Parallel Ray Tracer

Group 8:

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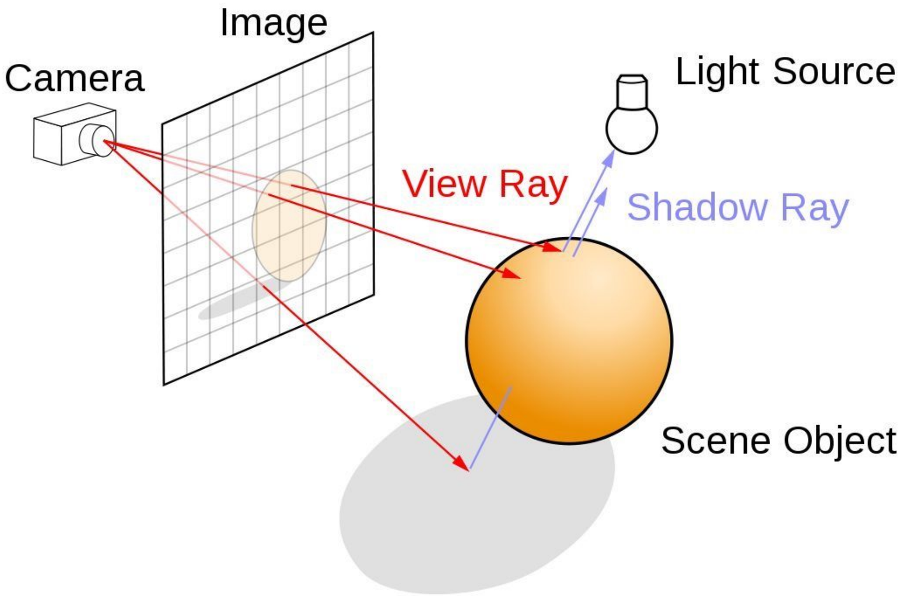
Outline

- Introduction
- Problem Statement
- Proposed Solution
- Evaluation
- Conclusion

Introduction

Introduction

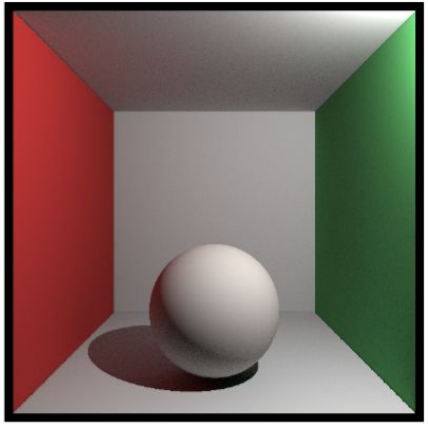
- Ray tracing is a rendering method that simulates the behavior of light to create realistic images



Problem Statement

Problem Statement

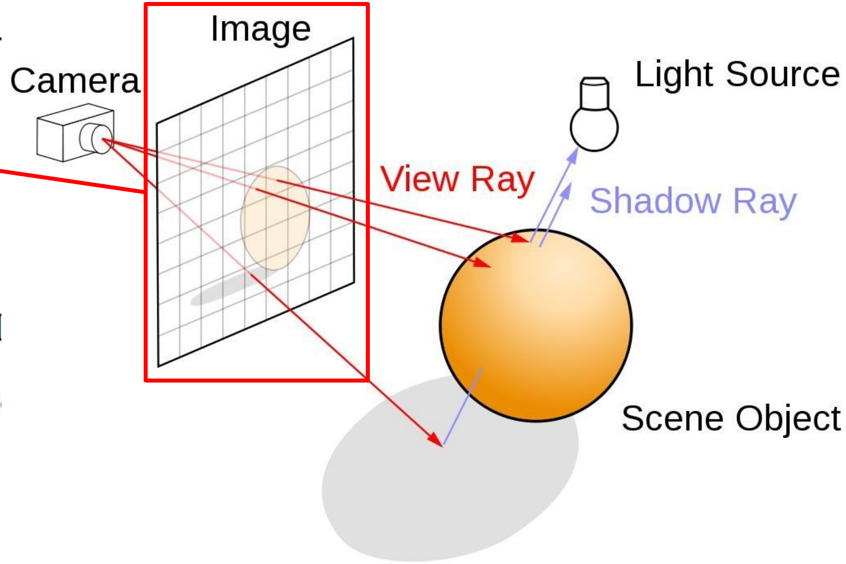
- Serial version of the Ray Tracer requires rendering one pixel before proceeding to the next, resulting in significant time wastage.
- Utilize parallelism methods to minimize computational costs.



Ray Tracing Renderer

Algorithm 1: The Conceptual Workflow of Ray Tracing

```
for p = 1 to P do
    Image[p] = [0 0 0]
    for s = 1 to S do
        Ray = GenerateRay(p)
        for b = 1 to B do
            Initialize IntersectionResult
            for g = 1 to G do
                IntersectionResult = IntersectionTesting(Ray, GeometricObjects[
            if IntersectionResult.Hit then
                Image[p] = Image[p] + CalculateColor(LightSource, Ray, Interse
                Ray = GenerateNextRay(Ray, IntersectionResult)
            else
                break
    Image[p] = Image[p] / S
```



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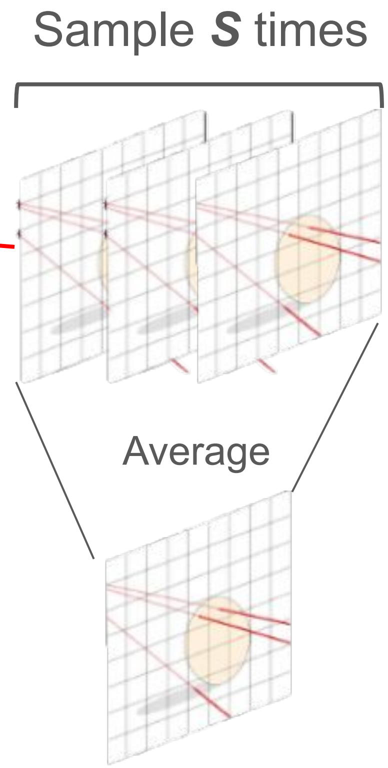

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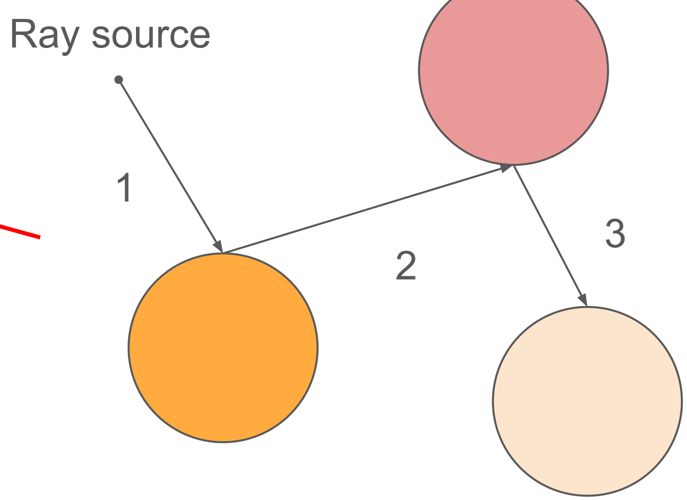
```

Bounce ***B*** times per ray



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```
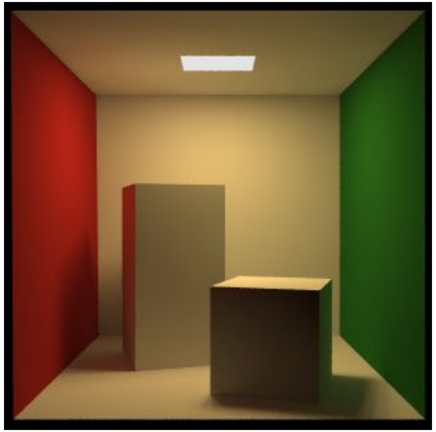

Number of Objects ***G***



Ray Tracing Renderer

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```

C vector components

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix}$$

Ray Tracing Renderer

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        for b = 1 to B do
            Initialize IntersectionResult
            for g = 1 to G do
                IntersectionResult = IntersectionTesting(Ray, GeometricObjects[g], IntersectionResult)
            if IntersectionResult.Hit then
                Image[p] = Image[p] + CalculateColor(LightSource, Ray, IntersectionResult)
                Ray = GenerateNextRay(Ray, IntersectionResult)
            else
                break
    Image[p] = Image[p] / S
```
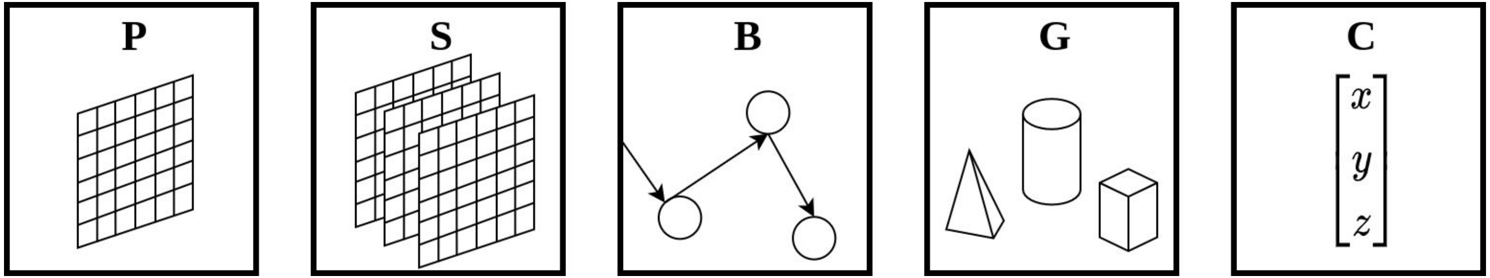
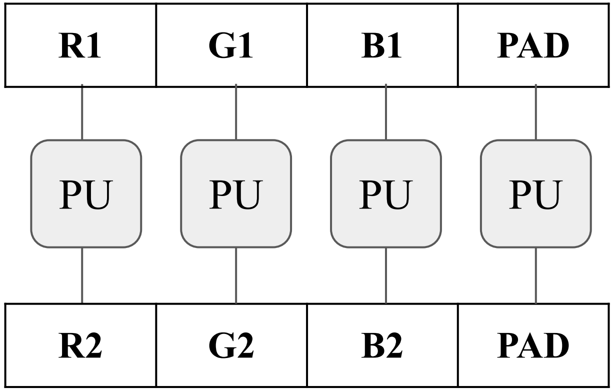



Proposed Solution

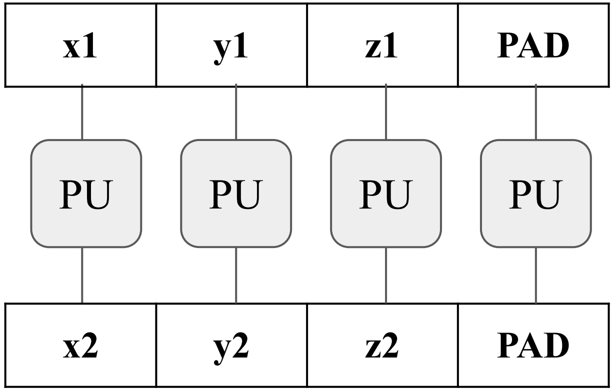
Proposed Solution (SIMD)

- Parallelize vector computation on arithmetic operations of floating point values
  - Addition, Multiplication, Dot Product, …

RGB computation



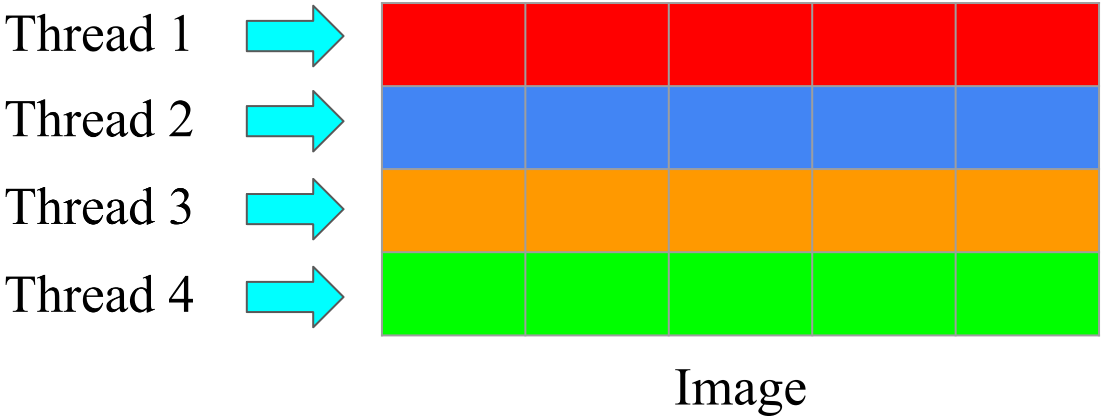
Coordinates computation



Proposed Solution (OpenMP)

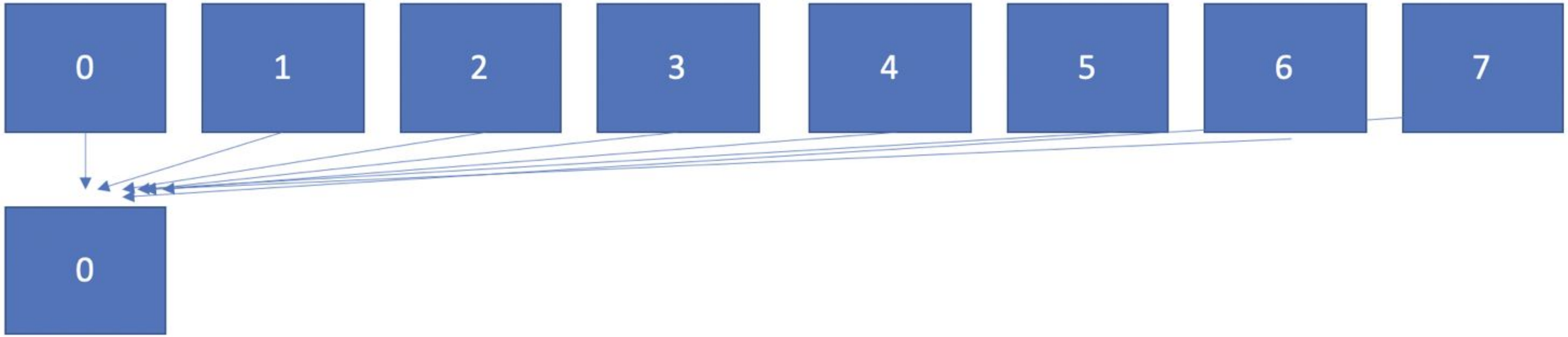
- Utilize the dynamic scheduling provided by OpenMP to dynamically allocate threads for parallel computation of each row in the image.

```
#pragma omp parallel for schedule(dynamic)
```



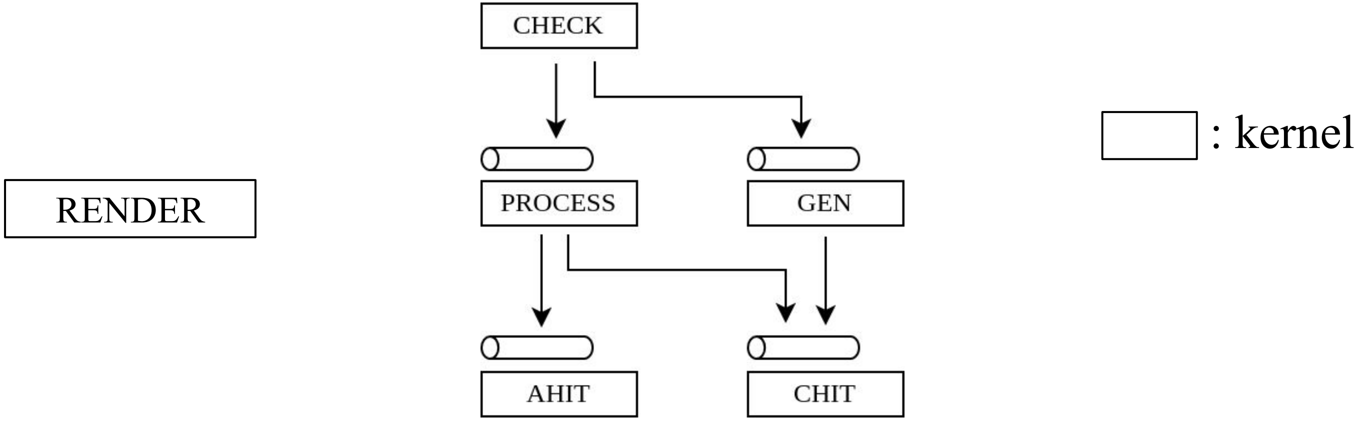
Proposed Solution (MPI)

- Distribute the rows of the image evenly among different servers for parallel computation.
- Finally, consolidate all calculations to generate the ultimate rendered image.



Proposed Solution (CUDA Mega/Split)

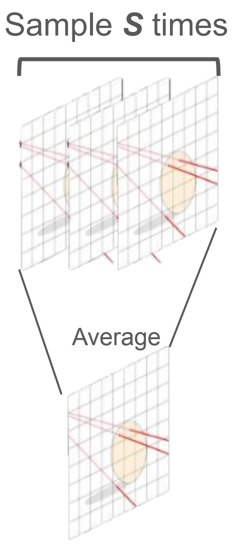
- We developed two versions of CUDA implementations to accelerate ray tracing
  - 1. Mega: Consolidates computations into a single “mega” kernel
  - 2. Split: Divides mega kernel into smaller kernels

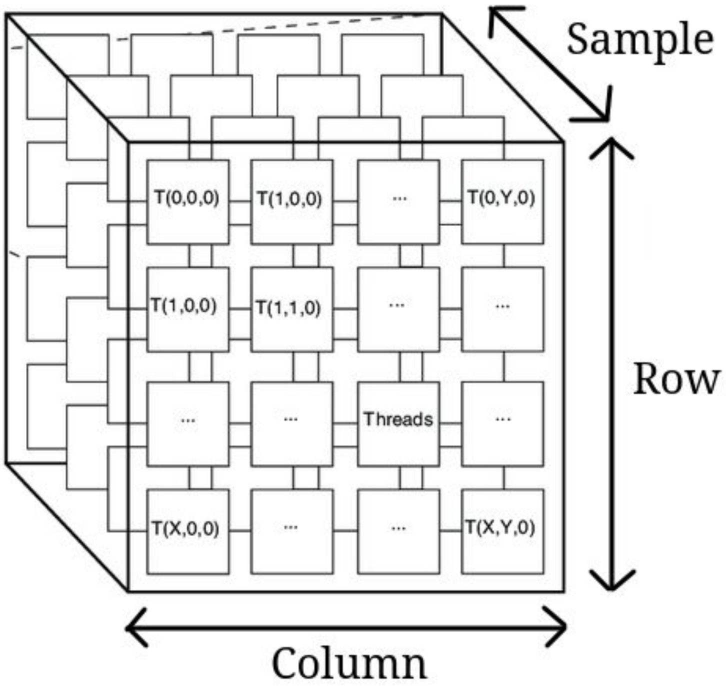


CUDA Mega CUDA Split

Proposed Solution (CUDA Mega)

- The CUDA Mega simply assign each CUDA thread a sample to work with

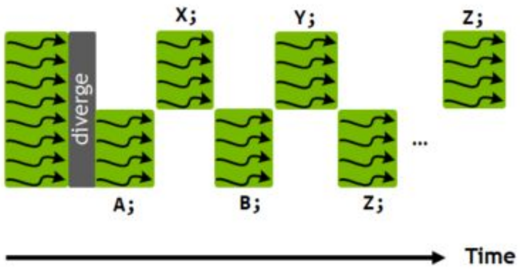




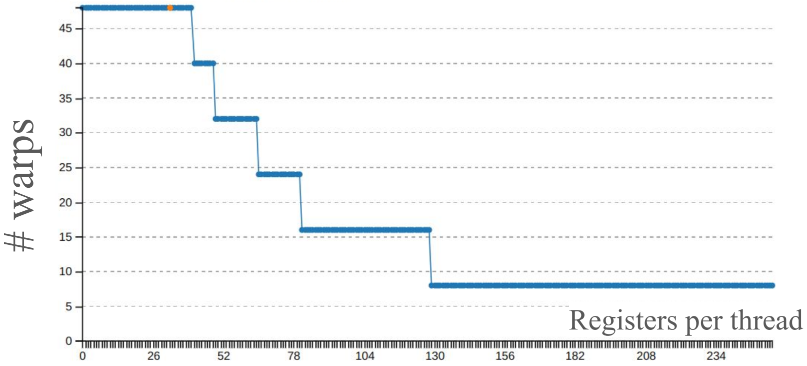
Proposed Solution (CUDA Mega)

- Disadvantages of mega kernel:
  - Divergence in control flow
  - High register usage ⇒ decreased concurrent warps

```
if (threadIdx.x < 4) {
    A;
    B;
} else {
    X;
    Y;
}
Z;
```



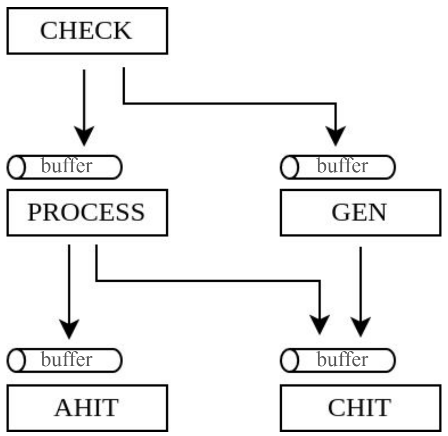
CUDA occupancy
Impact of Varying Register Count Per Thread

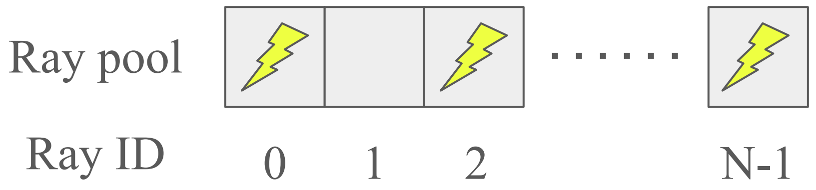


Megakernels Considered Harmful: Wavefront Path Tracing on GPUs [Laine et al., HPG 2013]

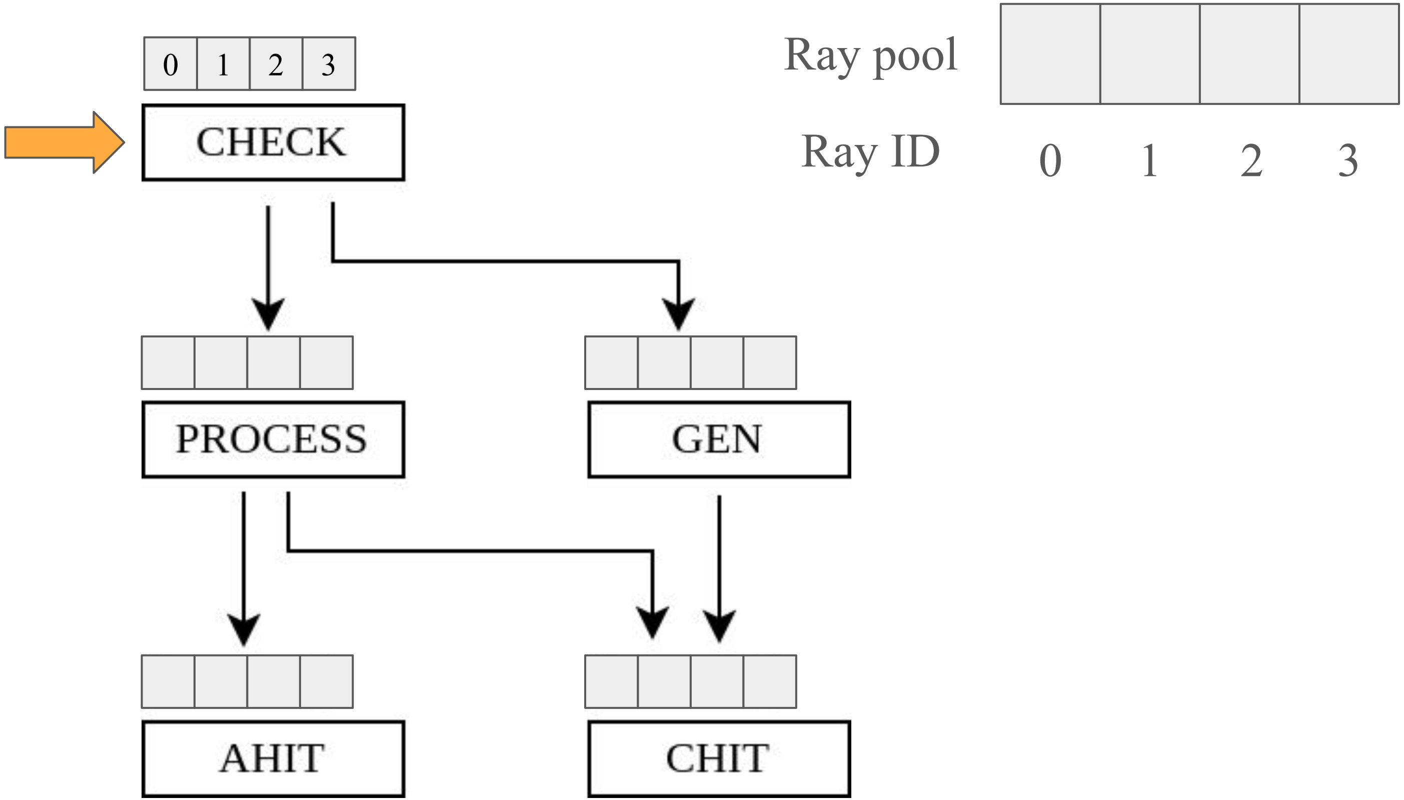
Proposed Solution (CUDA Split)

- We split mega kernel into five small kernels
  - CHECK, PROCESS, GEN, AHIT, CHIT
  - Rays are stored in ray pool
  - Different kernels communicate by passing ray ID to the target kernel's buffer





Proposed Solution (CUDA Split)



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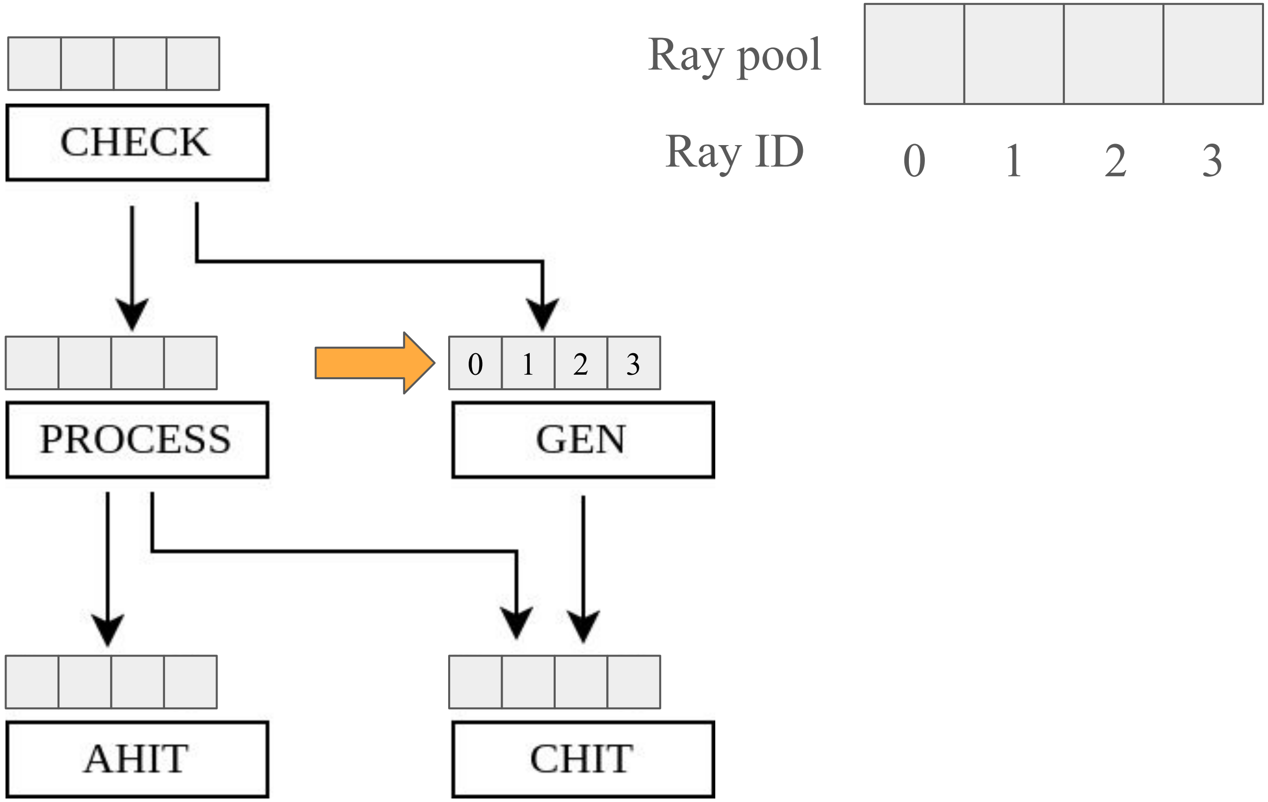

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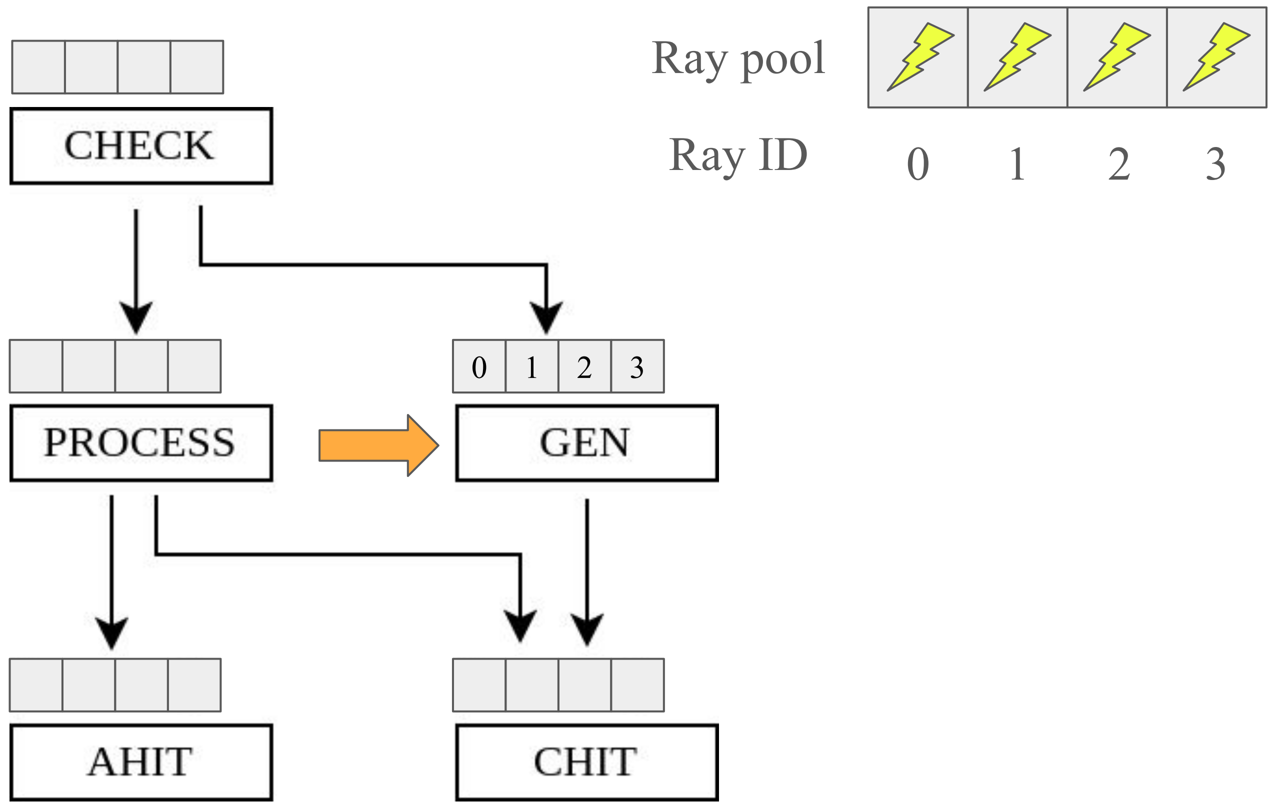

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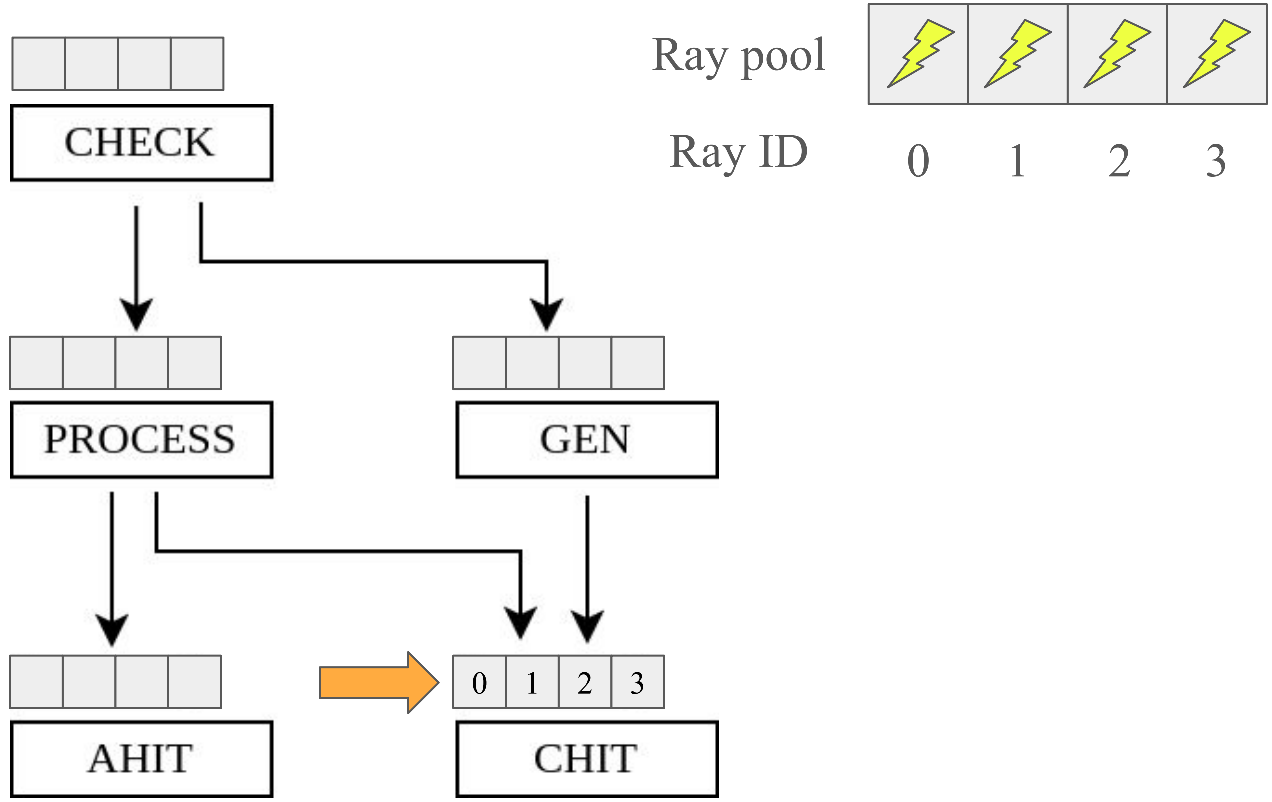

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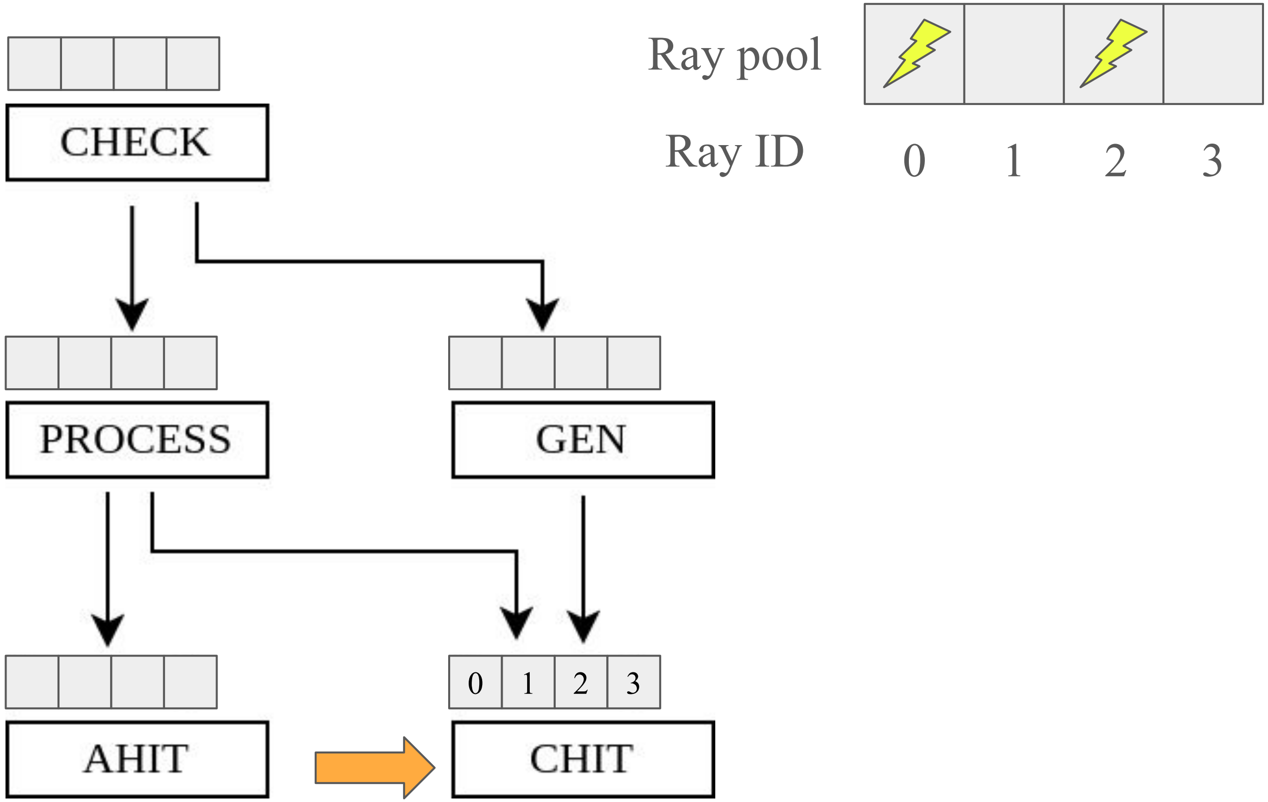

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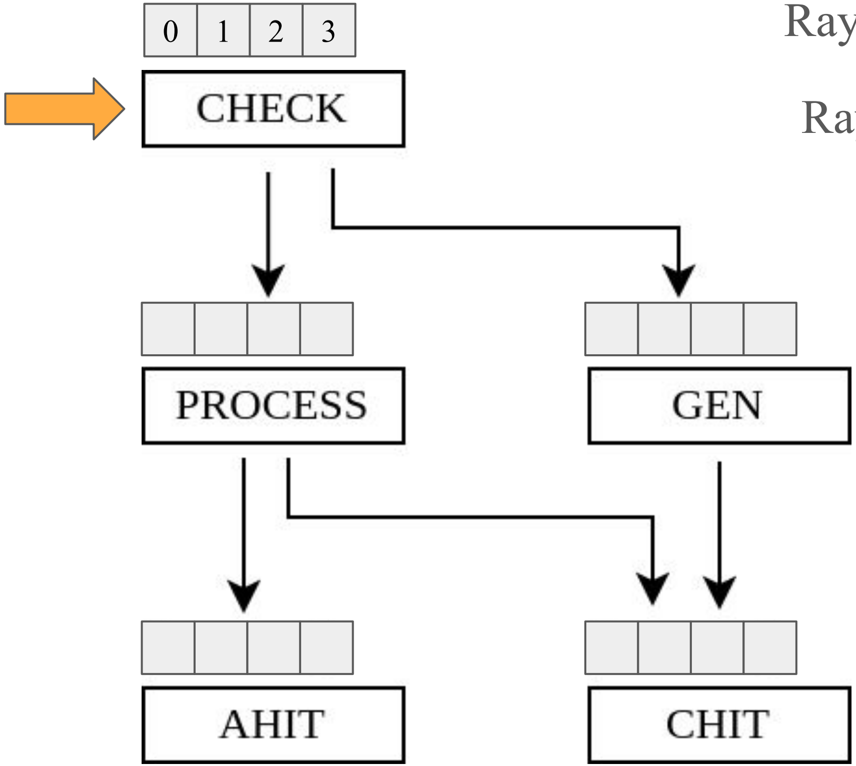

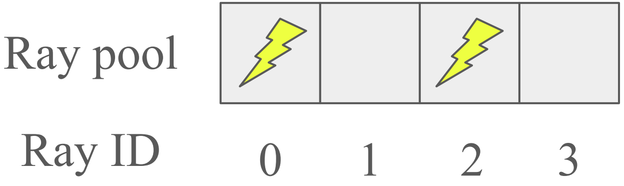

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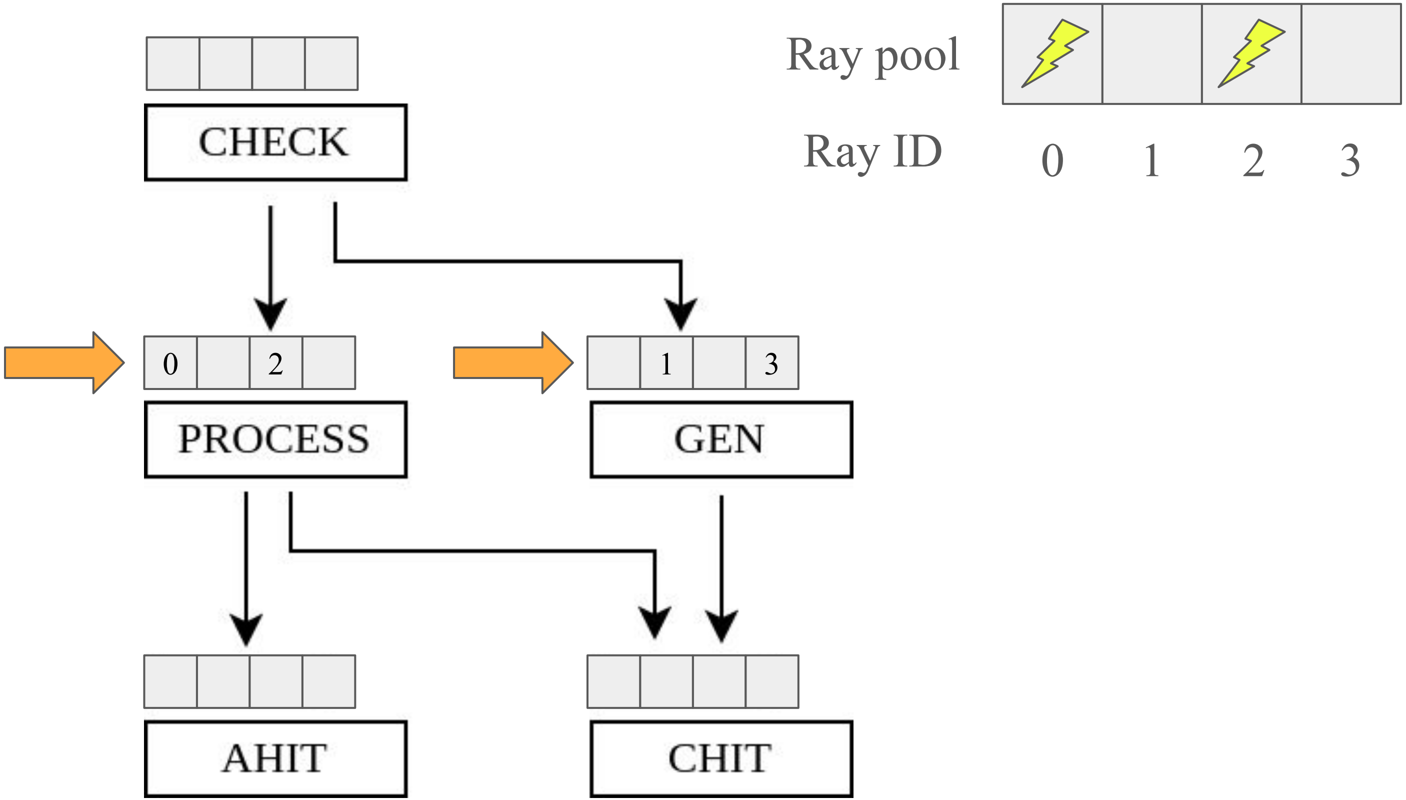

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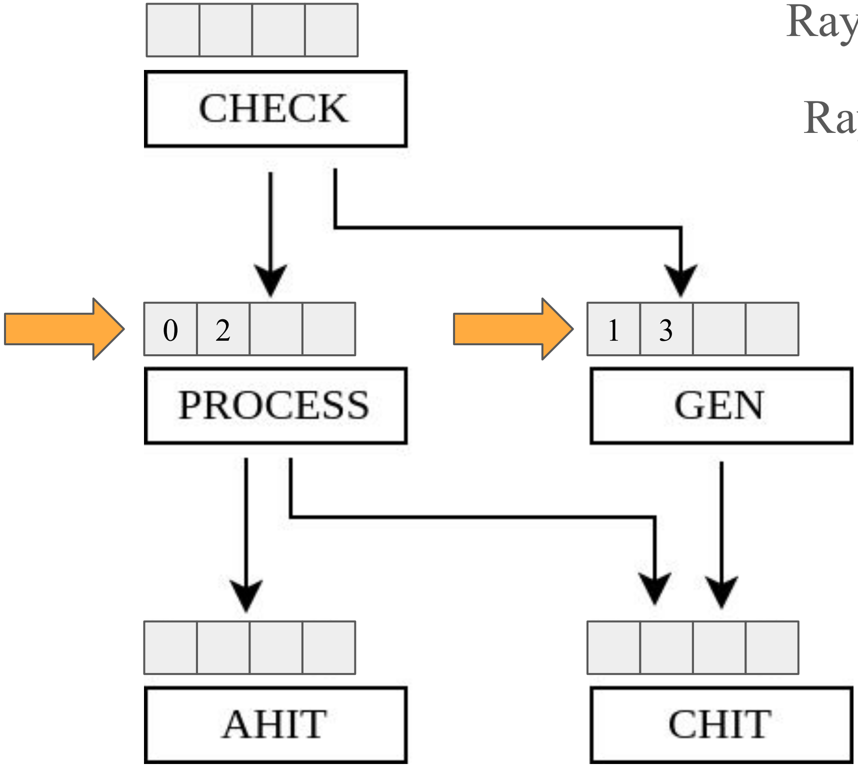
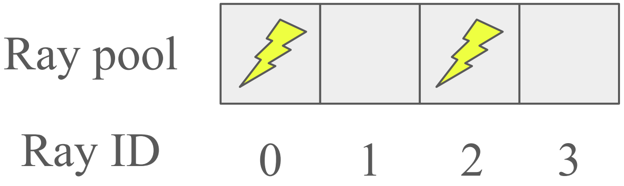
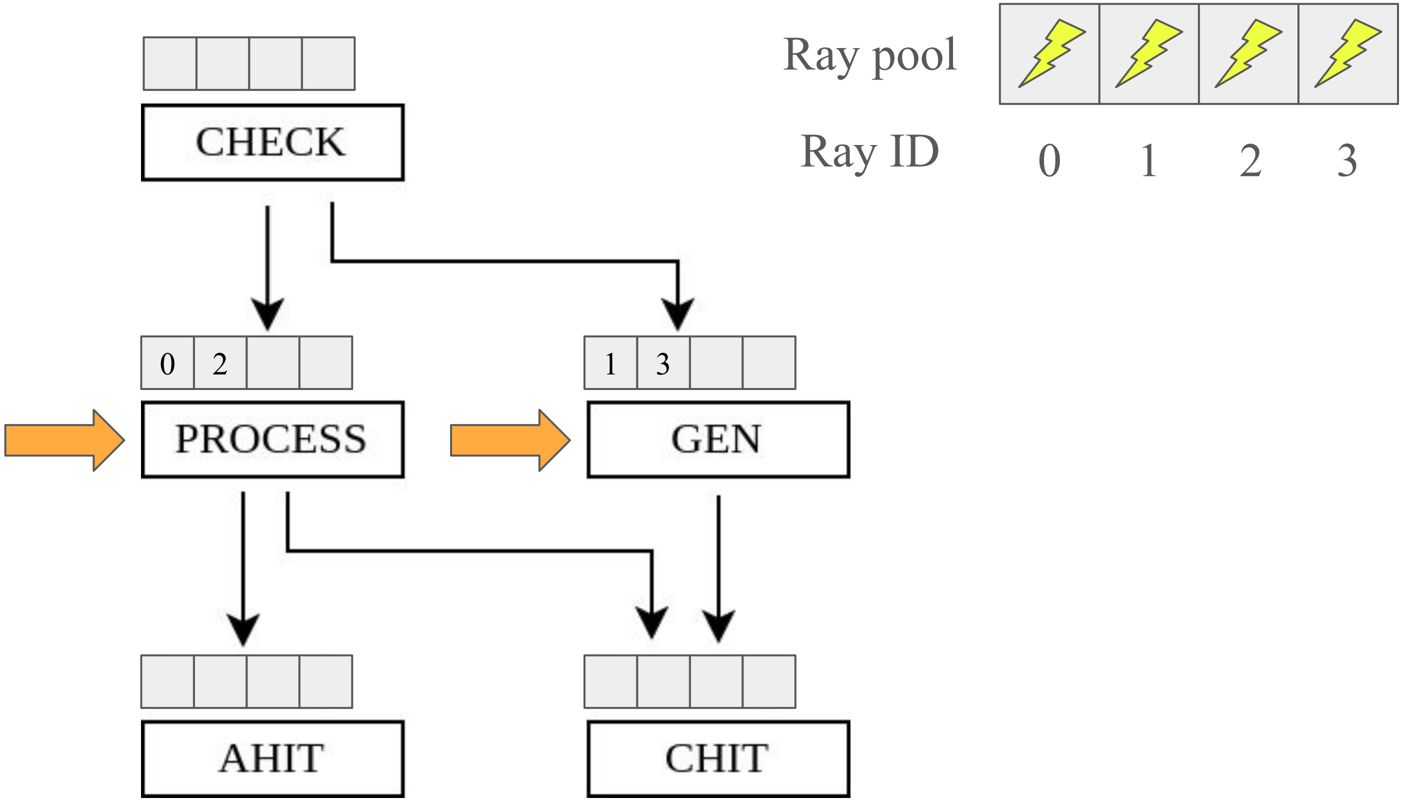




cub::DeviceSelect::Flagged()

Proposed Solution (CUDA Split)



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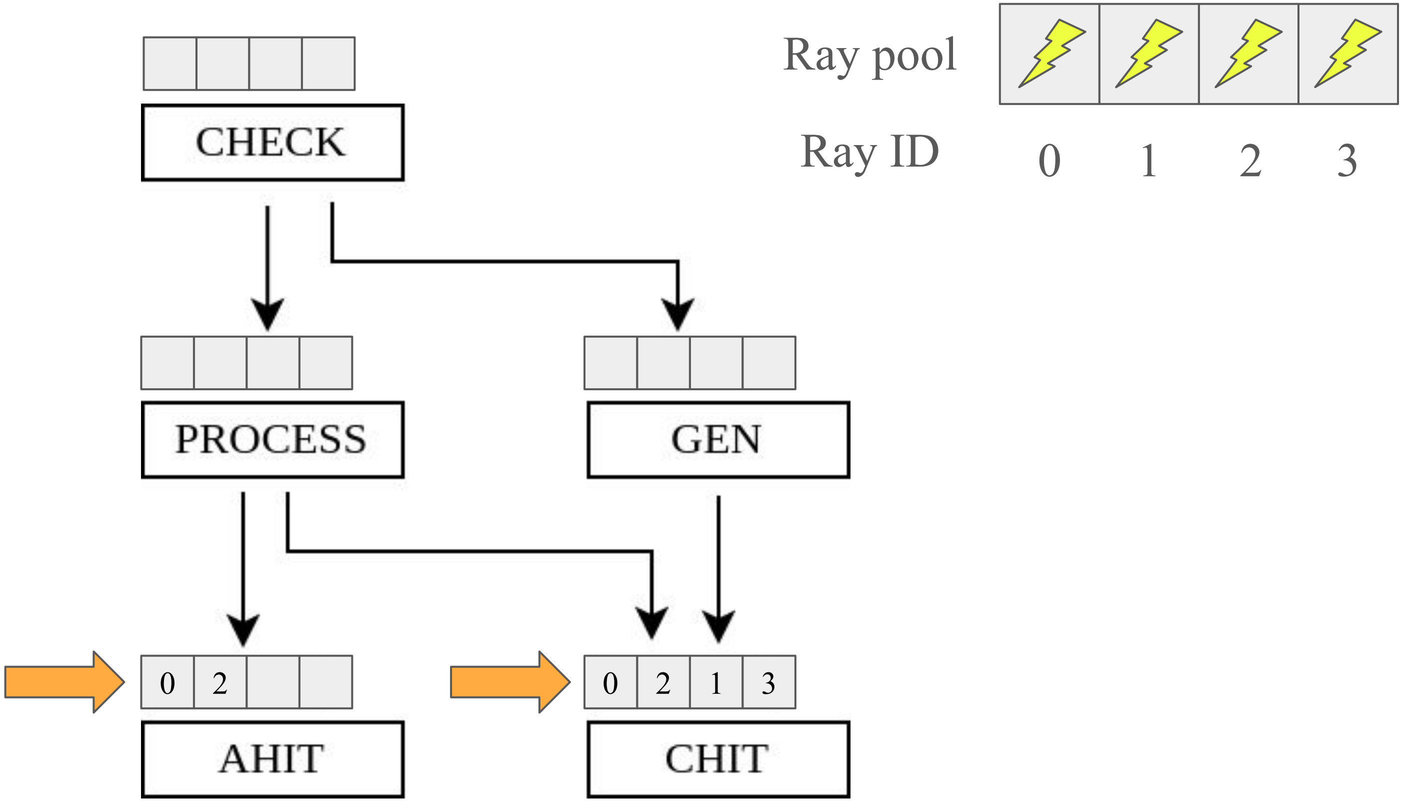

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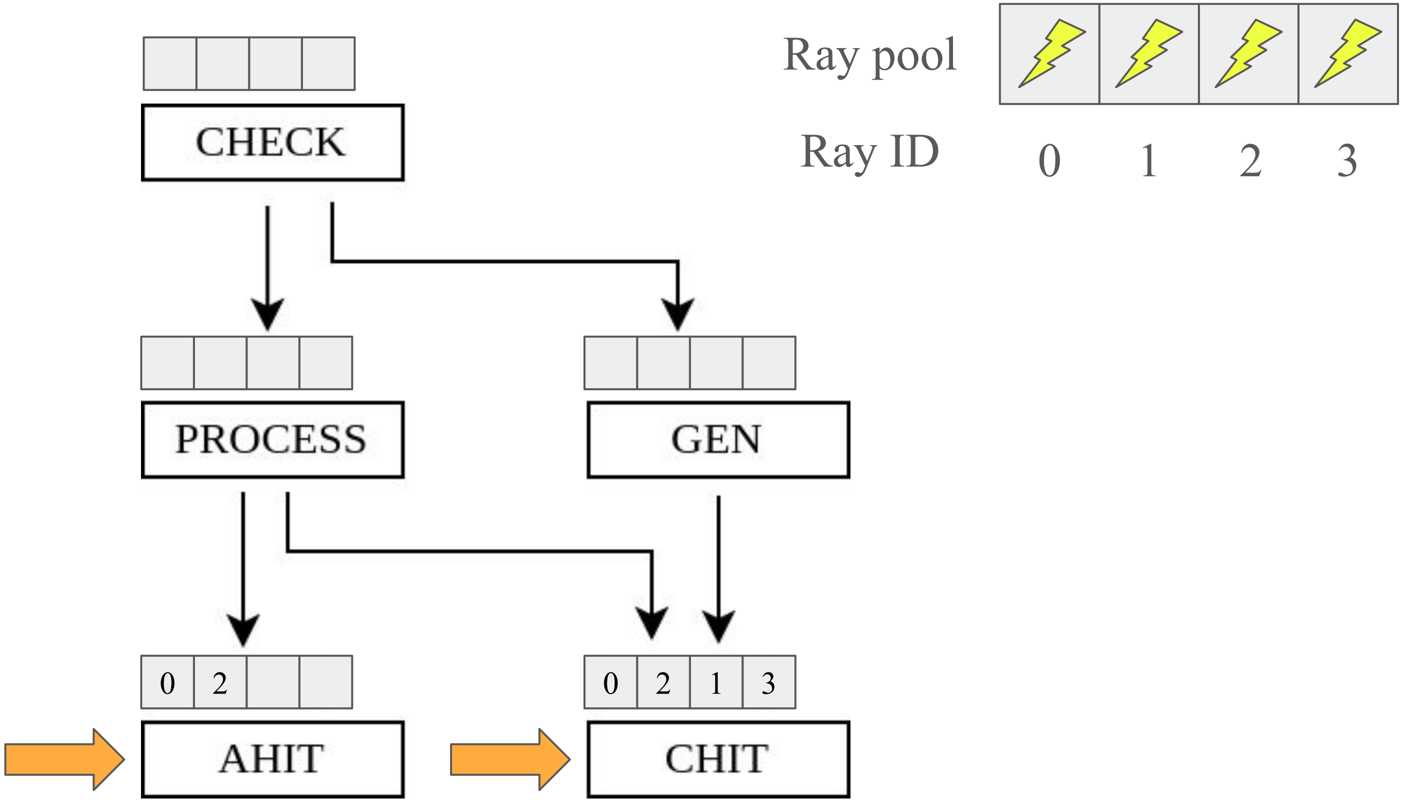


Proposed Solution (CUDA Split)

- Register usage before/after splitting kernels

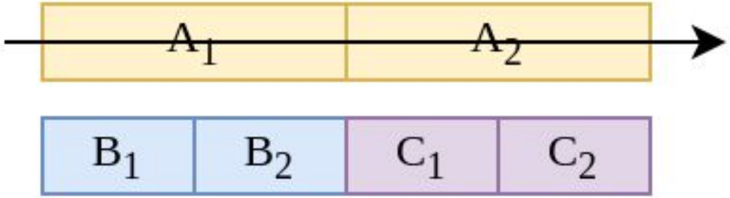
Kernel		Register Usage
Mega		65
Split	CHECK	14
	PROCESS	39
	GEN	28
	AHIT	32
	PHIT	43

Proposed Solution (CUDA Split)

- Coalescing memory access
  - array-of-structure ⇒ structure-of-array

array-of-structure

```
struct {
    double A;
    float B, C;
} S[2];
```

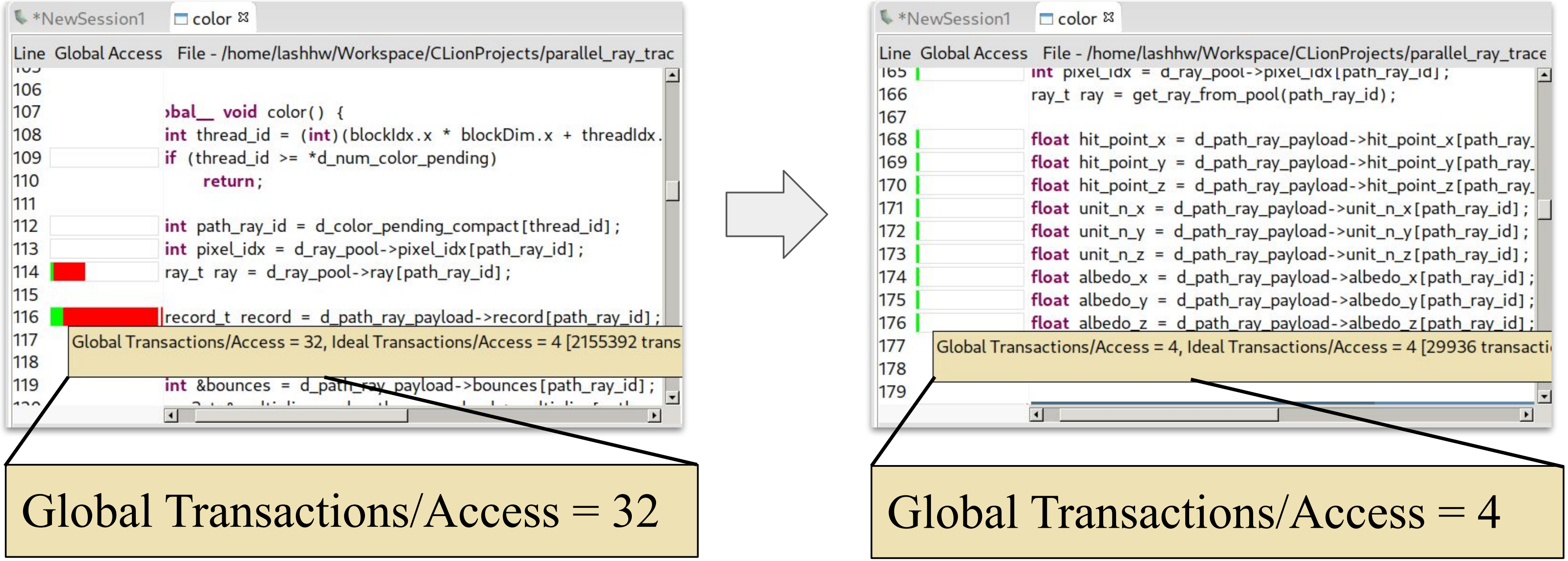


structure-of-array

```
struct {
    double A[2];
    float B[2], C[2];
} S;
```

Proposed Solution (CUDA Split)

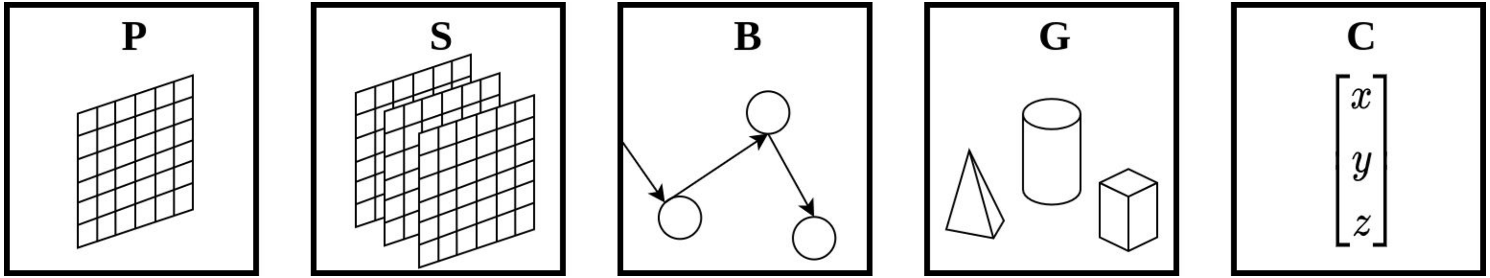
- array-of-structure ⇒ structure-of-array: 1.09x speedup!



Comparison of Parallelized Loops

Method	Parallized Loop
SIMD	C
OpenMP	P
MPI	P
CUDA	P, S

$\Rightarrow$ SIMD can be combined with OpenMP and MPI



Evaluation

Platform

OS	Ubuntu 20.04.2
CPU	Intel(R) Core(TM) i5-7500 @ 3.4GHz
GPU	NVIDIA Tesla T4
RAM	12GB
GCC	9.4.0
NVCC	10.1.243
Open MPI	4.0.3
CUDA	12.2
OpenMP	4.5

Evaluation

- Basic setting:
  - Image size: 600 x 600
  - Samples per pixel: 512
  - Maximum bounces per ray: 4

- Factors:
  - Image size
  - Samples per pixel
  - Maximum bounces per ray

Implementation	SIMD	Time (s)	Speedup
Serial	✗	102.46	1.00x
	✓	95.00	1.08x
OpenMP*	✗	39.65	2.58x
	✓	38.90	2.63x
MPI†	✗	15.75	6.51x
	✓	15.65	6.55x
CUDA (Mega)	✗	6.64	15.43x
CUDA (Split)	✗	3.12	32.84x

*4 threads †8 processes

Experiment 1

- Different image size *(P)*

	150 x 150		300 x 300		600 x 600	
	Time (s)	Speedup	Time (s)	Speedup	Time (s)	Speedup
Serial	5.99	1.00x	25.08	1.00x	95.00	1.00x
OpenMP*	2.98	2.01x	9.70	2.58x	38.90	2.44x
MPI†	3.52	1.70x	4.59	5.46x	15.65	6.55x
CUDA	0.39	15.36x	0.92	27.26x	3.12	30.45x

*4 threads †8 processes

Experiment 2

- Different number of samples per pixel *(S)*

	256		512		1024	
	Time (s)	Speedup	Time (s)	Speedup	Time (s)	Speedup
Serial	47.43	1.00x	95.00	1.00x	189.46	1.00x
OpenMP*	24.22	1.96x	38.90	2.44x	77.79	2.44x
MPI†	8.32	5.7x	15.65	6.55x	30.29	6.25x
CUDA	1.64	28.92x	3.12	30.25x	6.02	31.47x

*4 threads †8 processes

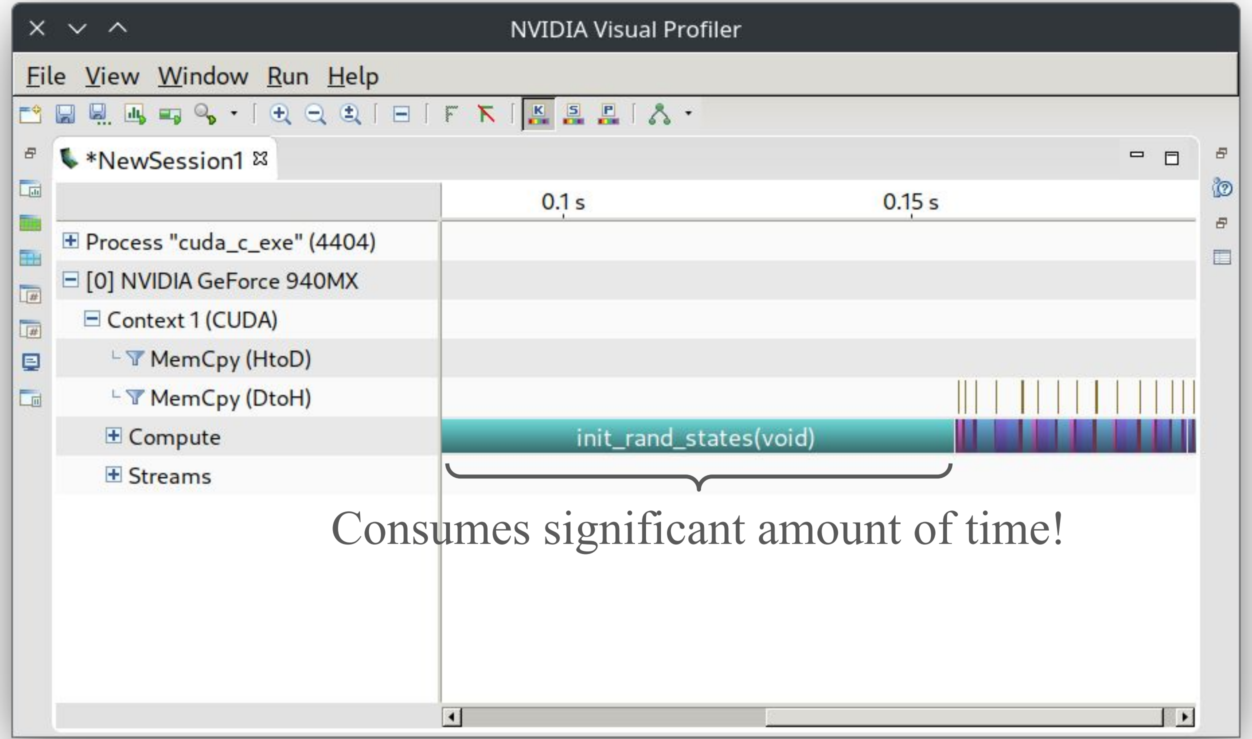
Experiment 3

- Different number of bounces per ray *(B)*

	2		4		8	
	Time (s)	Speedup	Time (s)	Speedup	Time (s)	Speedup
Serial	49.78	1.00x	95.00	1.00x	146.39	1.00x
OpenMP*	21.83	2.28x	38.90	2.44x	60.15	2.43x
MPI†	7.94	6.27x	15.65	6.55x	24.82	5.90x
CUDA	2.21	22.52x	3.12	30.45x	4.02	36.42x

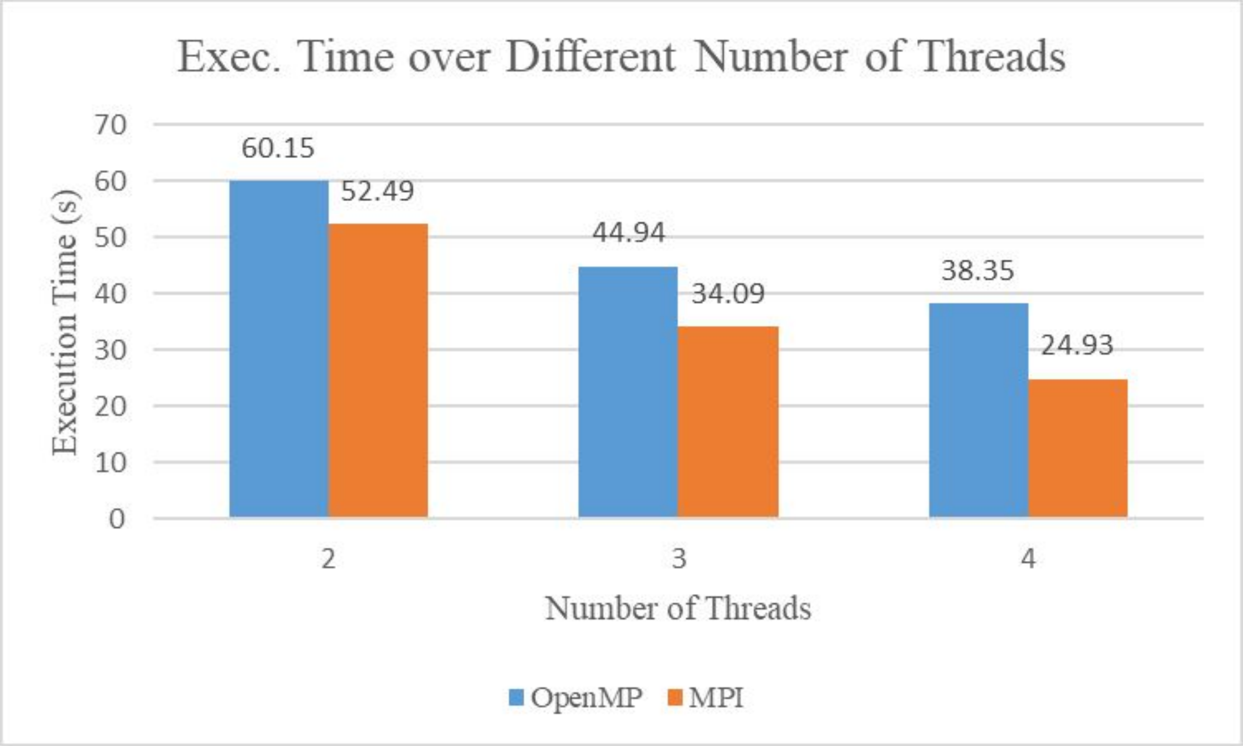
*4 threads †8 processes

Experiment 3



Experiment 4

- Compare OpenMP with MPI at same number of threads



Conclusion

Conclusion

- Our study demonstrated that CUDA significantly outperformed CPU methods in parallelizing a ray tracing renderer.

- Notably, the split kernel approach of CUDA showed the highest speedup, highlighting the effectiveness of parallel computing.