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Towards Scalable and Efficient GPU-Enabled Slicing Acceleration in Continuous 3D Printing

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Outline

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01 **Motivation**

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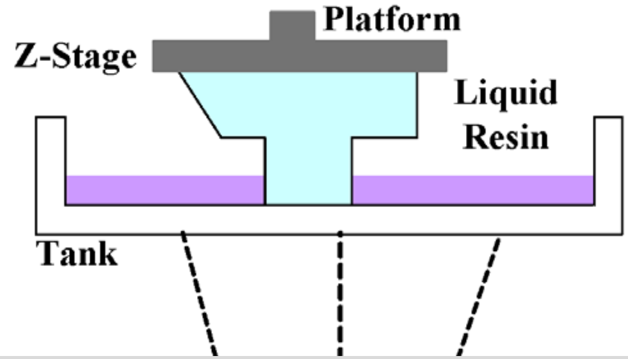
Continuous 3D Printing

- Continuous 3D printing is a recent technical breakthrough in additive manufacturing [2015]. (Carbon3D)

Two Orders of Magnitude on Printing Acceleration

* This picture comes from internet: https://techcrunch.com/2015/08/20/ with-100m-in-funding-carbon3d-will-make-3d-manufacturing-a-reality/

Principle of Continuous 3D Printing (Carbon 3D)

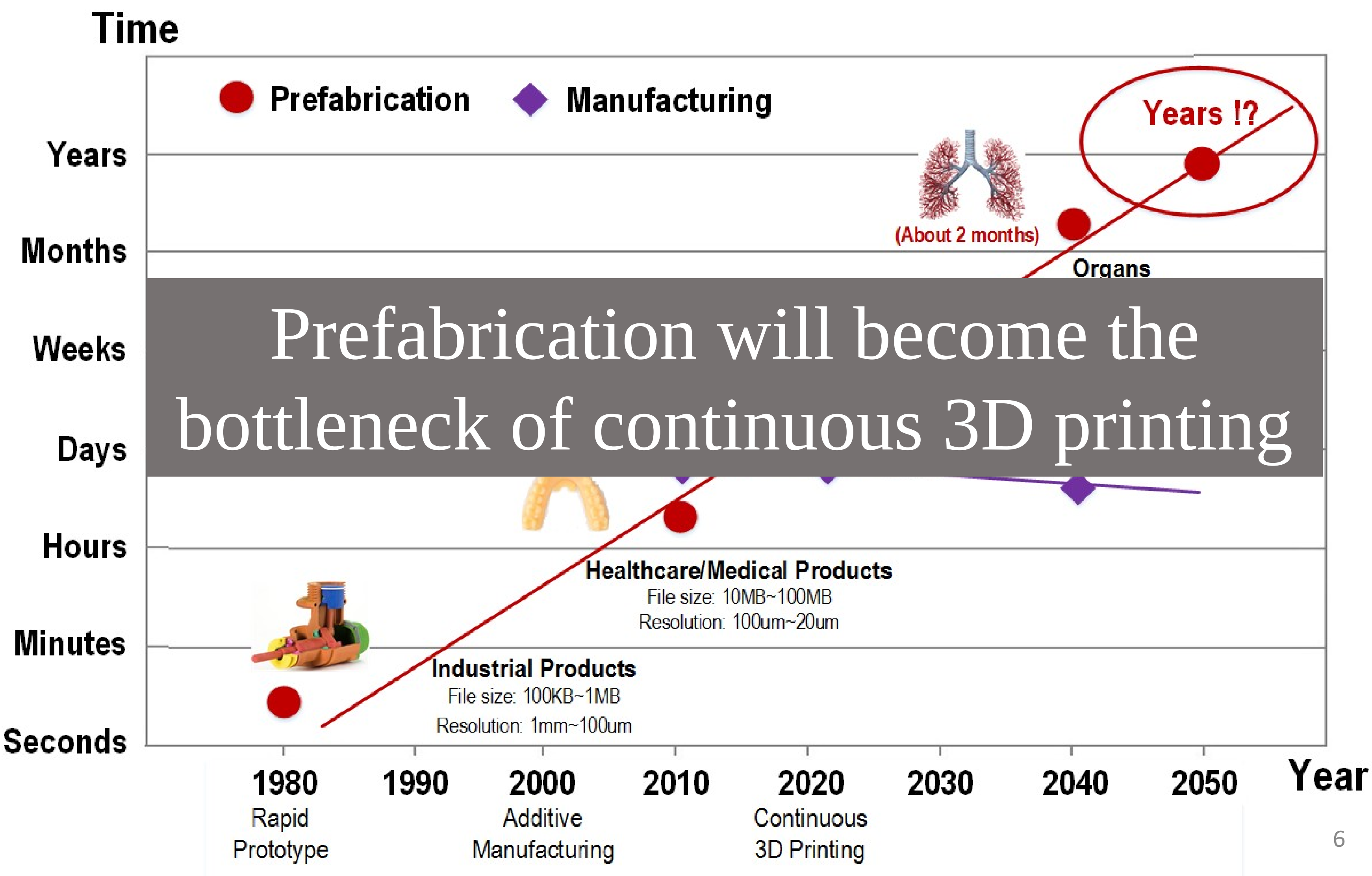


Speedup of Carbon 3D is mainly from Manufacturing (wet part)

- ✓ Dry Part (Prefabrication)
  Computing unit slices of the layer images.

- ✓ Wet Part (Manufacturing)
  Mechanical operations to fabricate 3D object from liquid materials.

Prefabrication V.S. Manufacturing



Prefabrication will become the bottleneck of continuous 3D printing

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02 **Background - Slicing**

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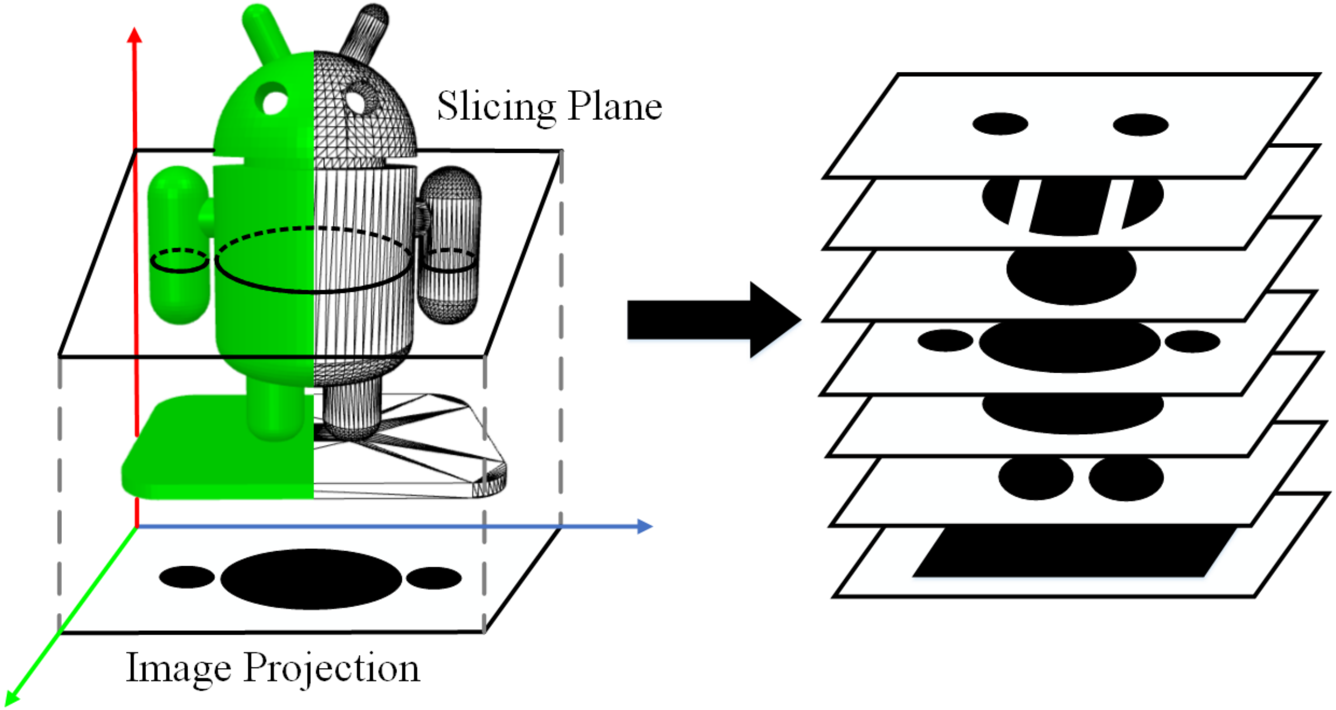
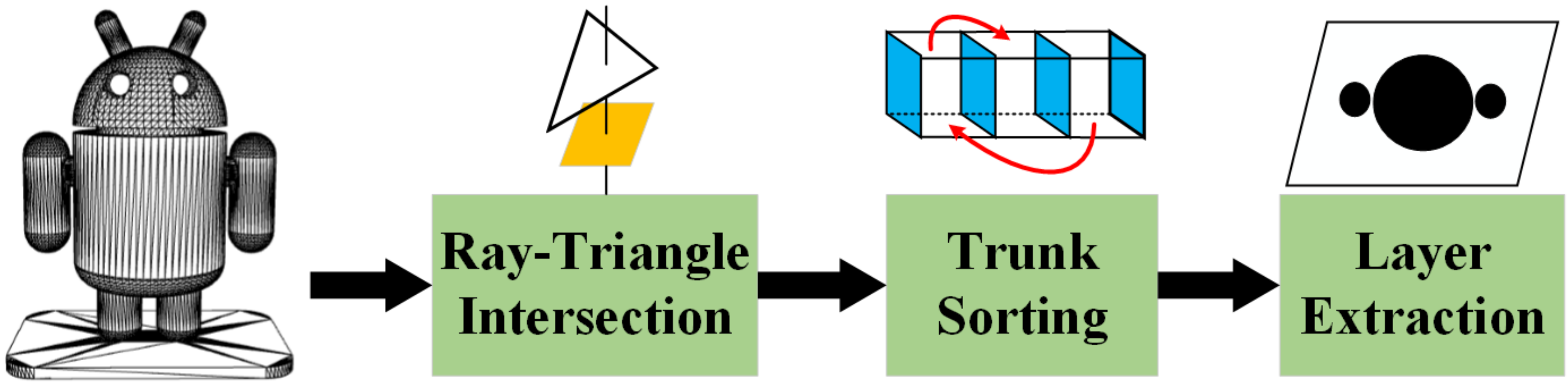
Background (Slicing)

- The task in prefabrication includes three sequential procedures, i.e., slicing, path planning and support generation. Slicing dominates time efficiency in “dry part”.

- In continuous 3D printing, image-mask-projection based slicing algorithm is employed. This pixel-independent processing enables massive parallel acceleration.



Methodology (Slicing Algorithm Analysis)



- The e… …triangle interse…

Trunk Sorting takes up a minor part of computation

  - … rays on image pixel center and the triangles from STL file.
  - The trunk sorting sorts the out-of-order intersection points by ascending order using the bubble sorting in the trunk of each pixel.
  - The binary value of each pixel on projected images is identified by incremental updating, so that the topology information is extracted for binary slicing image.

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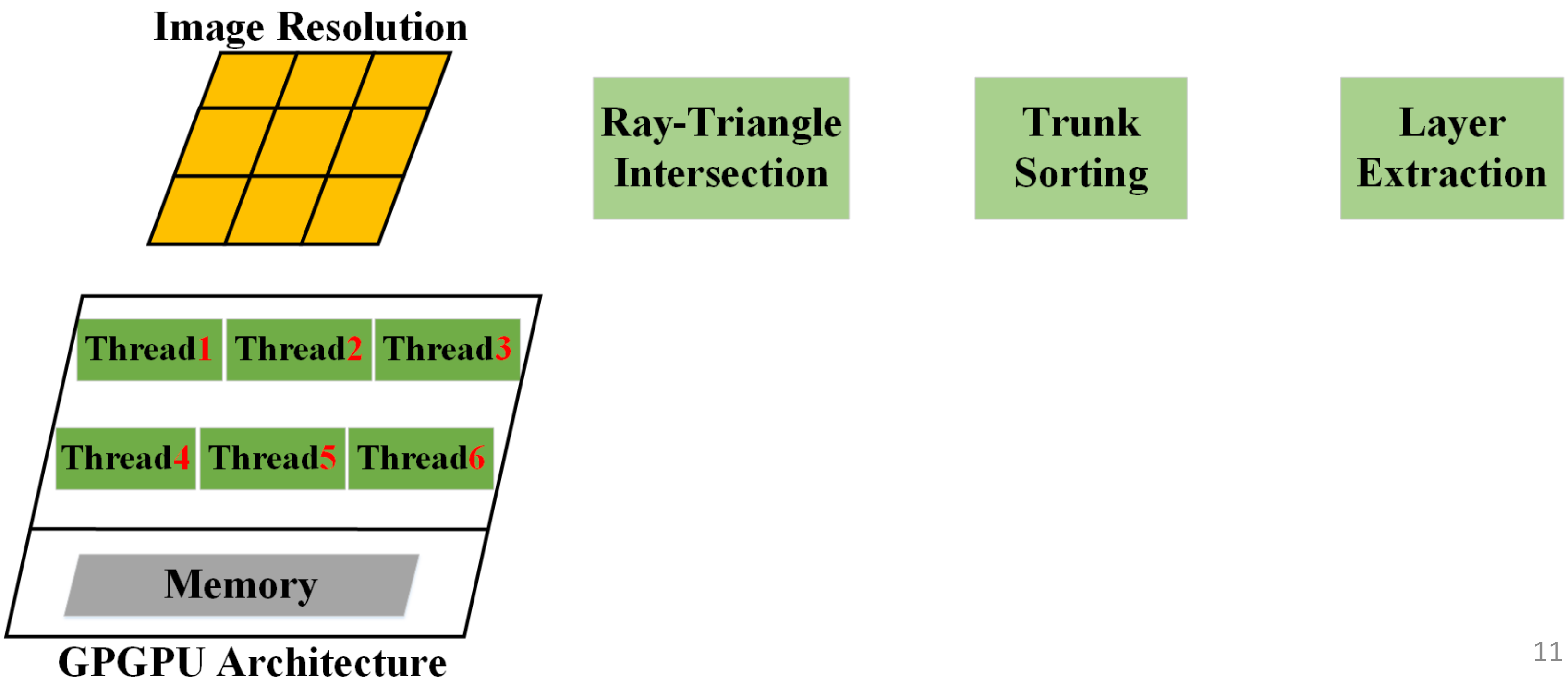
GPU-Enabled Slicing-I
(Pixelwise Parallel Slicing)

- By the sequential algorithm analysis, we exploit the pixelwise parallelism based on GPGPU architecture.



GPU-Enabled Slicing-I (Pixelwise Parallel Slicing)

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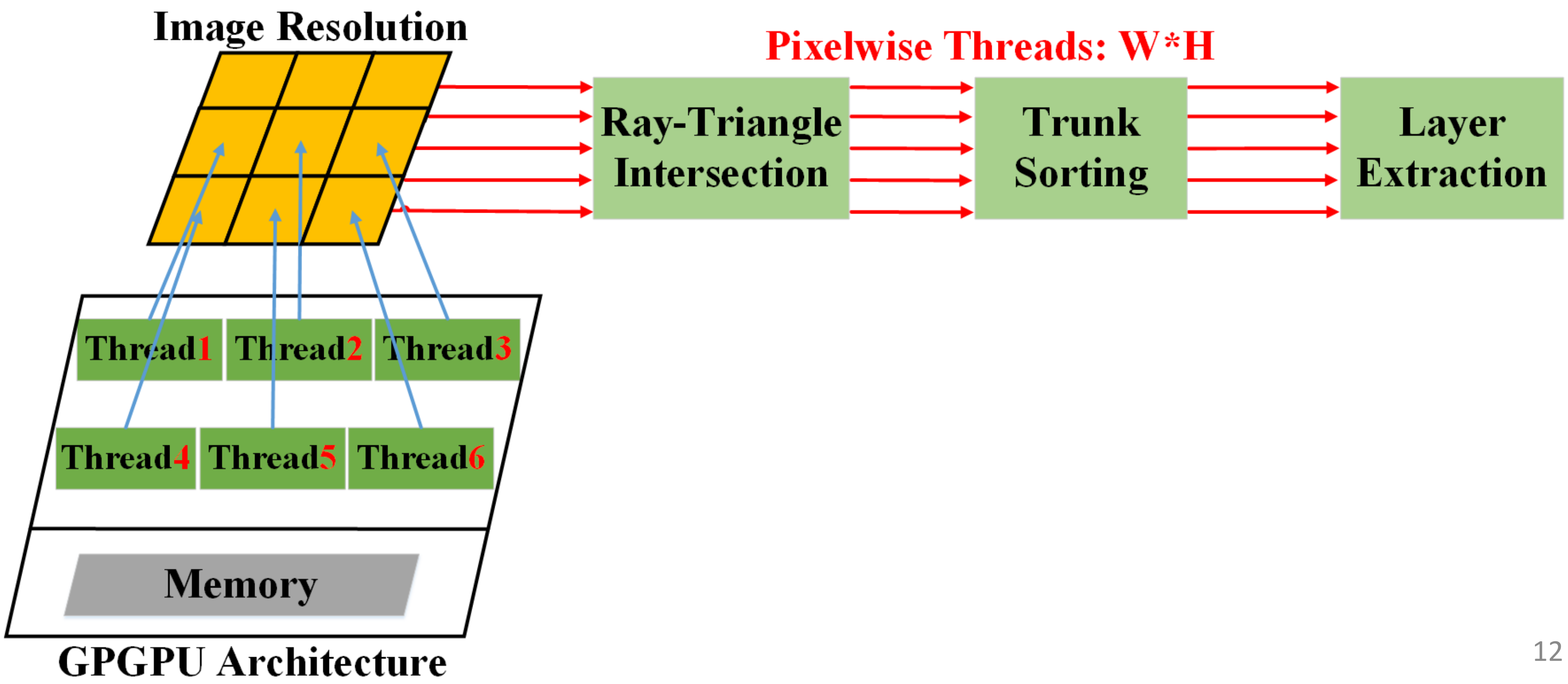
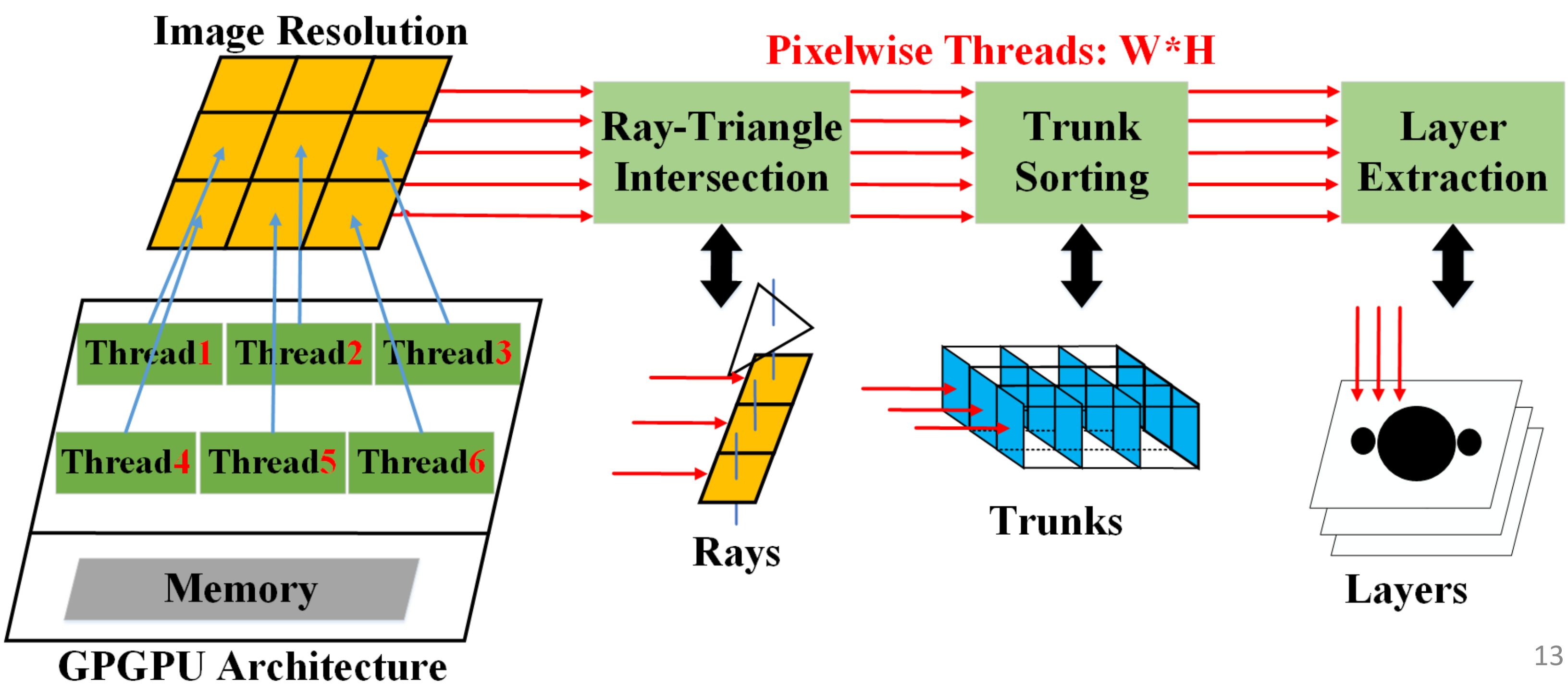
- The entire processing in all three functional modules for one pixel is assigned to a specific thread.

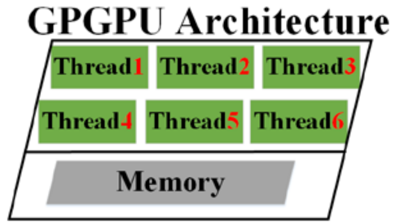


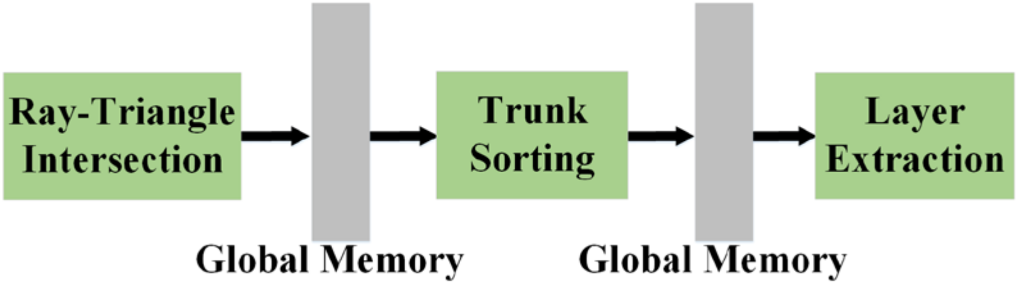
GPU-Enabled Slicing-I
(Pixelwise Parallel Slicing)

- By the sequential algorithm analysis, we exploit the pixelwise parallelism based on GPGPU architecture.
- The entire processing in all three functional modules for one pixel is assigned to a specific thread.
- Fully use of precious shared memory on GPU to reduce time-consuming global memory intersections.



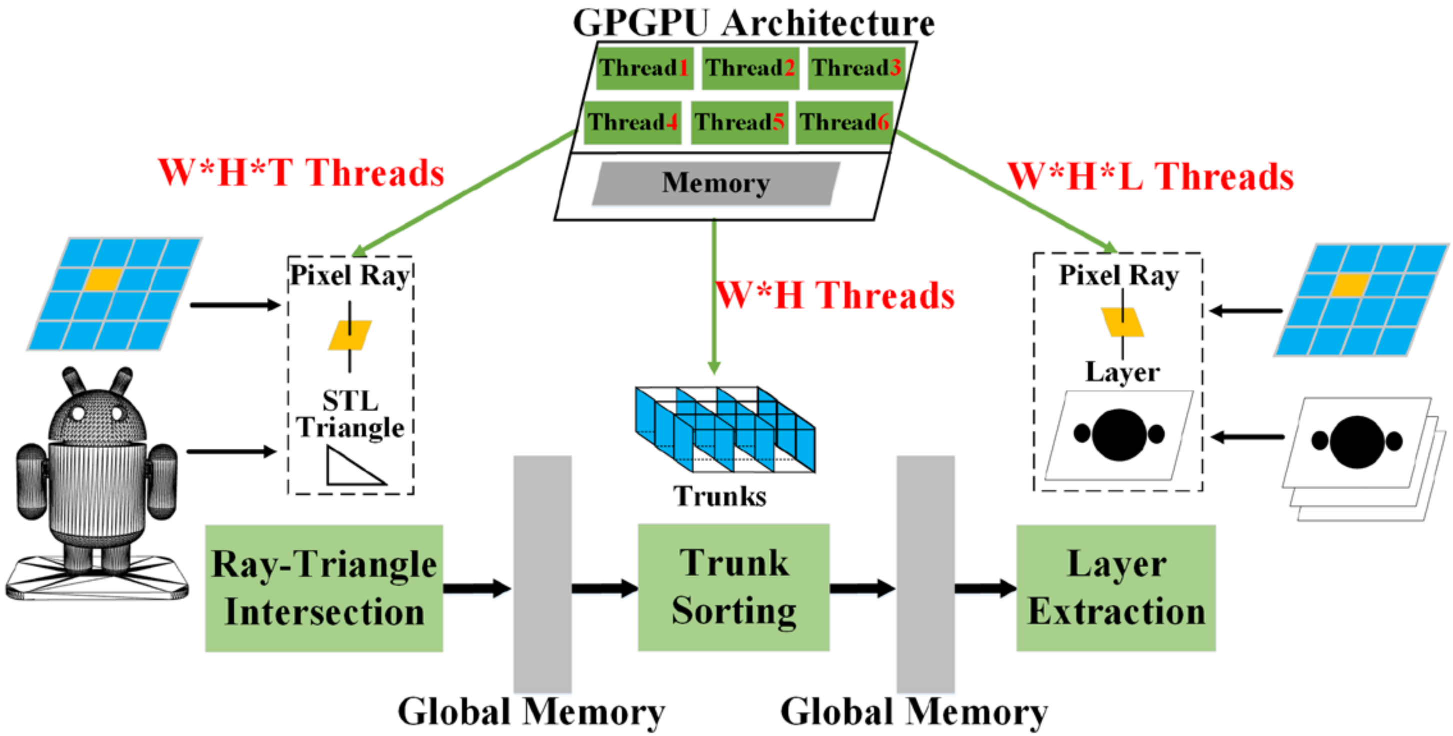
GPU-Enabled Slicing-II (Fully Parallel Slicing)





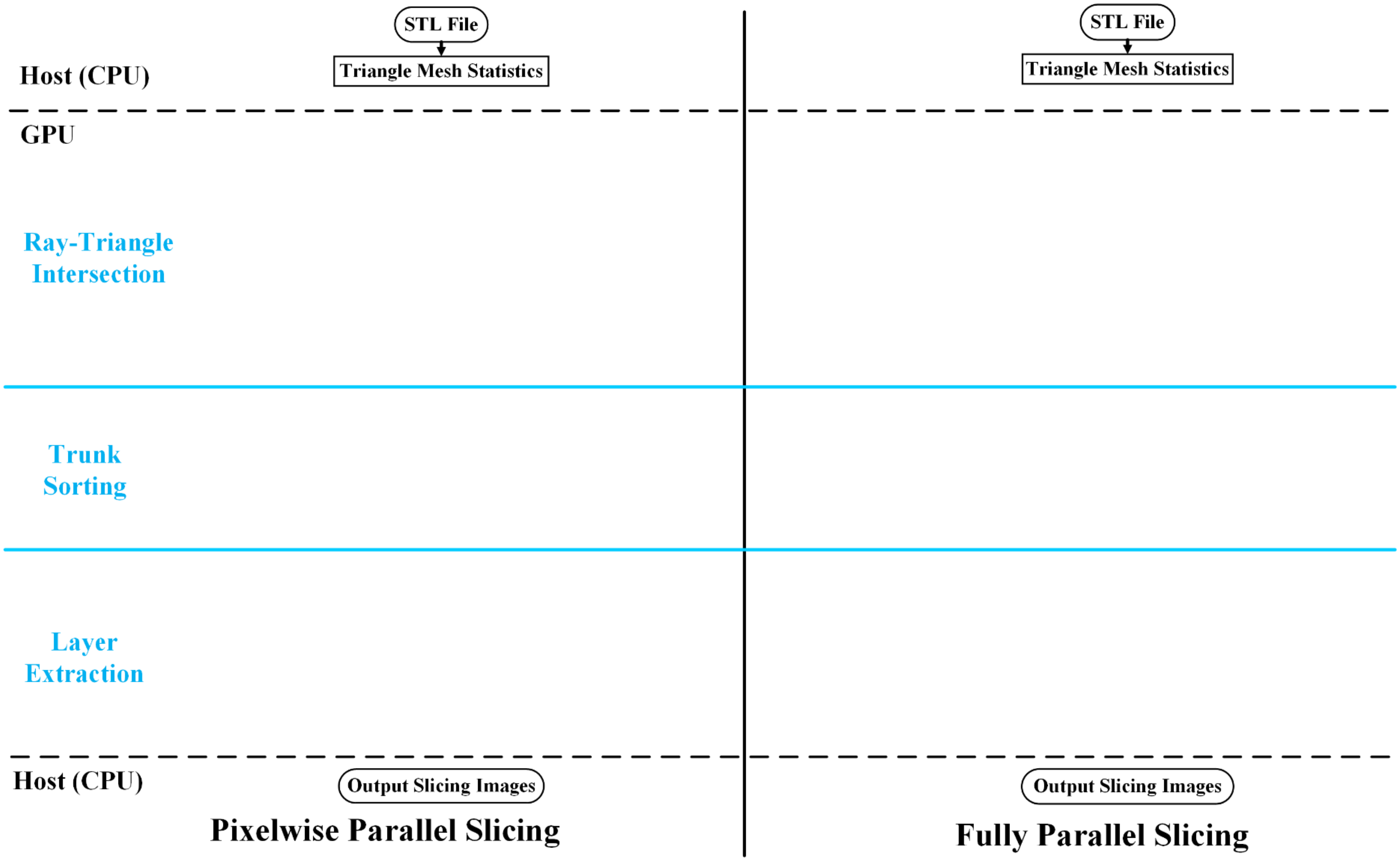
- PPS still has serial computing components.
- FPS explores the massive thread concurrency

GPU-Enabled Slicing-II (Fully Parallel Slicing)



- PPS still has serial computing components.
- FPS explores the massive thread concurrency
- This method increases global memory accessing pattern, but is scalable for large-size problem.
- The issue of multi-thread memory writing conflict arises and can be addressed by atomic operation based critical area.

Comparison of Two GPU Implementations



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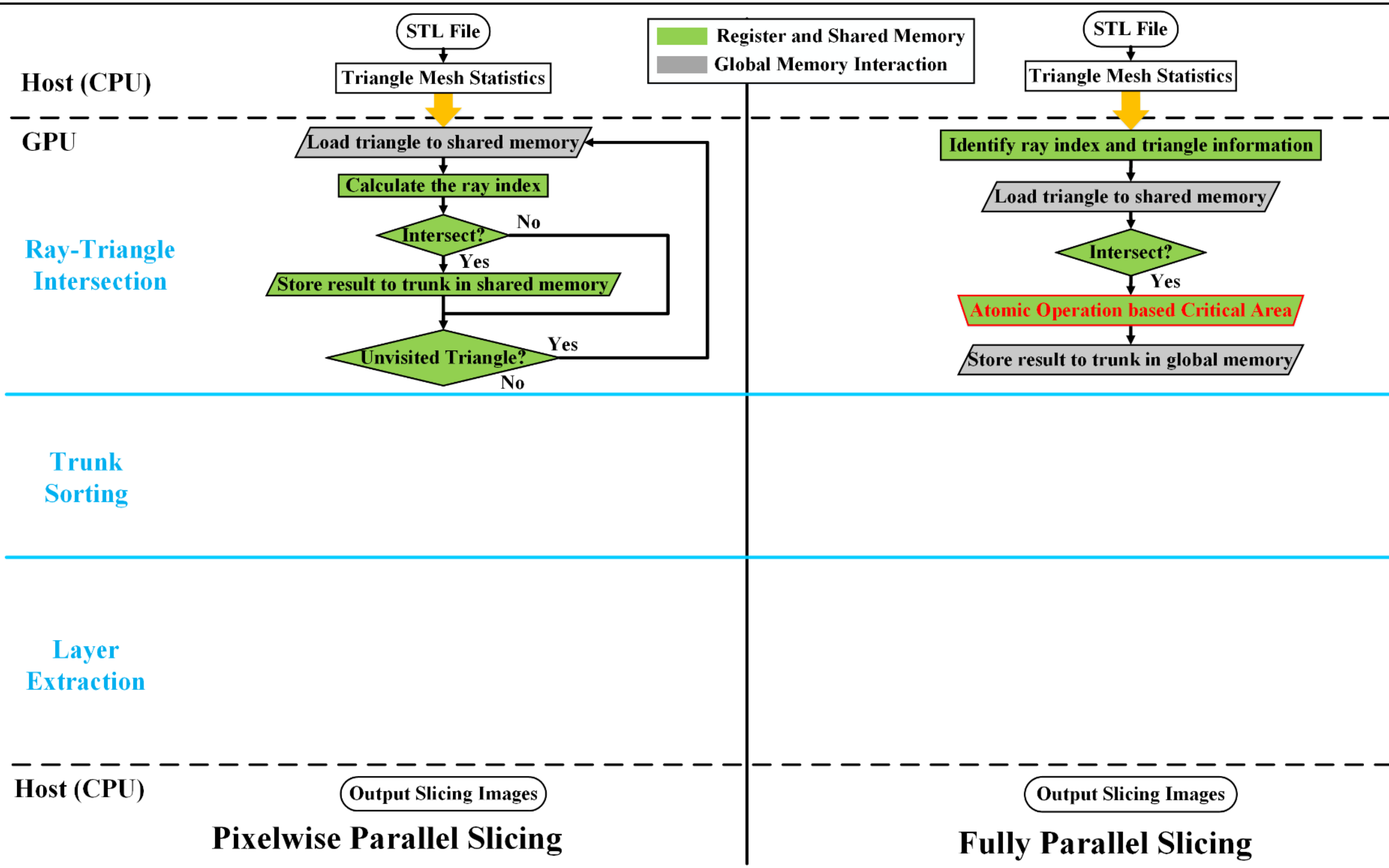

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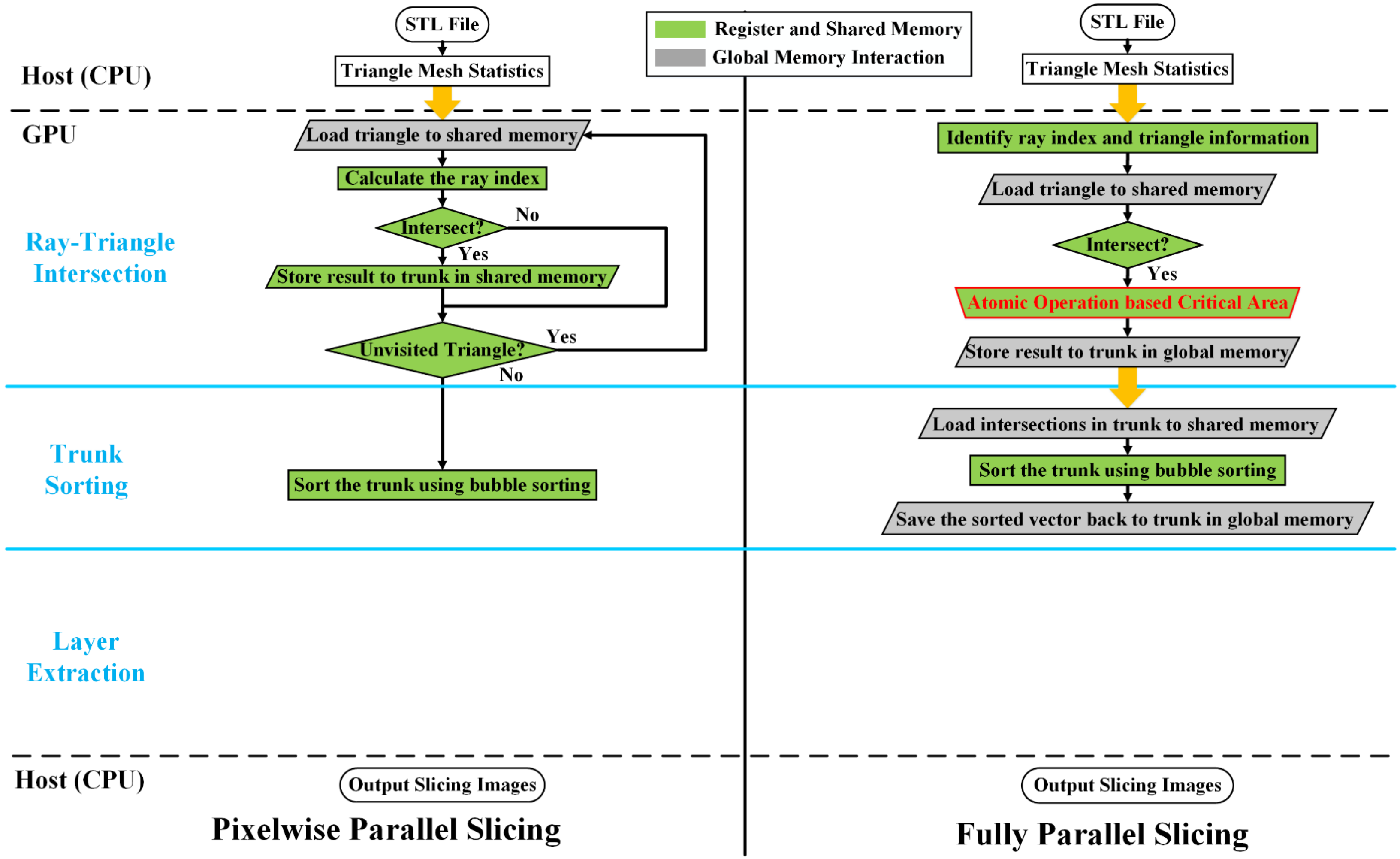

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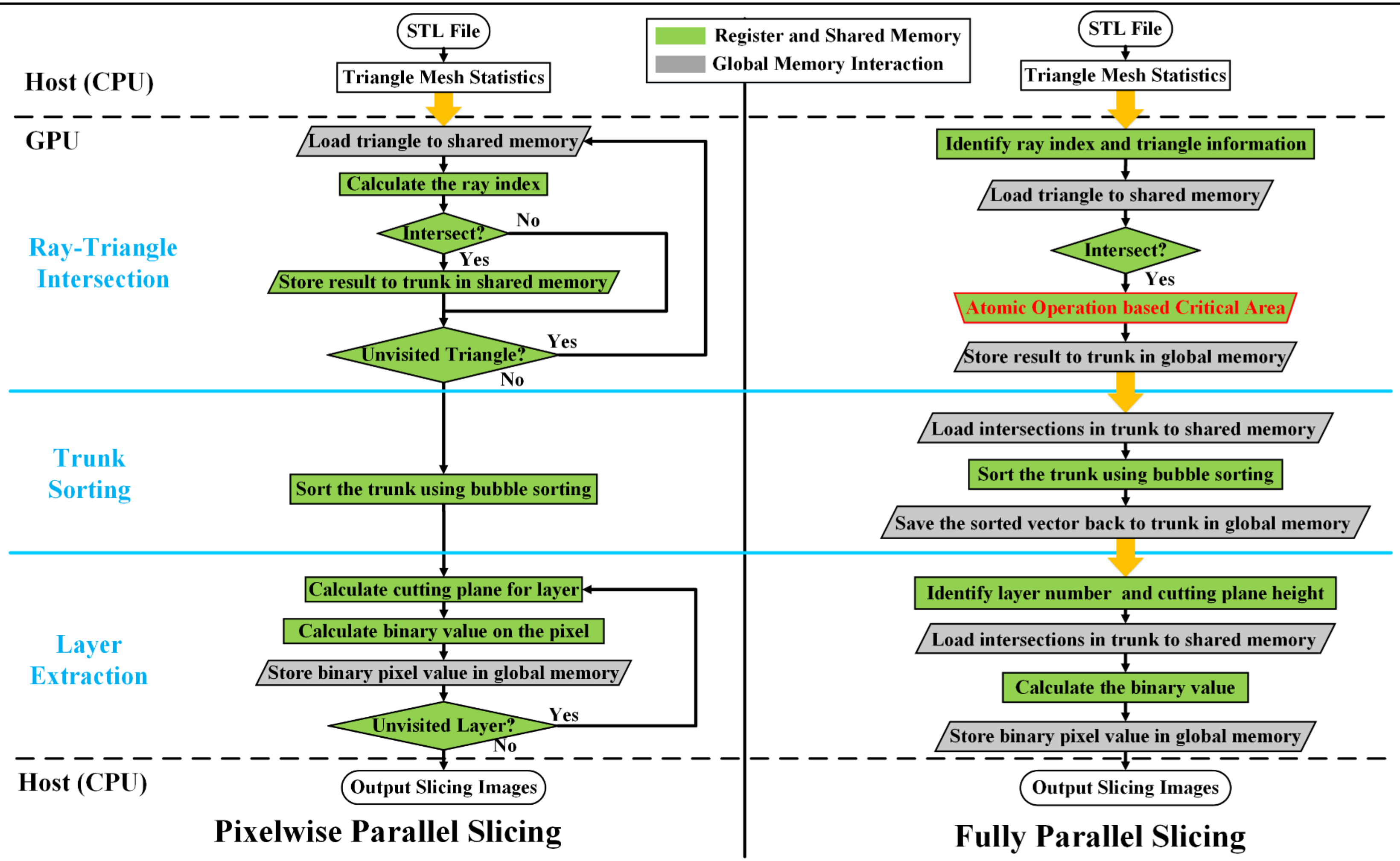

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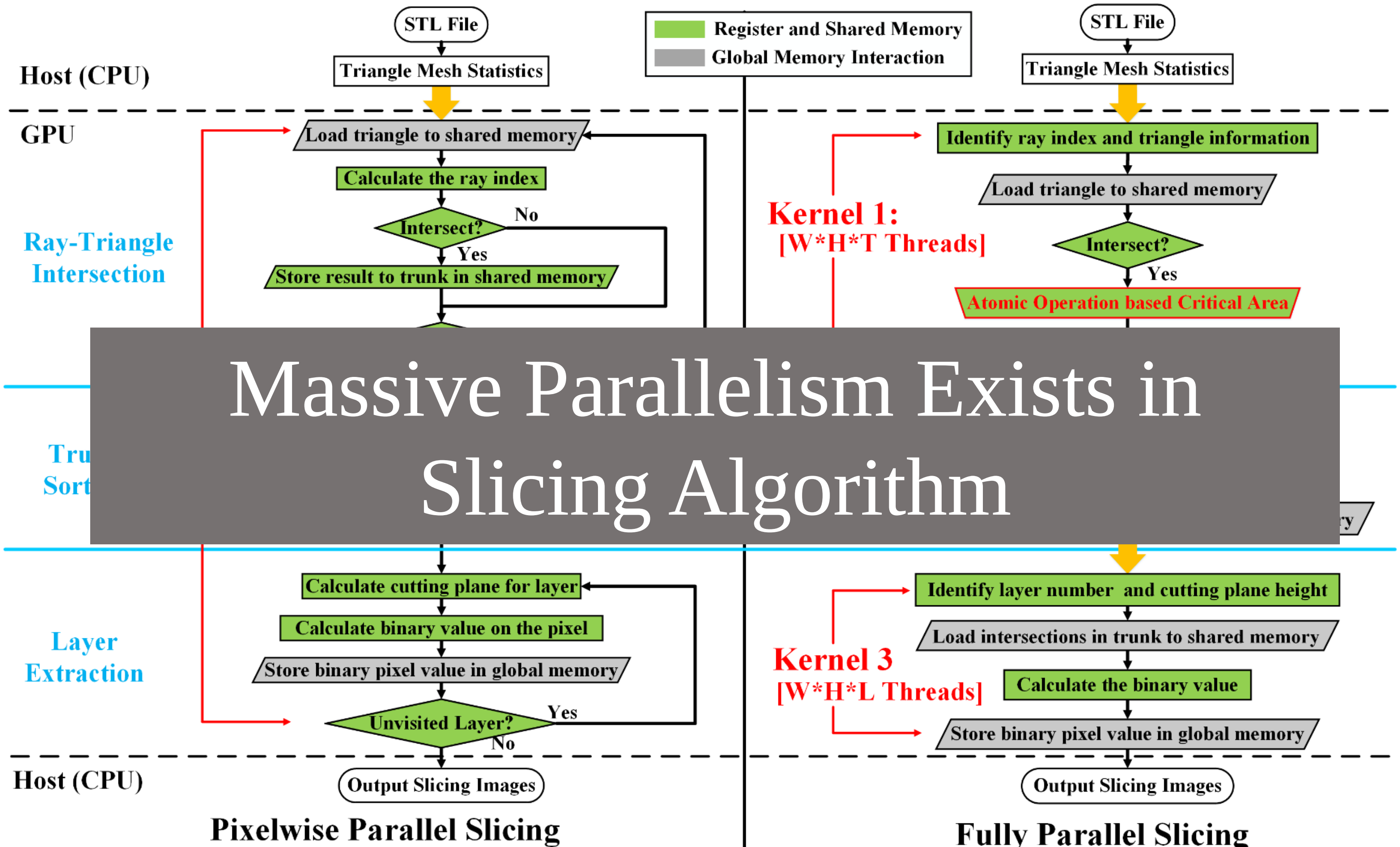

Massive Parallelism Exists in Slicing Algorithm

- **PPS**: all tasks in fast shared memory, less global memory access, no multi-thread conflict.
- **FPS**: recycle-free processing, atomic operation based critical area to address conflict issue.

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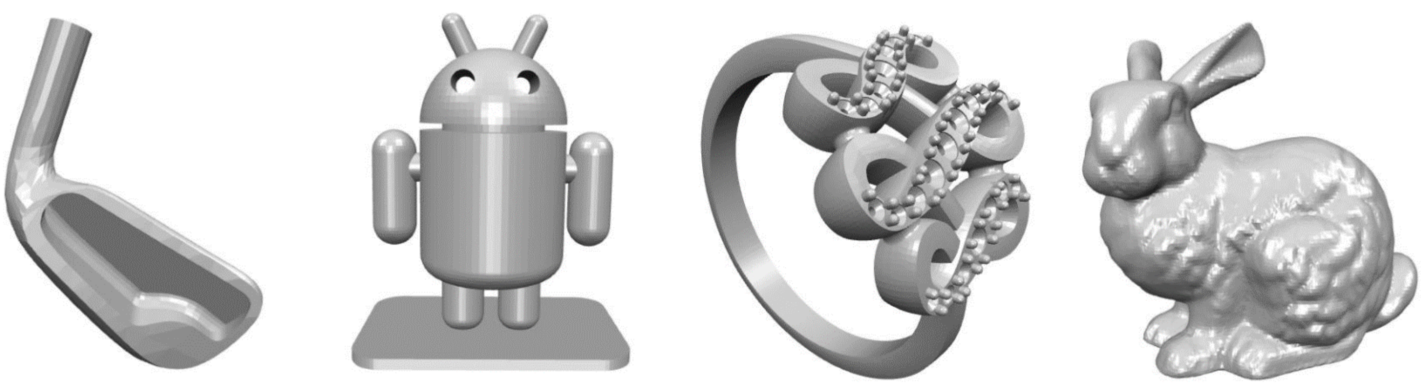
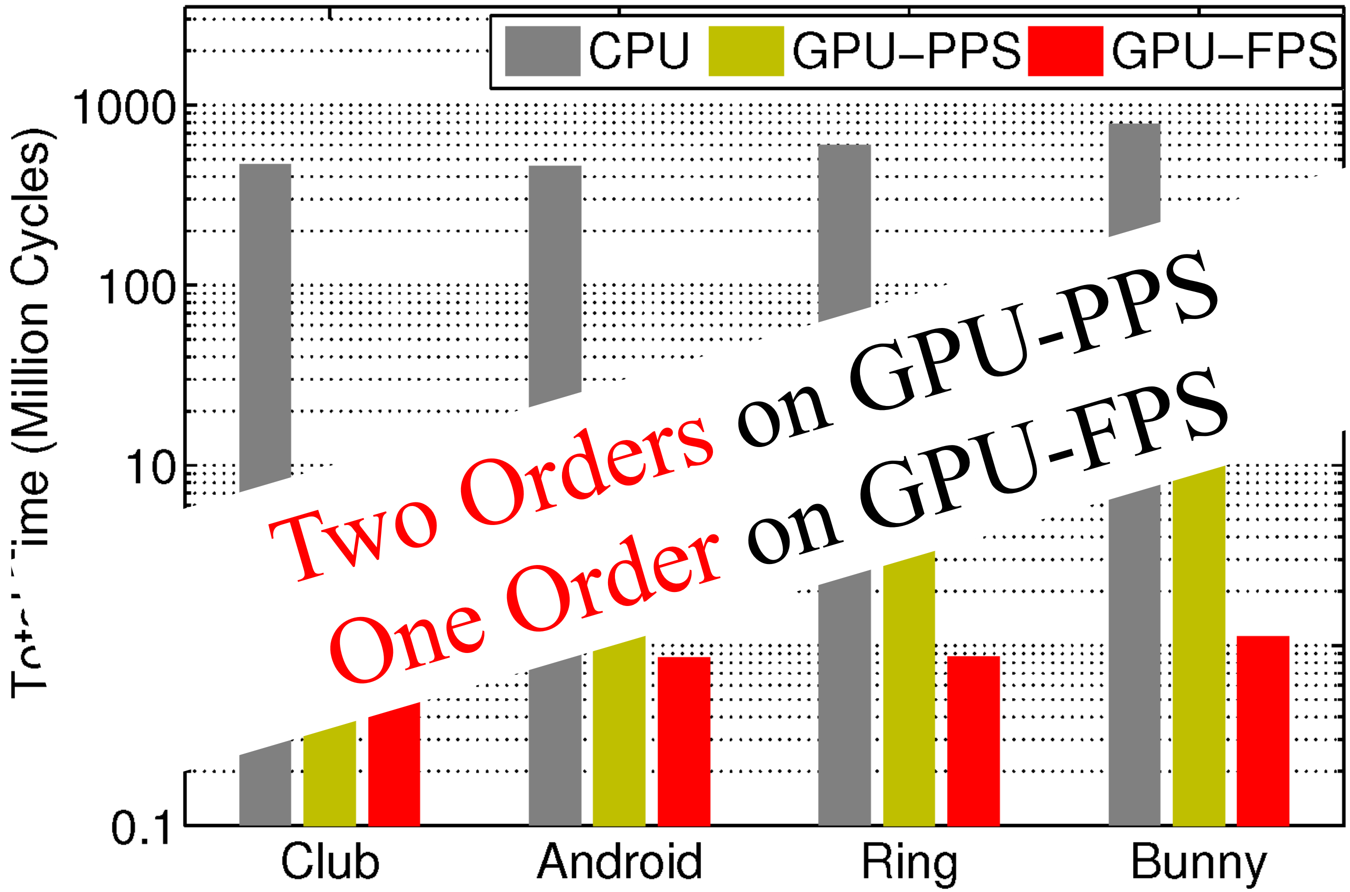
Experimental Setup

- We use cycle-accurate simulators for CPU and GPU computing platforms
- Sniper is a typical simulator for x86 architecture and GPGU-Sim is a good simulating tool to check statistics of GPGPU architecture.
- Sniper is configured as Intel Xeon X5550 with 2.66GHz frequency while GPGPU-Sim is configured as Nvidia Geforce GTX480 with 700MHz.
- We choose four representative 3D objects: Club, Android, Ring and Bunny. They have different triangle mesh size, as 3290, 10926, 33730 and 69664.



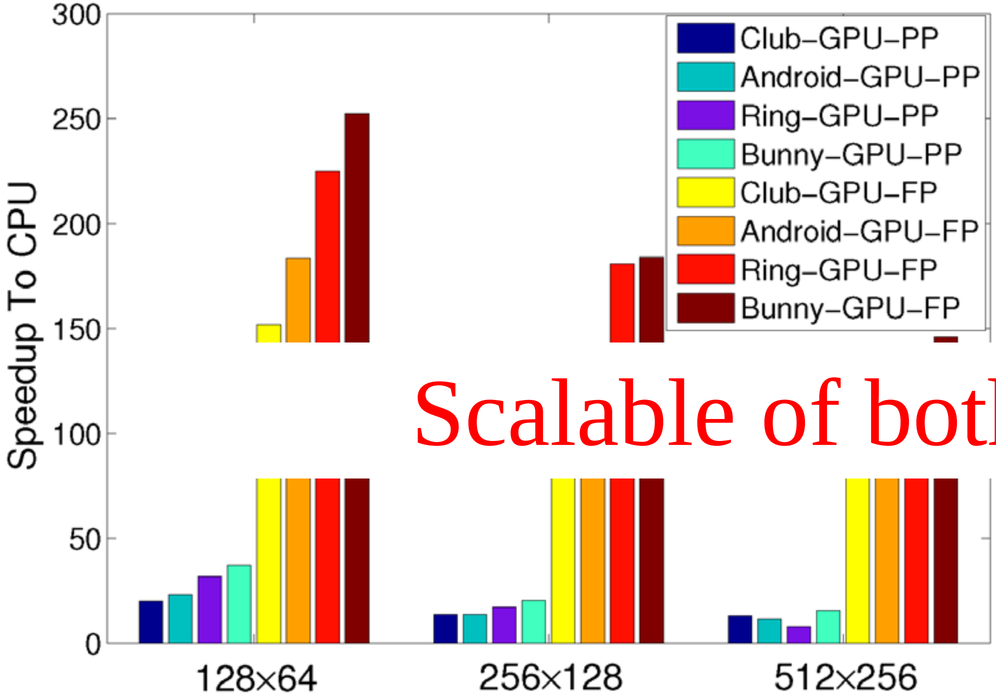
(a) Club (b) Android (c) Ring (d) Bunny

Experiment: Time Efficiency



- Fully parallel slicing achieves the best performance in three schemes.
- Considering the processing frequency difference, PPS gains one order of magnitude improvement and FPS even obtains two orders acceleration.

Experiment: Scalability



Time (Million Cycles)		Layer Number 10	100	1000
CPU	Ray-Triangle	517.38	517.34	517.51
	Trunk Sorting	12.06	11.99	12.08
	Layer Extract	**33.11**	**255.32**	**2459.17**
	Total	562.55	784.65	2988.76
[illegible]	Ray-Triangle	0.300	0.301	0.300
	Trunk Sorting	0.020	0.020	0.020
	[illegible]	[illegible]	[illegible]	**7.965**
	[illegible]	[illegible]	[illegible]	8.285

Scalable of both PPS and FPS

- We choose three image resolutions: 128*64, 256*128 and 512*256.
- PPS holds one order of magnitude speedup and FPS achieves about two orders time efficiency compared to CPU.

- We choose three layer numbers: 10, 100 and 1000.
- FPS scheme on GPU can achieve about two orders time efficiency compared with CPU case.
- As layer number increases, layer extraction dominates the entire runtime.
- Trunk Sorting takes a subtle proportion.

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05 **Conclusions**

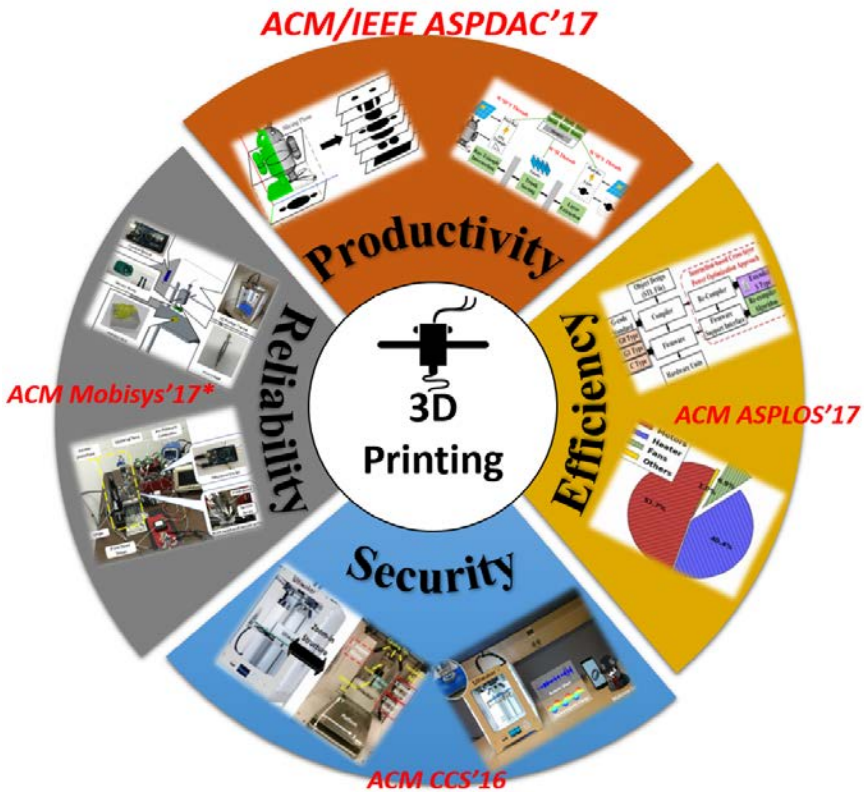
Conclusions

- We investigated slicing algorithm acceleration on GPGPU architecture for continuous 3D printing.
- We developed pixelwise parallel slicing and fully parallel slicing implementations.
- Experiments demonstrate the effectiveness and scalability of our implementation.

In the future:

- We will design new implementations on the new hardware platform, such as FPGA or more powerful GPU.
- We will exploit pipeline property between prefabrication and manufacturing.

Q & A



Thank you!

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