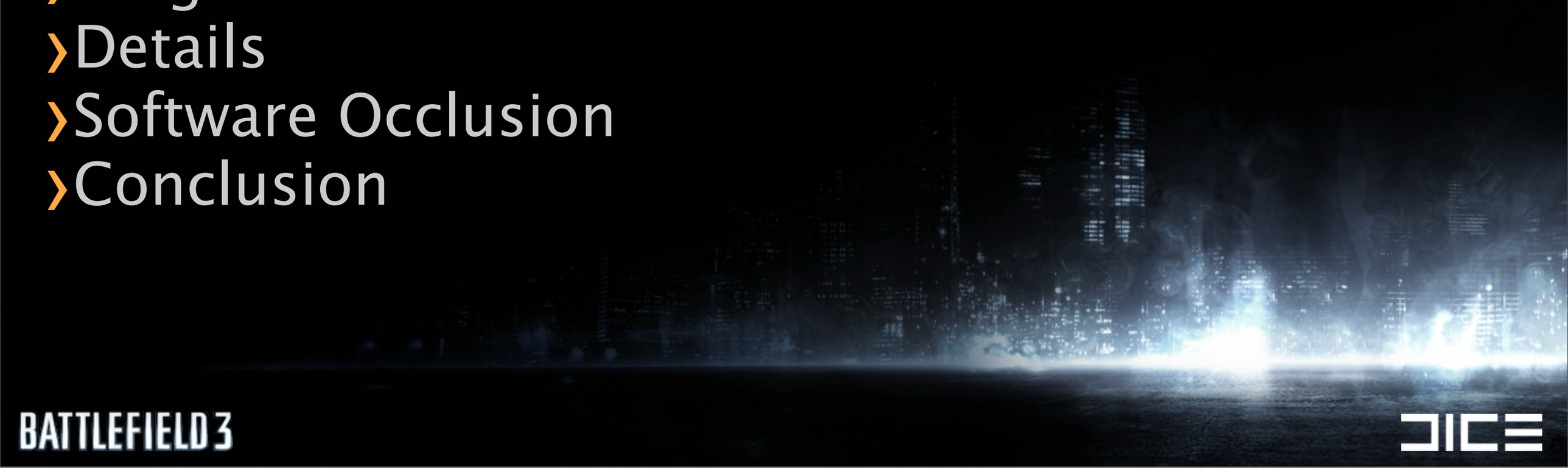
BATTLEFIELD 3

Culling the Battlefield

Daniel Collin (DICE)

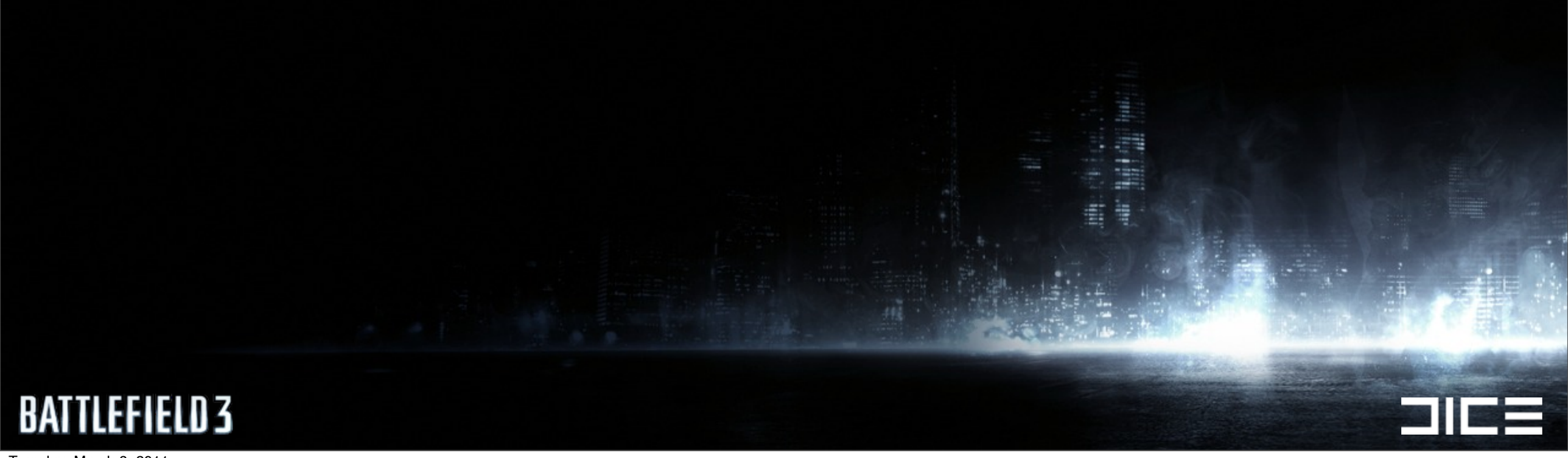
Overview

- Background
- Why rewrite it?
- Requirements
- Target hardware
- Details
- Software Occlusion
- Conclusion

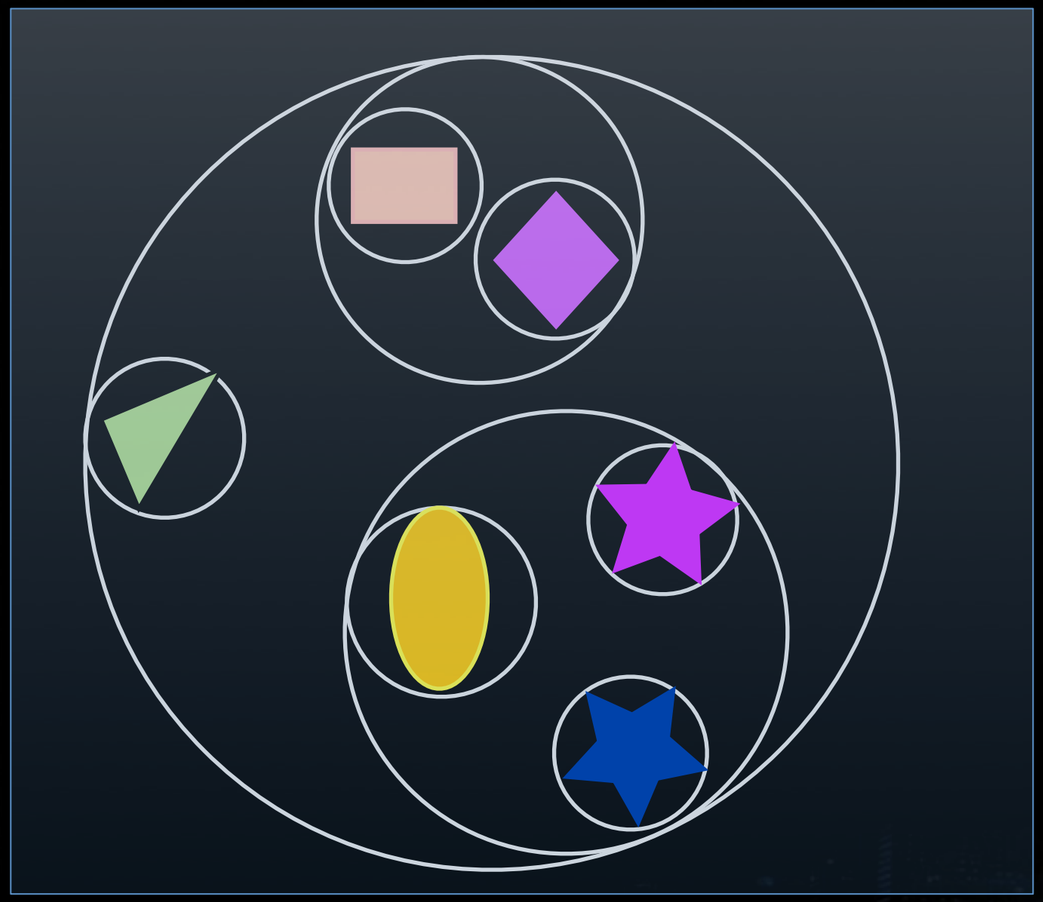


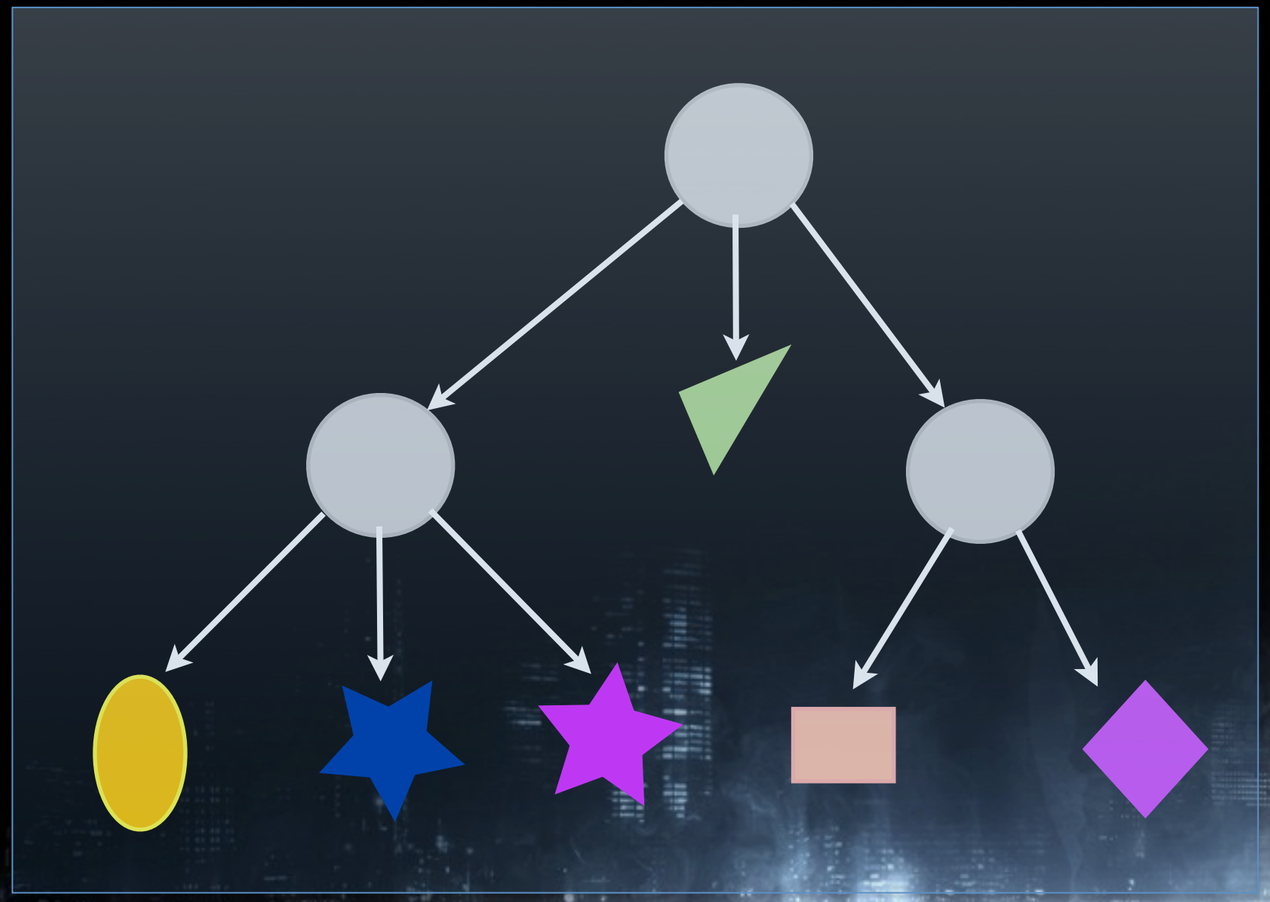
Background of the old culling

- Hierarchical Sphere Trees
- StaticCullTree
- DynamicCullTree



Background of the old culling





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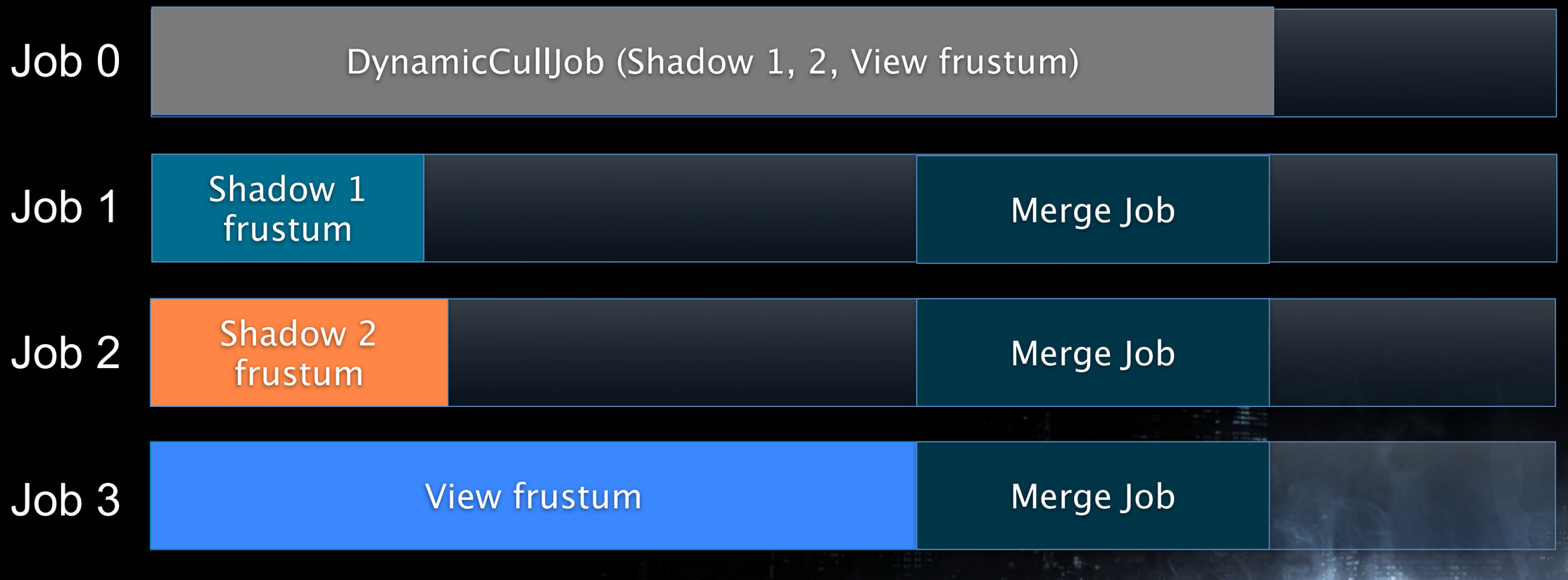
Why rewrite it?

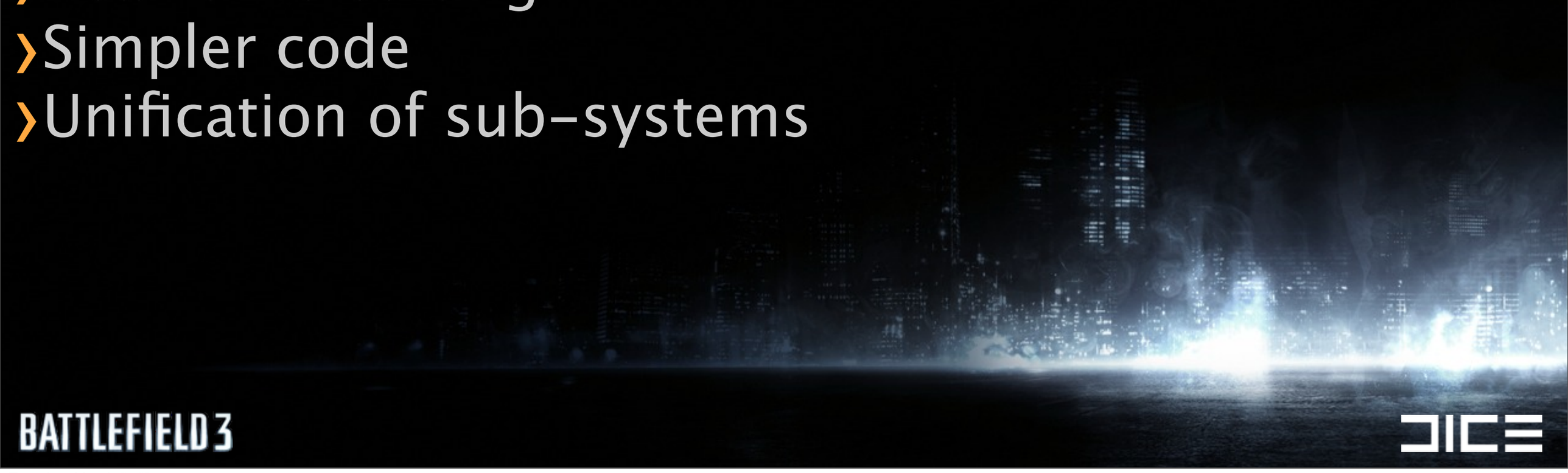
- DynamicCullTree scaling
- Sub-levels
- Pipeline dependencies
- Hard to scale
- One job per frustum

Job graph (Old Culling)



Requirements for new system

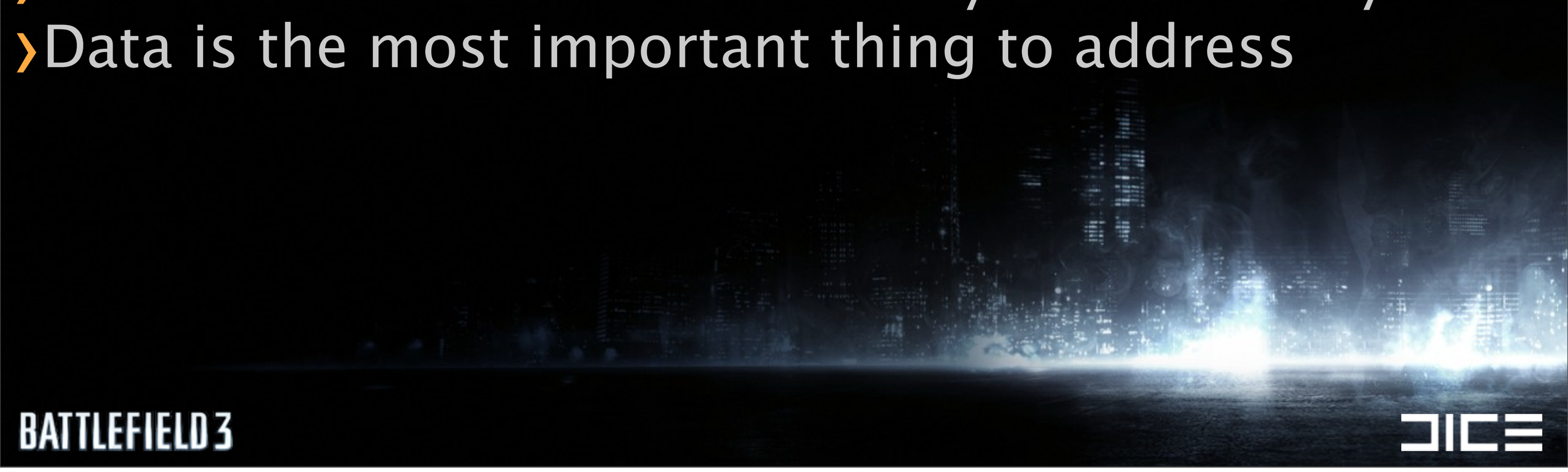
- Better scaling
- Destruction
- Real-time editing
- Simpler code
- Unification of sub-systems



Target hardware

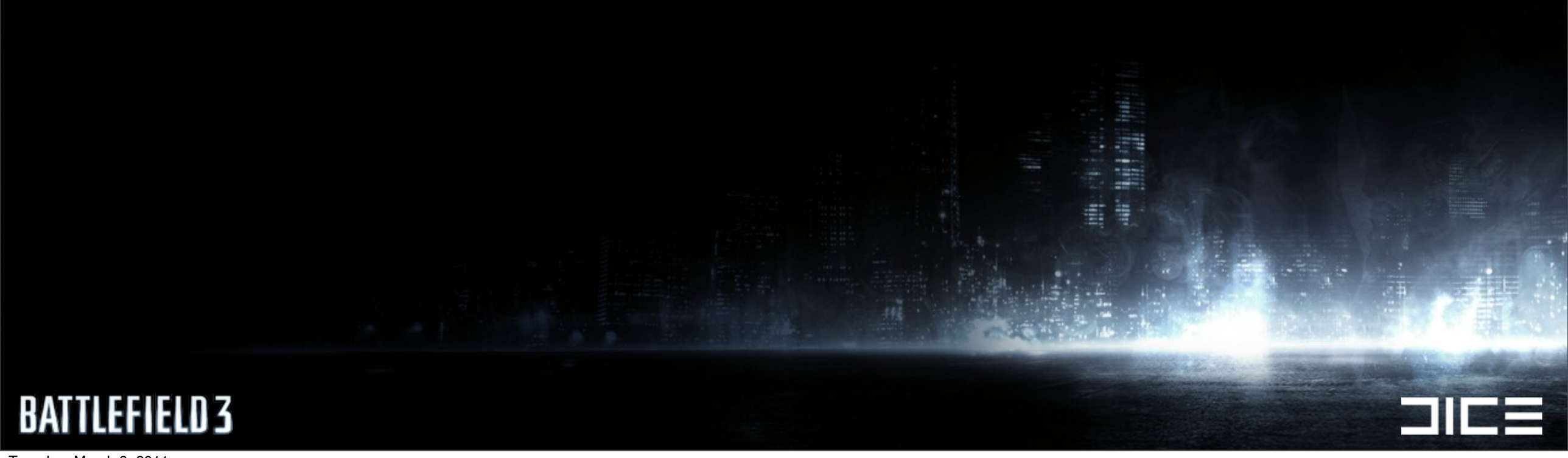
What **doesn't** work well on these systems?

- Non-local data
- Branches
- Switching between register types (LHS)
- Tree based structures are usually branch heavy
- Data is the most important thing to address



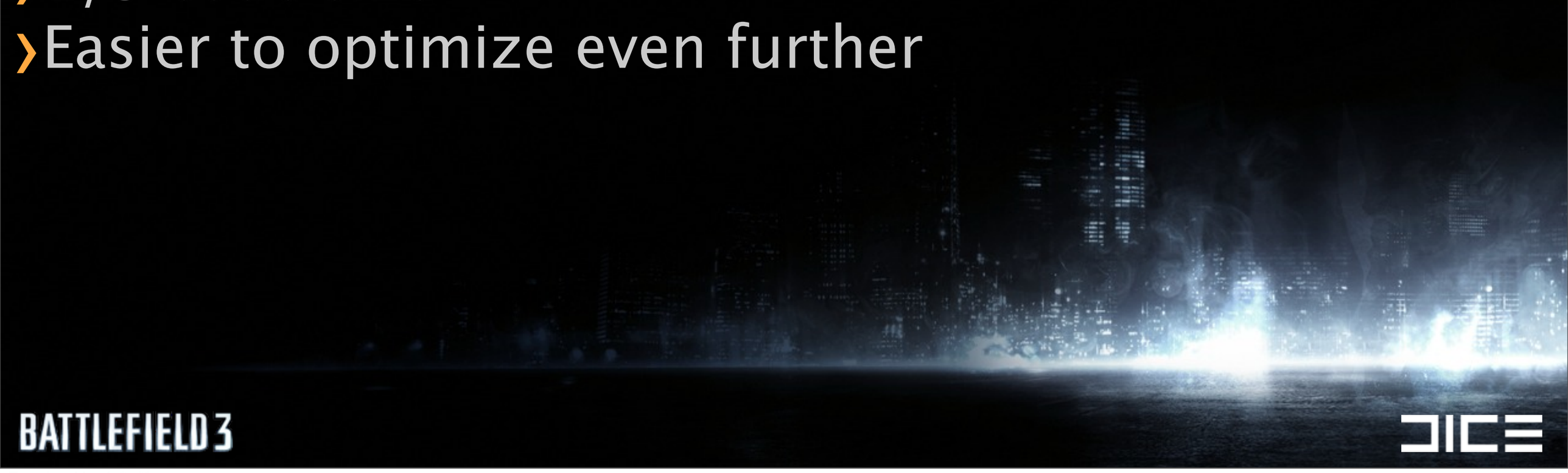
What does work **well** on these systems?

- Local data
- (SIMD) Computing power
- Parallelism



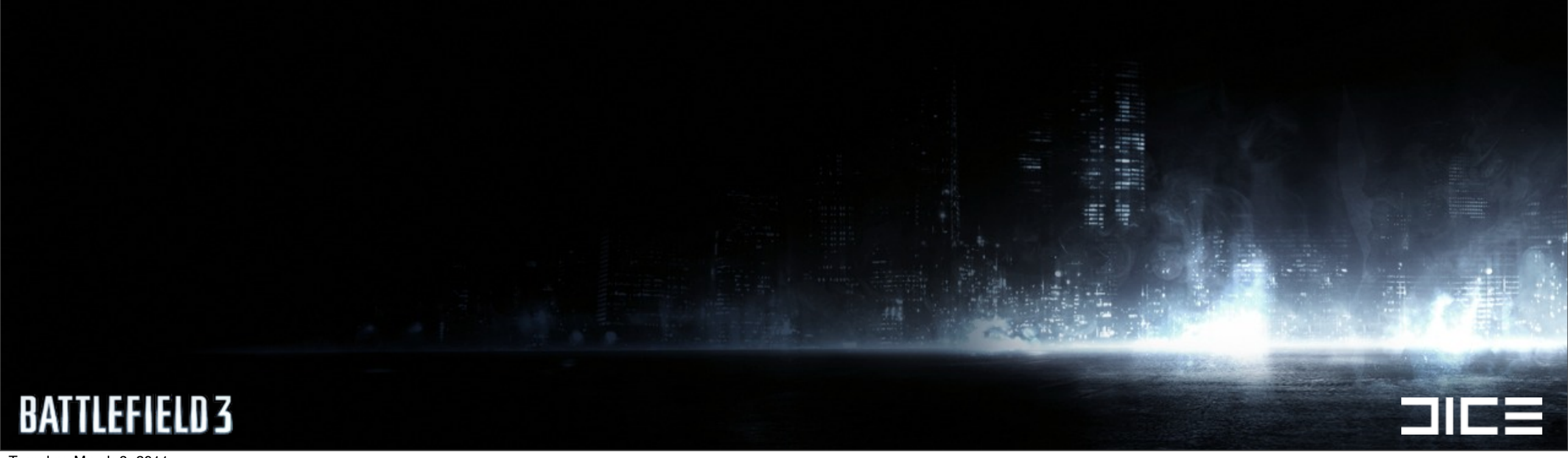
The new culling

- Our worlds usually has max ~15000 objects
- First try was to just use parallel brute force
- 3x times faster than the old culling
- 1/5 code size
- Easier to optimize even further

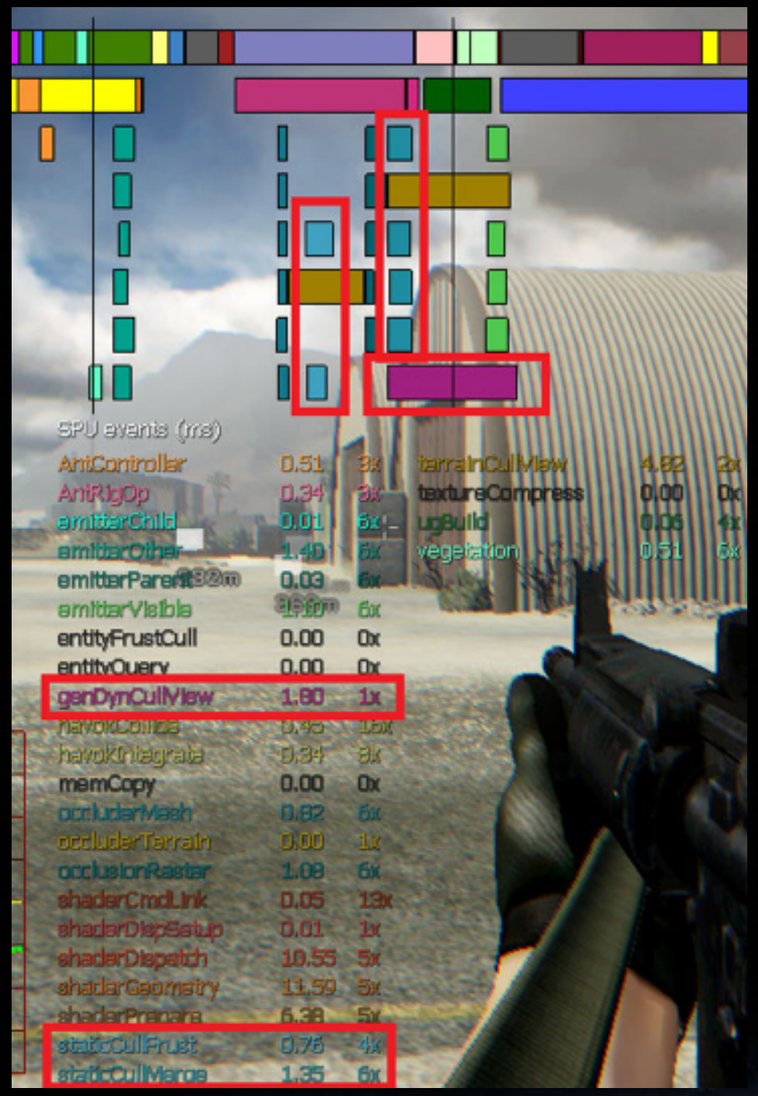


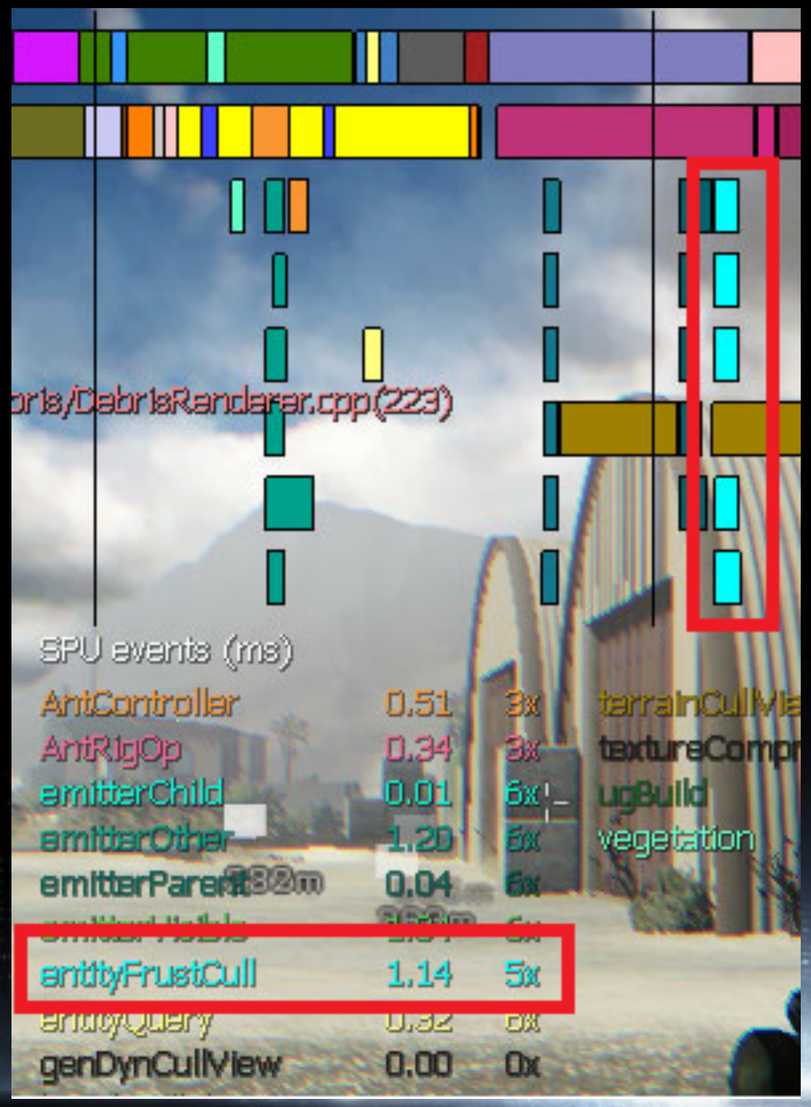
The new culling

- Linear arrays scale great
- Predictable data
- Few branches
- Uses the computing power



The new culling





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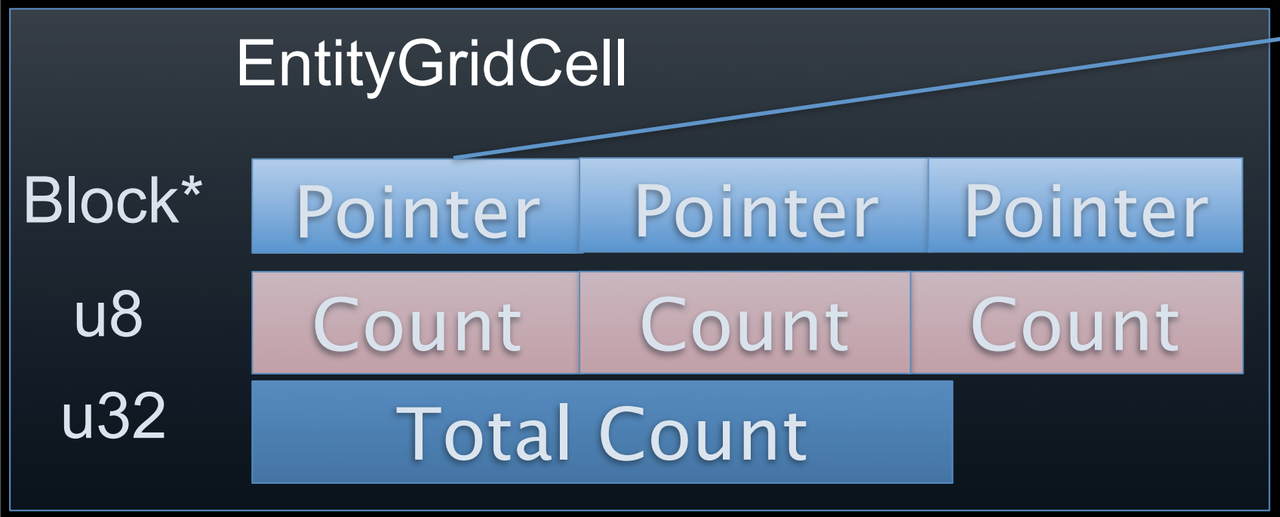
Performance numbers (no occlusion)
15000 Spheres

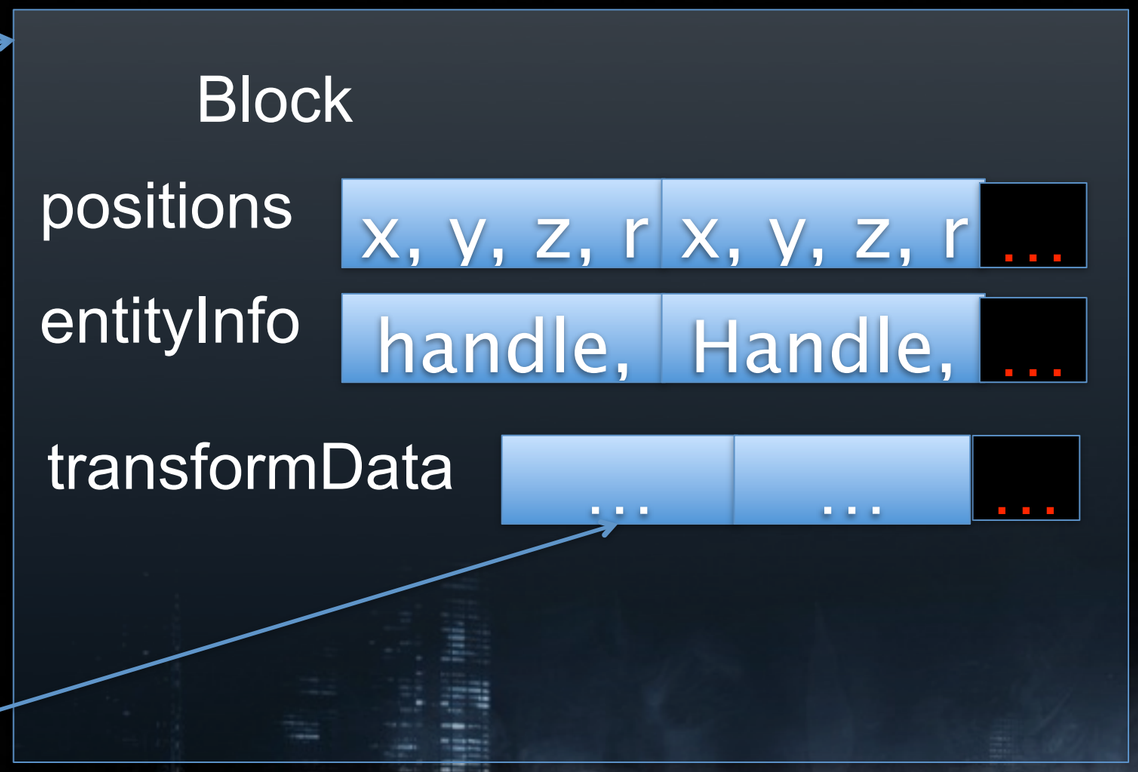
Platform	1 Job	4 Jobs
Xbox 360	1.55 ms	(2.10 ms / 4) = 0.52
x86 (Core i7, 2.66 GHz)	1.0 ms	(1.30 ms / 4) = 0.32
Playstation 3	0.85 ms	(0.95 ms / 4) = 0.23
Playstation 3 (SPA)	0.63 ms	(0.75 ms / 4) = 0.18

Details of the new culling

- Improve performance with a simple grid
- Really an AABB assigned to a “cell” with spheres
- Separate grids for
-
  - Rendering: Static
  - Rendering: Dynamic
  - Physics: Static
  - Physics: Dynamic

Data layout

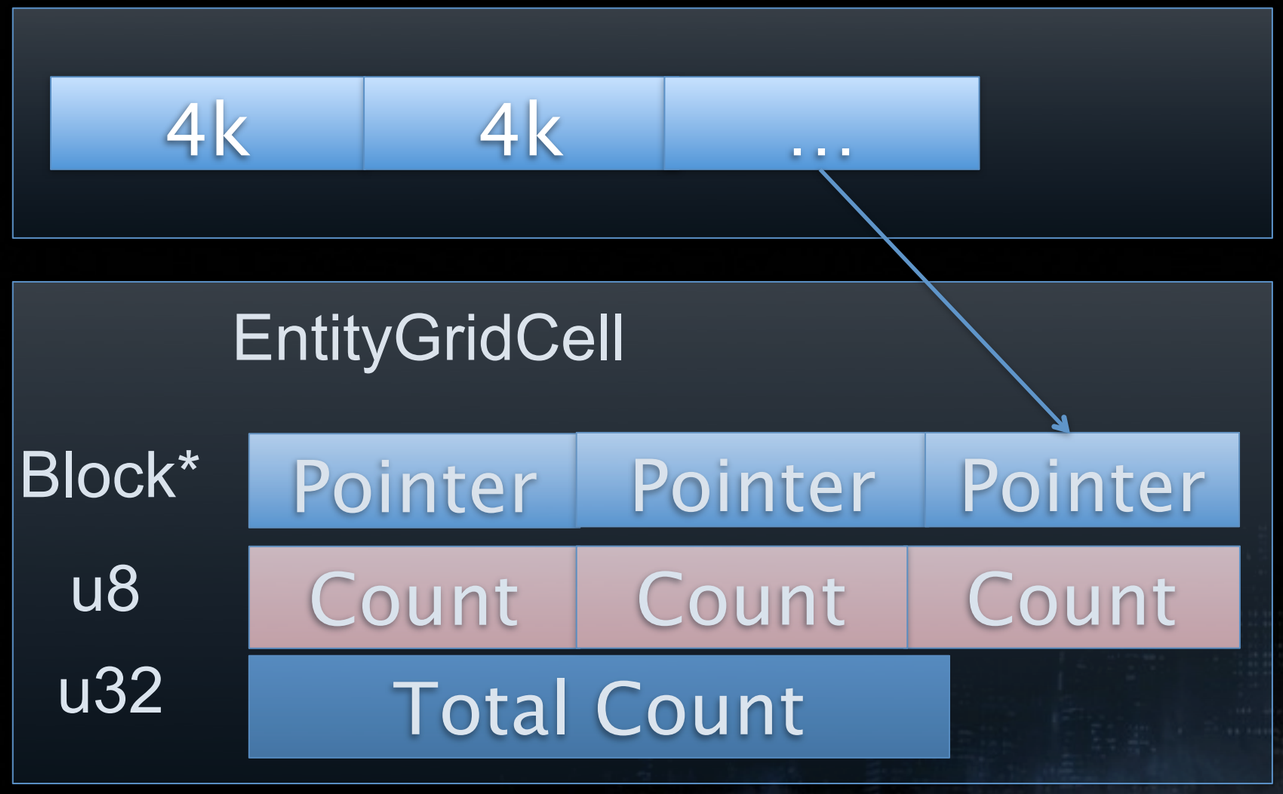





```
struct TransformData
{
        half rotation[4];
        half minAabb[3];
        half pad[1];
        half maxAabb[3];
        half scale[3];
};
```

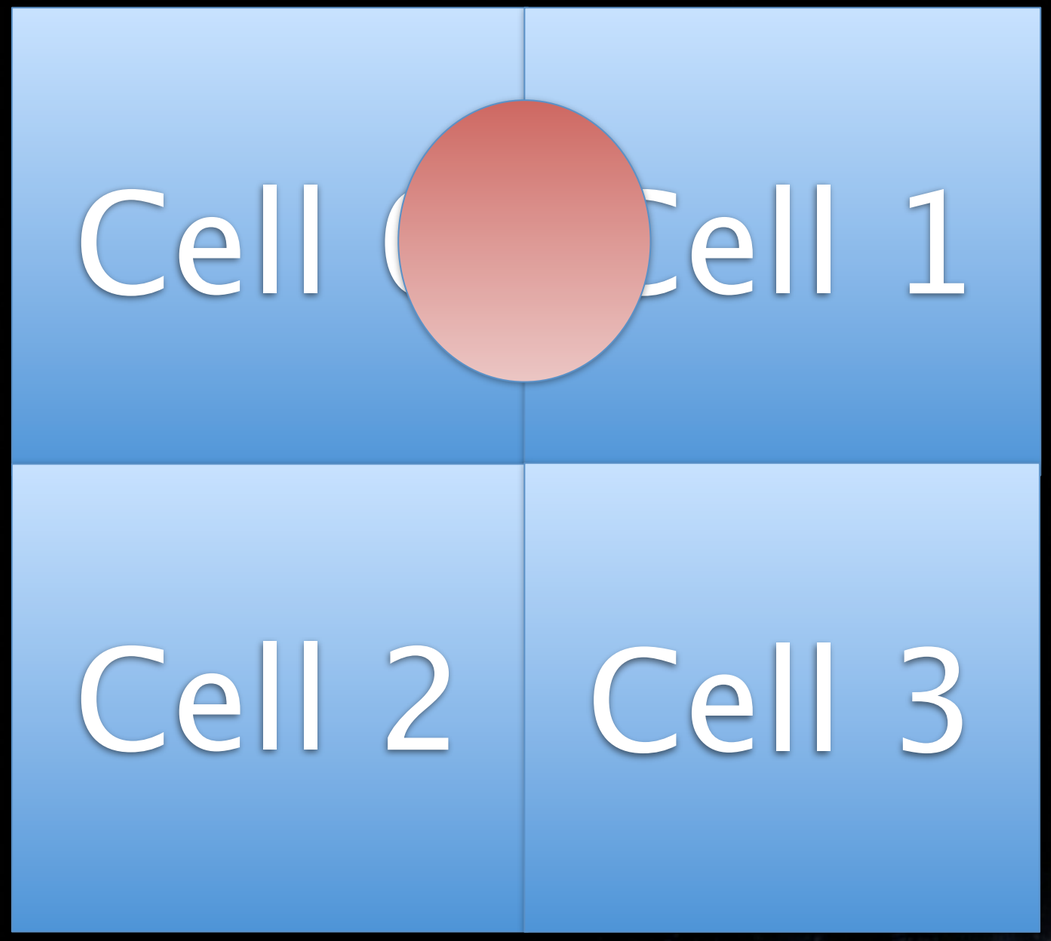
Adding objects

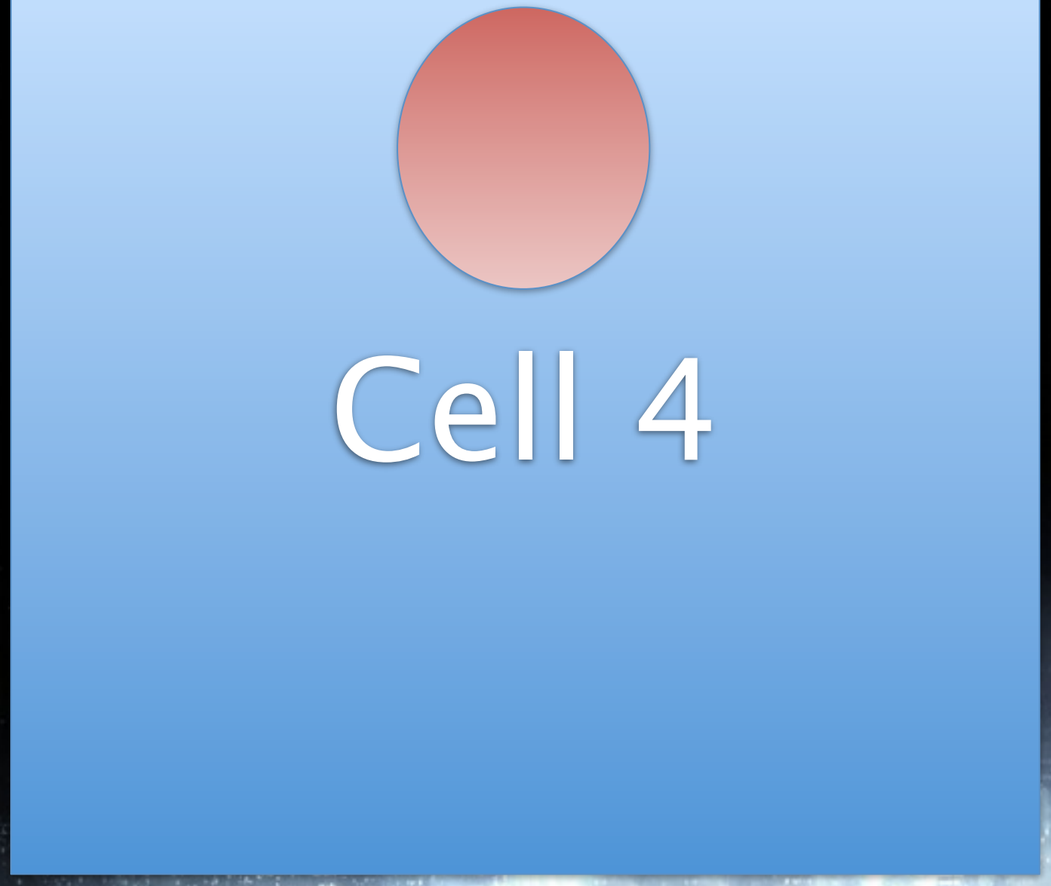
- Pre-allocated array that we can grab data from



AtomicAdd(…) to “alloc” new block

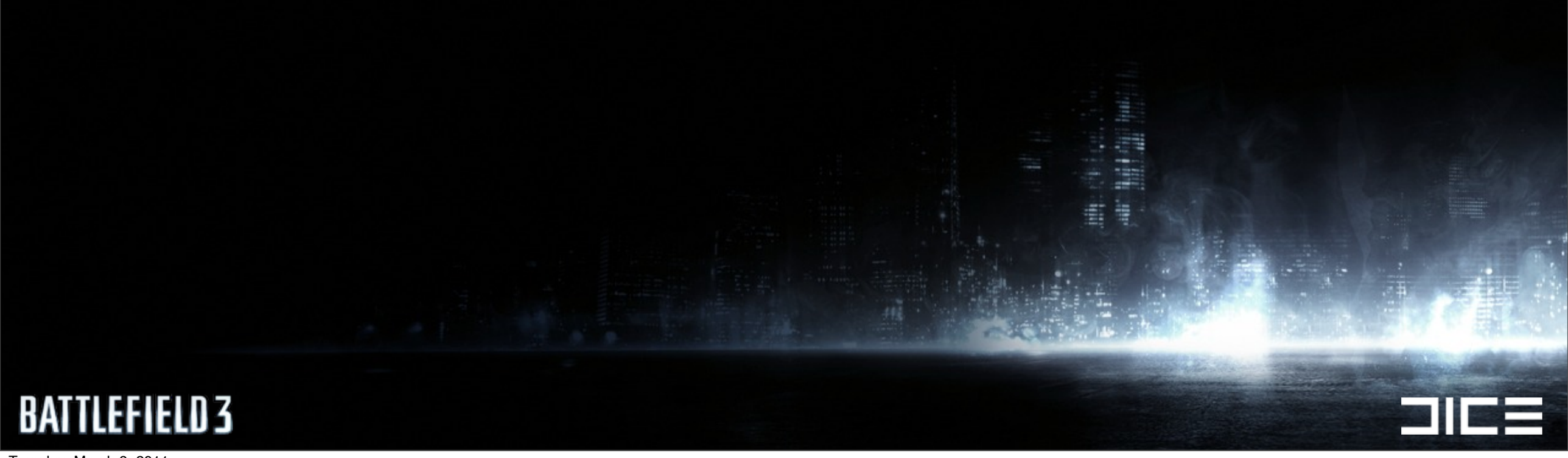
Adding objects





Removing objects

- Use the “swap trick”
- Data doesn’t need to be sorted
- Just swap with the last entry and decrease the count



Rendering culling

- Let’s look at what the rendering expects

```
struct EntityRenderCullInfo
{
    Handle entity;    // handle to the entity
    u16 visibleViews; // bits of which frustums that was visible
    u16 classId;      // type of mesh
    float screenArea; // at which screen area entity should be culled
};
```

Culling code

```
while (1)
{
        uint blockIter = interlockedIncrement(currentBlockIndex) - 1;

        if (blockIter >= blockCount) break;

        u32 masks[EntityGridCell::Block::MaxCount] = {}, frustumMask = 1;
        block = gridCell->blocks[blockIter];

        foreach (frustum in frustums, frustumMask <<= 1)
        {
                for (i = 0; i < gridCell->blockCounts[blockIter]; ++i)
                {
                        u32 inside = intersect(frustum, block->postition[i]);
                        masks[i] |= frustumMask & inside;
                }
        }

        for (i = 0; i < gridCell->blockCounts[blockIter]; ++i)
        {
                // filter list here (if masks[i] is zero it should be skipped)
                // ...
        }
}
```

Intersection Code

```
bool intersect(const Plane* frustumPlanes, Vec4 pos)
{
	float radius = pos.w;
	if (distance(frustumPlanes[Frustum::Far], pos) > radius)
		return false;
	if (distance(frustumPlanes[Frustum::Near], pos) > radius)
		return false;
	if (distance(frustumPlanes[Frustum::Right], pos) > radius)
		return false;
	if (distance(frustumPlanes[Frustum::Left], pos) > radius)
		return false;
	if (distance(frustumPlanes[Frustum::Upper], pos) > radius)
		return false;
	if (distance(frustumPlanes[Frustum::Lower], pos) > radius)
		return false;

	return true;
}
```


ARGH! My eyes!

See “Typical C++ Bullshit” by @mike_acton

Intersection Code

```
intersect(const Plane* frustumPlanes, Vec4 pos)

    radius
if (distan                                  um::Far], pos) > radius)
    retur
    (dista                                  m::Near], pos) >
    retur
if (dista                                   m::Right], pos)
    retu
if (dista                                   m::Left], pos) >
    retur
    (distanc                                :Upper],
    return false;
if (distance(frustumPlanes[Frustum::Lower], pos)
    return false;

    rue;
```

LHS!

LHS!

LHS!

LHS!

So what do the consoles think?

:(

Float branch!

Float branch!

Float branch!

Float branch!

Inter Code

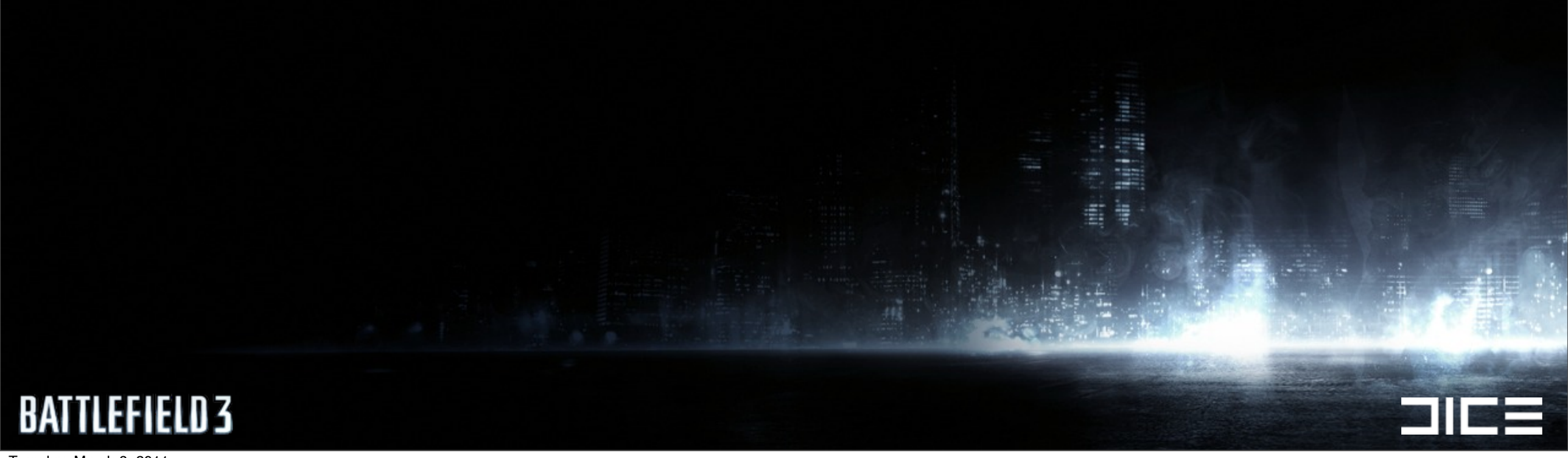
```
bool intersect                                    pos)
{
    float                                          ;
    if (d                 anes[Frustum::Fa                radius)

    if                  (f          [Frustum::Near],          radius)
                        false;
    if                  e(frustu          stum::Right],       radius)
                        false;
    if                  e(frustumPla          :Left],         adius)
                        false;
    if                   (frustumPlanes[          er]          radius)
                          lse;
    if (d                  ustumPlanes[Frust                > radius)
        re

    return tr
}
```

Intersection Code

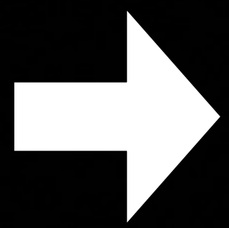
- How can we improve this?
- Dot products are not very SIMD friendly
- Usually need to shuffle data around to get result
- (x0 * x1 + y0 * y1 + z0 * z1 + w0 * w1)



Intersection Code

- Rearrange the data from AoS to SoA

```
Vec 0 X0 Y0 Z0 W0
Vec 1 X1 Y1 Z1 W1
Vec 2 X2 Y2 Z2 W2
Vec 3 X3 Y3 Z3 W3
```

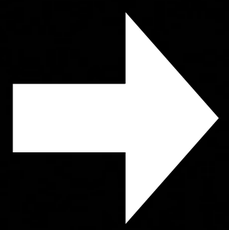


```
VecX X0 X1 X2 X3
VecY Y0 Y1 Y2 Y3
VecZ Z0 Z1 Z2 Z3
VecW W0 W1 W2 W3
```

- Now we only need 3 instructions for 4 dots!

Rearrange the frustum planes

```
Plane 0 X0 Y0 Z0 W0
Plane 1 X1 Y1 Z1 W1
Plane 2 X2 Y2 Z2 W2
Plane 3 X3 Y3 Z3 W3
Plane 4 X4 Y4 Z4 W4
Plane 5 X5 Y5 Z5 W5
```

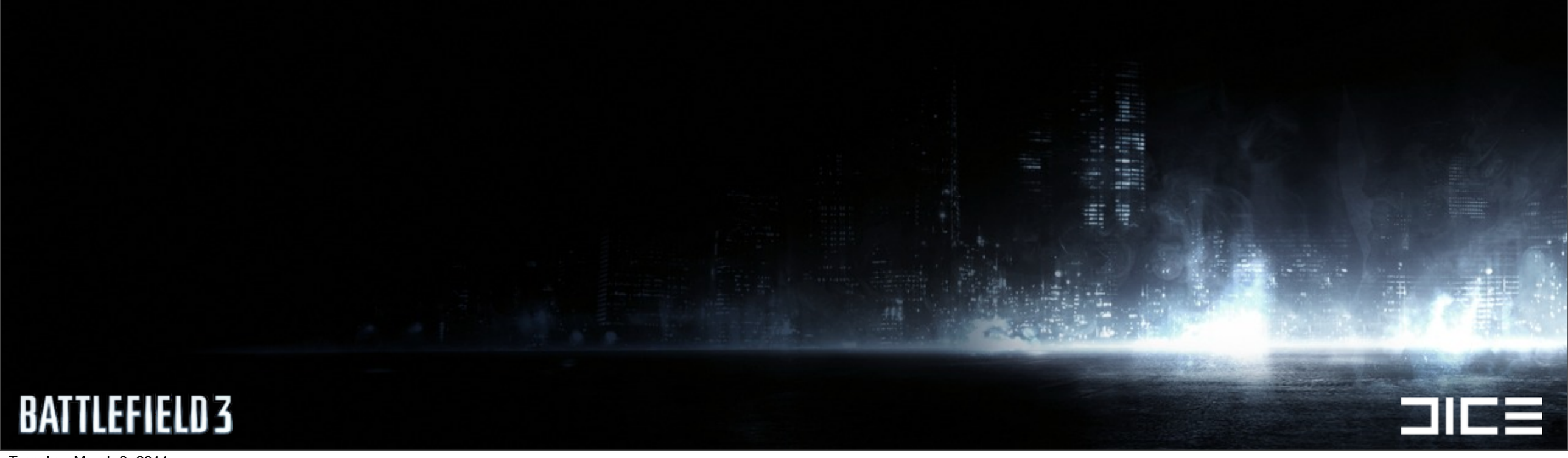


```
X0 X1 X2 X3
Y0 Y1 Y2 Y3
Z0 Z1 Z2 Z3
W0 W1 W2 W3

X4 X5 X4 X5
Y4 Y5 Y4 Y5
Z4 Z5 Z4 Z5
W4 W5 W4 W5
```

New intersection code

- Two frustum vs Sphere intersections per loop
- 4 * 3 dot products with 9 instructions
- Loop over all frustums and merge the result



New intersection code (1/4)

```
Vec posA_xxxx = vecShuffle<VecMask::_xxxx>(posA);
Vec posA_yyyy = vecShuffle<VecMask::_yyyy>(posA);
Vec posA_zzzz = vecShuffle<VecMask::_zzzz>(posA);
Vec posA_rrrr = vecShuffle<VecMask::_wwww>(posA);
```

```
// 4 dot products

dotA_0123 = vecMulAdd(posA_zzzz, pl_z0z1z2z3, pl_w0w1w2w3);
dotA_0123 = vecMulAdd(posA_yyyy, pl_y0y1y2y3, dotA_0123);
dotA_0123 = vecMulAdd(posA_xxxx, pl_x0x1x2x3, dotA_0123);
```

New intersection code (2/4)

```
Vec posB_xxxx = vecShuffle<VecMask::_xxxx>(posB);
Vec posB_yyyy = vecShuffle<VecMask::_yyyy>(posB);
Vec posB_zzzz = vecShuffle<VecMask::_zzzz>(posB);
Vec posB_rrrr = vecShuffle<VecMask::_wwww>(posB);
```

```
// 4 dot products

dotB_0123 = vecMulAdd(posB_zzzz, pl_z0z1z2z3, pl_w0w1w2w3);
dotB_0123 = vecMulAdd(posB_yyyy, pl_y0y1y2y3, dotB_0123);
dotB_0123 = vecMulAdd(posB_xxxx, pl_x0x1x2x3, dotB_0123
```

New intersection code (3/4)

```
Vec posAB_xxxx = vecInsert<VecMask::_0011>(posA_xxxx, posB_xxxx);
Vec posAB_yyyy = vecInsert<VecMask::_0011>(posA_yyyy, posB_yyyy);
Vec posAB_zzzz = vecInsert<VecMask::_0011>(posA_zzzz, posB_zzzz);
Vec posAB_rrrr = vecInsert<VecMask::_0011>(posA_rrrr, posB_rrrr);

// 4 dot products

dotA45B45 = vecMulAdd(posAB_zzzz, pl_z4z5z4z5, pl_w4w5w4w5);
dotA45B45 = vecMulAdd(posAB_yyyy, pl_y4y5y4y5, dotA45B45);
dotA45B45 = vecMulAdd(posAB_xxxx, pl_x4x5x4x5, dotA45B45);
```

New intersection code (4/4)

```
// Compare against radius

dotA_0123 = vecCmpGTMask(dotA_0123, posA_rrrr);
dotB_0123 = vecCmpGTMask(dotB_0123, posB_rrrr);
dotA45B45 = vecCmpGTMask(dotA45B45, posAB_rrrr);
```

```
Vec dotA45 = vecInsert<VecMask::_0011>(dotA45B45, zero);
Vec dotB45 = vecInsert<VecMask::_0011>(zero, dotA45B45);

// collect the results

Vec resA = vecOrx(dotA_0123);
Vec resB = vecOrx(dotB_0123);

resA = vecOr(resA, vecOrx(dotA45));
resB = vecOr(resB, vecOrx(dotB45));
```

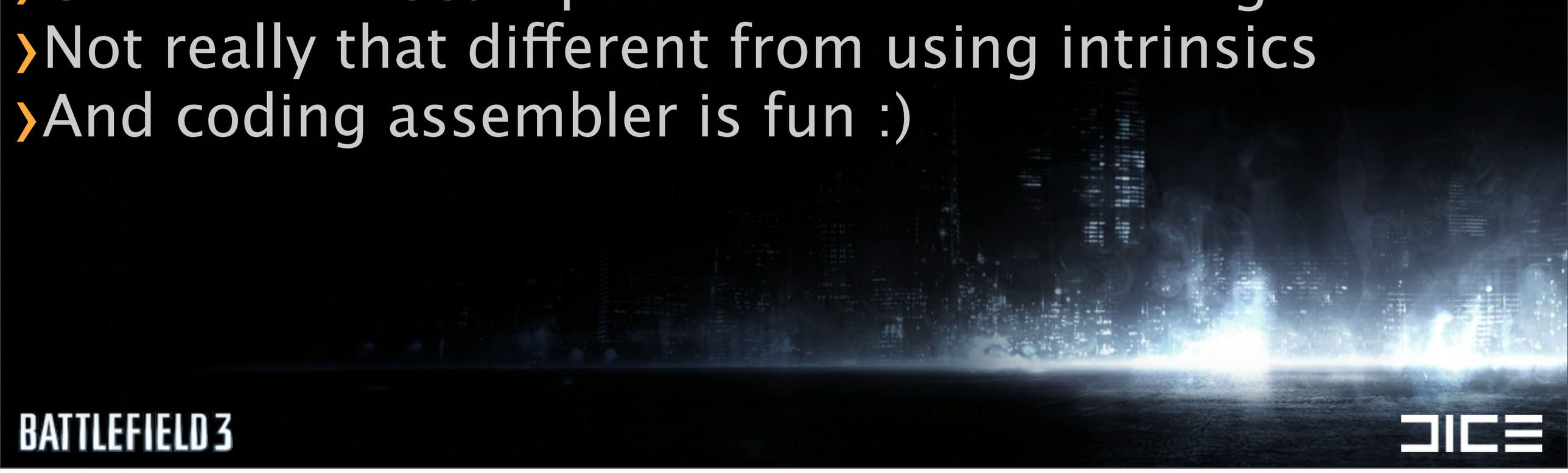
```
// resA = inside or outside of frustum for point A, resB for point B

Vec rA = vecNotMask(resA);
Vec rB = vecNotMask(resB);

masksCurrent[0] |= frustumMask & rA;
masksCurrent[1] |= frustumMask & rB;
```

SPU Pipelining Assembler (SPA)

- Like VCL (for PS2) but for PS3 SPU
- Can give you that extra boost if needed
- Does software pipelining for you
- Gives about 35% speed boost in the culling
- Not really that different from using intrinsics
- And coding assembler is fun :)



SPA Inner loop (partly)

```
lqd    posA, -0x20(currentPos)
lqd    posB, -0x10(currentPos)

shufb  posA_xxxx, posA, posA, Mask_xxxx
shufb  posA_yyyy, posA, posA, Mask_yyyy
shufb  posA_zzzz, posA, posA, Mask_zzzz
shufb  posA_rrrr, posA, posA, Mask_wwww

// 4 dot products

fma    dotA_0123, posA_zzzz, pl_z0z1z2z3, pl_w0w1w2w3
fma    dotA_0123, posA_yyyy, pl_y0y1y2y3, dotA_0123
fma    dotA_0123, posA_xxxx, pl_x0x1x2x3, dotA_0123

shufb  posB_xxxx, posB, posB, Mask_xxxx
shufb  posB_yyyy, posB, posB, Mask_yyyy
shufb  posB_zzzz, posB, posB, Mask_zzzz
shufb  posB_rrrr, posB, posB, Mask_wwww

// 4 dot products

fma    dotB_0123, posB_zzzz, pl_z0z1z2z3, pl_w0w1w2w3
fma    dotB_0123, posB_yyyy, pl_y0y1y2y3, dotB_0123
fma    dotB_0123, posB_xxxx, pl_x0x1x2x3, dotB_0123
```

SPA Inner loop

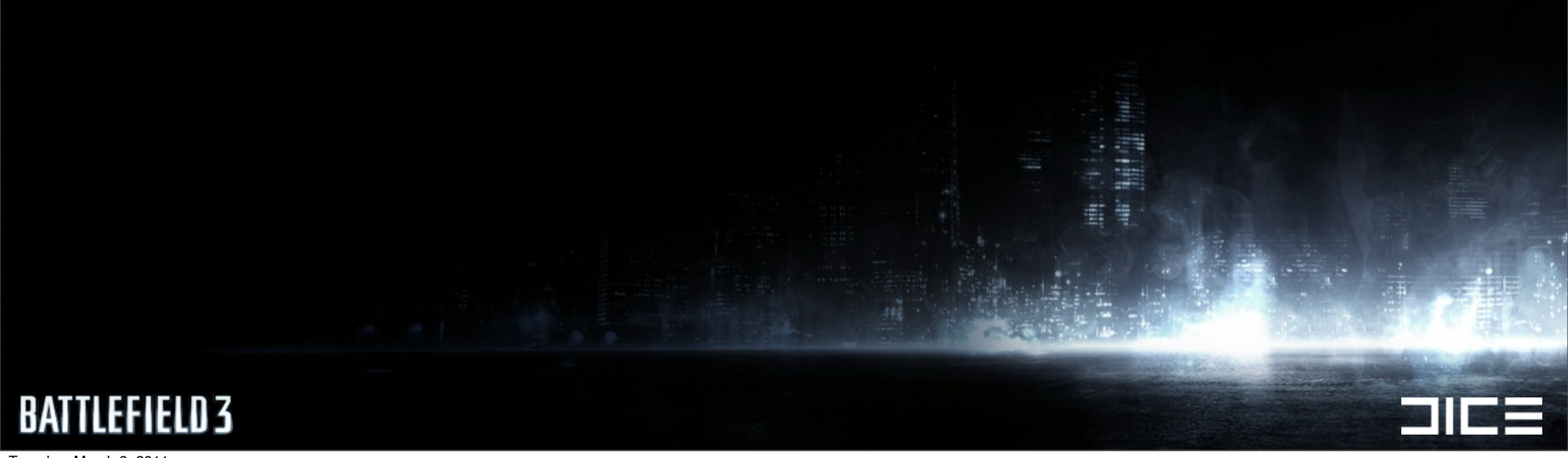
```
# Loop stats - frustumCull::loop
# (ims enabled, sms disabled, optimisation level 2)
#       resmii : 24 (*)          (resource constrained)
#       recmii : 2               (recurrence constrained)
# resource usage:
#       even pipe : 24 inst. (100% use) (*)
#                     FX[15] SP[9]
#       odd pipe  : 24 inst. (100% use) (*)
#                     SH[17] LS[6] BR[1]
# misc:
#       linear schedule = 57 cycles (for information only)
# software pipelining:
#       best pipelined schedule = 24 cycles (pipelined, 3 iterations in parallel)
# software pipelining adjustments:
#       not generating non-pipelined loop since trip count >=3 (3)
# estimated loop performance:
#       =24*n+59 cycles
```

SPA Inner loop

```
_local_c0de000000000002:
    fma         $46,$42,$30,$29;        /* +1 */    shufb       $47,$44,$37,$33         /* +2 */
    fcgt        $57,$20,$24;            /* +2 */    orx         $48,$15                 /* +2 */
    selb        $55,$37,$44,$33;        /* +2 */    shufb       $56,$21,$16,$33         /* +1 */
    fma         $52,$16,$28,$41;        /* +1 */    orx         $49,$57                 /* +2 */
    ai          $4,$4,32;                           orx         $54,$47                 /* +2 */
    fma         $51,$19,$26,$45;        /* +1 */    orx         $53,$55                 /* +2 */
    fma         $50,$56,$27,$46;        /* +1 */    shufb       $24,$23,$23,$34         /* +1 */
    ai          $2,$2,32;               /* +2 */    lqd         $13,-32($4)
    or          $69,$48,$54;            /* +2 */    lqd         $23,-16($4)
    fma         $20,$18,$26,$52;        /* +1 */    lqd         $12,-32($2)             /* +2 */
    nor         $60,$69,$69;            /* +2 */    lqd         $43,-16($2)             /* +2 */
    or          $62,$49,$53;            /* +2 */    shufb       $59,$22,$17,$33         /* +1 */
    and         $39,$60,$35;            /* +2 */    shufb       $11,$14,$24,$33         /* +1 */
    nor         $61,$62,$60;            /* +2 */    shufb       $22,$13,$13,$36
    fcgt        $15,$51,$14;            /* +1 */    shufb       $17,$23,$23,$36
    and         $58,$61,$35;            /* +2 */    shufb       $19,$13,$13,$3
    fma         $10,$59,$25,$50;        /* +1 */    shufb       $18,$23,$23,$3
    fma         $9,$22,$32,$31;                     shufb       $16,$23,$23,$38
    or          $8,$58,$43;             /* +2 */    shufb       $21,$13,$13,$38
    or          $40,$39,$12;            /* +2 */    shufb       $14,$13,$13,$34
    ai          $7,$7,-1;               /* +2 */    shufb       $42,$19,$18,$33
    fma         $41,$17,$32,$31;                    stqd        $8,-16($2)              /* +2 */
    fcgt        $44,$10,$11;            /* +1 */    stqd        $40,-32($2)             /* +2 */
    fma         $45,$21,$28,$9;                     brnz        $7,_local_c0de000000000002 /* +2 */
    nop         ;                                   hbrr
```

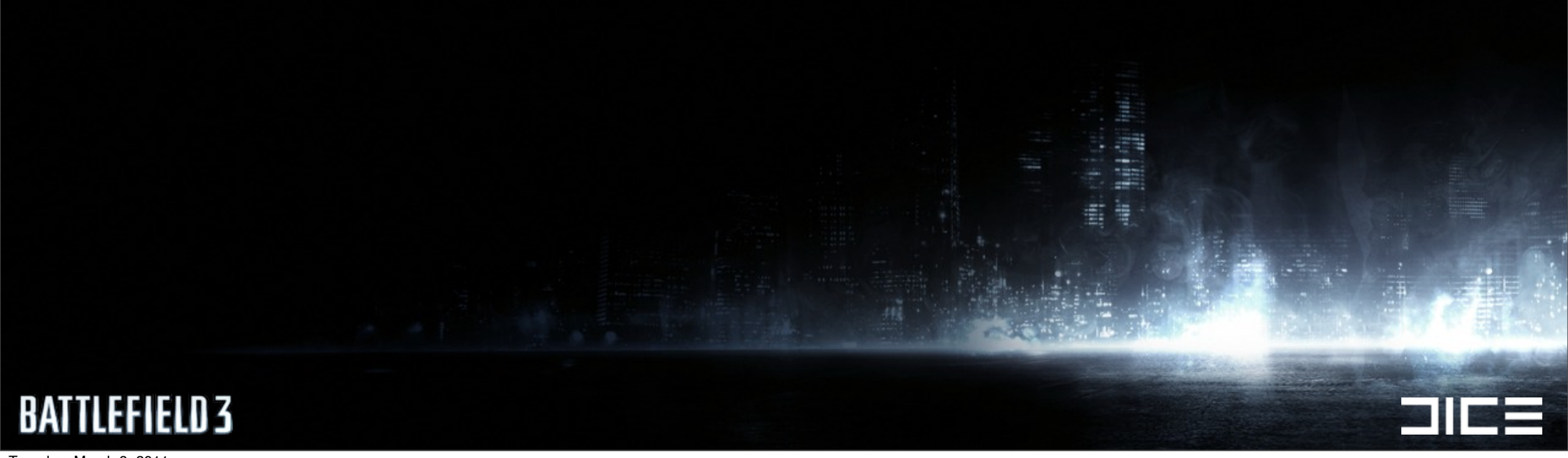
Additional culling

- Frustum vs AABB
- Project AABB to screen space
- Software Occlusion



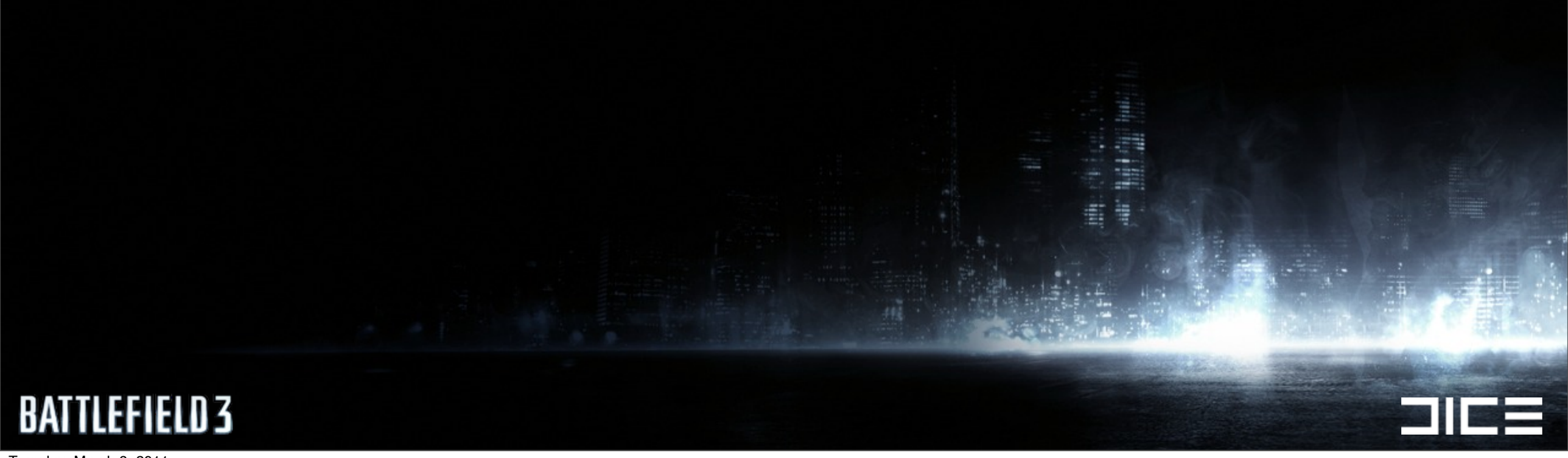
Project AABB to screen space

- Calculate the area of the AABB in screen space
- If area is smaller than setting just skip it
- Due to FOV taking distance doesn't work



Software Occlusion

- Used in Frostbite for 3 years
- Cross platform
- Artist made occluders
- Terrain

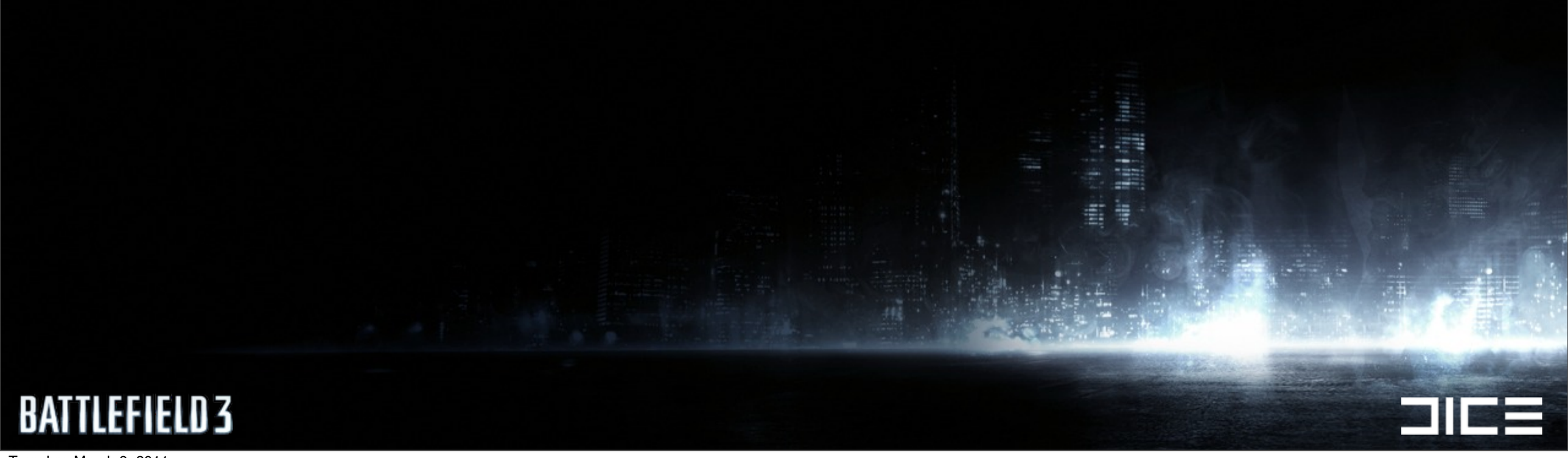


Why Software Occlusion?

- Want to remove CPU time not just GPU
- Cull as early as possible
- GPU queries troublesome as lagging behind CPU
- Must support destruction
- Easy for artists to control

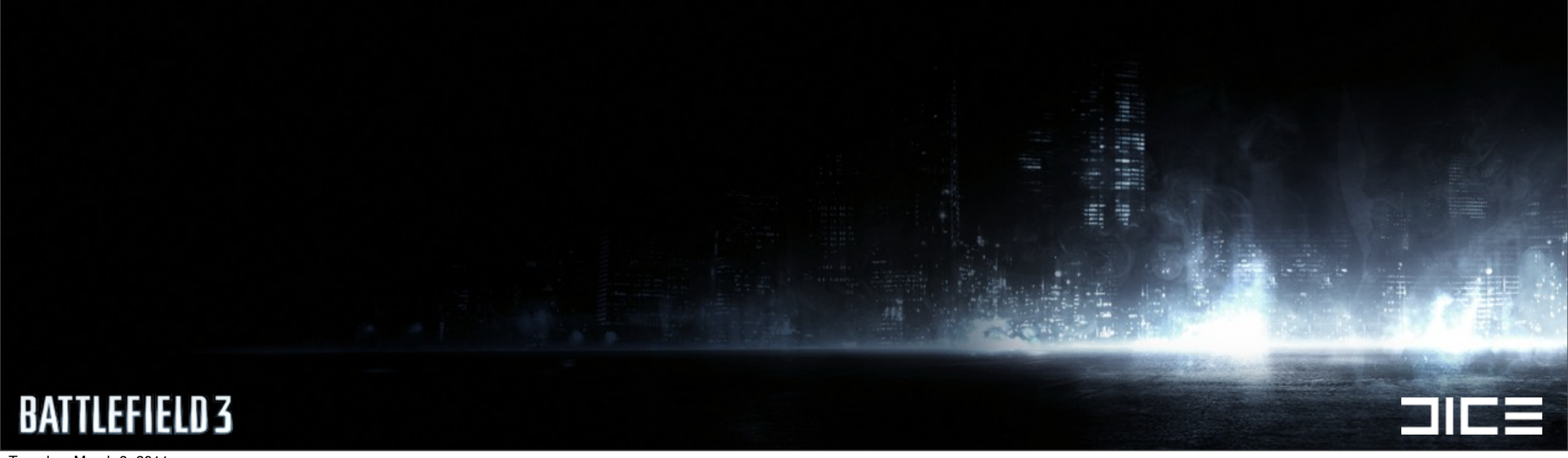
Software Occlusion

- So how does it work?
- Render PS1 style geometry to a zbuffer using software rendering
- The zbuffer is 256 x 114 float

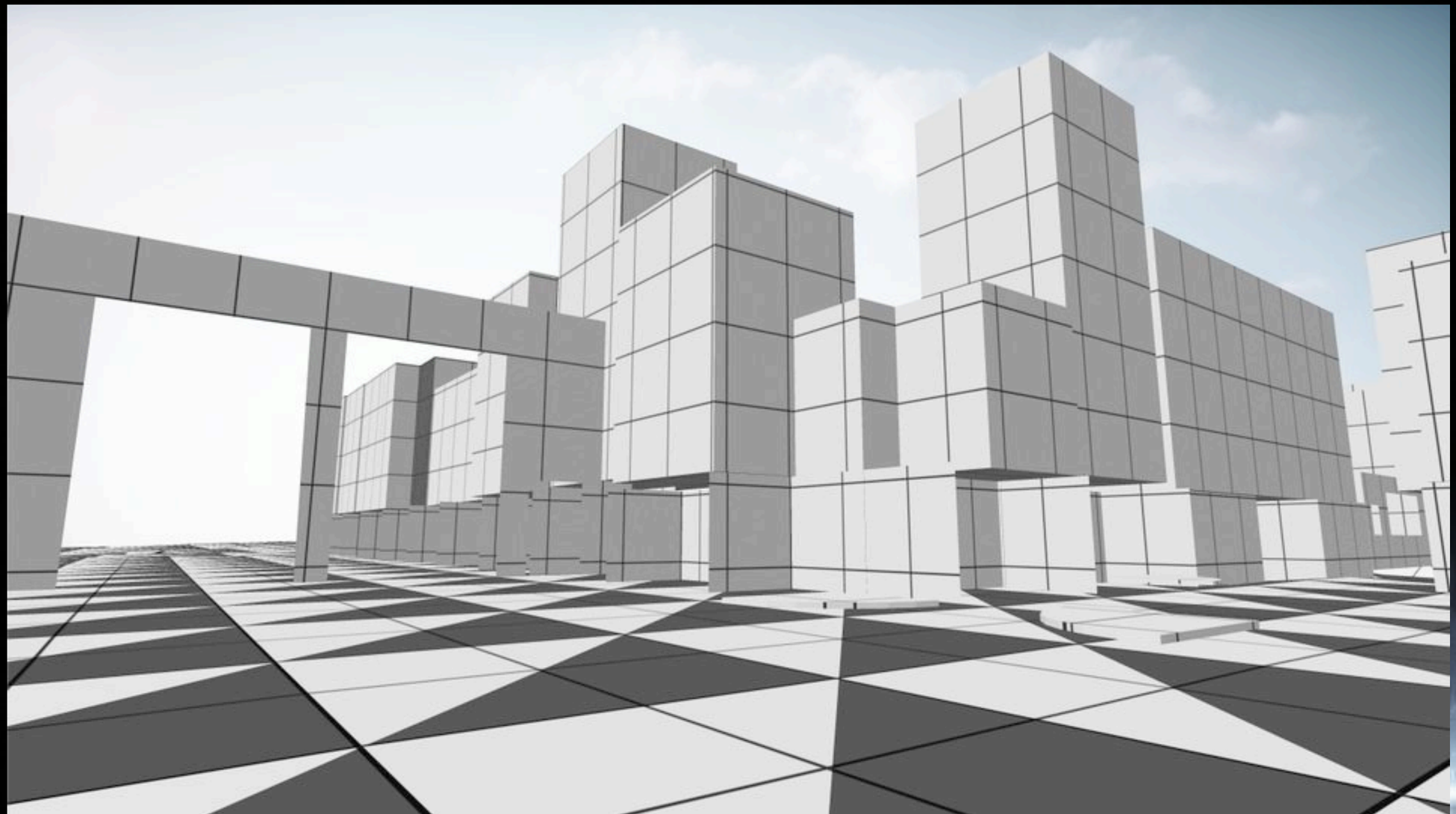


Software Occlusion

- Occluder triangle setup
- Terrain triangle setup
- Rasterize triangles
- Culling



Software Occlusion (Occluders)



BATTLEFIELD 3

DICE

Software Occlusion (In-game)

BATTLEFIELD 3

DICE

Software Occlusion (In-game)

BATTLEFIELD 3

DICE

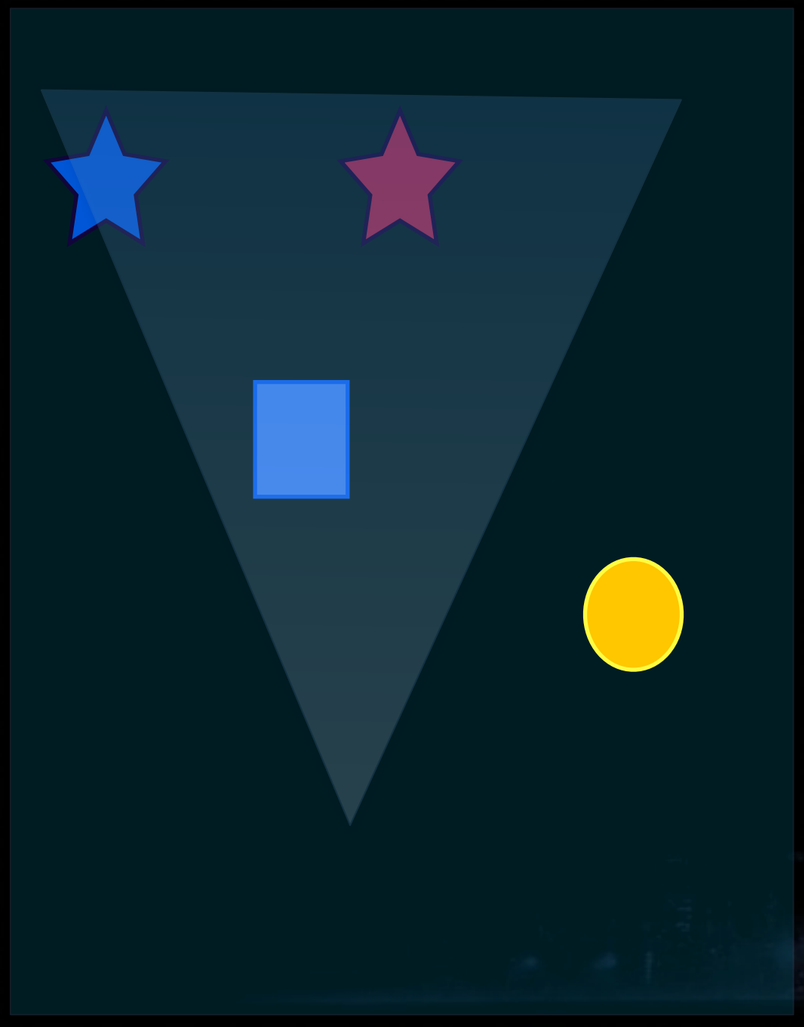
Software Occlusion (In-game)

BATTLEFIELD 3

DICE

Culling jobs

Occluder triangles



Job 0 — Inside, Project triangles

Job 1 — Inside, Project triangles

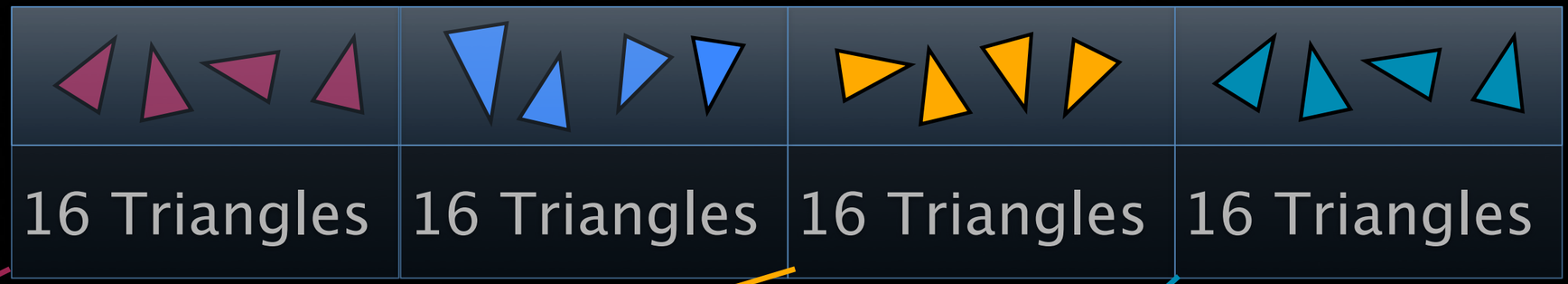
Job 2 — Intersecting, Clip, Project

Job 3 — Outside, Skip

Output

Occluder triangles

Input



256 x 114 zbuffer

256 x 114 zbuffer

256 x 114 zbuffer

Job 0

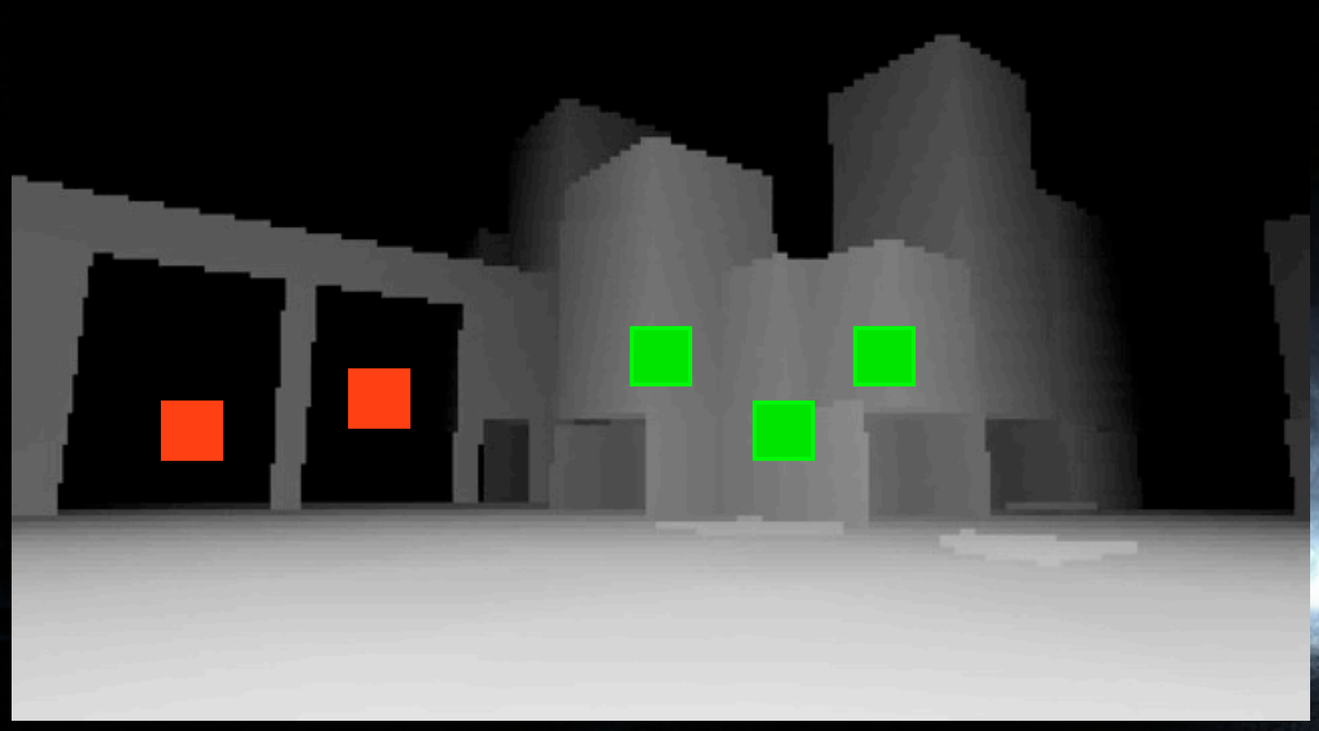
Job 1

Merge step

BATTLEFIELD 3

z-buffer testing

- Calculate screen space AABB for object
- Get single distance value
- Test the square against the z-buffer

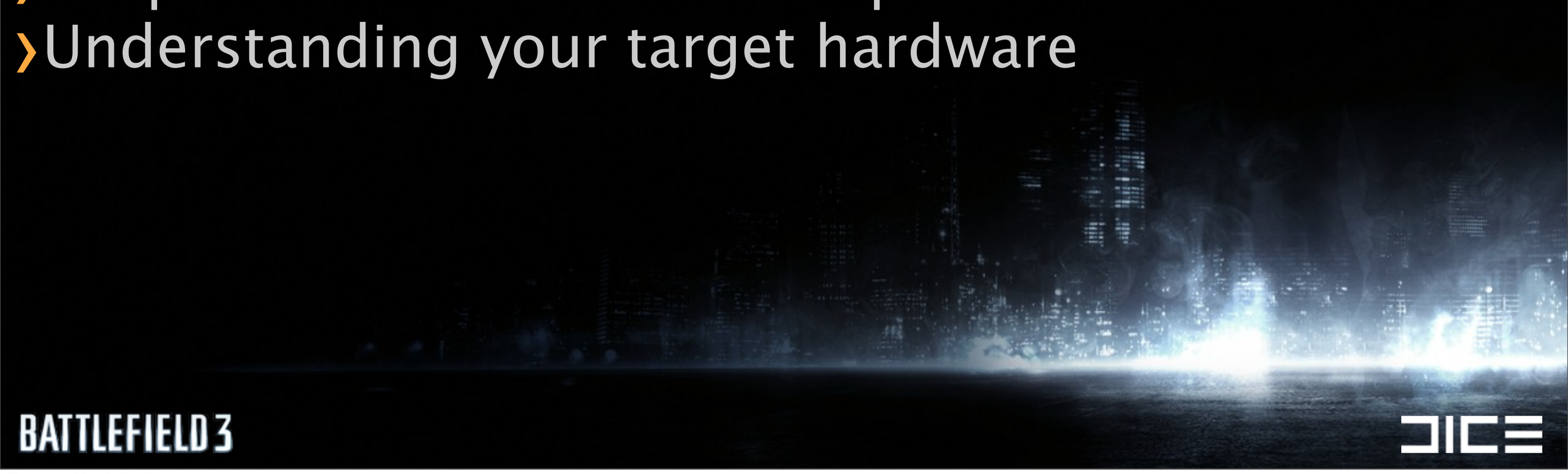


BATTLEFIELD 3

DICE

Conclusion

- Accurate and high performance culling is essential
- Reduces pressure on low-level systems/rendering
- It's all about data
- Simple data often means simple code
- Understanding your target hardware



Thanks to

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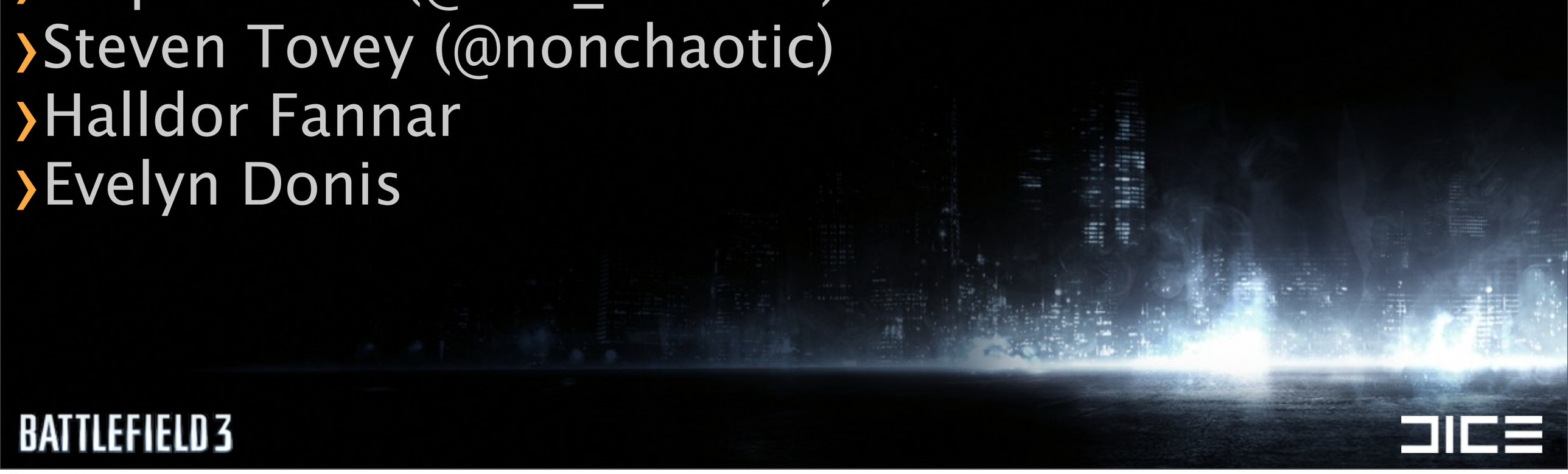
- Steven Tovey (@nonchaotic)
- Halldor Fannar
- Evelyn Donis



Questions?

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Battlefield 3 & Frostbite 2 talks at GDC'11:

Mon 1:45	*DX11 Rendering in Battlefield 3*	Johan Andersson
Wed 10:30	*SPU-based Deferred Shading in Battlefield 3 for PlayStation 3*	Christina Coffin
Wed 3:00	*Culling the Battlefield: Data Oriented Design in Practice*	Daniel Collin
Thu 1:30	*Lighting You Up in Battlefield 3*	Kenny Magnusson
Fri 4:05	*Approximating Translucency for a Fast, Cheap & Convincing Subsurface Scattering Look*	Colin Barré-Brisebois

GDC

For more DICE talks: http://publications.dice.se

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