Analysis of the Path Tracing rendering method on CPU and GPU

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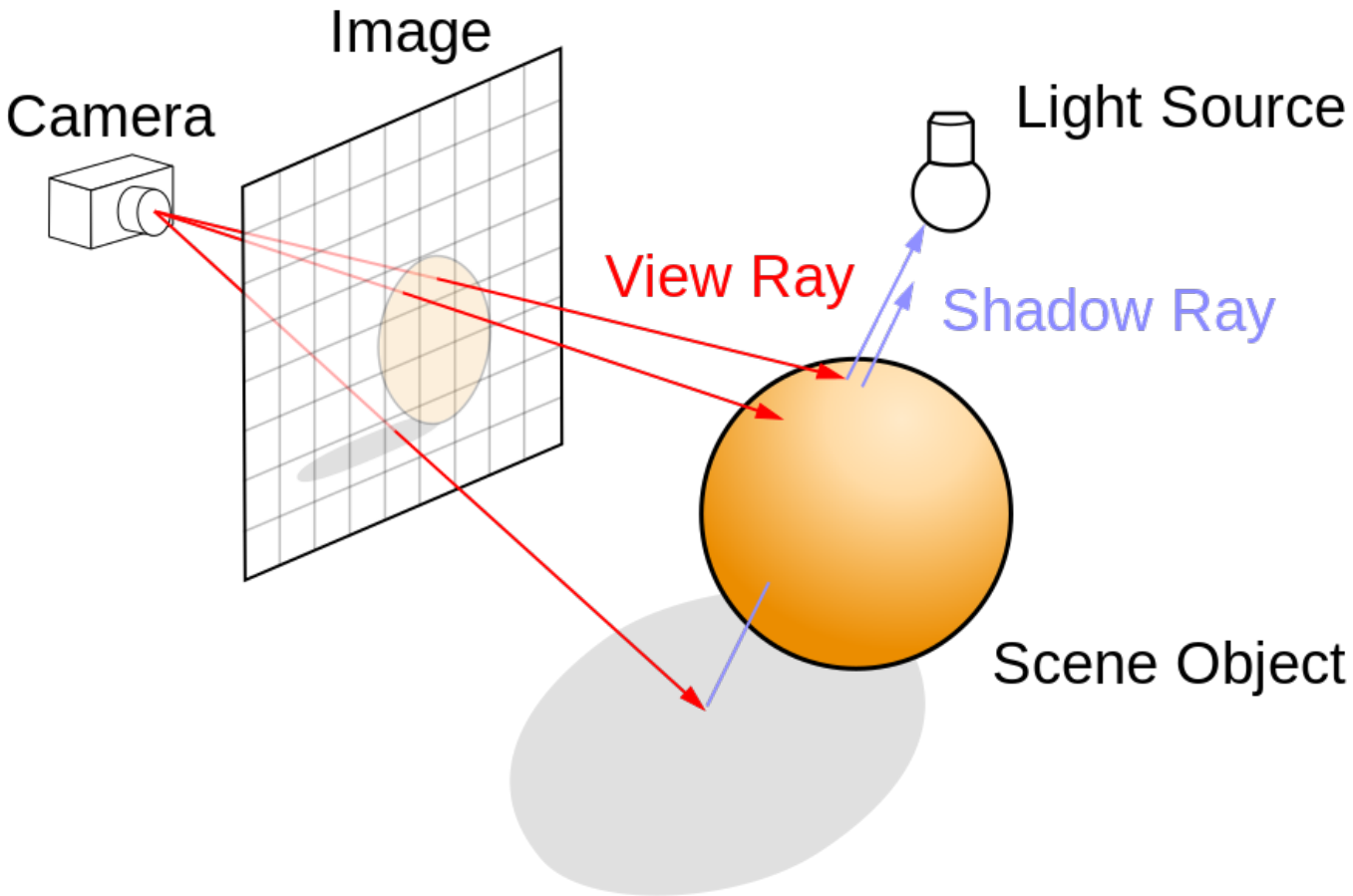
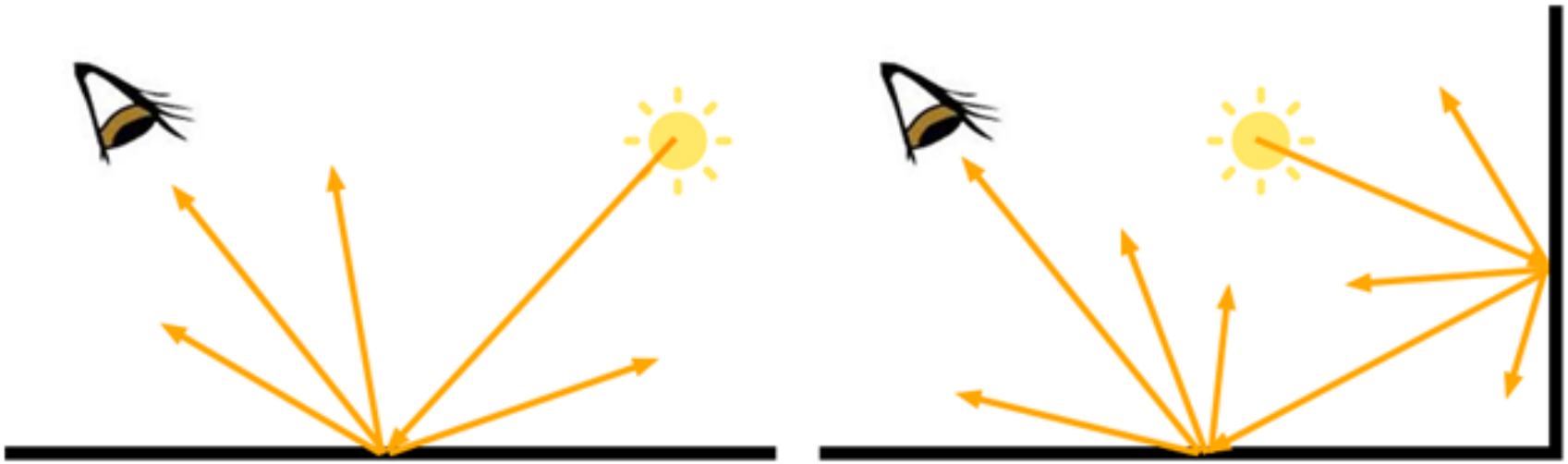
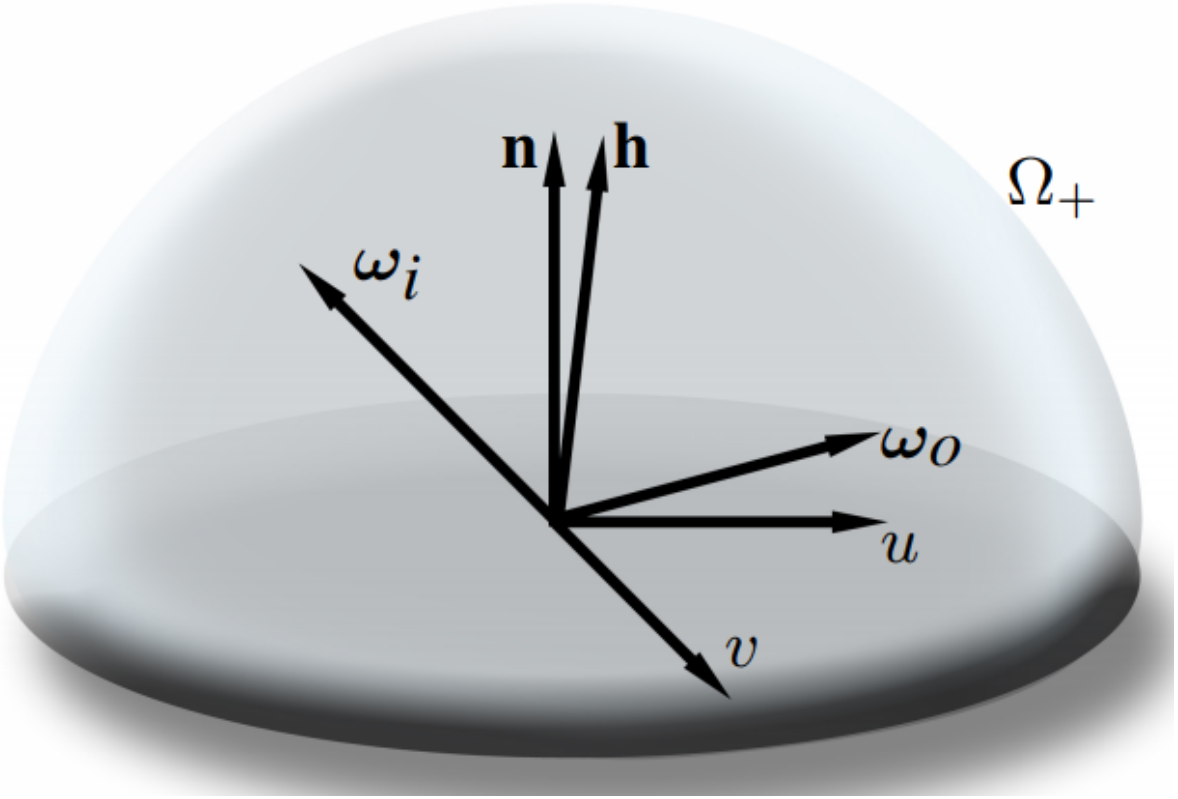
What is Path Tracing?



Direct illumination vs. Global illumination



Rendering Equation

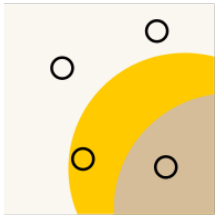


$$L_o(x, \omega_o, \lambda, t) = L_e(x, \omega_o, \lambda, t) + L_r(x, \omega_i, \omega_o, \lambda, t) L_i(x, \omega_i, \lambda, t)$$

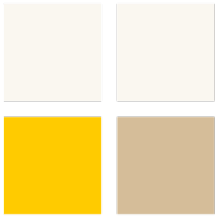
$$L_o(x, \omega_o, \lambda, t) = L_e(x, \omega_o, \lambda, t) + \int_\Omega f_r(x, \omega_i, \omega_o, \lambda, t) L_i(x, \omega_i, \lambda, t)(\omega_i \cdot n) d\omega_i$$

Anti-aliasing

- Supersampling



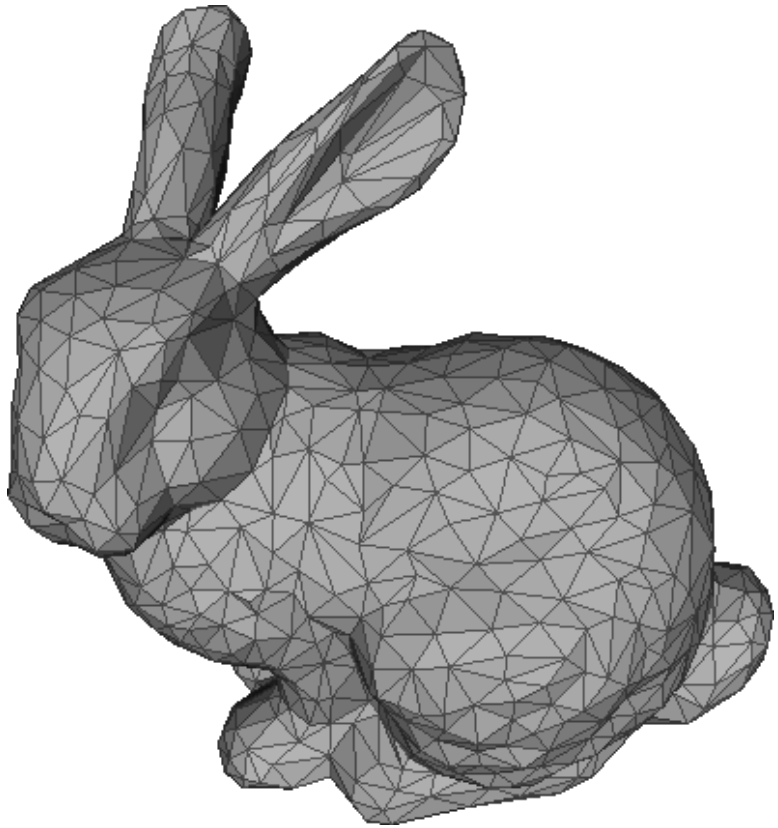
Pixel with sampling positions



Sampled colours

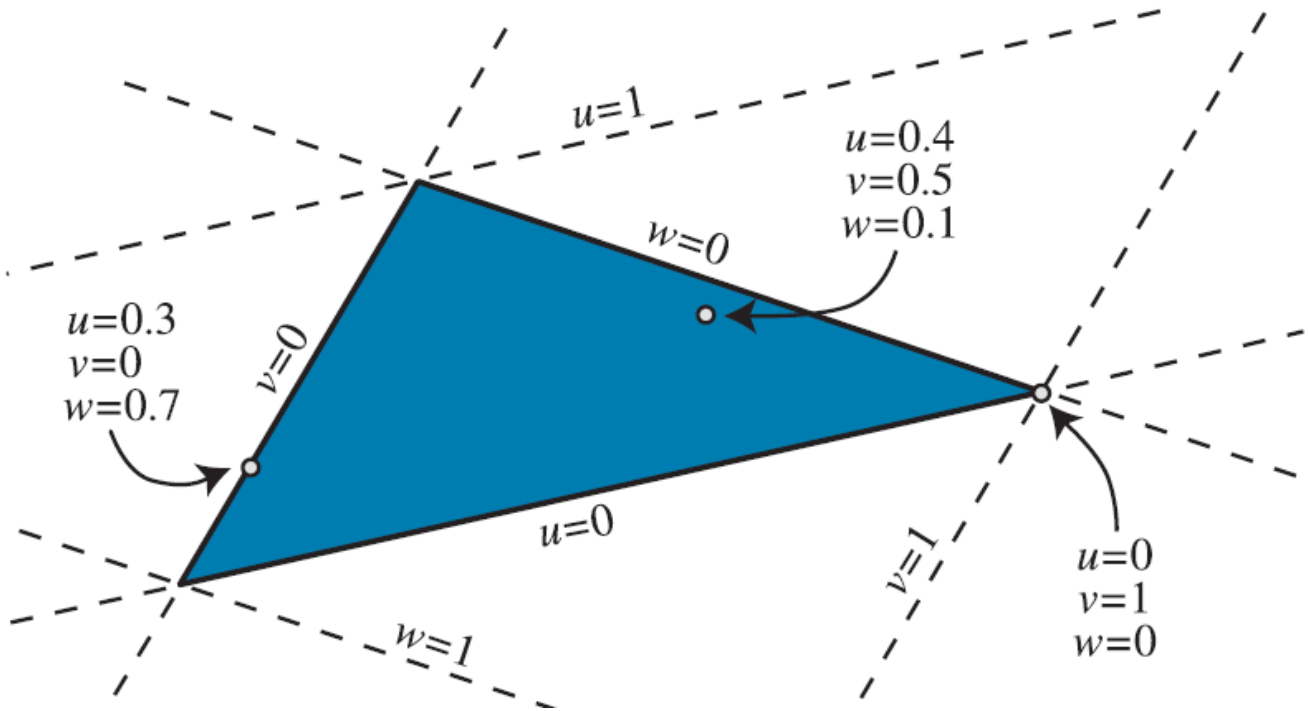
Average = displayed colour

Triangles



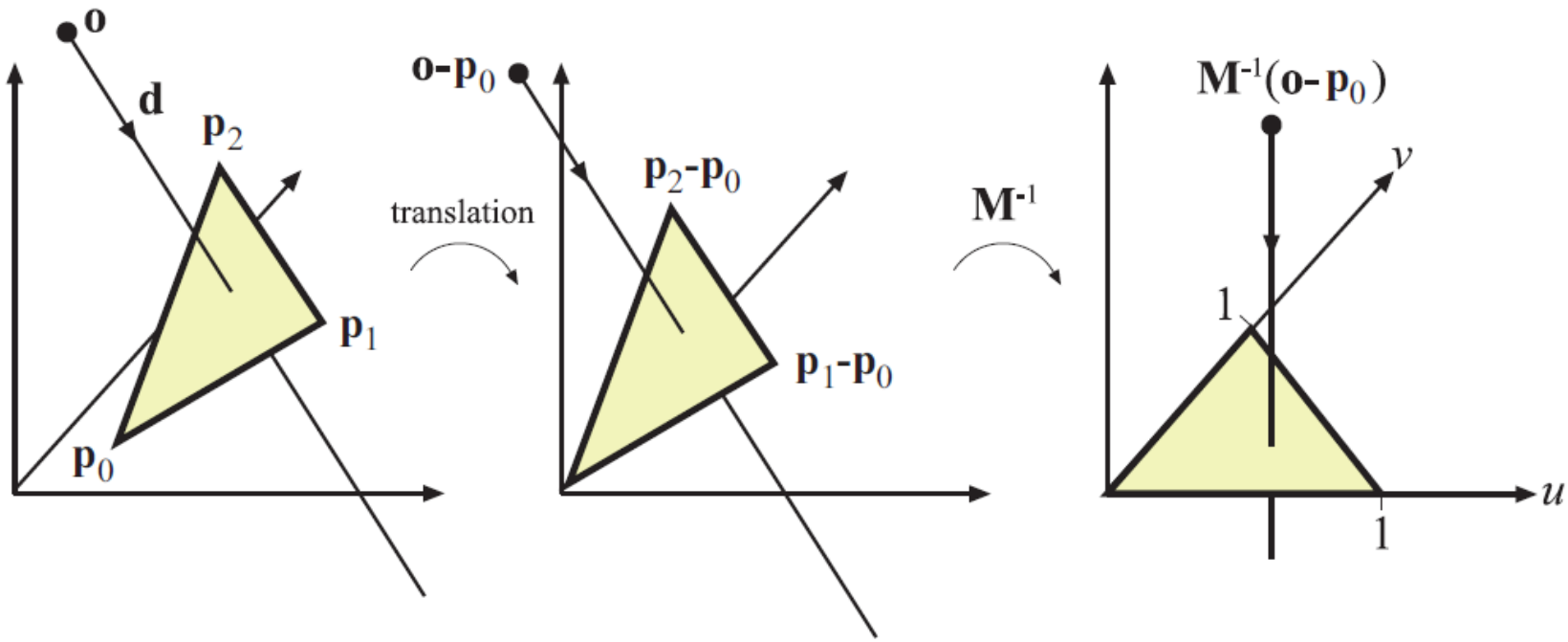
Möller-Trumbore

$$f(u, v) = p_0 + y \cdot p_1 + v \cdot p_2, \text{ with } u \geq 0,\ v \geq 0 \text{ and } u + v \leq 1$$

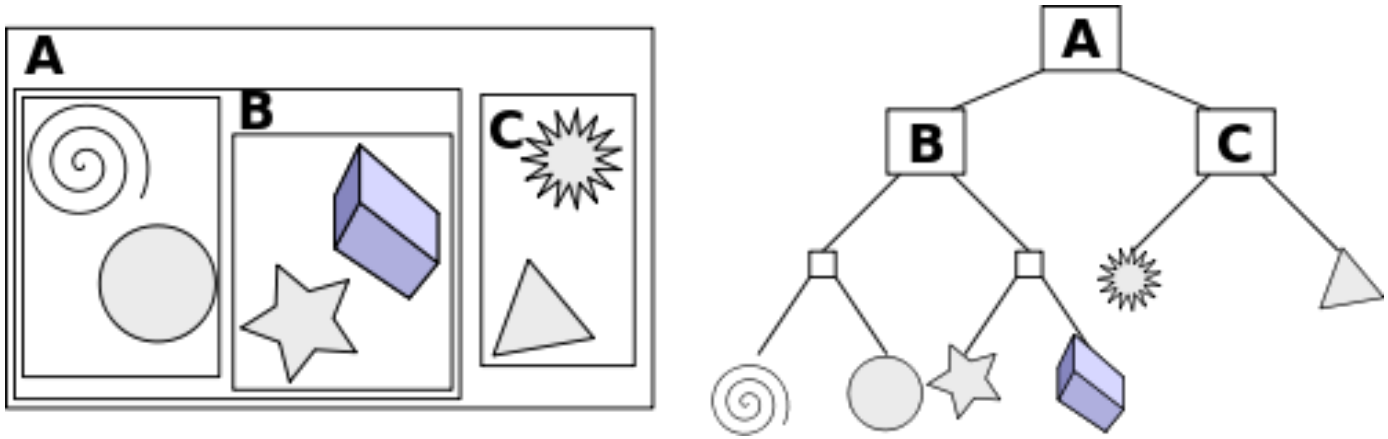


Möller-Trumbore

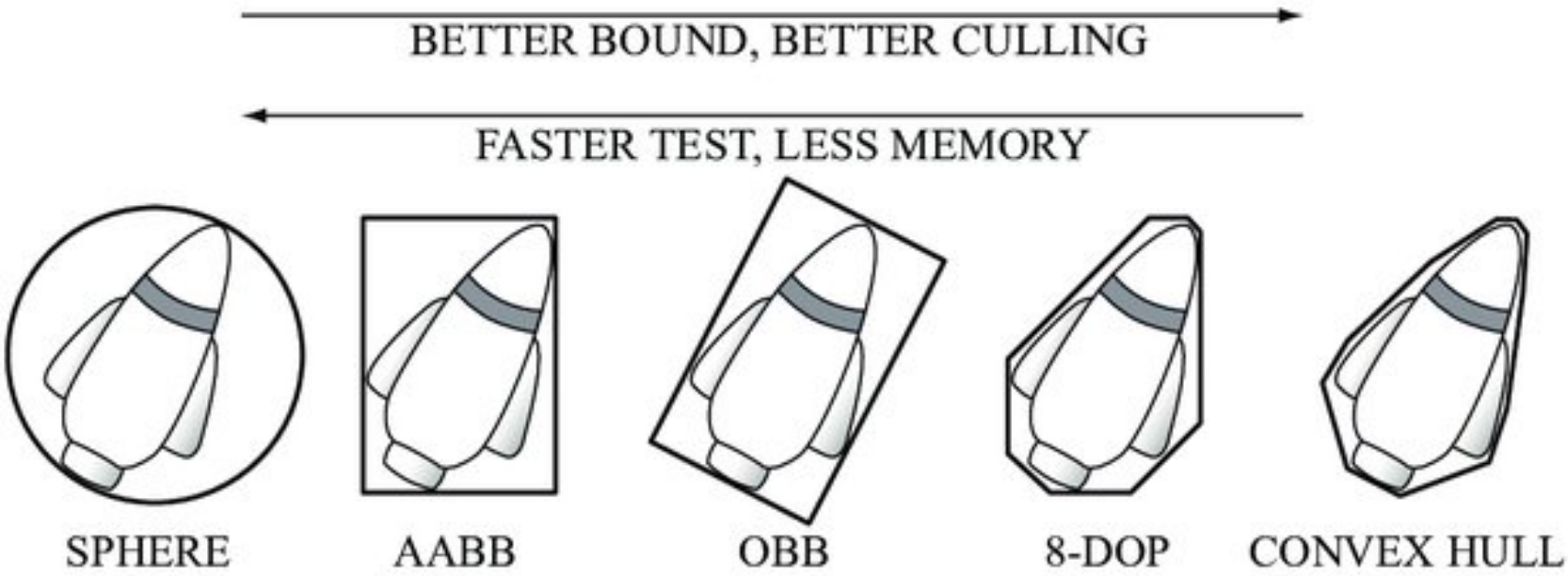
$$\begin{bmatrix} -d & p_1 - p_0 & p_2 - p_0 \end{bmatrix} \begin{bmatrix} t \\ u \\ v \end{bmatrix} = o - p_o$$



Bounding Volume Hierarchy I



Bounding Volume Hierarchy II



Ray-slab intersection I

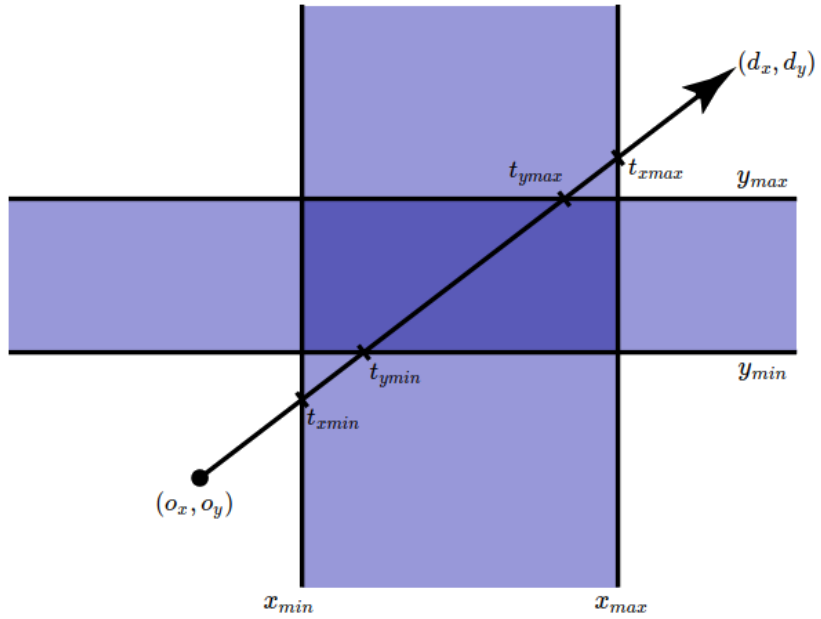
- Example with t_{min}. Same for t_{max}

$$p_x + t_{x_{min}} d_x = x_{min}$$

$$t_{x_{min}} = \frac{(x_{min} - o_x)}{d_x}$$

$$p_y + t_{y_{min}} d_y = y_{min}$$

$$t_{y_{min}} = \frac{(y_{min} - o_y)}{d_y}$$



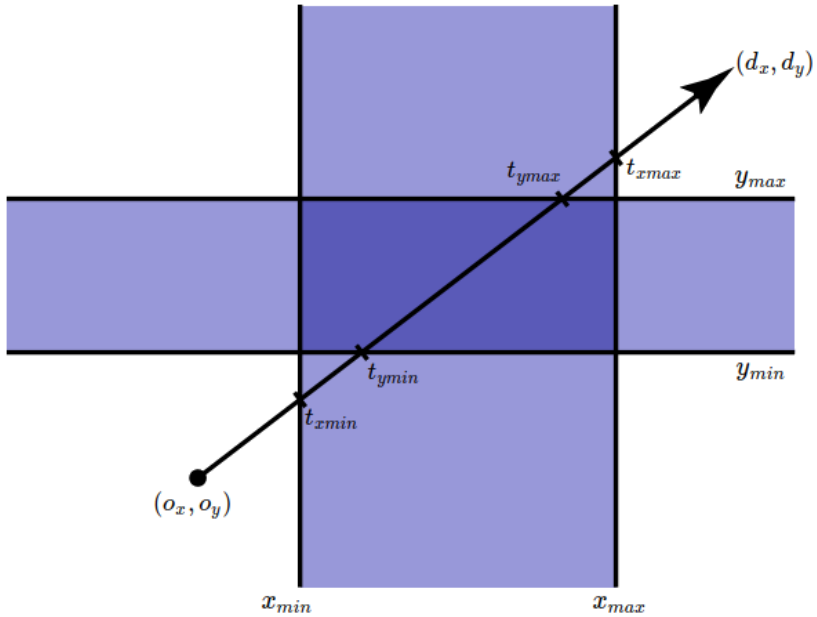
$$t_{min} = \left(\frac{(x_{min} - o_x)}{d_x}, \frac{(y_{min} - o_y)}{d_y} \right)$$

Ray-slab intersection II

- Each intersection is an interval
- We want the last entry point $t_{smaller}$, and first exit point t_{bigger}

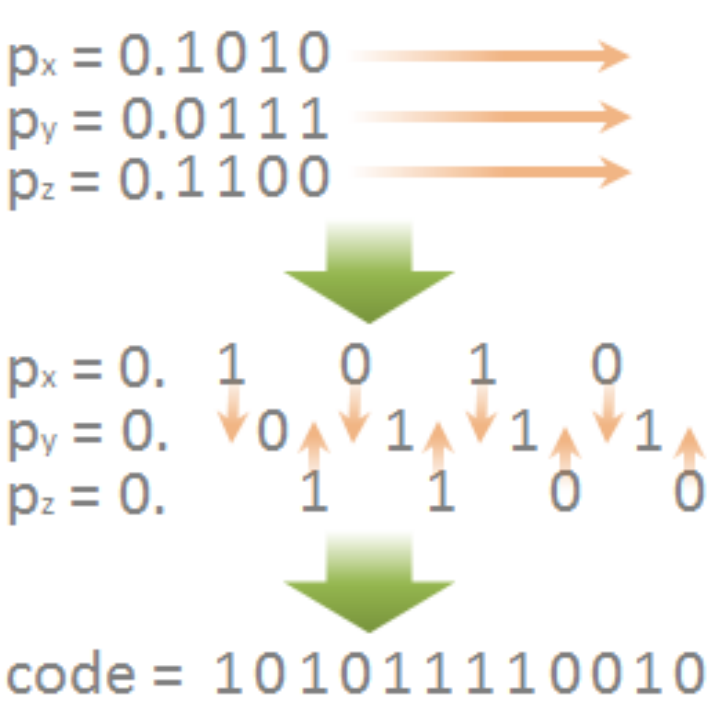
$$t_{smaller} = min(t_{min}, t_{max})$$

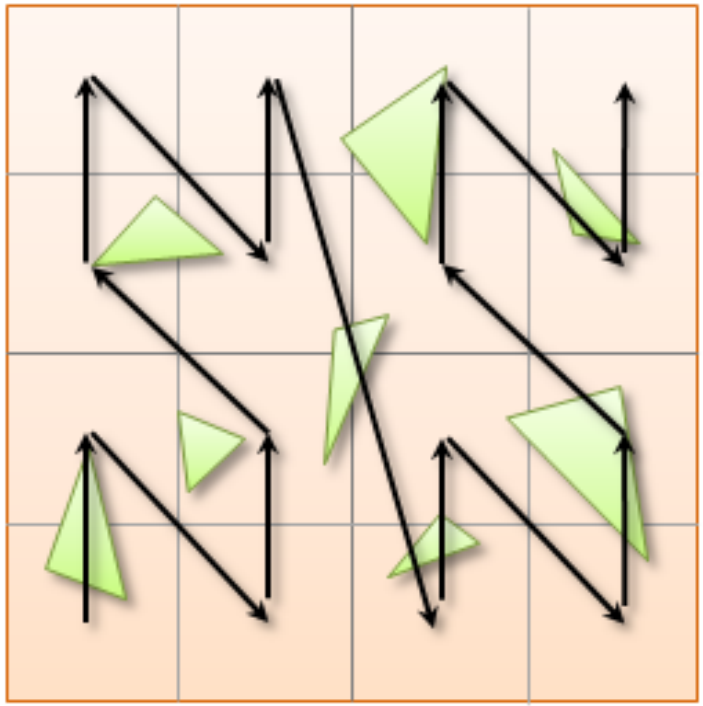
$$t_{bigger} = max(t_{min}, t_{max})$$



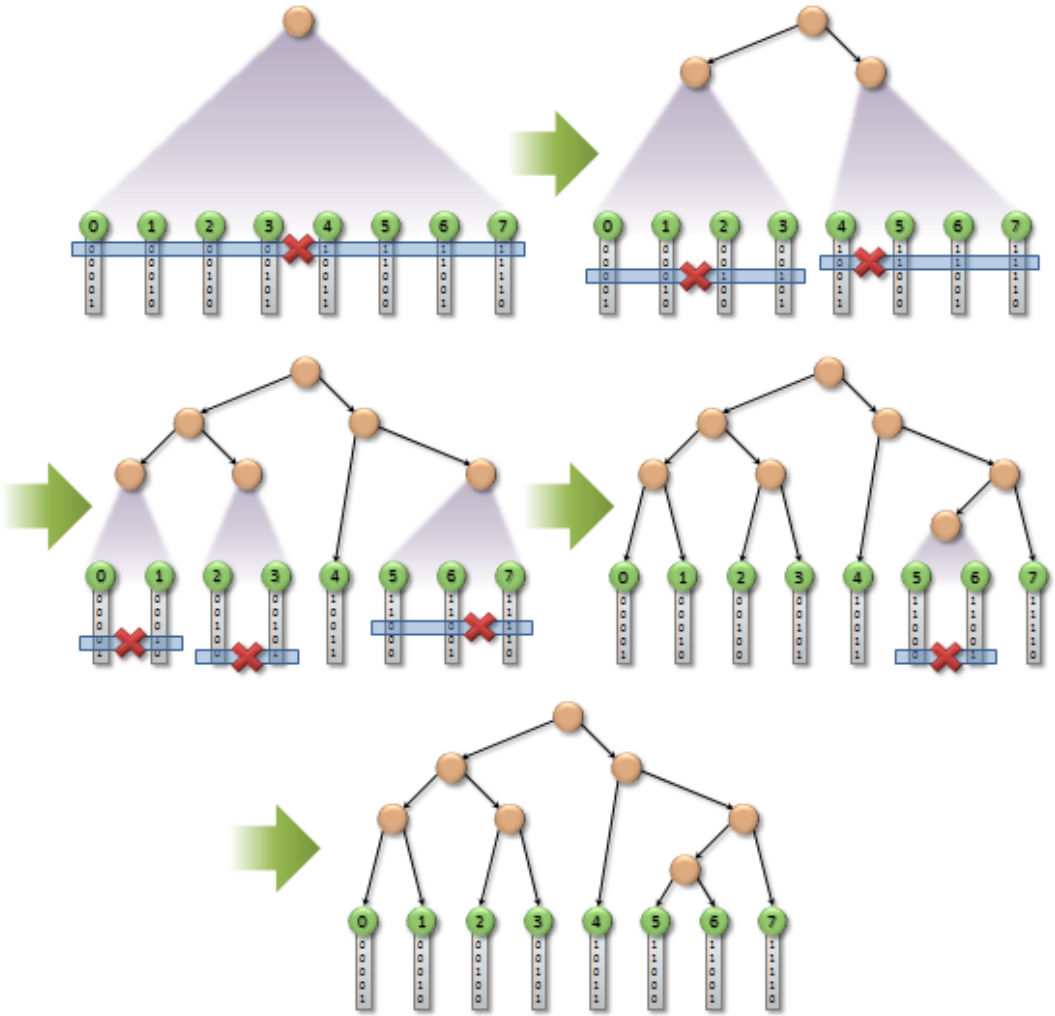
- $max(t_{x_{min}}, t_{y_{min}}, t_{z_{min}}) < min(t_{x_{max}}, t_{y_{max}}, t_{z_{max}})$

LBVH - Tero Karras





LBVH - Tero Karras



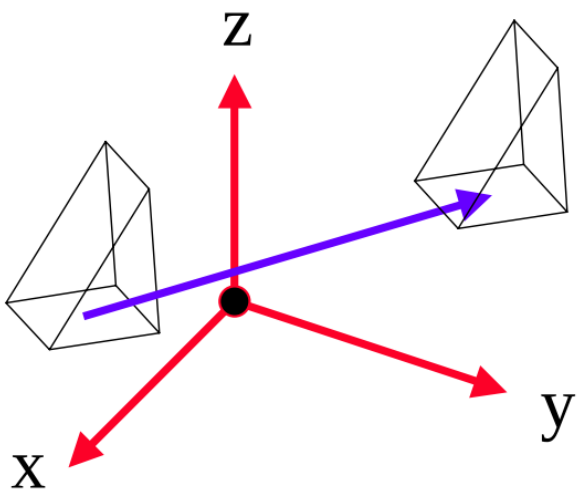
Geometry Transforms

- Translation
- Scaling
- Rotation

Translation

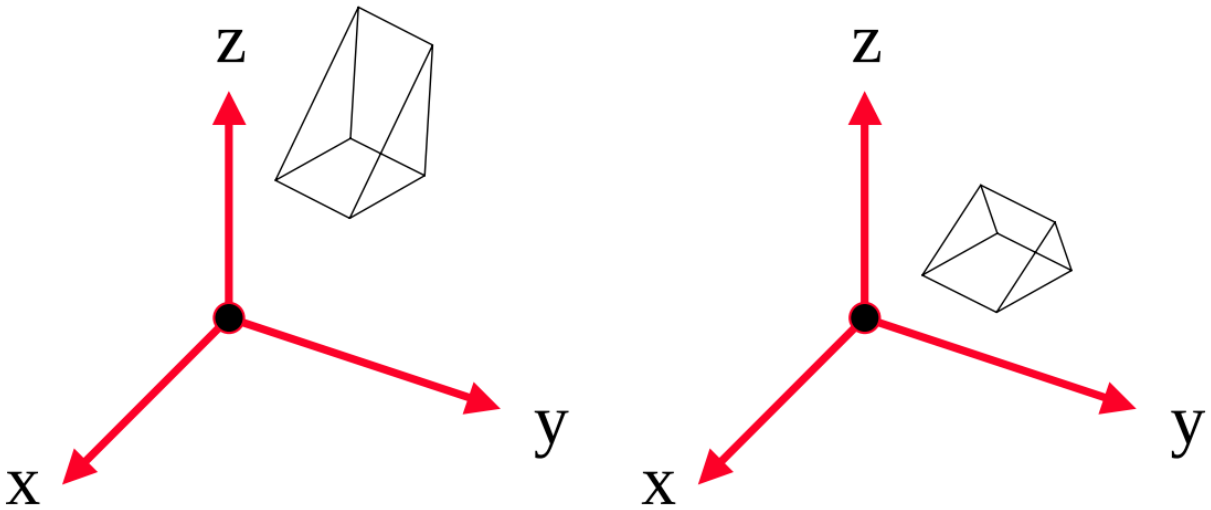
- P in translated to P' by:

$$\begin{bmatrix} 1 & 0 & 0 & t_x \\ 0 & 1 & 0 & t_y \\ 0 & 0 & 1 & t_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix} = \begin{bmatrix} x' \\ y' \\ z' \\ 1 \end{bmatrix} = \begin{bmatrix} x + t_x \\ y + t_y \\ z + t_z \\ 1 \end{bmatrix}$$



Scaling

$$\begin{bmatrix} s_x & 0 & 0 & 0 \\ 0 & s_y & 0 & 0 \\ 0 & 0 & s_z & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix} = \begin{bmatrix} x' \\ y' \\ z' \\ 1 \end{bmatrix} = \begin{bmatrix} xs_x \\ ys_y \\ zs_z \\ 1 \end{bmatrix}$$



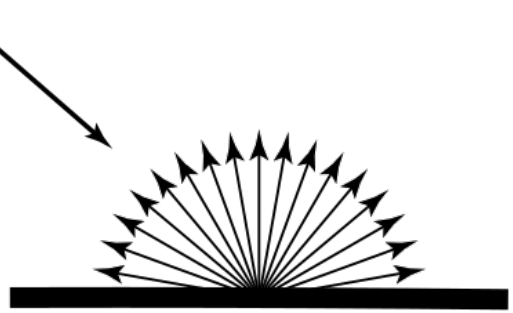
Rotation

$$R_x = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & cos\theta_x & -sin\theta_x & 0 \\ 0 & sin\theta_x & cos\theta_x & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} R_y = \begin{bmatrix} cos\theta_y & 0 & sin\theta_y & 0 \\ 0 & 1 & 0 & 0 \\ -sin\theta_y & 0 & cos\theta_y & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} R_z = \begin{bmatrix} cos\theta_z & \sin\theta_z & 0 & 0 \\ sin\theta_z & cos\theta_z & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

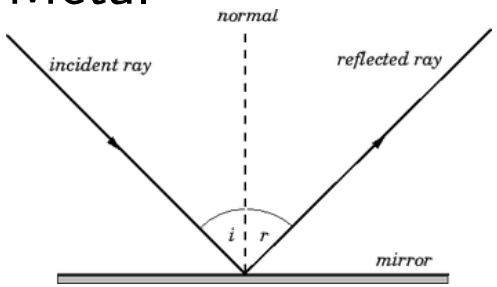
$$R = R_z \cdot R_y \cdot R_x = \begin{bmatrix} cos\theta_y cos\theta_z & -cos\theta_x sin\theta_z + sin\theta_x sin\theta_y cos\theta_z & sin\theta_x sin\theta_z + cos\theta_x sin\theta_y cos\theta_z & 0 \\ cos\theta_y sin\theta_z & cos\theta_x cos\theta_z + sin\theta_x sin\theta_y sin\theta_z & -sin\theta_x cos\theta_z + cos\theta_x sin\theta_y sin\theta_z & 0 \\ -sin\theta_y & sin\theta_x cos\theta_y & cos\theta_x cos\theta_y & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

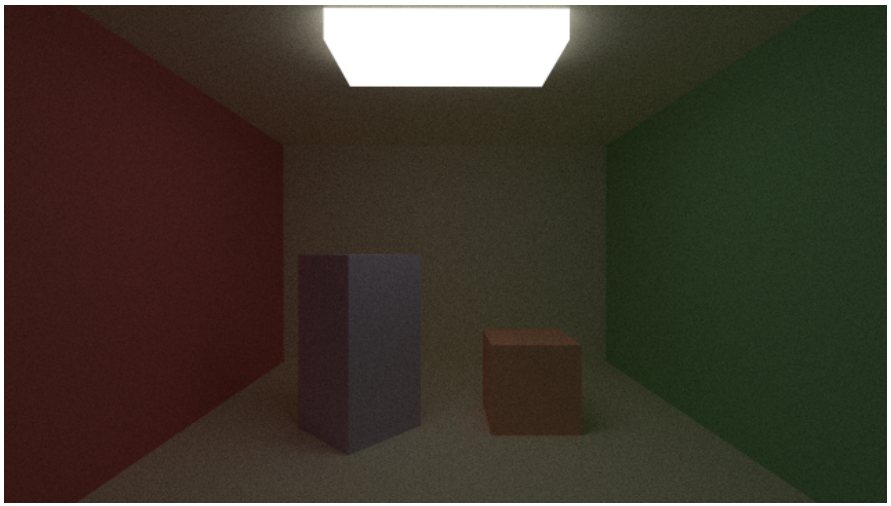
Materials I - Diffuse & Metals

- Diffuse



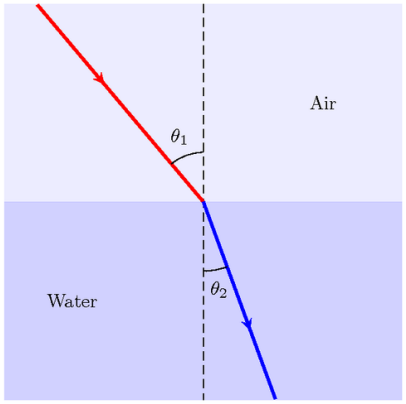
- Metal



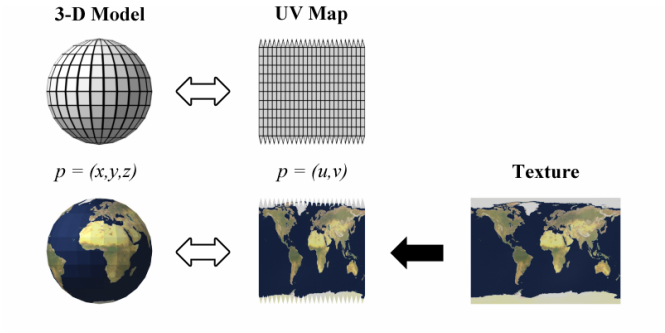


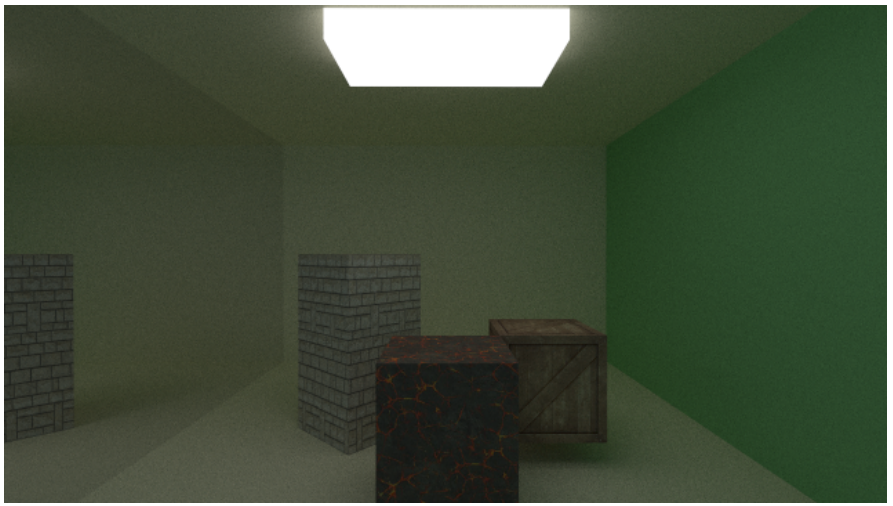
Materials II - Dielectrics & Textures

- Dielectrics



- Textures

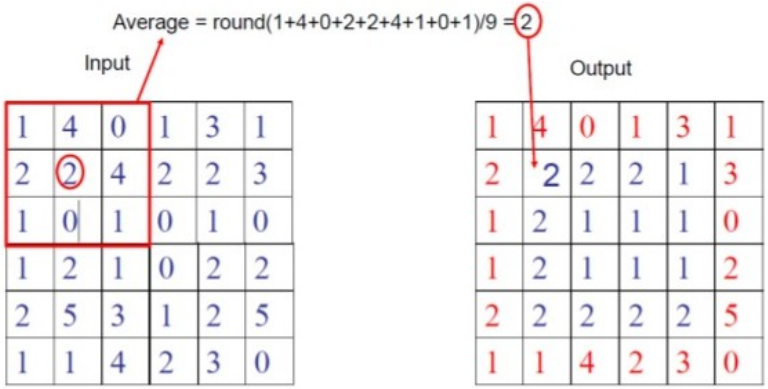




Materials III - Skybox

Image Filters

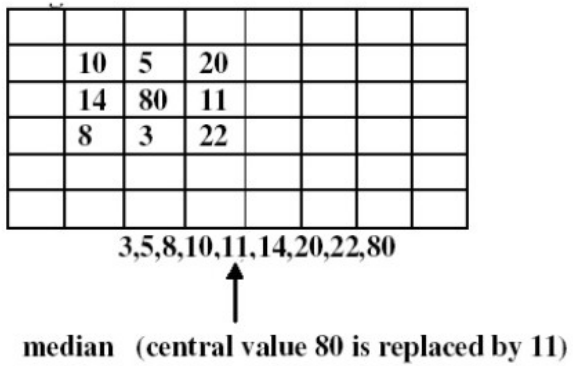
- Mean Filter



1	4	0	1	3	1
2	2	4	2	2	3
1	0	1	0	1	0
1	2	1	0	2	2
2	5	3	1	2	5
1	1	4	2	3	0

1	4	0	1	3	1
2	2	2	2	1	3
1	2	1	1	1	0
1	2	1	1	1	2
2	2	2	2	2	5
1	1	4	2	3	0

- Median Filter



- Bilateral Filter

$$BF[I]_p = \frac{1}{W_p} \sum_{q \epsilon S} G_{\sigma_s}(||p-q||) G_{\sigma_r}(|I_p - I_q|) I_q$$

Results

Figure: Scene one

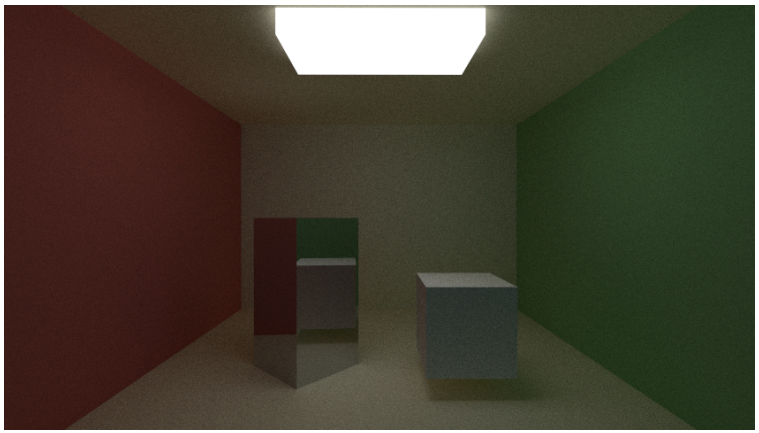


Figure: Scene two

Figure: Scene three

Scene one

Version			Machine	Scene one Time (*seconds*)				
				1 sample(s)	10 sample(s)	50 sample(s)	100 sample(s)	200 sample(s)
CPU	Seq.	List	Lenovo	15,50	154,14	774,44	1542,36	3095,65
			Desktop	14,12	139,79	742,83	1445,64	2809,16
		BVH It.	Lenovo	30,85	300,05	1493,99	3045,05	6081,05
			Desktop	27,51	273,01	1369,04	2729,36	5462,02
		BVH Rec.	Lenovo	28,22	282,373	1407,27	2815,23	5632,42
			Desktop	26,06	258,99	1285,07	2568,13	5156,55
	OpenMP	List	Lenovo	9,54	94,16	480,20	982,87	1929,72
			Desktop	8,79	88,81	460,89	877,24	1859,07
		BVH It.	Lenovo	10,08	102,17	525,59	1194,84	2159,8
			Desktop	9,01	90,48	451,49	916,96	1801,08
		BVH Rec.	Lenovo	11,40	122,50	601,731	1169,89	2033,67
			Desktop	9,24	88,62	449,78	896,47	1762,38
GPU	CUDA	List	Lenovo	2,58	25,76	128,43	257,42	513,87
			Desktop	0,93	9,38	46,57	91,85	187,2
			BOADA - 1 GPU(s)	3,13	27,53	135,83	271,39	-
			BOADA - 2 GPU(s)	2,07	14,88	71,67	142,867	285,18
			BOADA - 3 GPU(s)	1,87	10,58	49,32	97,80	194,22
			BOADA - 4 GPU(s)	1,83	8,45	37,77	74,38	147,36
		BVH It.	Lenovo	5,68	56,58	285,36	1138,34	1703,40
			Desktop	1,495	15,11	75,14	149,00	300,13
			BOADA - 1 GPU(s)	4,46	45,66	226,37	452,18	-
			BOADA - 2 GPU(s)	3,05	24,26	118,67	236,20	-
			BOADA - 3 GPU(s)	2,53	16,66	79,75	158,22	316,99
			BOADA - 4 GPU(s)	2,40	13,17	61,34	120,84	240,43
		BVH Rec.	Lenovo	6,09	60,79	304,07	608,53	1216,93
			Desktop	9,09	108,15	557,74	1092,76	-
			BOADA - 1 GPU(s)	21,64	212,176	-	-	-
			BOADA - 2 GPU(s)	11,83	111,84	555,42	-	-
			BOADA - 3 GPU(s)	8,51	75,54	375,68	-	-
			BOADA - 4 GPU(s)	6,99	57,98	284,42	-	-

Scene two

Version			Machine	Scene two Time (*seconds*)				
				1 sample(s)	10 sample(s)	50 sample(s)	100 sample(s)	200 sample(s)
CPU	Seq.	List	Lenovo	997,50	9945,55	-	-	-
			Desktop	895,25	8947,03	-	-	-
		BVH It.	Lenovo	63,40				
			Desktop	54,94	549,40	2752,72	-	-
		BVH Rec.	Lenovo	61,14	574,35	2879,1	-	-
			Desktop	52,63	517,39	2590,70	-	-
	`OpenMP`	List	Lenovo	200,01	2049,1	-	-	-
			Desktop	162,58	1628,67	-	-	-
		BVH It.	Lenovo	15,98	186,40	830,45	1603,2	3725,69
			Desktop	13,72	134,73	683,68	1046,53	2684,10
		BVH Rec.	Lenovo	17,99	155,20	774,82	1508,78	3045,93
			Desktop	12,42	127,13	642,18	1303,50	2590,35
GPU	`CUDA`	List	Lenovo	107,52	1075,6	5370,88	-	-
			Desktop	28,19	297,74	1473,80	2928,41	6178,08
			BOADA - 1 GPU(s)	89,72	-	-	-	-
			BOADA - 2 GPU(s)	47,12	466,79	-	-	-
			BOADA - 3 GPU(s)	32,19	313,57	-	-	-
			BOADA - 4 GPU(s)	24,86	236,67	-	-	-
		BVH It.	Lenovo	21,05	206,84	1031,70	2076,09	-
			Desktop	2,88	28,578	145,64	281,75	561,86
			BOADA - 1 GPU(s)	13,82	131,13	650,972	-	-
			BOADA - 2 GPU(s)	7,49	69,67	344,18	-	-
			BOADA - 3 GPU(s)	5,56	46,65	228,36	456,21	-
			BOADA - 4 GPU(s)	4,83	36,34	178,22	353,11	-
		BVH Rec.	Lenovo	42,59	425,59	2123,99	4253,62	8512,77
			Desktop	20,70	236,11	1252,08	2736,14	-
			BOADA - 1 GPU(s)	40,82	402,58	-	-	-
			BOADA - 2 GPU(s)	21,92	214,38	-	-	-
			BOADA - 3 GPU(s)	15,09	142,44	-	-	-
			BOADA - 4 GPU(s)	10,23	120,35	-	-	-

Scene three

Version			Machine	Scene three Time (*seconds*)				
				1 sample(s)	10 sample(s)	50 sample(s)	100 sample(s)	200 sample(s)
CPU	Seq.	List	Lenovo	1656,54	16501,10	-	-	-
			Desktop	1520,31	15442,7	-	-	-
		BVH It.	Lenovo	2,81	27,89	-	-	-
			Desktop	3,17	30,65	-	-	-
		BVH Rec.	Lenovo	2,90	27,94	-	-	-
			Desktop	3,25	31,74	-	-	-
	OpenMP	List	Lenovo	367,03	3665,89	-	-	-
			Desktop	325,6	3154,44	-	-	-
		BVH It.	Lenovo	0,77	7,92	40,46	1603,2	3725,69
			Desktop	0,80	8,12	40,41	-	-
		BVH Rec.	Lenovo	0,79	8,1	40,52	1059,78	3045,93
			Desktop	0,98	8,94	40,71	-	-
GPU	CUDA	List	Lenovo	303,90	3073,21	-	-	-
			Desktop	121,31	1320,21	6472,71	-	-
			BOADA - 1 GPU(s)	402,82	-	-	-	-
			BOADA - 2 GPU(s)	221,20	-	-	-	-
			BOADA - 3 GPU(s)	185,33	-	-	-	-
			BOADA - 4 GPU(s)	144,05	-	-	-	-
		BVH It.	Lenovo	1,55	15,43	76,68	153,65	307,55
			Desktop	0,27	2,38	11,93	23,6	45,94
			BOADA - 1 GPU(s)	2,25	17,46	85,99	169,99	339,61
			BOADA - 2 GPU(s)	1,88	9,46	45,72	90,15	178,83
			BOADA - 3 GPU(s)	2,04	9,42	41,60	82,52	168,632
			BOADA - 4 GPU(s)	2,29	7,98	33,77	65,64	128,26
		BVH Rec.	Lenovo	4,42	39,62	198,03	398,34	793,71
			Desktop	2,51	26,99	137,24	284,24	567,90
			BOADA - 1 GPU(s)	6,99	63,56	316,55	-	-
			BOADA - 2 GPU(s)	4,29	34,10	164,44	330,92	-
			BOADA - 3 GPU(s)	4,347	32,79	158,46	317,07	-
			BOADA - 4 GPU(s)	3,93	25,69	123,68	243,43	-

Results

Figure: Mean filter with window size $[11 \times 11]$.

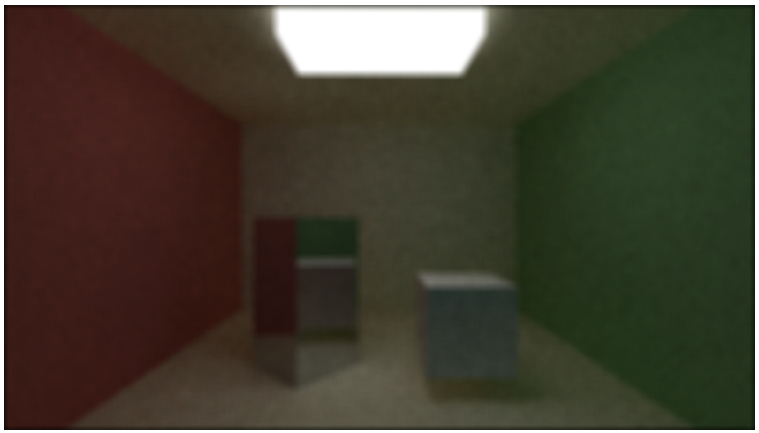
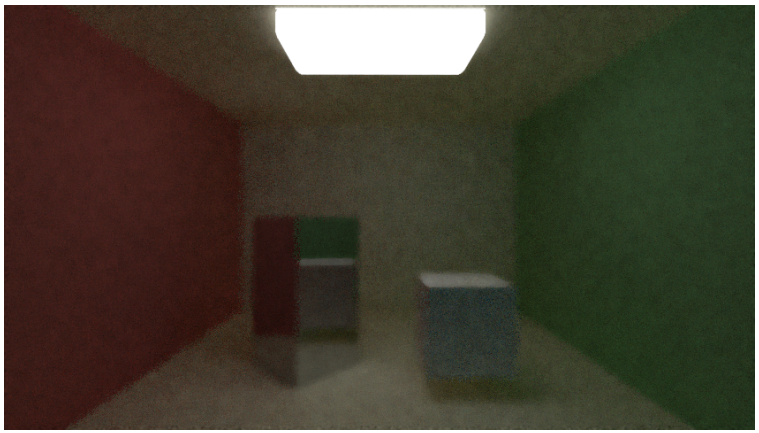


Figure: Median Filter with window size $[11 \times 11]$.



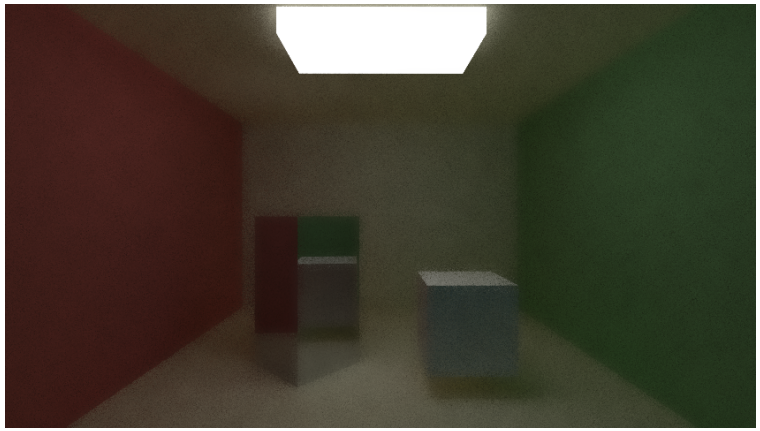


Figure: Bilateral Filter. Image with 50 SPP, $\delta_s = 15$ and $\delta_r = 10$

Thank you for your attention!