TCLOUD

gVulkan: Scalable GPU Pooling for Pixel-Grained Rendering in Ray Tracing

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Yufan Jiang, Xuyan Hu, Zhengwei Qi, Haibing Guan

Shanghai Jiao Tong University

Ray Tracing Delivers Realistic Visual Experiences

- **Rendering technologies**
  - Rasterization
  - Ray Tracing

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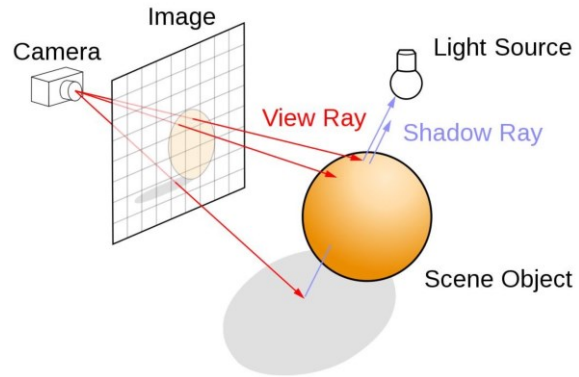

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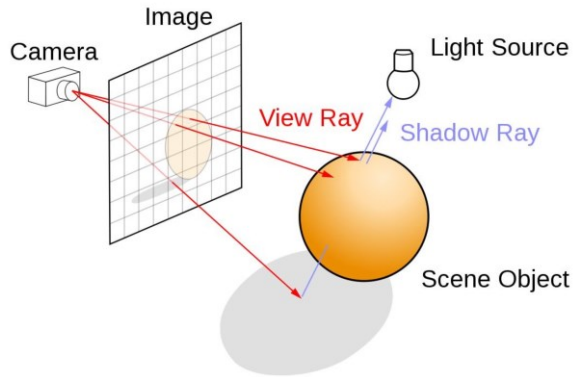

- The advent of hardware ray tracing acceleration
- Engine, game support for real-time ray tracing
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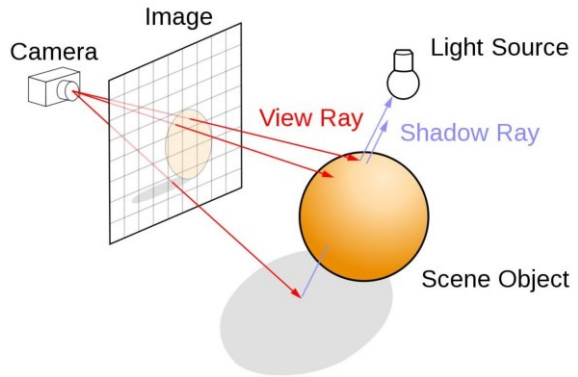

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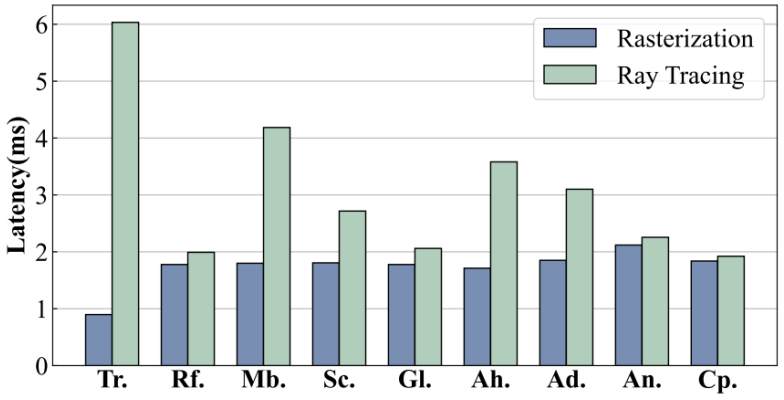
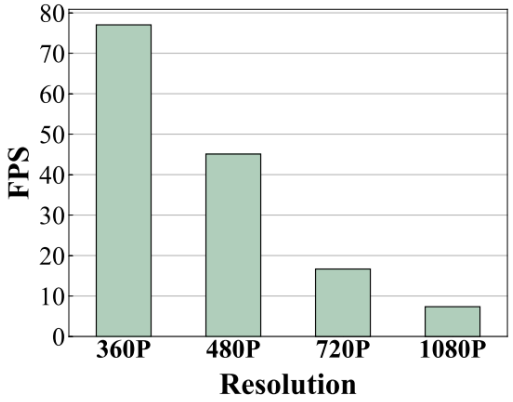
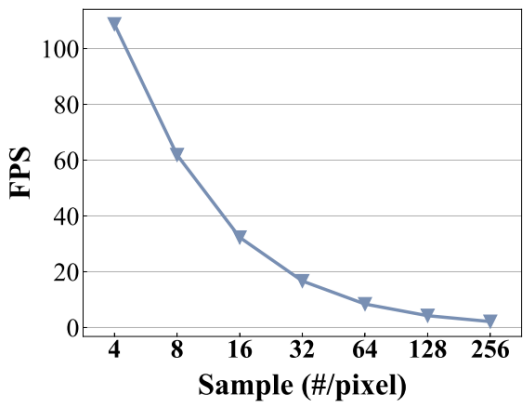
- **Limitation of users**
- **Higher ray tracing latency compared to rasterization**







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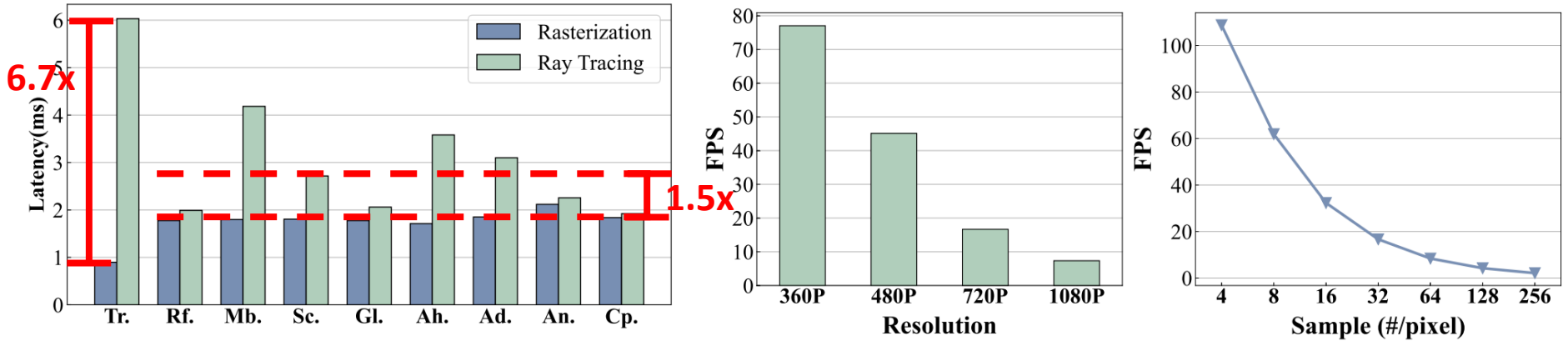

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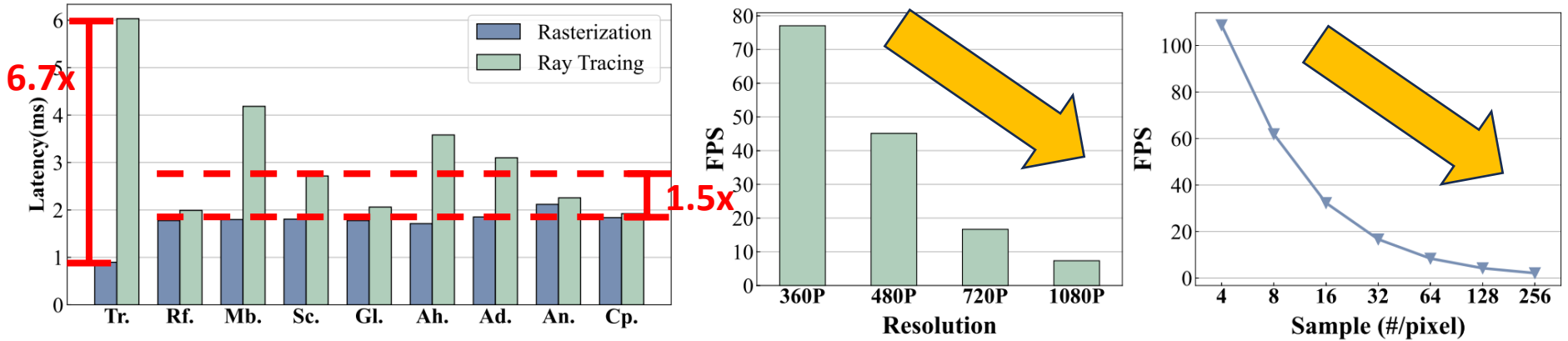

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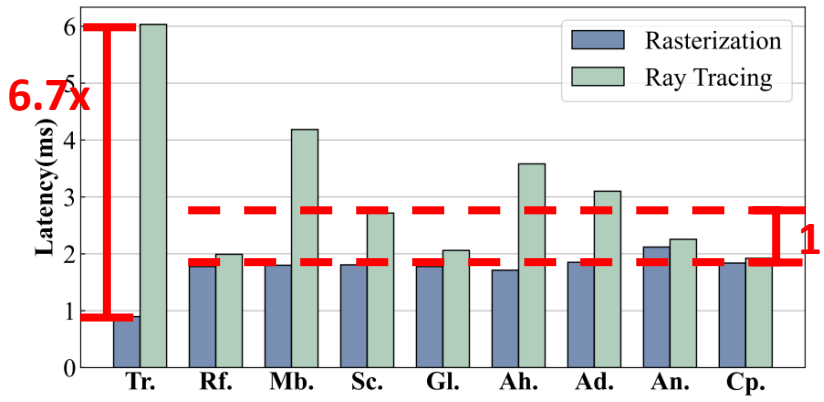

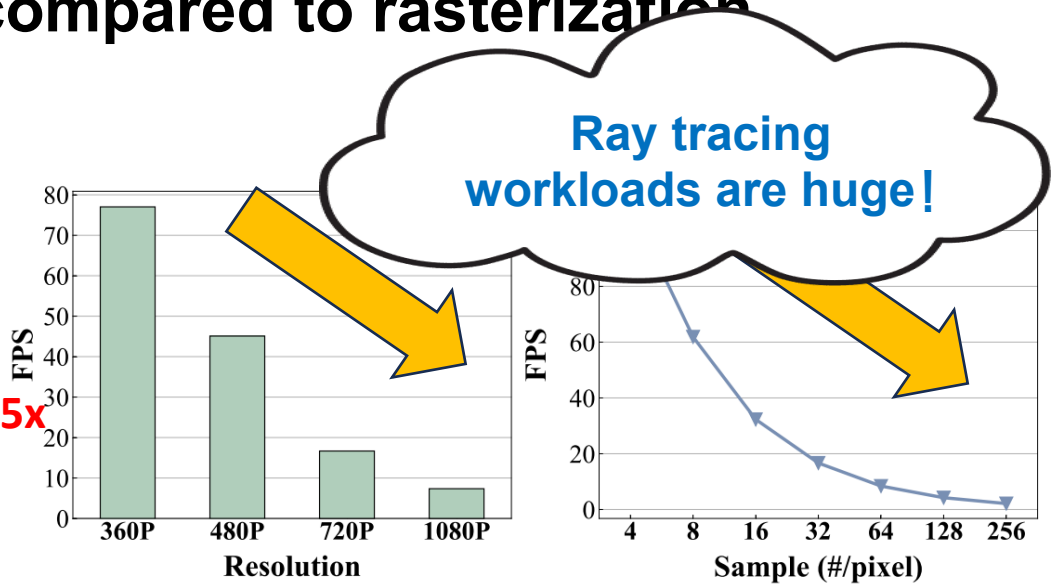

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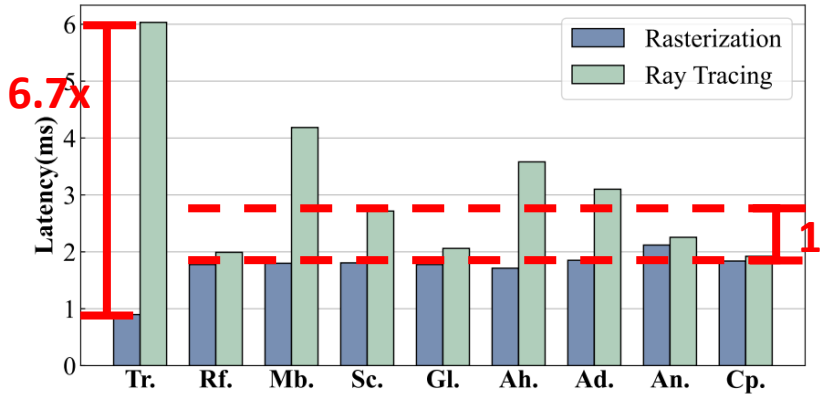

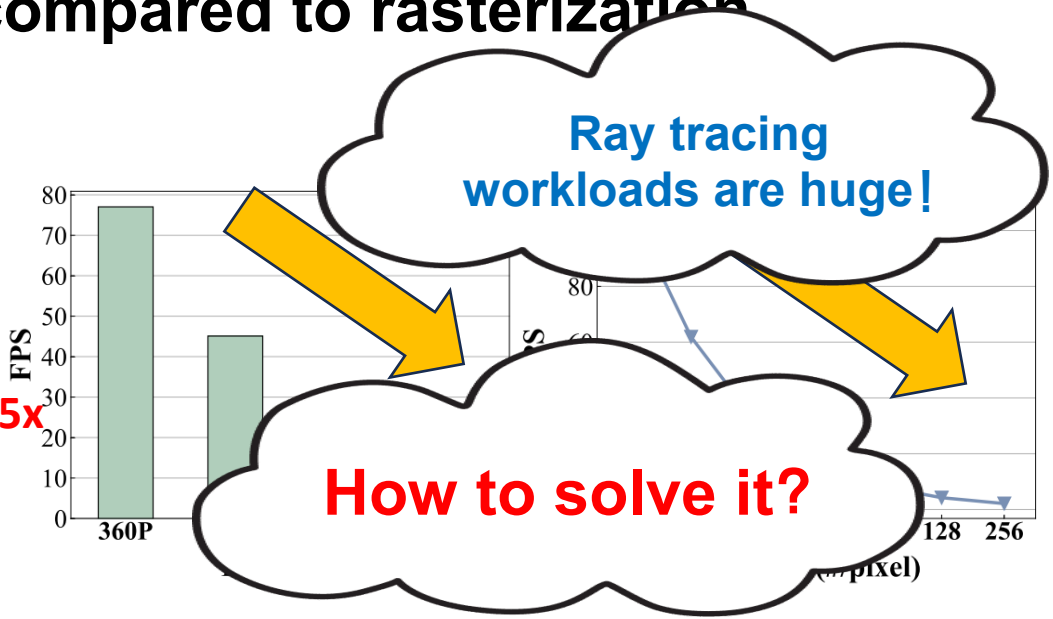

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Reduce latency for ray tracing

- **Reduce workloads**
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- **Multi-GPU solutions**
  - AFR (Alternate Frame Rendering)
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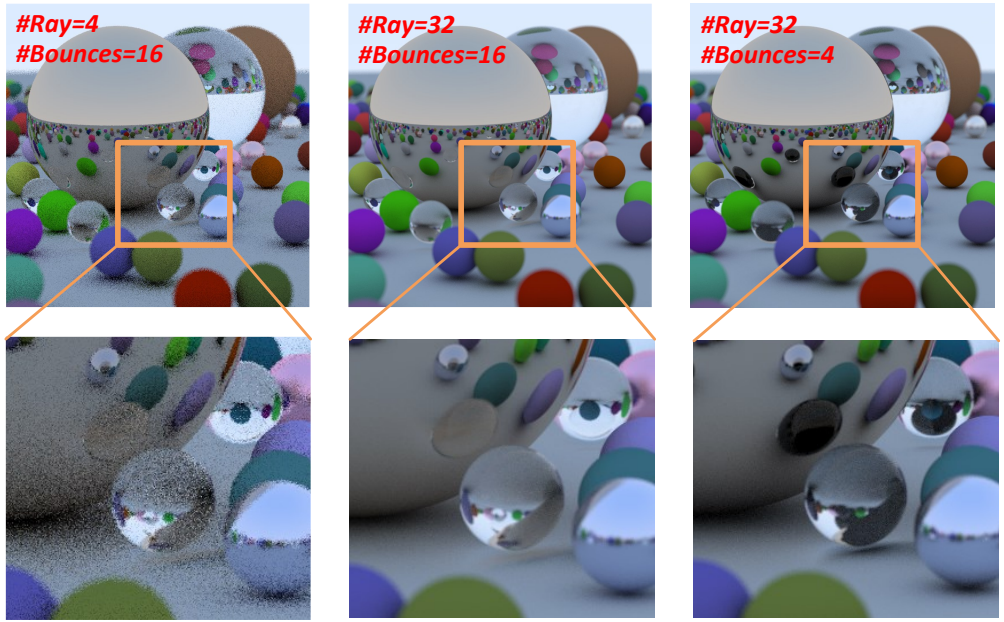

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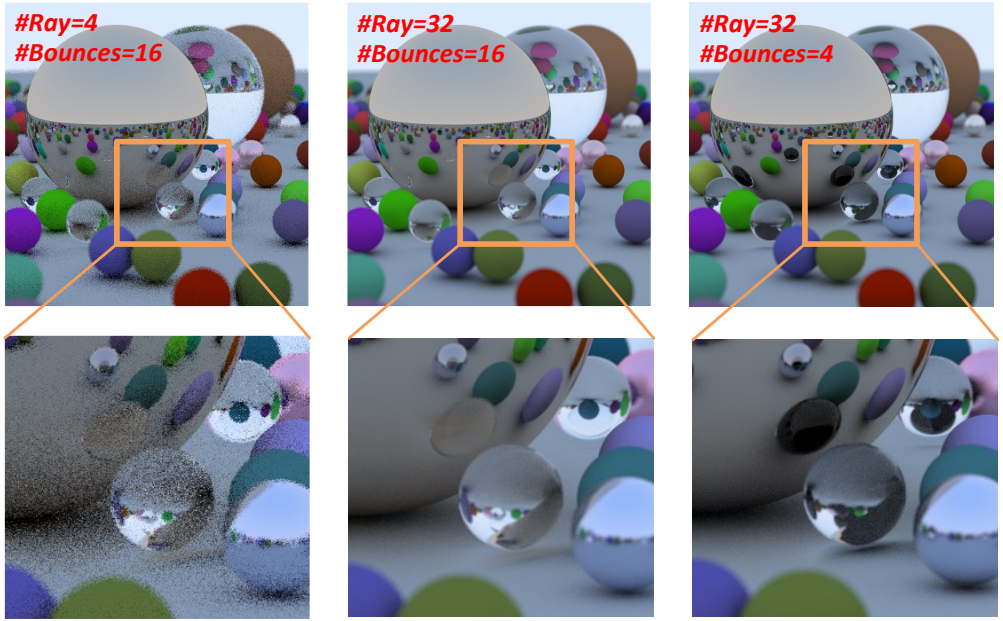

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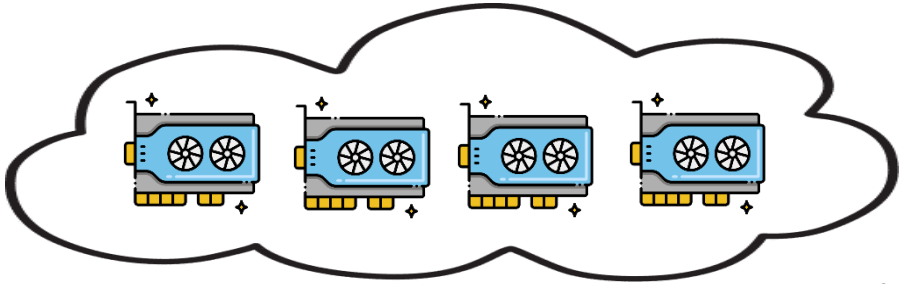

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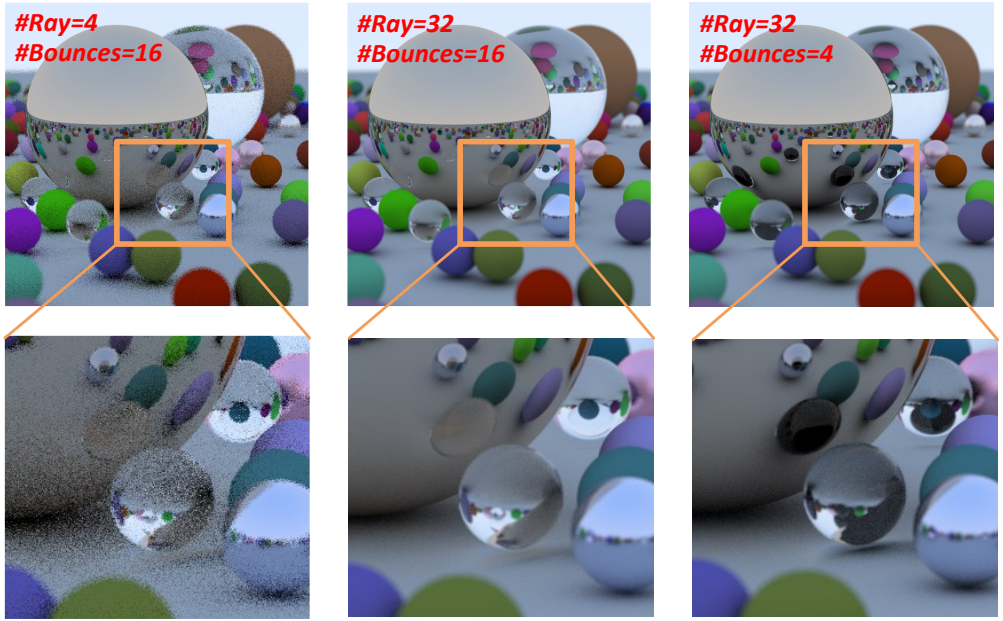

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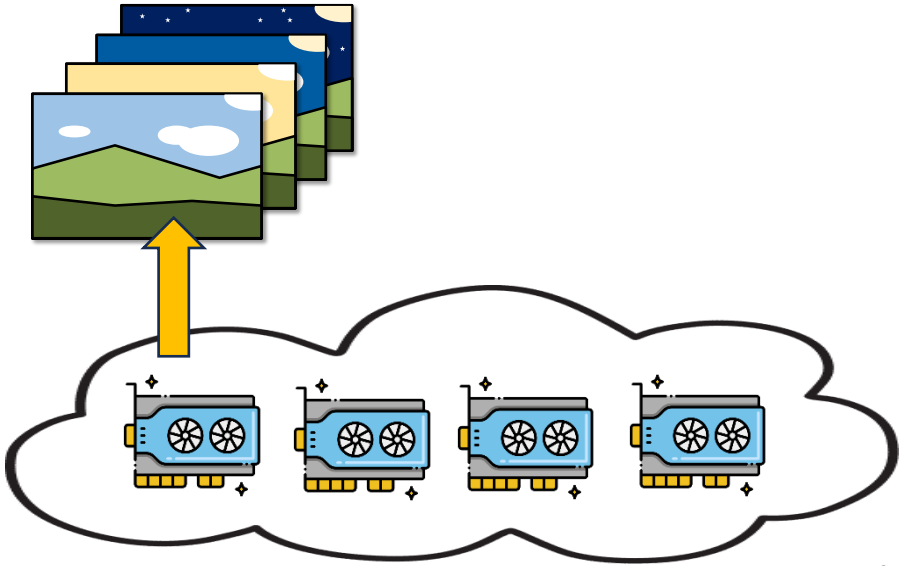

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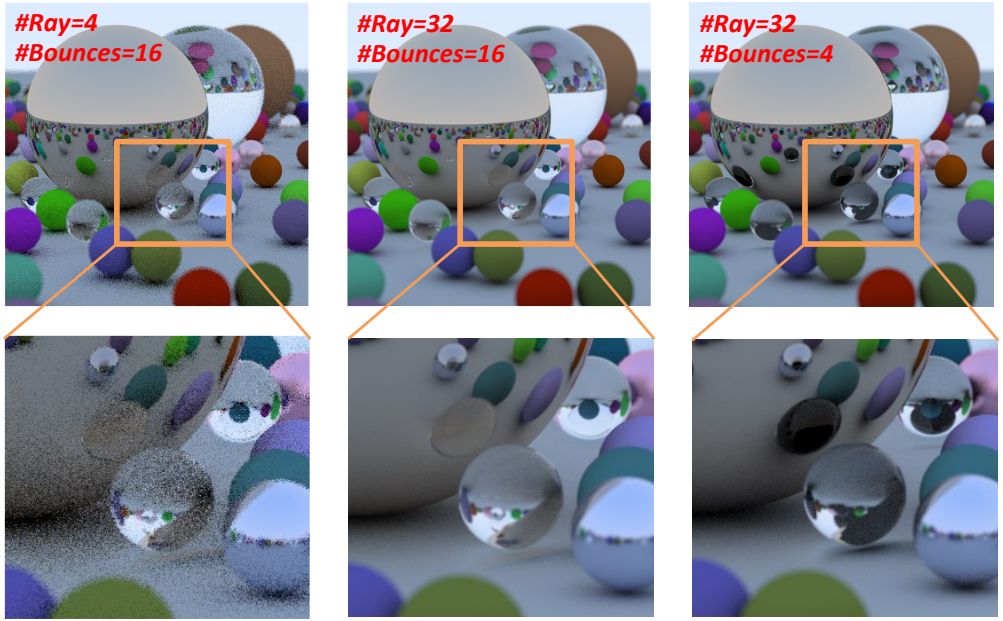

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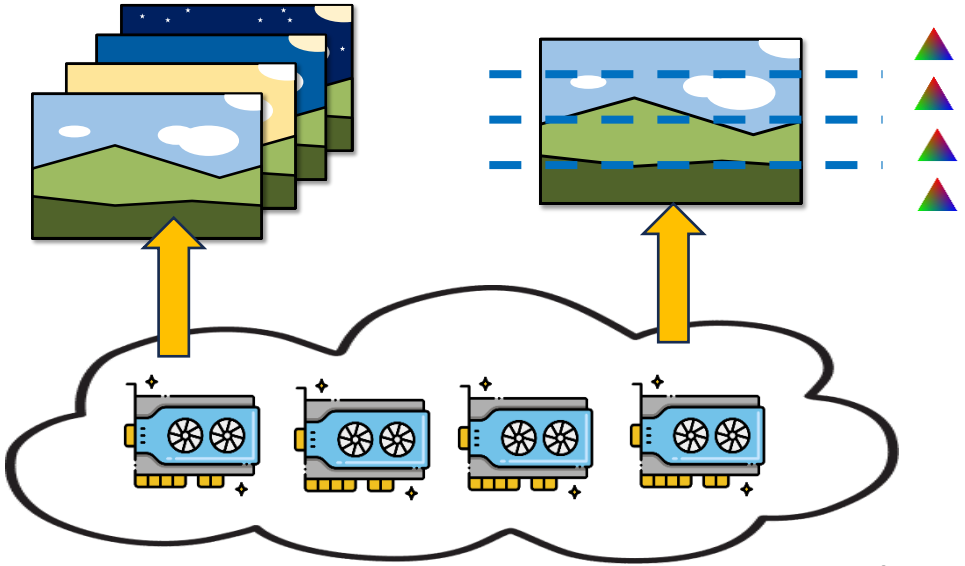

Why is Vulkan

- **Increase Efficiency with Vulkan**
  - the Next-Generation Graphics API

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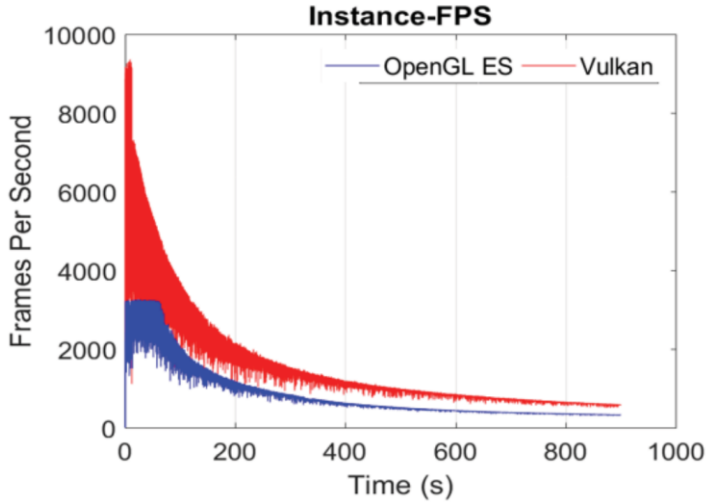

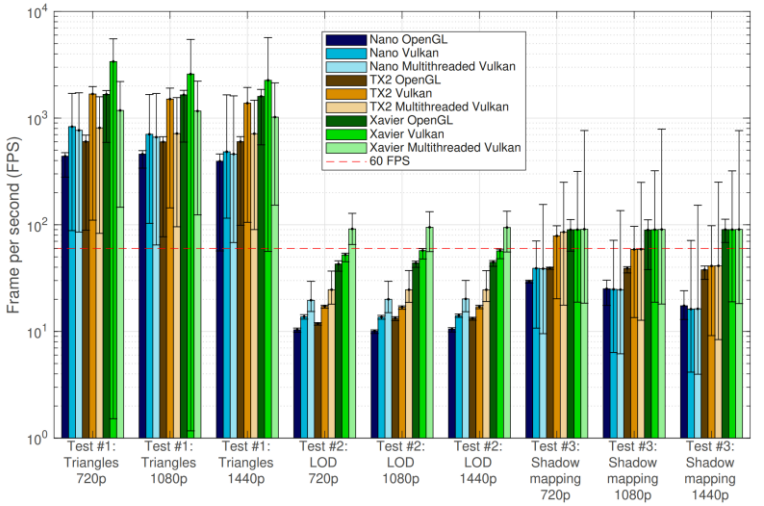

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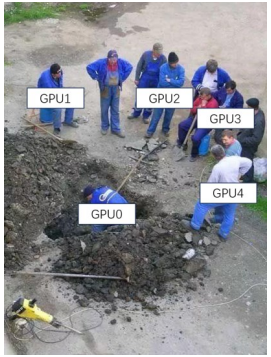

Challenges of multi-GPU ray tracing

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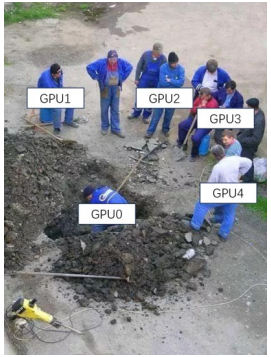

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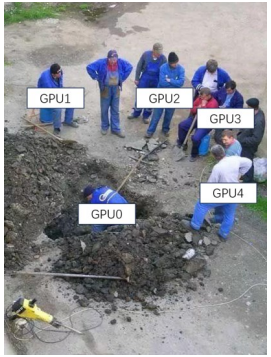

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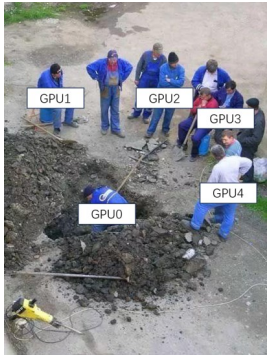

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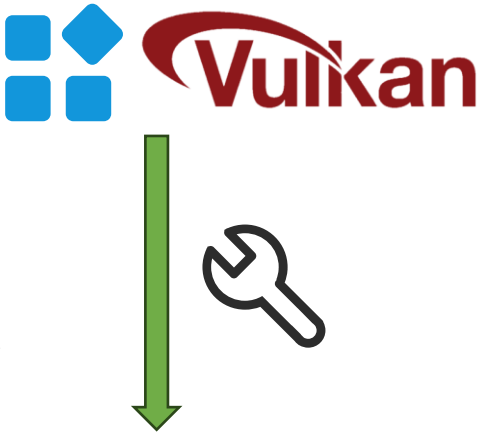

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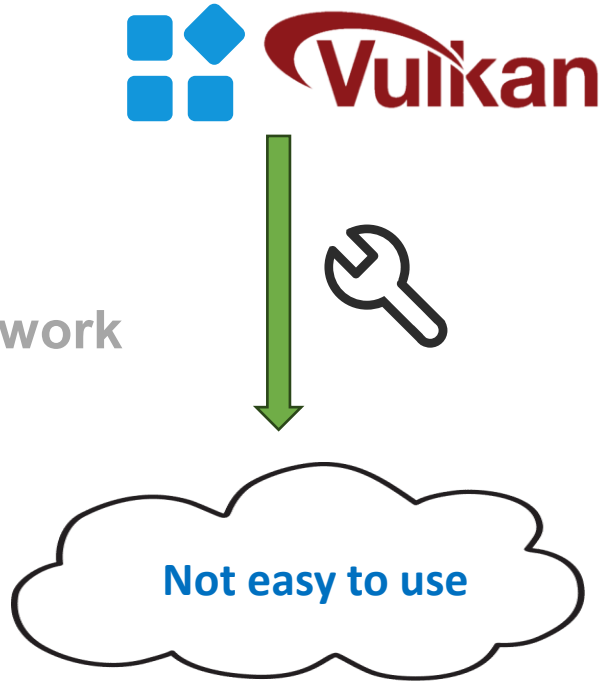

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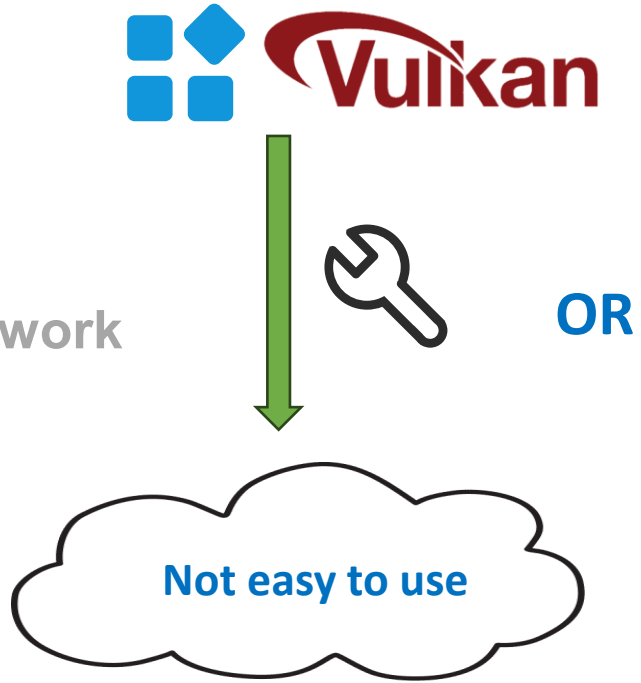

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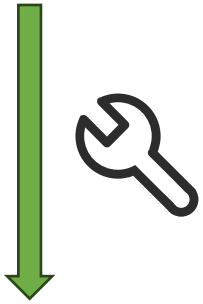

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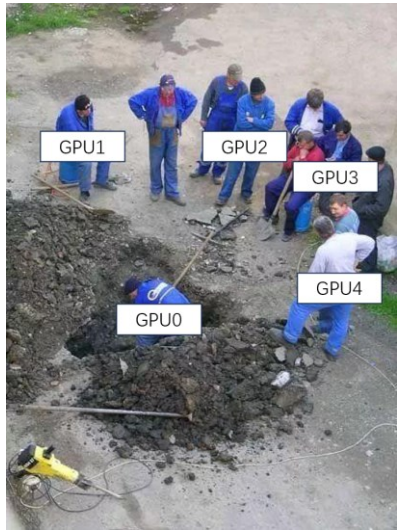

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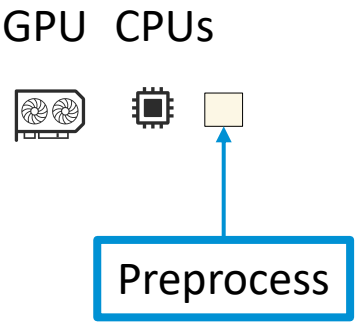

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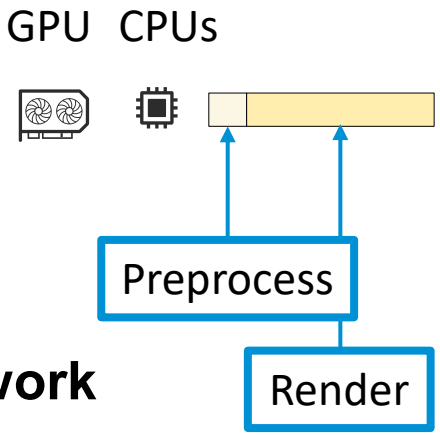

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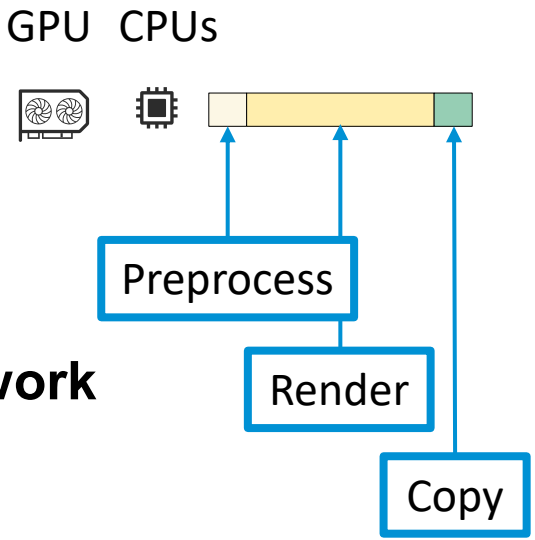

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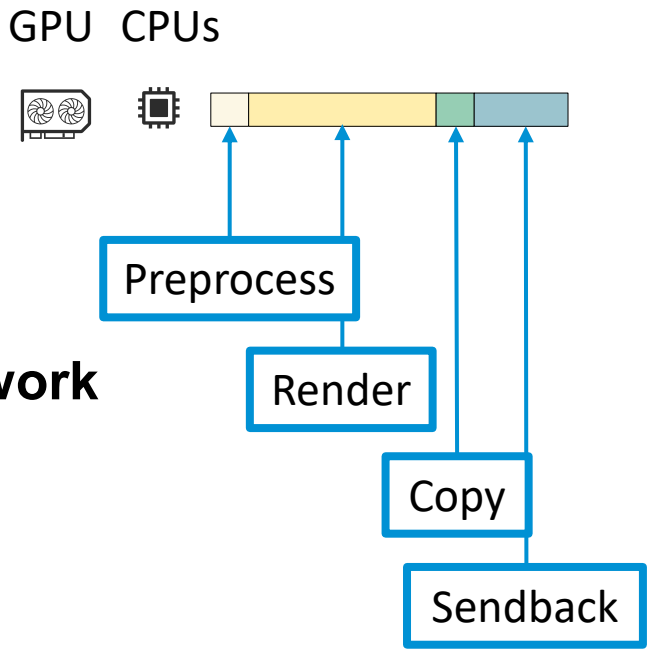

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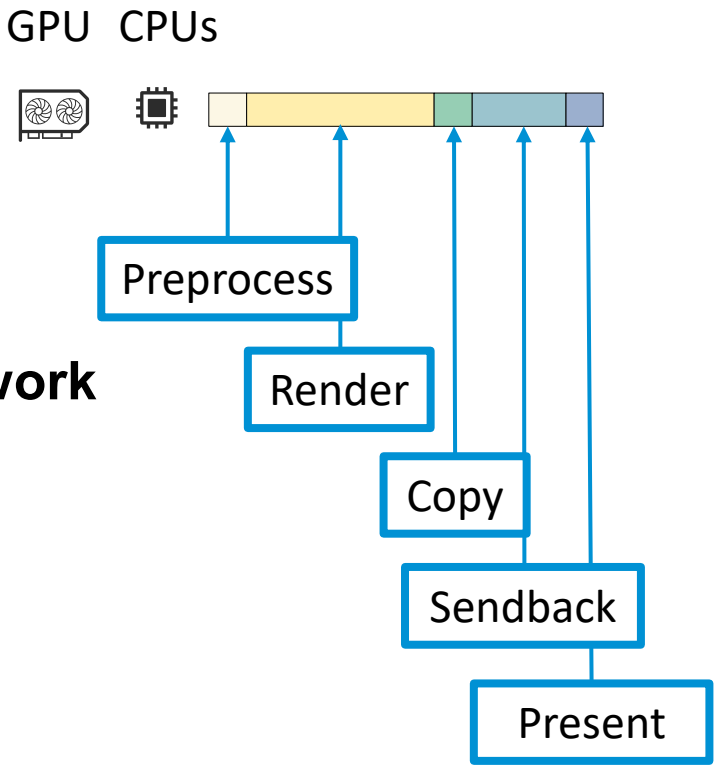

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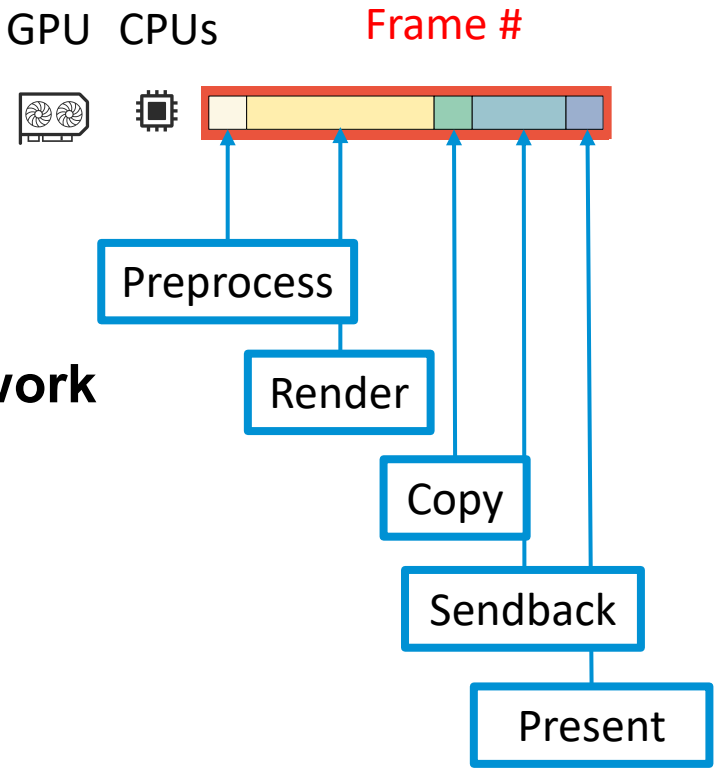

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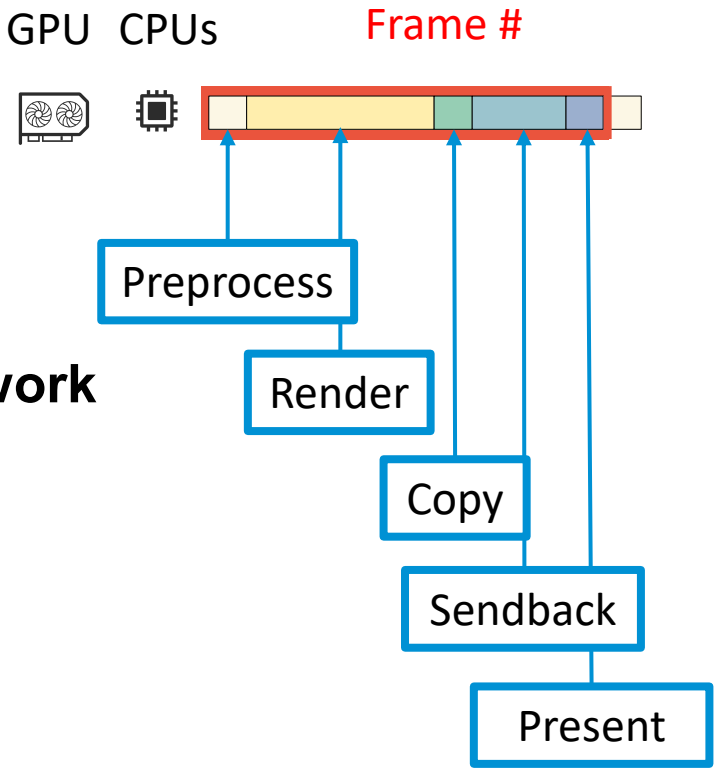

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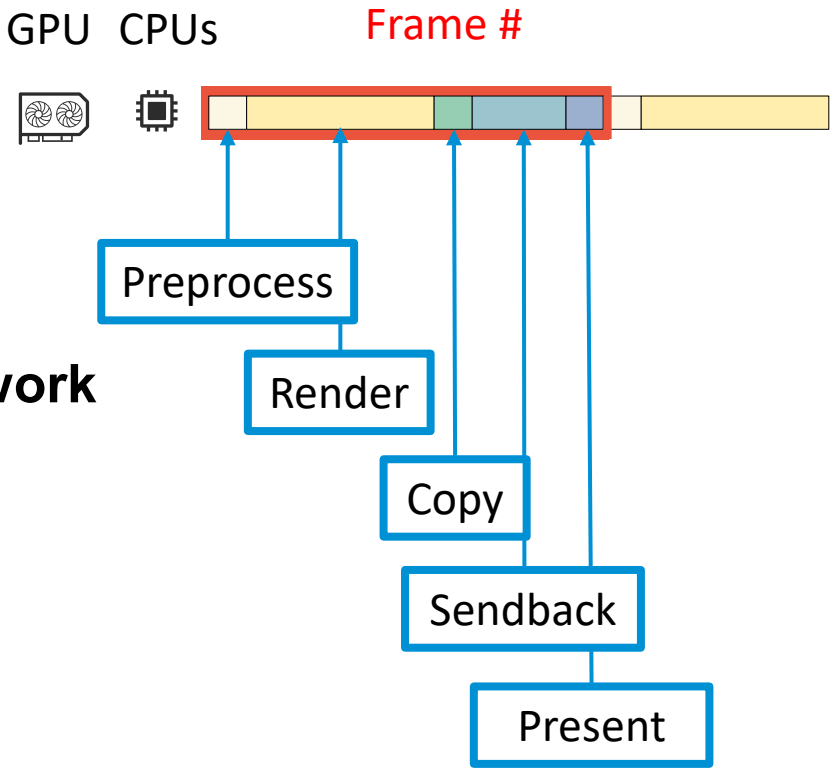

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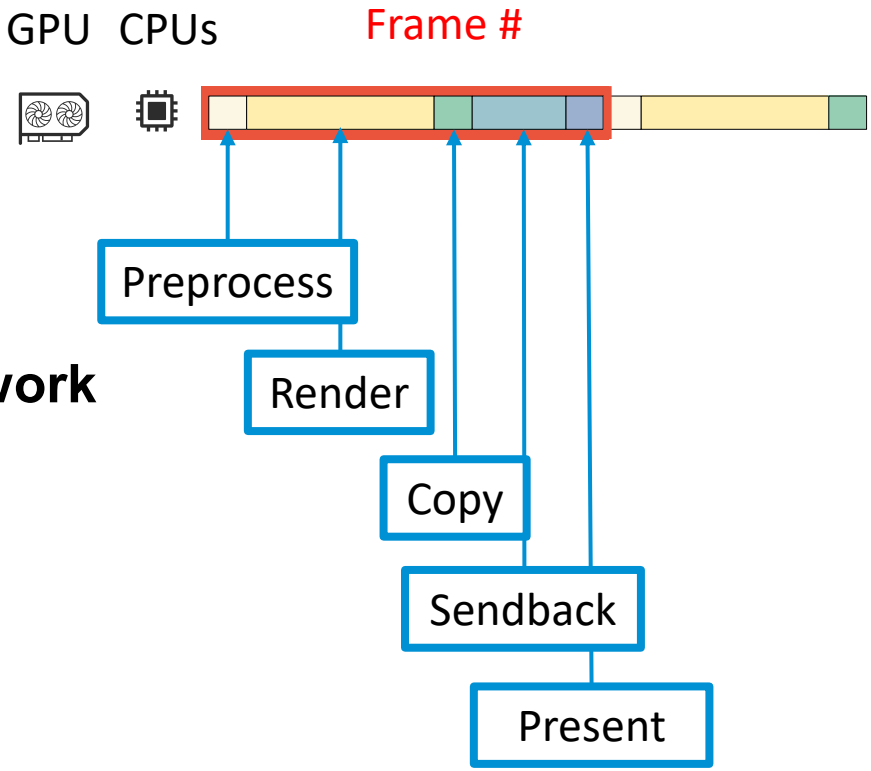

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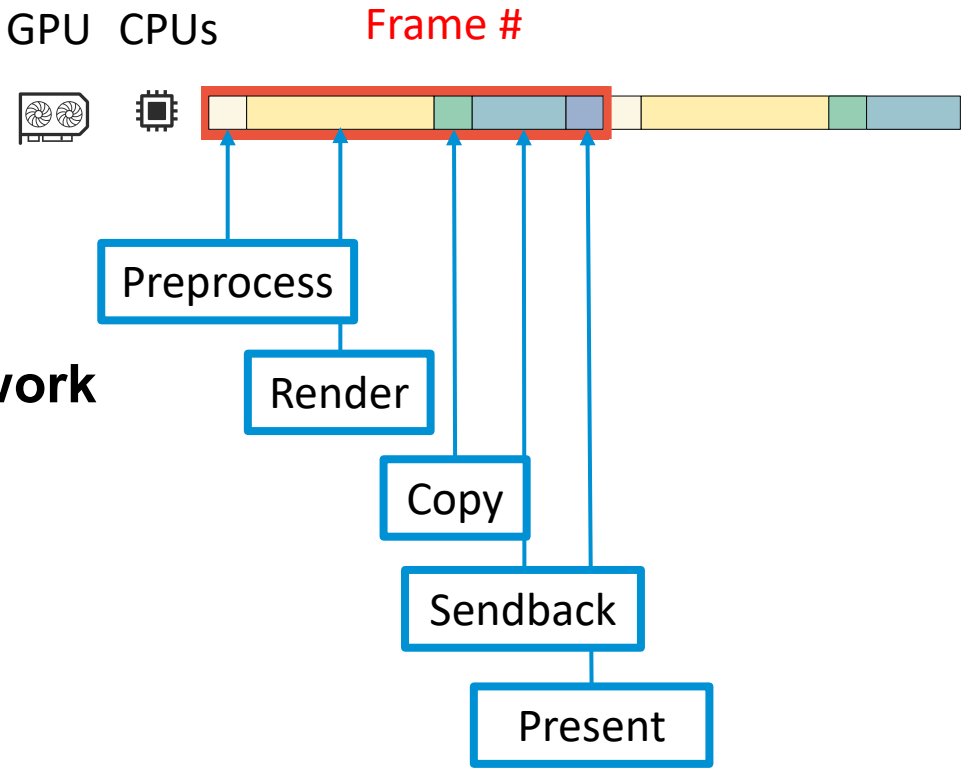

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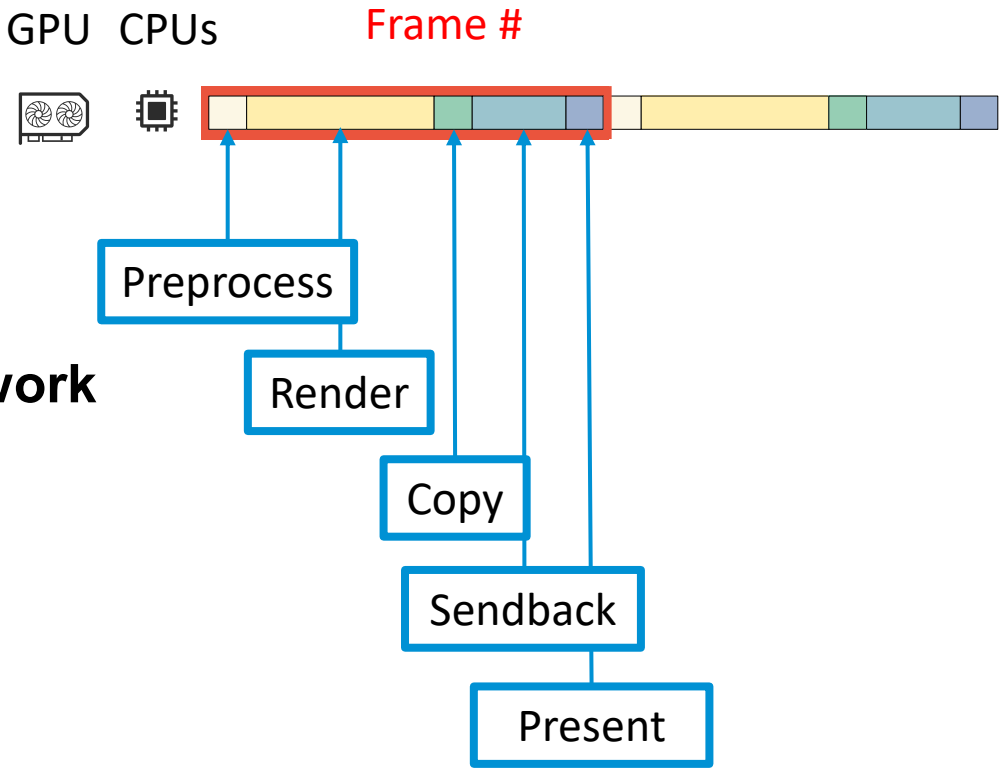

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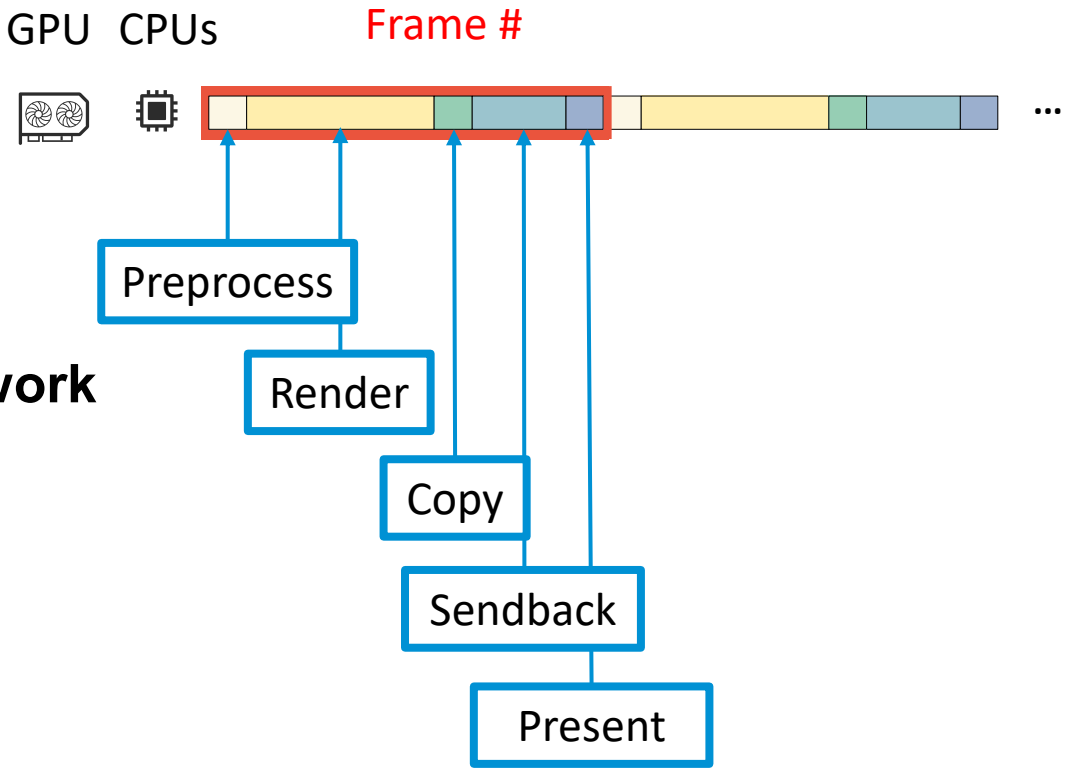

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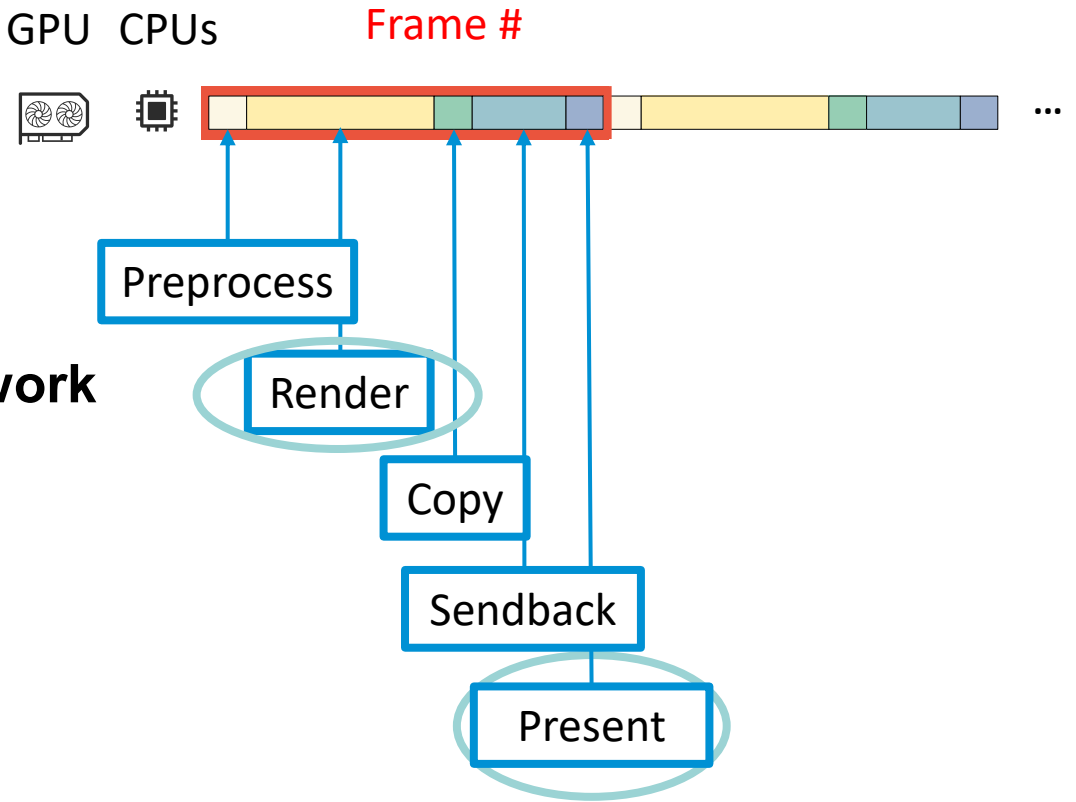

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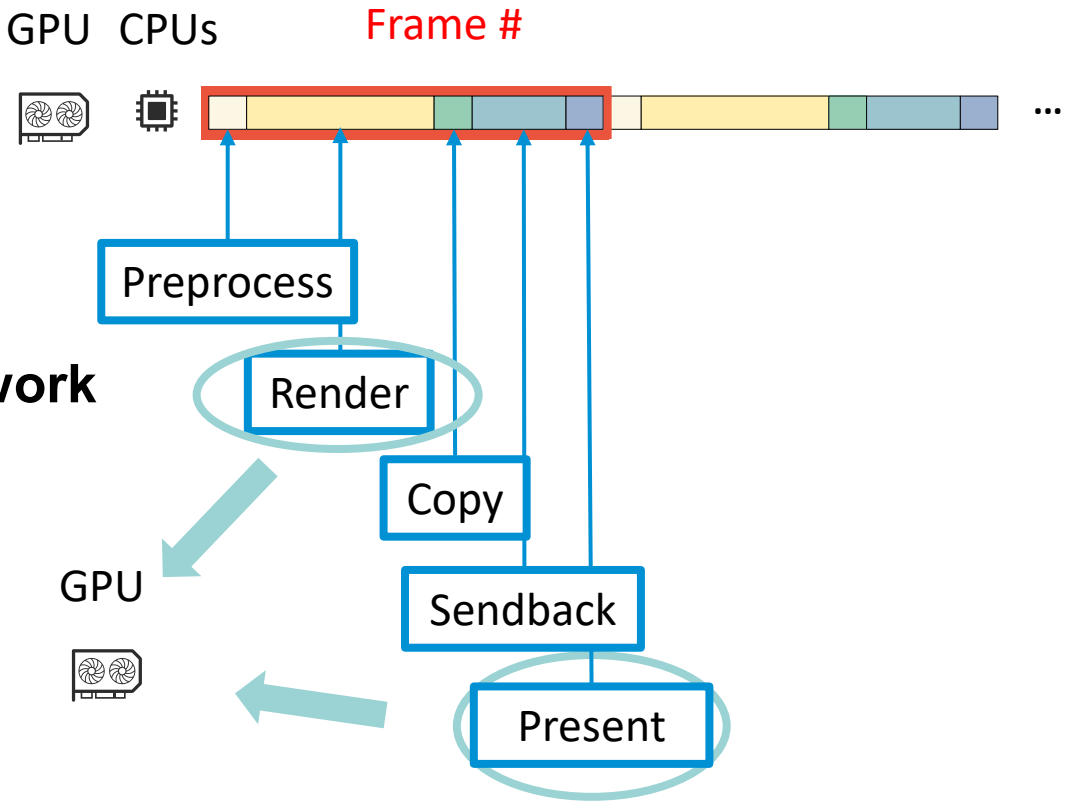

Challenges of multi-GPU ray tracing

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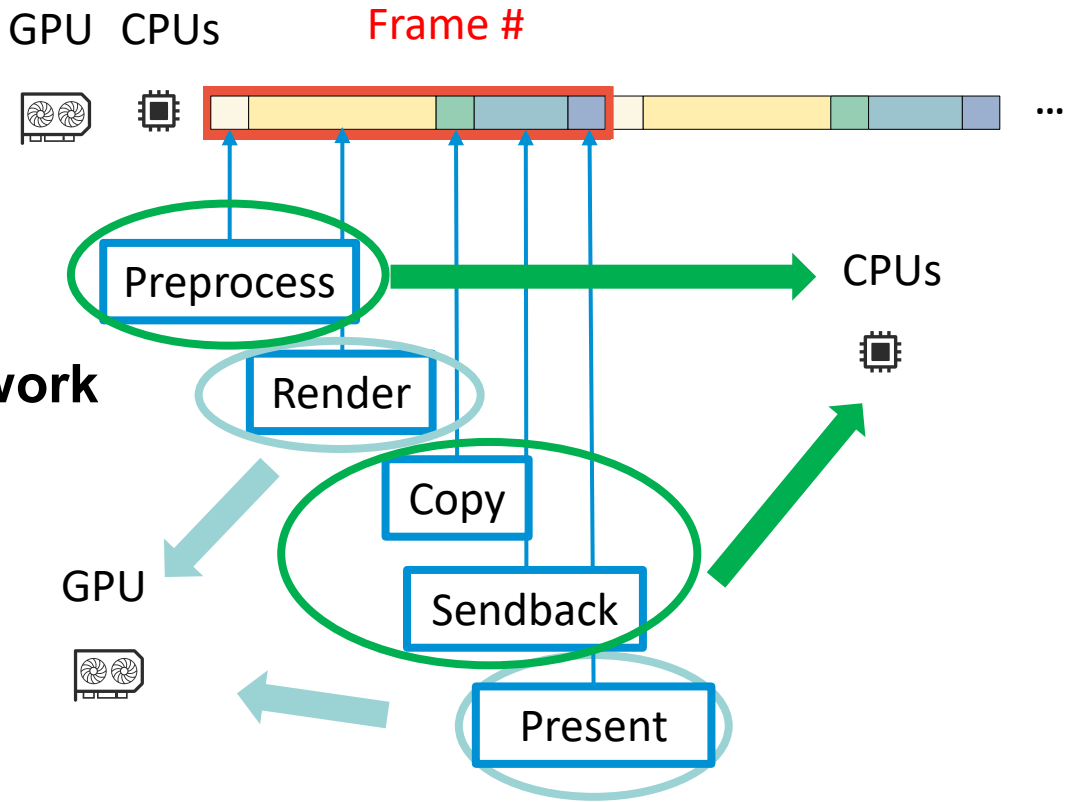

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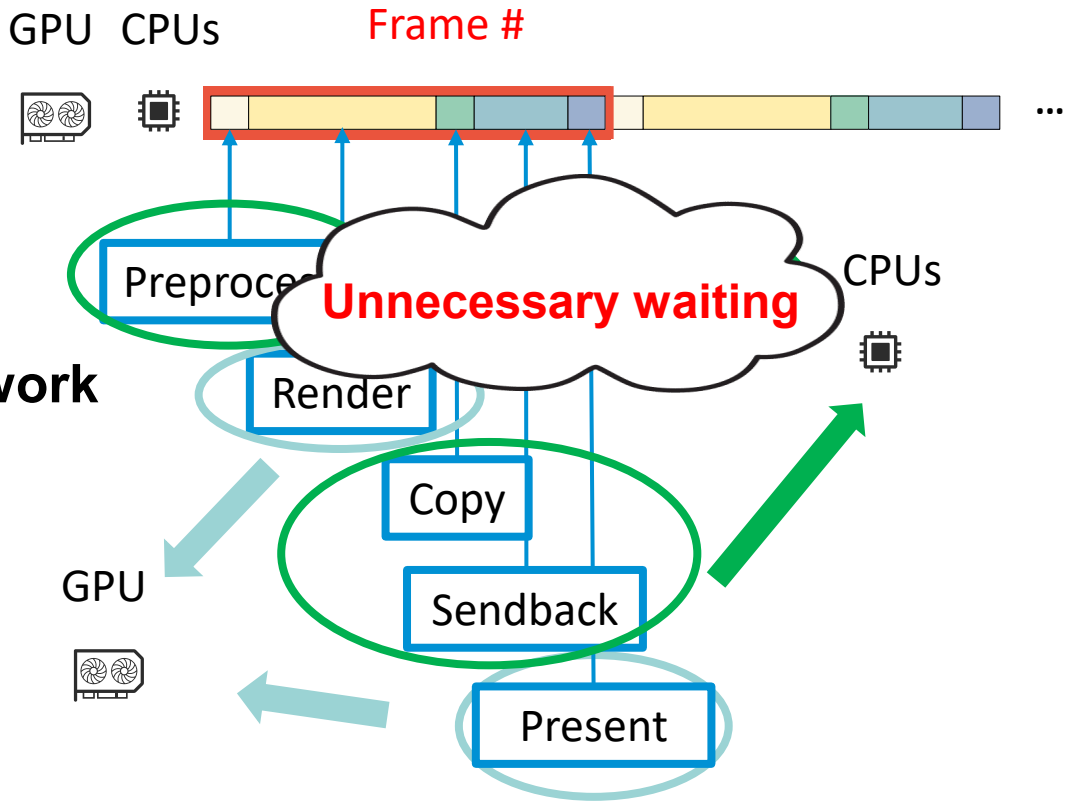

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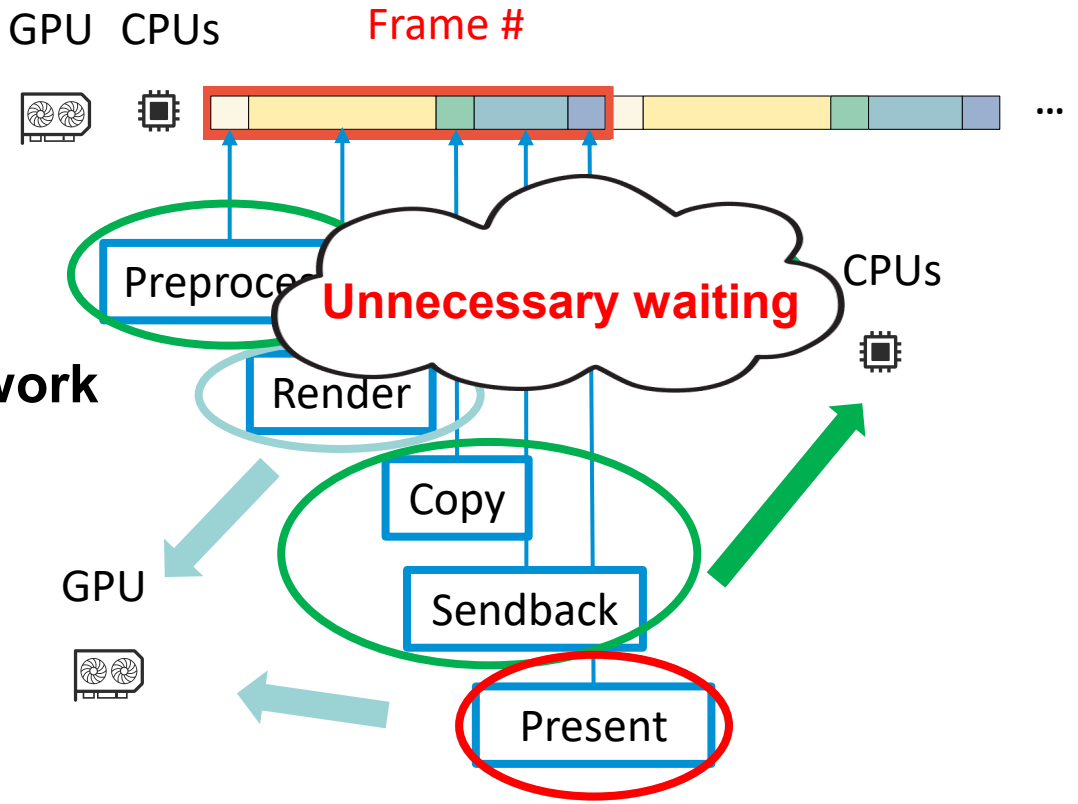

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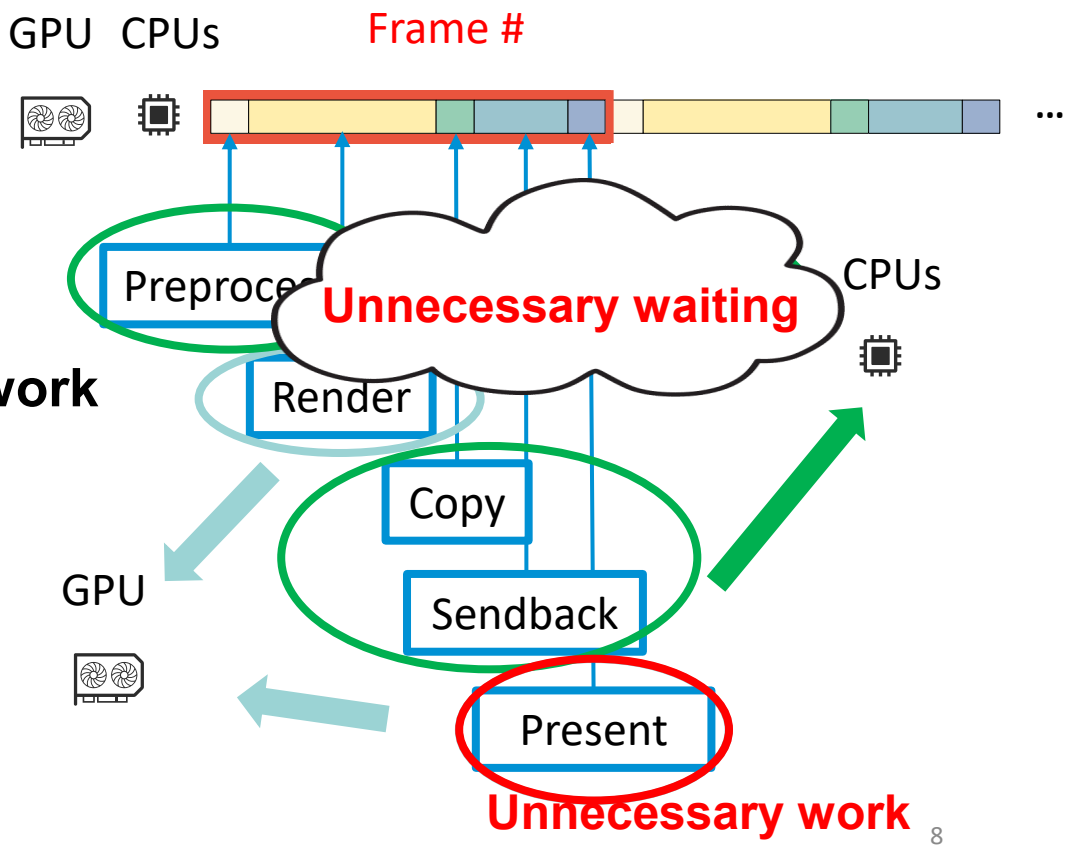

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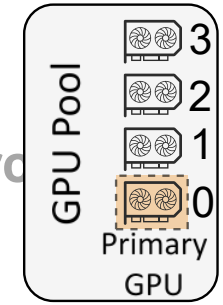

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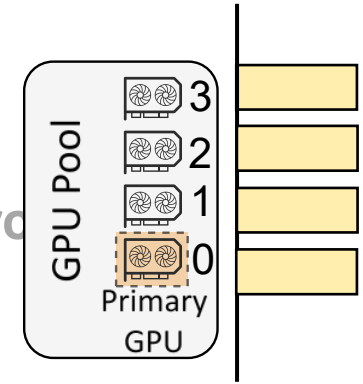

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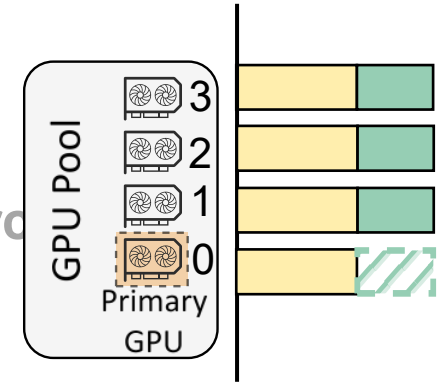

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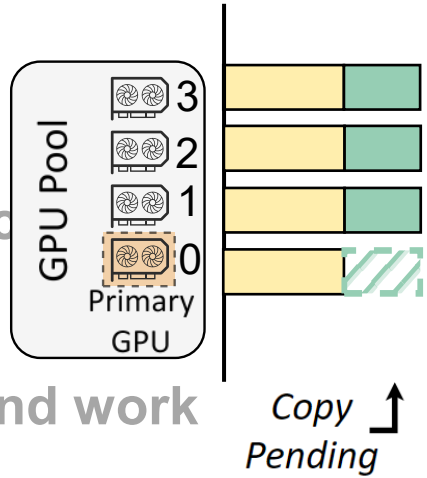

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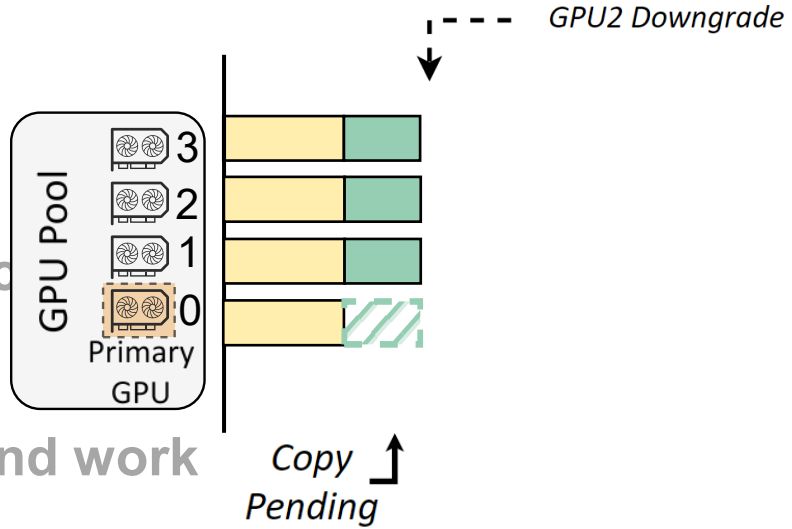

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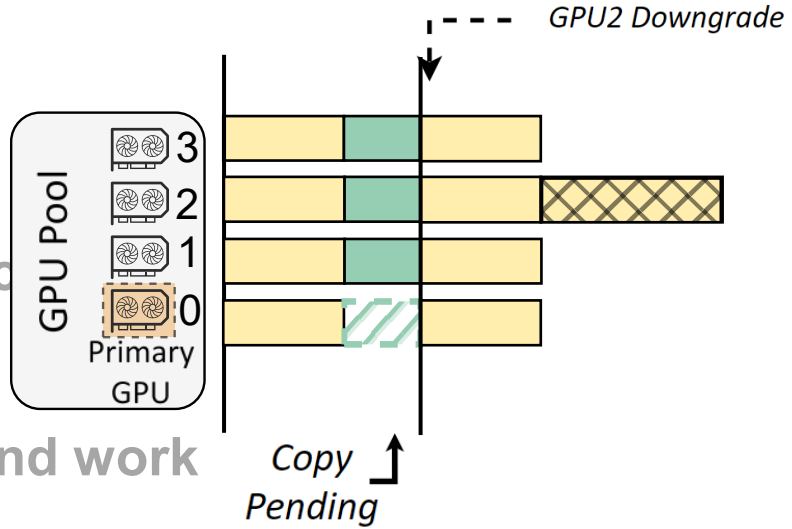

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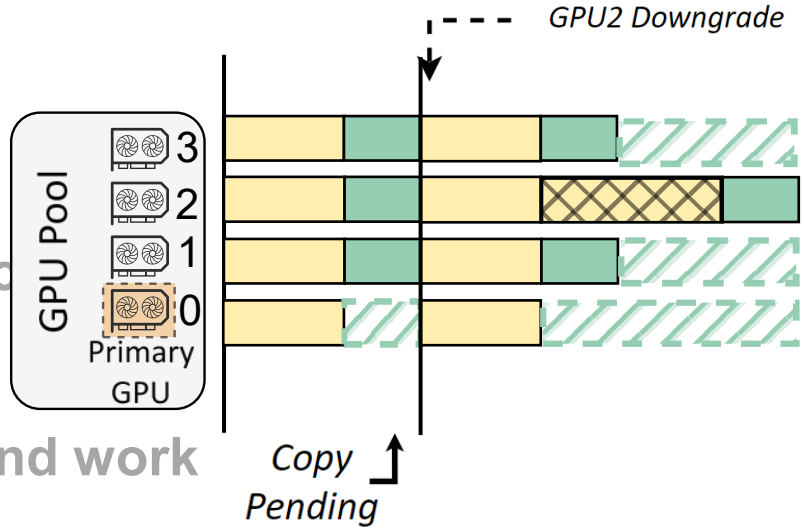

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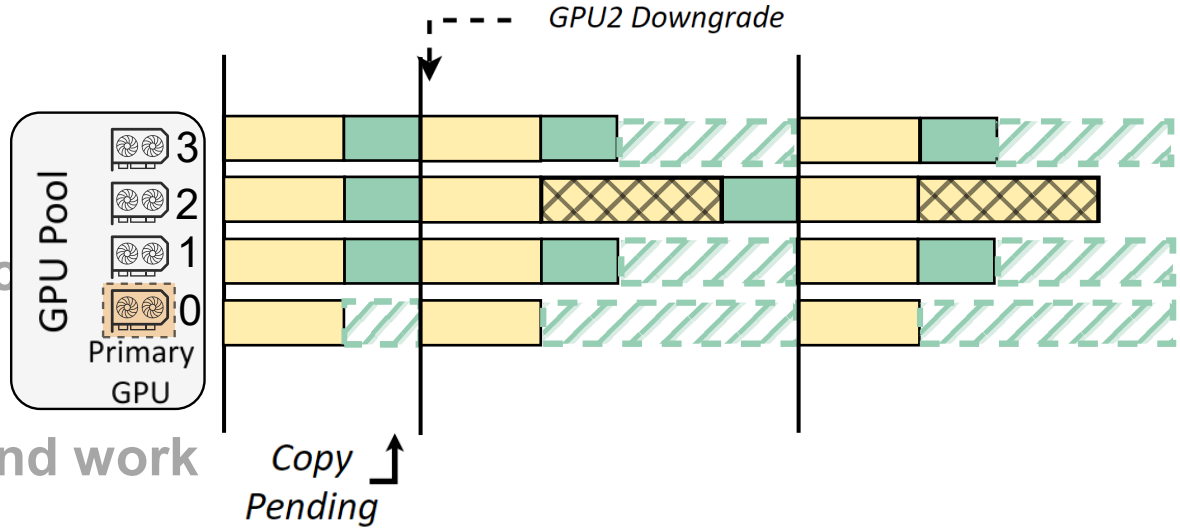

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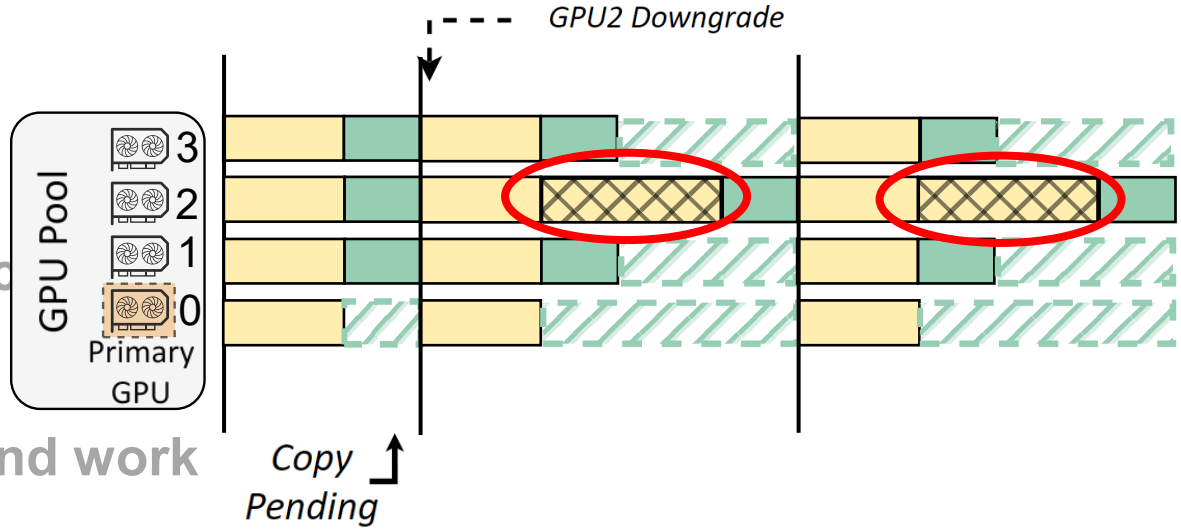

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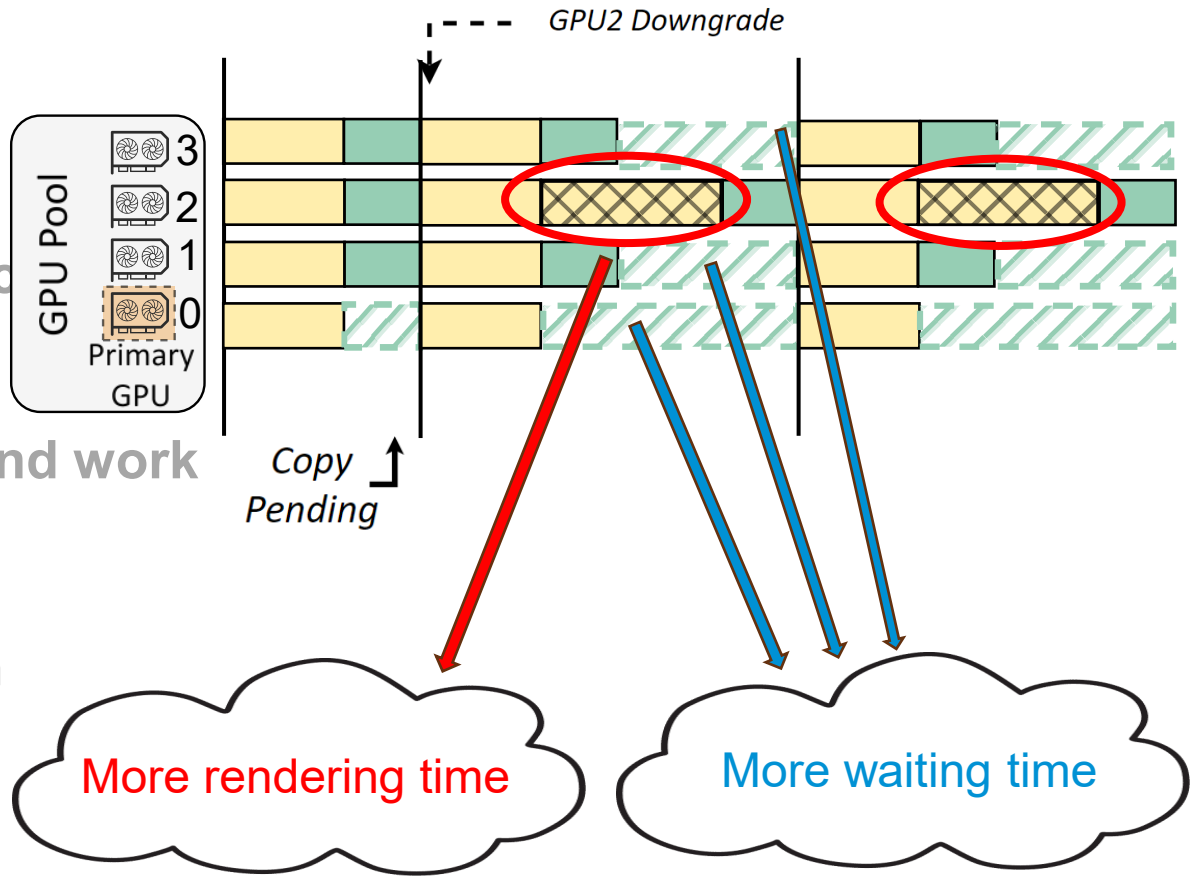
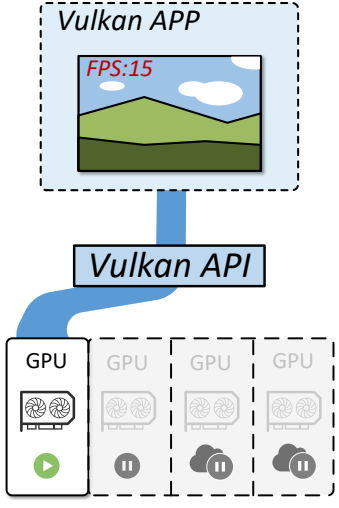
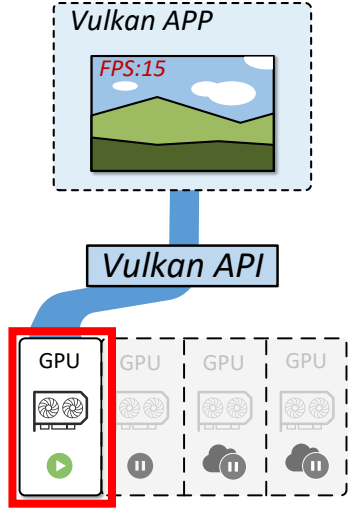




Our Design : gVulkan



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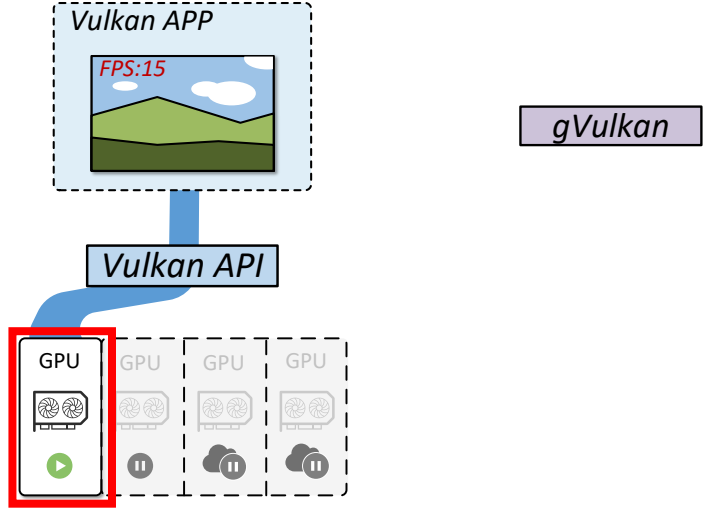

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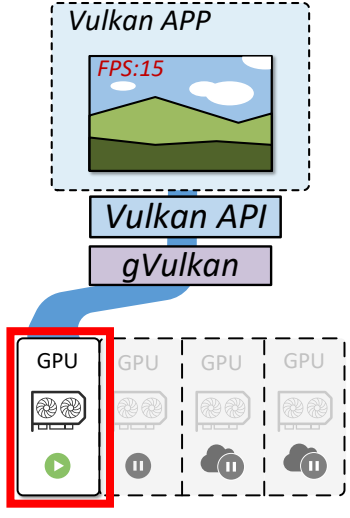

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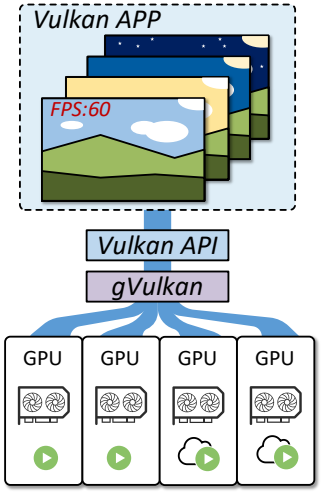

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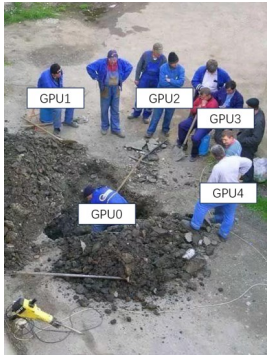
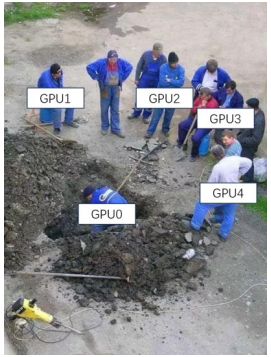
gVulkan goals



gVulkan goals

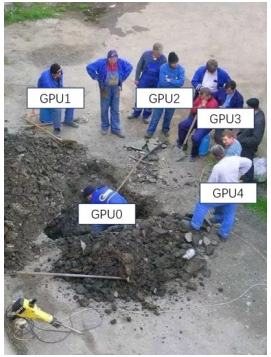
Ecosystem compatibility : API-forwarding, Cloud Rendering



gVulkan goals

Ecosystem compatibility : **API-forwarding, Cloud Rendering**

Intra-GPU : **Optimize the current framework**



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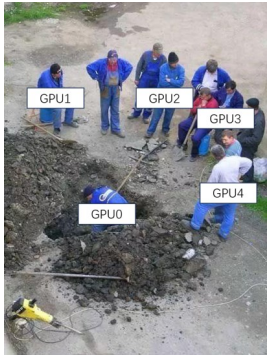
Intra-GPU : Optimize the current framework

Inter-GPU : workload self-rebalancing

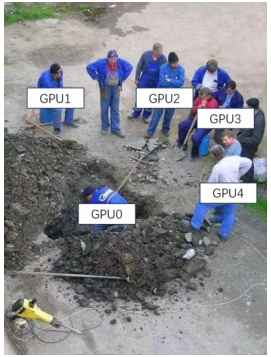


gVulkan goals

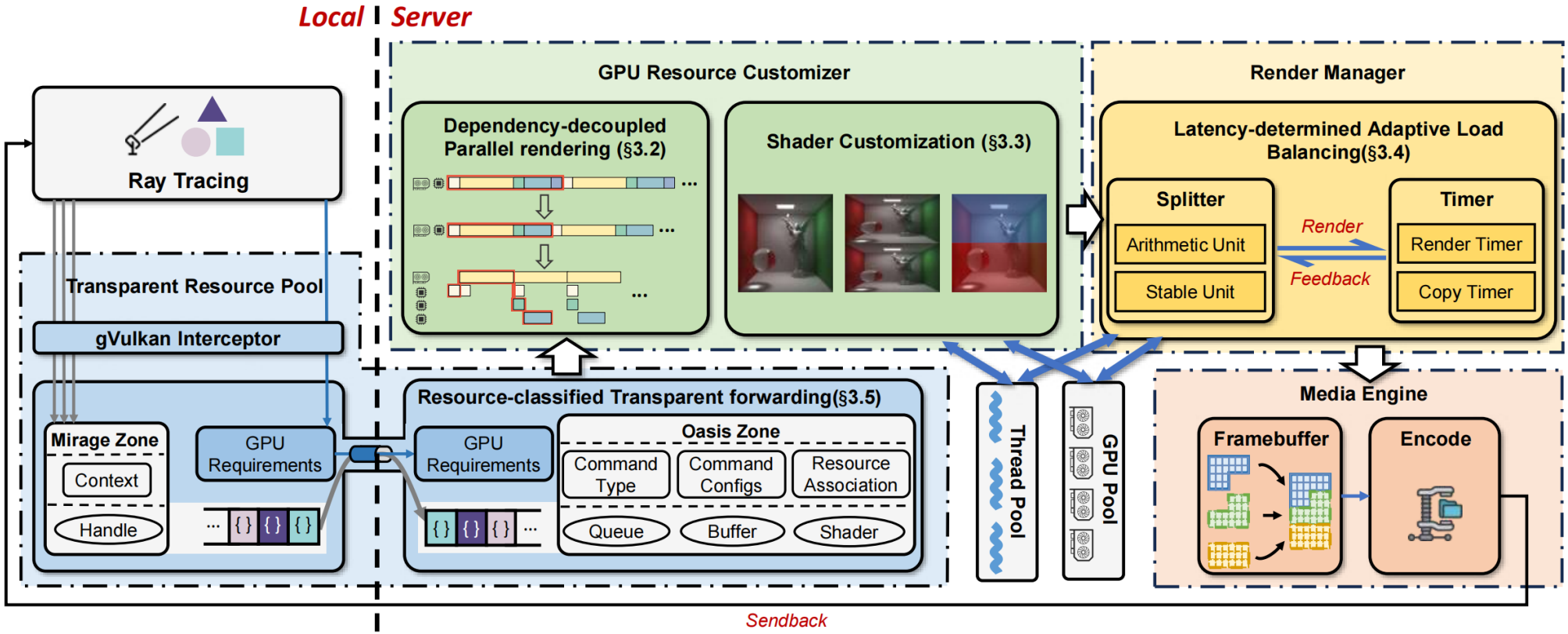
Ecosystem compatibility : API-forwarding, Cloud Rendering

Enables cloud-based code conversion from single-GPU to multi-GPU rendering tasks locally without modifying native Vulkan applications.

Inter-GPU : workload self-rebalancing



Architecture of gVulkan



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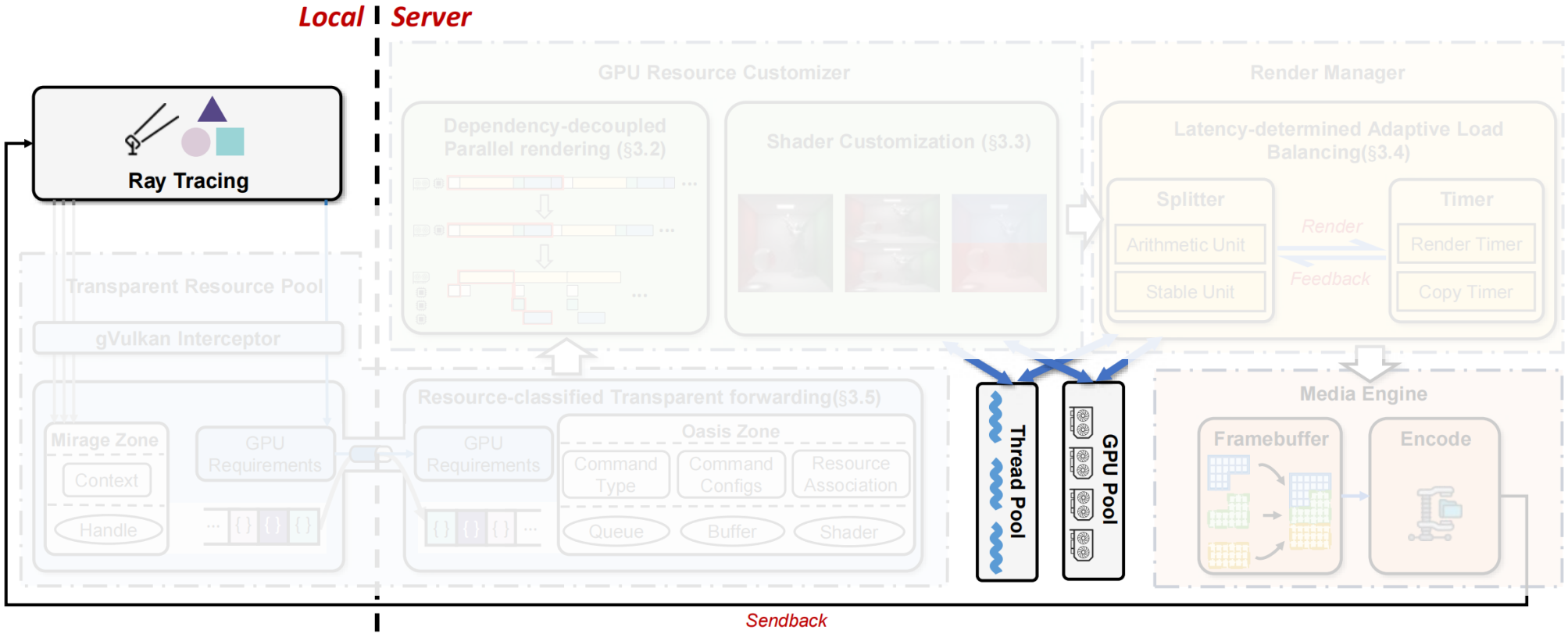

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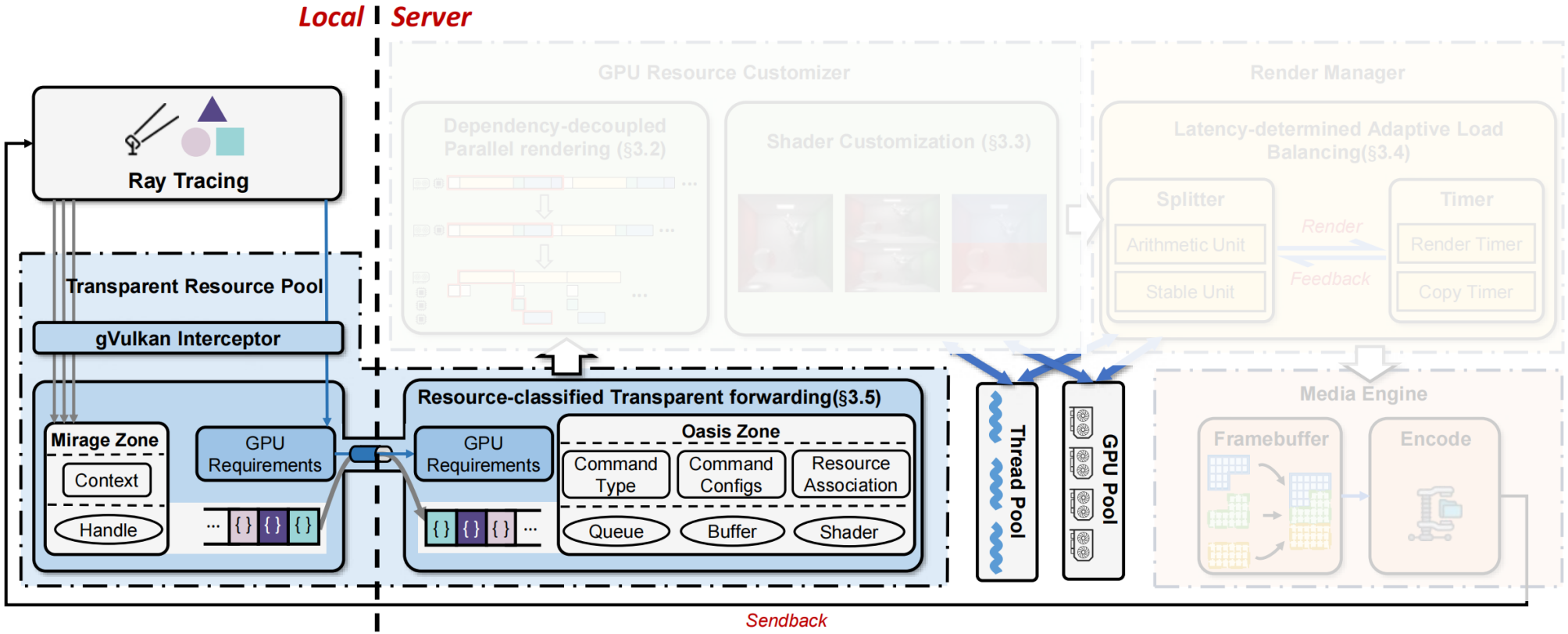

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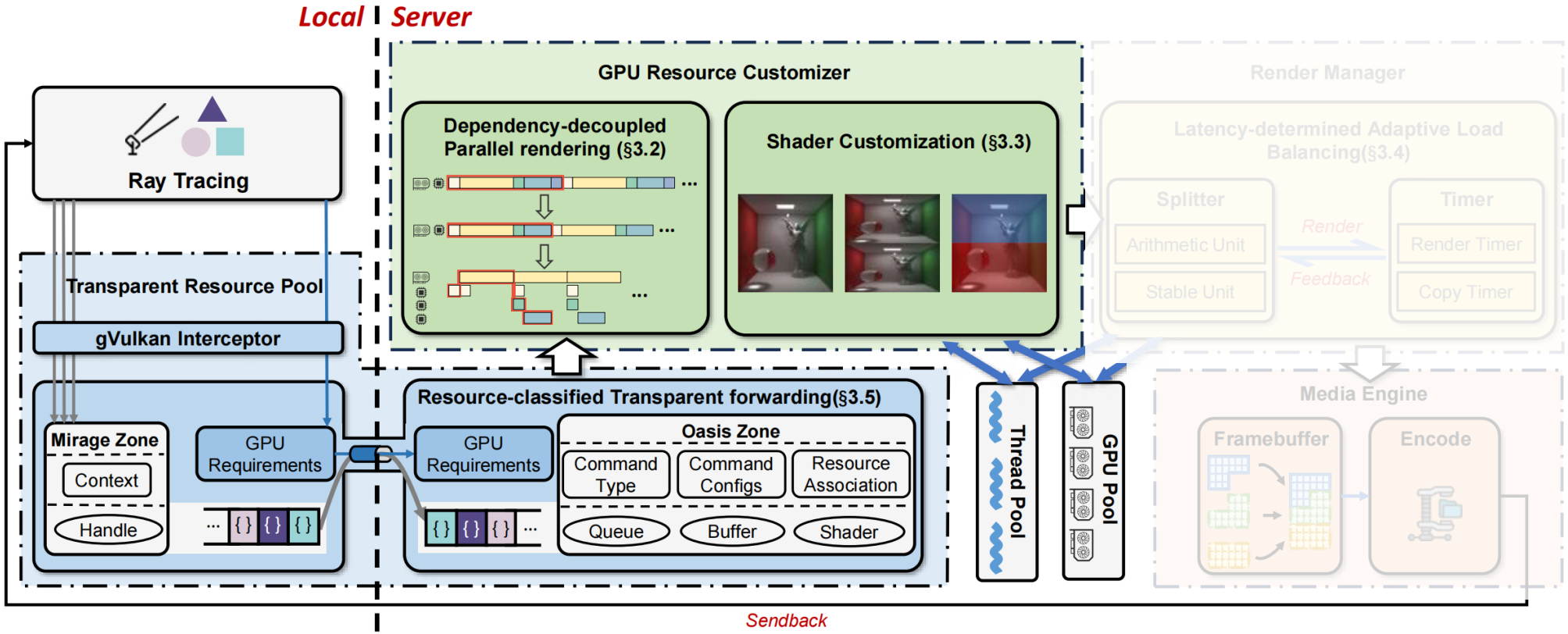

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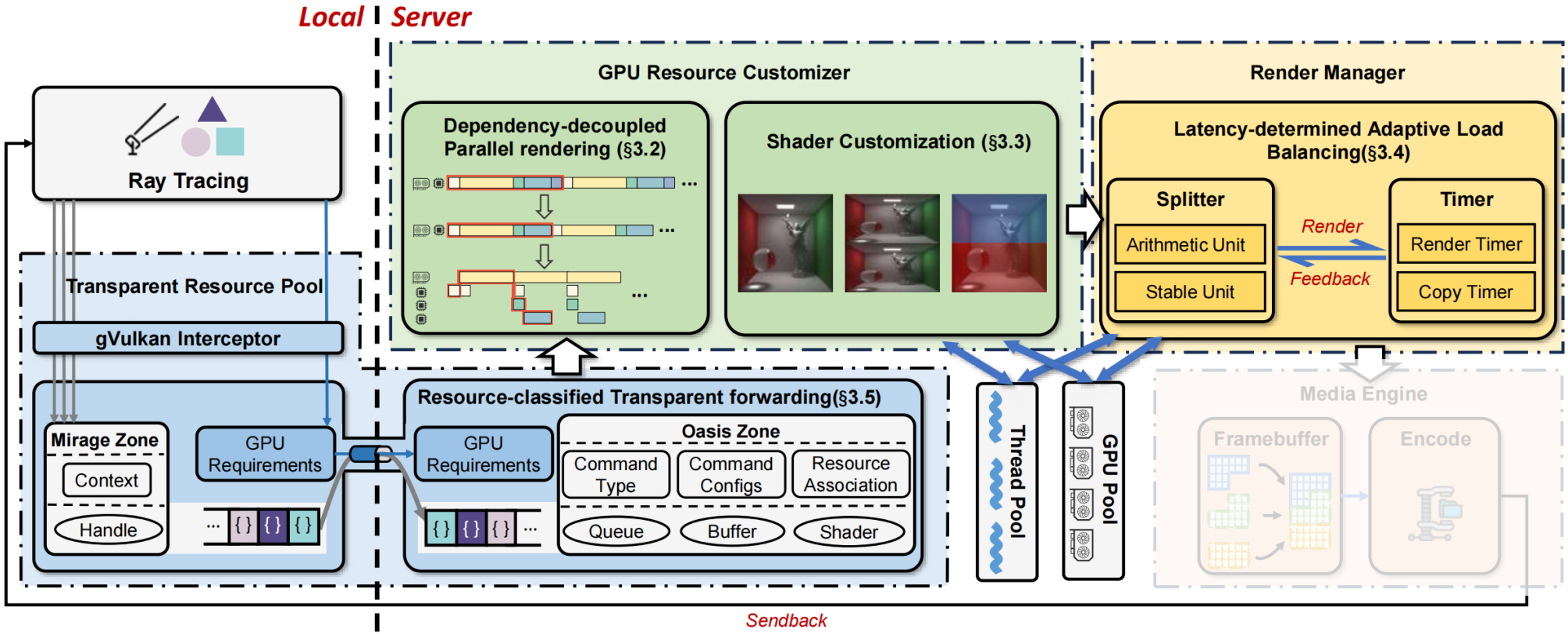

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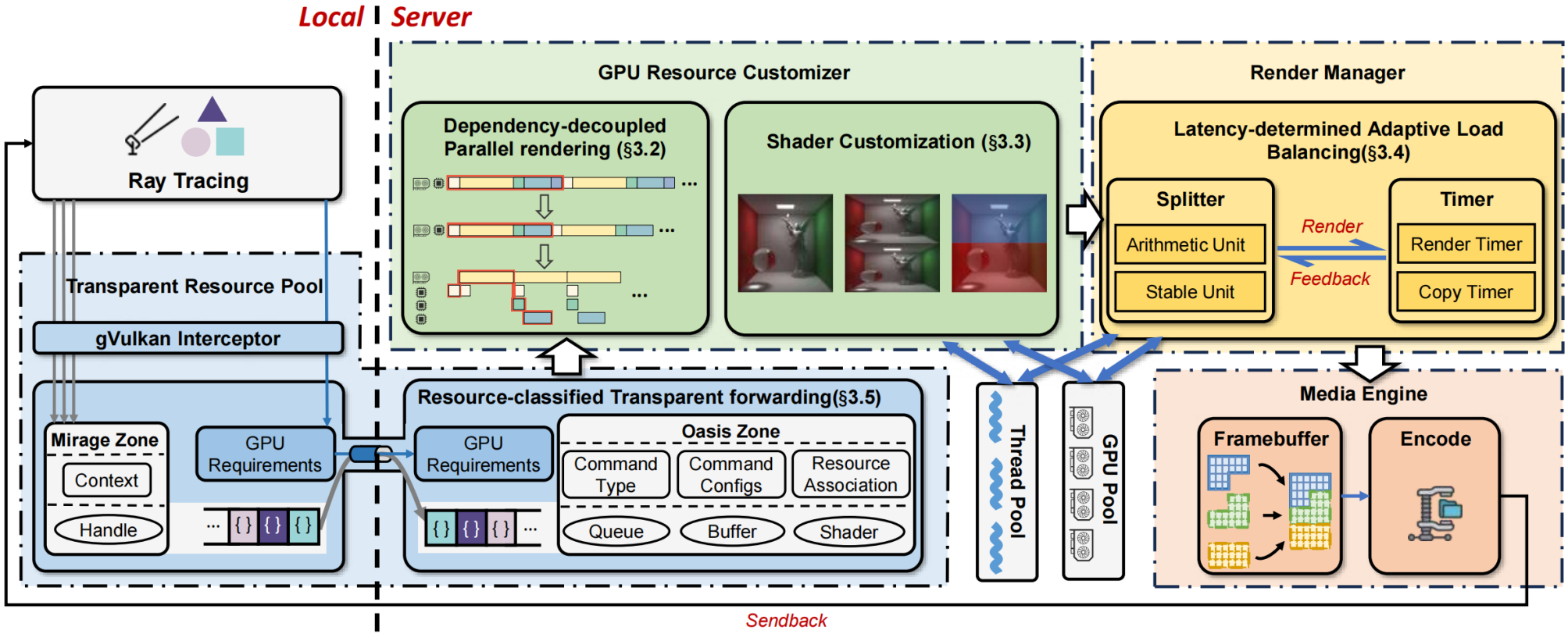

Resource-classified Transparent Forwarding

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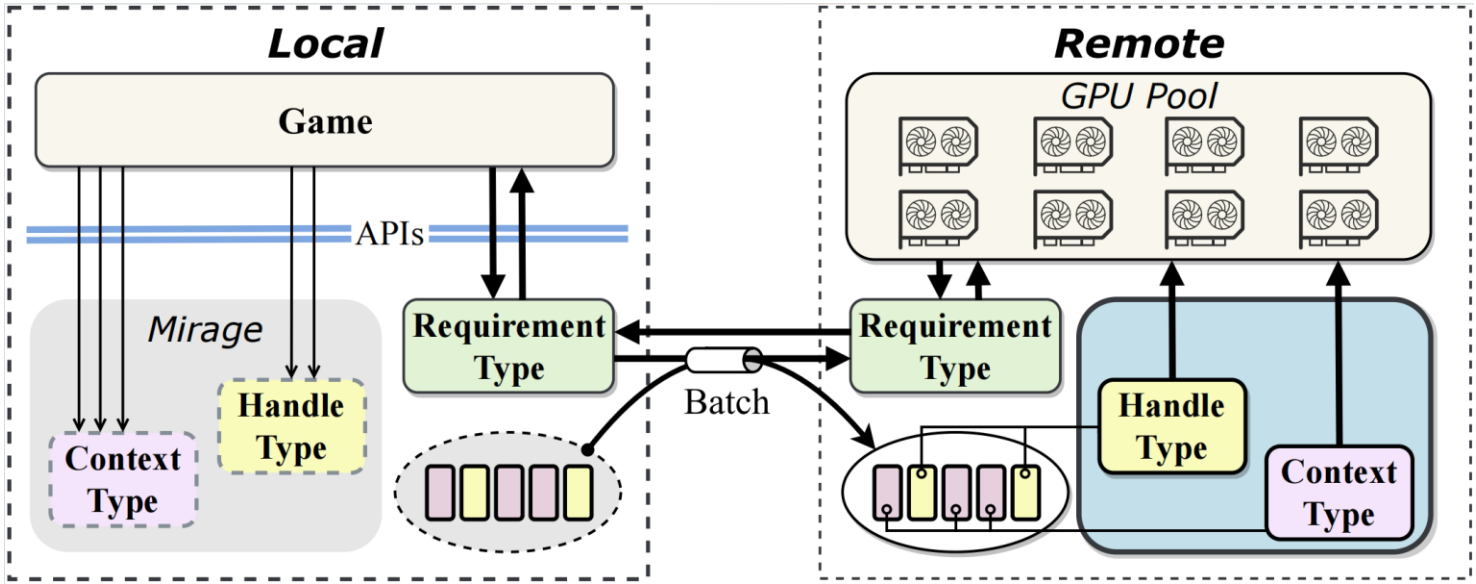

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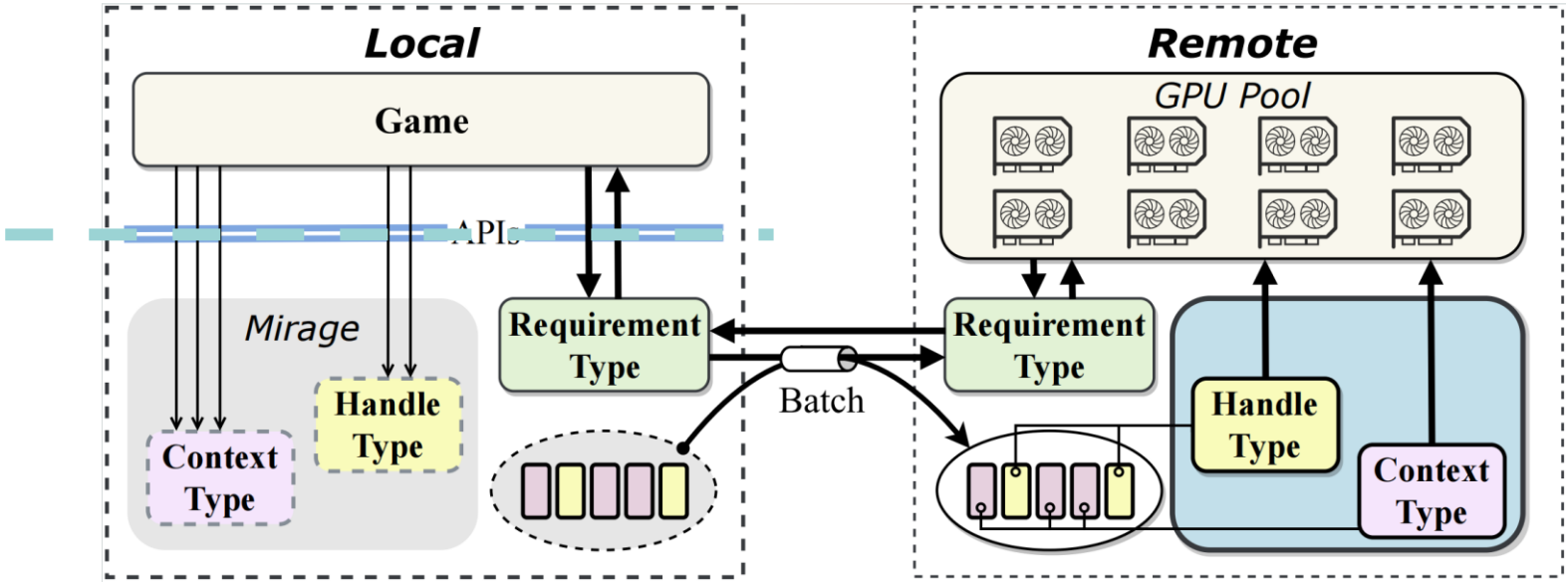

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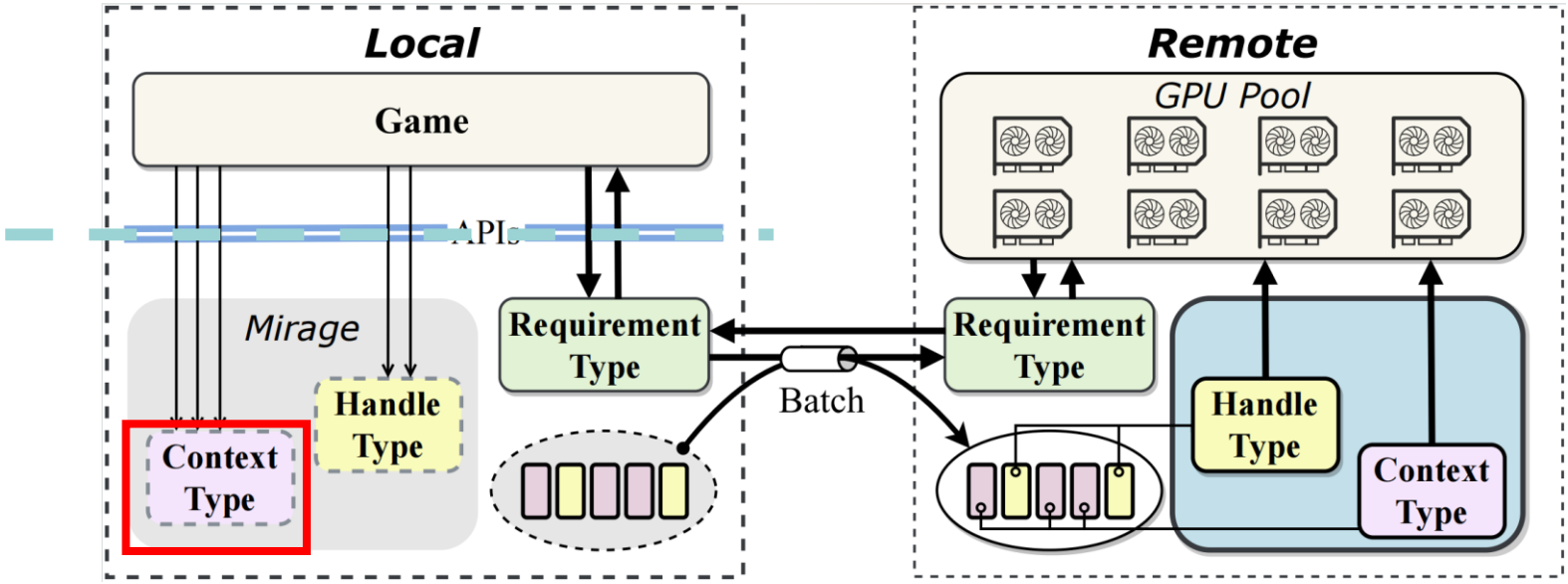

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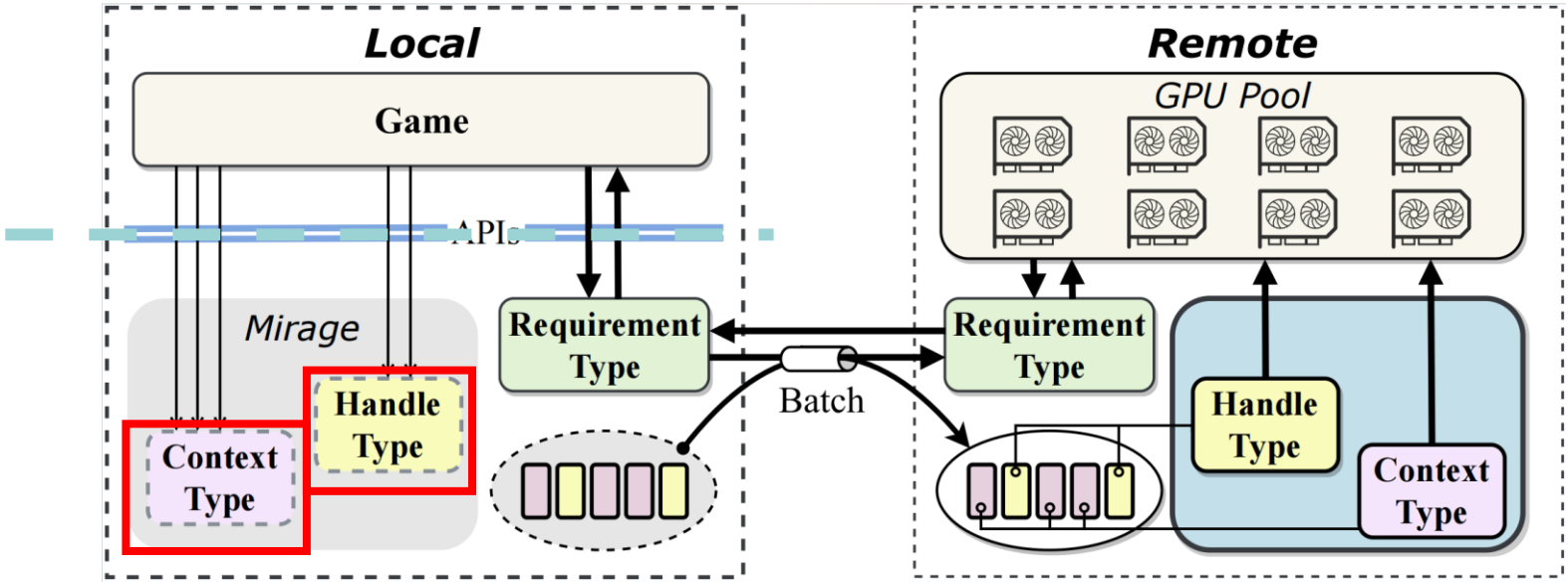

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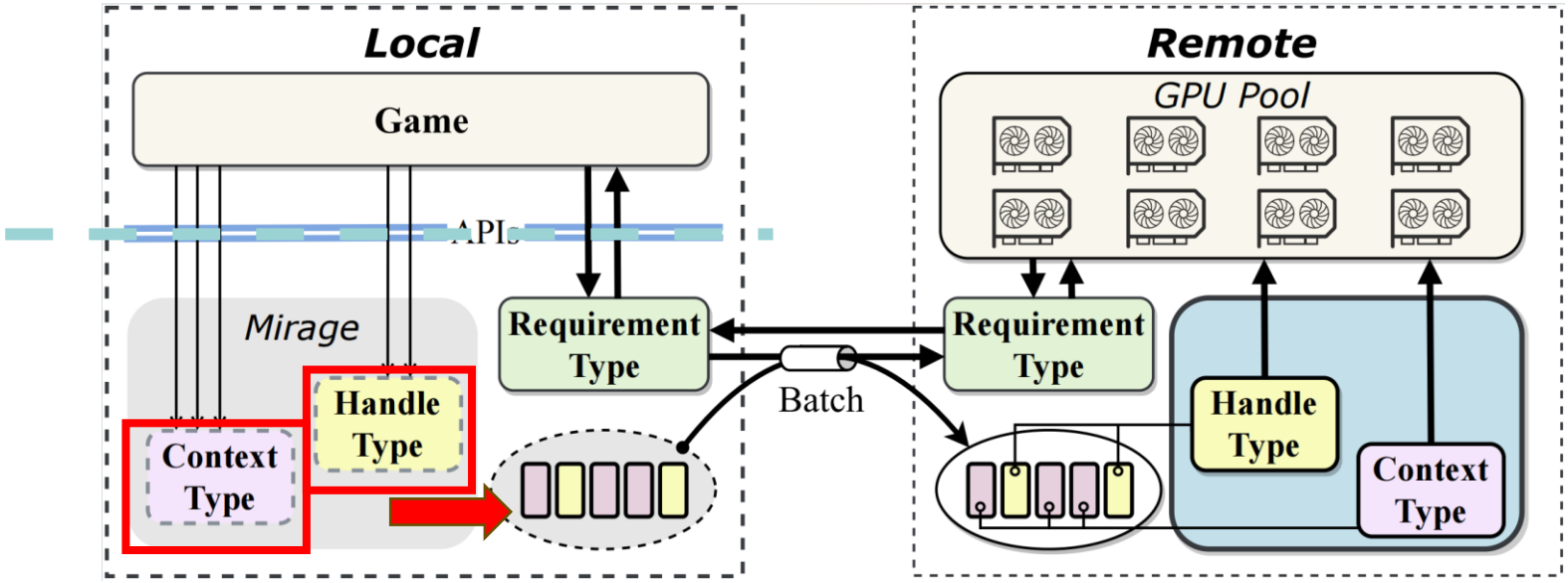

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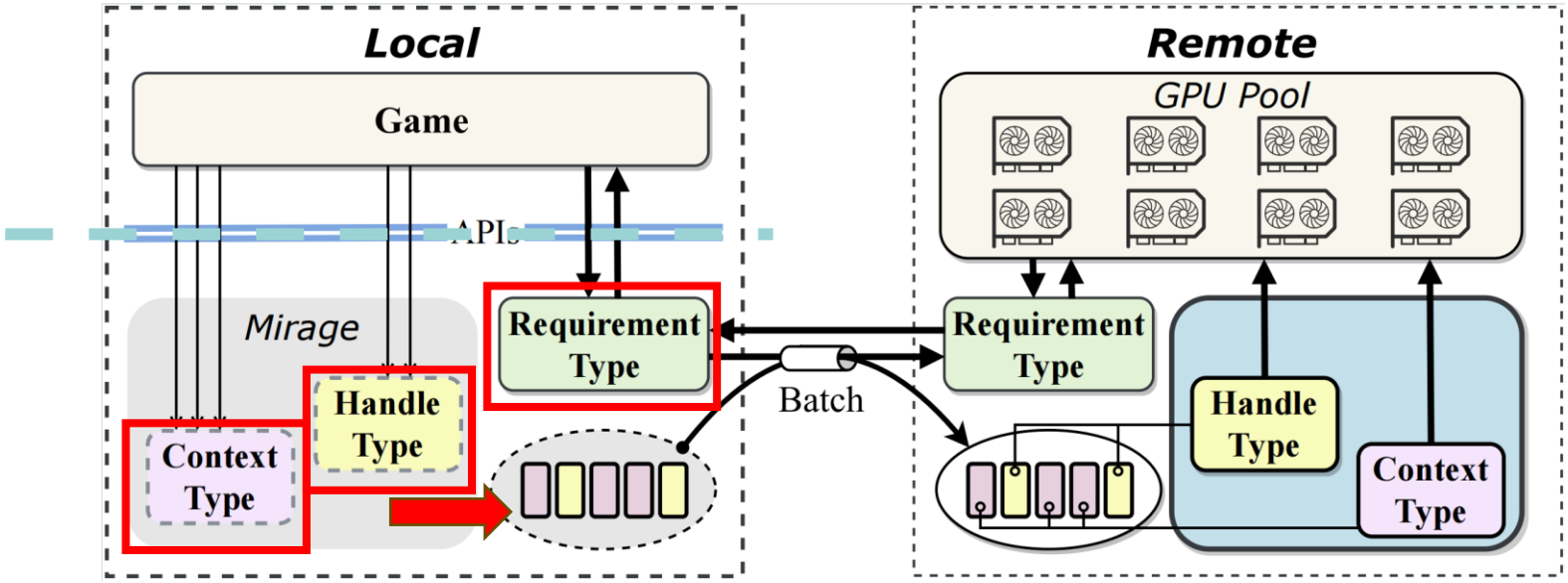

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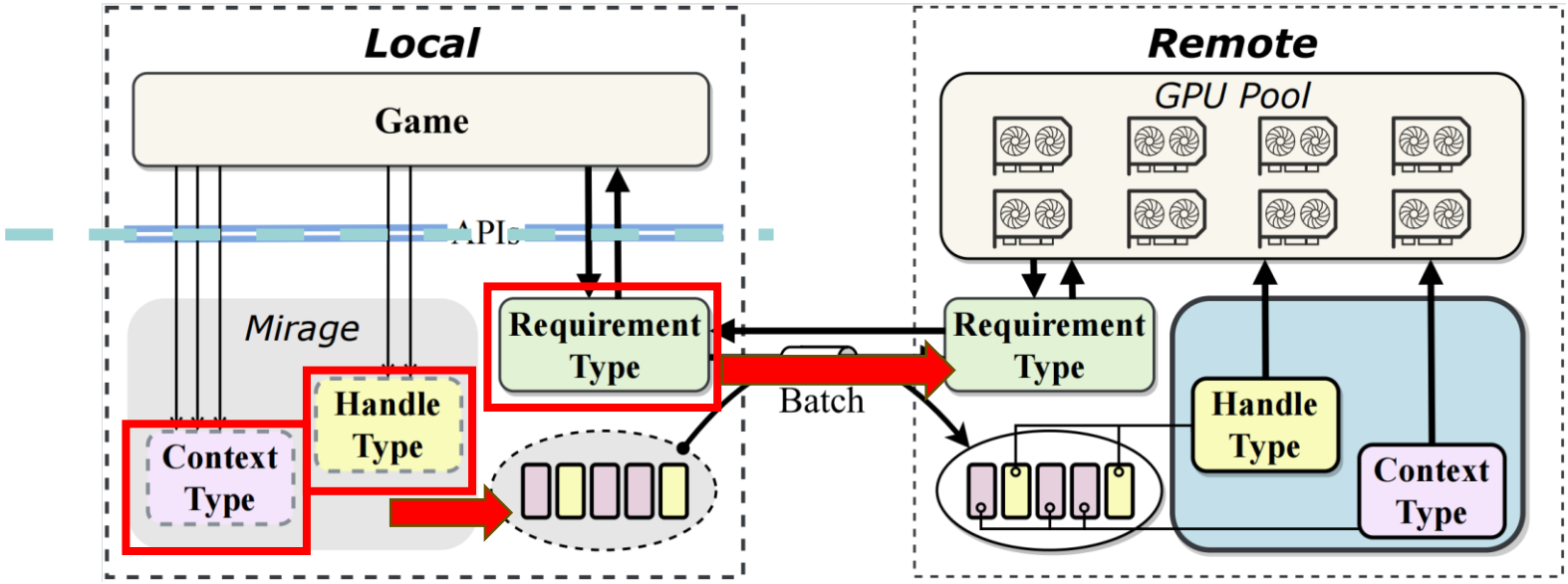

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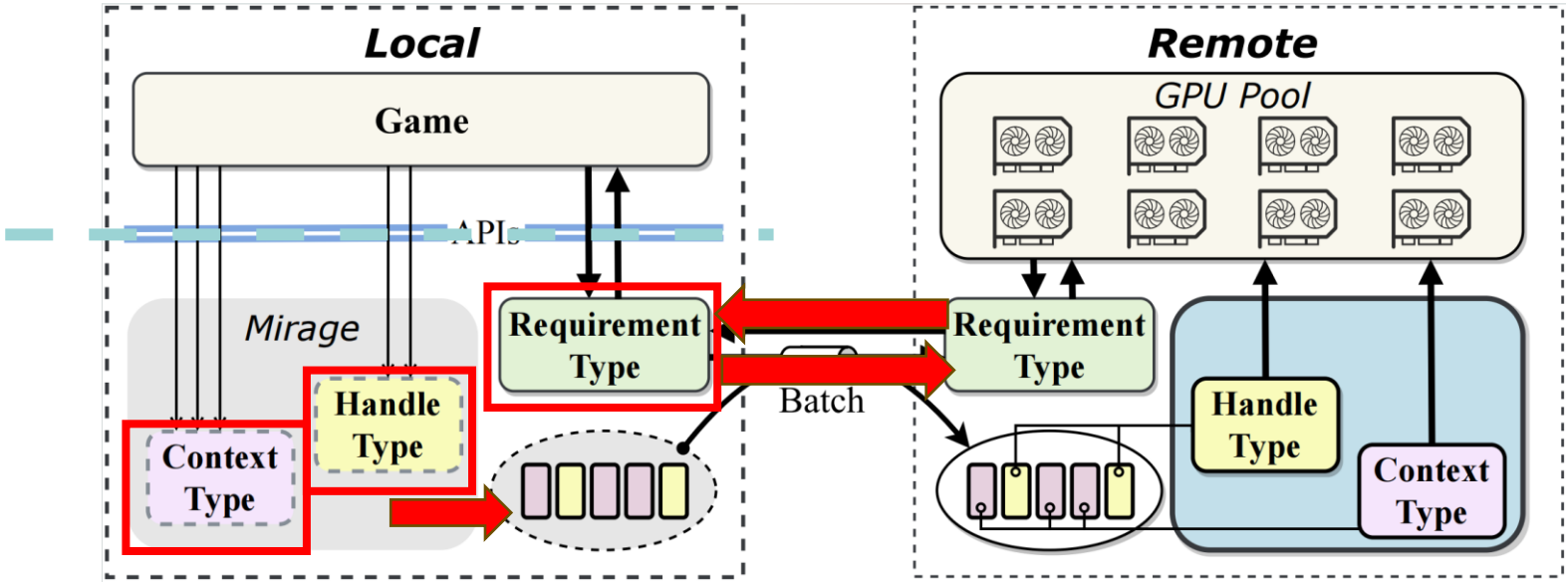
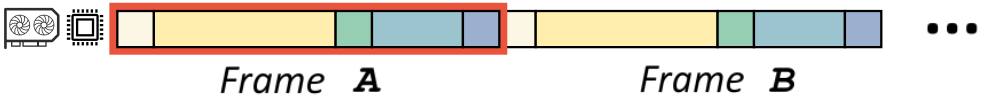
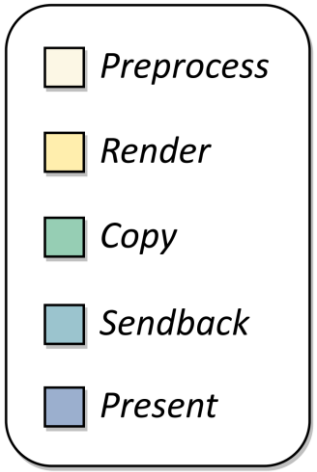


Dependency-decoupled parallel rendering

- Decouples the phases in a frame based on dependency relationships.
- Utilizes multi-threading to maximize GPU computation.





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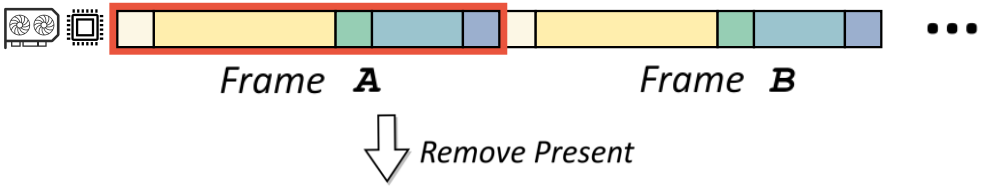

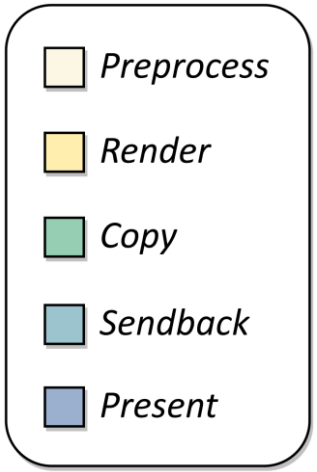

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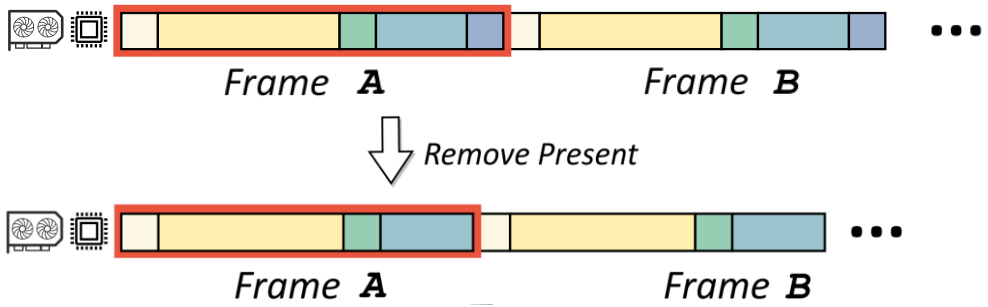

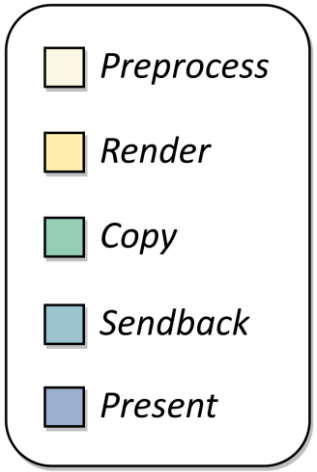

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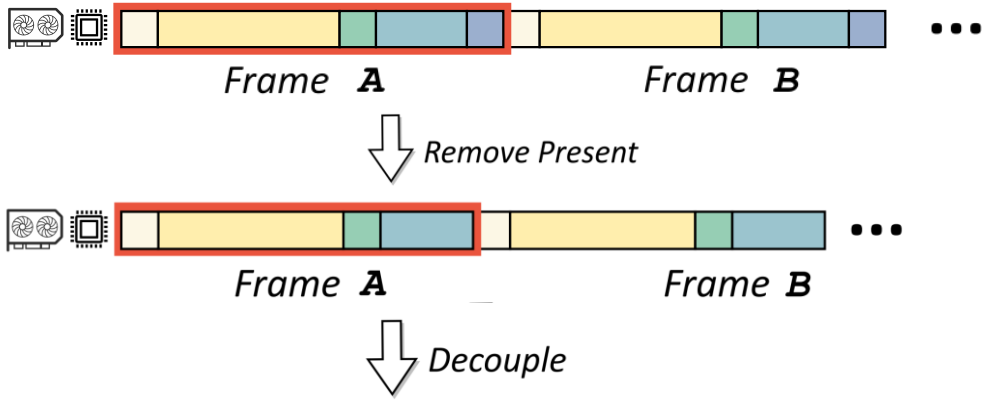

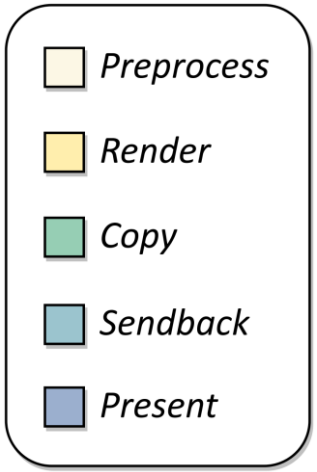

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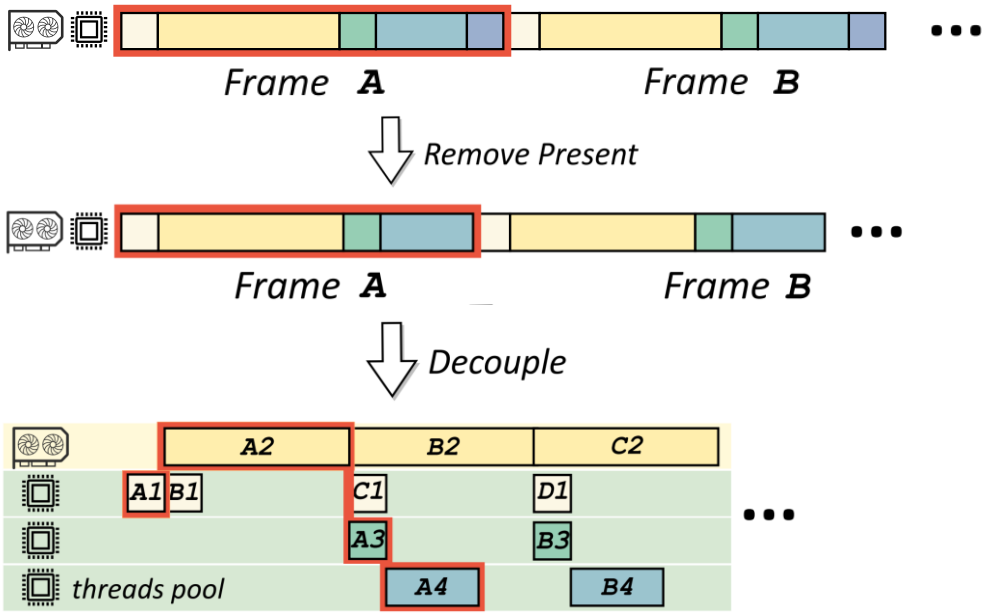
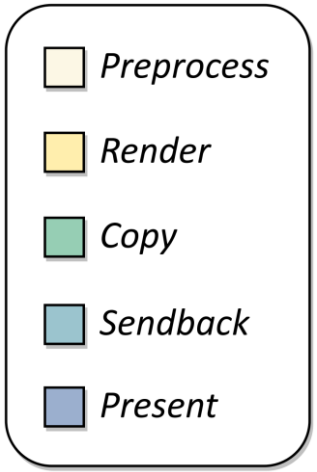
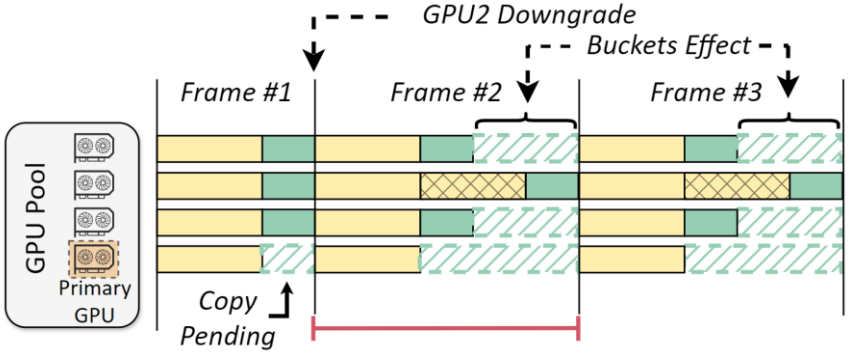
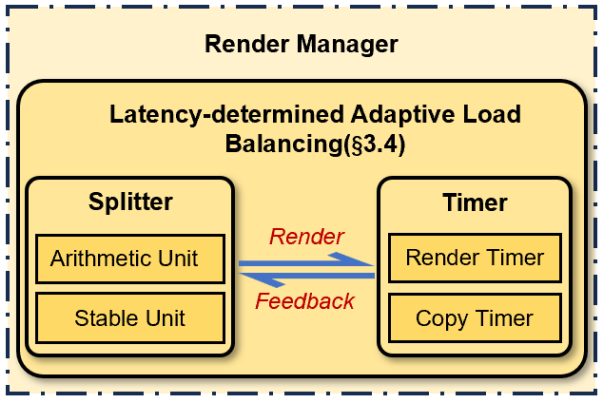


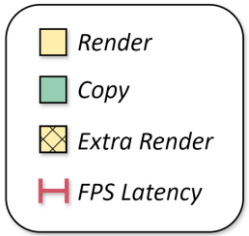


Latency-determined adaptive load balancing

- Obtaining the rendering and copying latency of GPUs through the Timer.
- Calculating the optimal allocation scheme based on the algorithm.
- Reducing Jitter with stable unit.







Latency-determined adaptive load balancing

- Obtaining the rendering and copying latency of GPUs through the Timer.
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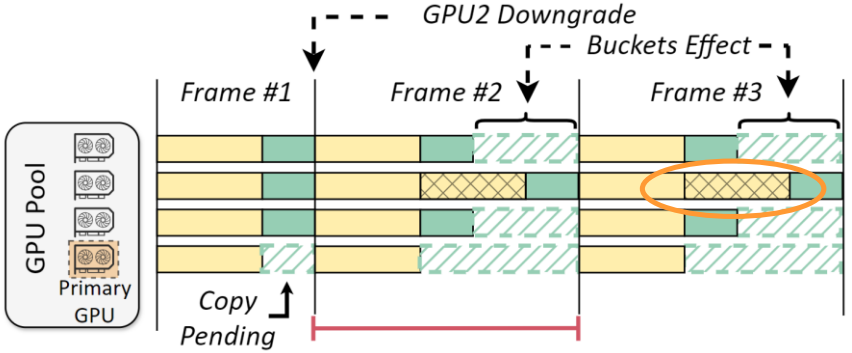

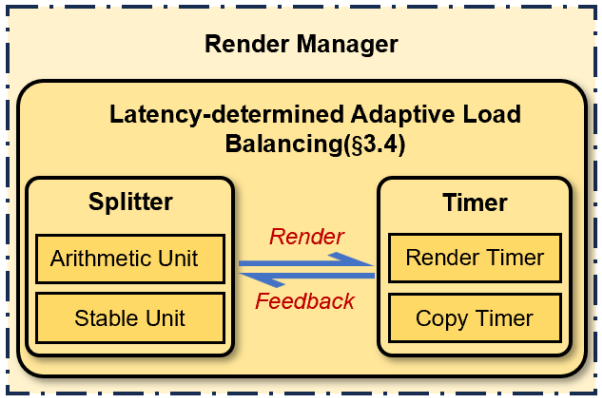

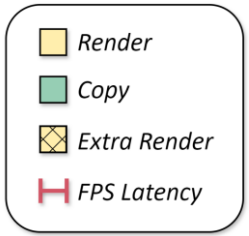

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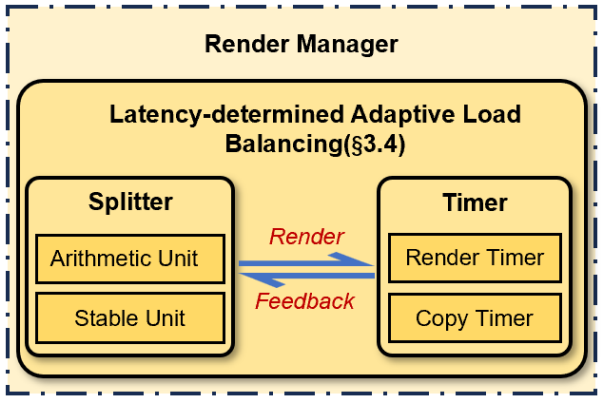

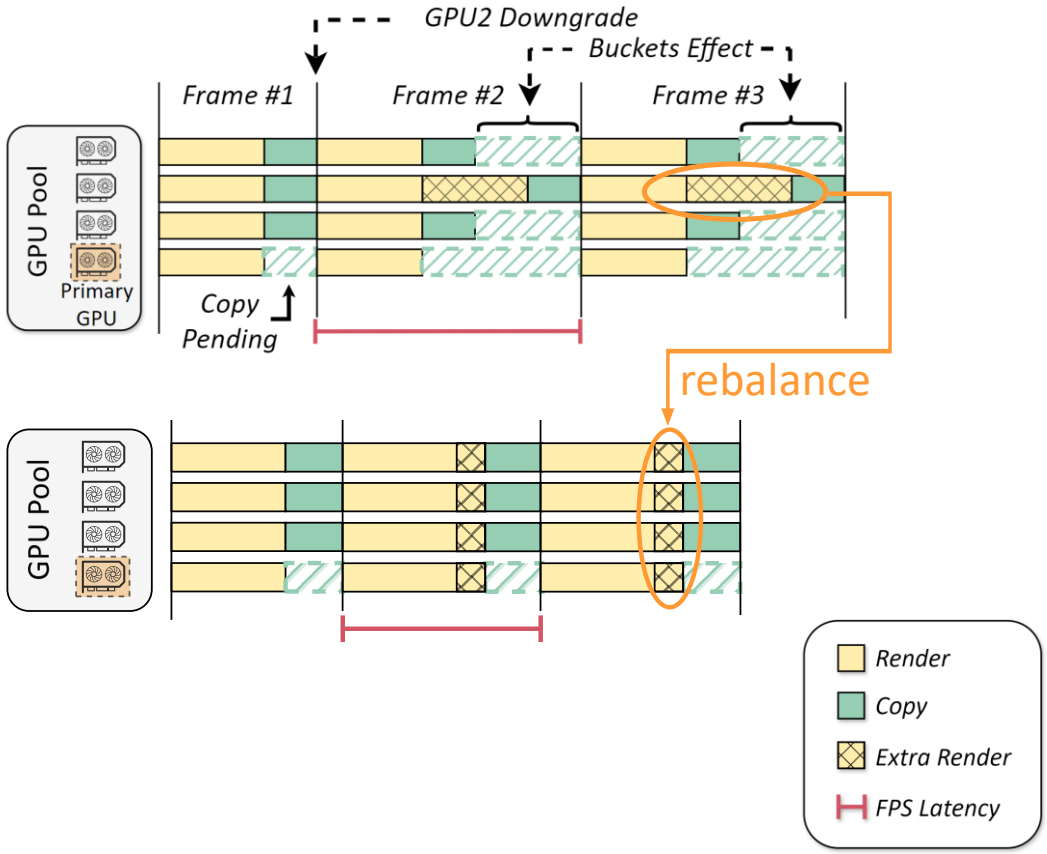

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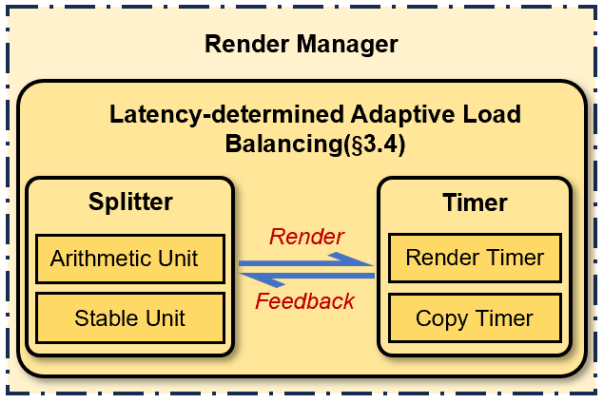

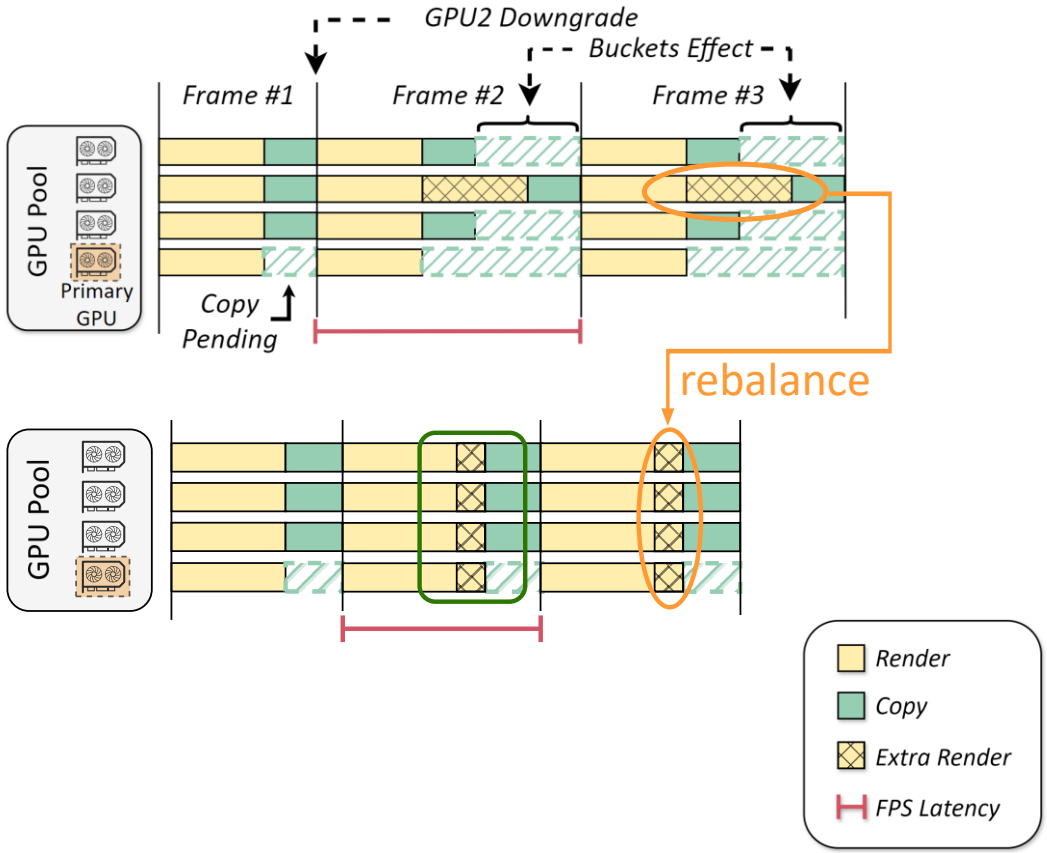

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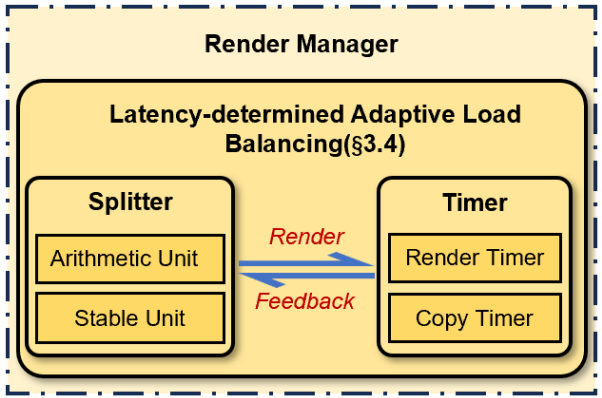

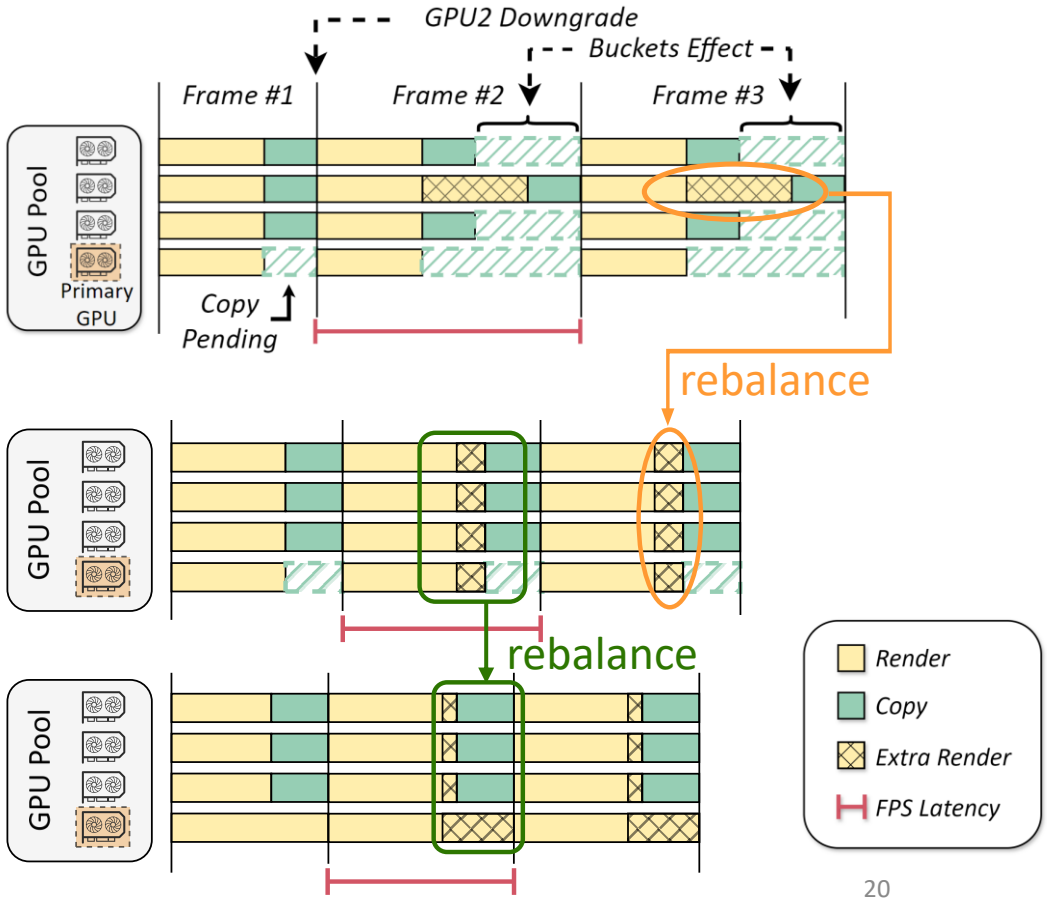

Ecosystem compatibility： improvement in FPS, image quality

Intra-GPU： performance of gVulkan

Inter-GPU: dynamic self-rebalancing

Evaluation

Ecosystem compatibility

- gVulkan reduces the impact of network latency on FPS.
- gVulkan can improve the rendering rate while maintaining image quality.

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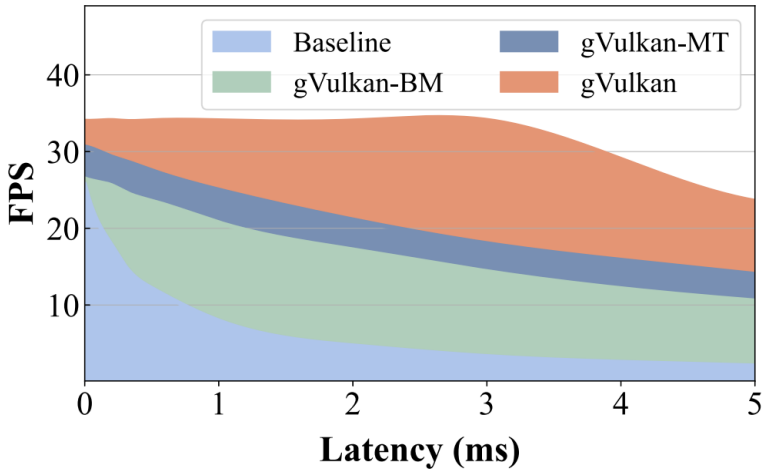

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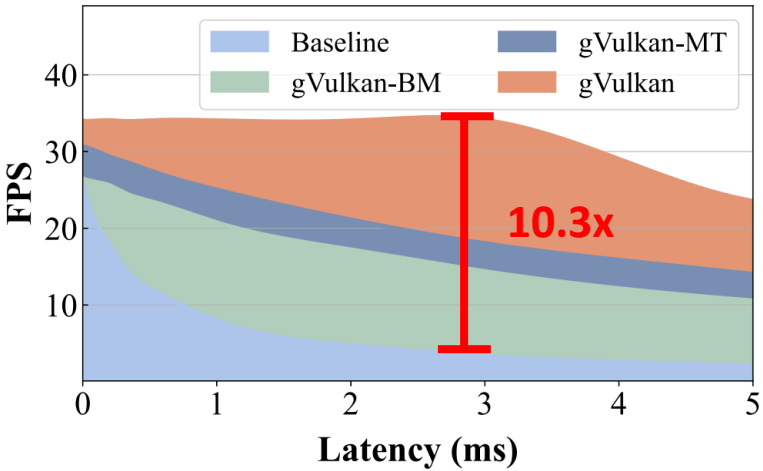

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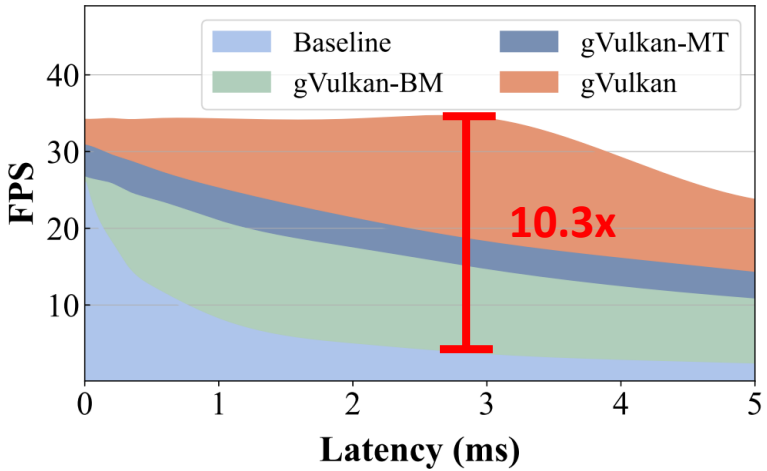

	360P	480P	720P	1080P
Outdoor-Simple	54.60	54.63	54.68	54.68
Outdoor-Lucy	41.64	41.70	42.06	42.07
Cornell-Simple	30.25	30.25	31.52	38.78
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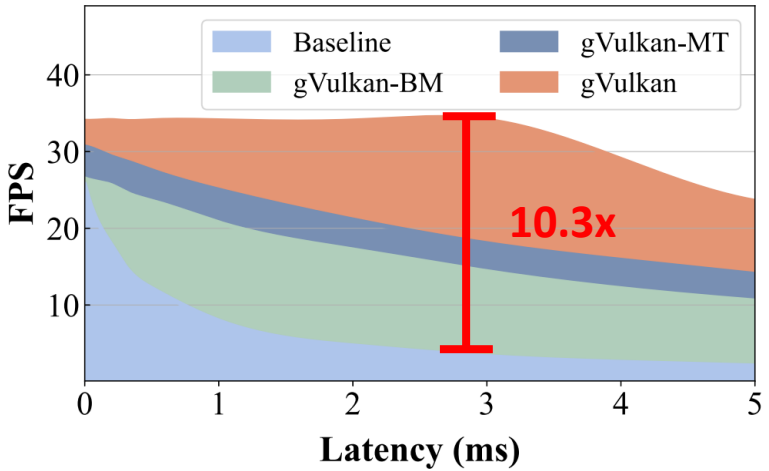

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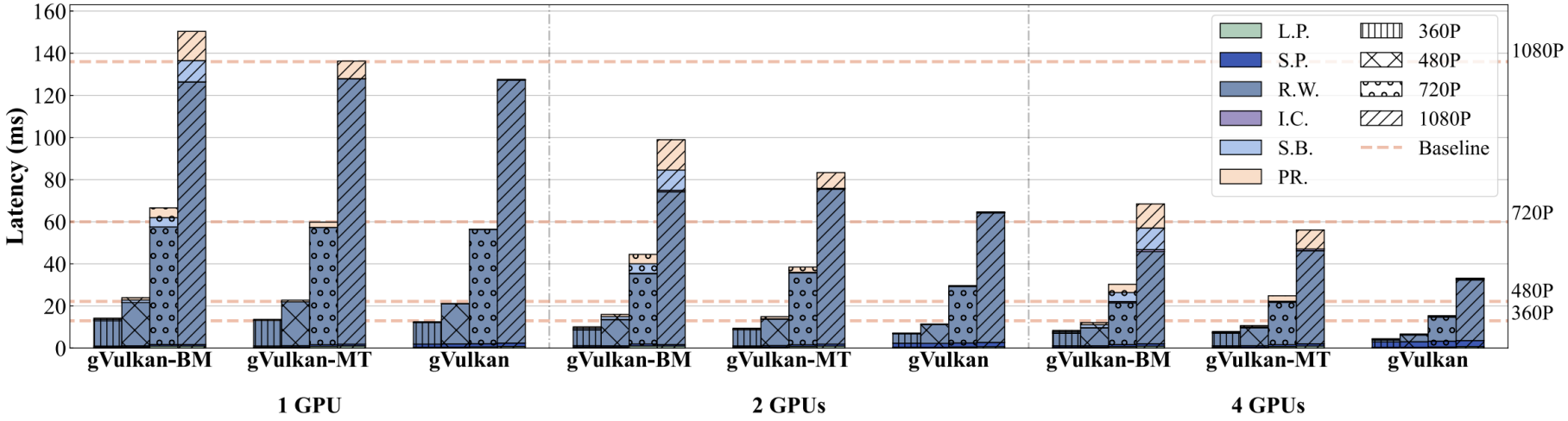
All PSNR >30

Performance of gVulkan

- While the local application fails to reach the 30 FPS threshold, gVulkan successfully achieved the QoS guarantee of 60 FPS with 4 GPUs.
- The average speedup for the four scenes under the gVulkan with 4 GPUs can reach 3.81.



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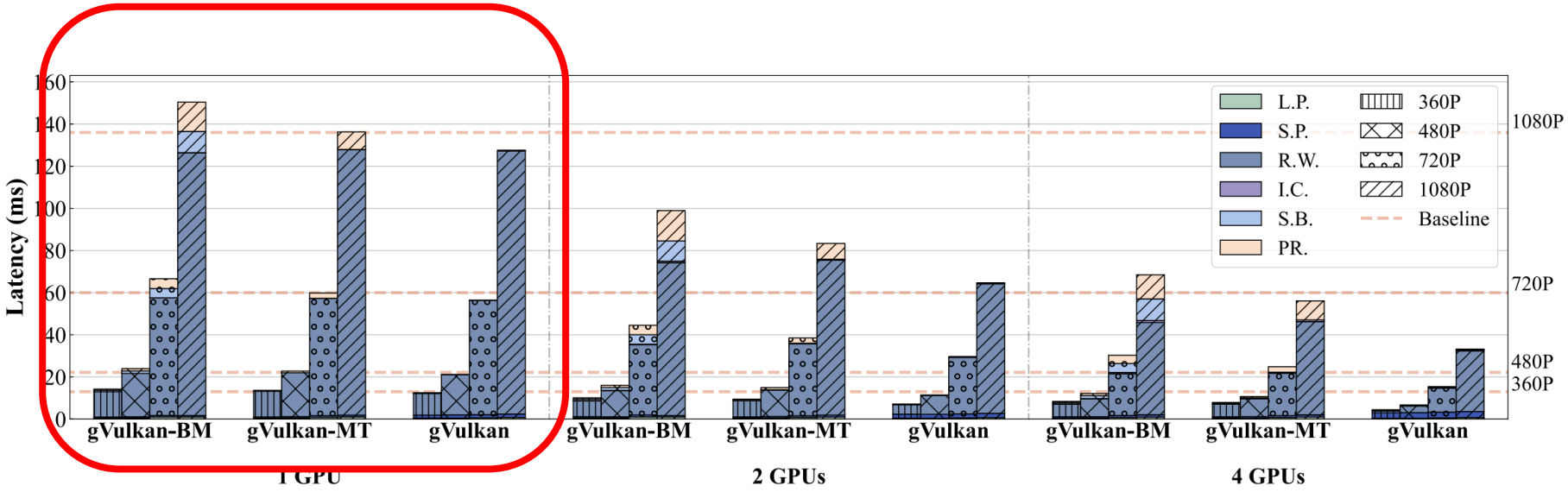

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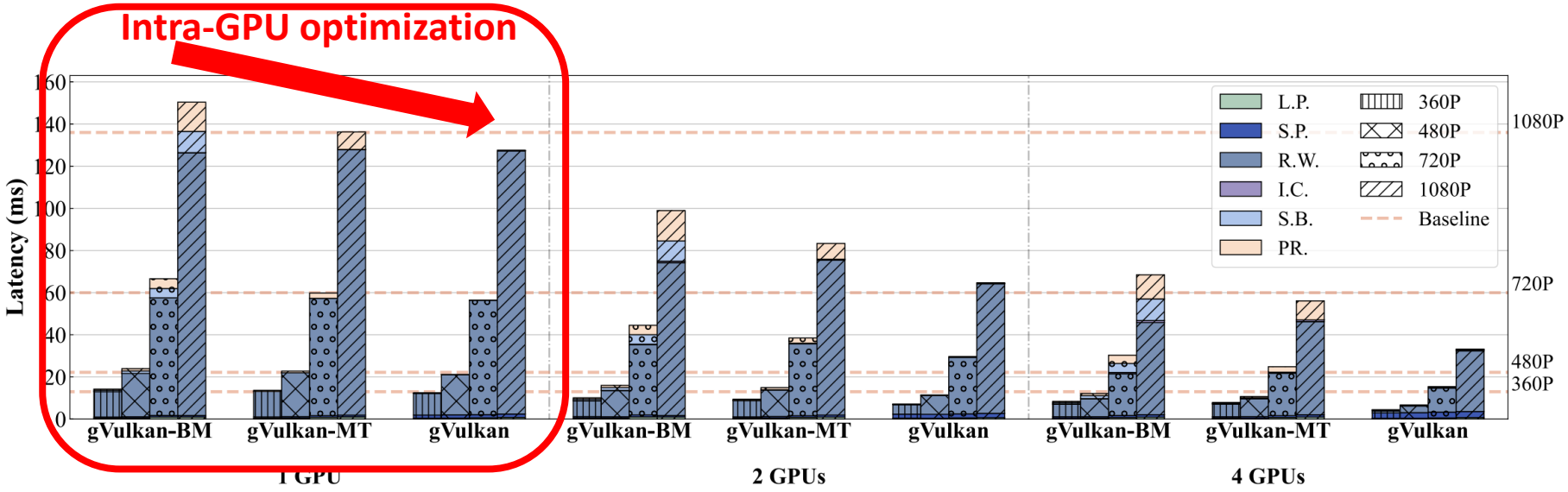

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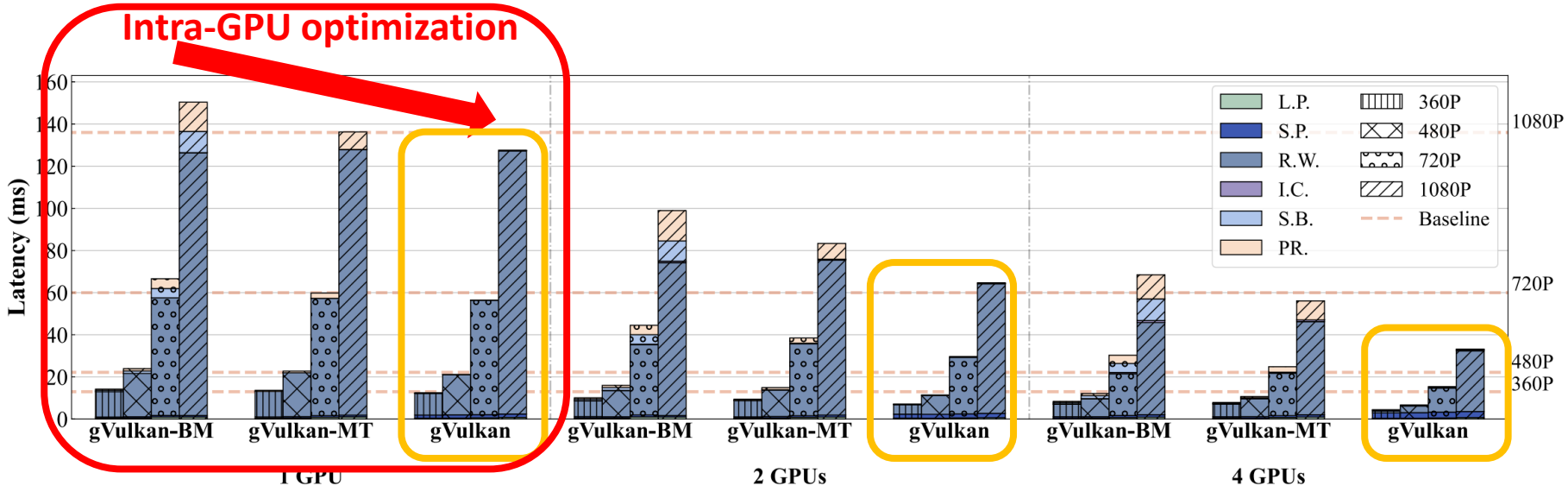

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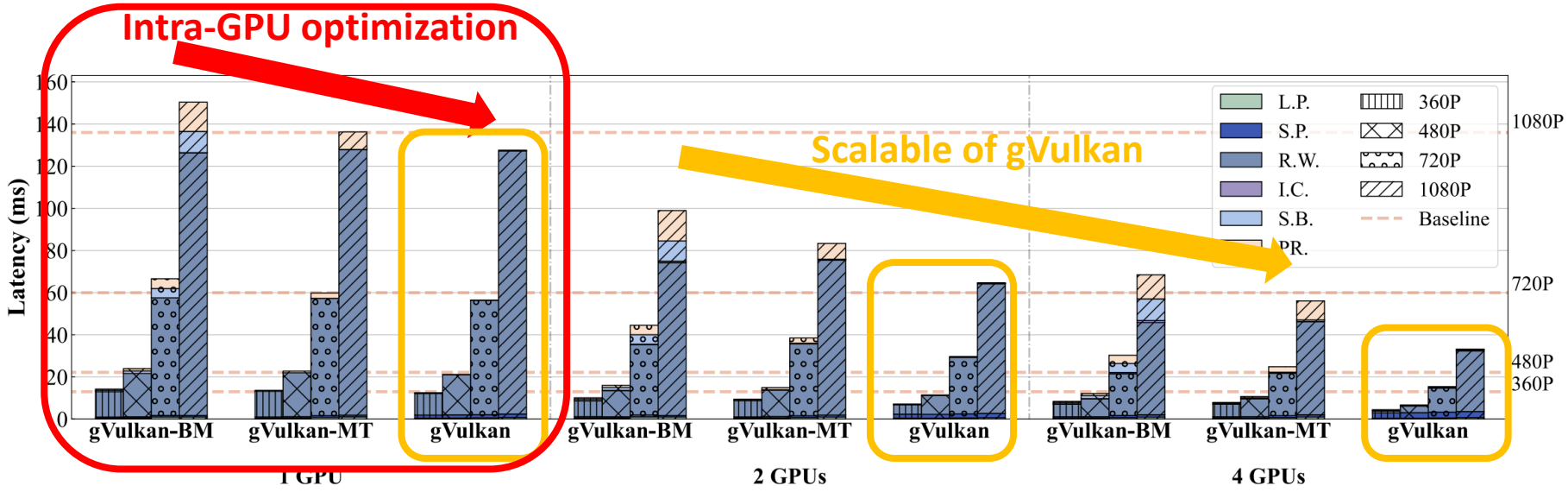

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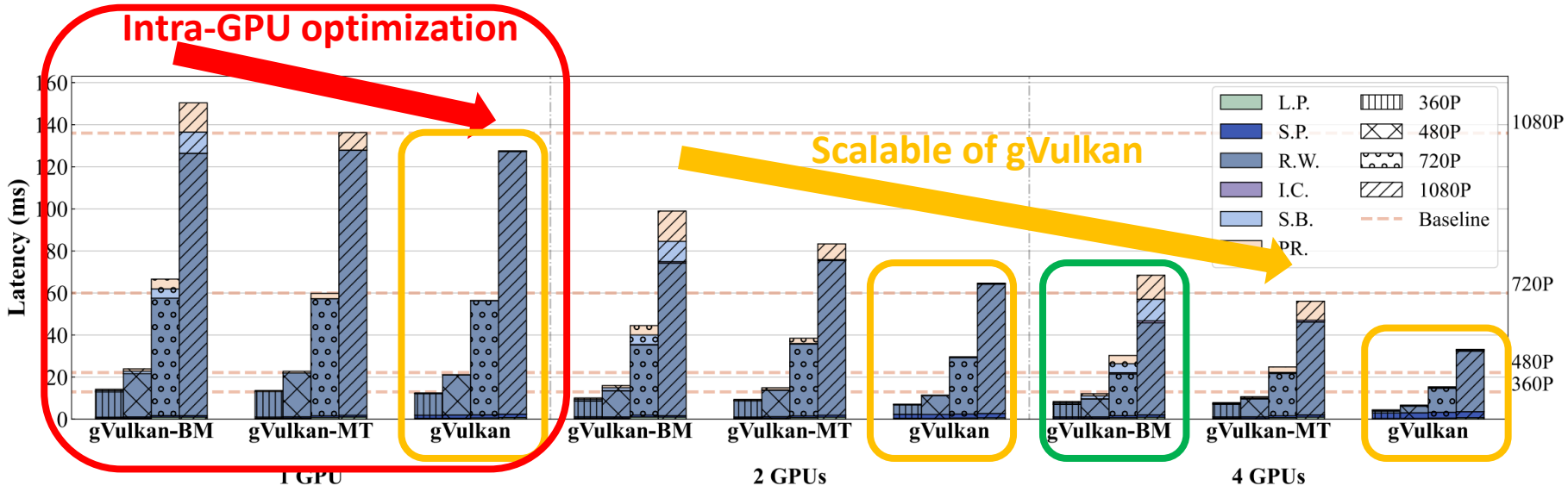

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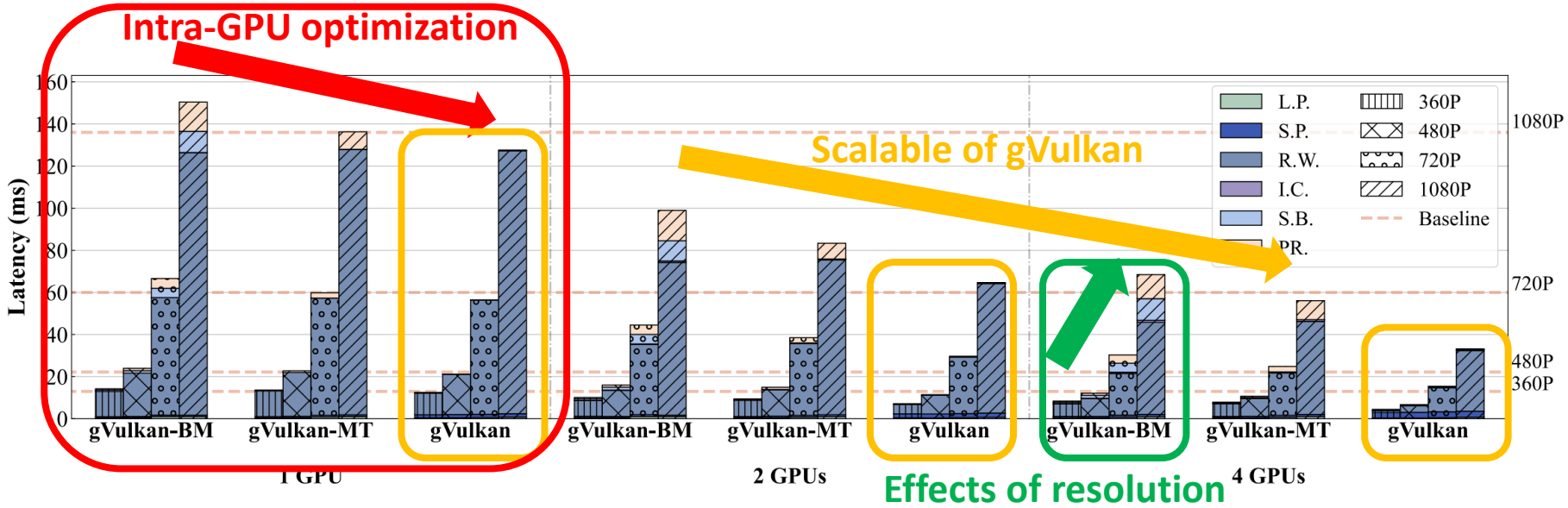
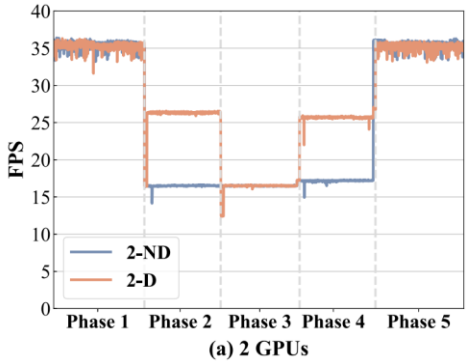
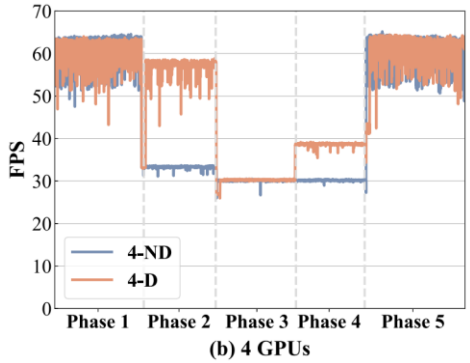
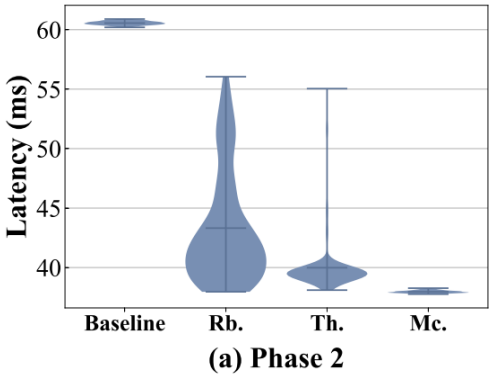


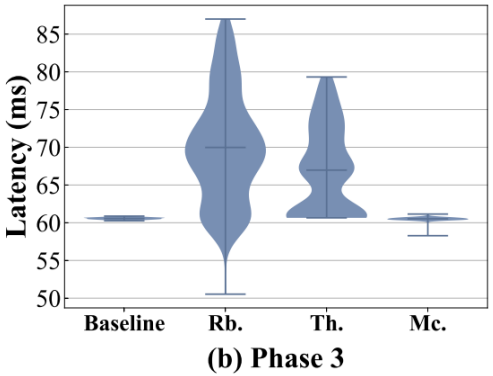
Dynamic self-rebalancing

- Dynamic rebalancing significantly reduces maximum latency when the GPU's rendering power is not evenly distributed
- Stable units can effectively reduce fluctuations and latency.









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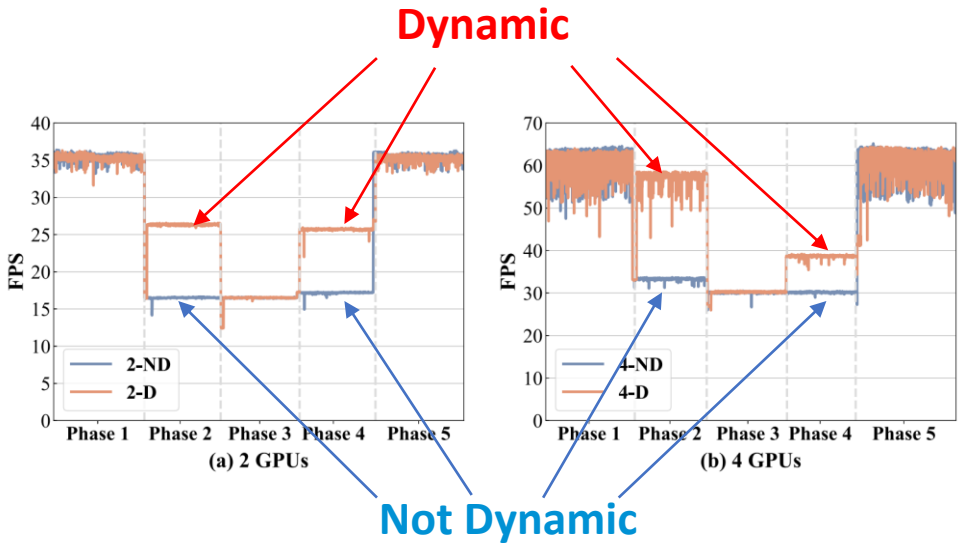

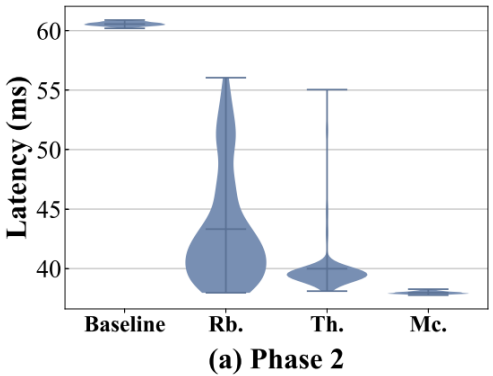

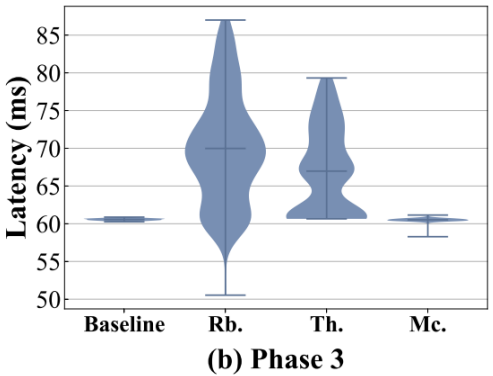

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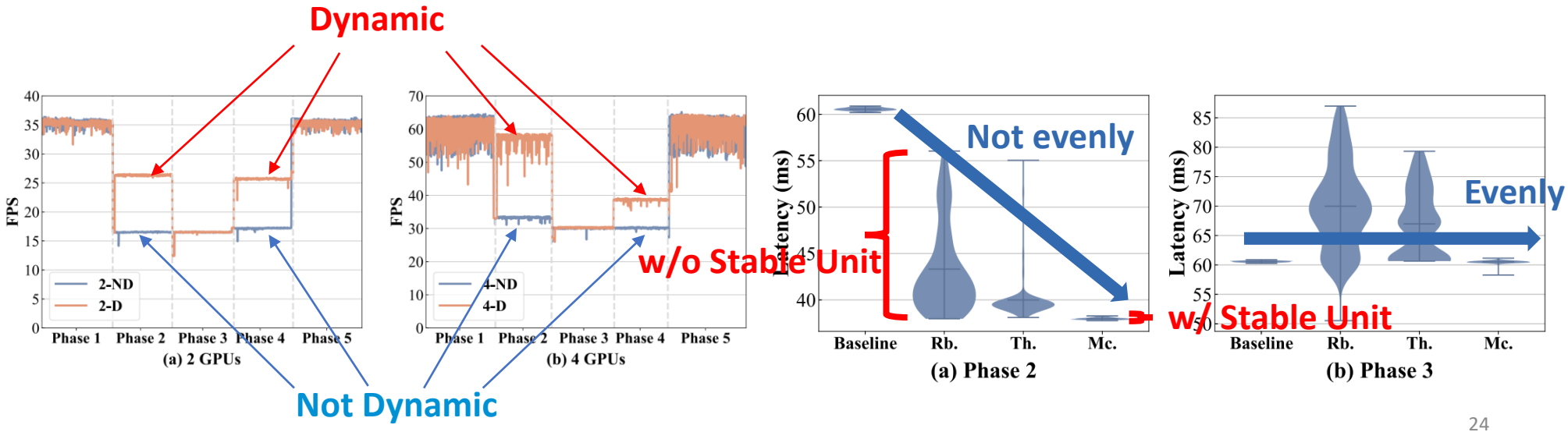

Conclusion

gVulkan is the first transparent multi-GPU acceleration rendering solution for Vulkan-based ray tracing rendering.

- A resource-classified transparent forwarding scheme.
- A latency-determined adaptive load balancing mechanism.
- A dependency-decoupled parallel rendering approach.

- gVulkan achieves good linearity with 3.81× speedup across 4 GPUs on average.

https://github.com/funnygyc/gVulkan-artifact

THANK YOU

上海交通大學
SHANGHAI JIAO TONG UNIVERSITY

Q&A

USENIX ATC '24

Yicheng Gu, Yun Wang, Yunfan Sun, Yuxin Xiang,
Yufan Jiang, Xuyan Hu, Zhengwei Qi, Haibing Guan