

## 1 Motivation

Cloud providers like AWS, or containerization systems like Kubernetes, support reserving CPU for *latency critical* (LC) services. Developers choose reservations based on expected peak load [9, 14, 15], but load is variable, leading to a utilization problem.

*Best effort* (BE) workloads do not have reservations, so providers run them opportunistically on the same resources as LCs reserved; the resource that this work focuses on is CPU. The challenge is to honor resource reservations for LCs while opportunistically running BEs.

Current popular scheduling systems fail to honor reservations. Figure 1 shows the latency of an endpoint in a web application on Kubernetes that gets a users feed, and the throughput of a BE image resize job on the same cores. The mean response latency of the server jumps from ~7ms to ~15ms after starting the BE.

## 2 Background & Problem

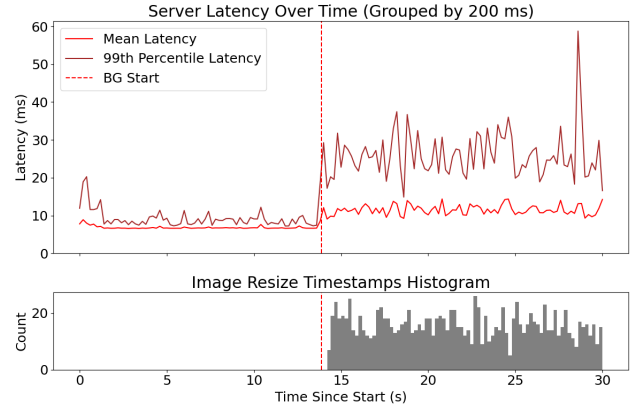
All Open Container Initiative compliant containers, including Kubernetes, enforce CPU reservations using cgroups' weight interface [3, 11, 12], as do VM frameworks, including Firecracker and libvirt [1, 4, 5].

A simplified experiment shows cgroups weights are unable to enforce reservations. We run a simple CPU-bound server sharing four cores with an image resize job, each in their own group. cgroups supports weights in the range of [1,10000]. Figure 2 shows that running the server with different weights has no effect on the latency impact of the BE.

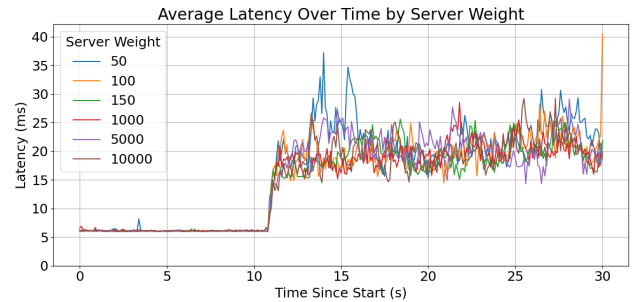
This latency impact happens because the BE occasionally runs uncontended on one core, while another has queued server threads. Figure 3 shows this happening in the trace: on core 6, the red BE thread runs for 10ms, while server threads, in shades of blue, are queued on the other cores.

This happens because weights are only enforced within per-CPU runqueues. Load balancing eventually remedies imbalances, but runs less frequently than scheduling does. For workloads with request processing times in the millisecond range, waiting for the load balancer influences final processing times.

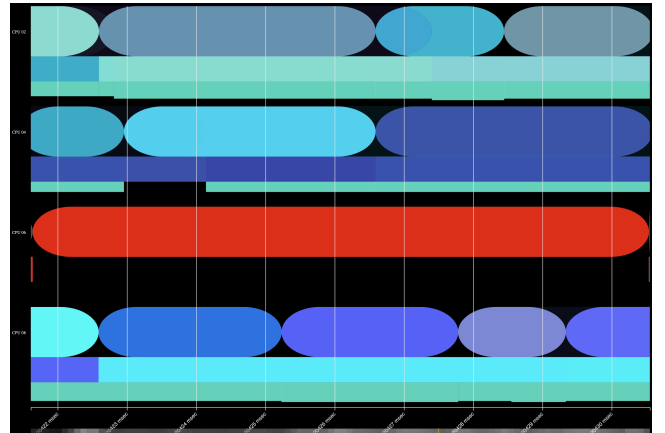
In order to globally enforce weights, each scheduling decision would require a search of all runqueues for potentially higher-weight processes, which is too costly.



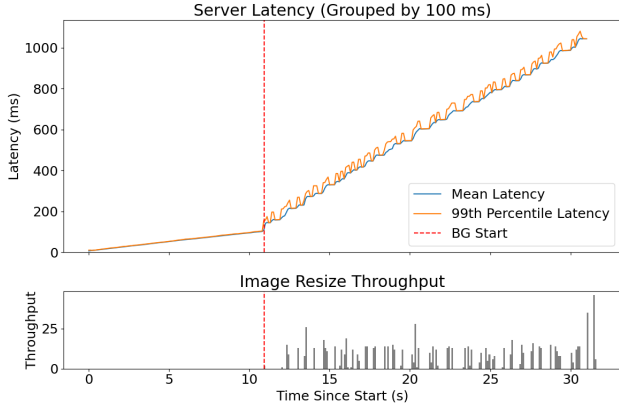
**Figure 1:** In Kubernetes, running a BE has latency impacts on an LC with reservations



**Figure 2:** the weight of the server has little impact on how much the weight 1 BE task interferes



**Figure 3:** Core 6 runs an image resize process, unaware that the other cores have queued server threads



**Figure 4:** when running the server in real time, throttling degrades performance at high load

### 3 Related work

Some work focuses on isolating real-time applications in Linux [2, 13]. Wasted Cores [10] addresses the idle behavior of Linux.

Linux’s `sched_idle` policy addresses the observed weight inversion, but is still inadequate: running the microbenchmark using `sched_idle` leads to an increase in the mean latency from 6ms to 8ms.

Other systems work around the kernel scheduler, by running primarily in userspace [6–8].

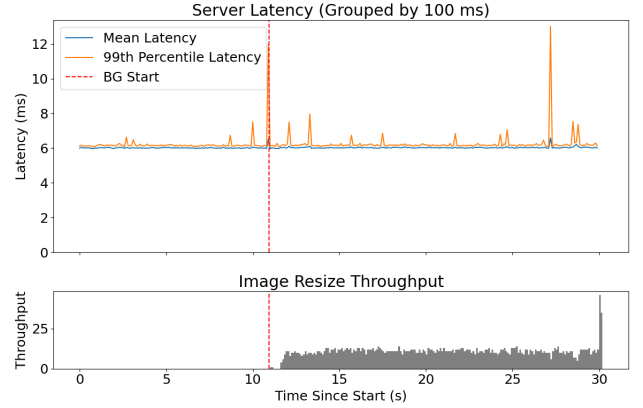
### 4 Approach & Uniqueness

In order to enforce reservations while running BE jobs opportunistically, our approach replaces weights with priority scheduling.

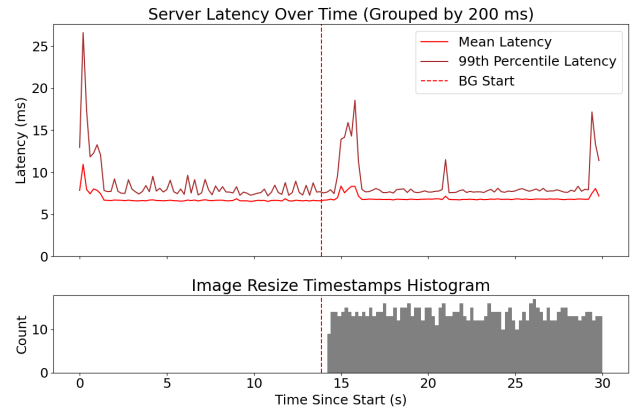
Enforcing priorities requires fewer global runqueue searches than weights, because searches only need to happen on *class boundary crossings*: on *exit*, when switching to running a low-class process, and on *entry*, when enqueueing a high-class process. These checks ensure that a core running a BE thread  $t$  knows that there are no queued LC threads anywhere: the *exit* check ensures there’s none when starting to run  $t$ , and the *entry* check ensures if one wakes up while running  $t$  it will interrupt  $t$ .

Linux enforces priority across scheduling classes, but higher class schedulers are designed for real-time applications. Additionally, if these experience high load, Linux throttles them in order to not starve the default class. We see this happening in Figure 4, where throttling leads to spikes in the BE’s throughput, and corresponding spikes in the server’s latency.

We design a new scheduling class BeClass that sits at a lower priority than the default one, and enforces LCs’ uncontended access to CPUs they reserved. To enforce reservations under high load, without throttling LCs or killing BEs,



**Figure 5:** BeClass isolates the server’s latencies from BE jobs



**Figure 6:** Kubernetes using BeClass honors rservations

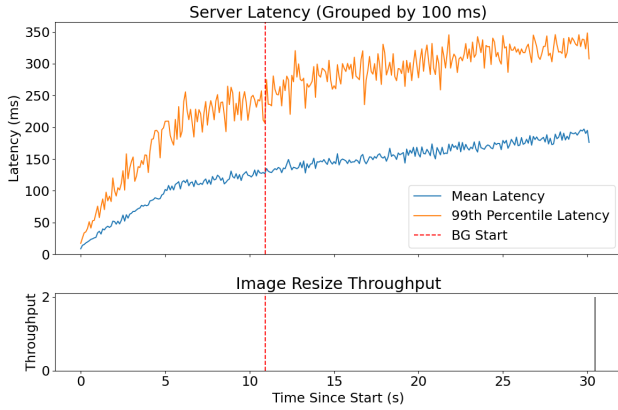
BeClass uses *parking*, wherein user-space code never runs, only kernel-level services.

### 5 Results

We run the microbenchmark experiment using BeClass; the results are in Figure 5. As desired, the latency of the server remains stable after the BE task starts, and the BE runs only in gaps where the core would otherwise be idle.

We also run the Kubernetes application using BeClass. Figure 6 shows that the baseline mean latency of the LC server stays around 7.4ms after starting the the BE image resizing.

Figure 7 shows parking enables the server to keep its reservation even under sustained 100% load. We run the same client load as Figure 4, with BeClass parking the BE. Notice that the BE does not make progress until the very end, when the server is done processing.



**Figure 7:** BeClass starves BE user-space threads, leaving all CPU-time to the LC

## 6 Contributions

We identify a serious limitation of cgroups weights: they are unable to honor the reservations of LC applications in the presence BE workloads. We show that this is because Linux uses per-core runqueues.

We propose an API that separates BE from LC by introducing BeClass. BeClass requires fewer cross-core interactions than a weight-based approach, and ensures that no BE is ever running when an LC is queued.

We implement this strict priority in Linux, and show that it allows cgroups and Kubernetes to ensure LCs’ access to their reserved cores while running BE workloads opportunistically.

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