Analyzing Parallel Real-Time Tasks Implemented with Thread Pools

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Motivations

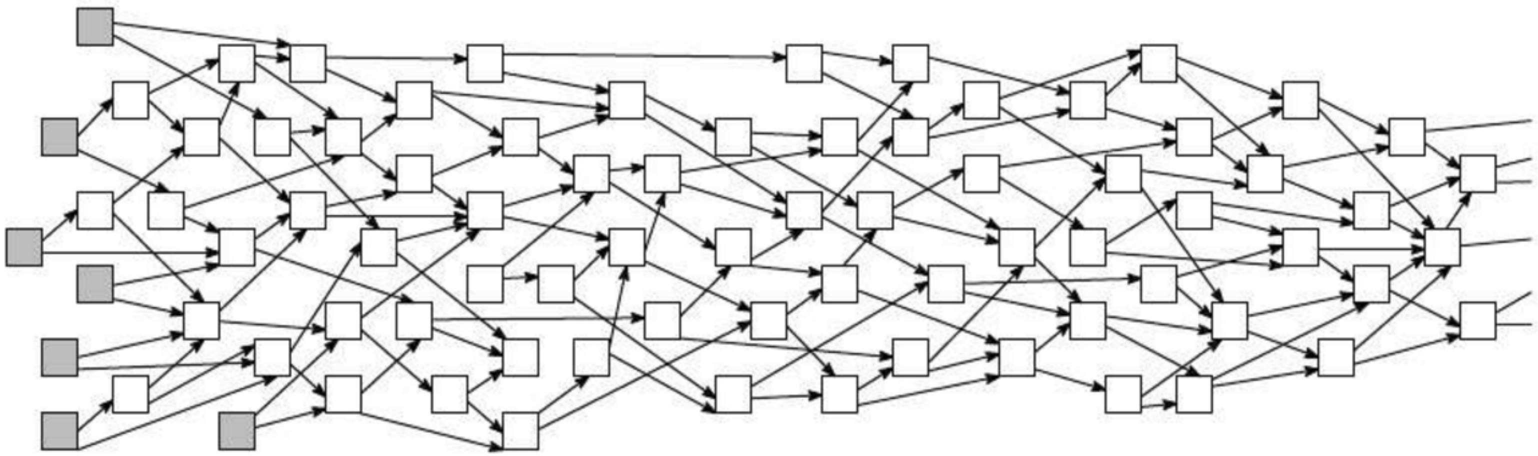
How to model the workload due to a Deep Neural Network?

How inference engines schedule Deep Neural Networks?

Case study

- InceptionV3: powerful image recognition DNN
- Tensorflow: open-source machine learning framework by Google
- Tensorflow with Eigen math library on CPUs
- Strongly parallel workload

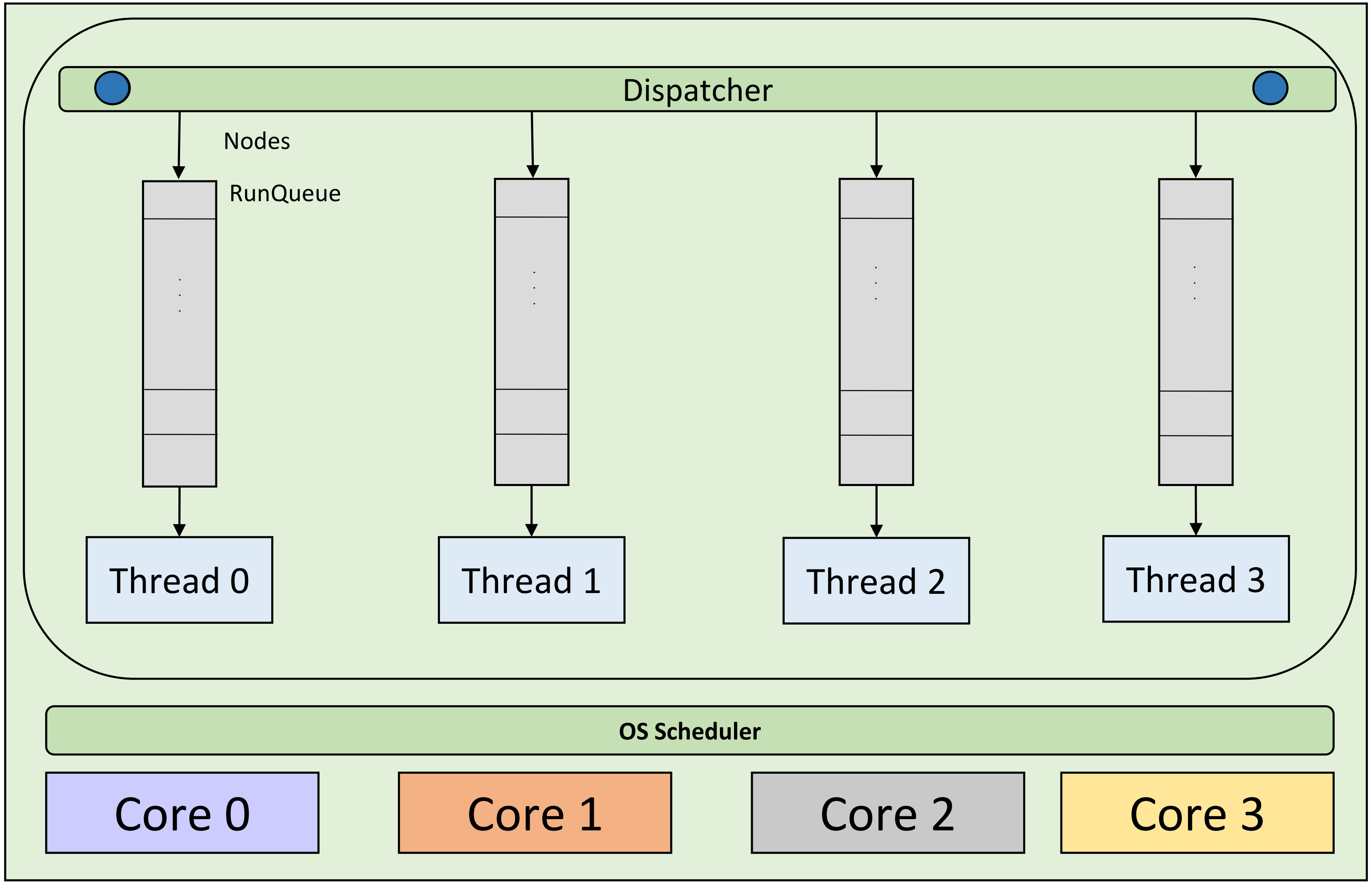
Nodes typically perform mathematical computations (e.g., tensor convolutions) whose implementation is platform-dependent and extremely parallel



DNN can be modeled as a **direct acyclic graph (DAG)**

How Tensorflow works on CPUs?

TensorFlow (Eigen) assigns ready nodes to threads of a thread pool



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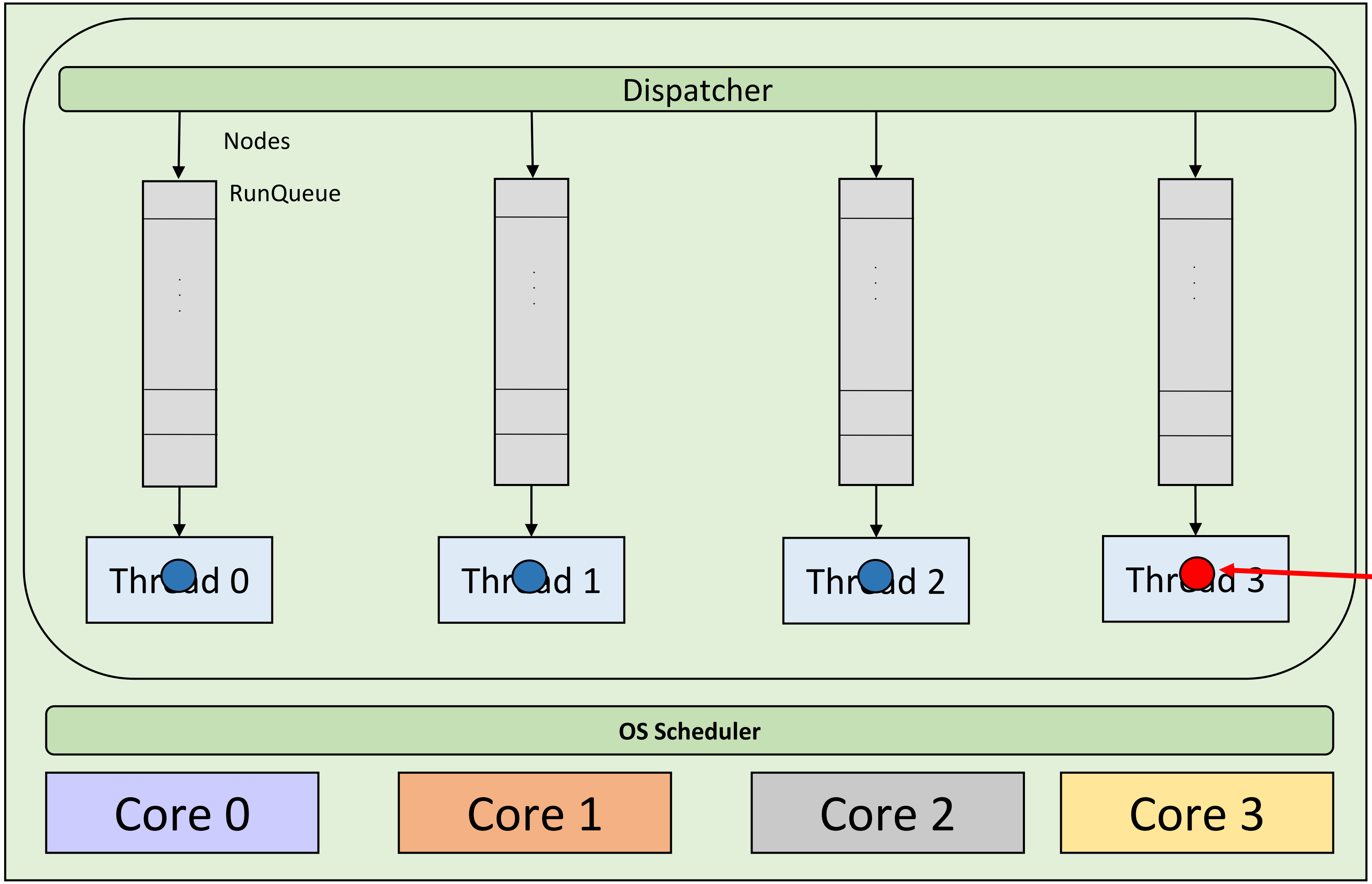

What if one of these functions **blocks** on a **condition variable**?

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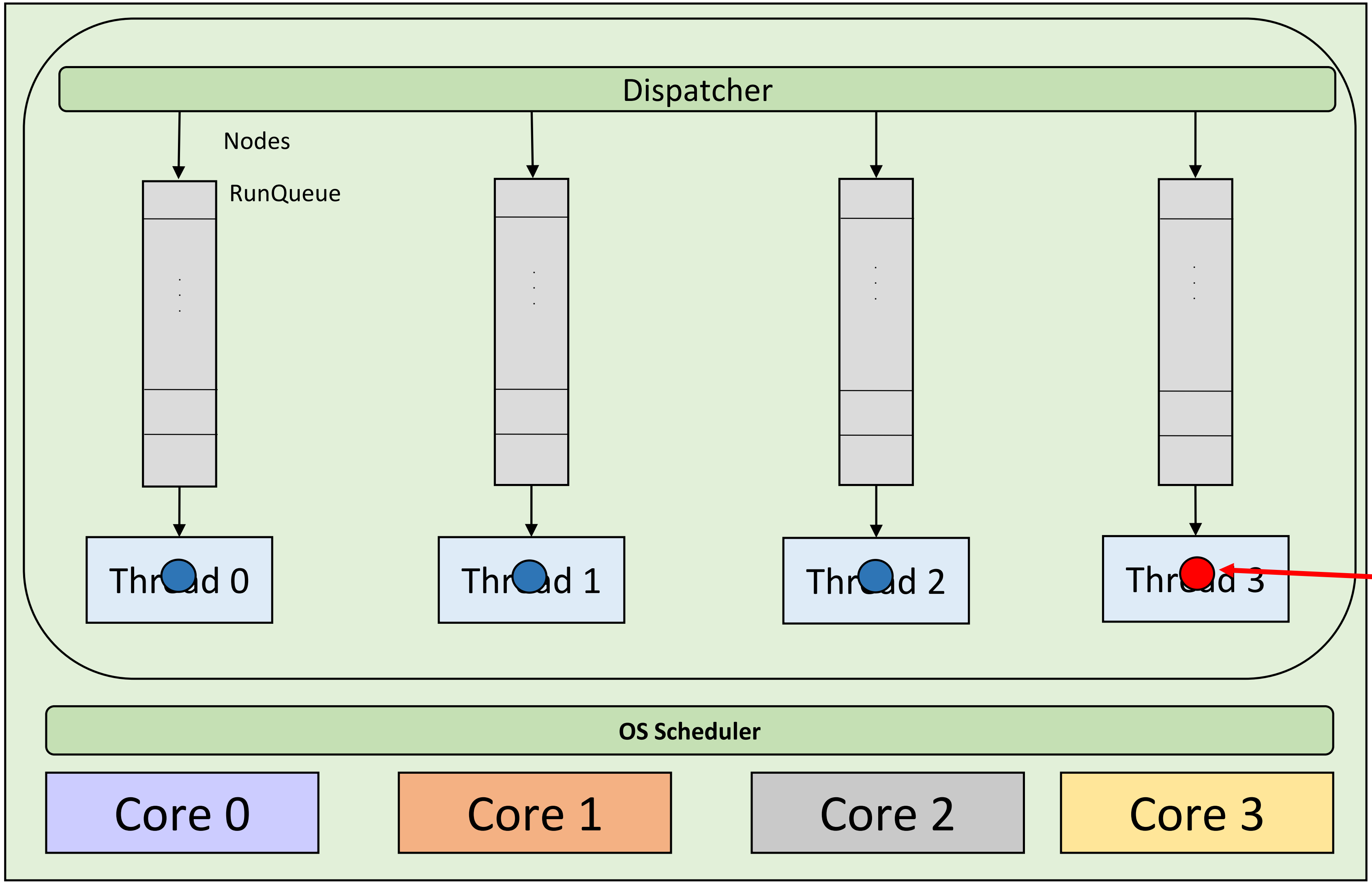

Nodes are C++ Functions: **the OS is not directly aware of them!**

What if one of these functions **blocks** on a **condition variable**?

How Tensorflow works on CPUs?

Blocking implementation of fork-join parallelism:

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Blocking implementation of fork-join parallelism:

A **sequential flow** of execution that forks in **multiple parallel branches** and and joins again in a sequential flow

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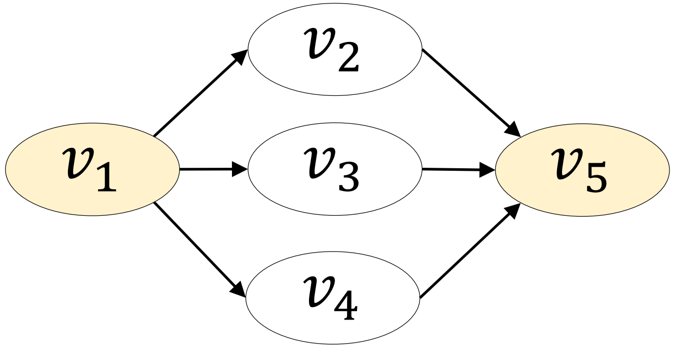


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  <execute v_i>
  <signal>
}
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void v1v5 ( ) {
  <execute v1>
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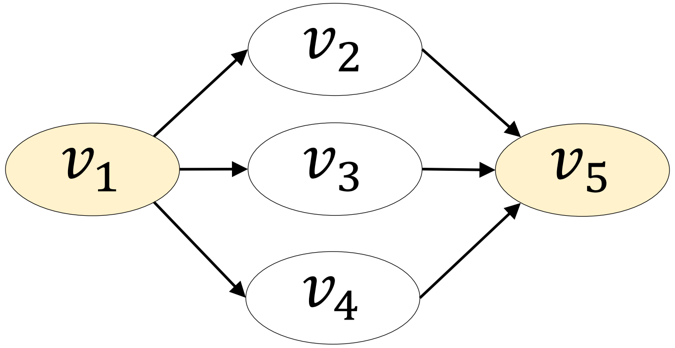


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signaling the condition variable

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blocking on a condition variable

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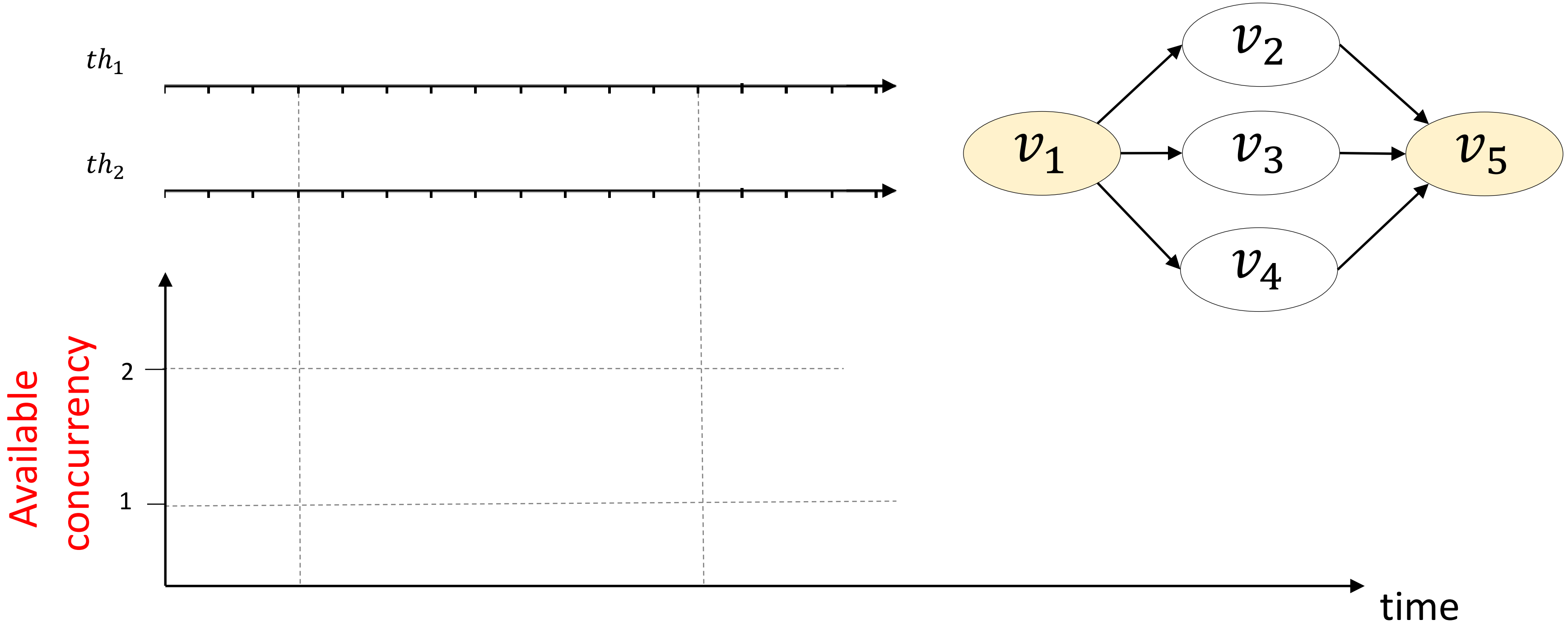

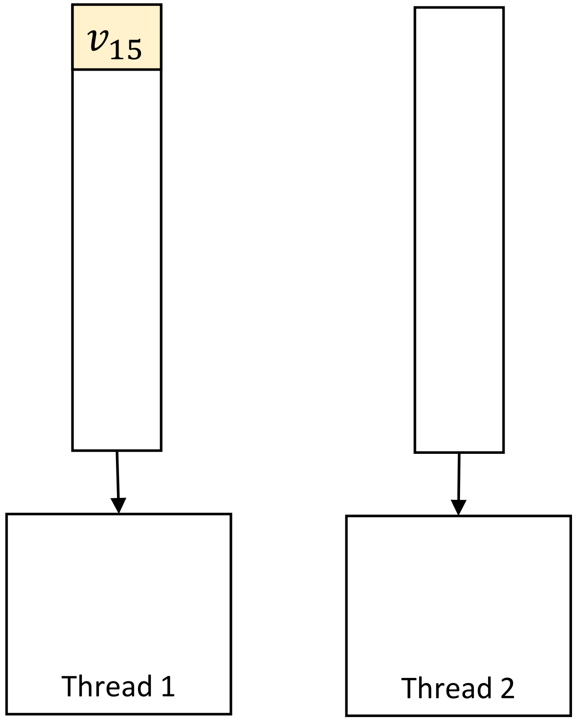


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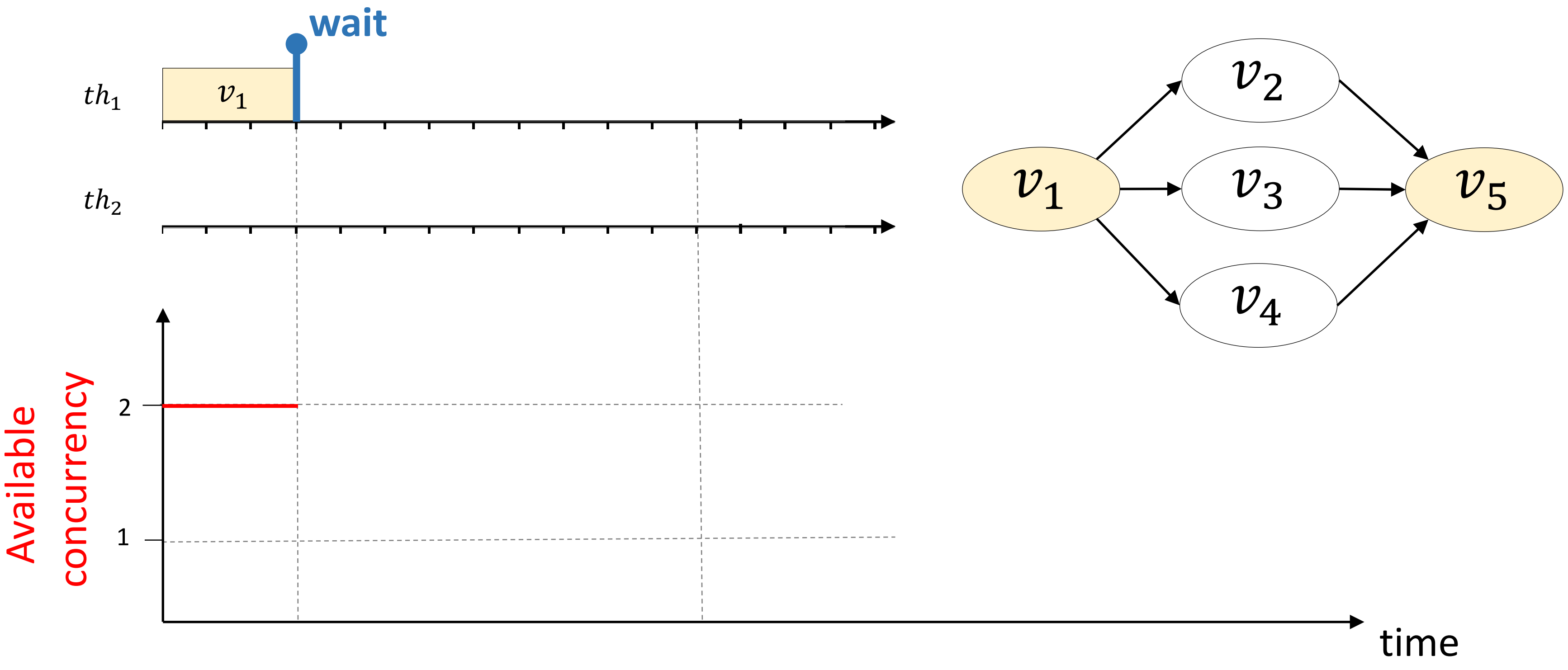

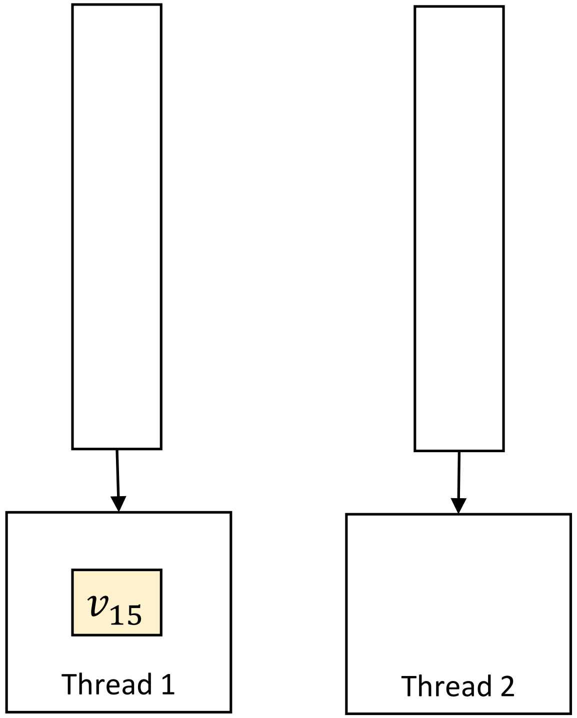


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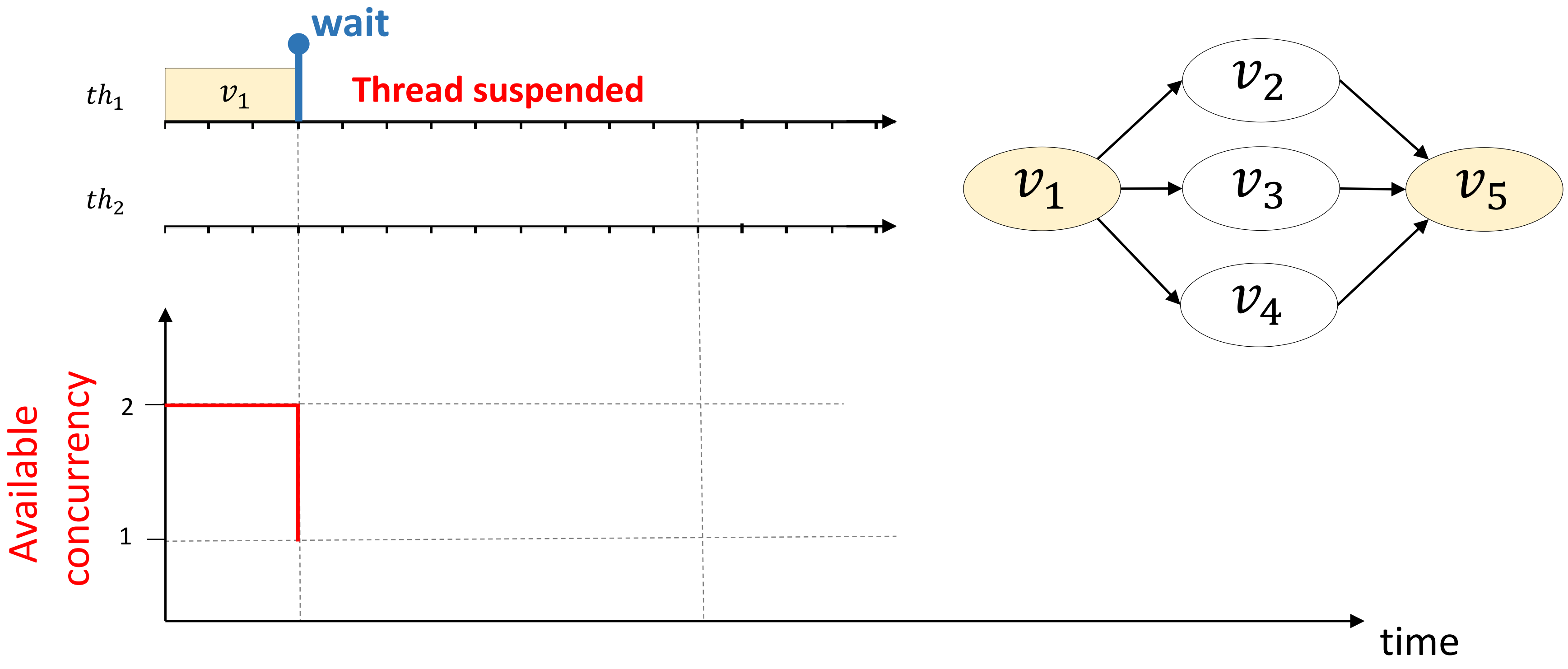

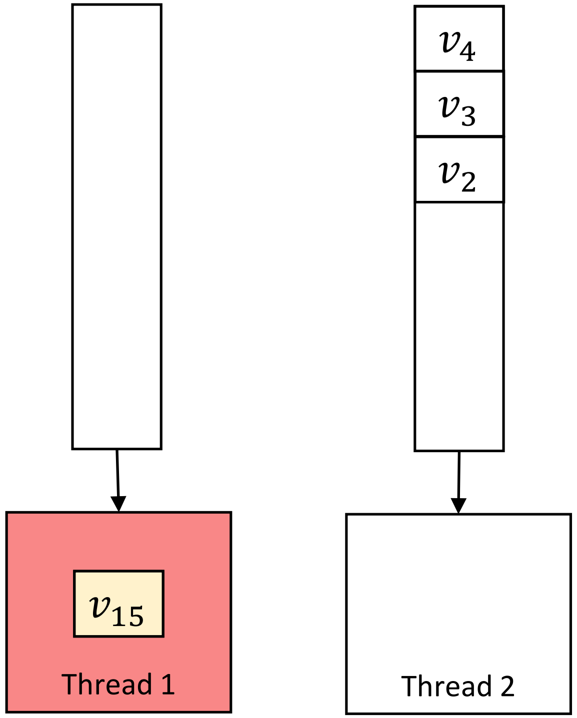


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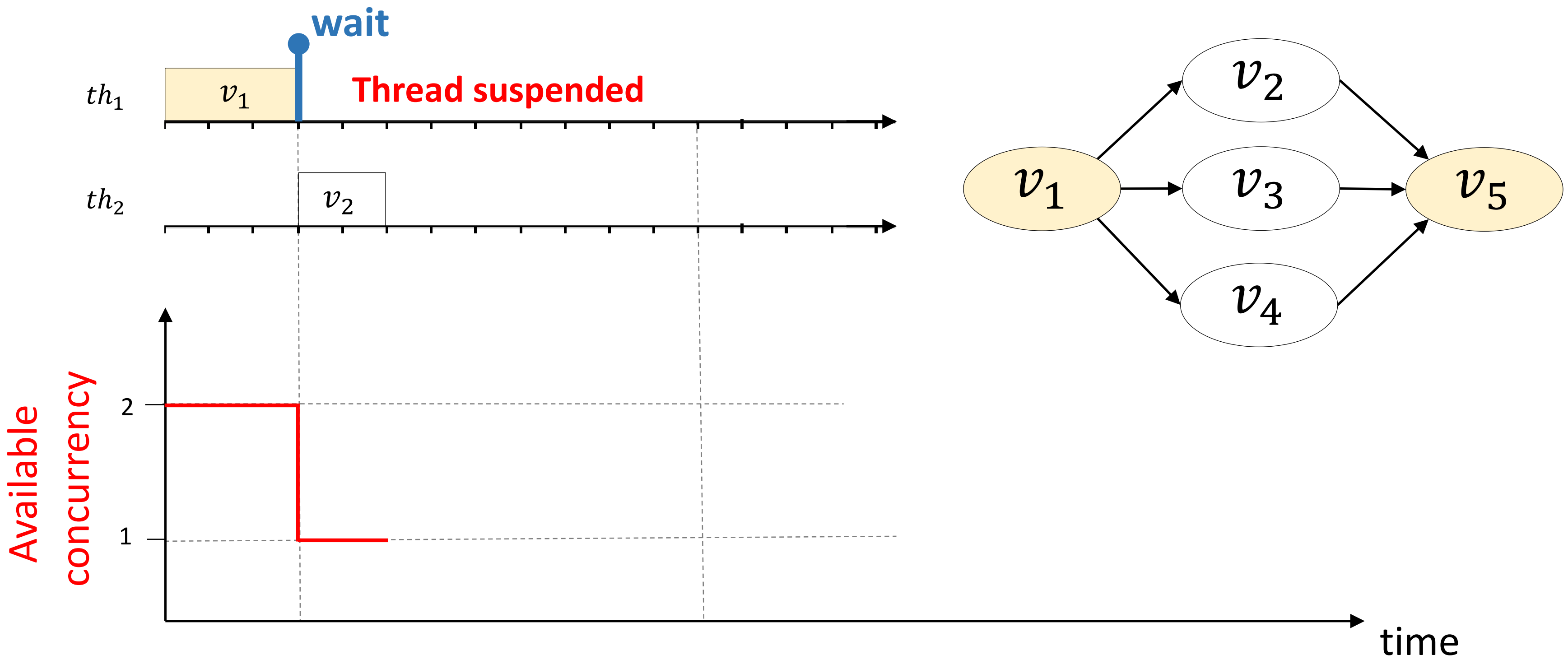

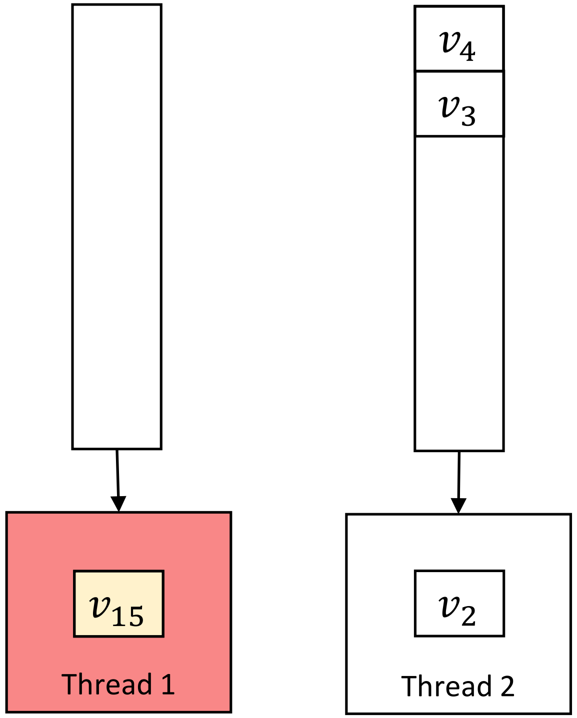


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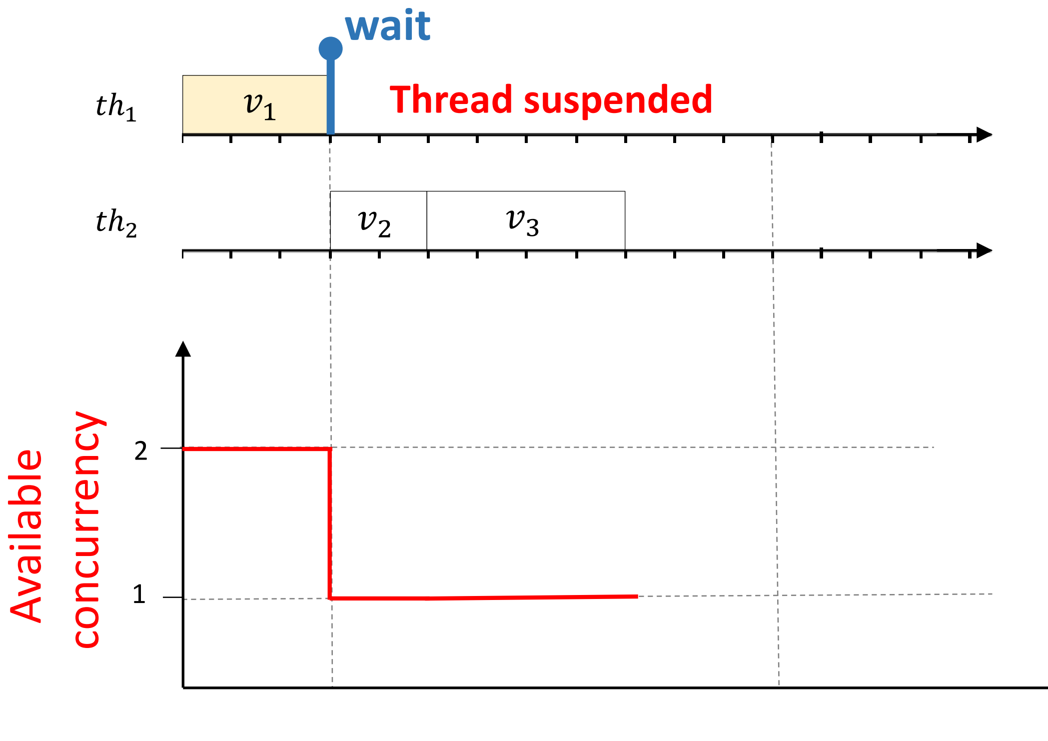

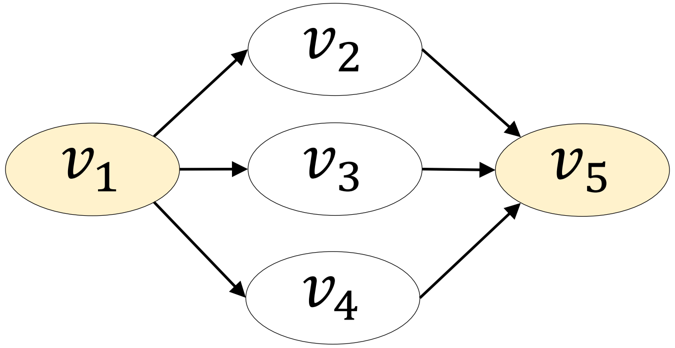

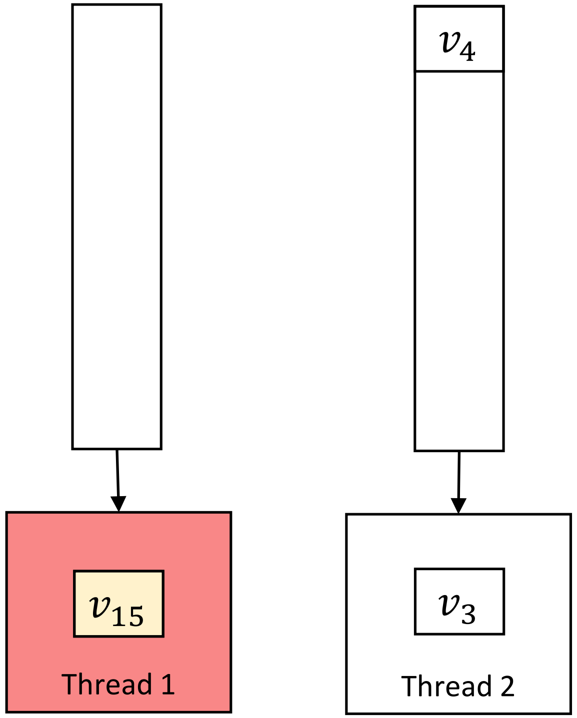


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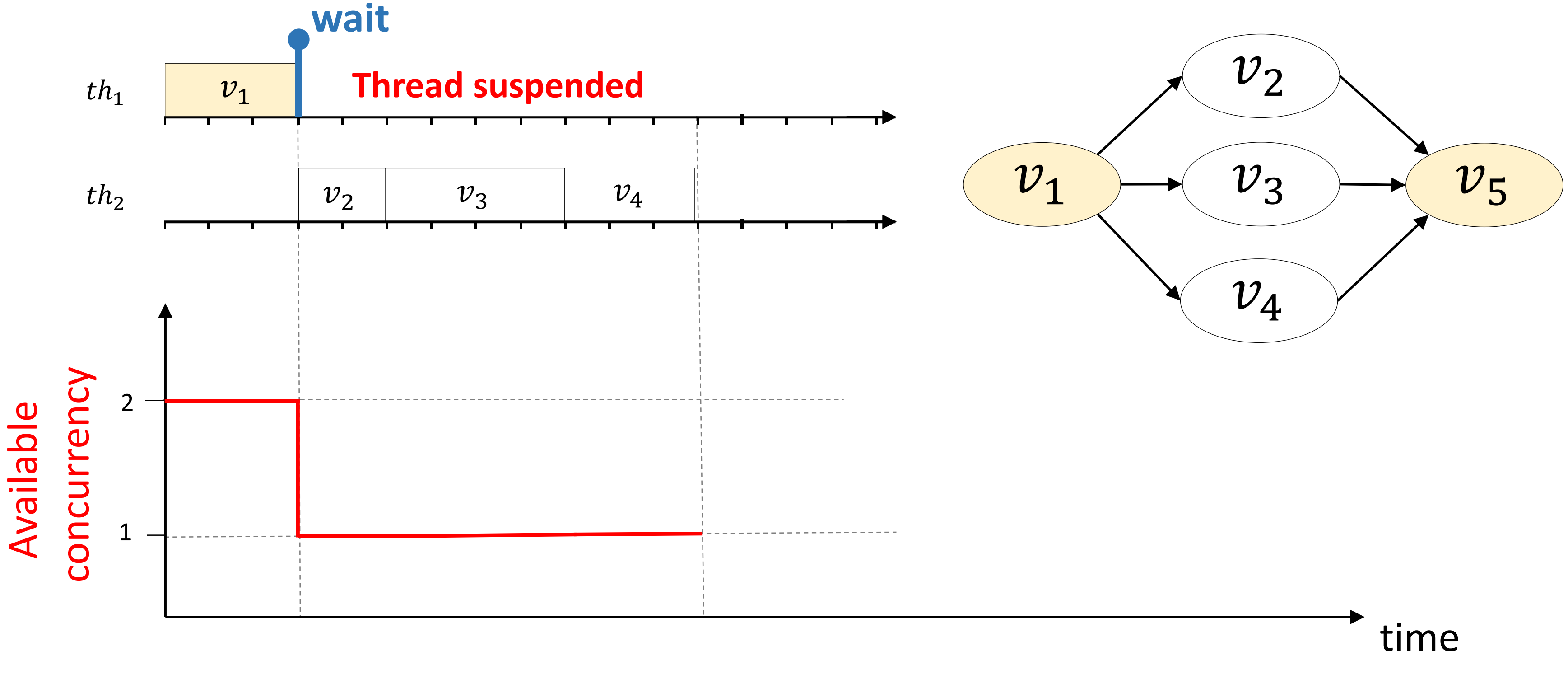

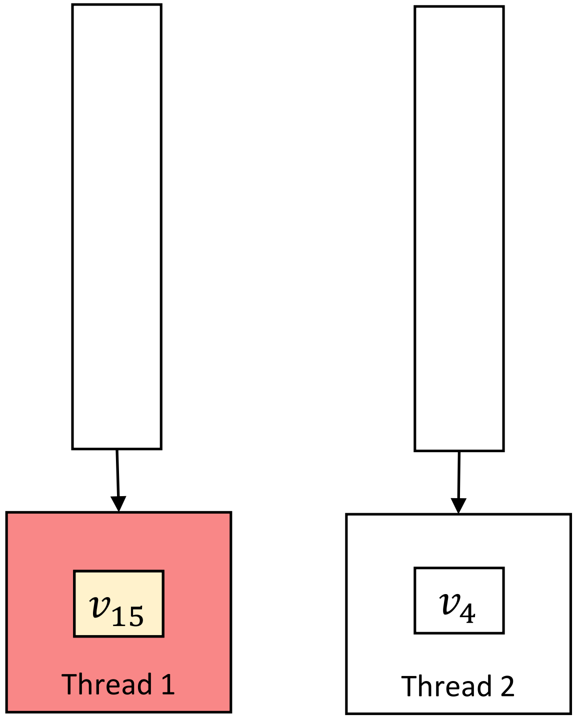


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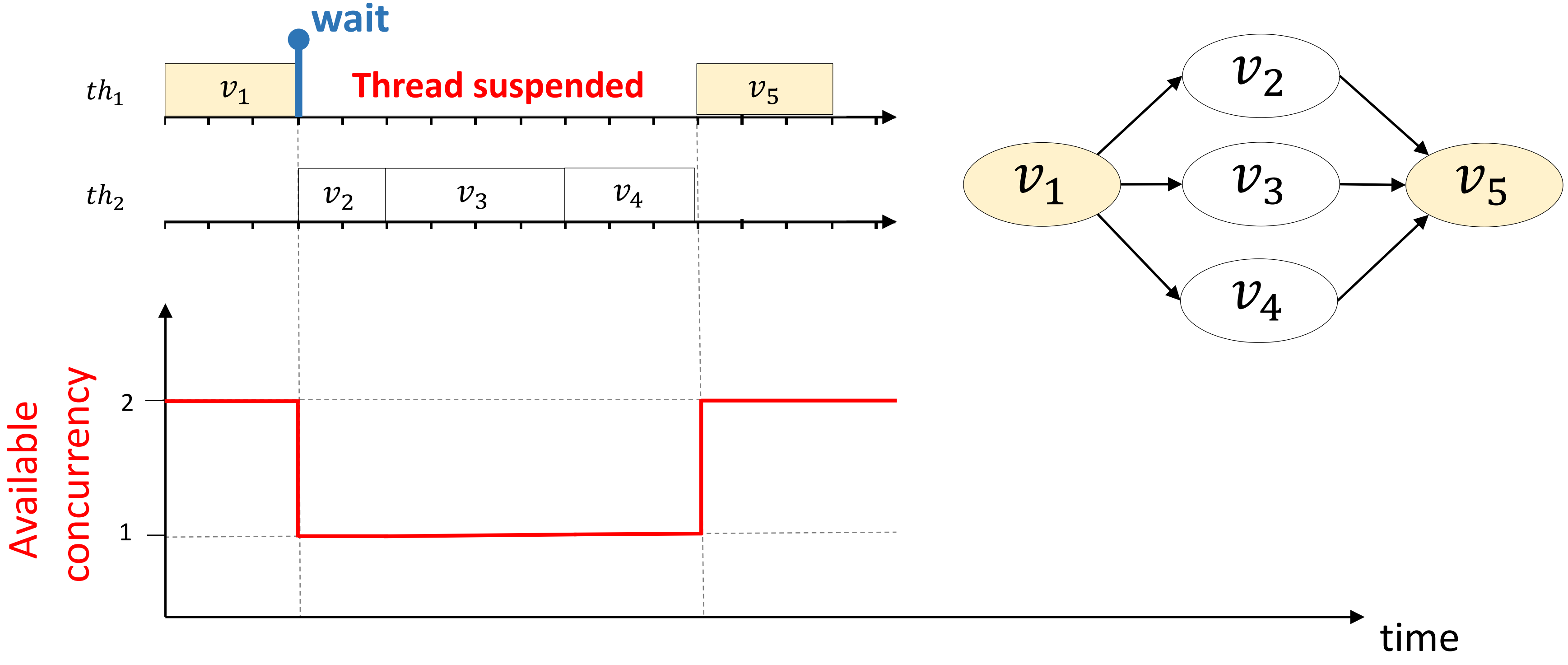

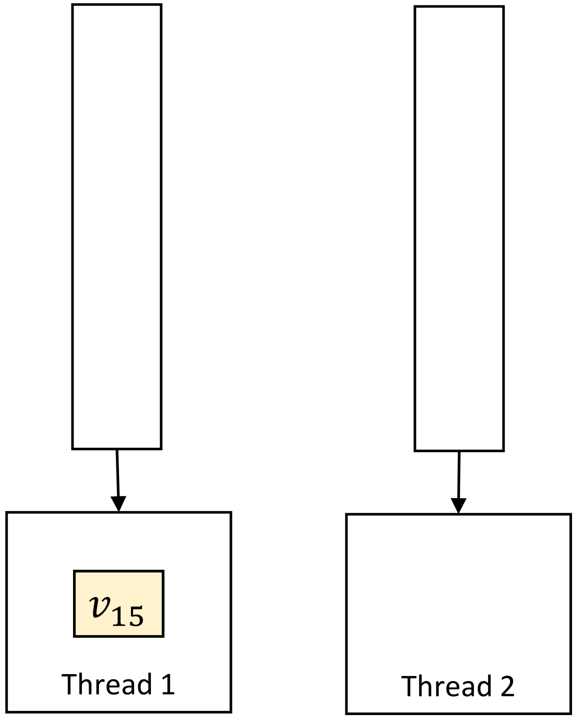


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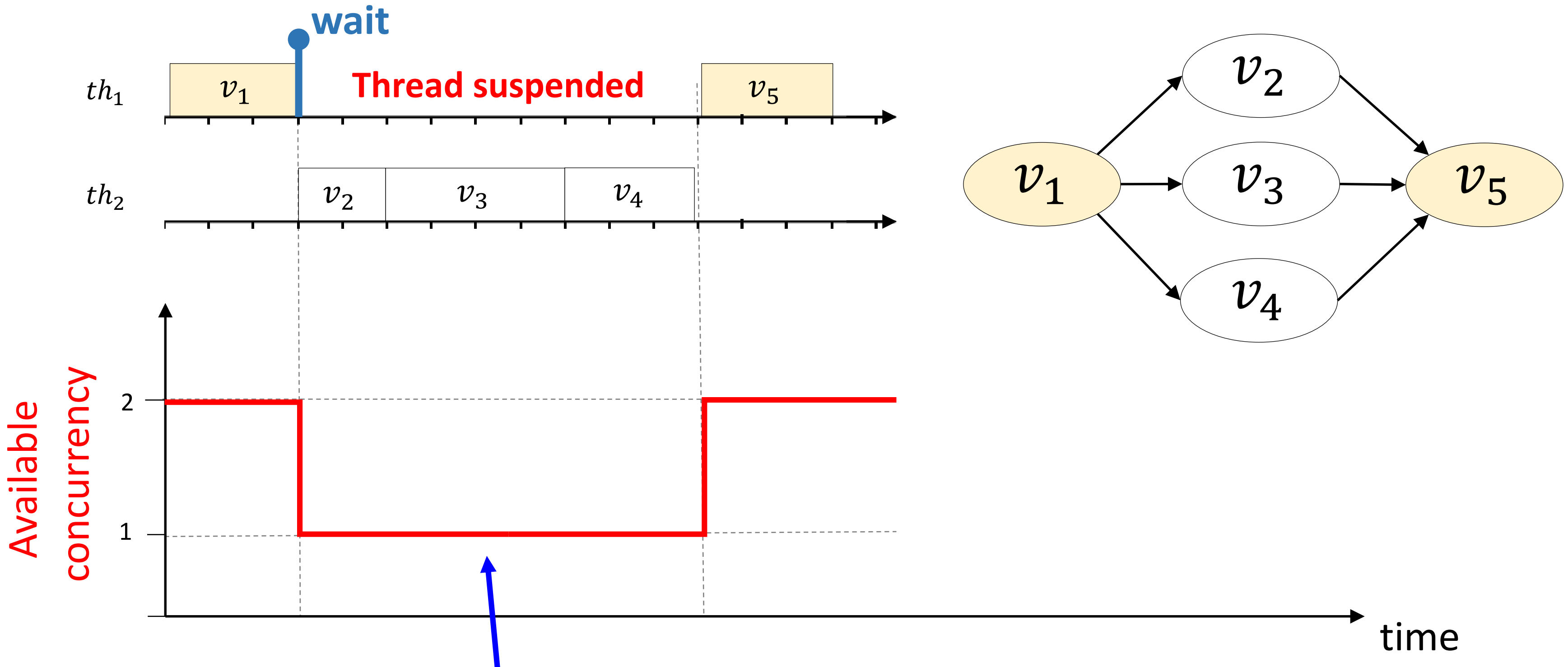

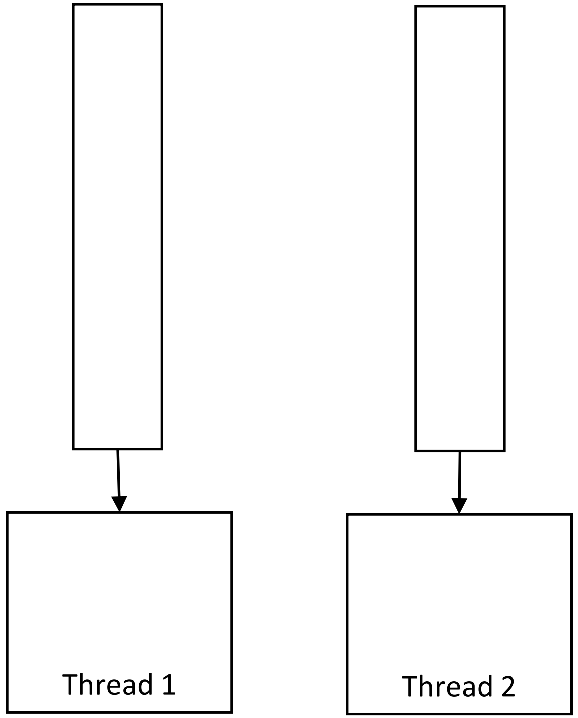

Reduction of the **concurrency** available to execute functions!

Current analysis techniques not considering this effect would produce **unsafe results**

How Tensorflow works on CPUs?

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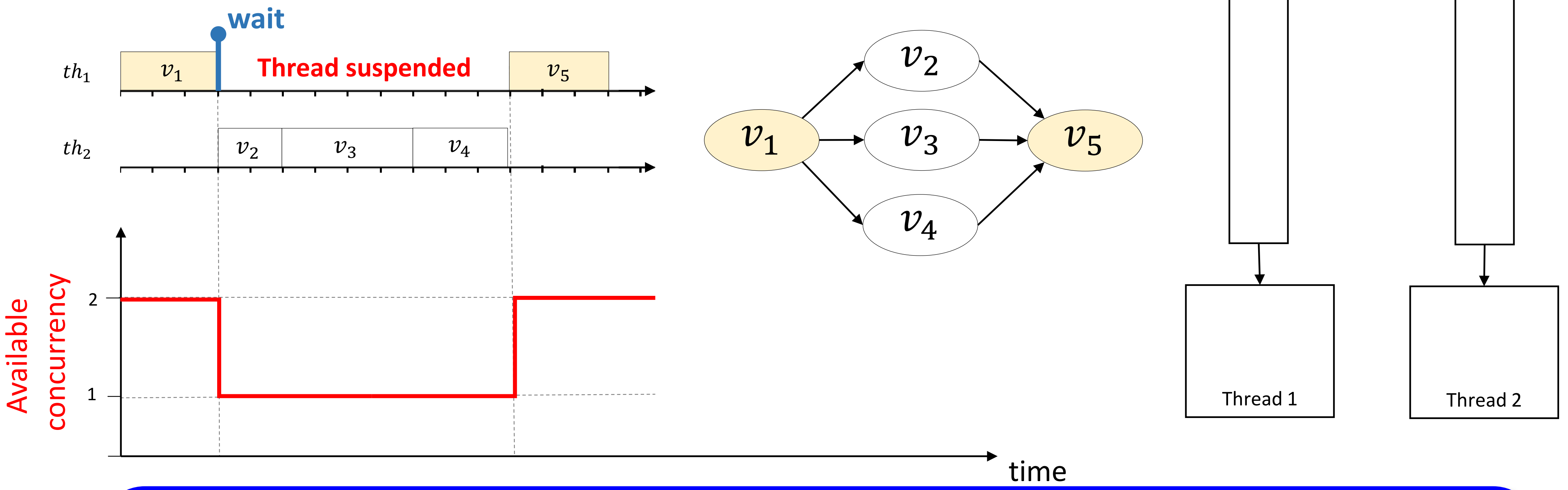
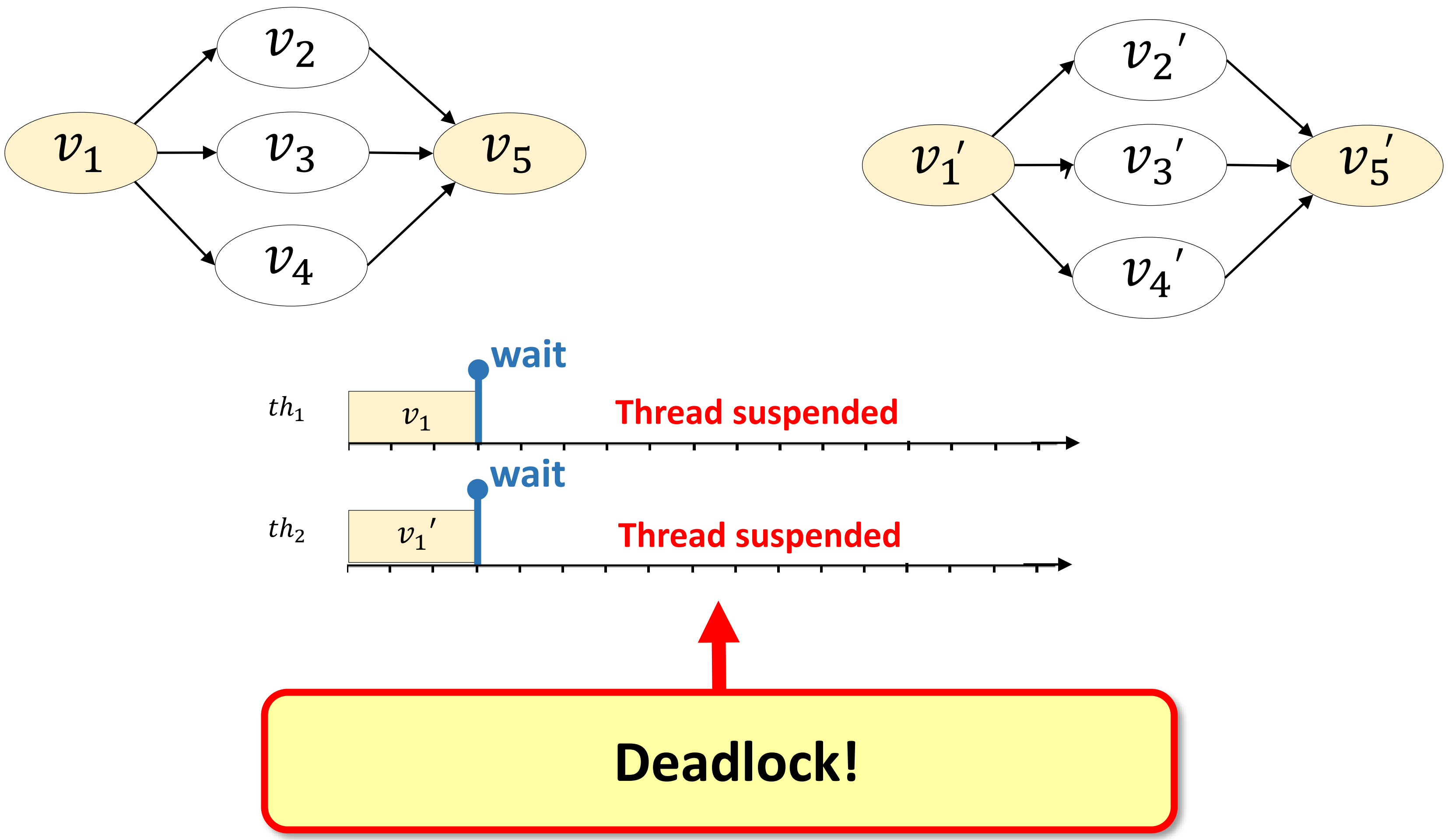


Target of this paper:

how to analyze **parallel real-time tasks** implemented with **thread pools** and blocking on **condition variables**?

Deadlocks can also occur

Assume two instances are released concurrently*



*Deadlocks are prevented in Tensorflow by serializing the execution of nodes blocking on condition variables

Discussion

We have shown that thread pools and blocking synchronization may reduce performance

Can we then conclude that this implementation paradigm should be avoided in real-time systems?

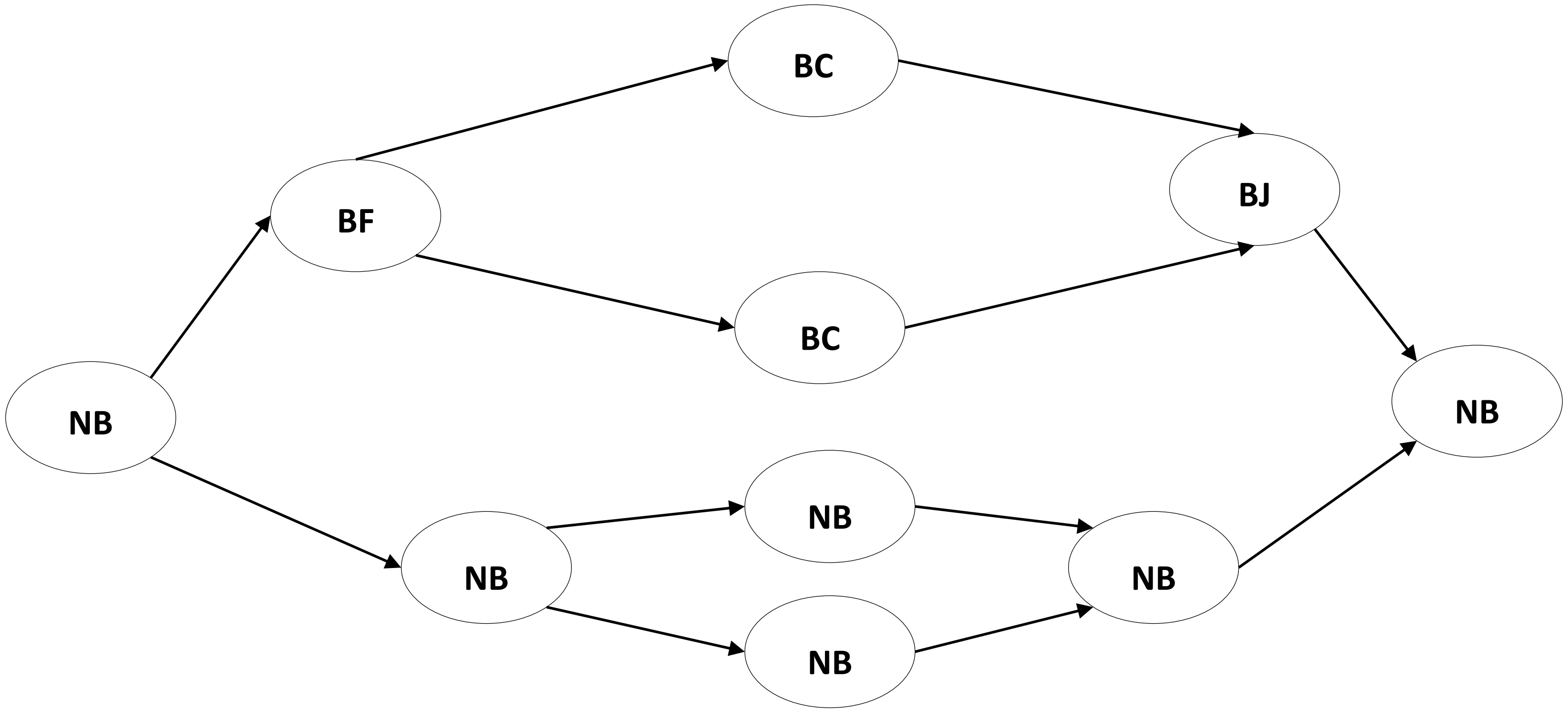
NO:

- Unfortunately, these paradigms are commonly used in **real implementations**
- Not only Deep Neural Networks and Tensorflow, thread pools are commonly adopted also for cloud computing and web-services

State-of-the-art analysis techniques do not consider this implementation paradigm and hence could lead to unsafe results!

Model

Nodes are assigned to types



Limited-concurrency model

Model

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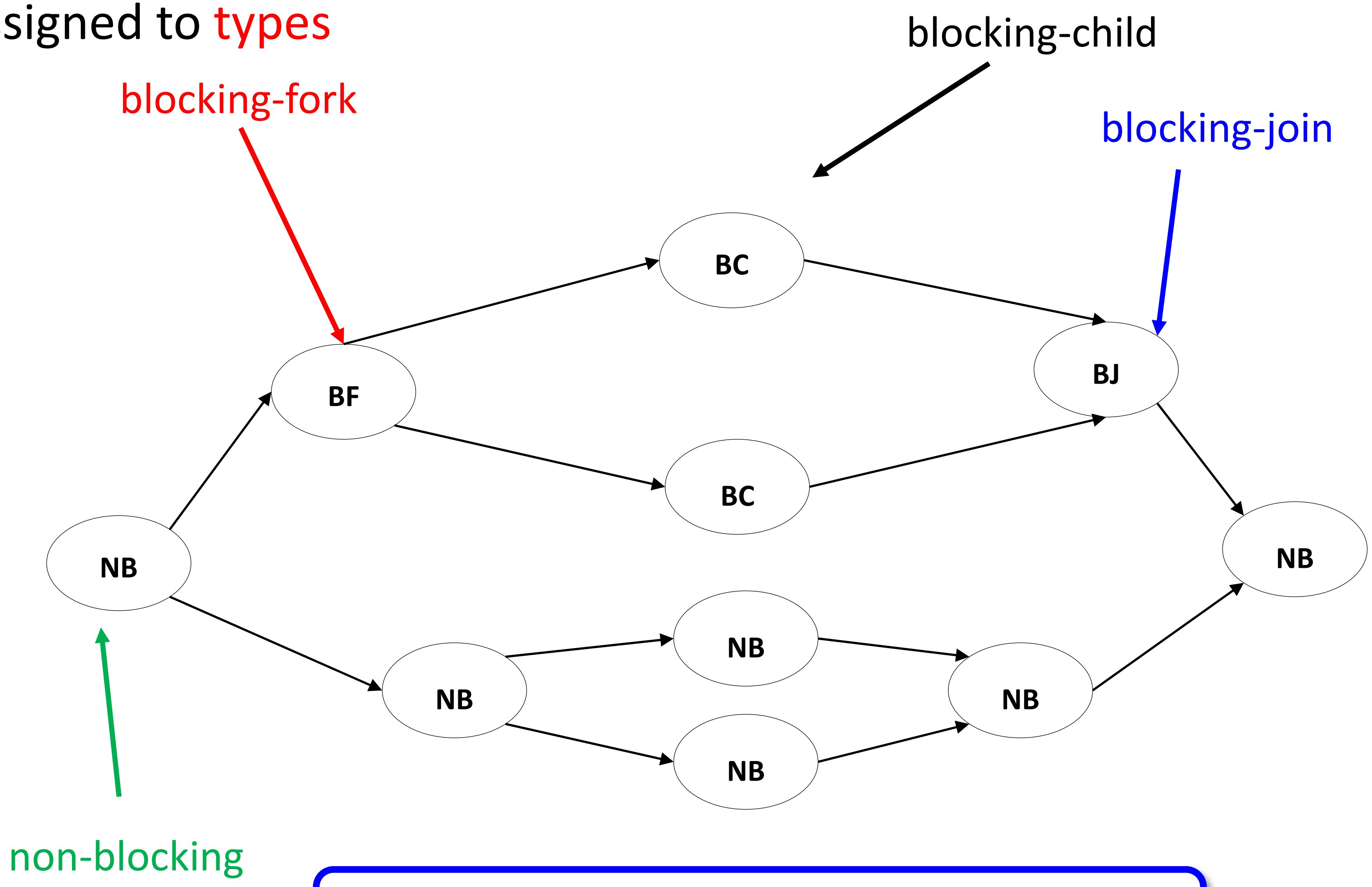

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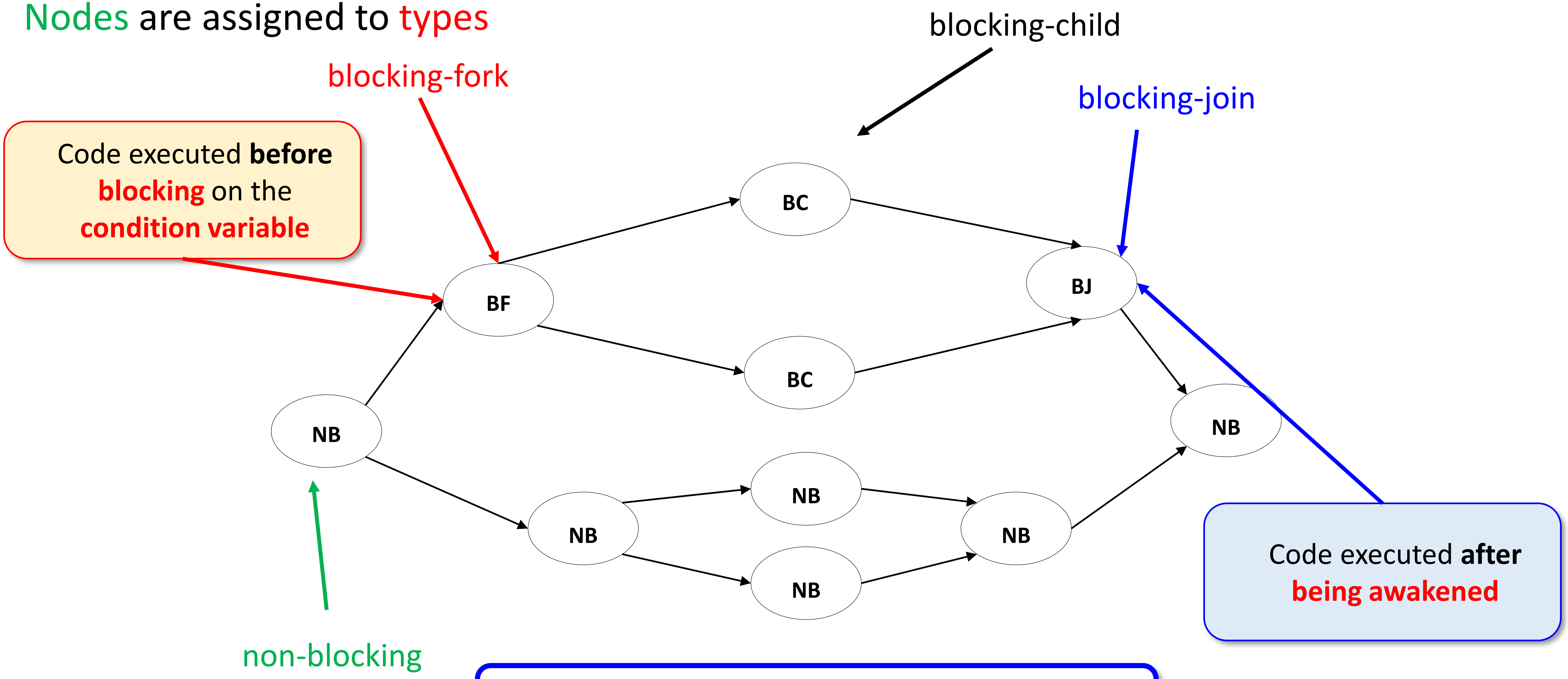

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Recall

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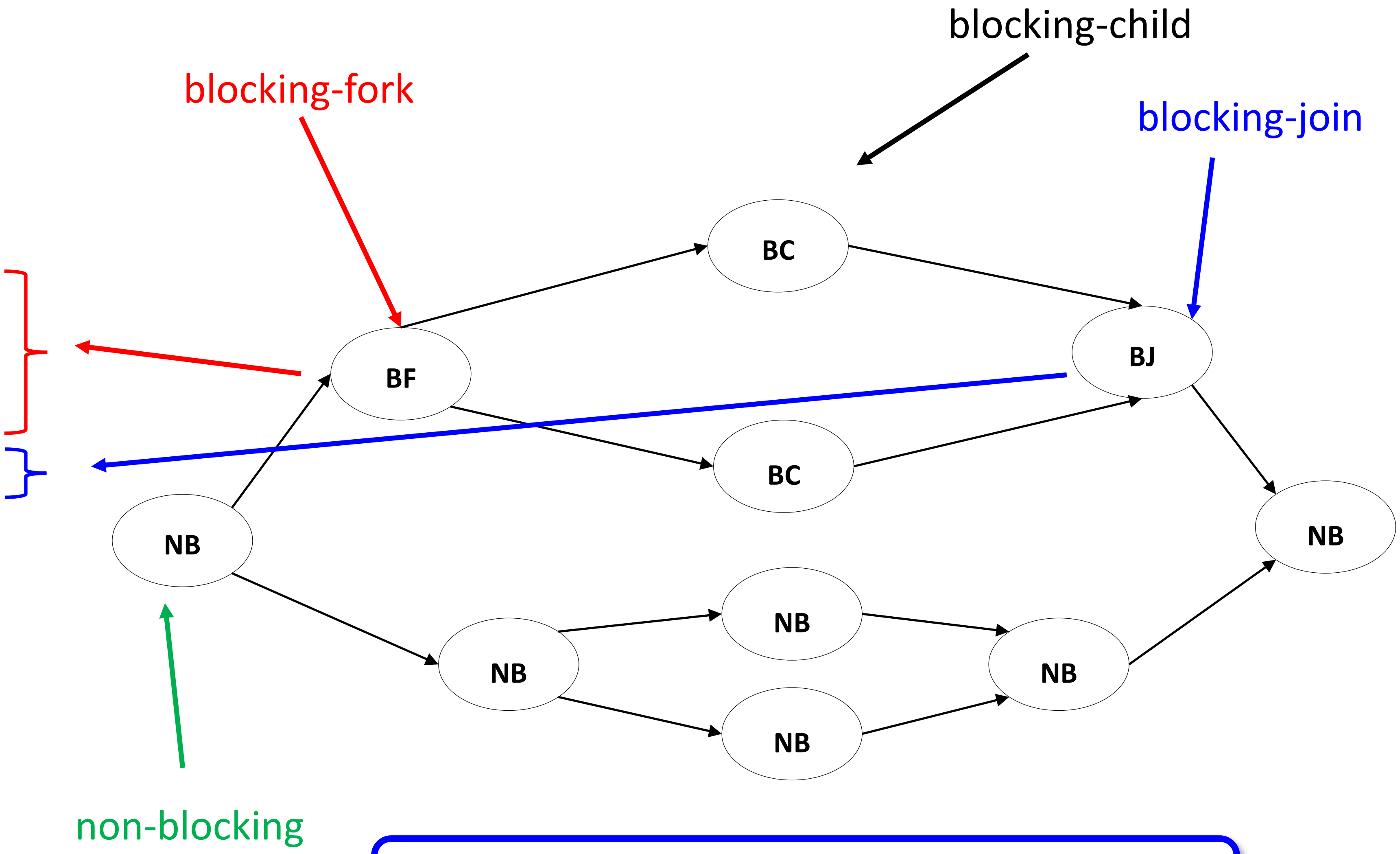
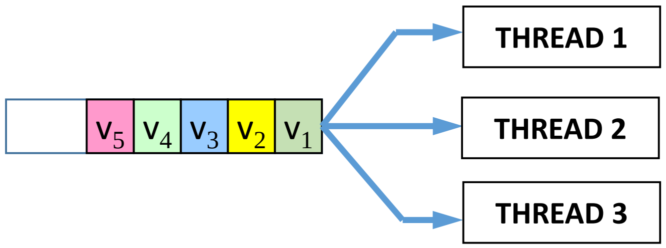


Limited-concurrency model

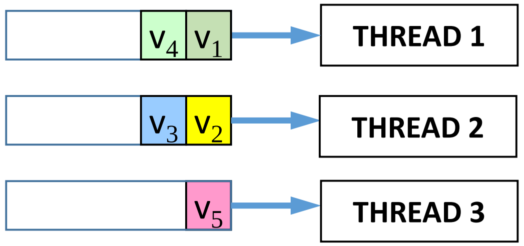
Schedulability Analysis: intuition

Global Scheduling



An approximate response-time bound is computed by leveraging the concept of available concurrency

Partitioned Scheduling

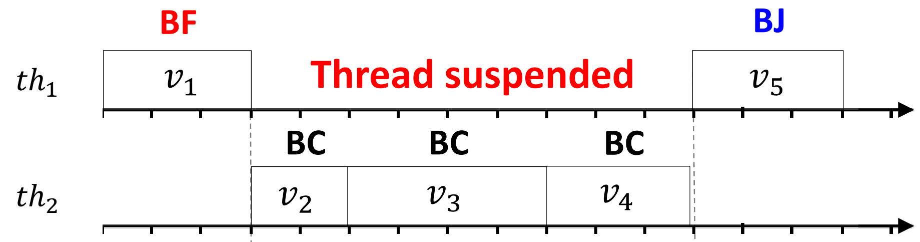


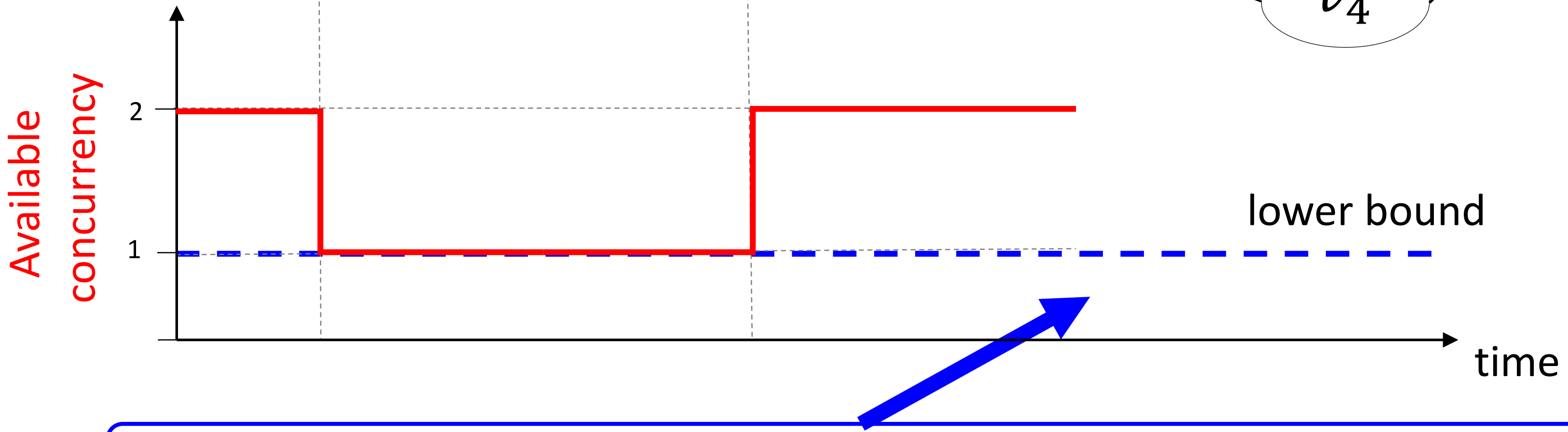
Partitioning algorithm allowing to safely re-use state-of-the-art analysis techniques by isolating concurrent BF nodes

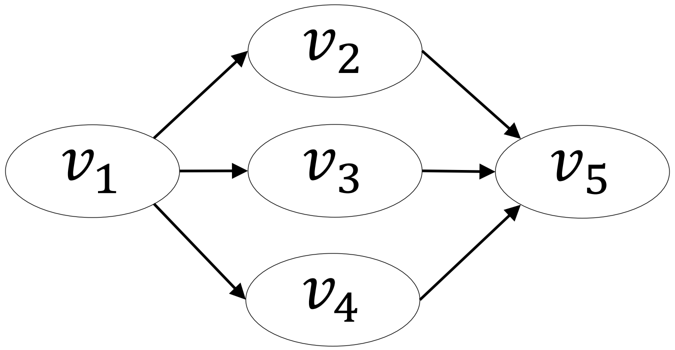
For additional details, please look at the paper

Avoiding deadlocks: intuition

Reason in terms of available concurrency





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Condition: Available concurrency > 0

Necessary condition for both **global** and **partitioned** scheduling

Sufficient for **global** scheduling

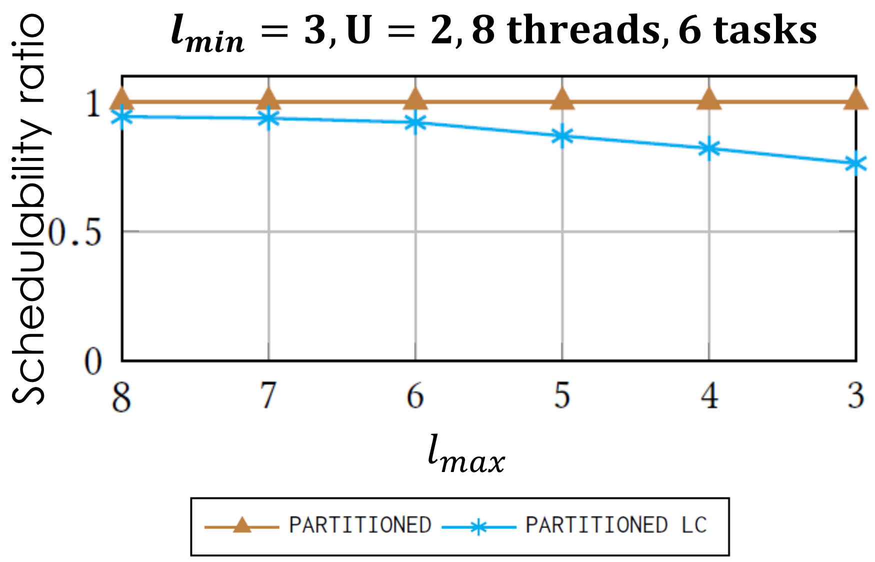
More details in the paper

Experimental Results

Goal: how much is the optimism incurred by analyzing parallel tasks with limited concurrency with state-of-the-art techniques?

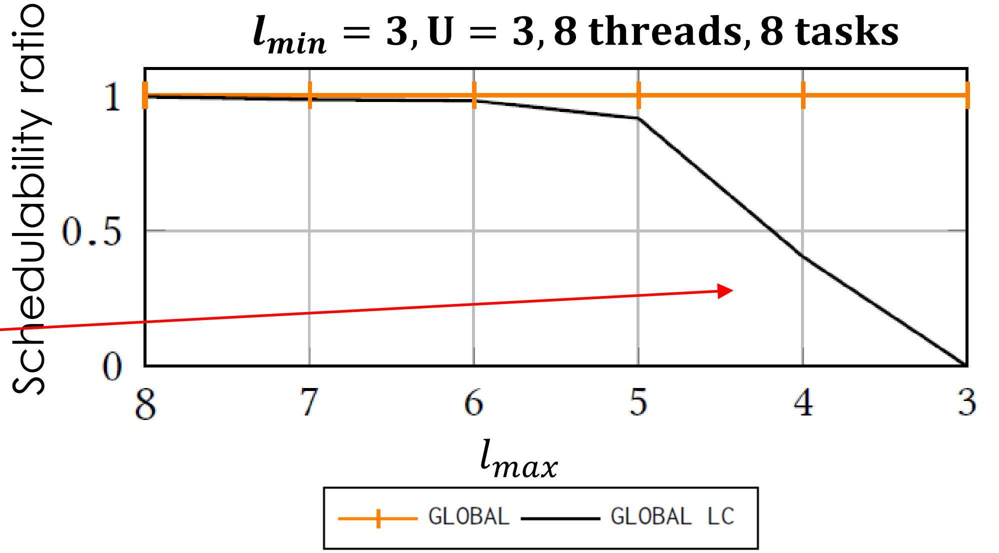
- Based on synthetic task sets
- Each task has a lower bound to the available concurrency in $[l_{min}, l_{max}]$

Partitioned Scheduling



Graceful degradation in the case of partitioned scheduling

Global Scheduling



Pessimism due to the usage of lower-bound to the available concurrency

Conclusions

Task model for analyzing parallel tasks implemented with thread pools

Conditions for guaranteeing the absence of deadlocks

Schedulability analysis

Experimental results

to assess the optimism incurred by state-of-the-art analyses when parallel tasks are implemented with thread pools

Future work:

- New analysis approaches for parallel tasks with thread pools
- Design of partitioning algorithms aimed at optimizing schedulability

Thank you!

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