Efficient Flow Scheduling in Distributed Deep Learning Training with Echelon Formation

Rui Pan*, Yiming Lei*, Jialong Li, Zhiqiang Xie, Binhang Yuan, Yiting Xia

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Deep Neural Networks (DNNs) are popular

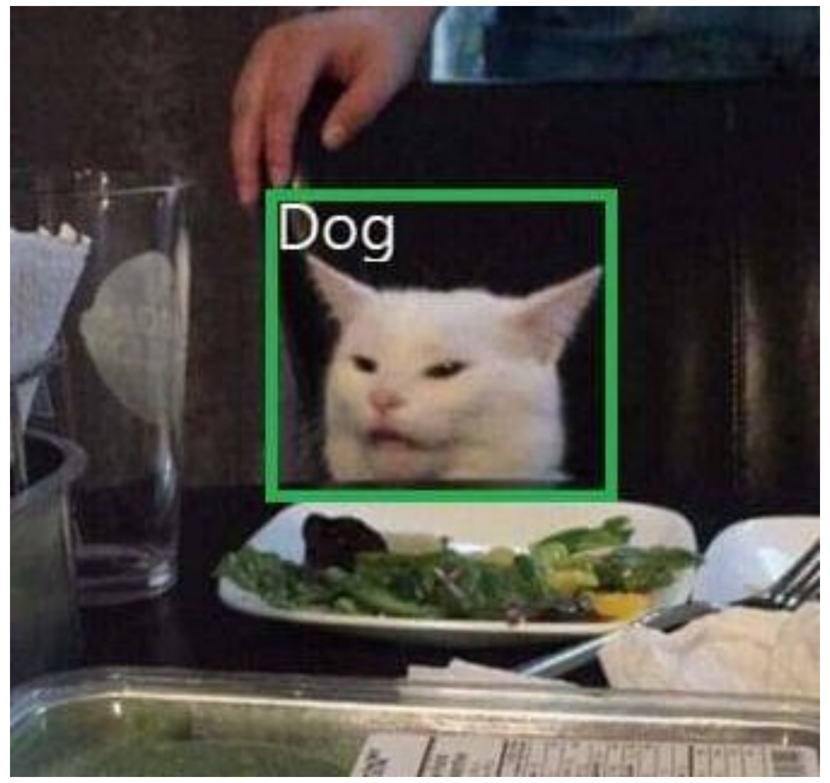


Image Classification

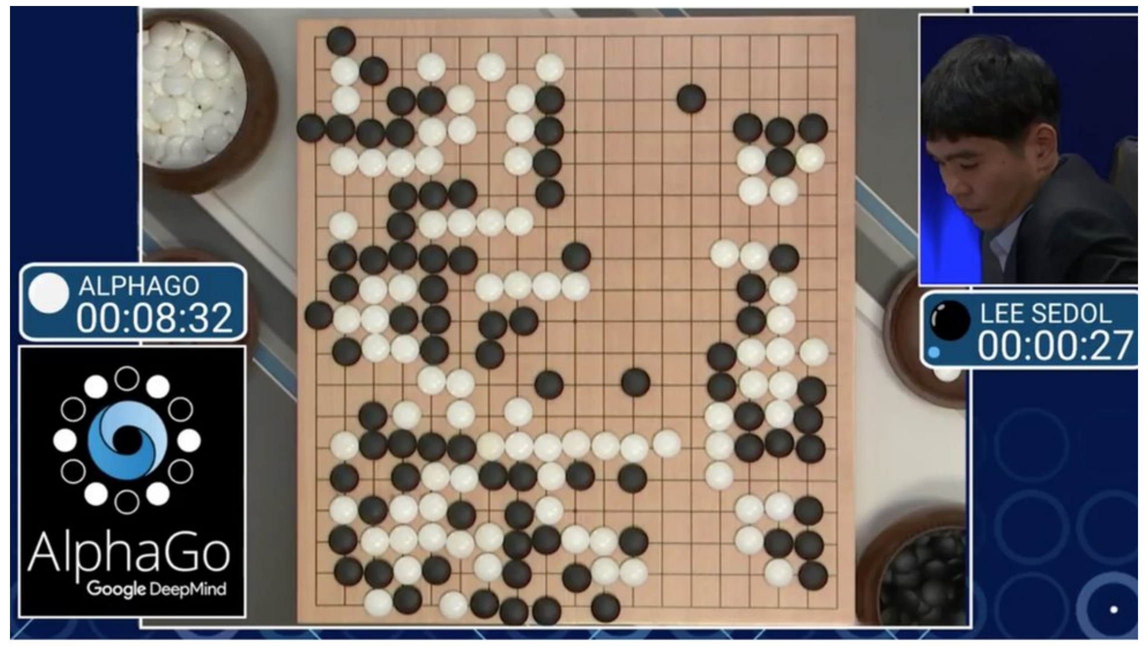
Machine Translation

Alexa

Google Assistant

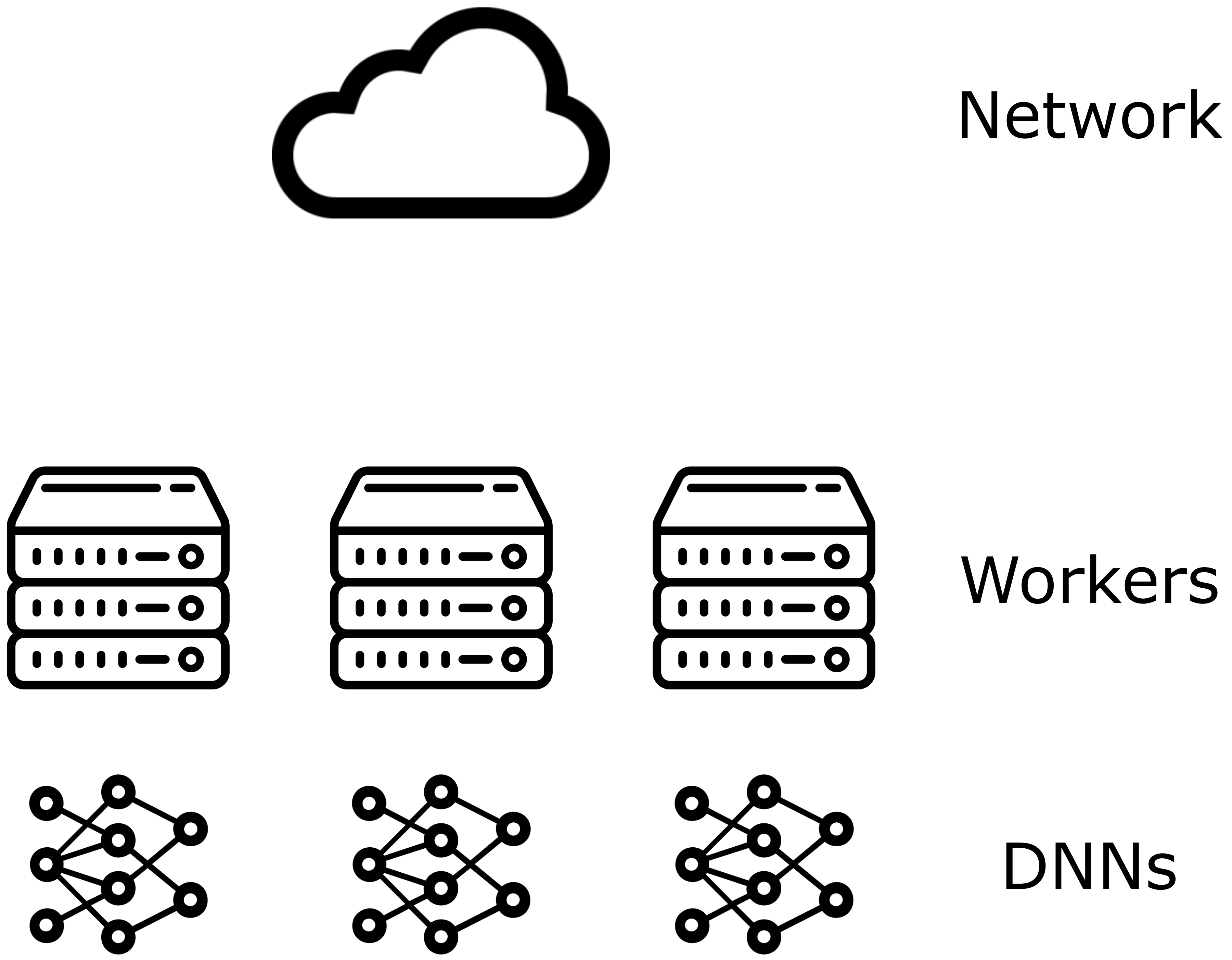
Siri

Speech-to-Text



Game Playing

Communication is a bottleneck in distributed DNN training



Distributed Training in GPU Clusters

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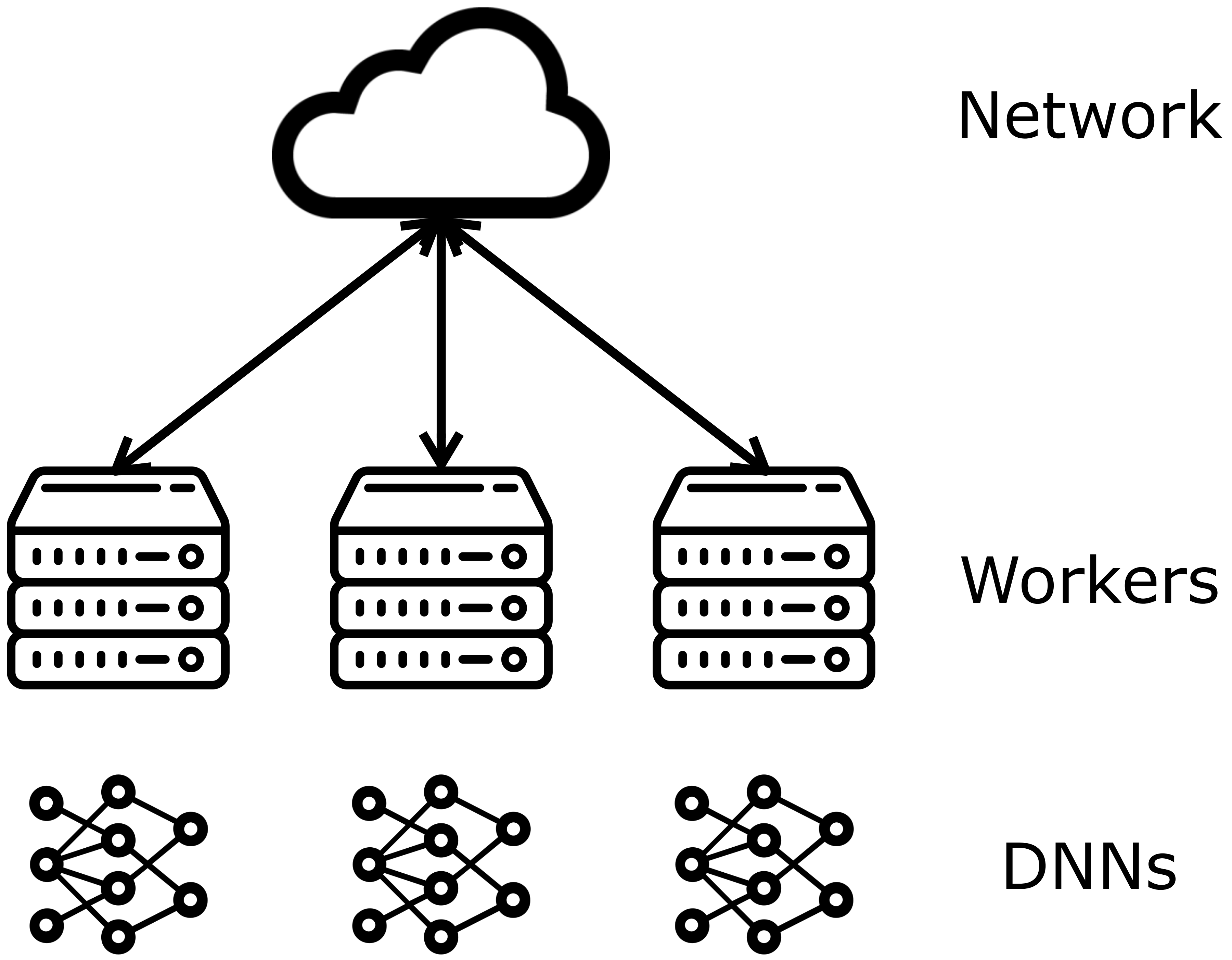

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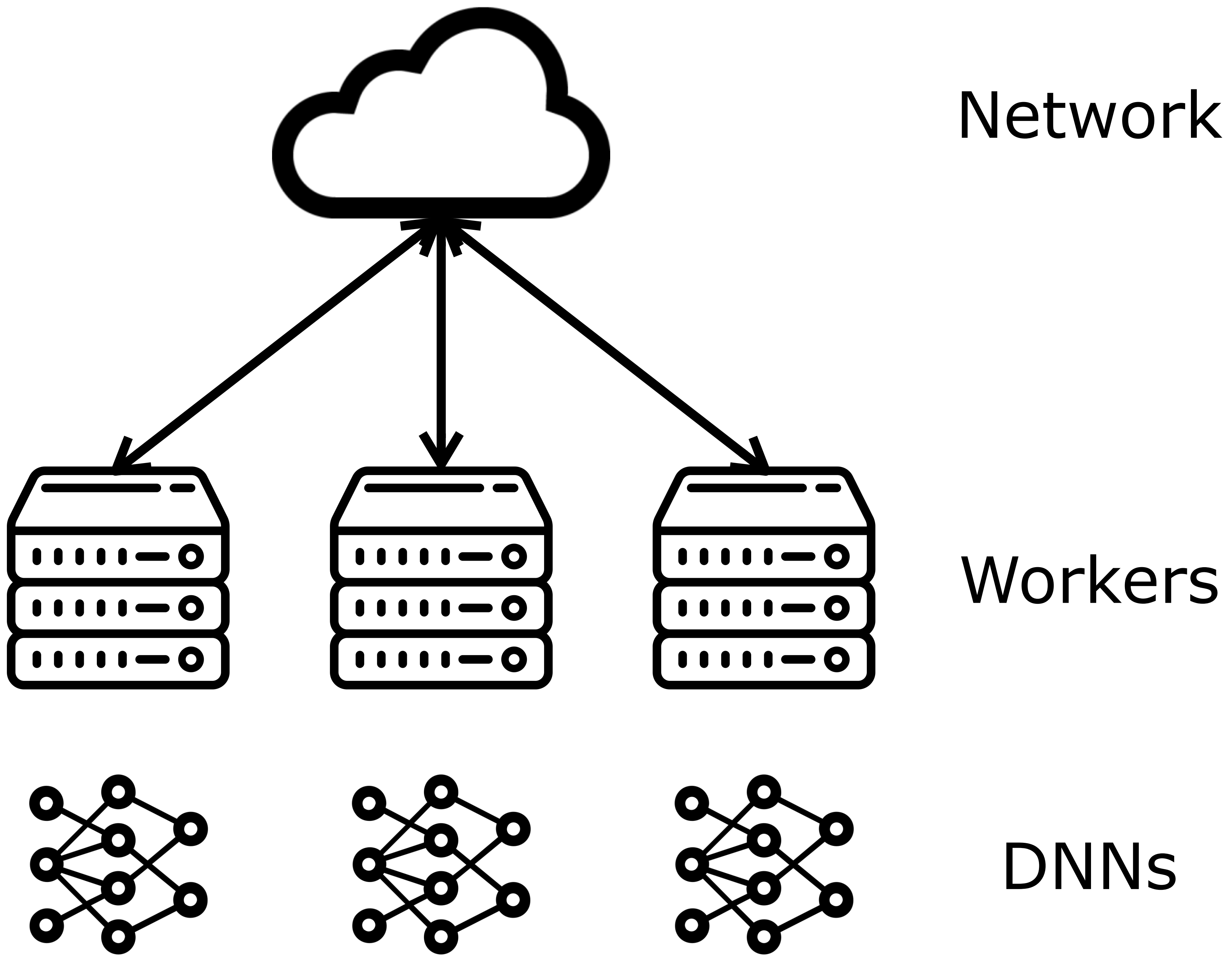

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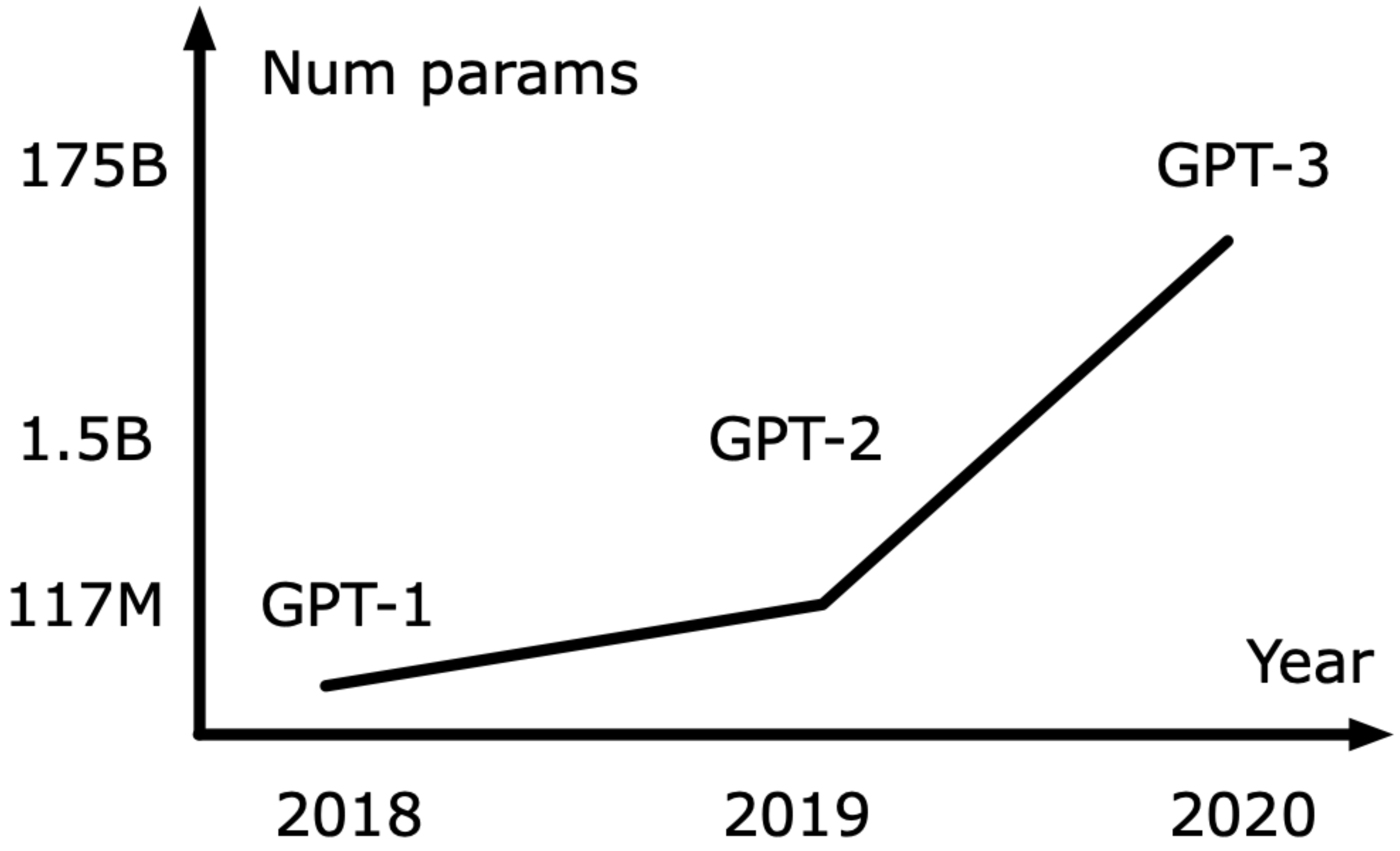
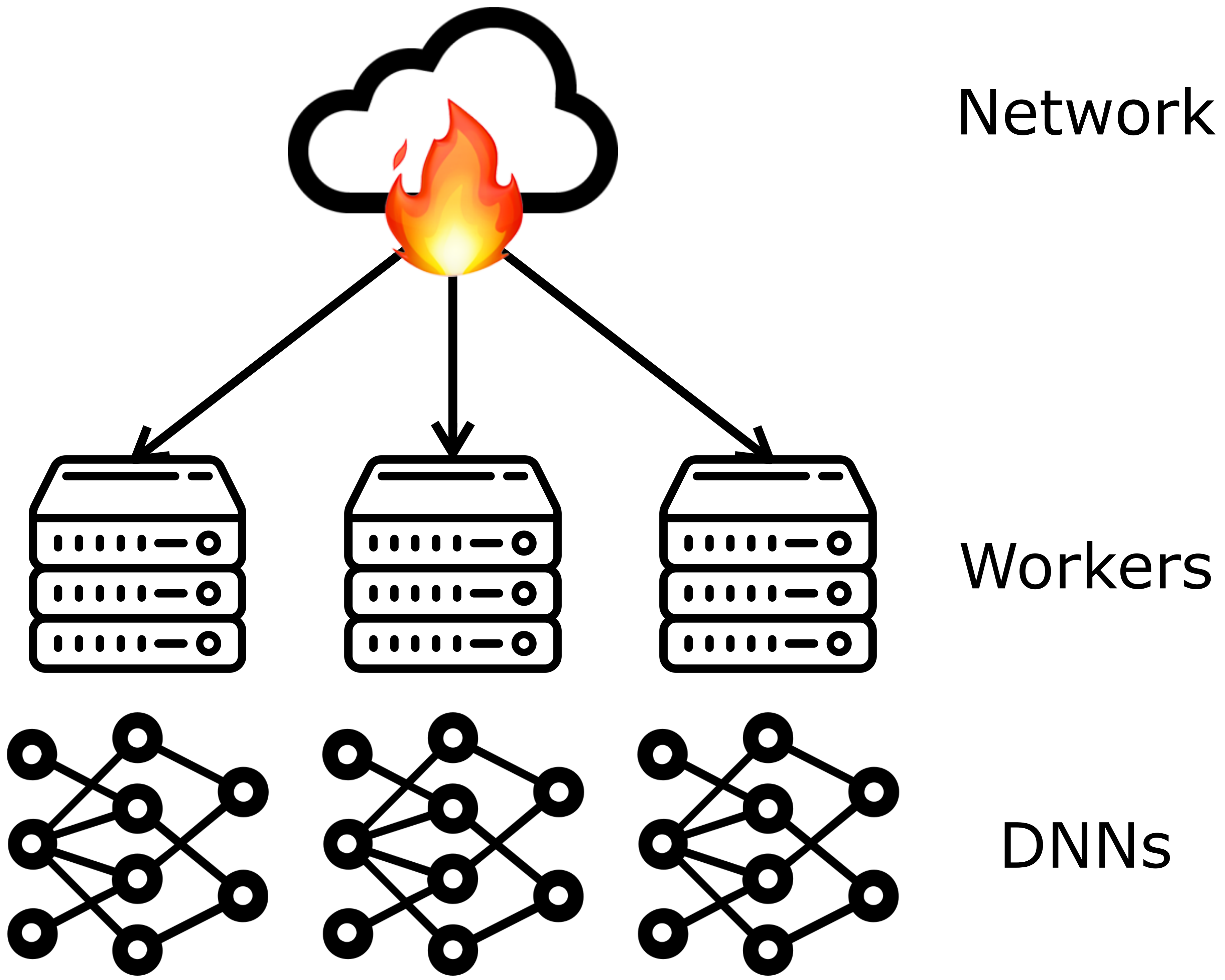


GPT Model Size Evolution

Communication is a bottleneck in distributed DNN training



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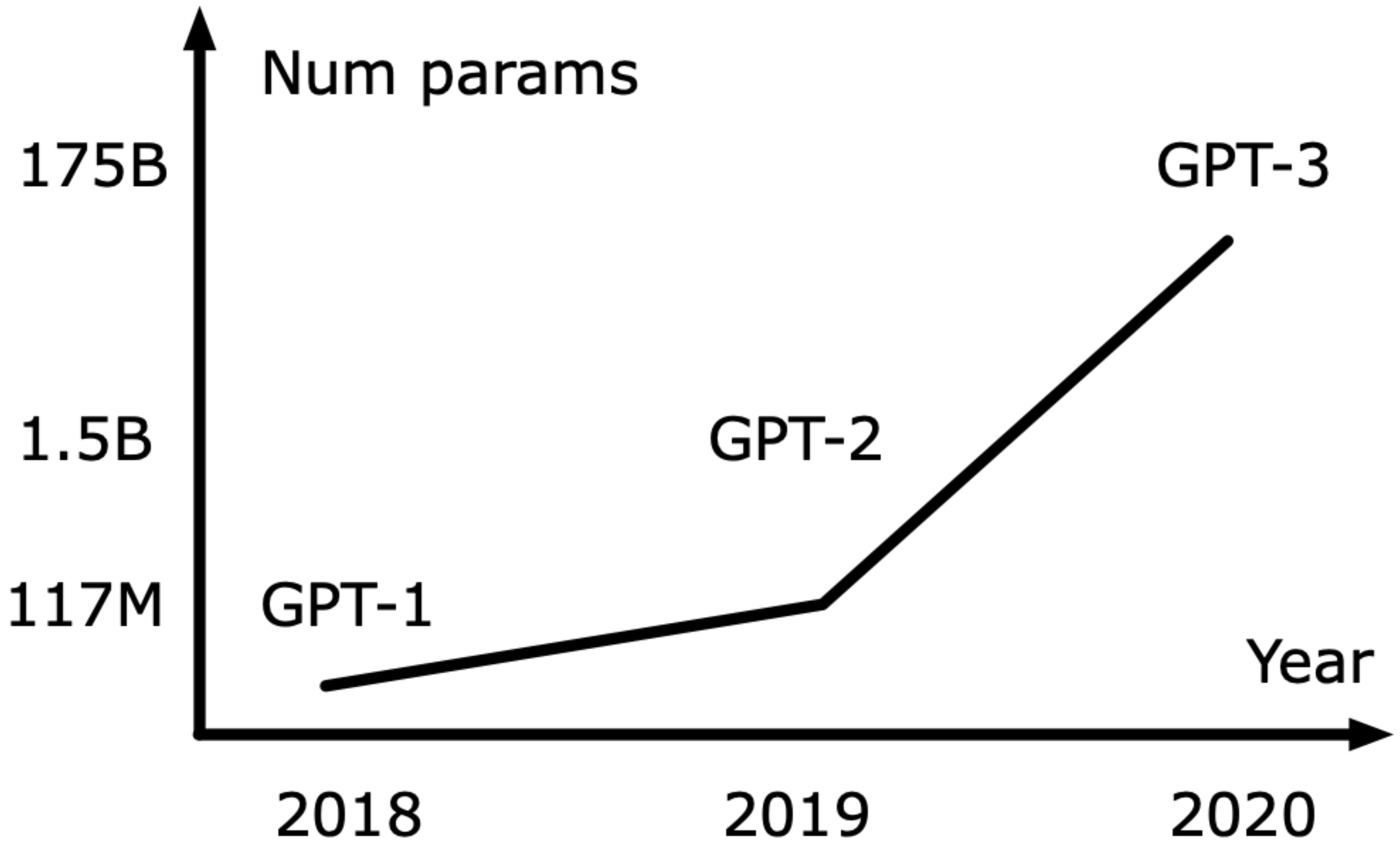

GPT Model Size Evolution

Flow scheduling mitigates the communication bottleneck

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- CoFlow: network abstraction for flow scheduling

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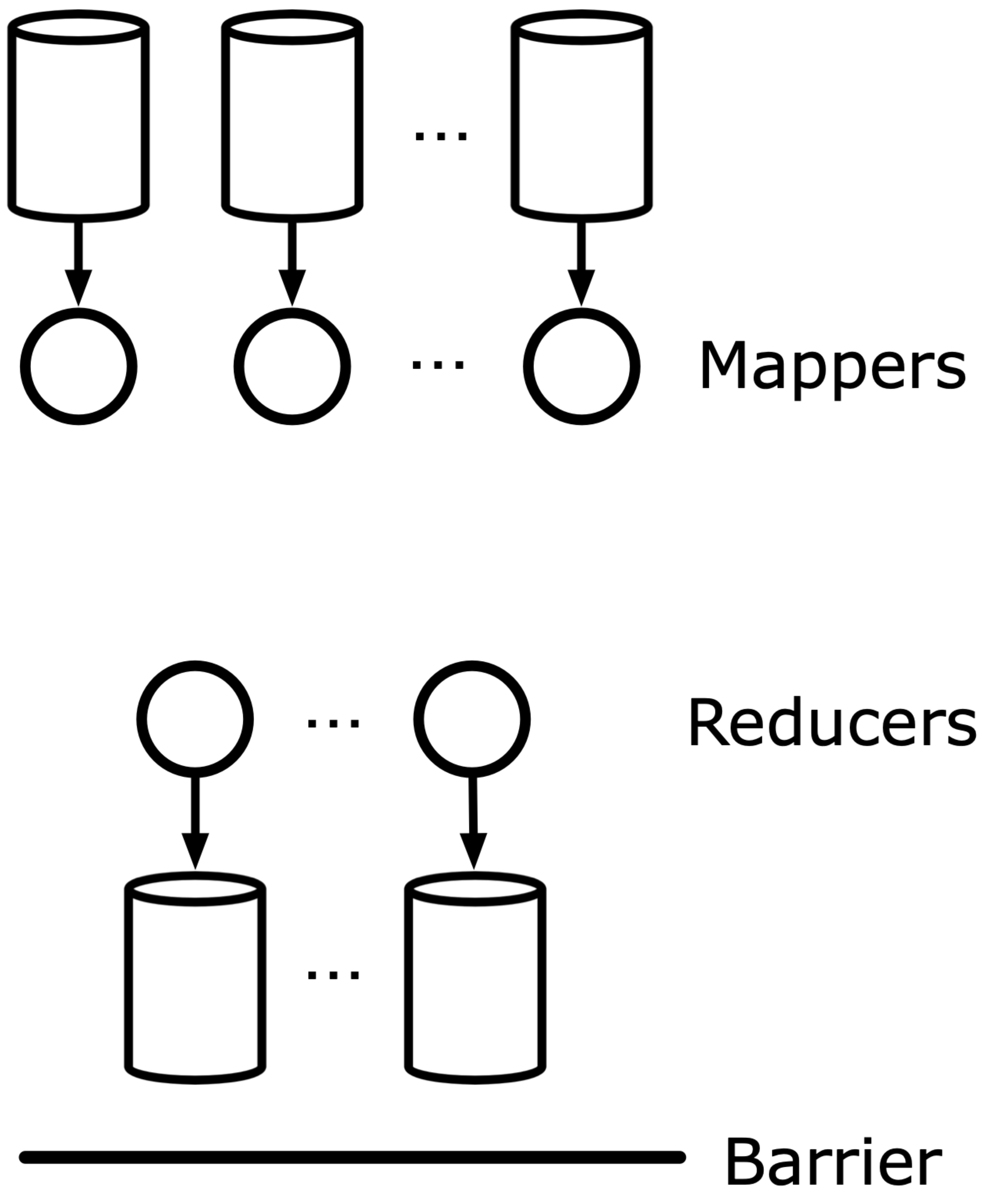

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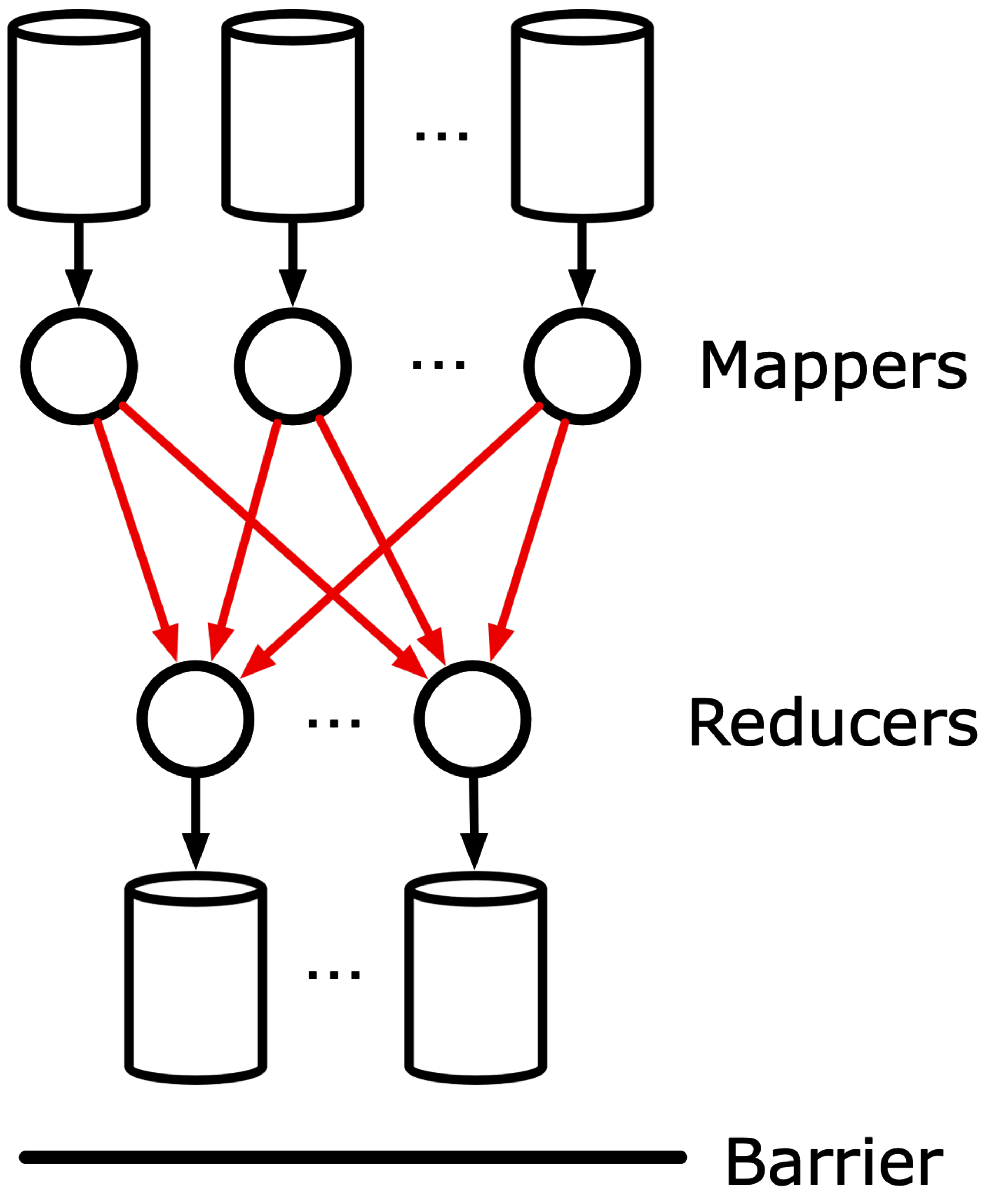

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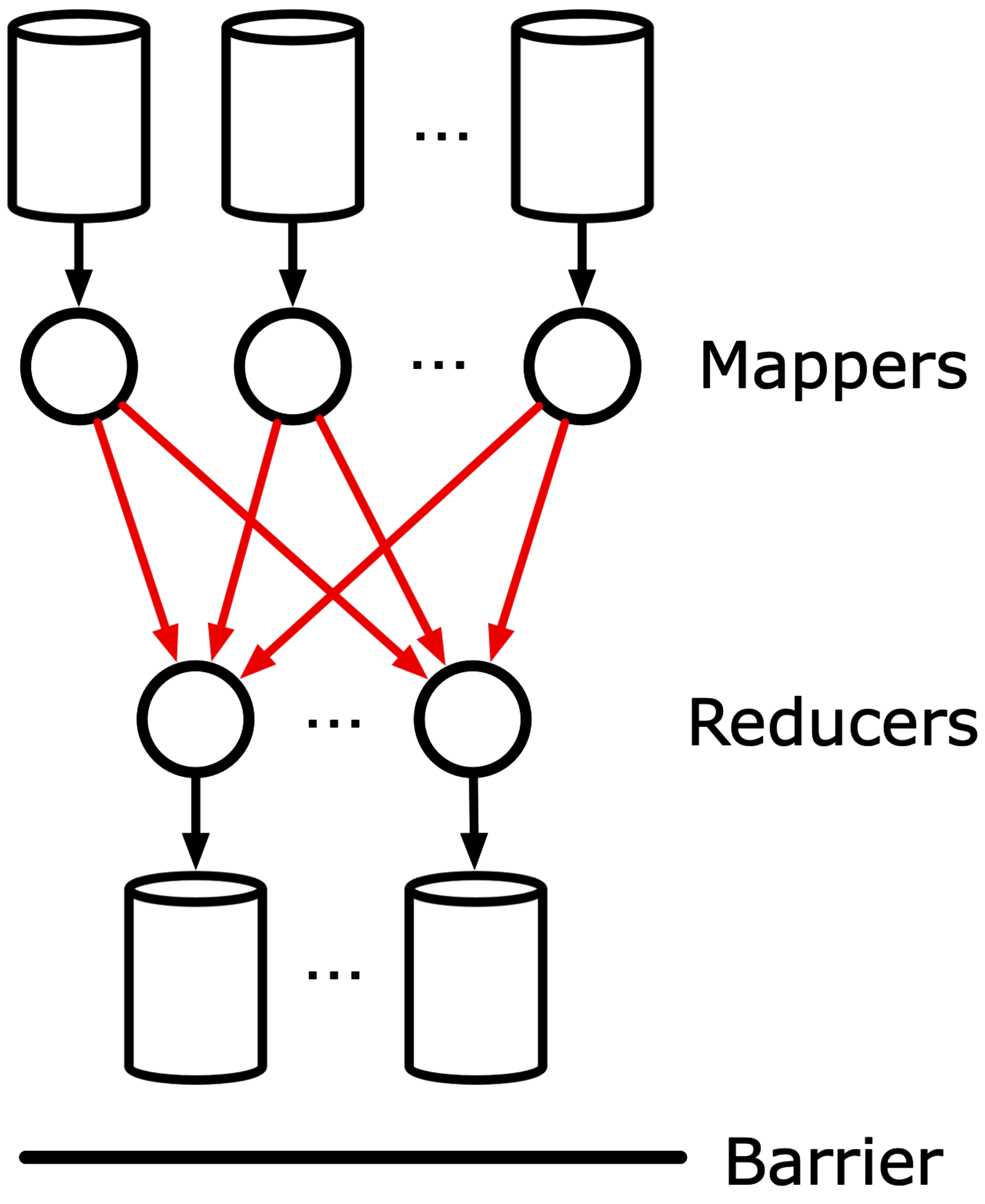

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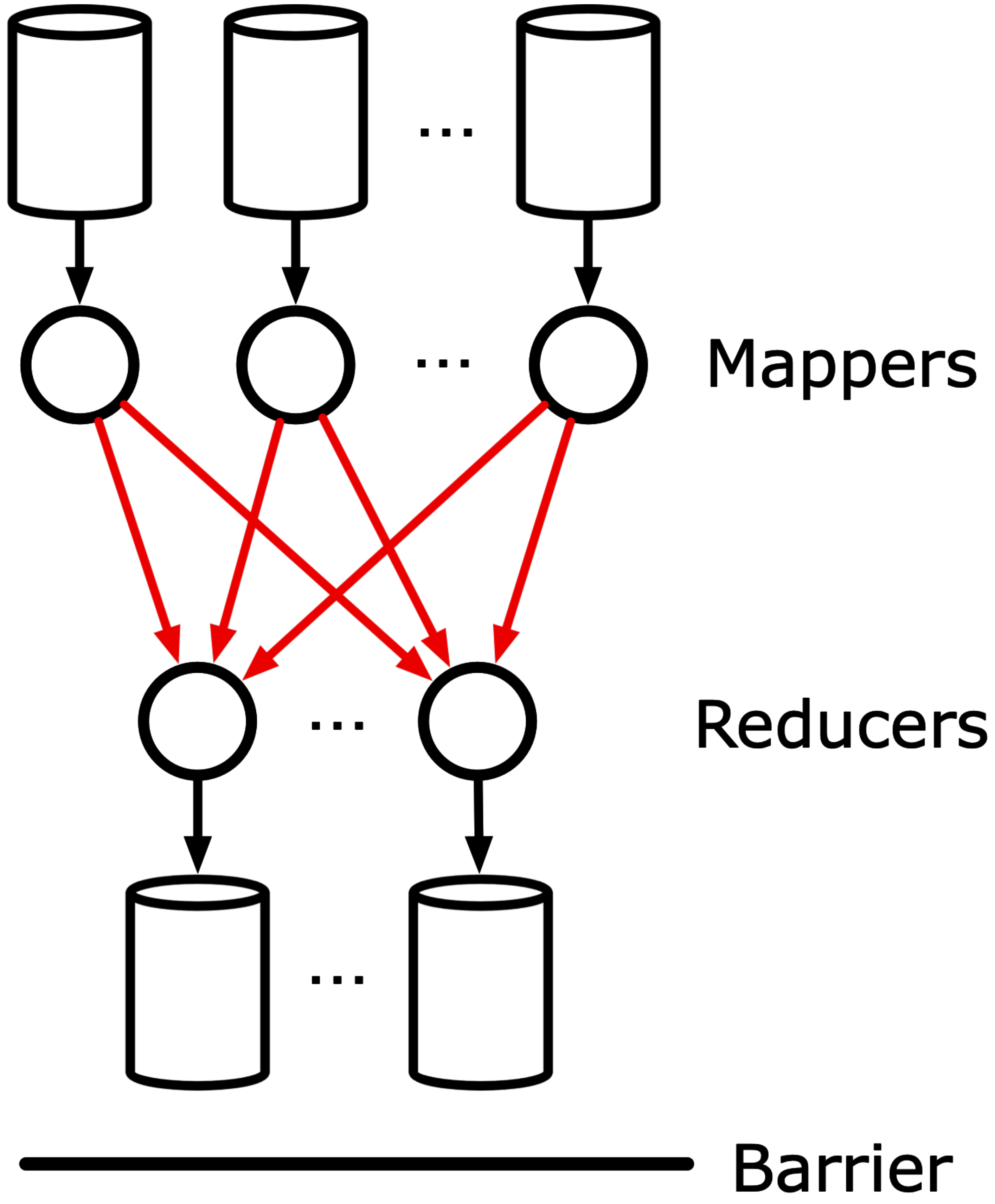

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    - Big data frameworks 👍
    - ML training paradigms 👎

Why not flow scheduling for ML?

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Training paradigm	Examples
Data Parallelism	AllReduce, Parameter Server
Pipeline Parallelism	GPipe, PipeDream
Tensor Parallelism	Megatron-LM
Fully Sharded Data Parallelism	ZeRO, FairScale

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- Lack of good network abstraction

Example: pipeline parallelism

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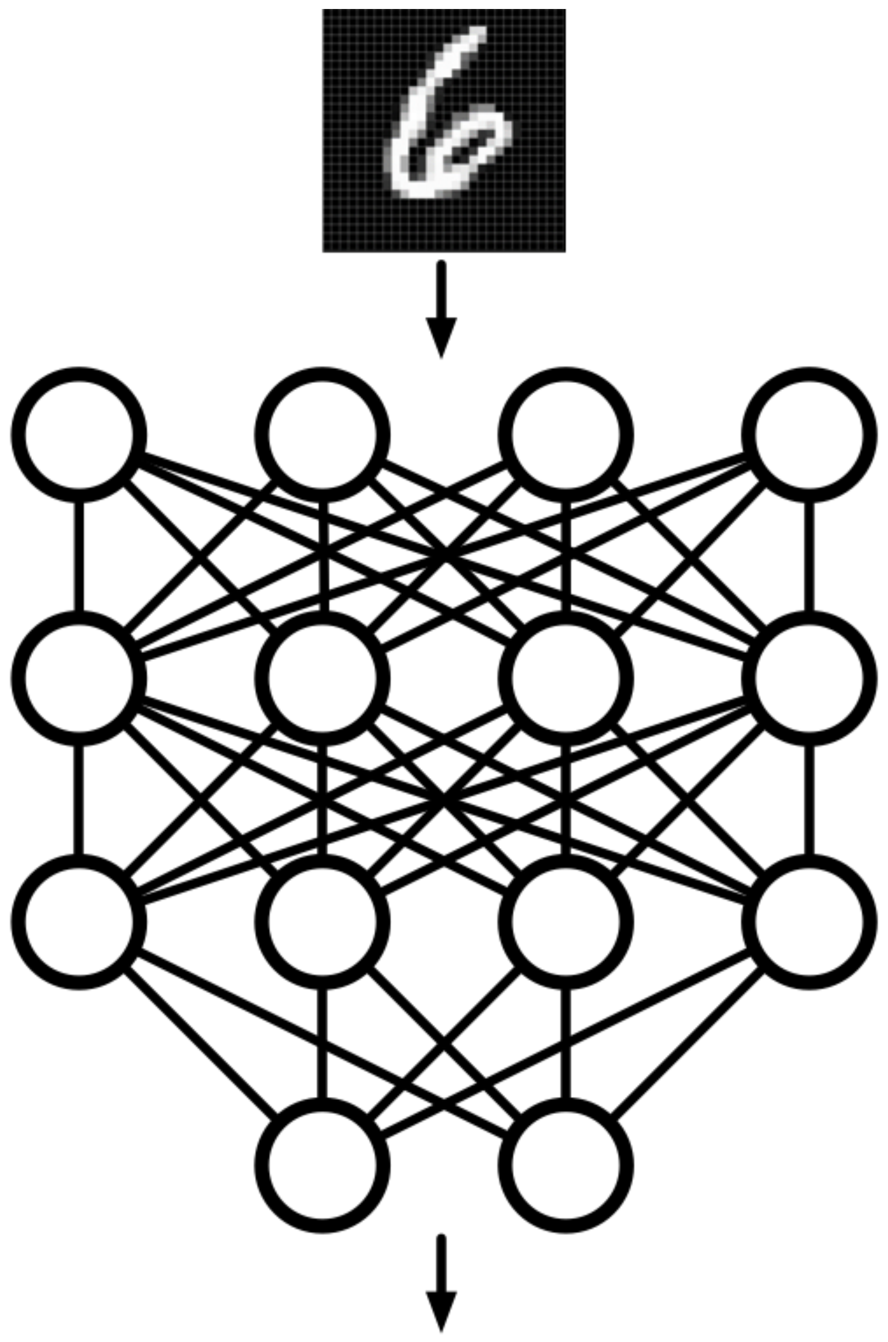

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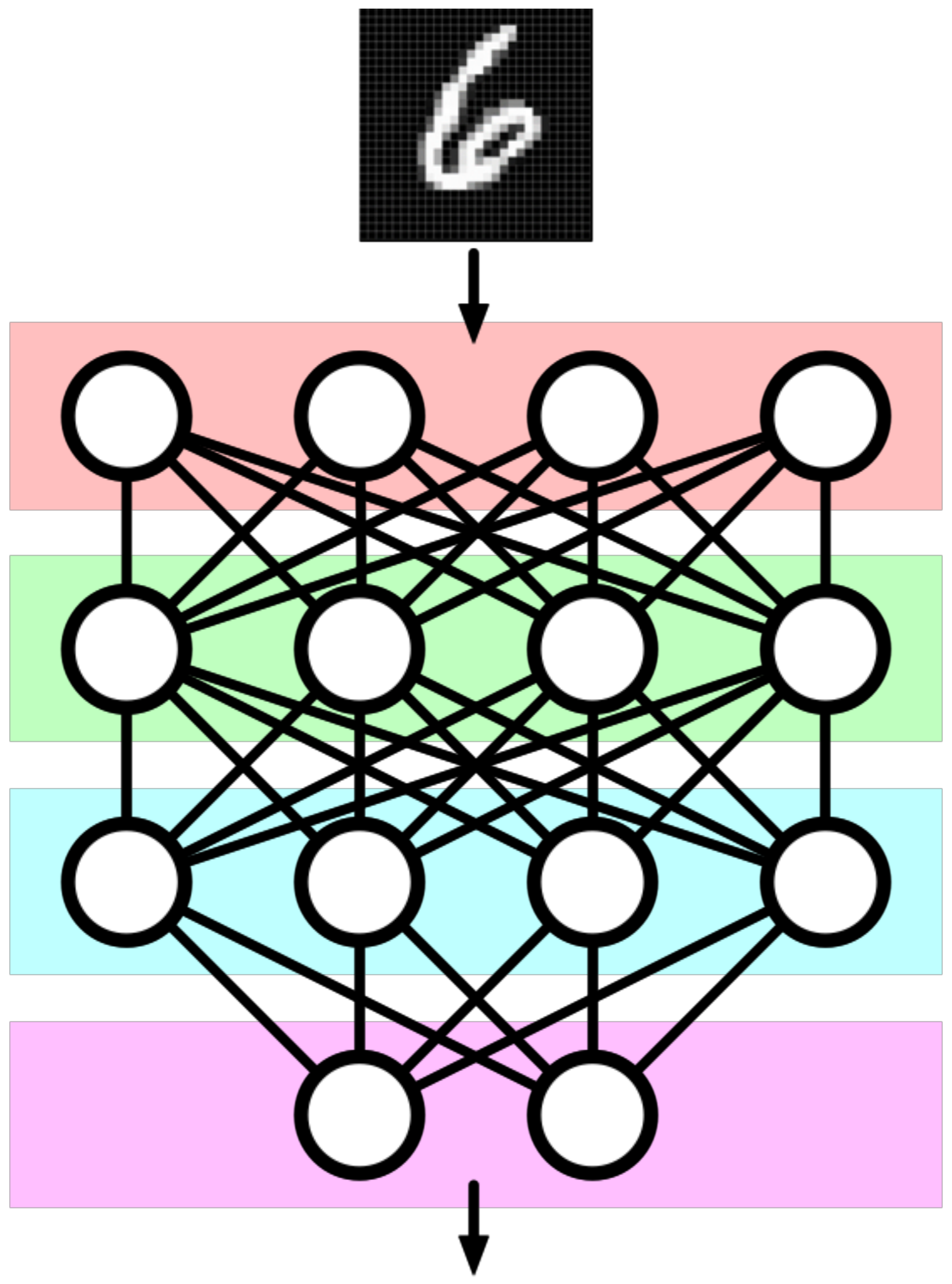

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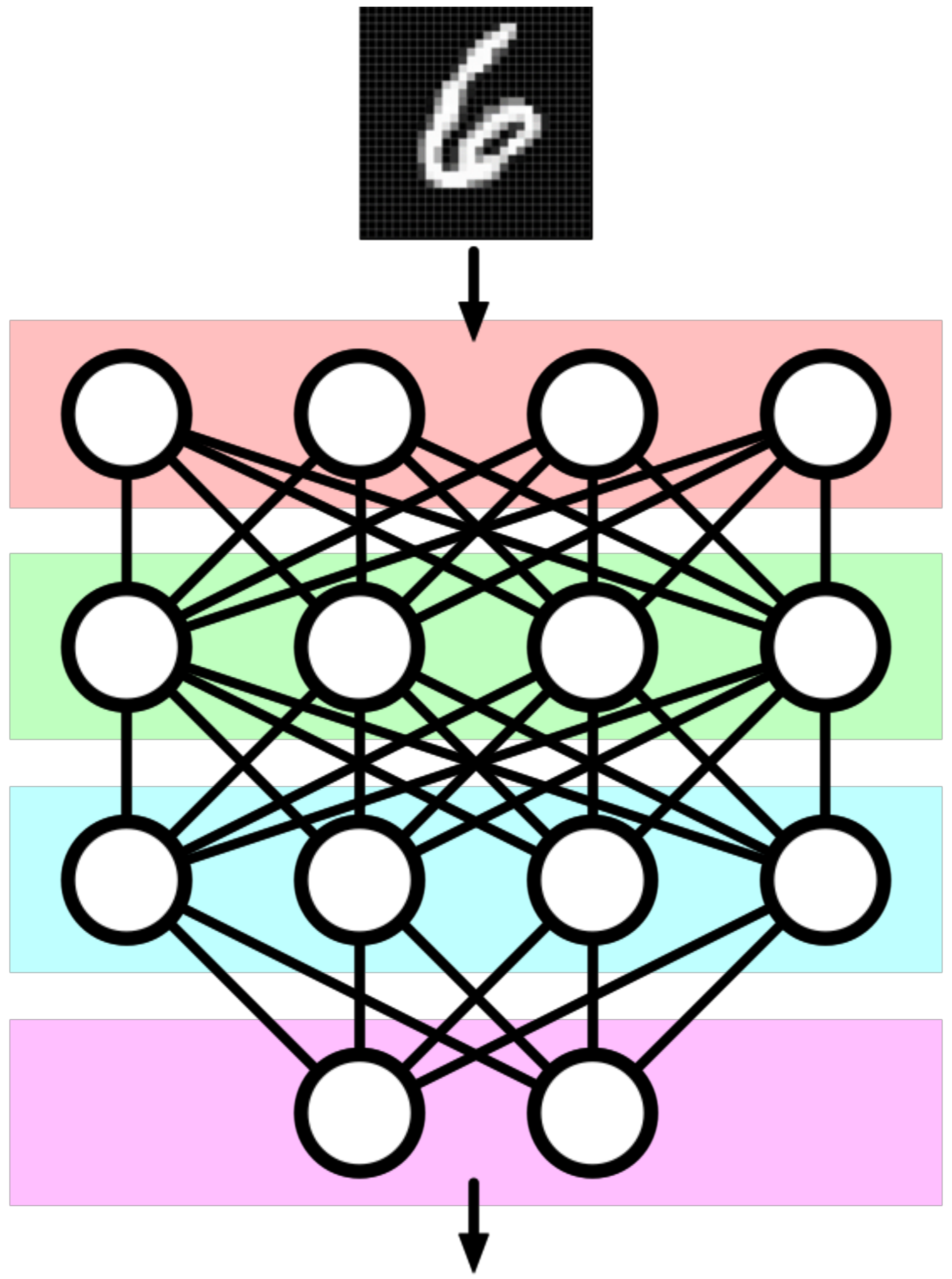

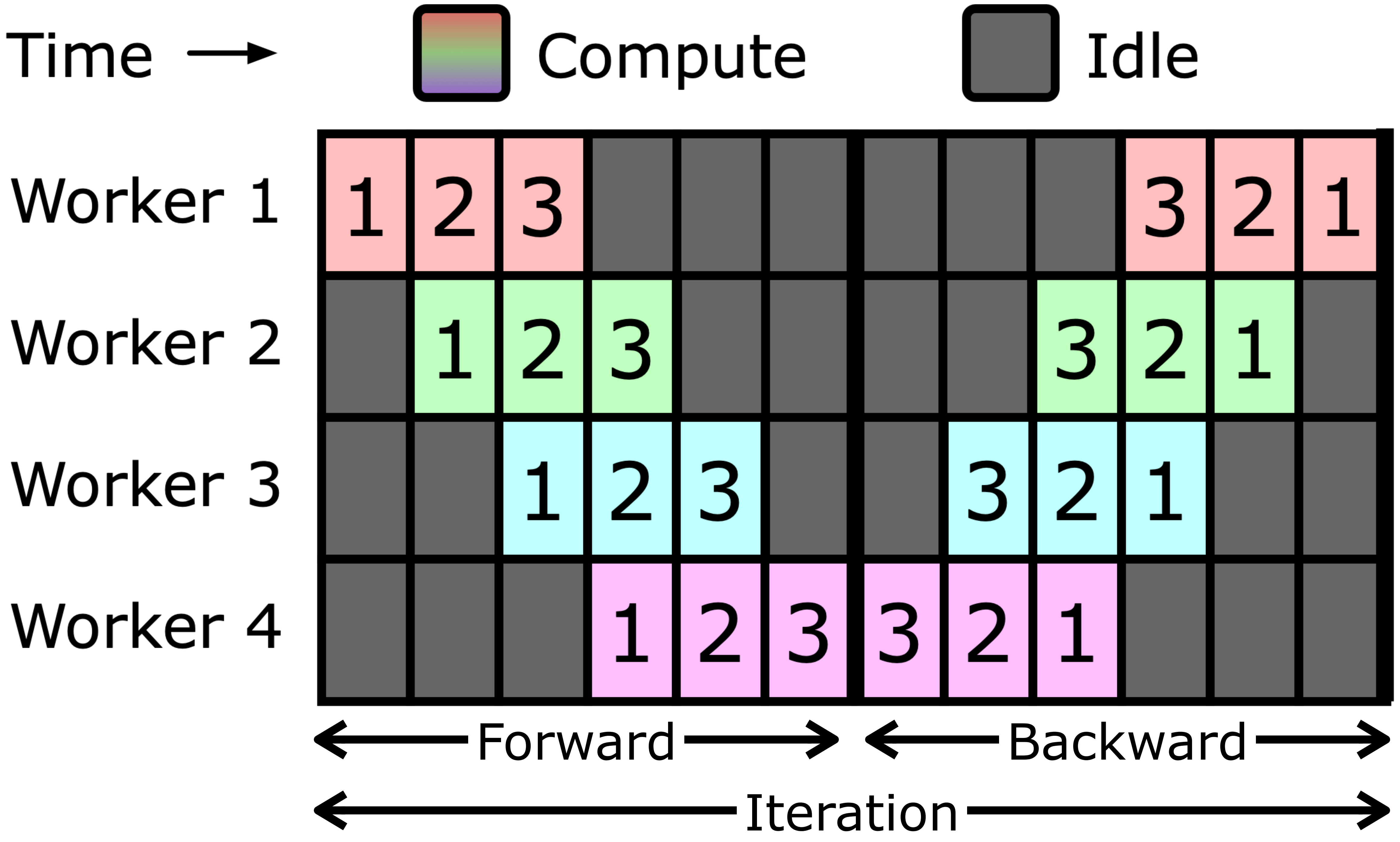

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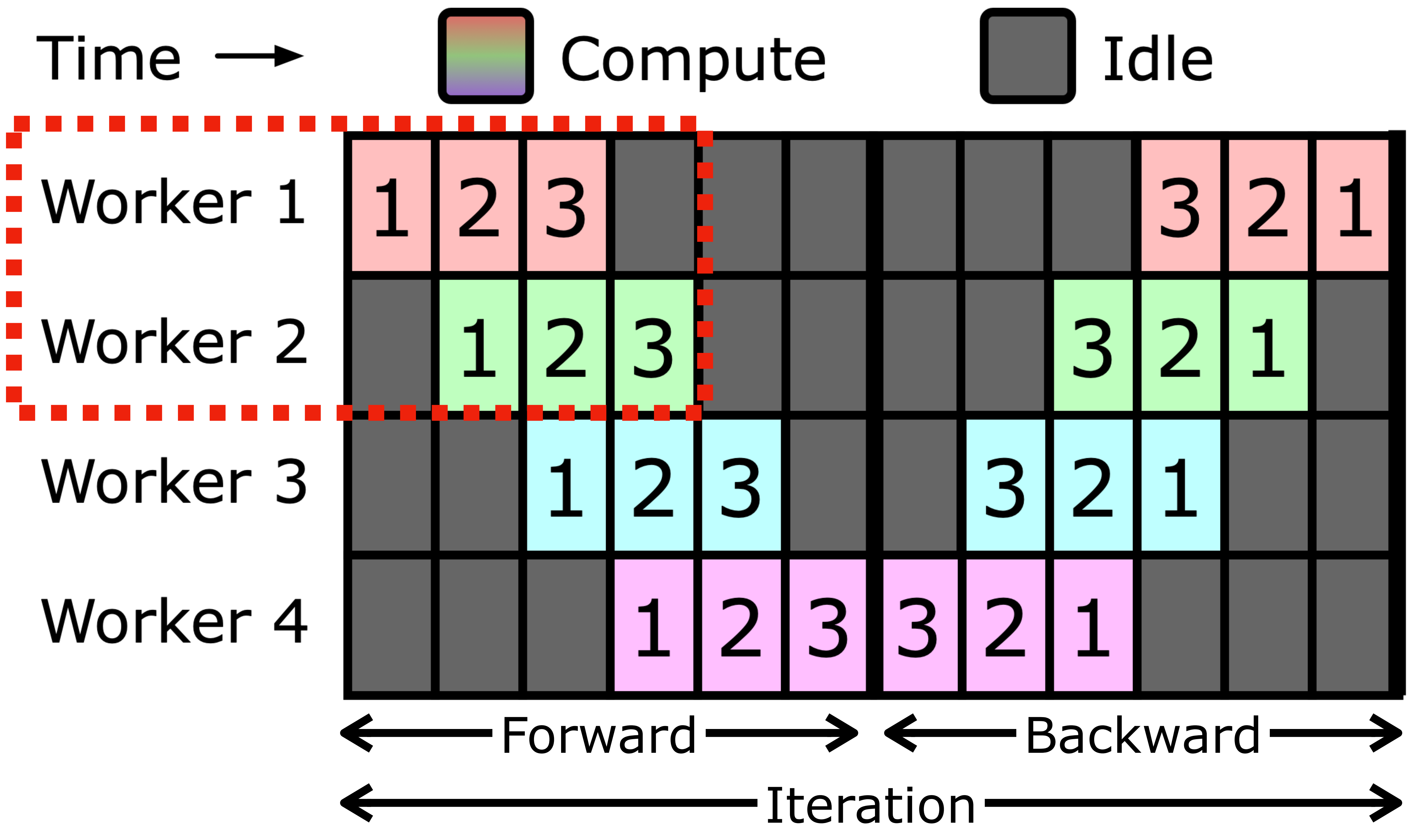

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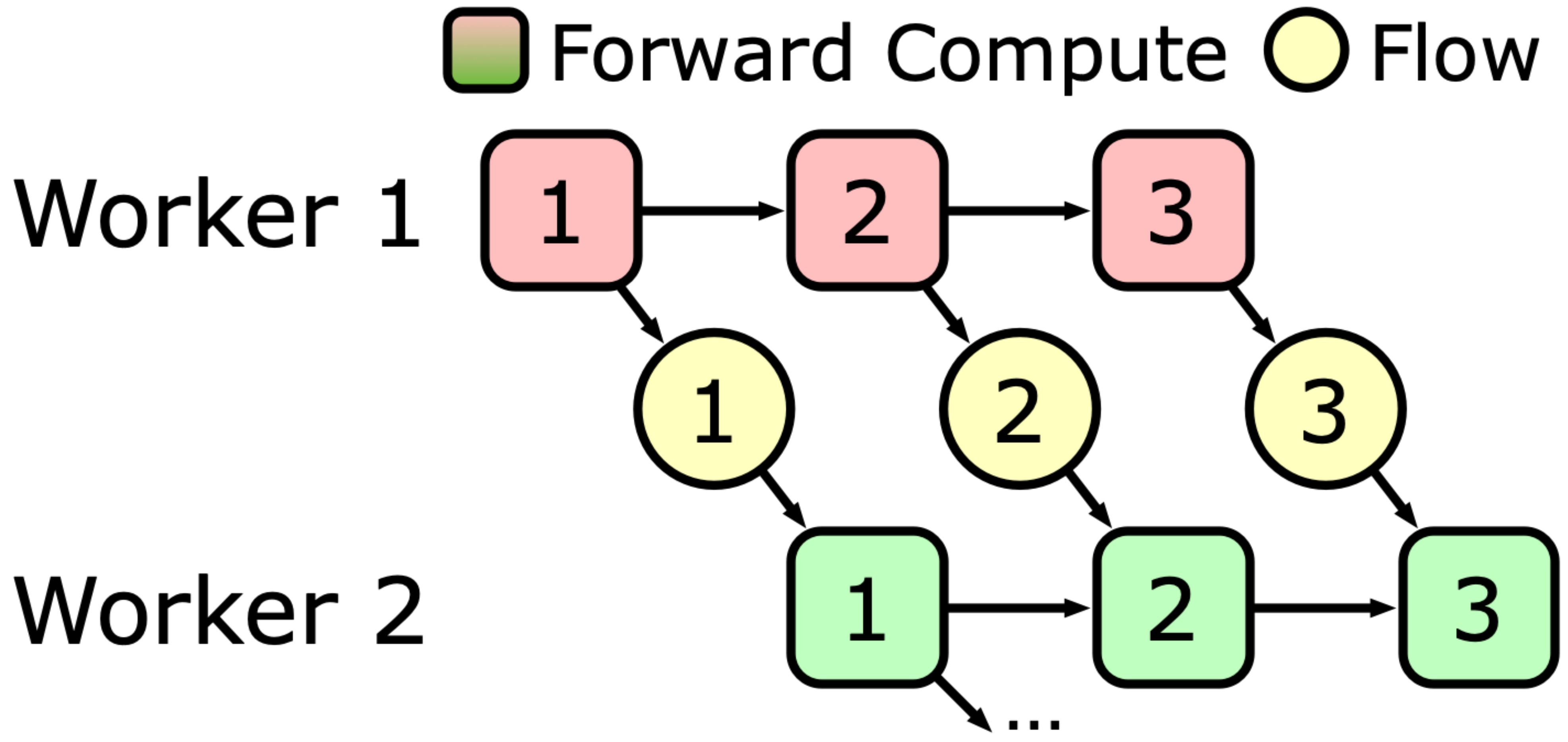

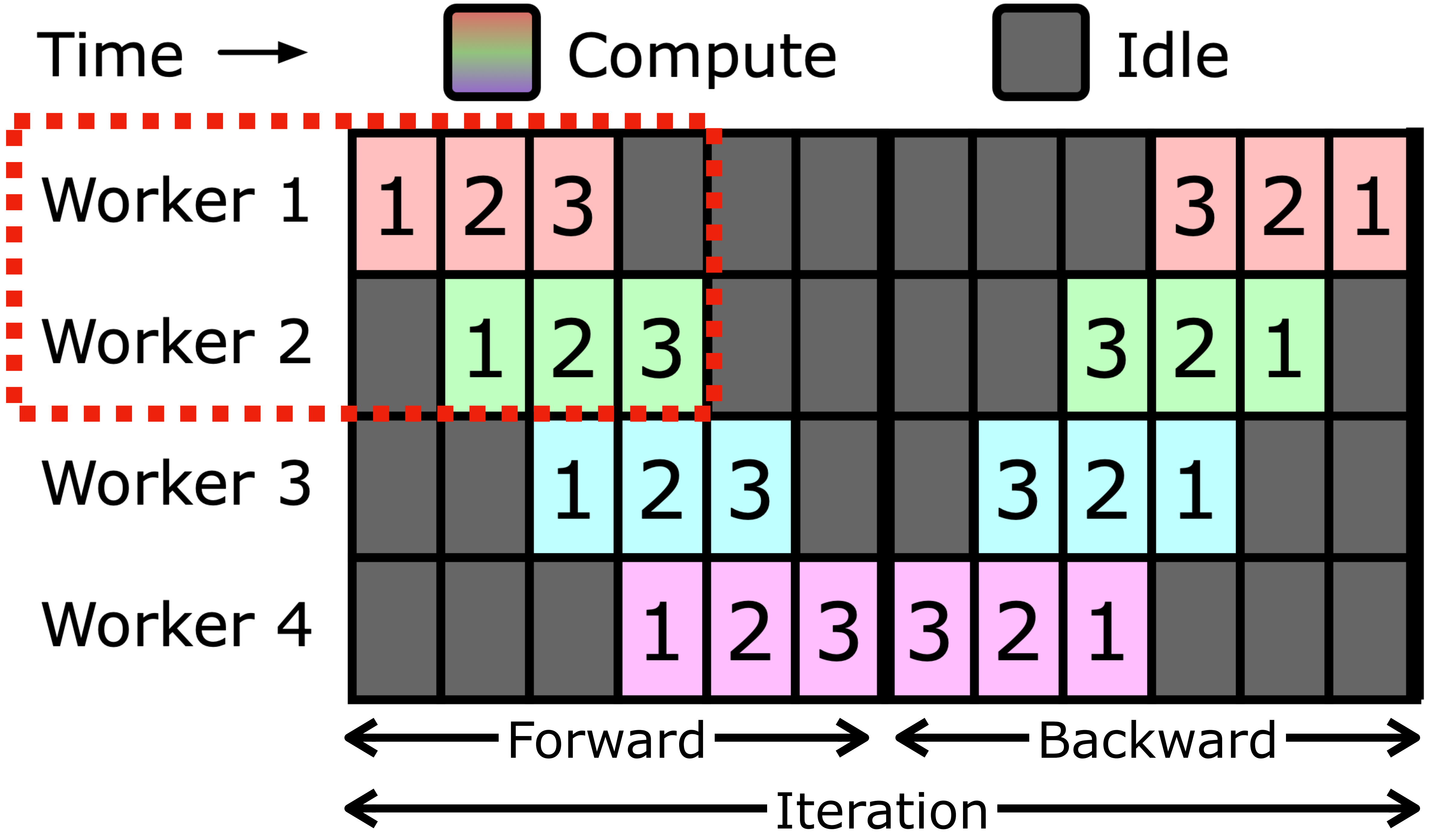

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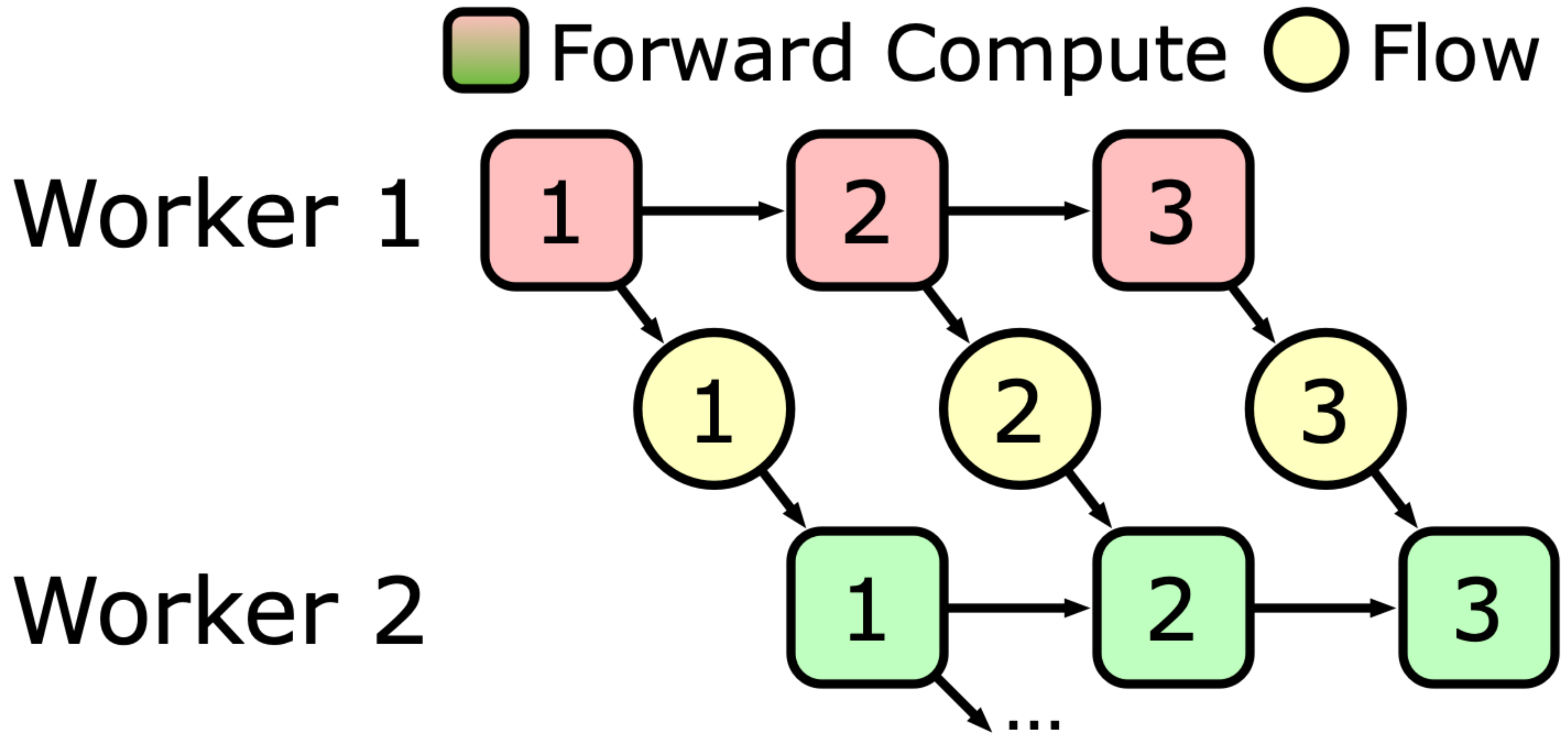

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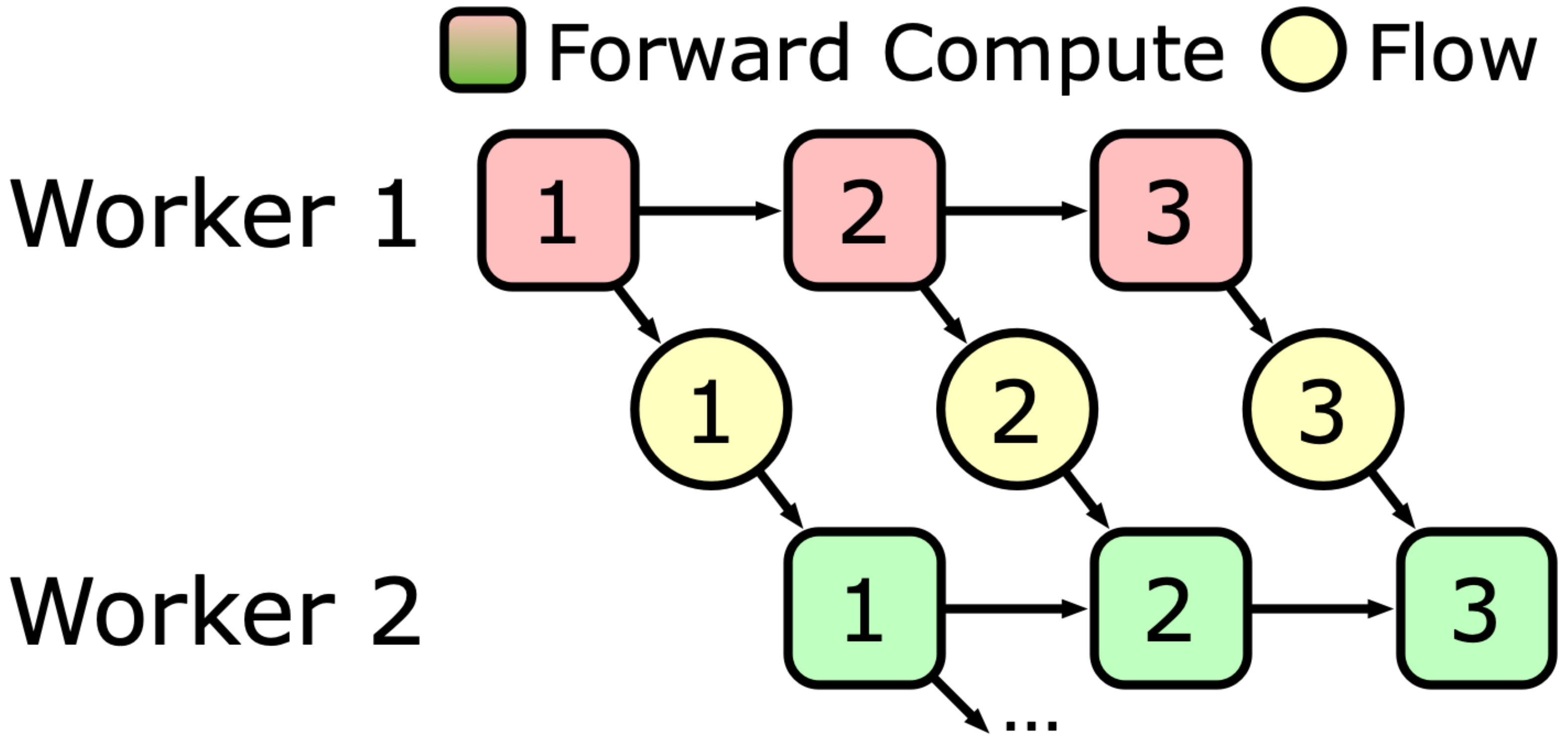

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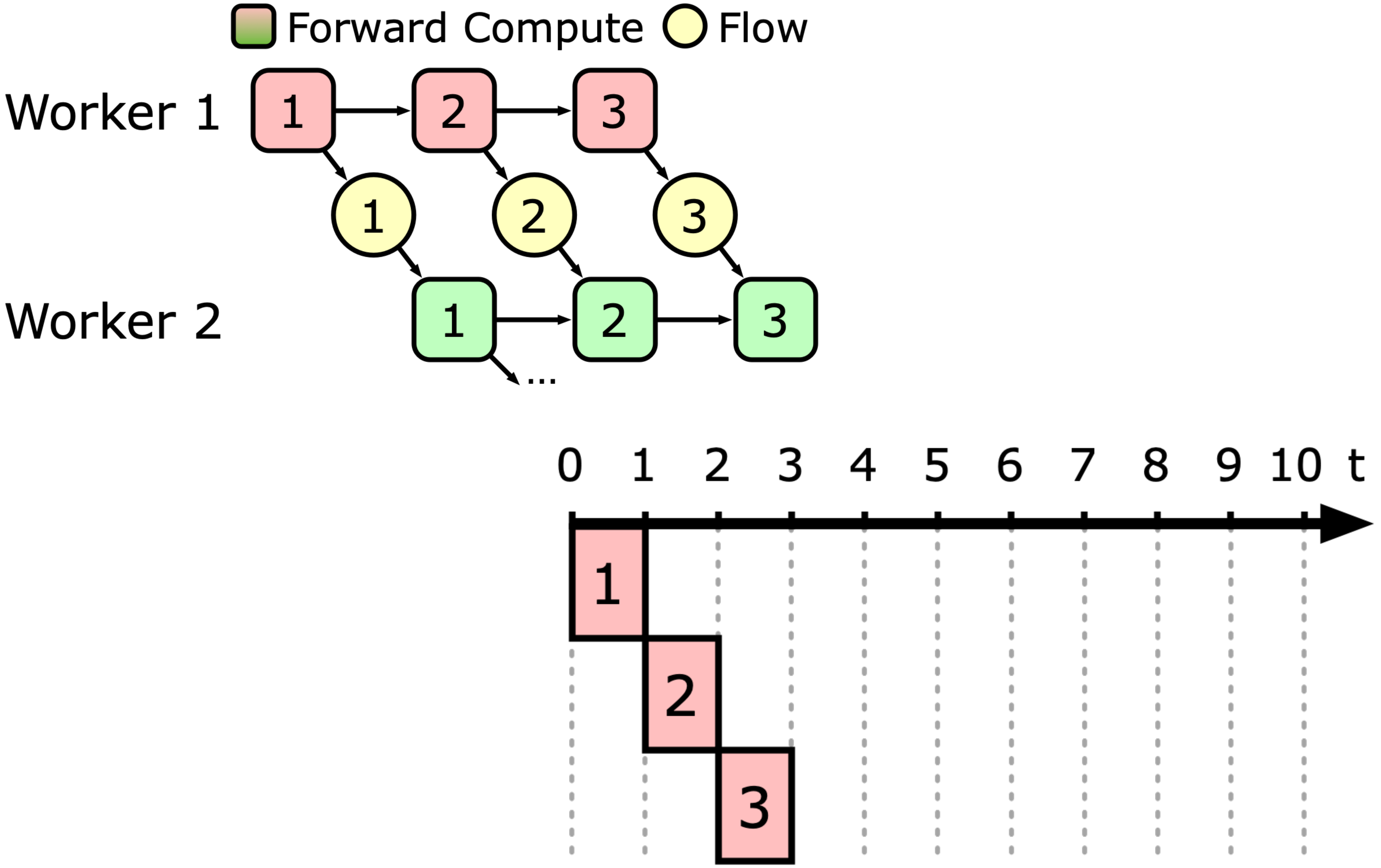

(b) Coflow Scheduling

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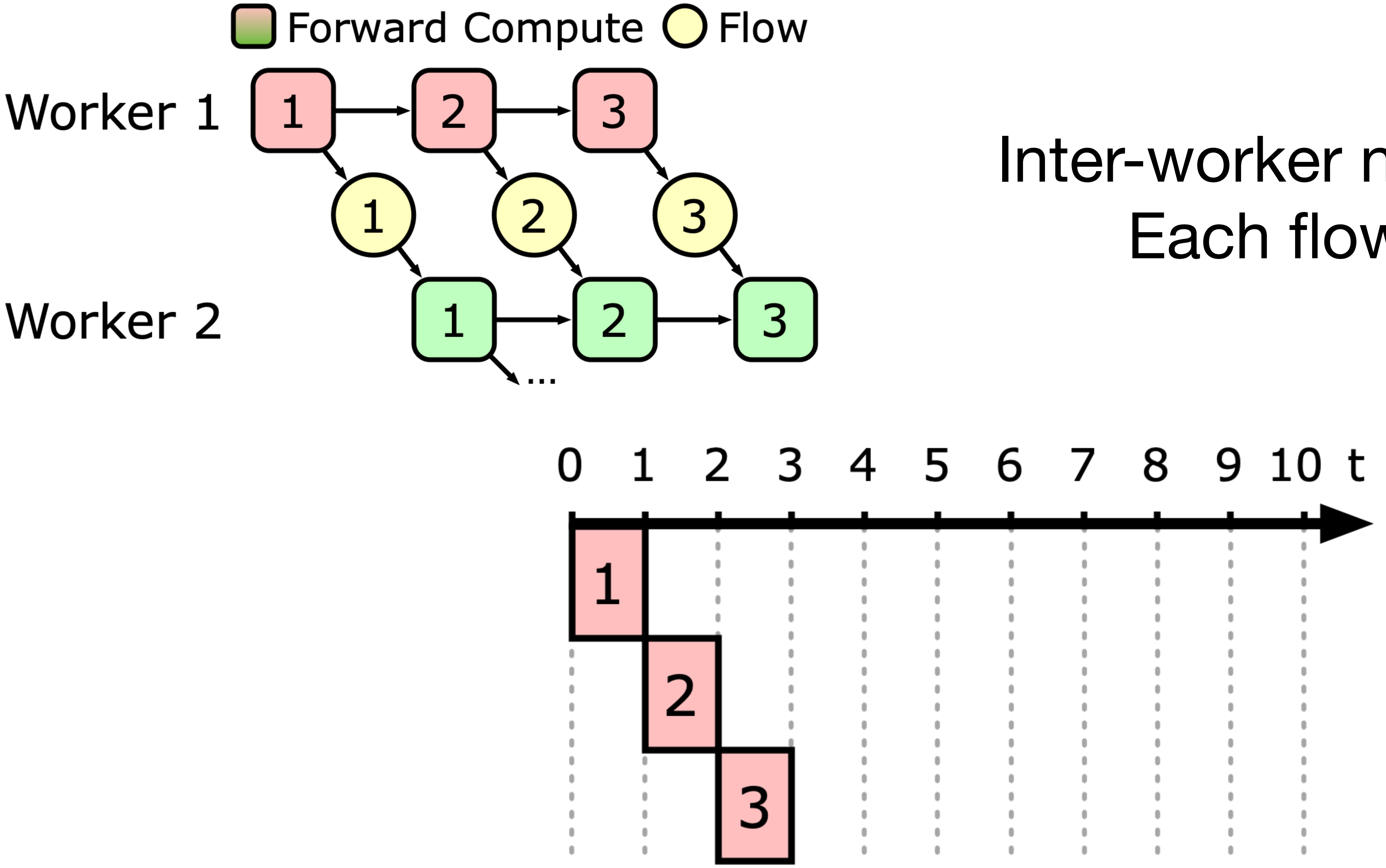

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Inter-worker network bandwidth: B
Each flow carries 2B data

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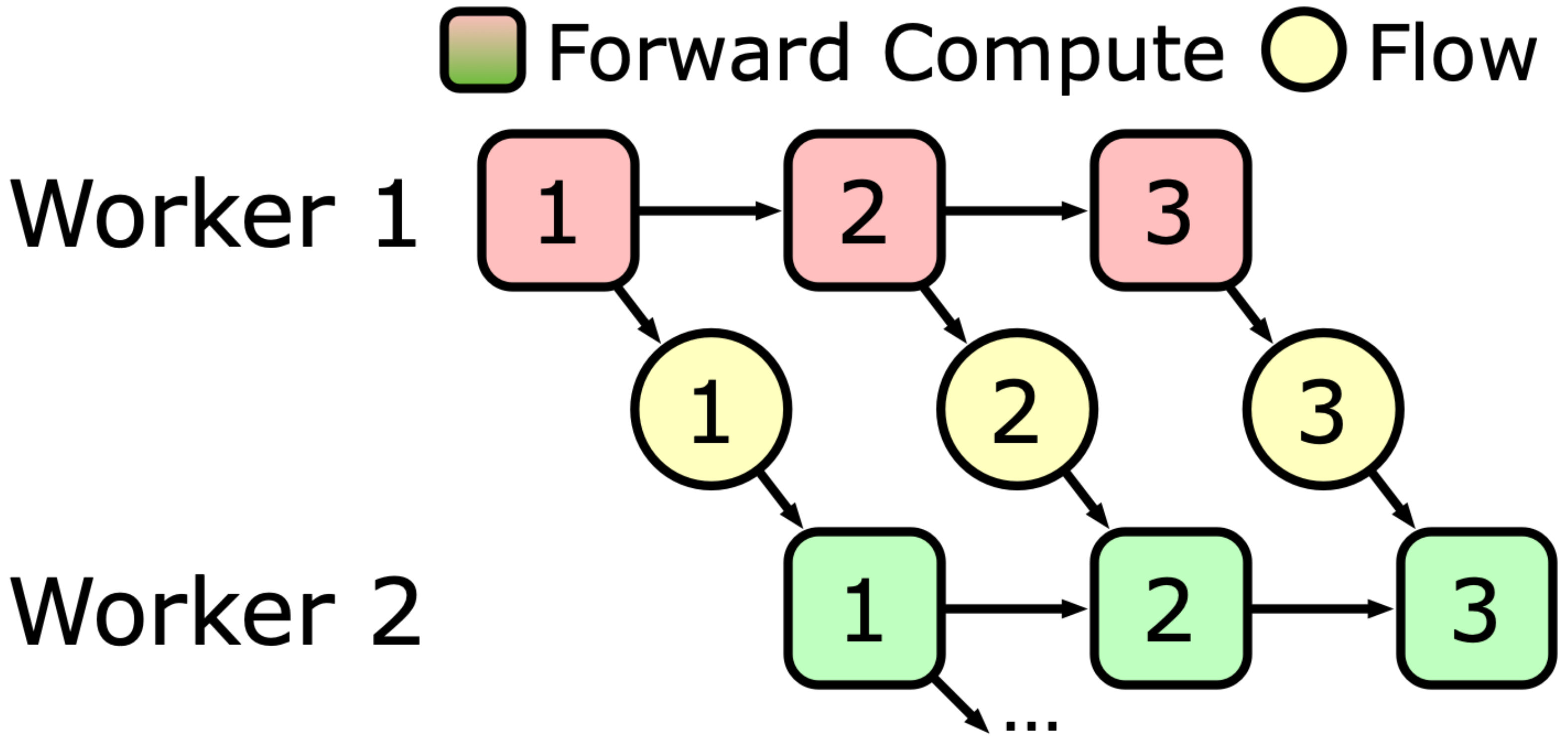

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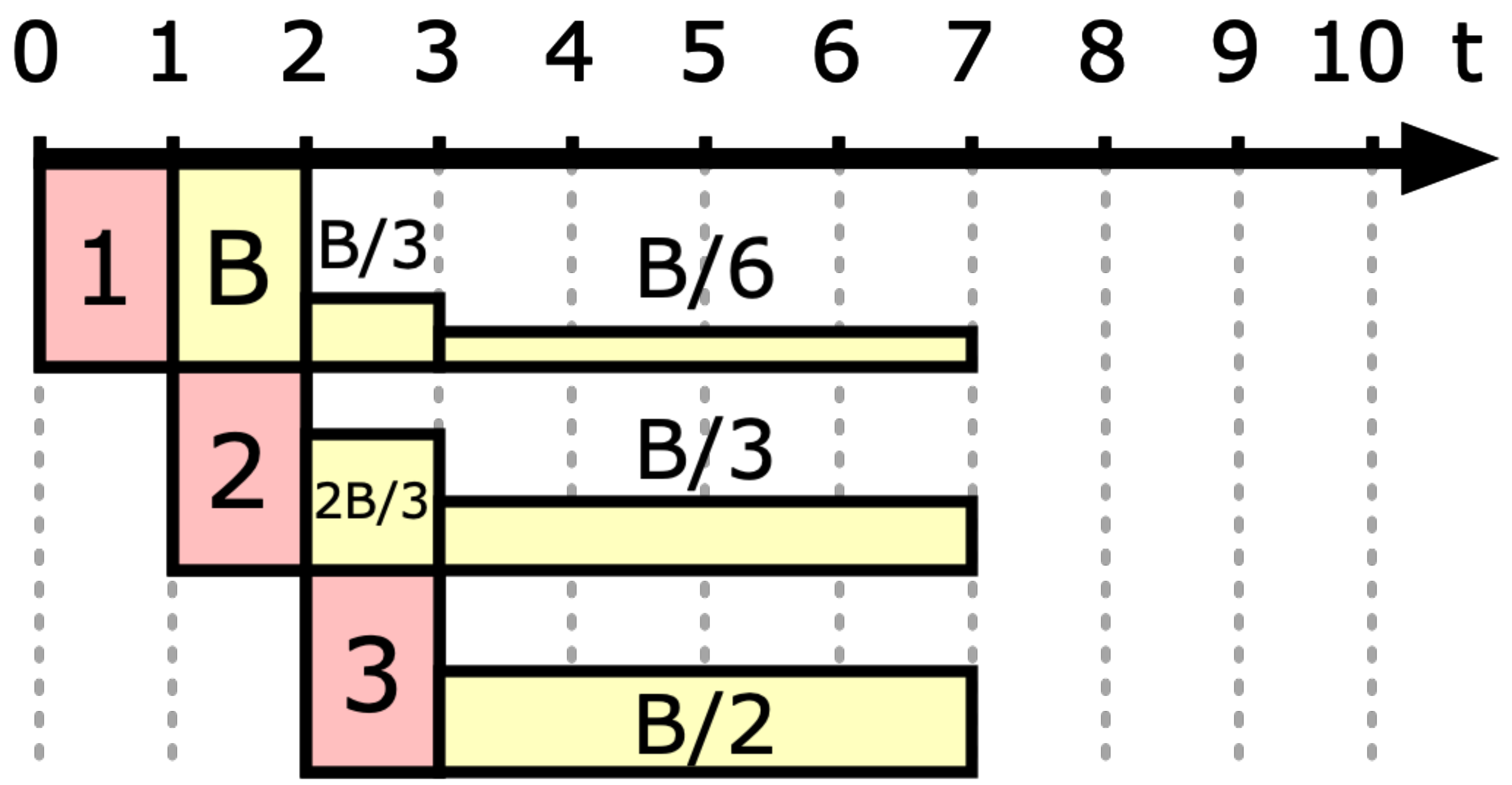

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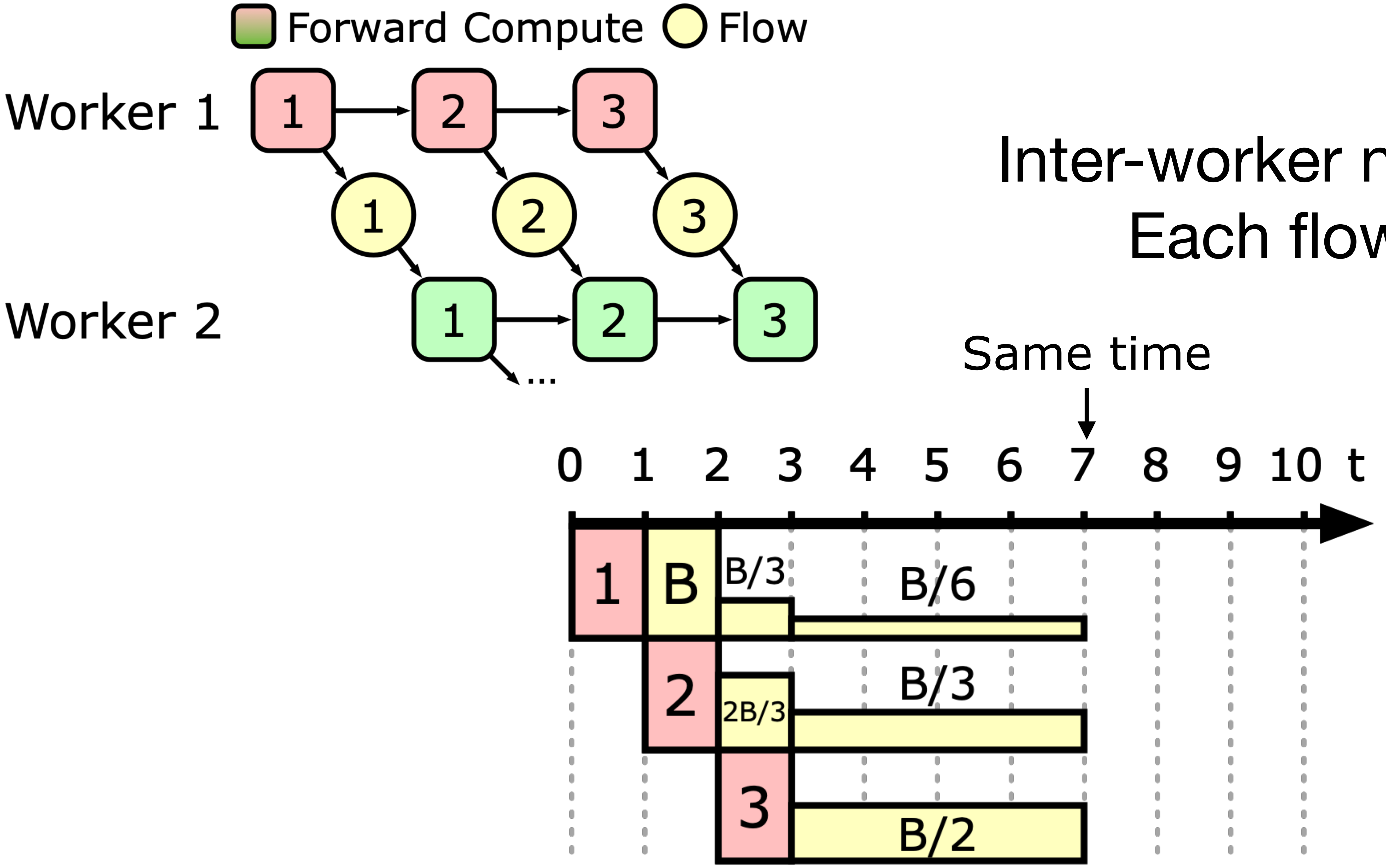

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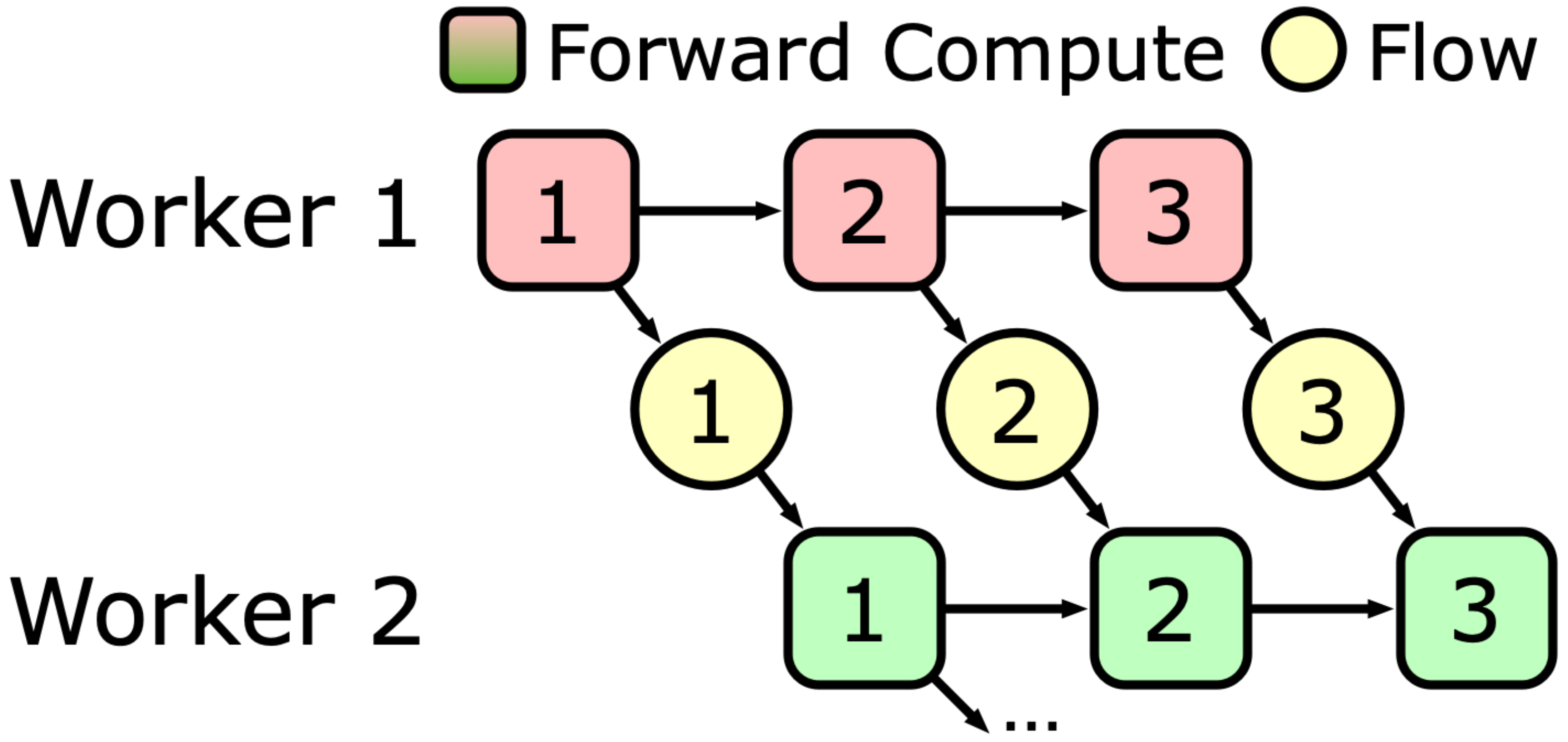

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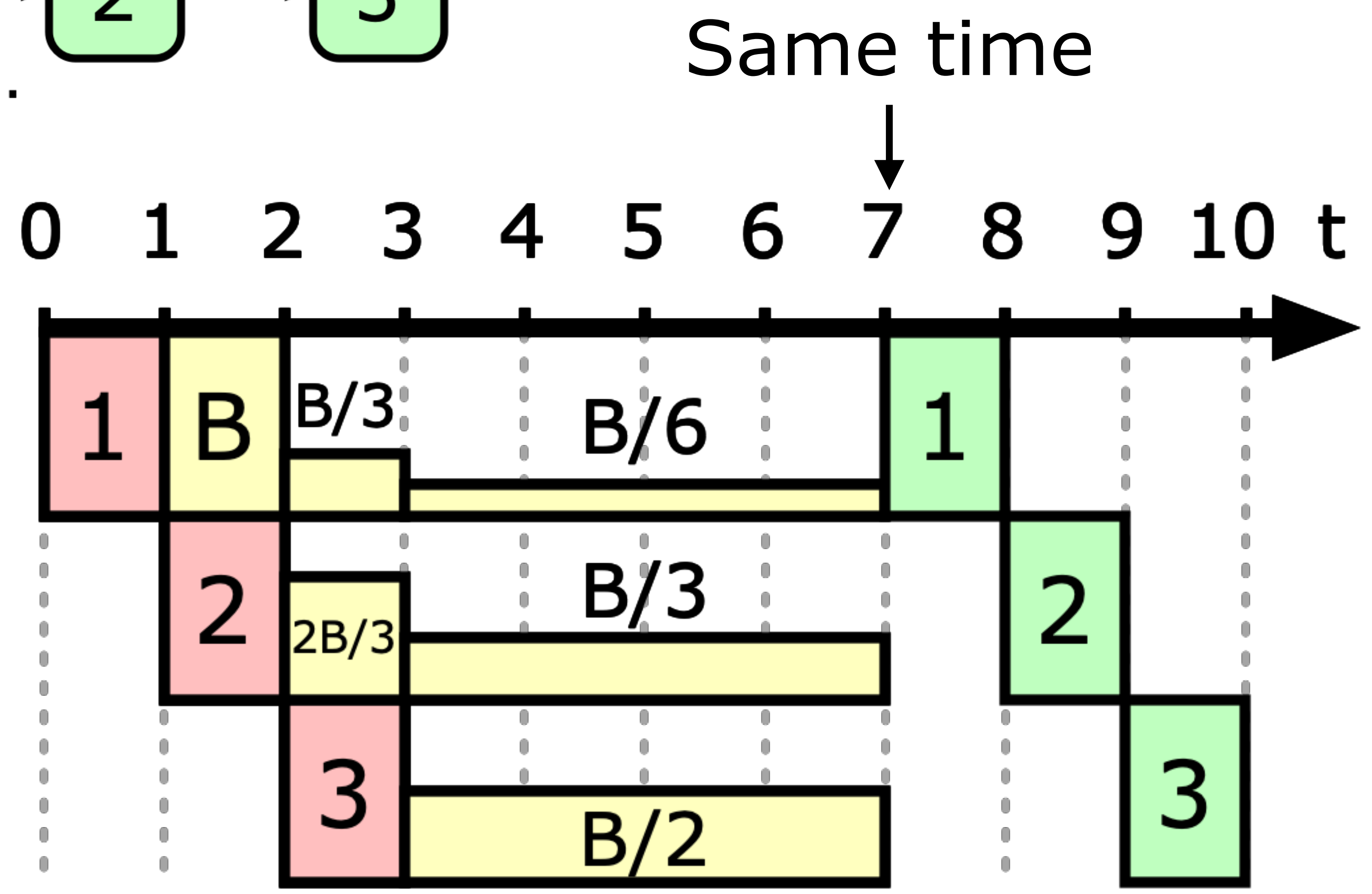

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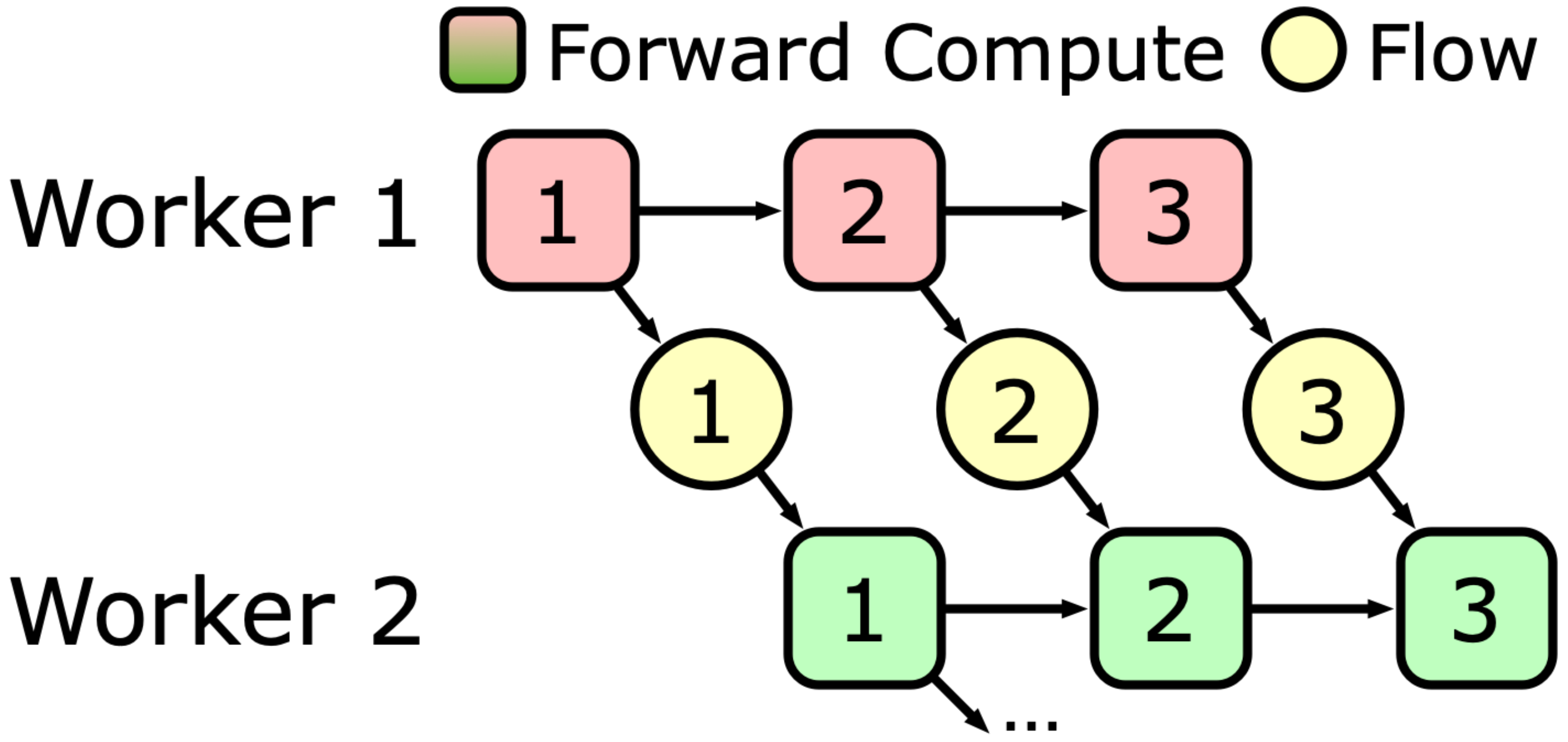

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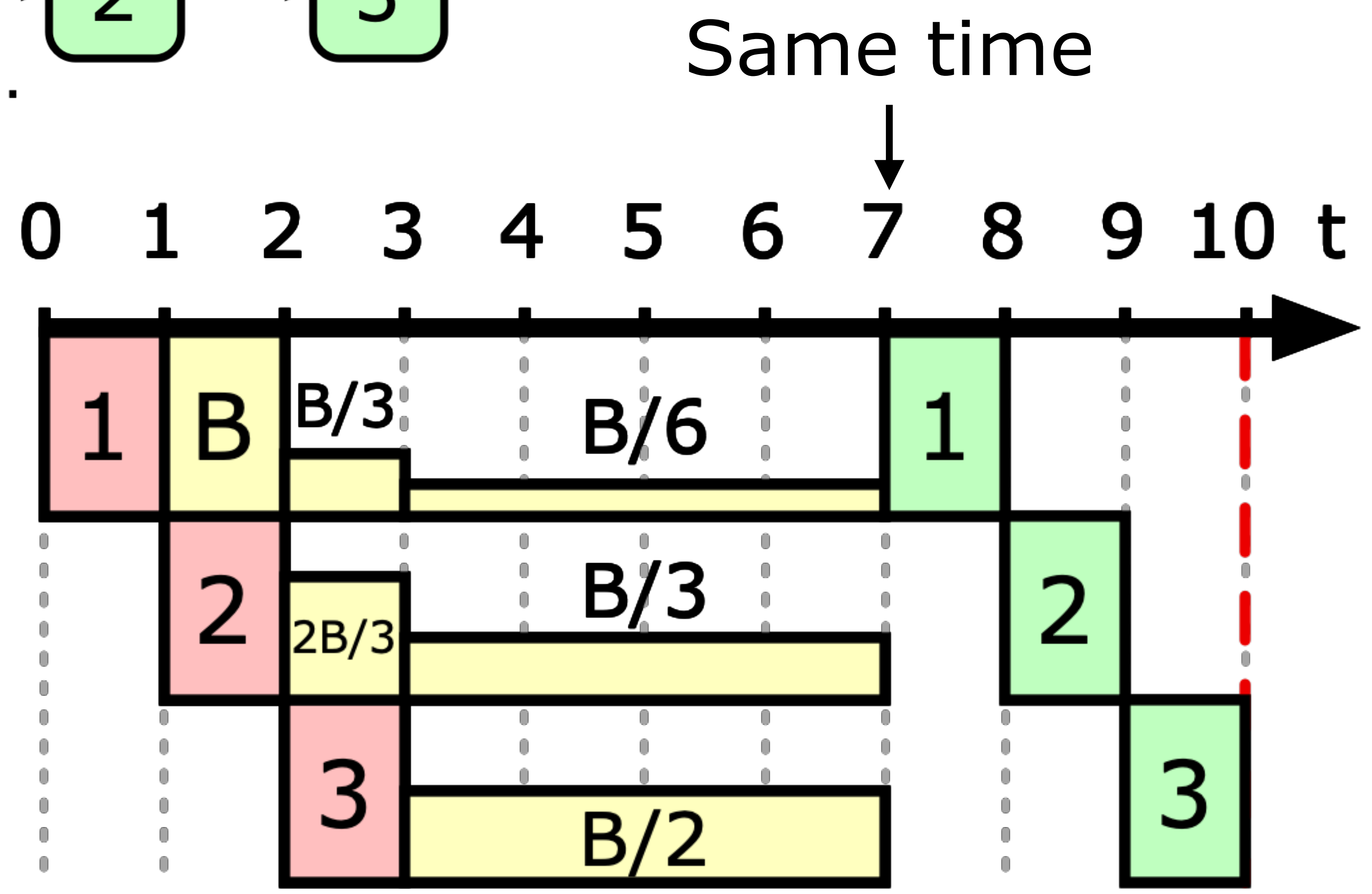

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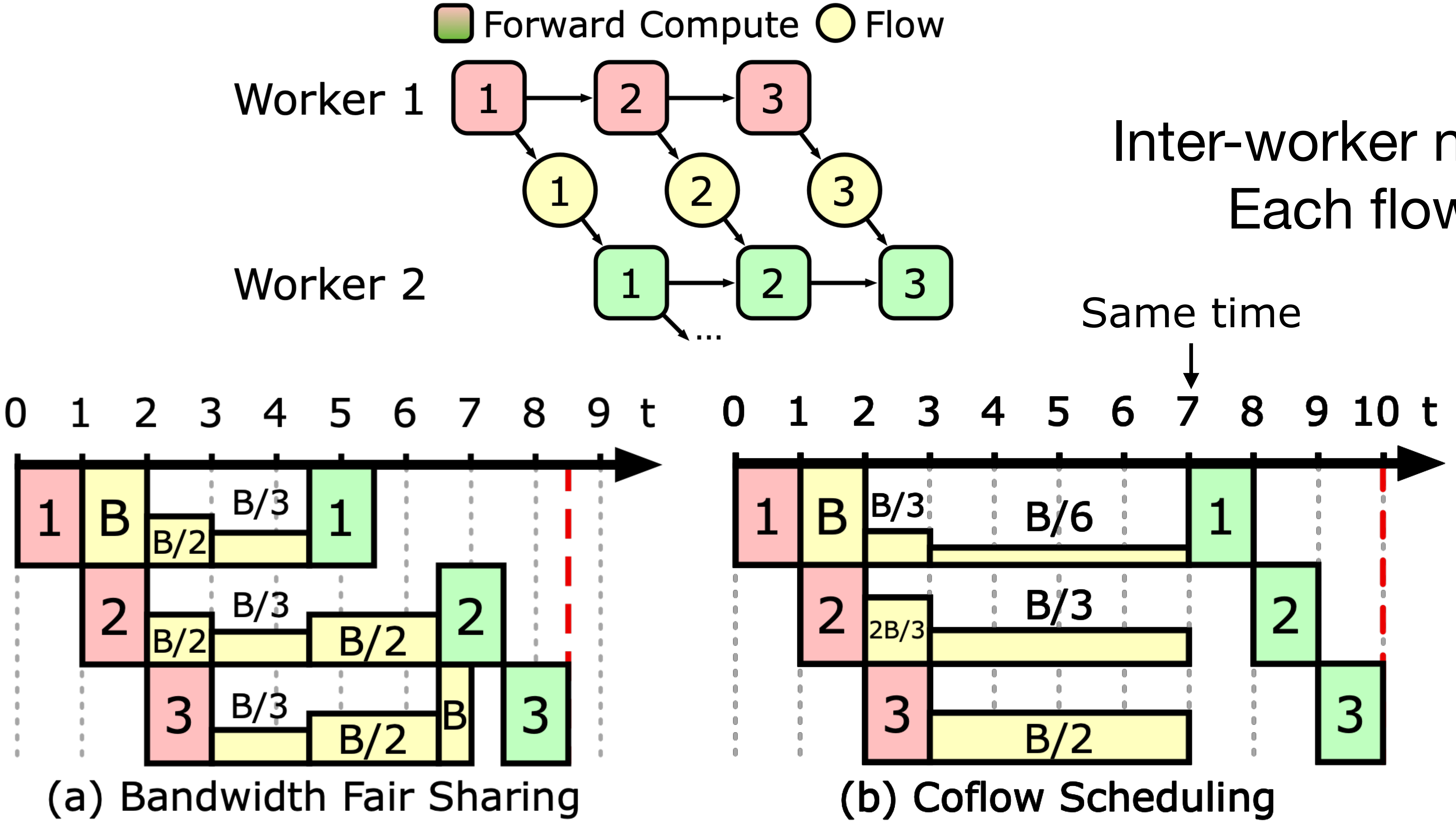

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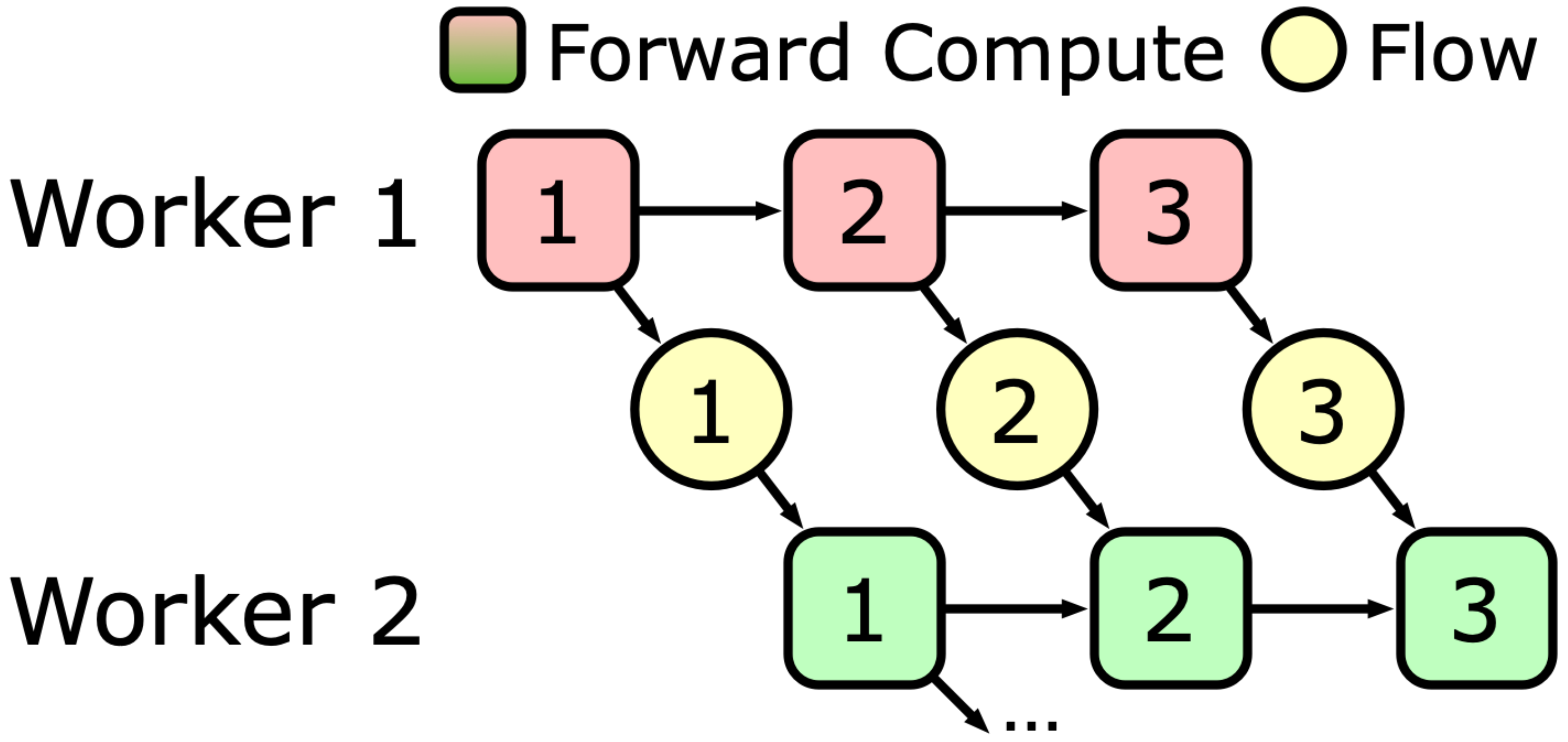

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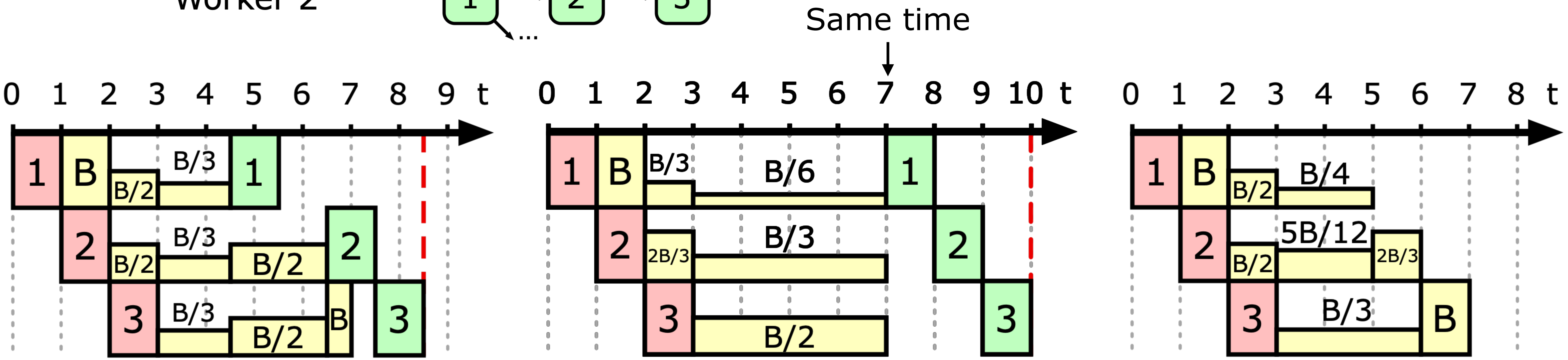

(a) Bandwidth Fair Sharing (b) Coflow Scheduling (c) EchelonFlow Scheduling

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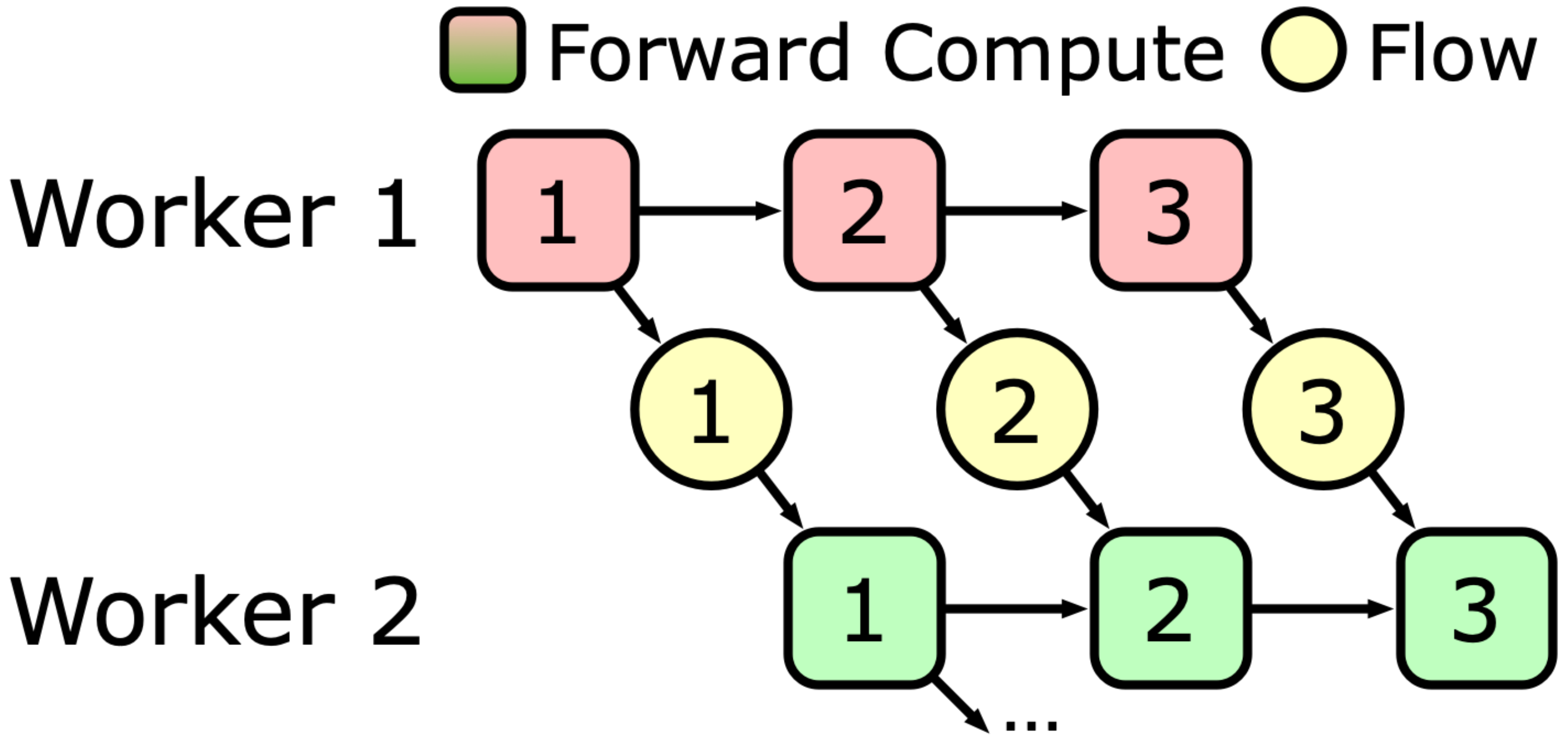

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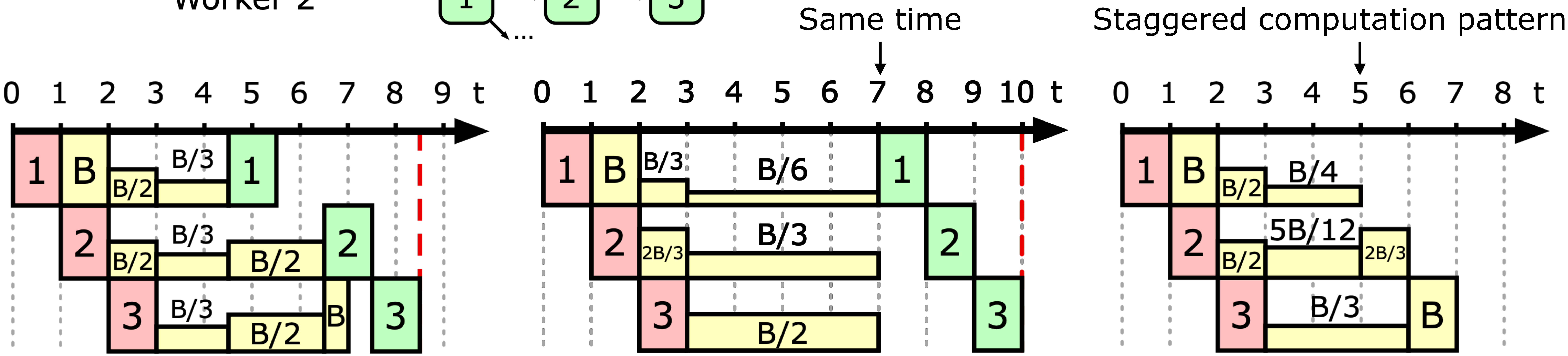

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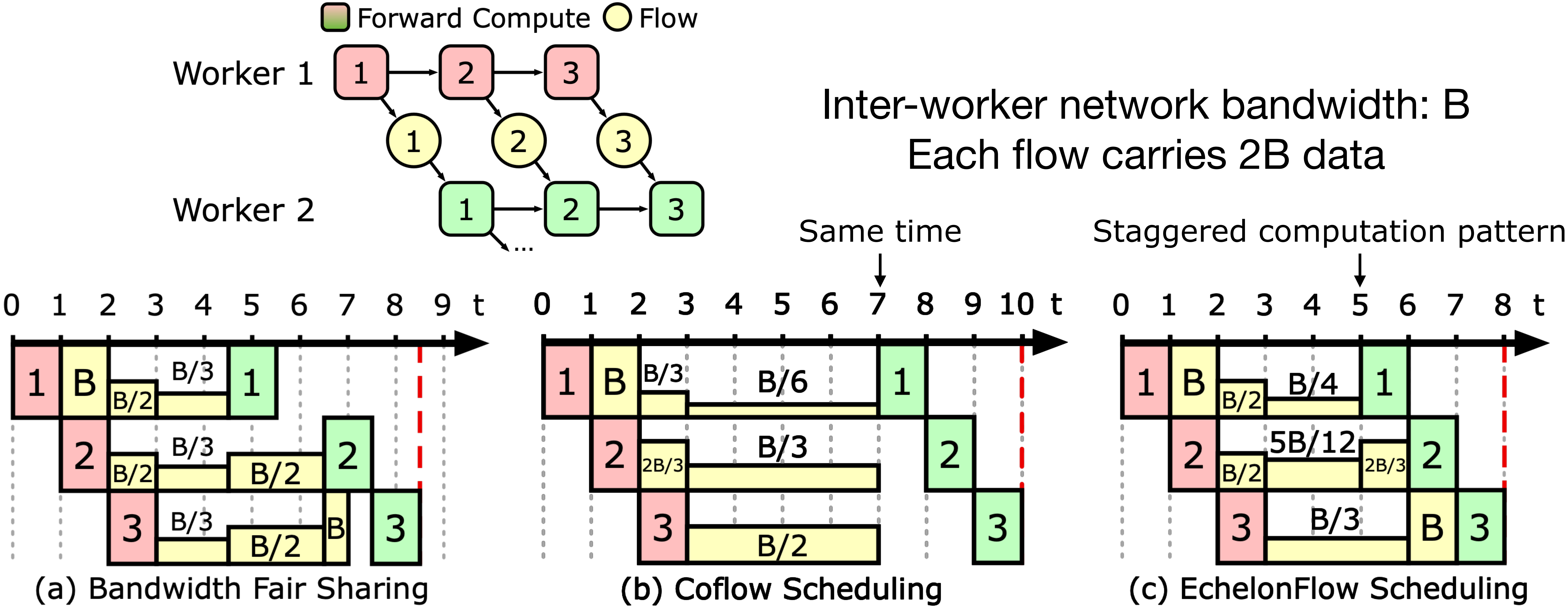

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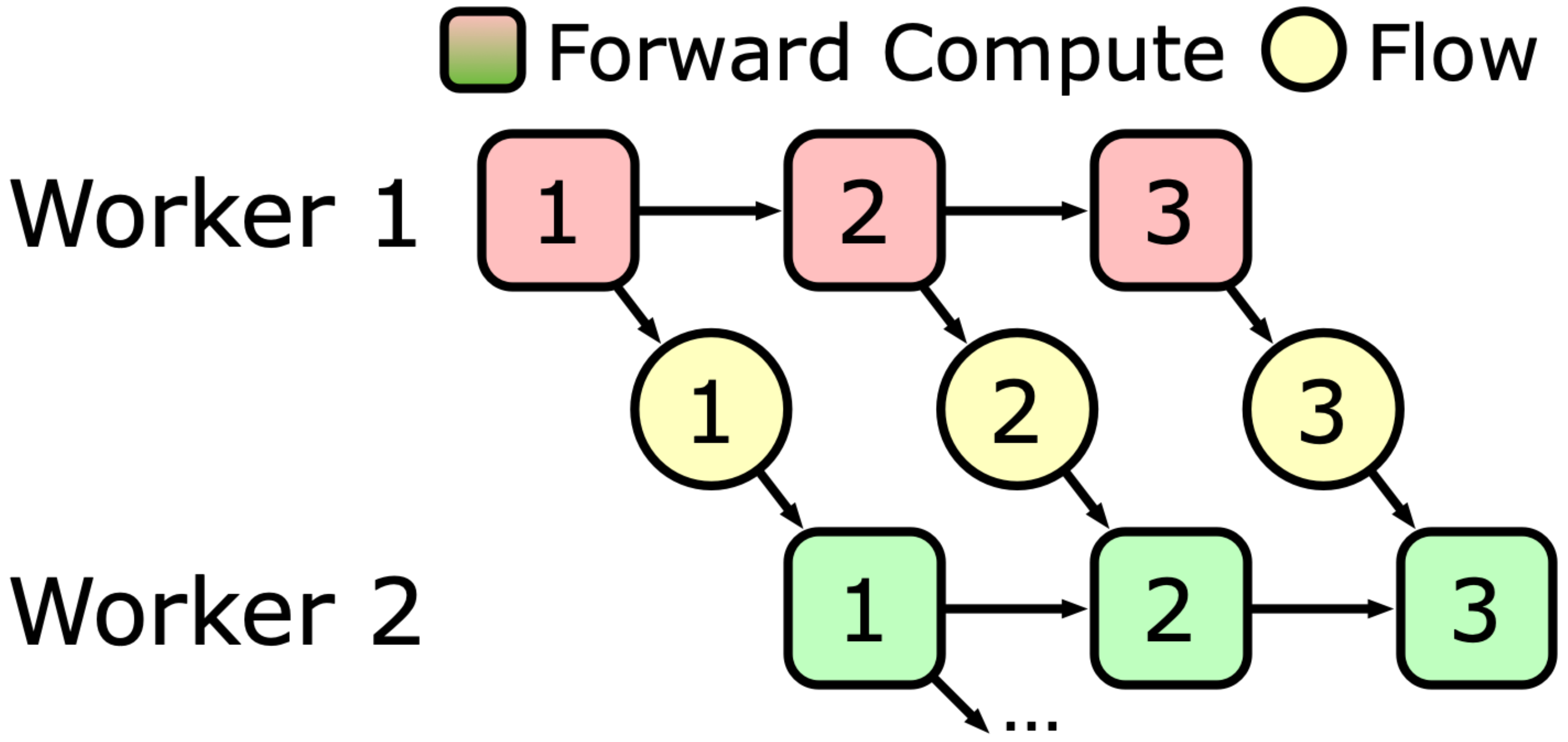

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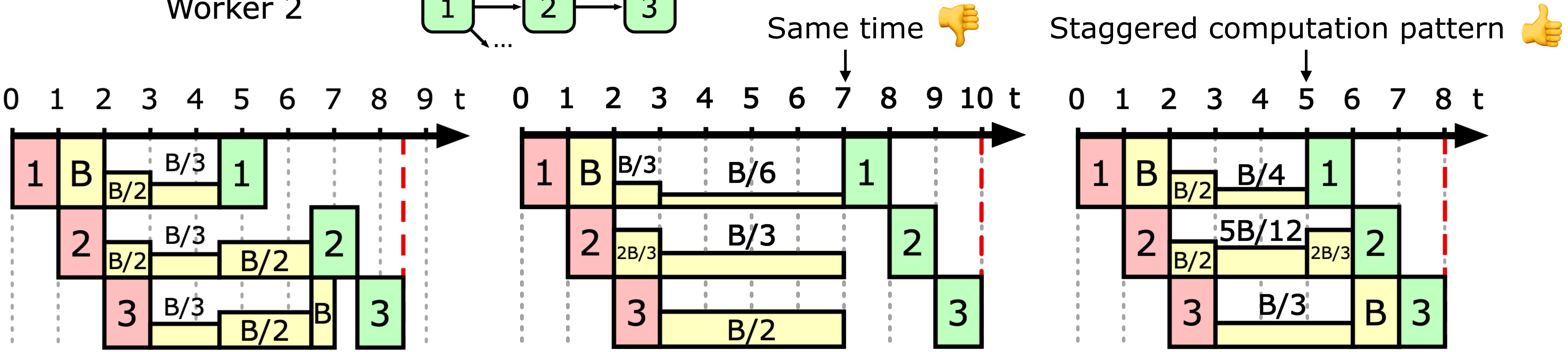

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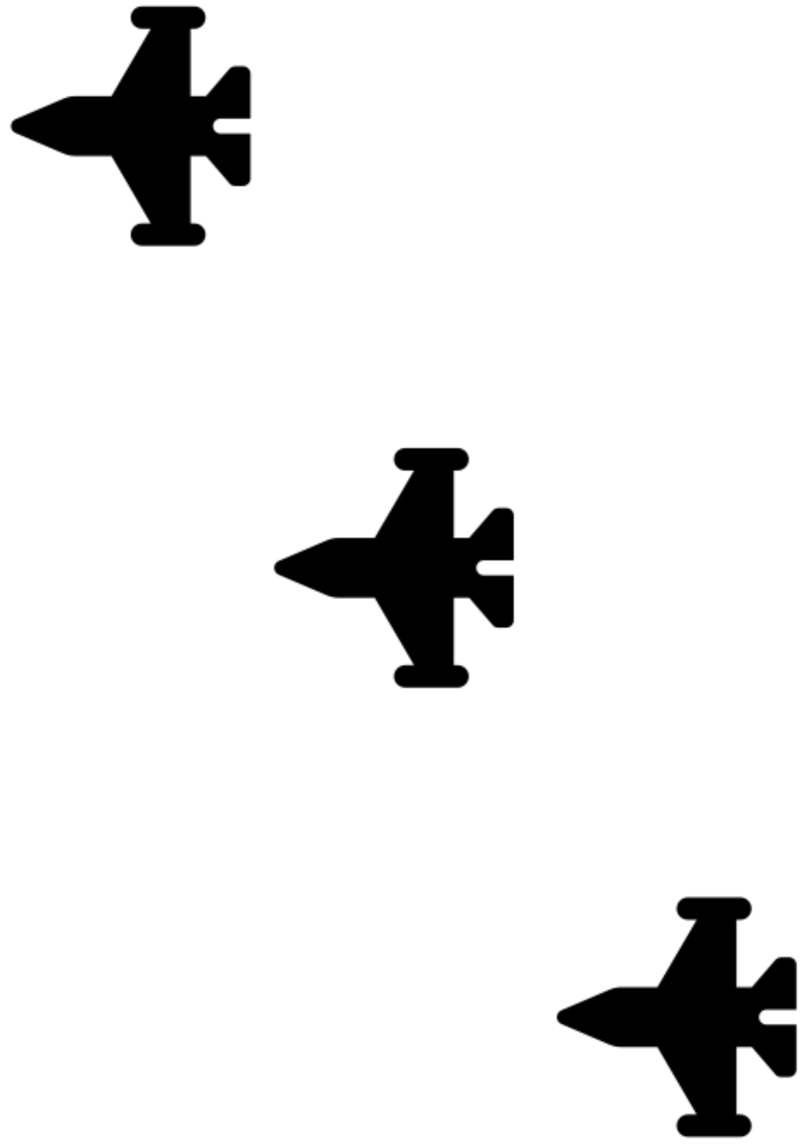

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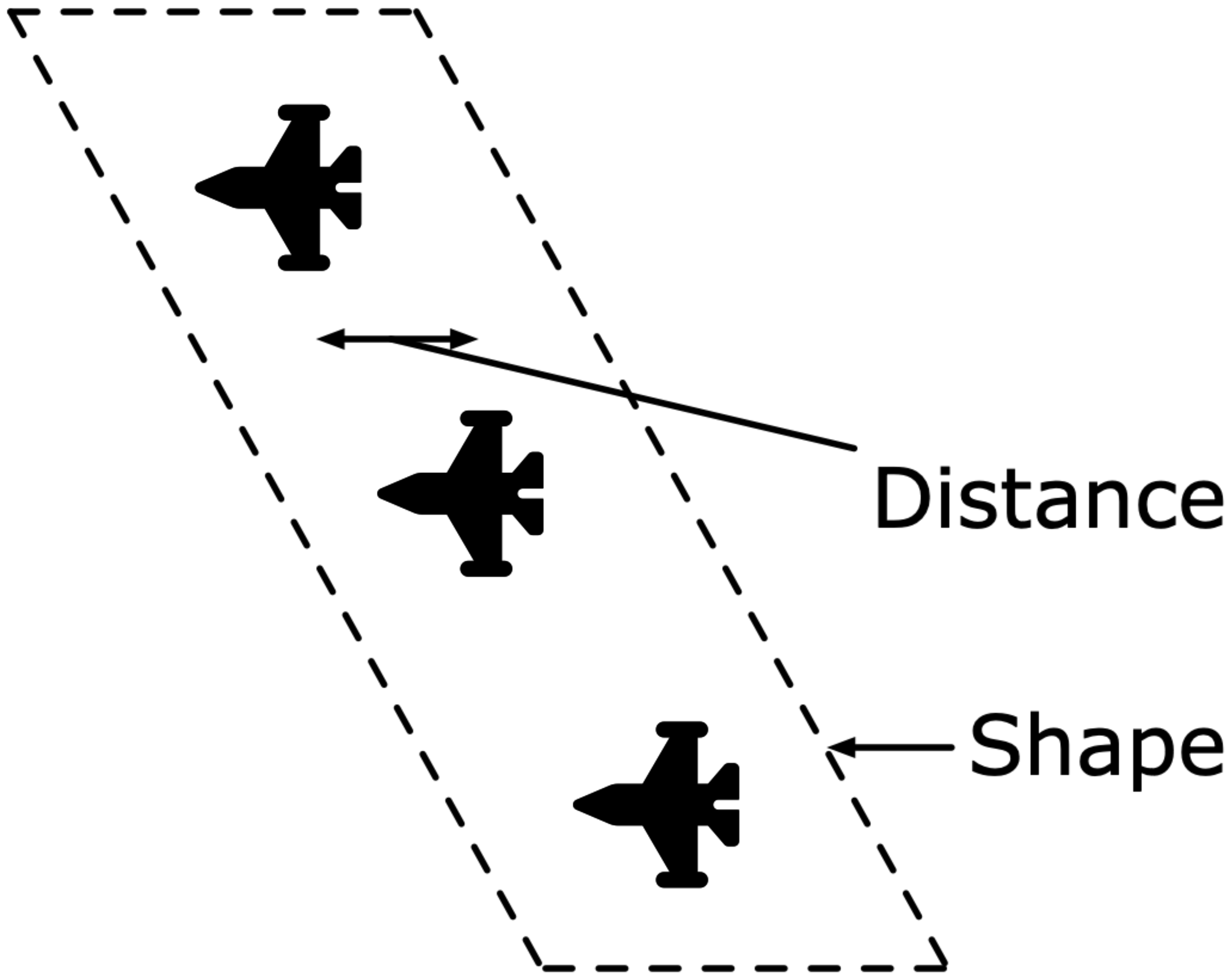

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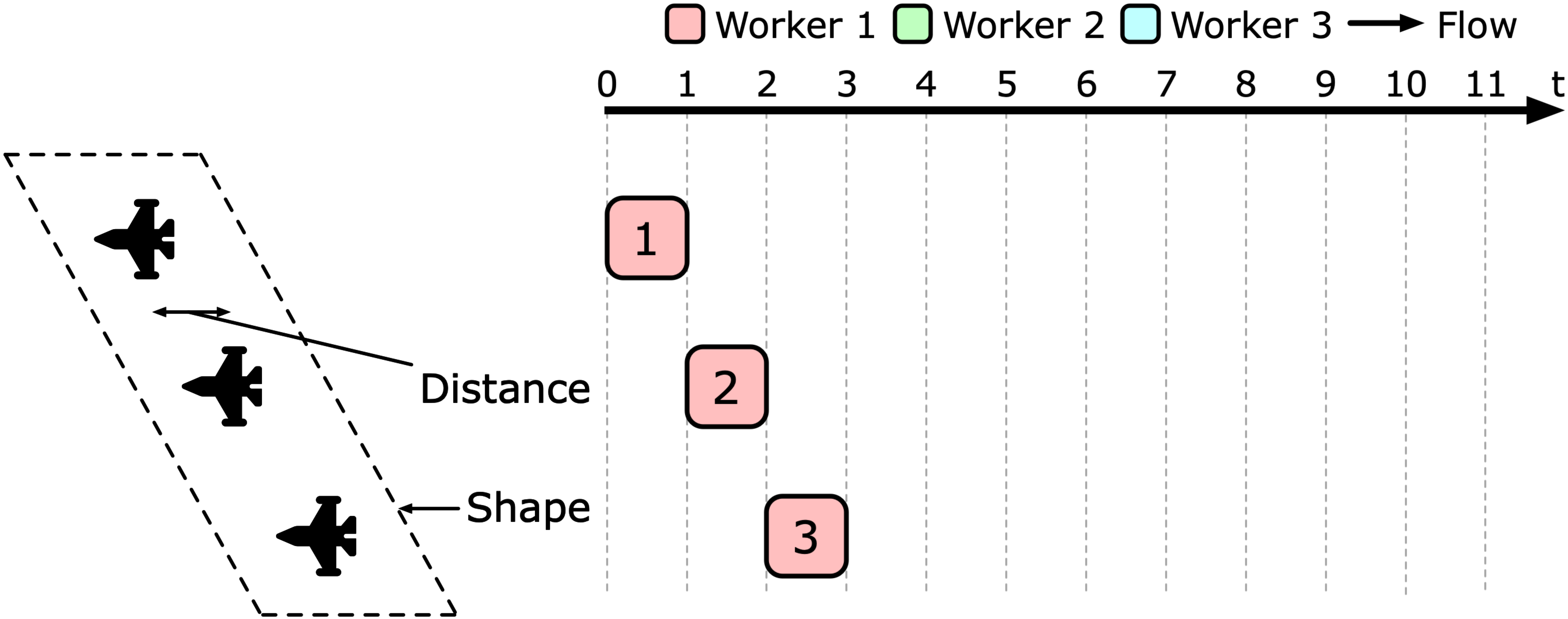

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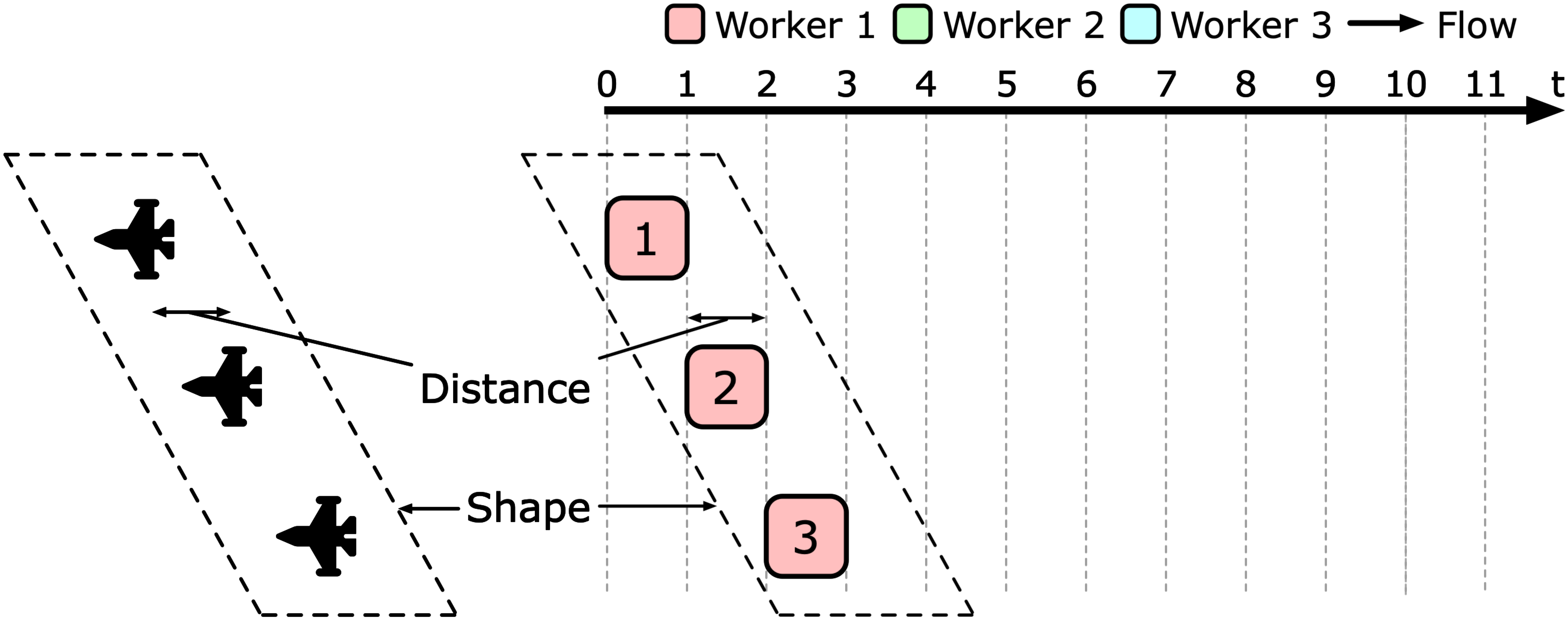

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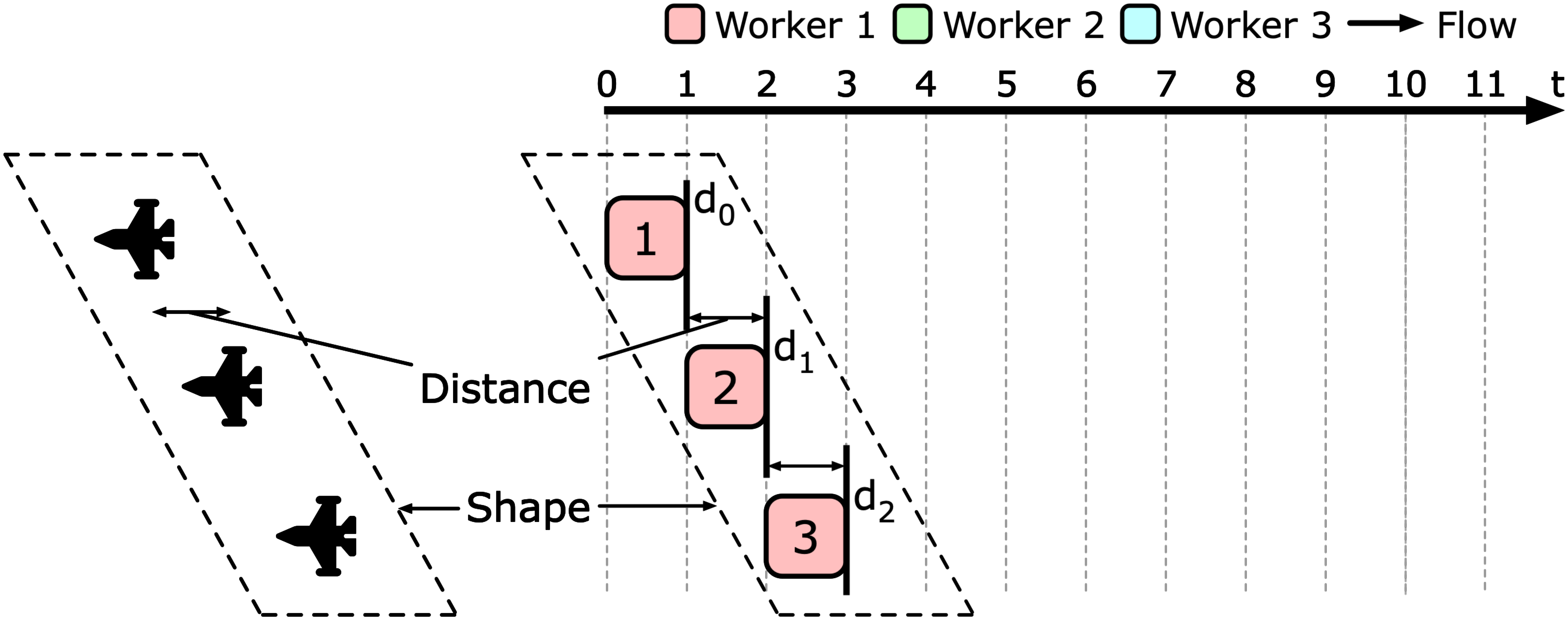

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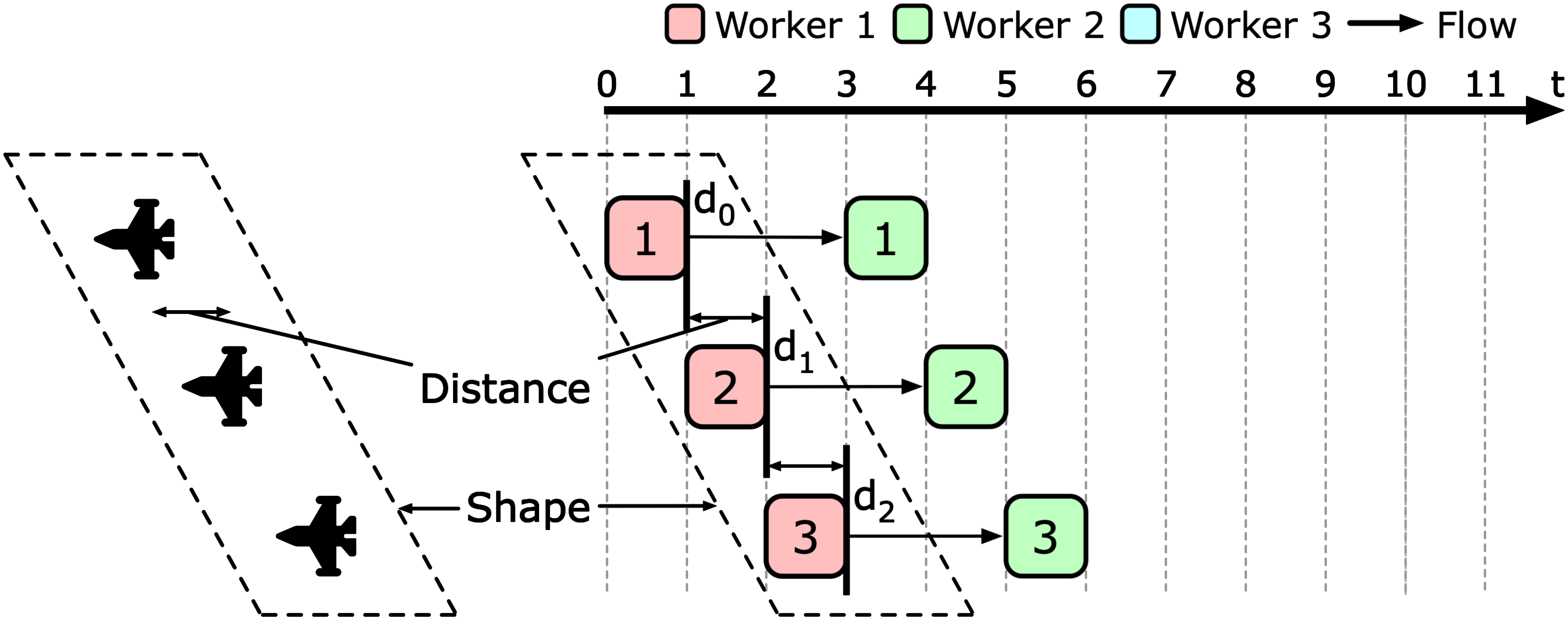

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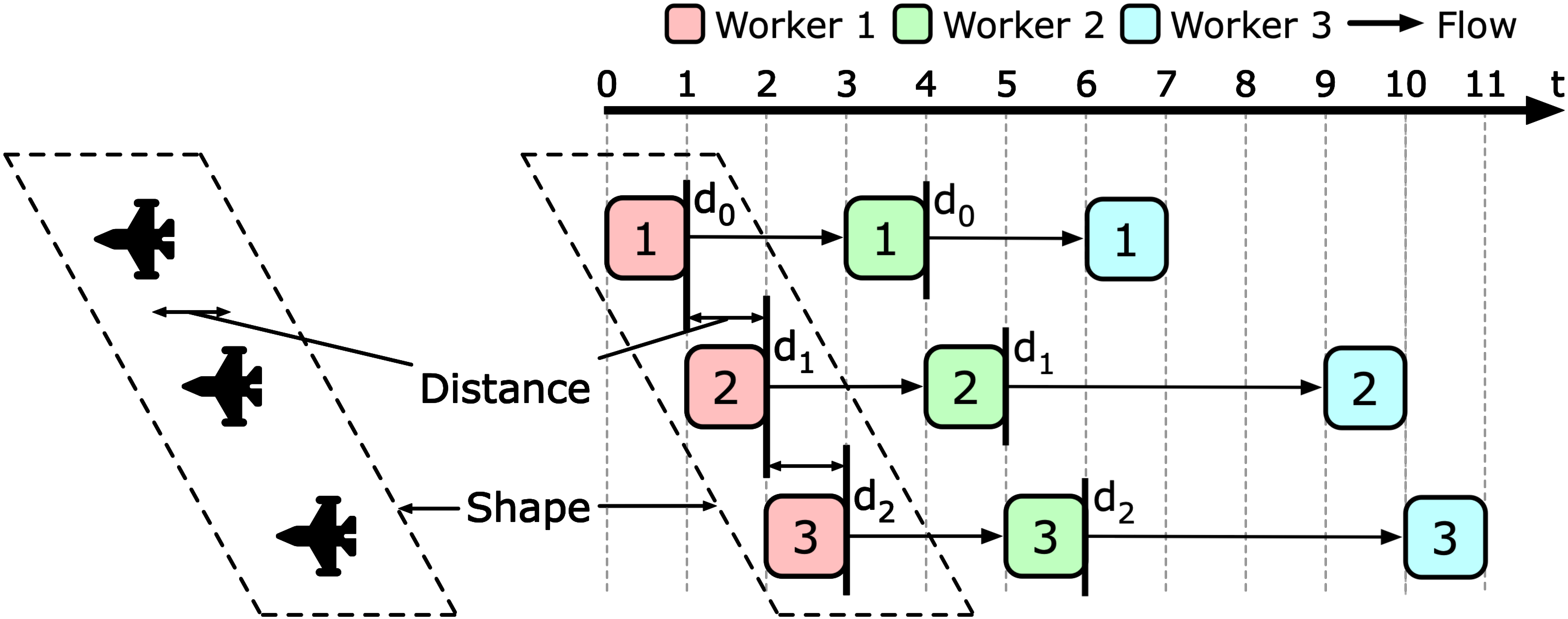

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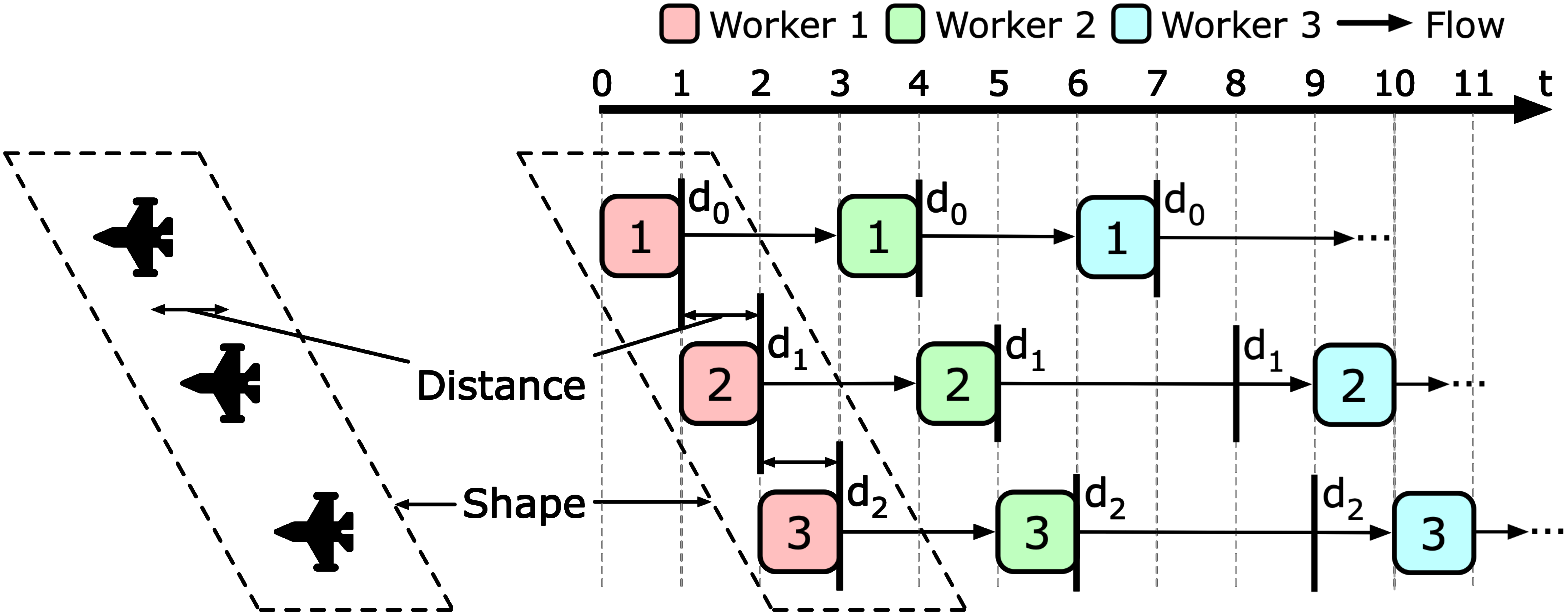

EchelonFlow

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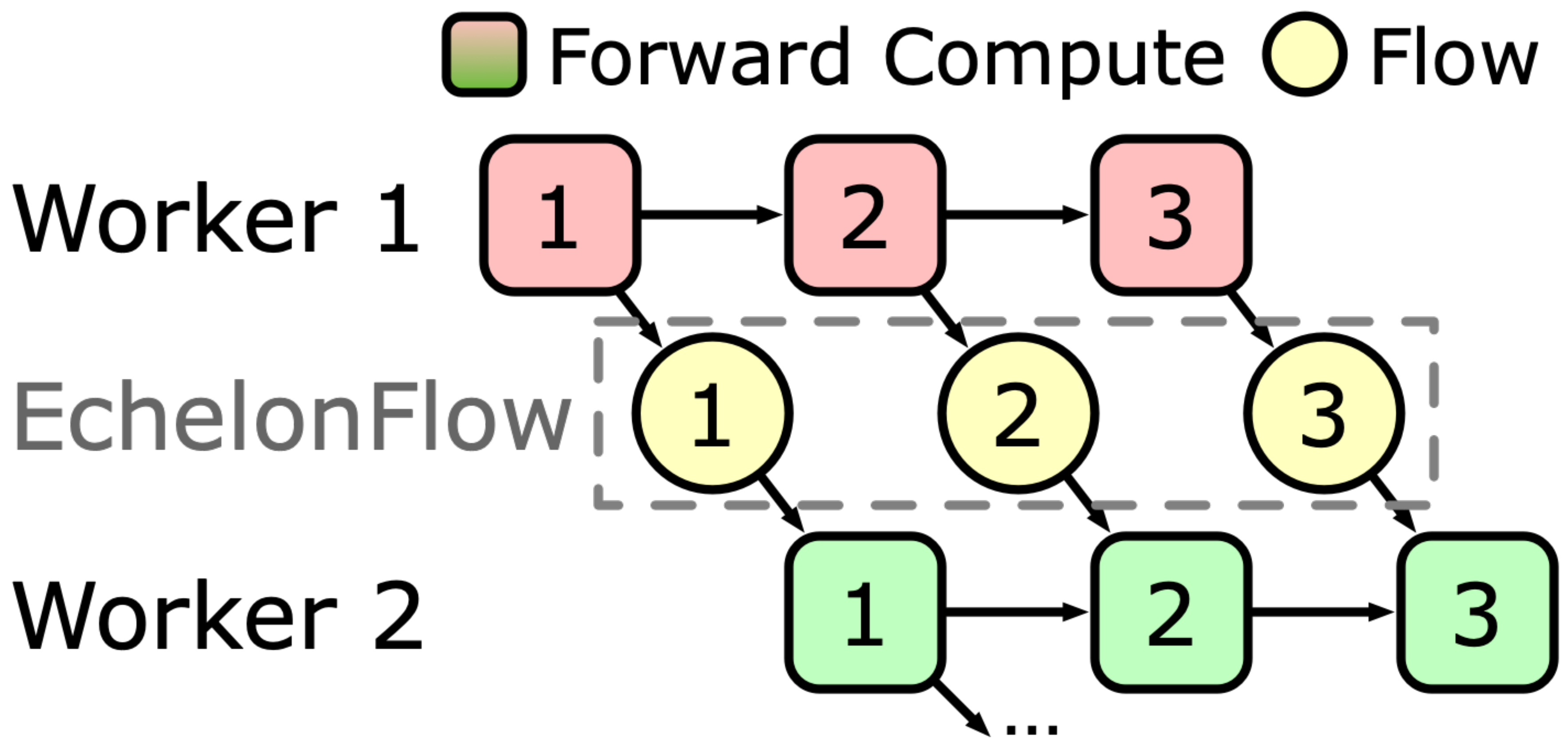
  - Not necessarily equal
  - Can be represented by an **arrangement function**

EchelonFlow

Expressiveness

Training paradigm	Examples	CoFlow compliance	EchelonFlow compliance
Data Parallelism	AllReduce, Parameter Server	✅	✅
Pipeline Parallelism	GPipe, PipeDream	❌	✅
Tensor Parallelism	Megatron-LM	✅	✅
Fully Sharded Data Parallelism	ZeRO, FairScale	❌	✅

Case study: pipeline parallelism



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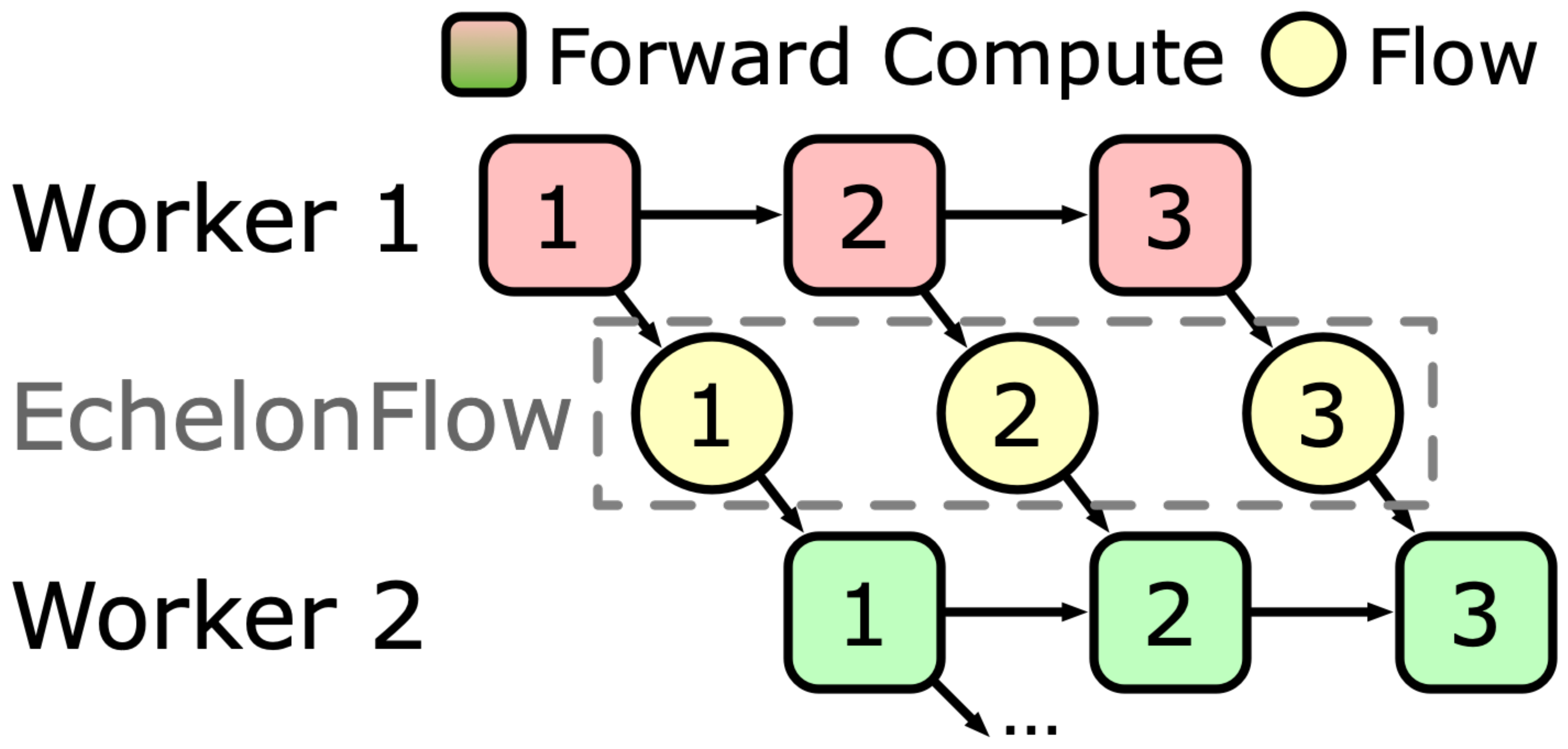


Arrangement function:

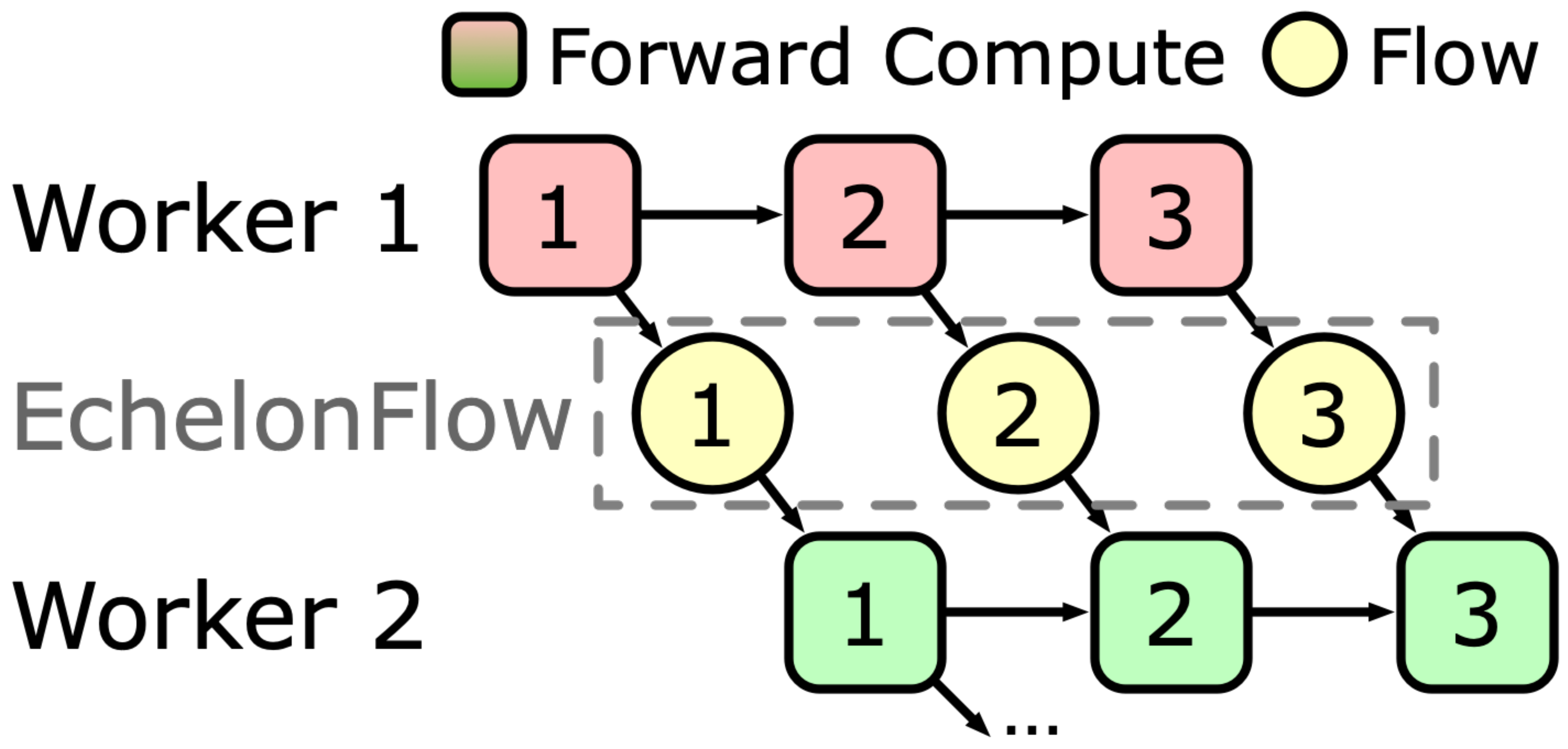
$$\boxed{d_j = d_{j-1} + T}$$

d_j: ideal finish time of flow j

T: time of one forward pass of one micro-batch

EchelonFlow

Properties



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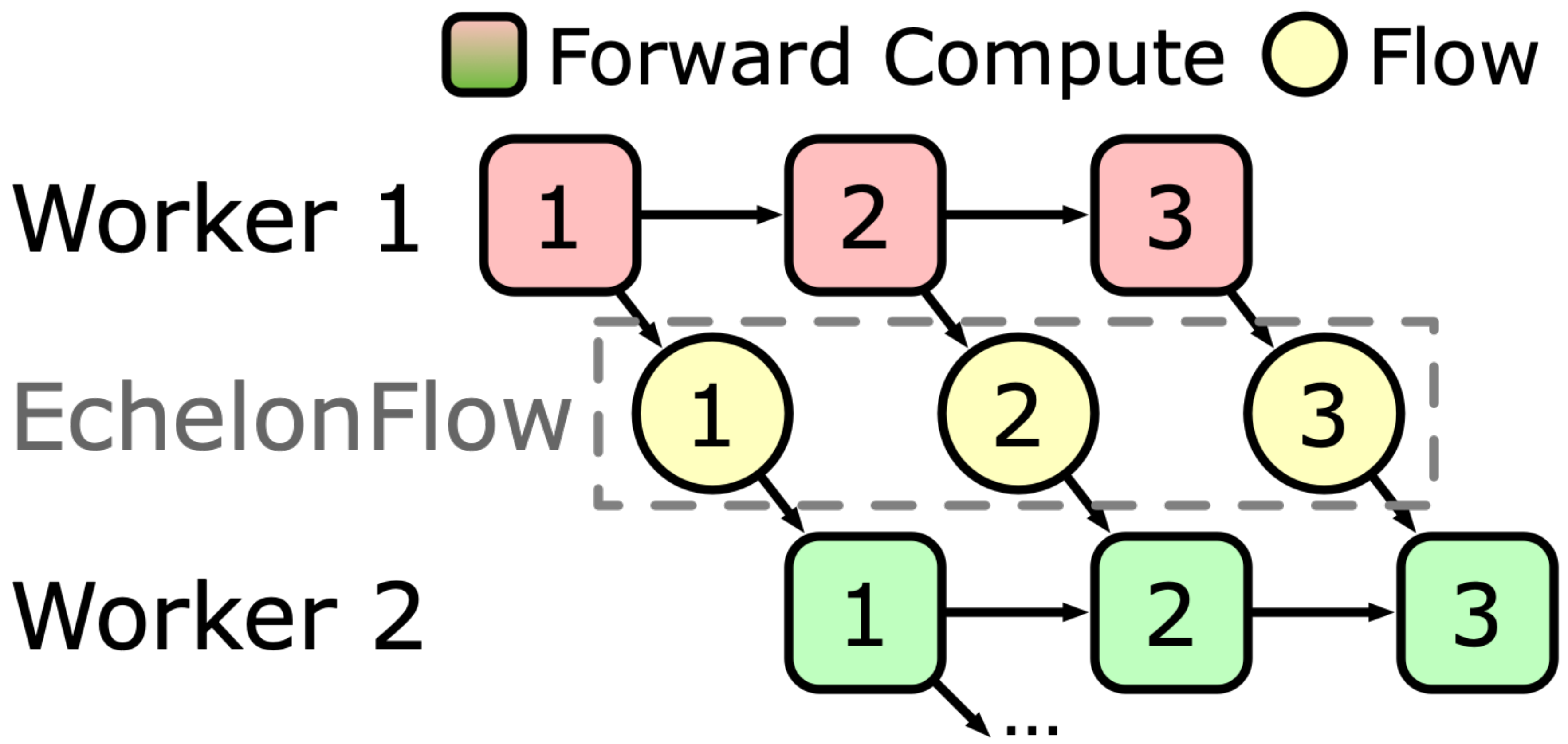

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EchelonFlow

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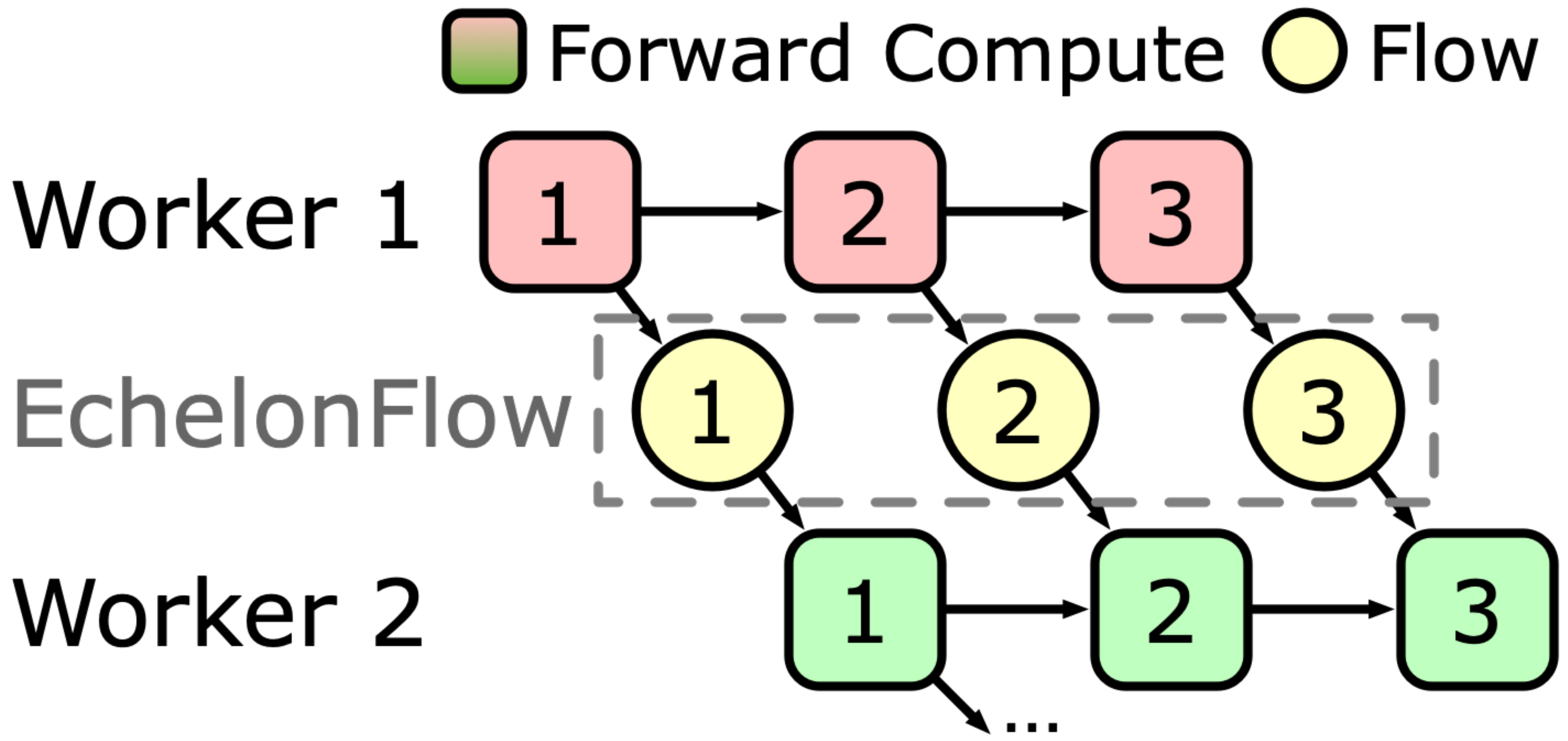

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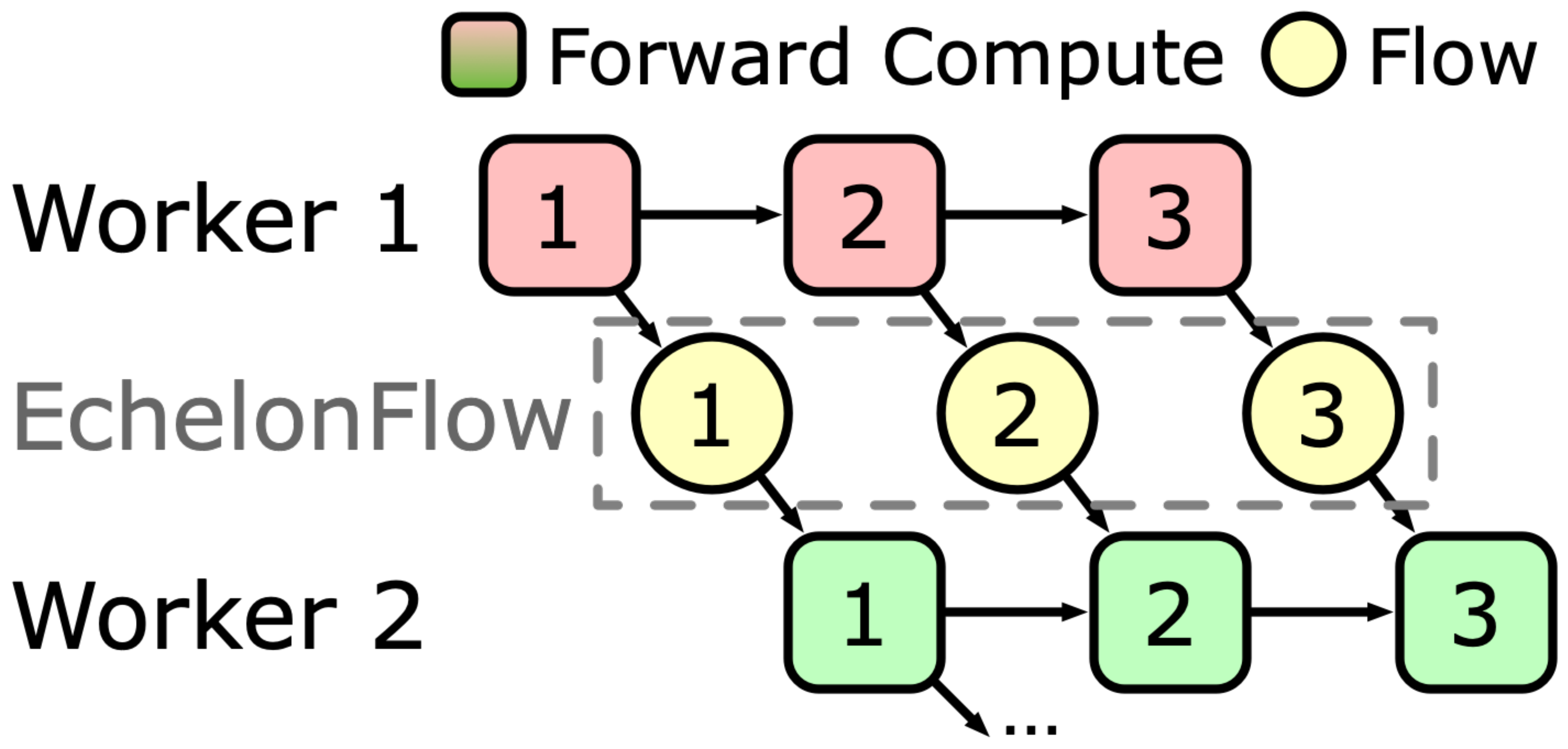

- General to diverse distributed training paradigms
- A superset of CoFlow
- Same complexity as CoFlow scheduling

EchelonFlow
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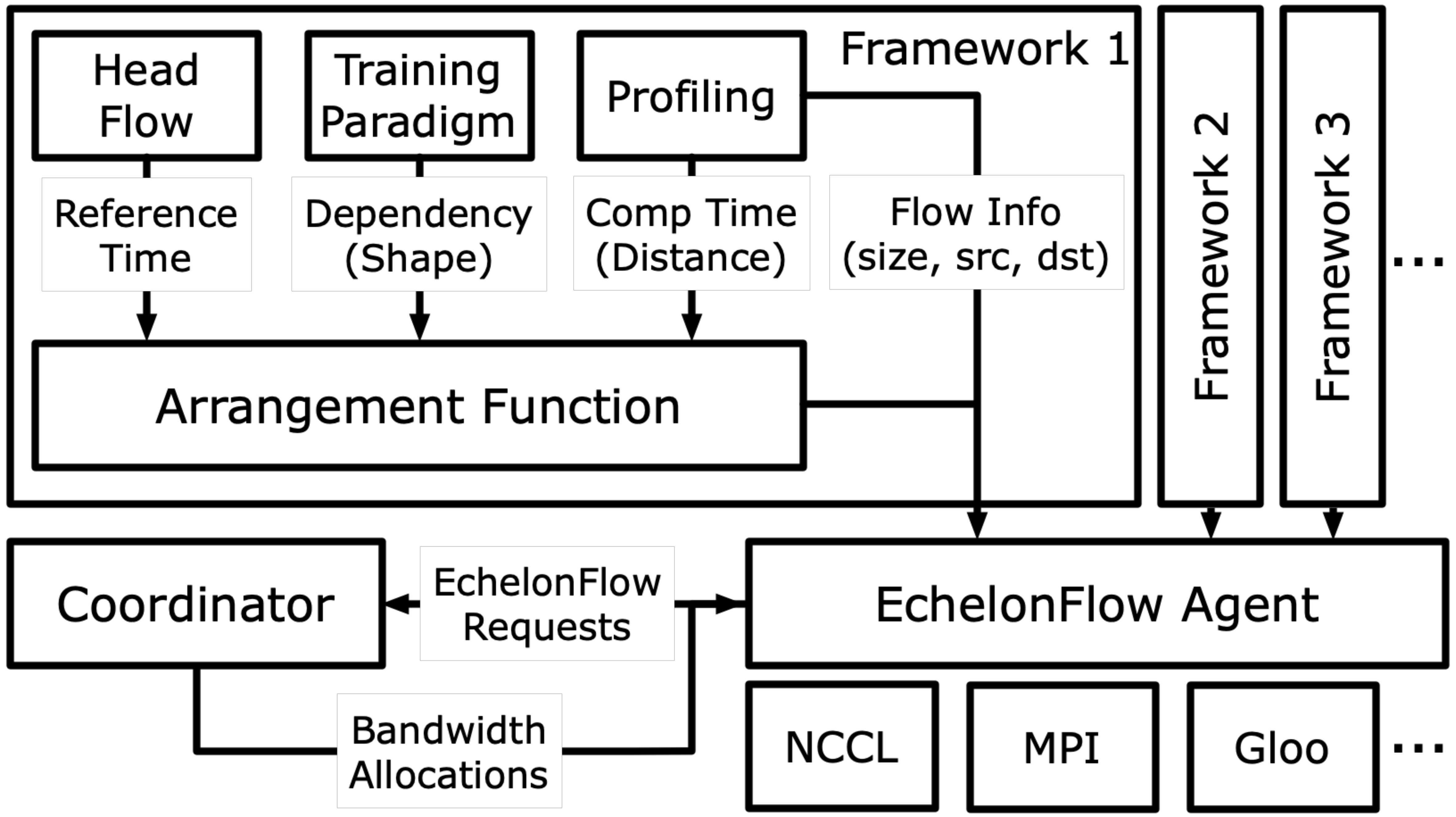

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- A new network abstraction
  - Flow finish times are not necessarily the same, but follow a pattern
  - Arrangement function for high training throughput