LUND UNIVERSITY | LTH FACULTY OF ENGINEERING

Succinct Opacity Micromaps

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Arm Sweden & Lund University

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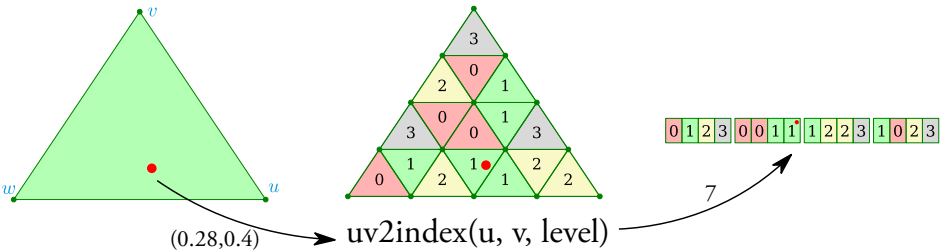
Agenda

1. What are Opacity Micromaps?
   - `uv2index` (`BarycentricsToSpaceFillingCurveIndex`)
2. *Succinct* Opacity Micromaps
   - Memory Footprint Comparison
3. Frametime Performance Evaluation

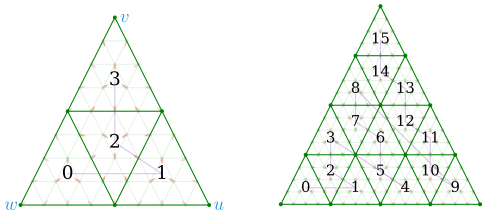
Opacity Micromaps

Opacity Micromaps

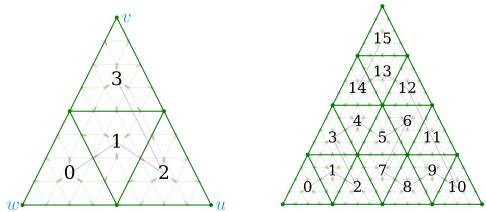
2-State		4-State	
0b0	Fully Transparent	0b00	Fully Transparent
0b1	Fully Opaque	0b01	Fully Opaque
		0b10	Unknown Transparent
		0b11	Unknown Opaque



Micromap Evolution



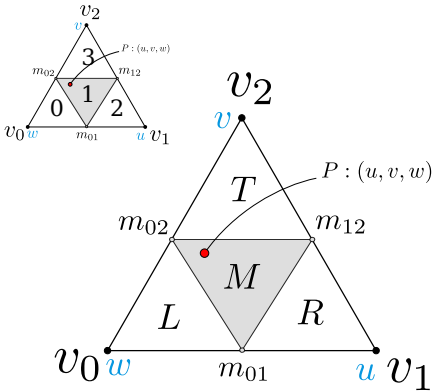
Gruen et al.



Vulkan® & DirectX® [Werness 2022]

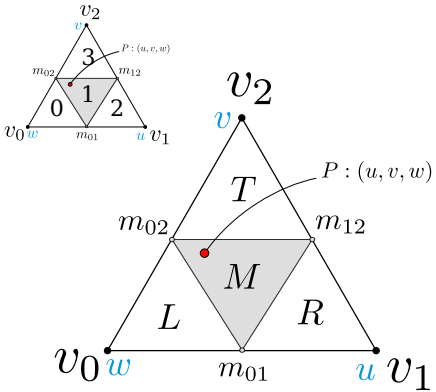
Opacity Micromaps Construction

`uv2index` `BarycentricsToSpaceFillingCurveIndex`



Opacity Micromaps Construction

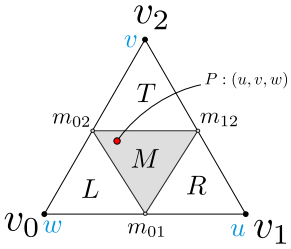
`uv2index` `BarycentricsToSpaceFillingCurveIndex`



$$\begin{cases} v_0 = m_{01} + m_{02} - m_{12} \\ v_1 = m_{01} + m_{12} - m_{02} \\ v_2 = m_{02} + m_{12} - m_{01} \end{cases}$$

Opacity Micromaps Construction

`uv2index` `BarycentricsToSpaceFillingCurveIndex`

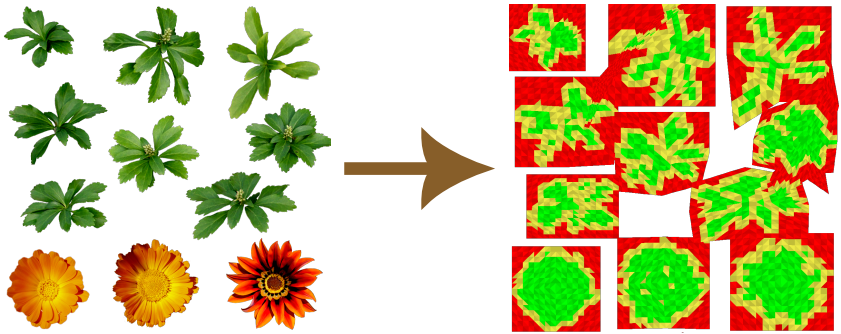


$$L \coloneqq \begin{cases} u_L &= u - v - w \\ v_L &= 2v \\ w_L &= 2w \end{cases} \qquad M \coloneqq \begin{cases} u_M &= u + v - w \\ v_M &= v + w - u \\ w_M &= u + w - v \end{cases}$$

$$R \coloneqq \begin{cases} u_R &= 2u \\ v_R &= v - u - w \\ w_R &= 2w \end{cases} \qquad T \coloneqq \begin{cases} u_T &= 2u \\ v_T &= 2v \\ w_T &= w - u - v \end{cases}$$

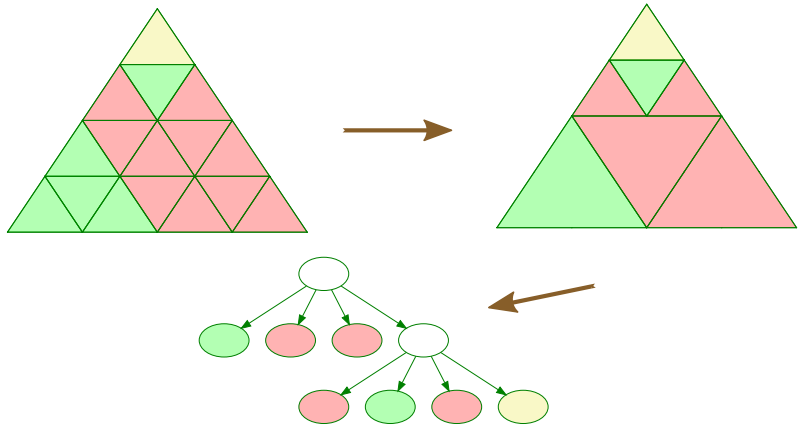
Succinct Opacity Micromaps

Succinct Opacity Micromaps



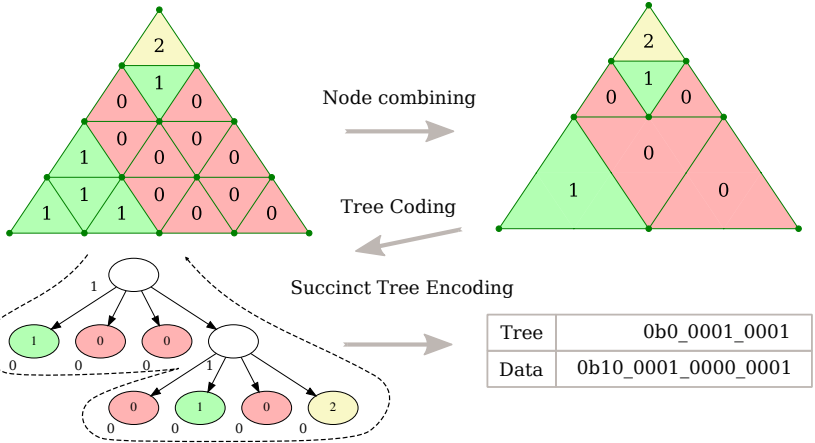
Succinct Opacity Micromaps

Tree Construction



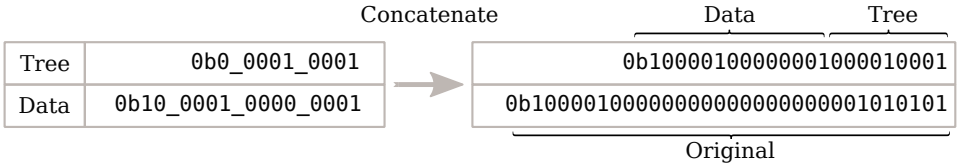
Succinct Opacity Micromaps

Tree Construction

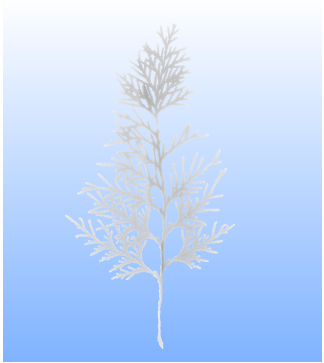


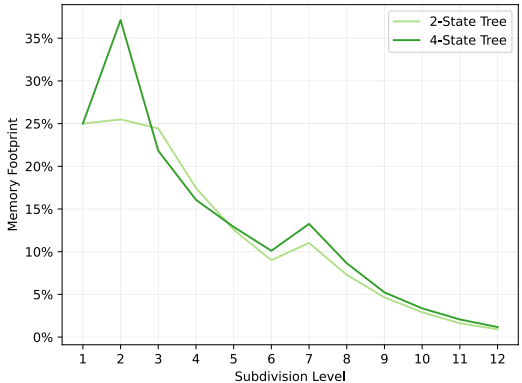
Succinct Opacity Micromaps

Tree Construction



Memory Footprint Improvement

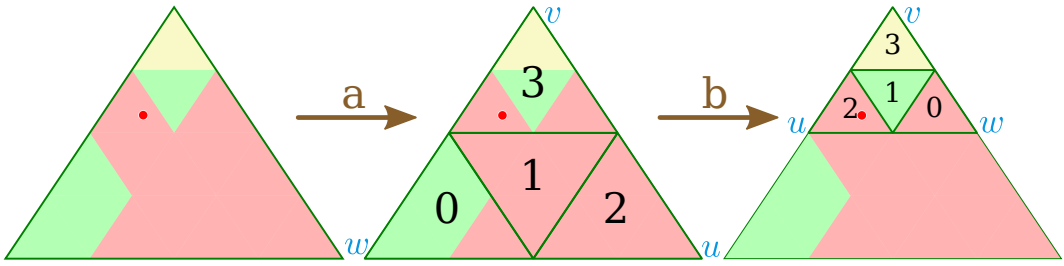


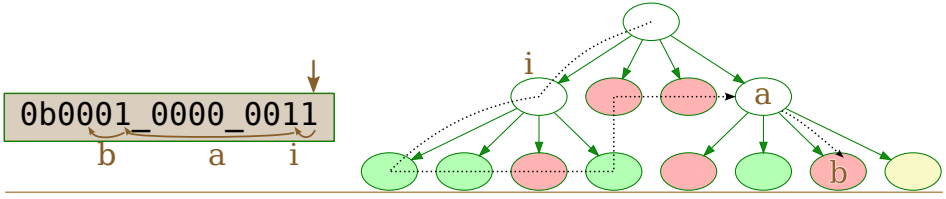


Best ≈ 1 % of the original size.

Succinct Opacity Micromaps

Look-up Algorithm

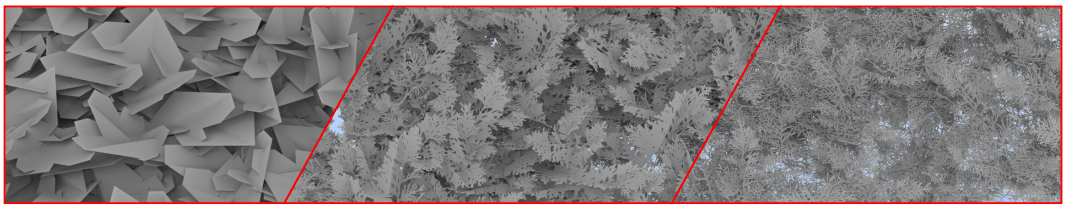




Frametime Performance

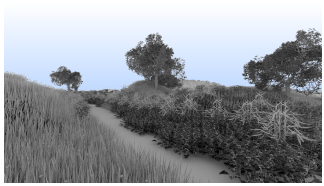
Methods

- Software Micromaps
- Succinct Tree
- Fast-Build Micromaps
- Fast-Trace Micromaps
- Bitmask
- Texture

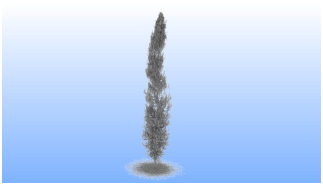


Scenes

CryTek Sponza [2011]

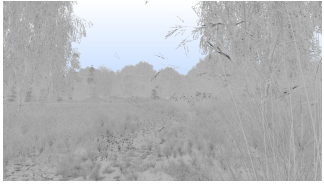


Ecosys [1998]



New Sponza [2022]

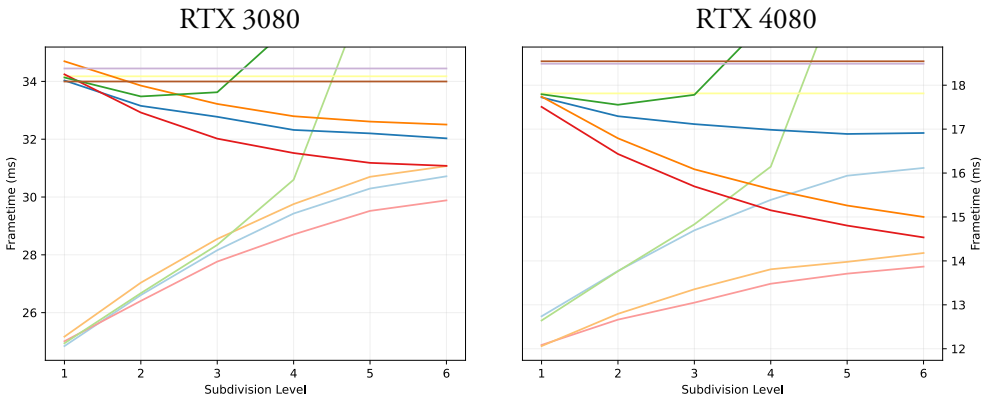
San Miguel [2010]



Landscape [2016]

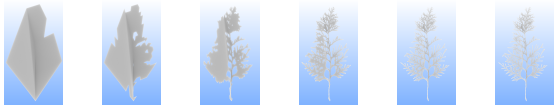
Frametime Performance

General Results — Landscape [2016]

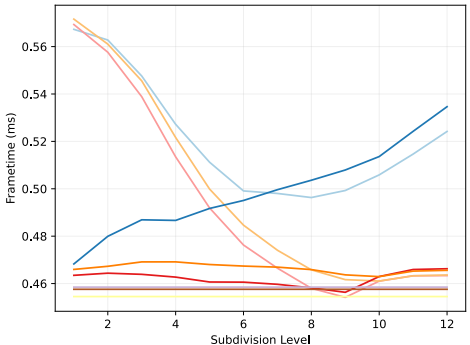


Frametime Performance

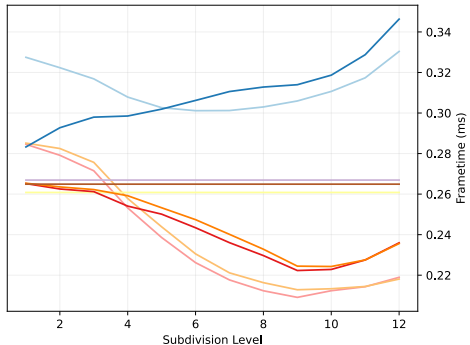
New Sponza [2022]



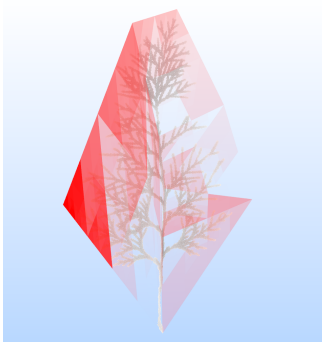
RTX 3080

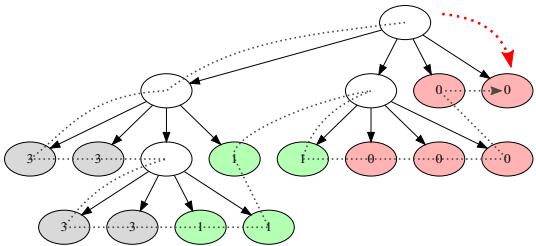


RTX 4080



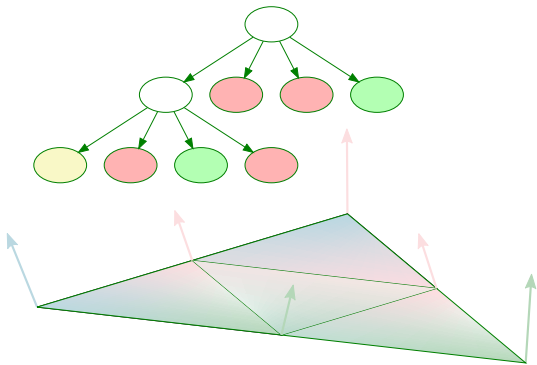
The Problem(s)





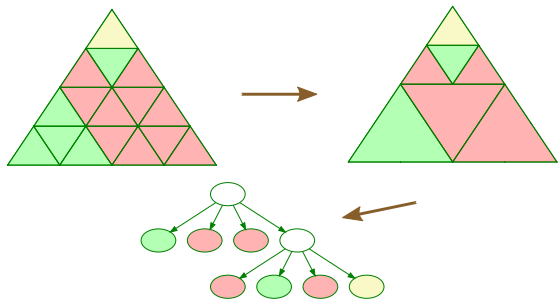
Future Work

- Need a different (succinct) tree
- Other micromap types?
  - Lossy micromaps?
  - Generalized micromaps?



Conclusion

1. Indexing Algorithm:
   - `uv2index`
2. Succinct Opacity Micromaps
3. Performance Comparison

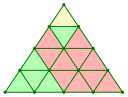
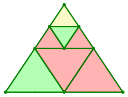


Thanks for Listening

Questions

- Thanks for listening!
- Questions and Answers

Acknowledgements


Succinct Opacity Micromaps

Gustaf Waldemarson Michael Doggett

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Special thanks to…
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- Simone Pellegrini @ Arm
- Mathieu Robart @ Arm

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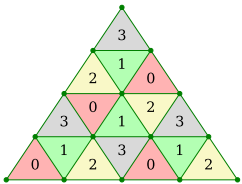
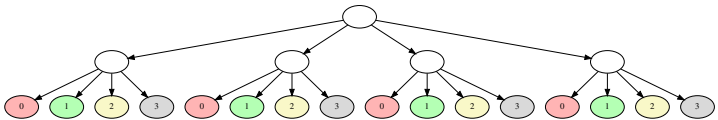
The End

Extras

Where may we *Lose* performance?

Degenerate Trees

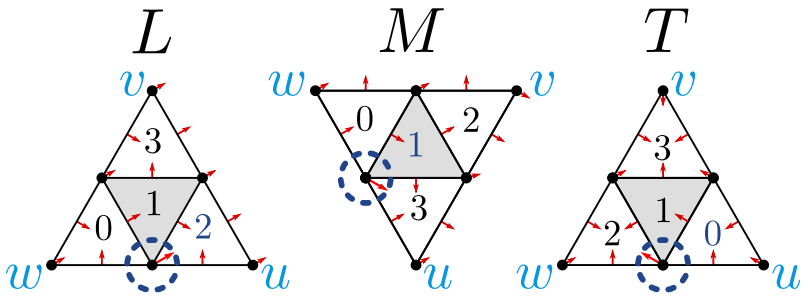




Example degenerate case for the succinct tree compression: Instead of actually reducing the number of nodes, it is forced to add 5 internal ones.

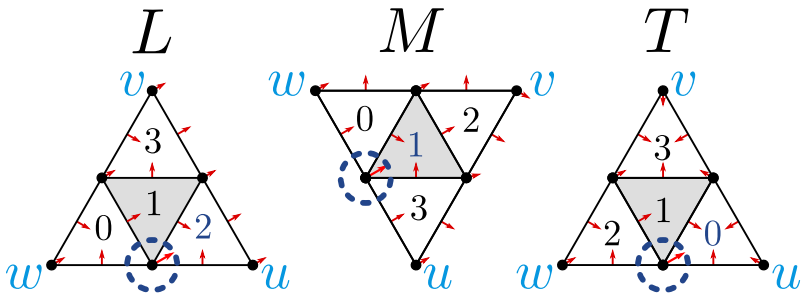
Opacity Micromaps Splits

Rounding Issues



Opacity Micromaps Splits

Rounding Issues



Opacity Micromaps Lookup Function – 1

```
def uv2index(u, v, level):
    w = 1.0 - (u + v)
    def rec(idx, d, u, v, w):
        if d == level:
            return idx
        L, M, R, T = 0, 1, 2, 3
        if w > 0.5:
            return rec(4 * idx + L, d + 1, 2*u, 2*v, (w - u - v))
        elif v >= 0.5:
            return rec(4 * idx + T, d + 1, 2*w, (v - u - w), 2*u)
        elif u >= 0.5:
            return rec(4 * idx + R, d + 1, (u - v - w), 2*v, 2*w)
        else:
            return rec(4 * idx + M, d + 1, (u + v - w), (w + u - v), (v + w - u))
    return rec(0, 0, u, v, w)
```

Opacity Micromaps Lookup Function – 2

```
def uv2index(u, v, level):
    w = (1.0 - (u + v))
    def rec(i, d, mflip, tflip, u, v, w):
        if d == level: return i
        L, M, R, T = (2, 1, 0, 3) if tflip else (0, 1, 2, 3)
        if w > 0.5:
            return rec(4 * i + L, d + 1, mflip, tflip, 2*u, 2*v, (w - u - v))
        elif v >= 0.5 and not (v == 0.5 and mflip):
            return rec(4 * i + T, d + 1, mflip, not tflip, 2*u, (v - u - w), 2*w)
        elif u >= 0.5 and not (v == 0.5 and mflip):
            return rec(4 * i + R, d + 1, mflip, tflip, (u - v - w), 2*v, 2*w)
        else:
            return rec(4 * i + M, d + 1, not mflip, tflip,
                       (u + v - w), (w + u - v), (v + w - u))
    return rec(0, 0, False, False, u, v, w)
```

Succinct Opacity Micromaps

Look-up Algorithm — 1

```
uint t = 0, d = 0;
while (true)
{
    bool is_internal = tree_bit(t);
    if (is_internal)
    {
        t += 1;
        uint c = step();
        t, d = bitscan(tree_len, c, t, d);
    }
    else
    {
        return opacity_value(tree_len, d);
    }
}
```

Succinct Opacity Micromaps

Look-up Algorithm — 2

```
uvec2 bitscan(uint tree_len, uint child, uint t, uint d)
{
    while (t < tree_len && c > 0)
    {
        bool is_internal = opacity_tree_bit(t);
        if (is_internal)
            child += 4;
        else
            d += 1;
        t += 1;
        child -= 1;
    }
    return uvec2(t, d);
}
```

References I

- Oliver Deussen, Pat Hanrahan, Bernd Lintermann, Radomı⊠r Mech, Matt Pharr, and Przemyslaw Prusinkiewicz. 1998. "Realistic modeling and rendering of plant ecosystems." In: *Proceedings of the 25th Annual Conference on Computer Graphics and Interactive Techniques* (SIGGRAPH '98). Association for Computing Machinery, New York, NY, USA, 275–286. ISBN: 0897919998. DOI: 10.1145/280814.280898.
- Morgan McGuire Frank Meinl Marko Dabrovic. 2011. *CryTek Sponza*. https://www.cryengine.com/asset-db/product/crytek/sponza-sample-scene. (2011).
- Holger Gruen, Carsten Benthin, and Sven Woop. Aug. 2020. "Sub-Triangle Opacity Masks for Faster Ray Tracing of Transparent Objects." *Proc. ACM Comput. Graph. Interact. Tech.*, 3, 2, (Aug. 2020). DOI: 10.1145/3406180.
- Timm Dapper Jan-Walter Schliep Burak Kahraman. 2016. *Landscape*. https://www.laubwerk.com. (2016).
- Guillermo M. Leal Llaguno. 2010. *San Miguel*. https://www.pbrt.com. (2010).

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References II

Frank Meinl, Katica Putica, Cristiano Siqueria, Timothy Heath, Justin Prazen, Sebastian Herholz, Bruce Cherniak, and Anton Kaplanyan. 2022. *Intel Sample Library*. https://www.intel.com/content/www/us/en/developer/topic-technology/graphics-processing-research/samples.html. (2022).

Eric Werness. Aug. 24, 2022. *VK_EXT_opacity_micromap*. The Khronos Group Inc. (Aug. 24, 2022). Retrieved May 11, 2023 from `https://registry.khronos.org/vulkan/specs/1.3-extensions/man/html/VK_EXT_opacity_micromap.html`.

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