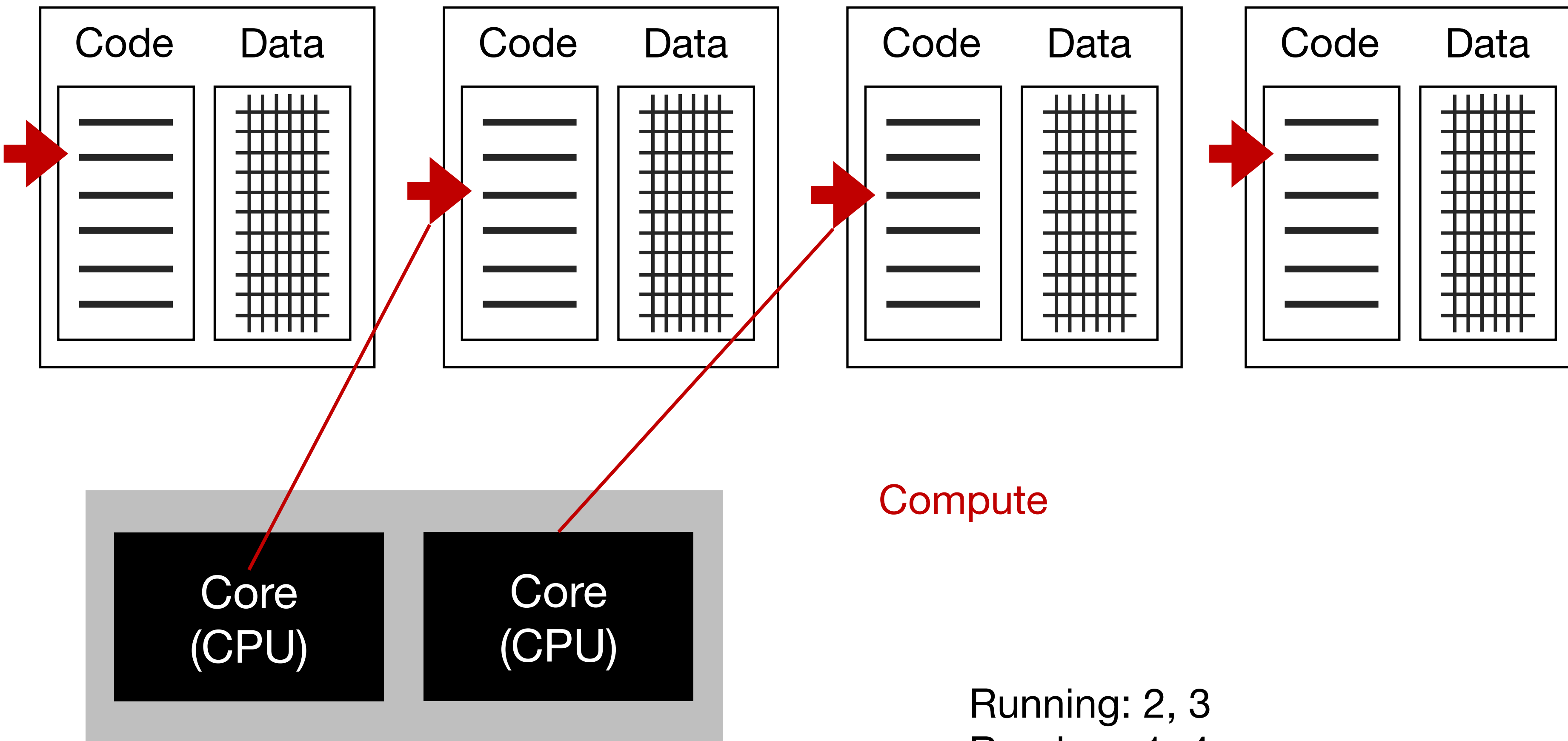
# Process-level parallelism



# Process-level parallelism



# Process-level parallelism

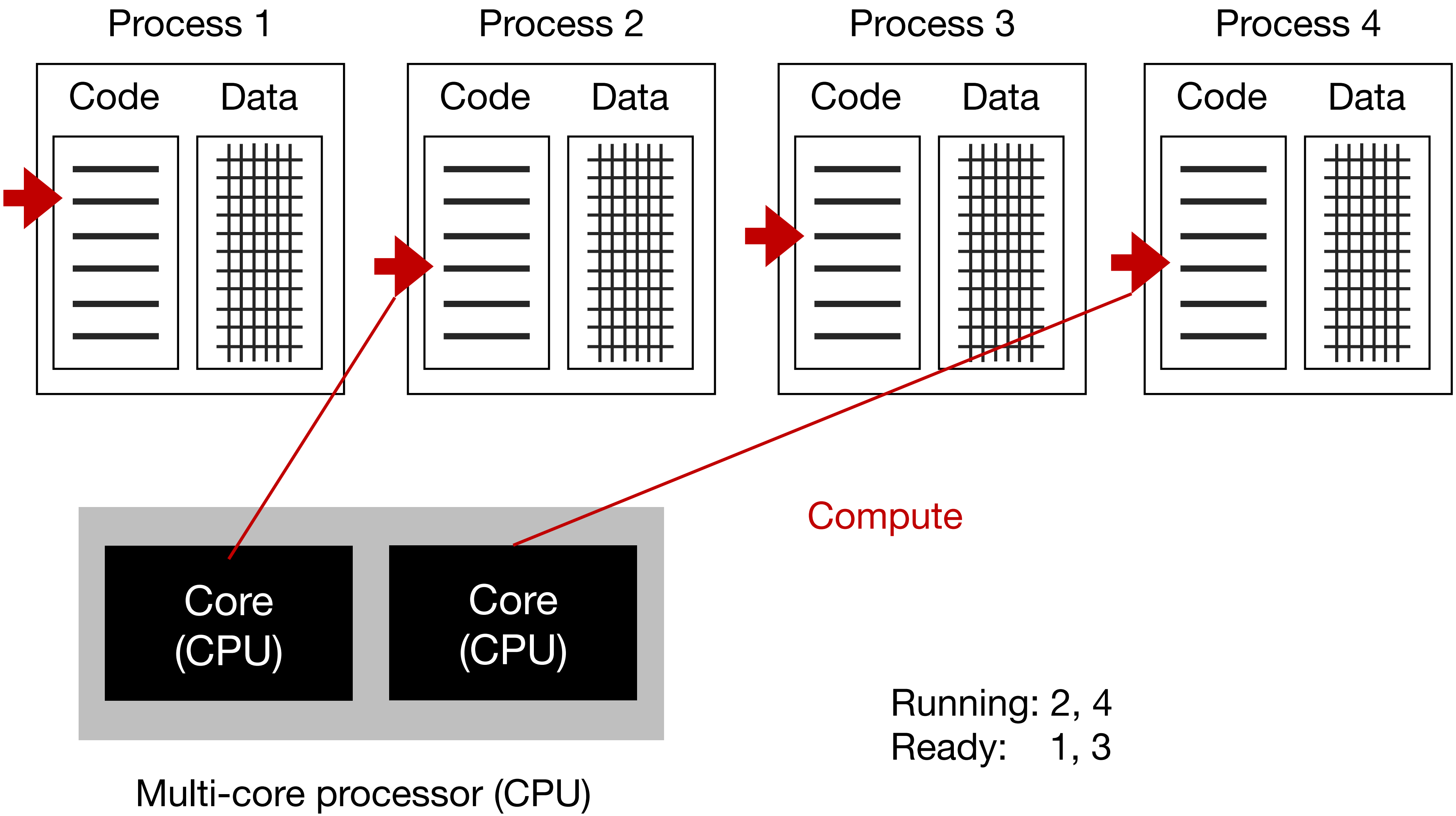



Multi-core processor (CPU)

Compute

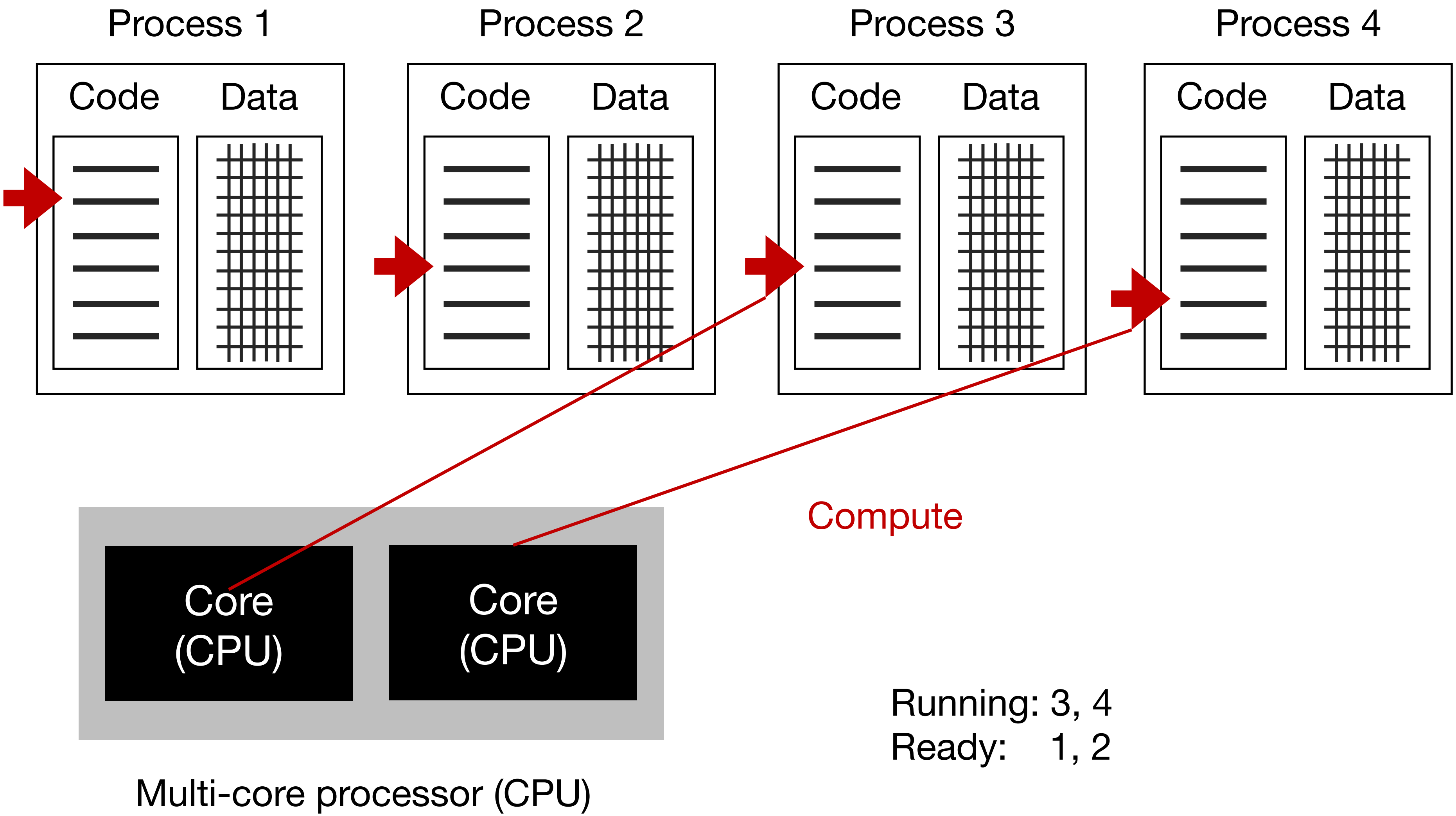
Running: 2, 3
Ready: 1, 4

# Process-level parallelism



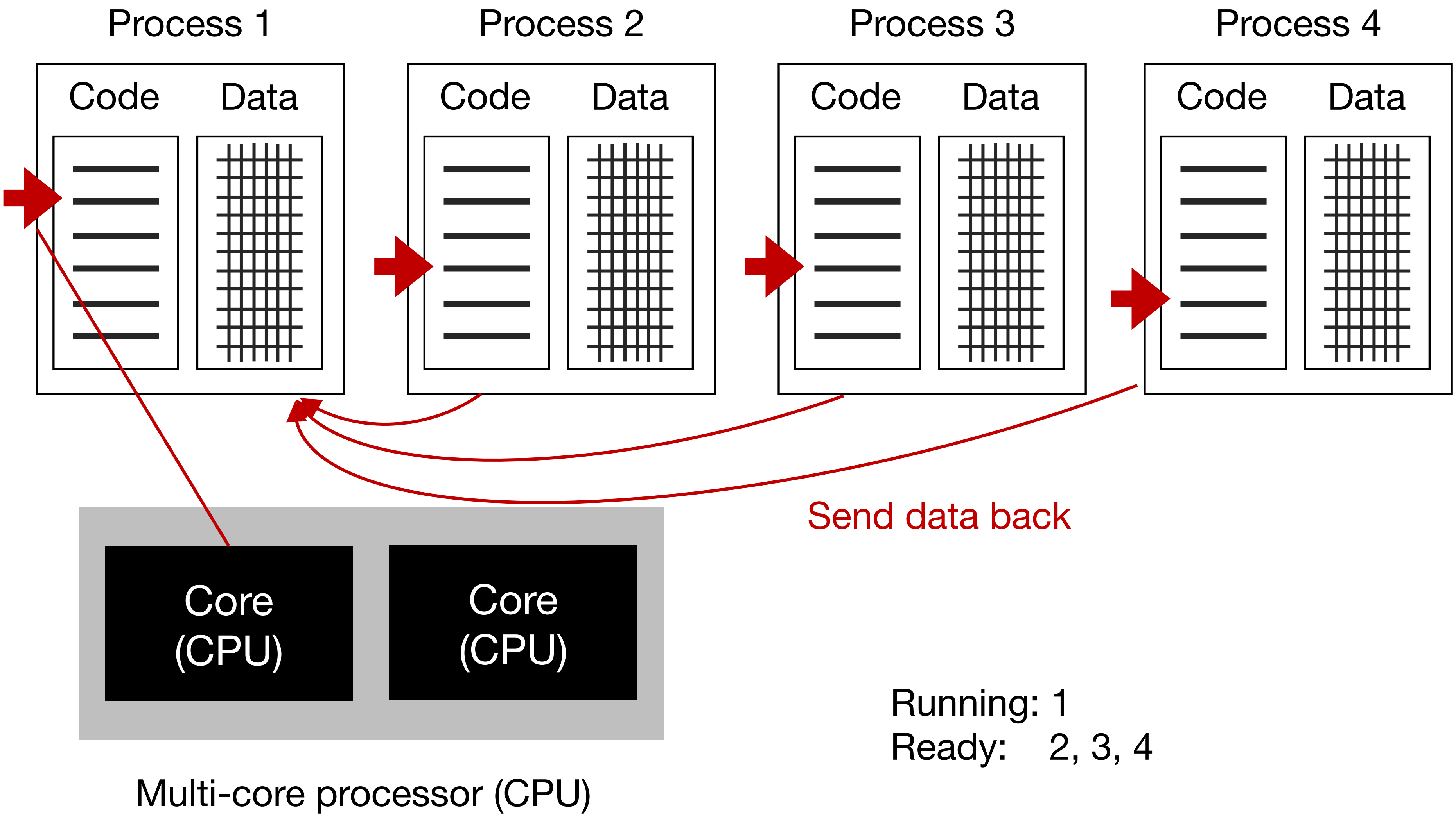

Running: 2, 4
Ready: 1, 3

# Process-level parallelism



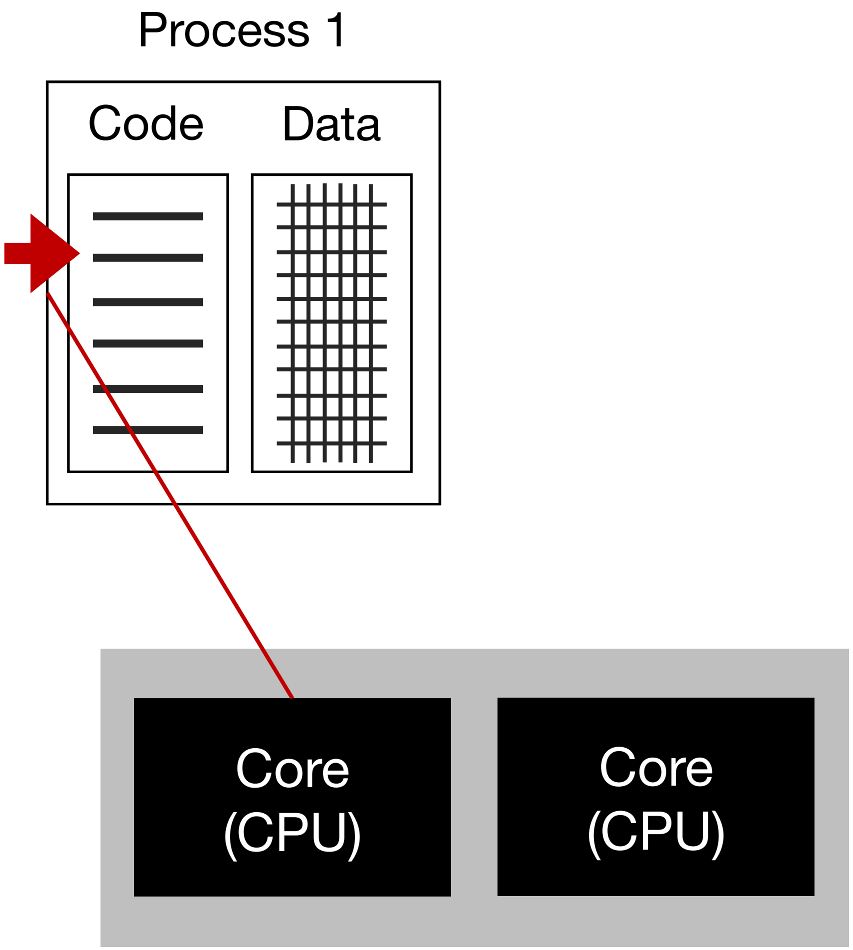

Running: 3, 4
Ready: 1, 2

# Process-level parallelism



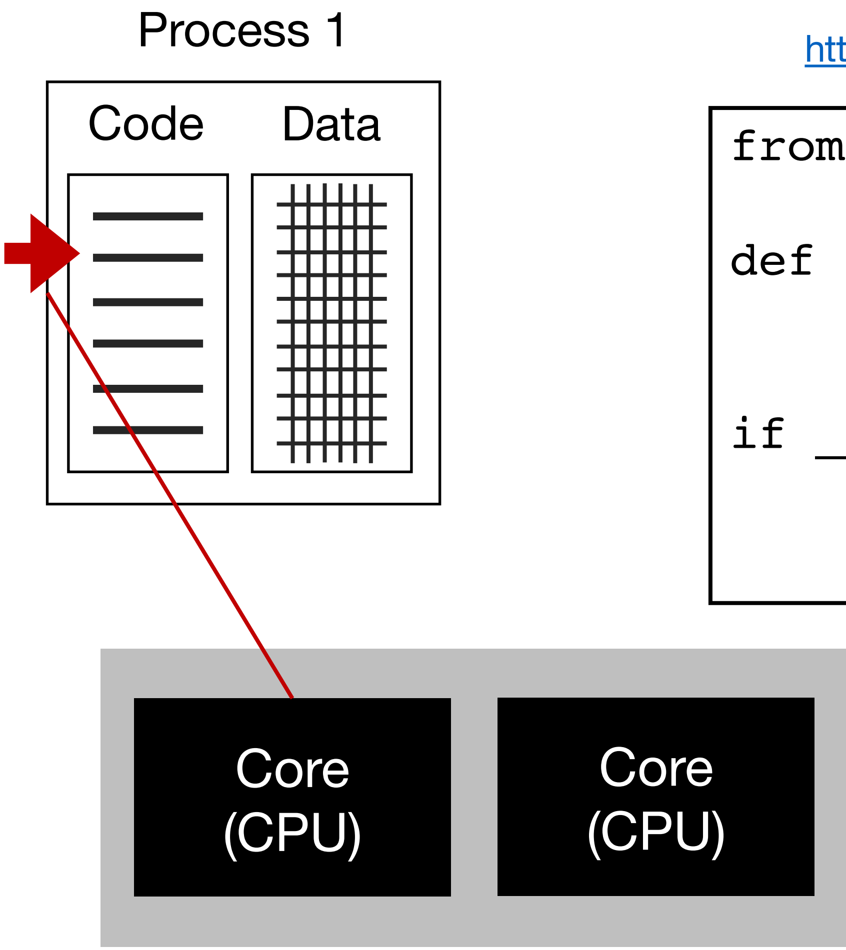

Running: 1
Ready: 2, 3, 4

# Process-level parallelism




Multi-core processor (CPU)

# Process-level parallelism in Python




Multi-core processor (CPU)

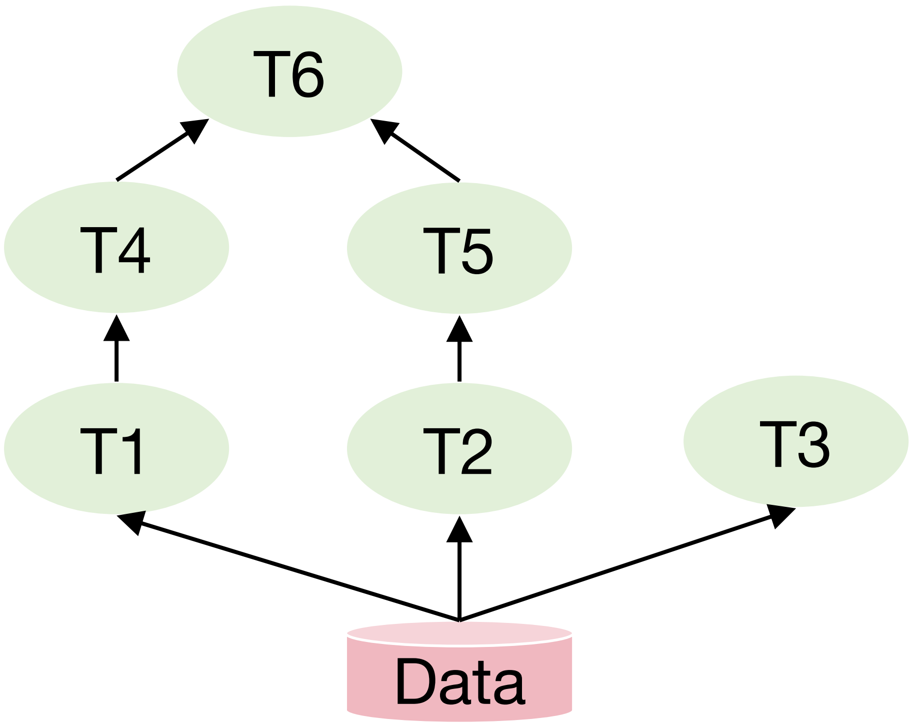
https://docs.python.org/3/library/multiprocessing.html

```
from multiprocessing import Pool

def f(x):
     return x*x

if __name__ == '__main__':
     with Pool(4) as p:
          print(p.map(f, [1,2,3]))
```

# Solution

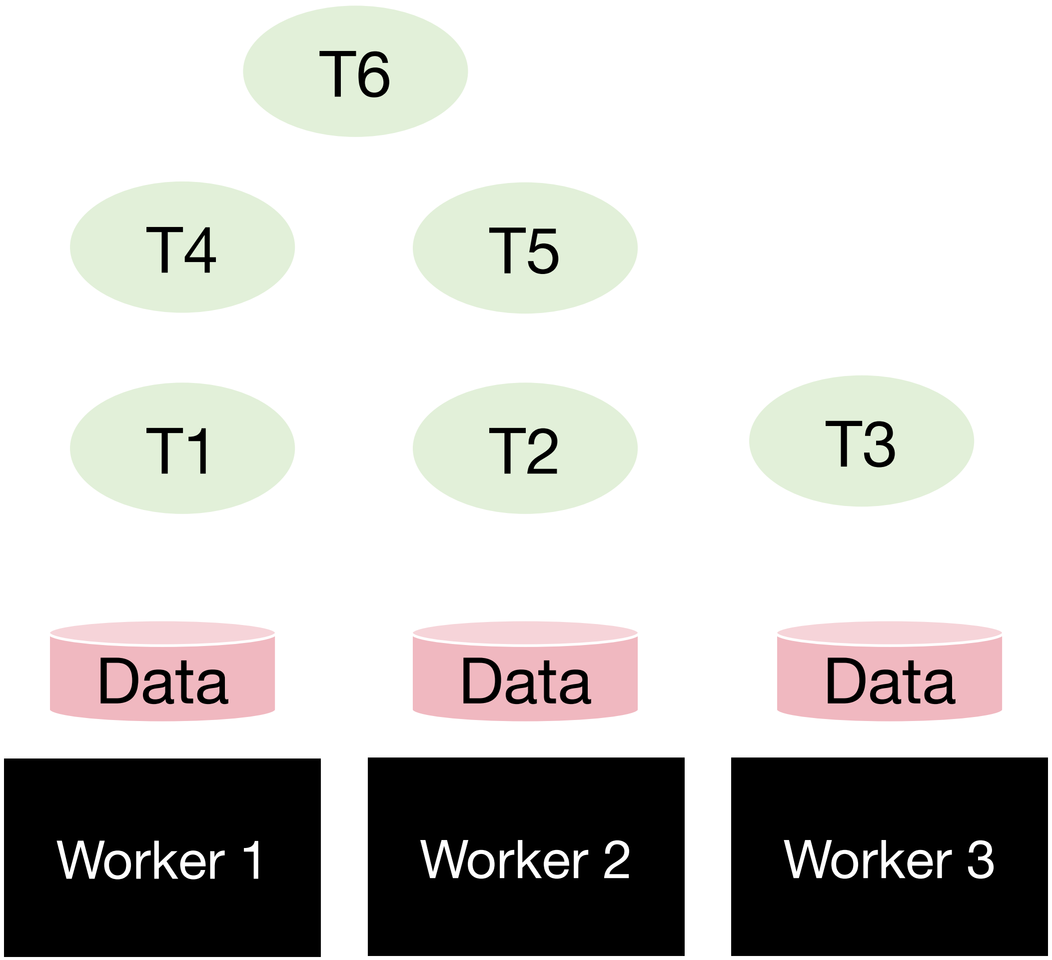
- Thread-level parallelism
- Process-level parallelism
- **Task-level parallelism**

# Task-level parallelism



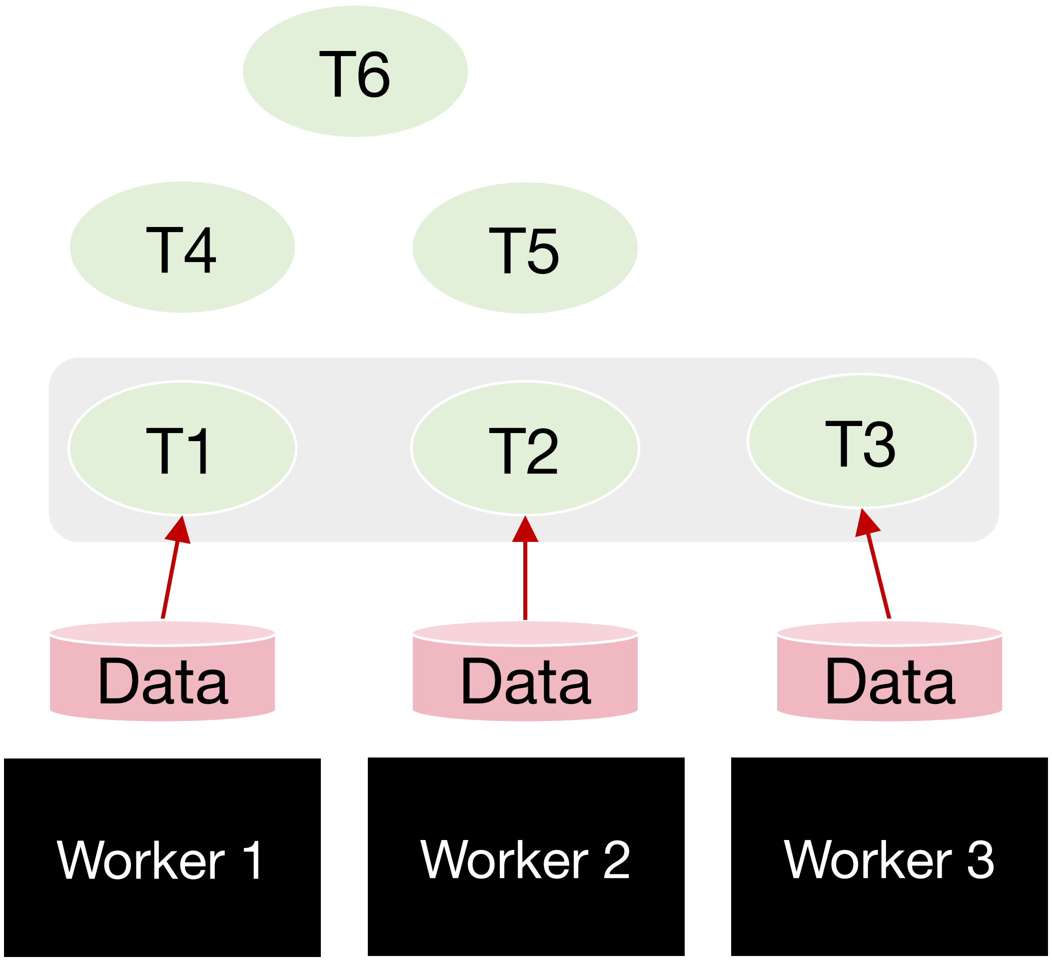

Task DAG
(Directed Acyclic Graph)

# Task-level parallelism




S1: Copy whole dataset to all workers

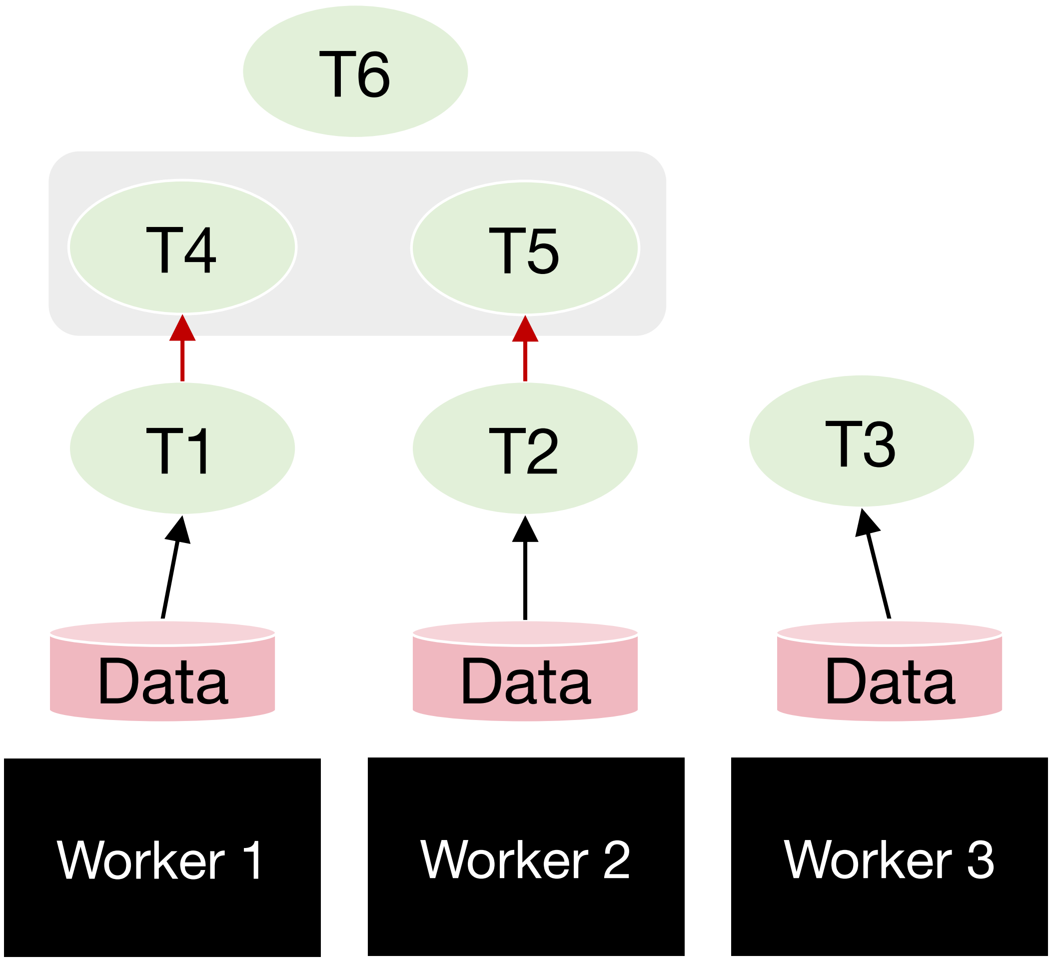
# Task-level parallelism




S2: Schedule T1 to W1, T2 to W2, T3 to W3

S1: Copy whole dataset to all workers

# Task-level parallelism

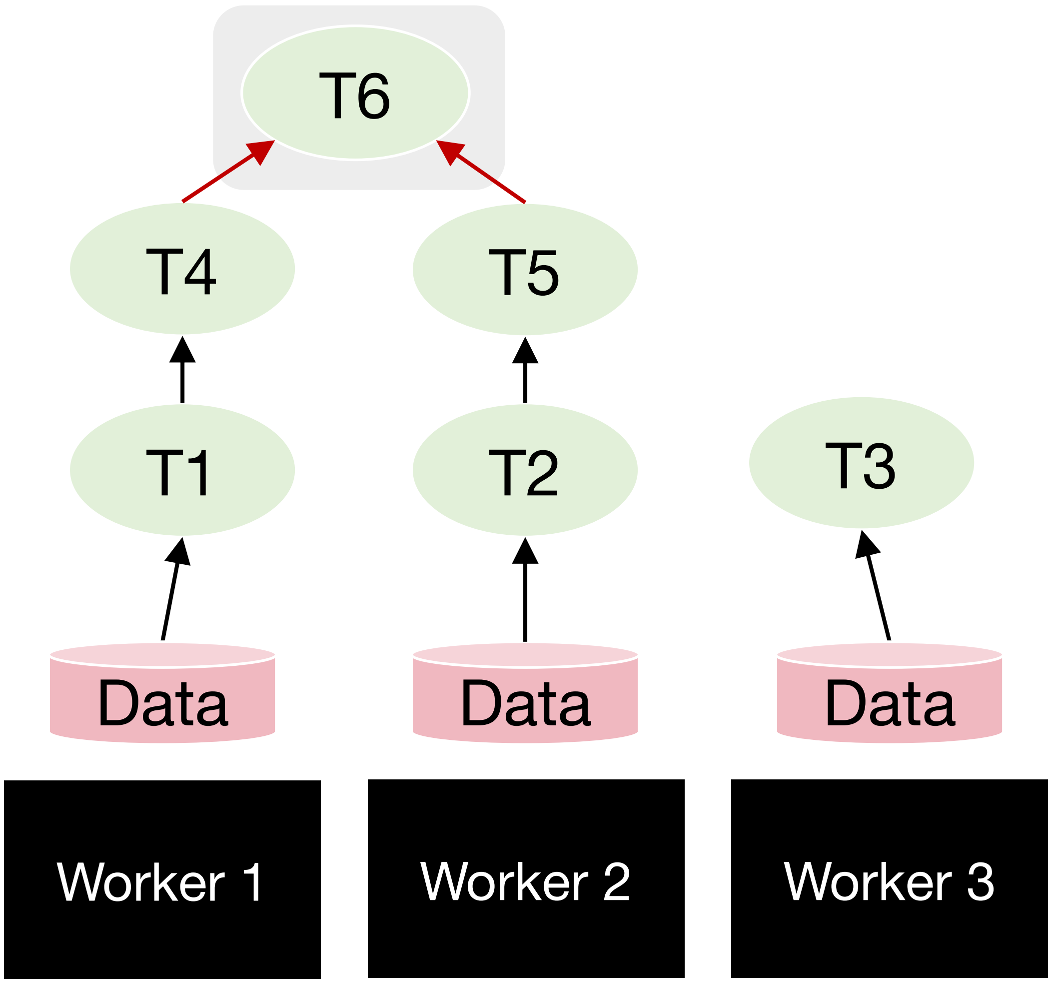



S3: Run T4 after T1 on W1, run T5 after T2 on W2; after T3, W3 is idle

S2: Schedule T1 to W1, T2 to W2, T3 to W3

S1: Copy whole dataset to all workers

# Task-level parallelism



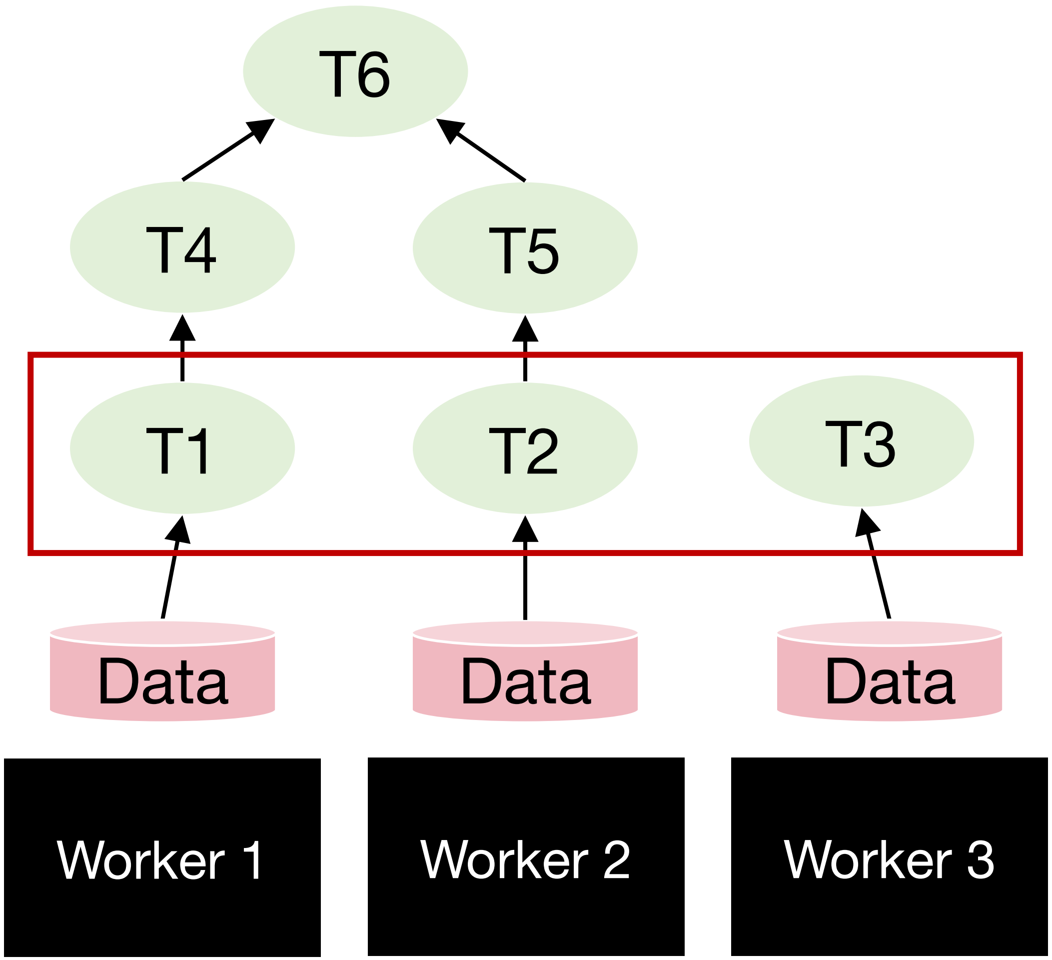

S4: After T4 and T4 ends, run T6 on W1; after T5, W2 is idle

S3: Run T4 after T1 on W1, run T5 after T2 on W2; after T3, W3 is idle

S2: Schedule T1 to W1, T2 to W2, T3 to W3

S1: Copy whole dataset to all workers

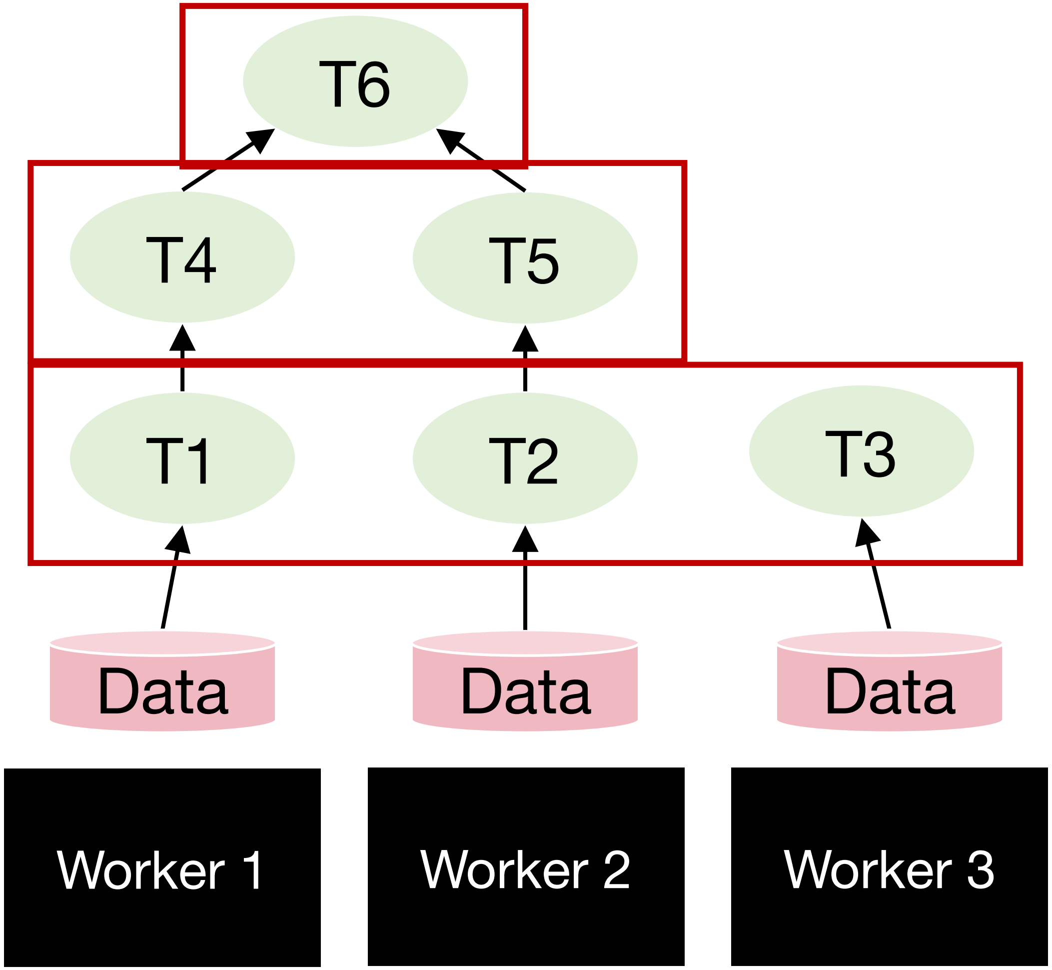
# Task-level parallelism




**Degree of parallelism** is the largest amount of parallelism possible in the DAG:

- How many tasks can be run in parallel at most

# Task-level parallelism




Resource wastage on idle workers

Overtime degree of parallelism drops!

**Degree of parallelism** is the largest amount of parallelism possible in the DAG:

- How many tasks can be run in parallel at most

# Quantify benefit of parallelism: Speedup

$$\textbf{Speedup} = \frac{\text{Completion time given 1 worker}}{\text{Completion time given N worker}}$$

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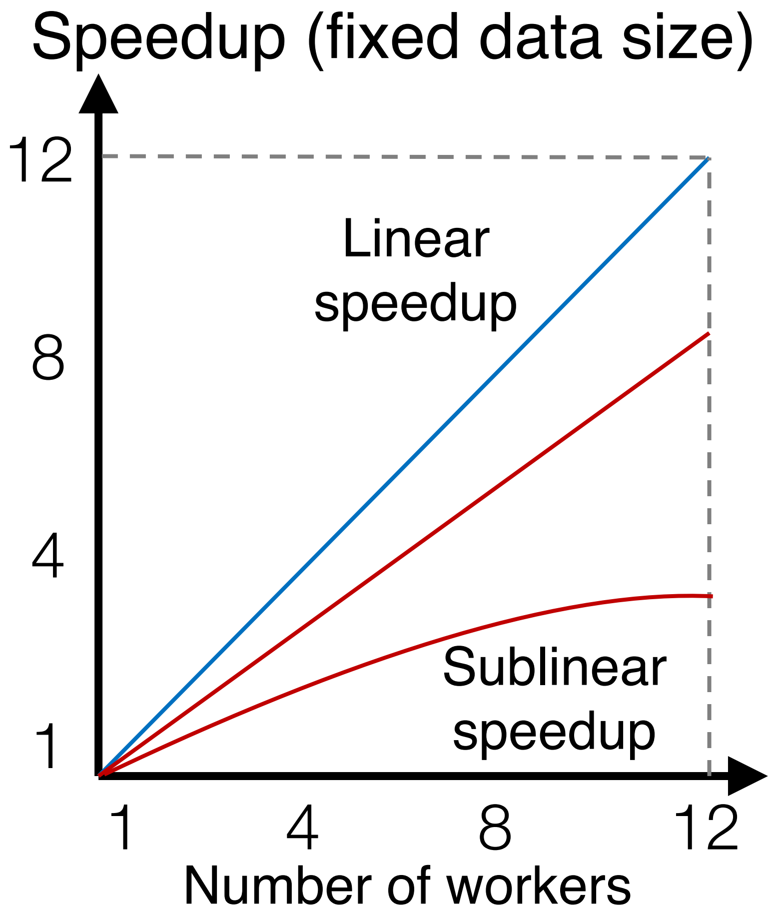
$$\textbf{Speedup} = \frac{\text{Completion time given 1 worker}}{\text{Completion time given N worker}}$$

Q: Given N workers, can we get a speedup of N?

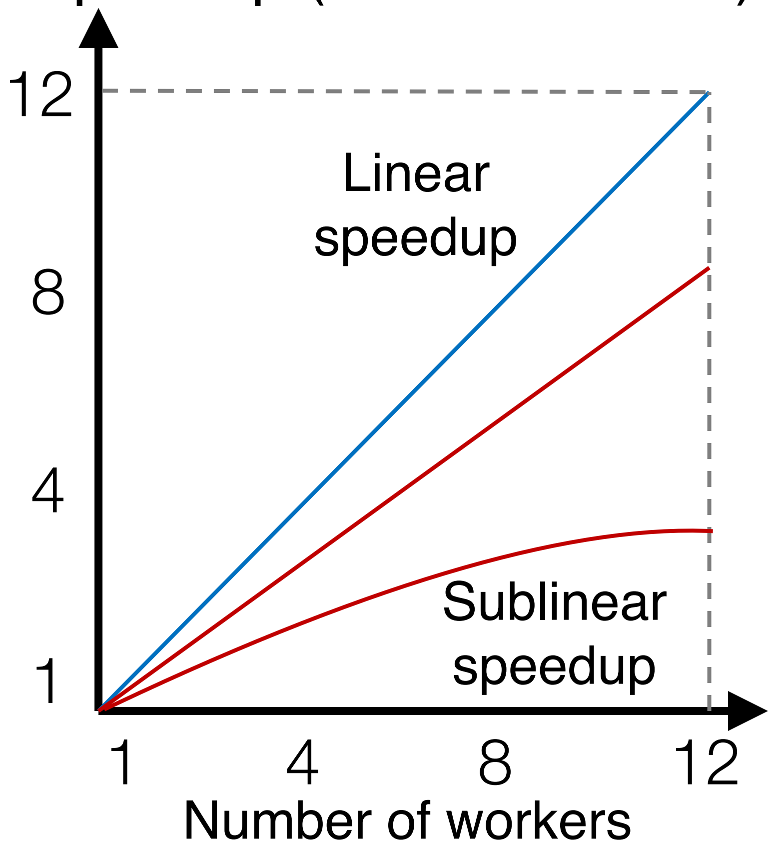
# Quantify speedup




**Strong scaling**

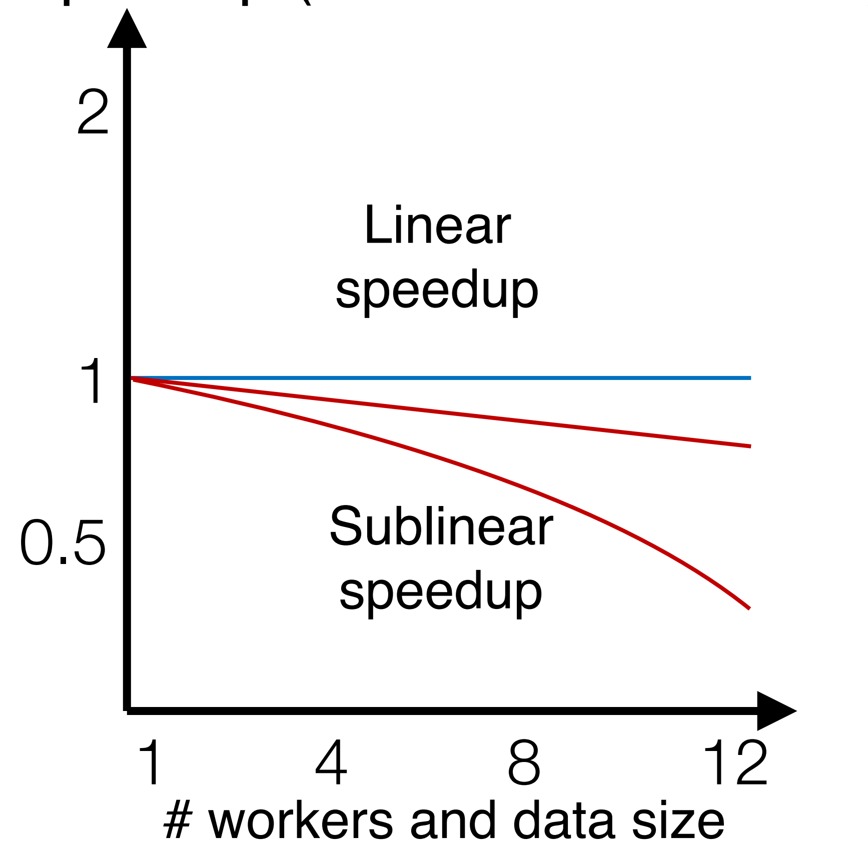
# Quantify speedup

Speedup (fixed data size)



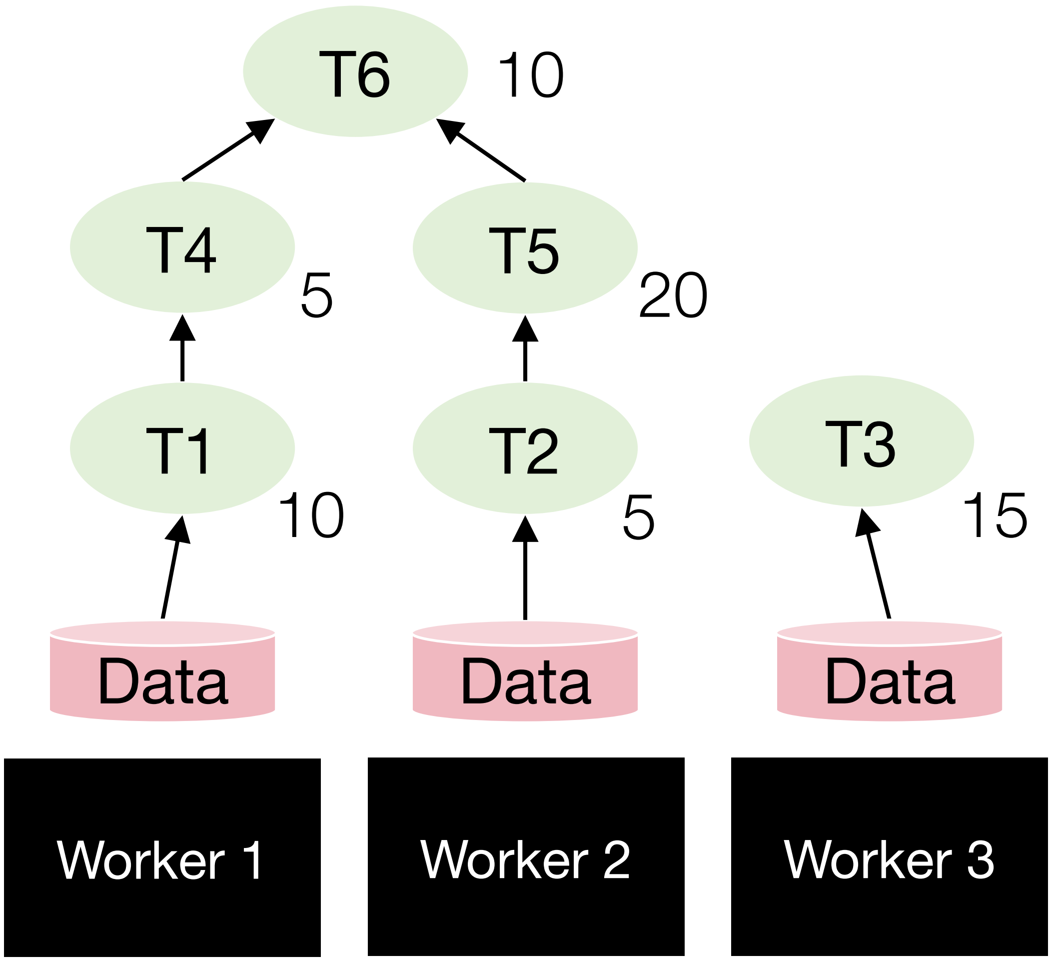

**Strong scaling**

Speedup (increased data size)



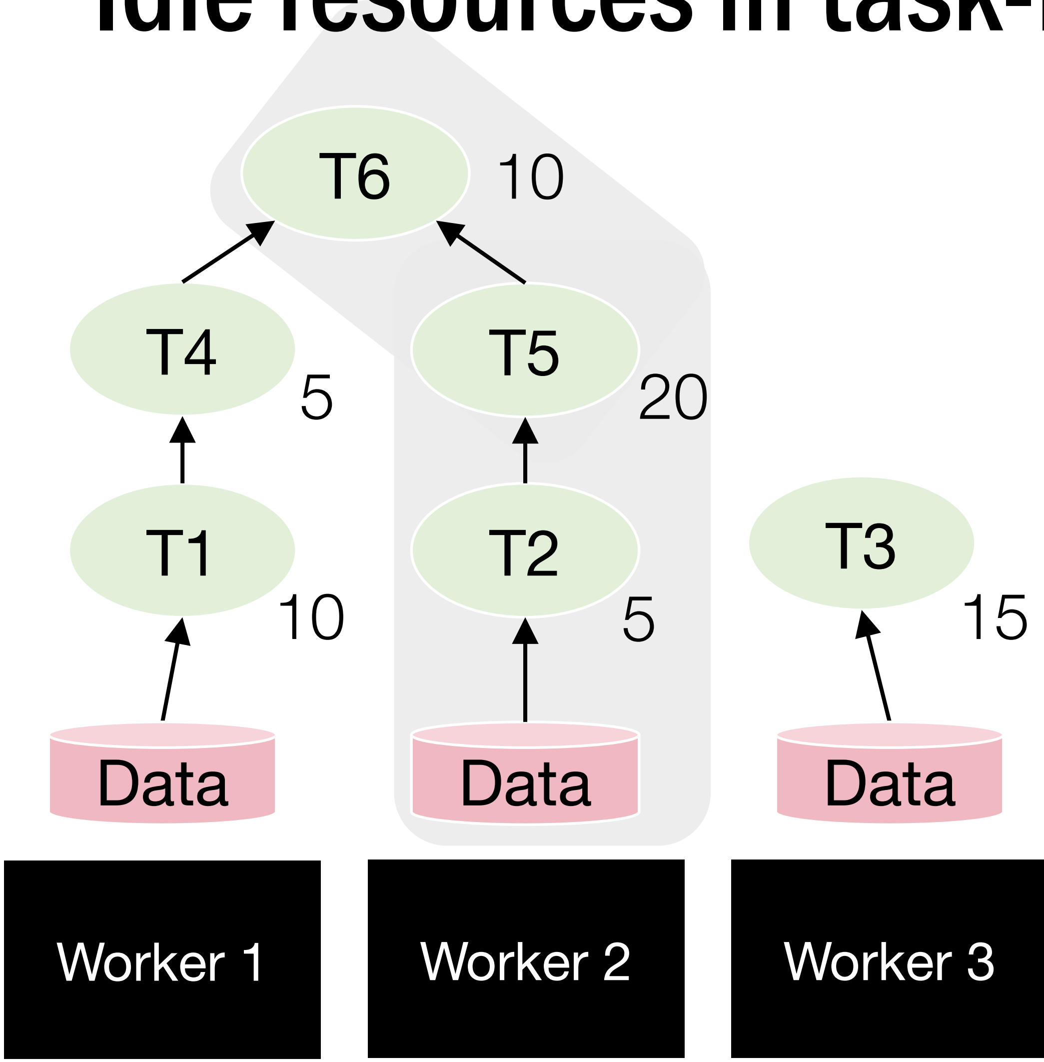

**Weak scaling**

# Idle resources in task-level parallelism




Task completion time varies

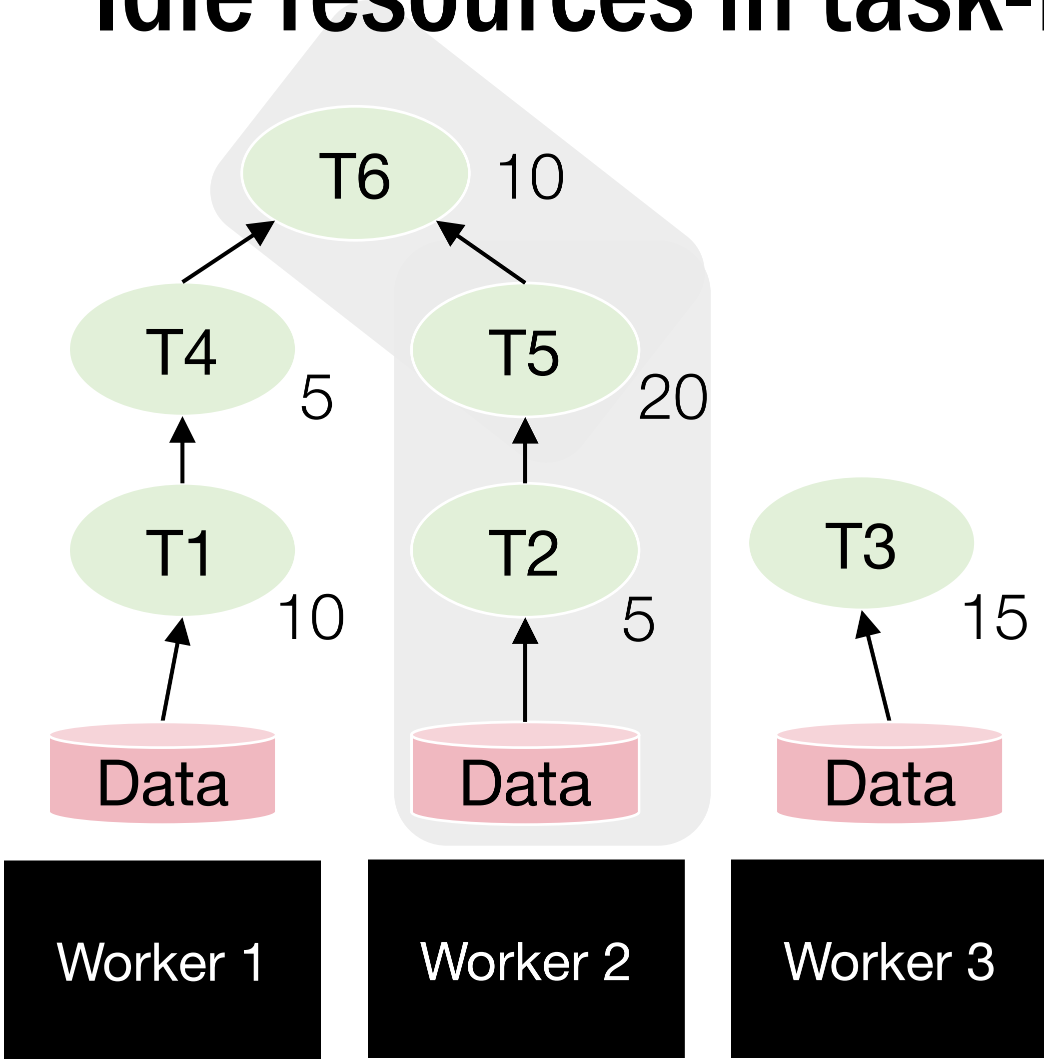
# Idle resources in task-level parallelism




Task completion time varies

- Job completion time is always bounded by the **longest path** in the DAG

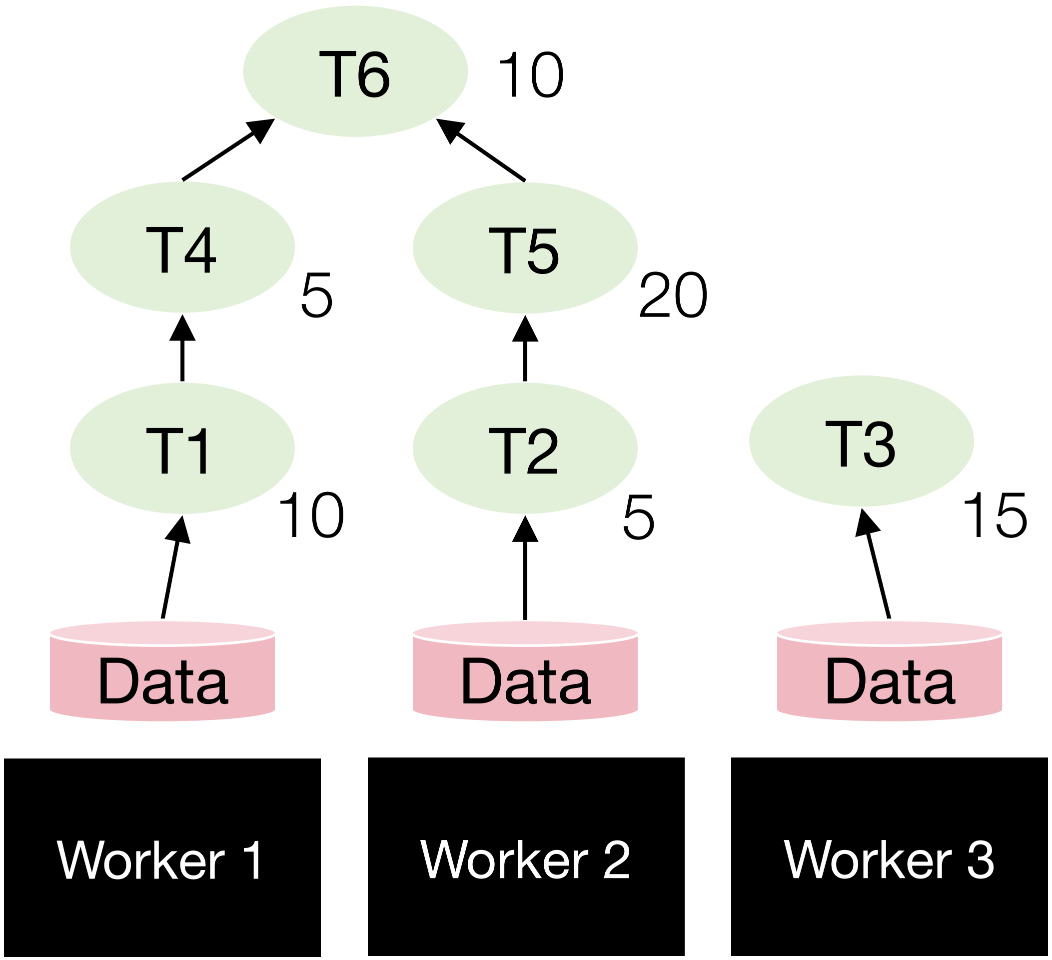
# Idle resources in task-level parallelism




Task completion time varies

- Job completion time is always bounded by the **longest path** in the DAG
- **Potential optimization:** The scheduler can elastically release a worker if it knows the worker will be idle till the end
  - Can **save $ cost** in cloud

# Idle resources in task-level parallelism

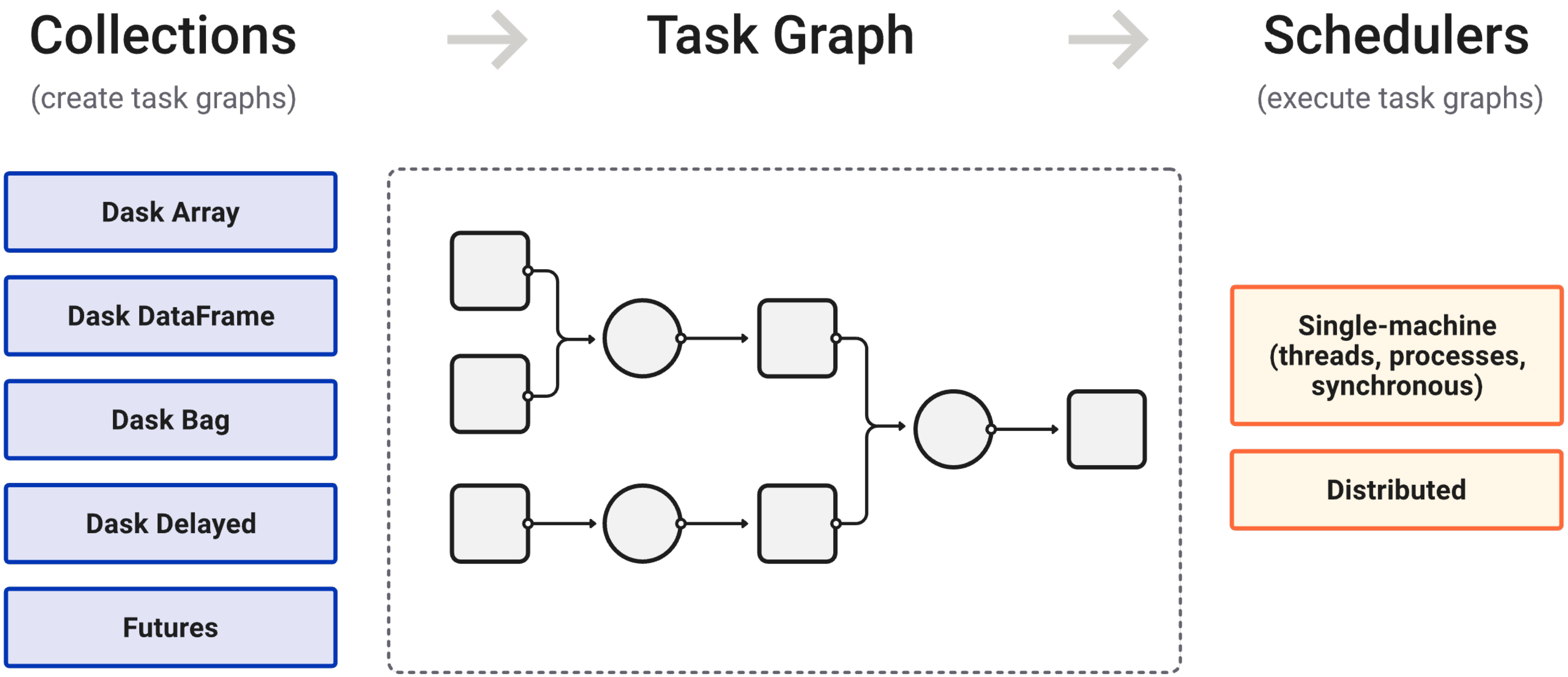



Q: What's the job completion time with 1 worker?

Q: What's the job completion time with 3 worker?

Q: What's the speedup?

# Task parallelism in Dask




* https://docs.dask.org/en/stable/
* https://docs.dask.org/en/stable/scheduling.html

# Dask's task graph and workflow

```
import dask
import dask.array as da
x = da.random.normal(size=1_000_000, chunks=100_000)
```

# Dask's task graph and workflow

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```
data = x.compute()
```

**Lazy evaluation:** Dask computation can be triggered manually, e.g., `.compute()`

- only when the result is needed

# Dask's task graph and workflow

```
import dask
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x = da.random.normal(size=1_000_000, chunks=100_000)
```

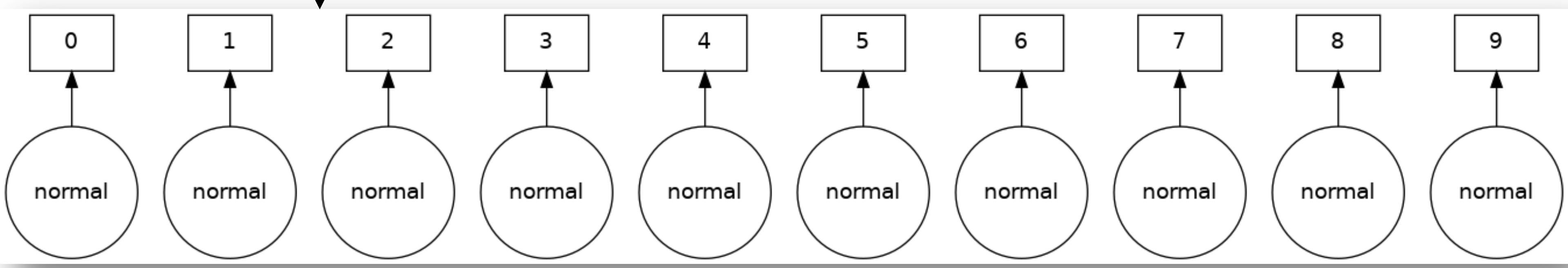
```
data = x.compute()
```

**Lazy evaluation:** Dask computation can be triggered manually, e.g., `.compute()`

- only when the result is needed

```
dask.visualize(x)
```

Draw the task graph using `.visualize()`




Dask task graph

# Next steps

- Assignment 2 is out
  - Due on Wednesday, 03/15, 11am ET

- Project bidding is due this Friday, 02/24

- Next Monday, 02/27
  - Midterm review

# Dask demo