Cinematic Depth Of Field

How to make big filters cheap

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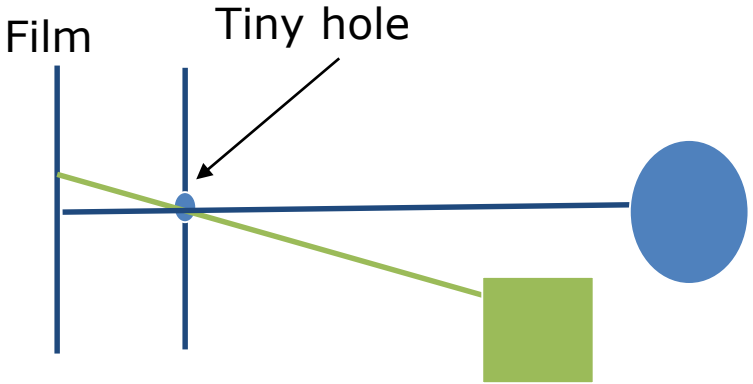
Outline

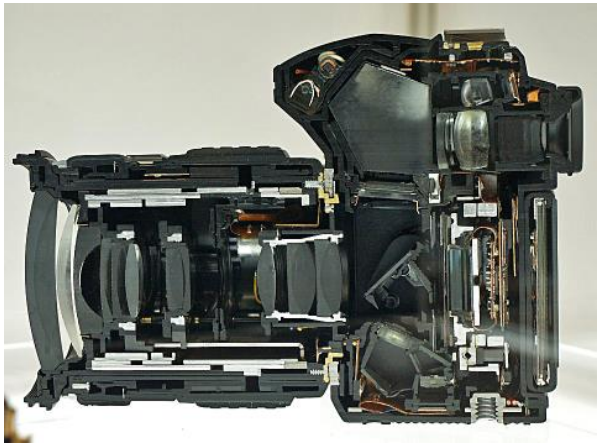
- Depth of Field
- Real-time approximations
- Fast Filter Spreading
- Implementation

Depth of Field

Depth of Field Optics



Pinhole Camera

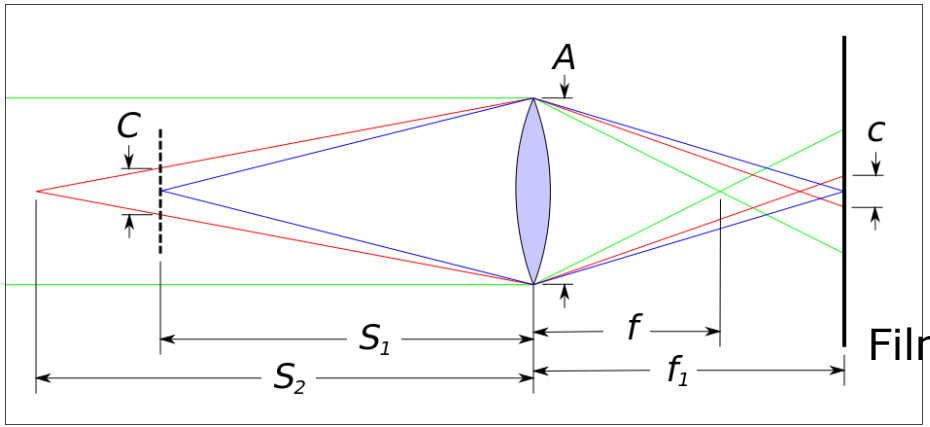


Real Camera

Thin Lens Model

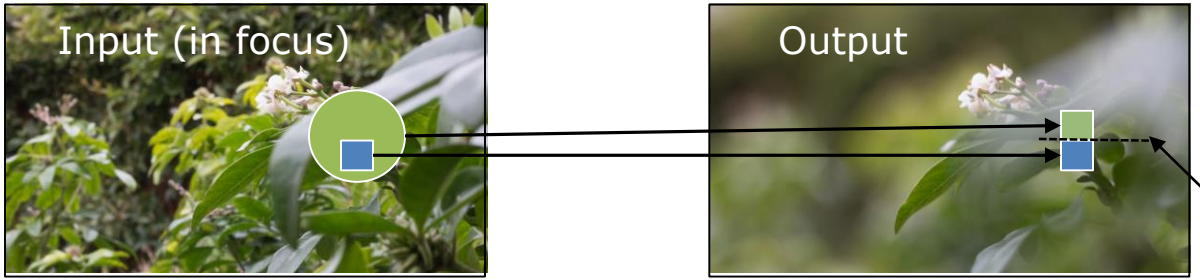
Lens focuses a distance onto film (blue in this case)

f = focal length
A = aperture width
c = circle of confusion (CoC) on film
C = CoC in world

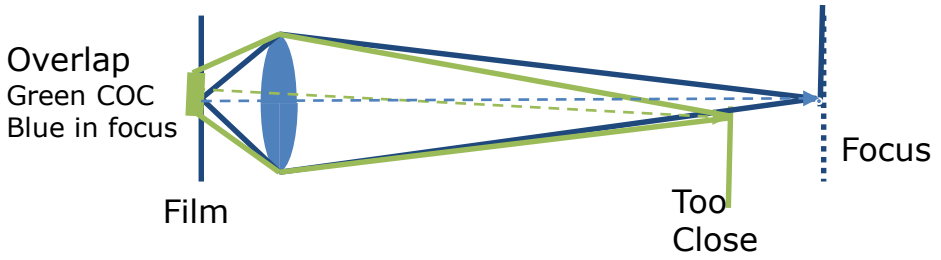


From Wikipedia "Circle of Confusion"

Gather Methods

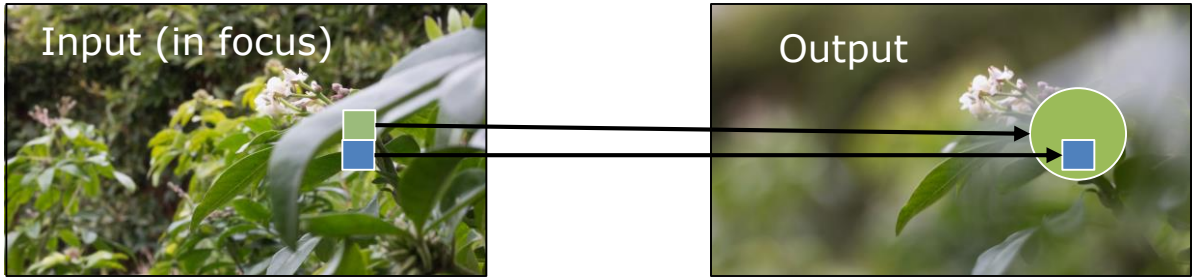



```
for i,j:
    CoC = f ( z(i,j) – zInFocus )
    Out_ij = Gather( CoC );
```



Scatter Methods

Where does each input go?




```
for i,j:
    CoC = f ( z(i,j) - zInFocus );
    Spread( Input_ij, CoC );
```

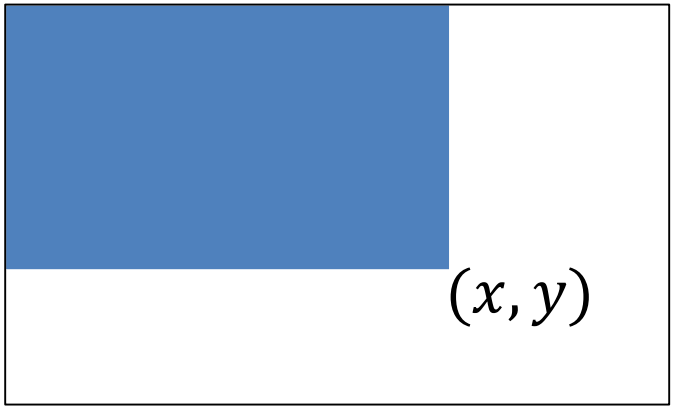
Draw a sprite for each input pixel

Gather from SAT

Compute Summed Area Table

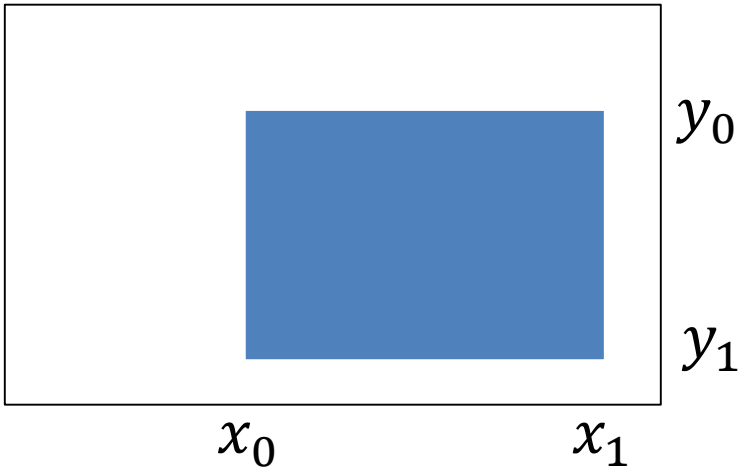
Gather with 4 lookups

Summed Area Table



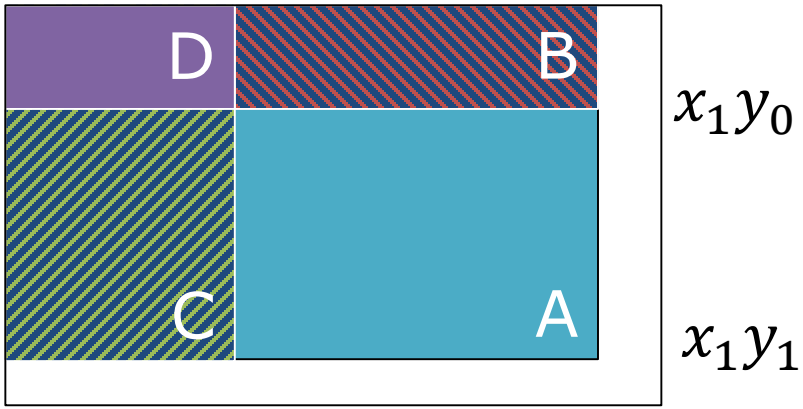
(x,y) contains $\sum_{i=0}^{x}\sum_{j=0}^{y} I_{i,j}$

Gather from SAT



$$S_A - S_B - S_C + S_D$$

=



$$S_A = \sum_{i=0}^{x_1} \sum_{j=0}^{y_1} I_{i,j} \qquad S_B = \sum_{i=0}^{x_1} \sum_{j=0}^{y_0} I_{i,j}$$

Gather SAT

Niceness

- O(1) in filter size

Problems

- Box filter
- Gather method
- Precision Problem

Fast Filter Spreading

- *Fast Filter Spreading and its Applications*
  Kosloff, Hensley, Barsky, UC Berkeley tech report.
- Scatter Method
- SAT in reverse
  - Poke (add) deltas at the corners
  - Then sum

Simple Example

Desired Result

1	1		
1	1		

+

	2	2	
	2	2	

=

1	1		
1	3	2	
	2	2	

Simple Example

Adding Deltas

1		-1	
-1		1	

+

	2		-2
	-2		2

=

1		-1	
	2		-2
-1		1	
	-2		2

Simple Example

Summing for the result

1		-1	
	2		-2
-1		1	
	-2		2

→

1	1		
	2	2	
-1	-1		
	-2	-2	

↓

1	1		
1	3	2	
	2	2	

Still Only 4 Each

1					-1		
			2				-2
-1					1		
			-2				2

1	1	1	1	1			
1	1	1	1	1			
1	1	1	1	1			
1	1	1	3	3	2	2	
1	1	1	3	3	2	2	
			2	2	2	2	
			2	2	2	2	

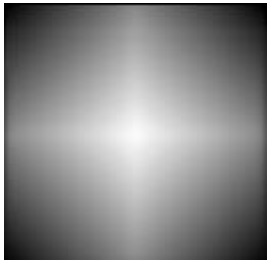
Bartlett

1	-2	1
-2	4	-2
1	-2	1

2 integrations

1	-1	0
-1	1	0
0	0	0

After 1st integration



Implementations

Ladybug

Big demo

Closed source

DOF FX

Simple demo

Open source

Implementation Topics

- Weights and Normalization
- Fixed point math
- Atomics

Weights and Normalization

- Box filter: divide by area
- Bartlett: divide by area*area
- Other filters/weights possible
- Catch all:
  - Accumulate weights in alpha
  - Divide at the end

Fixed Point Math

- Atomics
- Precision
- Scale examples @ ~ 64 x 64, 32 bits
  - 6*2 (box area) = 12 bits -> 20 remaining
  - 6*4 = 24 bits -> 8 remaining
  - 6*3 = 18 bits -> 14 remaining

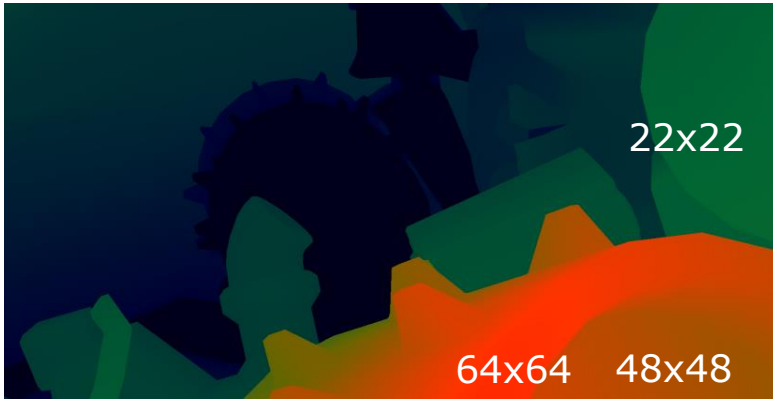
Compute Shader Sample

```
// Scale for fixed point and filter size
int4 intColor = normalizeBlurColor(float4(vColor, 1.0), blur_amount);
for (int i = 0; i < 9; ++i)
{
    // Offset the location by location of the delta and padding
    // Need to offset by (1,1) because the kernel is not centered
    const int2 delta = bartlettData[i].xy * (blur_amount + 1);
    int2 bufLoc = loc.xy + delta + padding + uint2(1, 1);

    // Filter weight
    const int delta_value = bartlettData[i].z;
```

Compute Shader Sample

```
for (int i = 0; i < 9; ++i)
{
    // Offset (previous slide)
    // Weight (previous slide)

    // Write the delta
    // Use interlocked add to prevent the threads from stepping on each other
    // 4 atomics, including alpha channel for normalization.
    InterlockedAddToBuffer(deltaBuffer, bufLoc, intColor * delta_value);
}
```

Results



DOF FX Performance

- Radeon™ RX 480
  - ~5 ms for 1080 p
  - ~3 ms for 1080 p with quarter res
- Looking for further optimizations

Results

64x64 = 4k / pixel

DOF FX Performance

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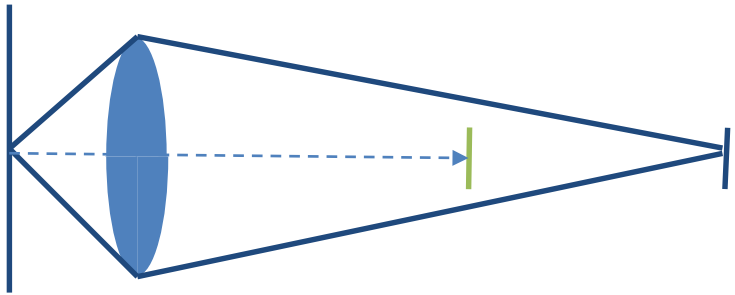
Depth of Field



Summary

- Scatter based DOF
- Fixed, but high-ish overhead
- Limited by precision
- Source available soon

Questions?

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