Visual Effects in Star Citizen

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Introduction to Star Citizen

- Ambitious futuristic space-sim
  - First person perspective
  - Space combat, exploration, trading, mining
  - ‘Instanced’ MMO
  - Full single player campaign – Squadron 42
  - Crowd funded project

CryEngine

- Mature FPS and Multi-platform Code Base
- AAA standard technology and effects
- Physically based rendering pipeline
- Deferred/Tiled-Deferred/Forward+
- 10 different modes of Anti-Aliasing

Arena Commander
DYING STAR

Arena Commander
BROKEN MOON


Arena Commander
NEW HORIZON

Visual Quality

Video…

Visual Quality

- Extremely high-end visuals
  - Long term focus on quality
  - High system specs
    - Current high-spec PC will be mid-spec by release
  - Currently DX11 only


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ESCAPE


8081
1808
DANGER

Ship Complexity

- Extremely high poly ships
  - 60%-40% split between texture and geometry memory rather than more typical 80-20
- Far more assets than can fit into typical GPU memory
- Heavy use of streaming

Ship Complexity

- Initially we allocated more geometry than we had space for on the GPU
- Mostly fine because only a small % on screen at once
  - Different LODs
  - Mutually exclusive assets (damage states)

Ship Complexity

- However memory paging to GPU eventually reared its ugly head
  - Difficult to predict and avoid
  - ‘GPU View’ tool can be useful in tracking this
  - As can GPU hardware vendors' assistance ☺
  - DX12 would help avoid/diagnose these from the application

Ship Complexity

- Ideally predict meshes required in advance
  - Easy for LODs
  - Impossible to predict when damage will occur and therefore require damage meshes
- Need to stay within GPU memory budget as much as possible
  - Avoid rarely-used / mutually-exclusive assets

Ship Complexity

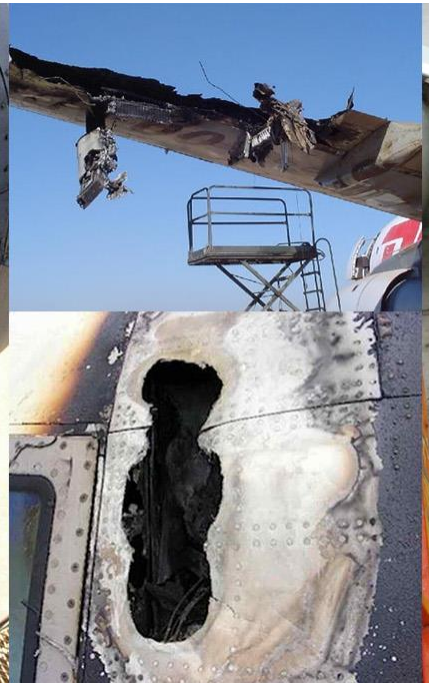
Ship Complexity

- Discrete damage models for each ship part
  - 0%, 25%, 50%, 75%, 100%
- Switch independently
- All need LODs
- 10+ parts, 5 damage states, 4 LODs
- 200+ meshes for one ship!

Ship Damage – Goals

- Identified need to improve system
- Key goals were:
  - Less art intensive
  - Better use of modern hardware & DX11
  - Lower memory usage
  - More accurate and location specific damage
  - Maintain or improve on visual fidelity

Ship Damage

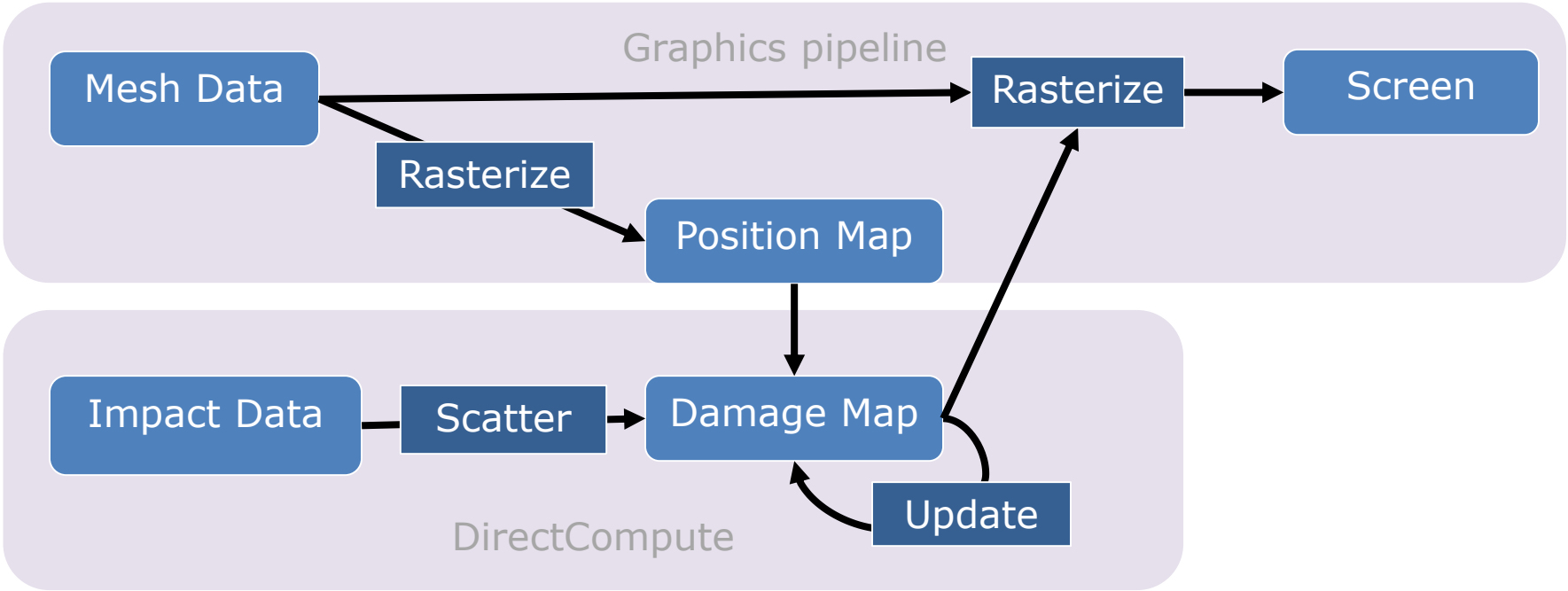


Ship Damage

Ship Damage – Overview

- Key idea was to ditch decals and 25% / 50% / 75% damage states as these are primarily just surface damage
- Store data about any damage on the GPU and feed this into the pixel shader to visualize the damage
- Use DX11 & DirectCompute to enable more complex damage model and improved visuals
- Keep 100% damage state for major silhouette changes

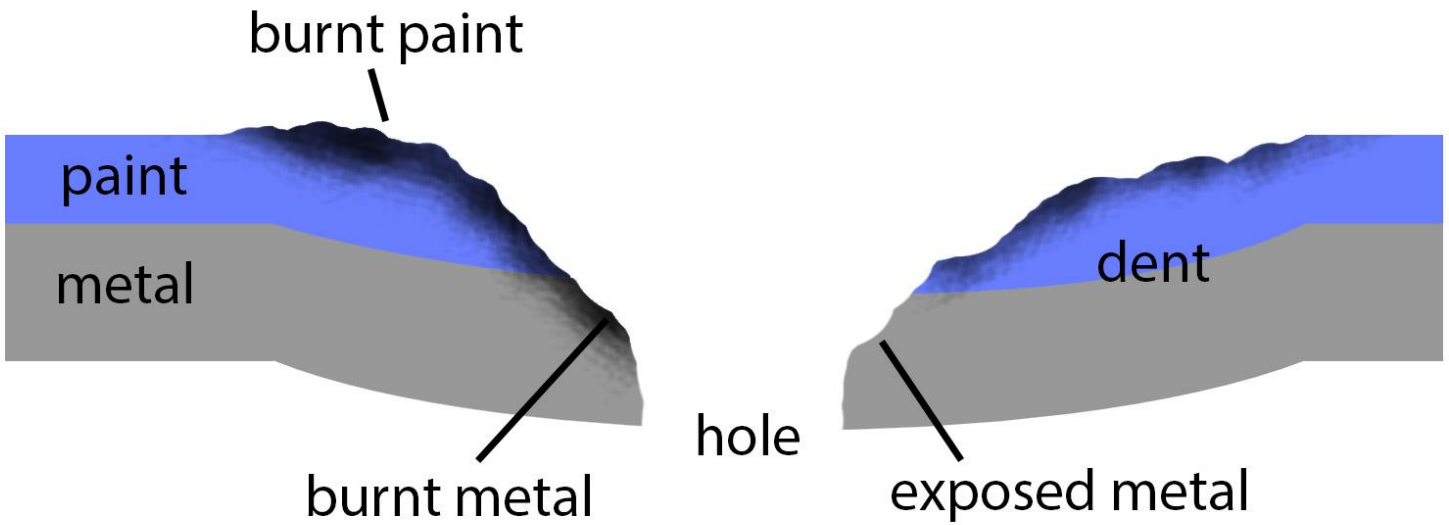
Ship Damage – Overview



Ship Damage – Damage Model

- We chose to model some more physical properties that just ‘damage’ to achieve more complex and dynamic results
  - Deformation
  - Thickness
  - Temperature
  - Burn

Ship Damage – Damage Model



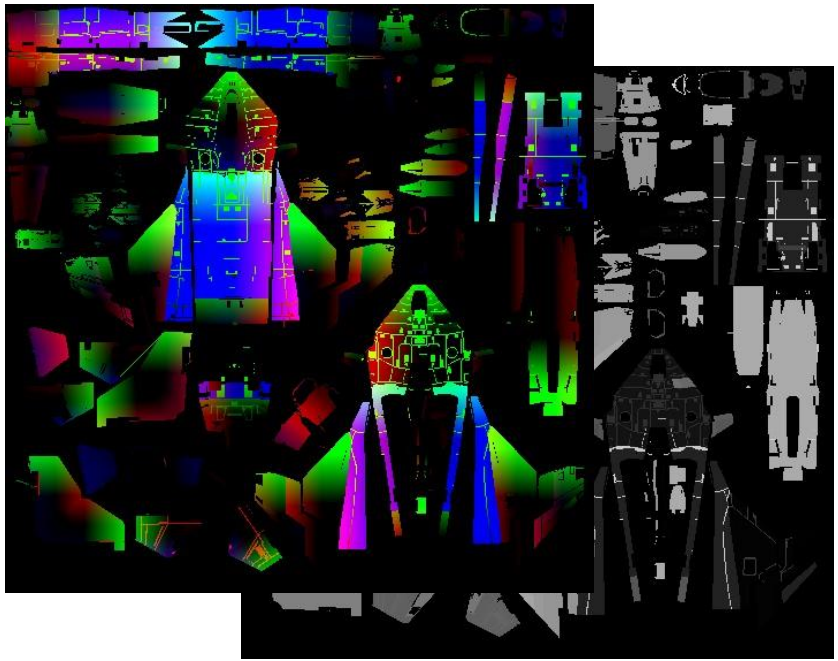
Ship Damage – Damage Model

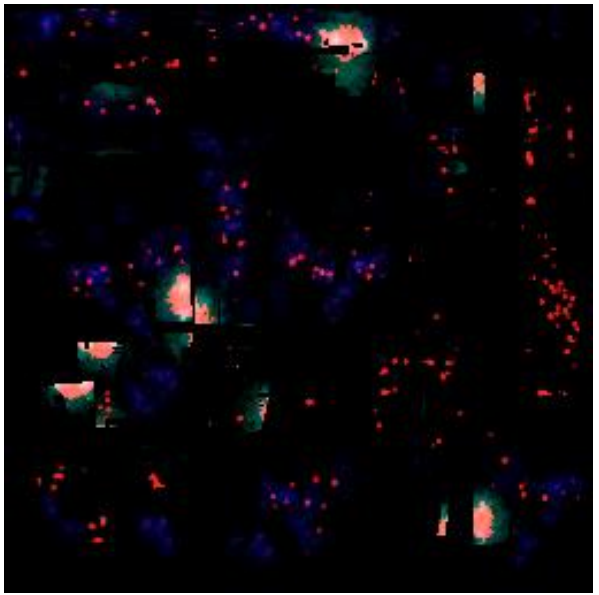
- Need to decide which space to store this data
  - Mostly just surface damage
  - Needs consistent resolution
- Opted for 2D textures as opposed to 3D textures or vertices
- Considered more complex structures such as octree's but overhead was considered too high

Ship Damage - Damage Model

- Need geometric representation of ship on GPU in order to paint into this Damage Map
- Solution is to use object space texture
- However ship parts animate
  - Store bone ID in alpha channel

Ship Damage – Damage Model





Ship Damage – Adding Damage

- Arbitrary artist-defined UV layout
- Read of position map and skinning limit performance
- However most impacts only effect <5% of damage map
- ~95% of the GPU work required to determine this

Ship Damage – Adding Damage

- Potentially multiple hits on multiple ships in a single frame
  - Especially for larger ships
  - In heavy combat could be a major performance hit
- Need to find a way to direct GPU work to the desired parts of the damage map

Ship Damage – Adding Damage

- Texture is 99% spatially coherent
- Logical to split into smaller tiles to avoid work
  - Calculate bounds of each tile
  - Use like Hi-Z buffer to early out
  - However texels aren’t static but are skinned!
    - Moving flaps / wings / turrets

Ship Damage – Adding Damage

- Hard to avoid wasted work with pixel shader
  - Every pixel still needs to read some memory, do some calculations then bail out – usually bandwidth limited
- Compute shaders open up many different ways to optimize
  - Thread group shared memory
  - DispatchIndirect

Ship Damage – Adding Damage

- Calculate N bounding spheres per tile
  - N isn't fixed, but in practice has an upper limit of about 4
- Each thread tests one bounding sphere against the impact location
- Only shade pixels if at least one passes
- Distributes the cost – *much* quicker rejection
- But most threads still idle during this stage

Ship Damage – Adding Damage

- Most impacts last multiple frames, and larger ships will likely receive many hits at once
- Use idle threads to calculate multiple hits
- threadGroupSize = maxBonesPerTile * maxHits
- More hits would require a loop per thread

Ship Damage – Adding Damage

- Alternate approach is to perform one tile-bone-impact calculation per thread and store results in a buffer and accumulate number of tiles visible
- DispatchIndirect can be used to trigger a 2nd compute on just the required tiles
- Theoretically less wastage, but overhead of intermediate buffer and 2nd dispatch are significant

Ship Damage – Extras

- Parallax occlusion mapping for internals
  - Perfect use case as silhouette is hidden and poly count needs to be low for memory & performance
- Screen space height-map
  - Use the differential to calculate surface gradient and perturb normal [Mikkelson 2010]
  - ddx/ddy on bilinear filtering looks bad under magnification
  - Take 2 extra samples and manually calculate forward difference

Ship Damage – Extras

- Heat dissipation in compute shader
- Hole cutting
  - clip()
  - Needs including in depth/shadow pass when close-up ☹
  - Investigating the possibility of identifying bones that have holes in the compute shader and using DispatchIndirect to limit the number of polys using clip()


no damage
NO STEP
NO STEP


+burn albedo


+ dent normals
NO STEP
NO STEP
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+ burn normals


+ bare metal
NO STEP
NO STEP
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+ hole cutting
NO STEP
NO STEP
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+ cut height/normals
NO STEP
NO STEP
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DANGER

Ship Damage – Results

Video…

Ship Damage – Extensions

- But we’re just scratching the surface!
  - Pun intended ☺
- Geometry Morphing
  - Create second version of ship which panels shrunk inwards
  - Export offsets in compacted 32bit RGBE format
  - Push vertices towards offset as they are dented
  - Could potentially use tessellation for more accuracy

Ship Damage – Extensions

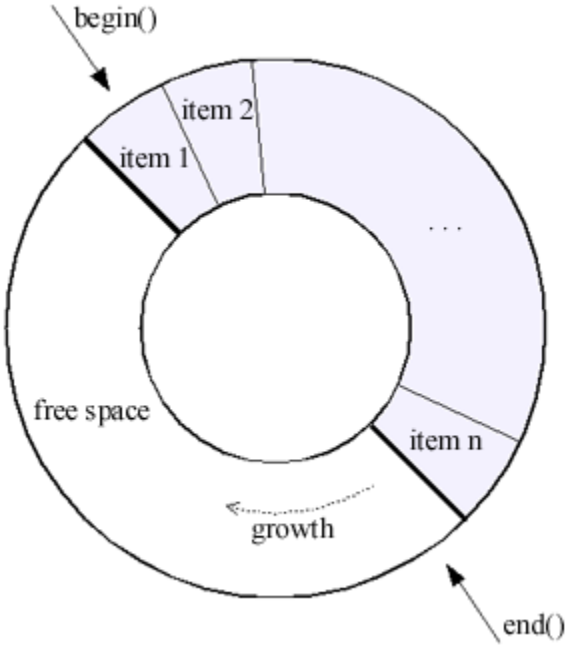
- GPU particles
  - Spawn in compute shader when thickness is modified
  - Use position map for location/orientation
  - Use thickness, temperature & diffuse map for color
  - Complete GPU solution for VFX ☺
  - But need to efficiently manage variable particle count

Ship Damage – Extensions

- Many GPU particle implementations don't handle arbitrary particle counts
- Can use append/consume buffer as free-list for spare slots in a fixed sized array – but hard avoid cost of empty slots in particle update & render
- Instead make the upper bound of the number of particles that can be spawned from each hit deterministic
- Treat particle array as a ring-buffer

Ship Damage – Extensions

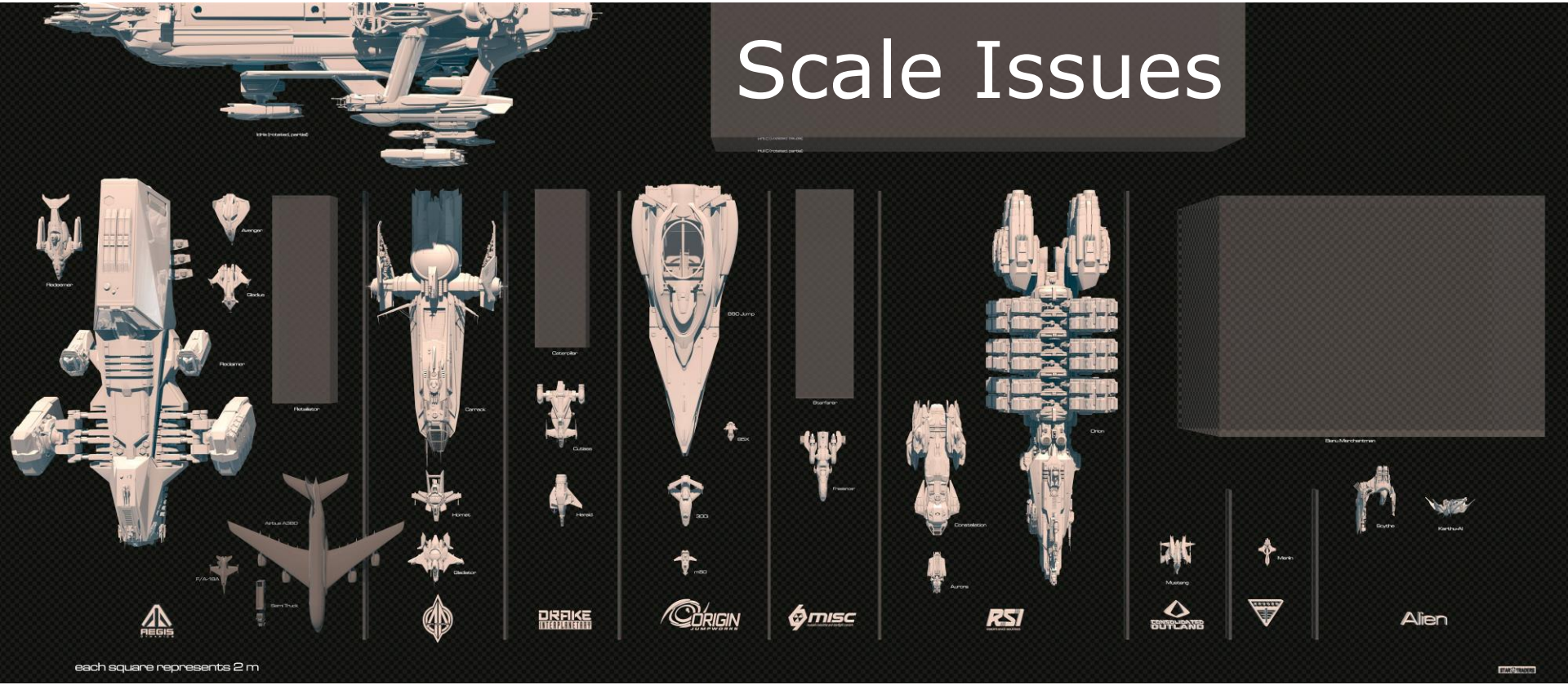
- Keep track of start/end points
- Dispatch updates just for the particles we need
- Skip unused particles in compute shader
- Different ring buffers for different particle life-times



Ship Damage – Extensions

- Sparse / Tiled memory
  - Most tiles are empty most of the time
    - Especially on larger ships
  - Ideally allocate on demand
  - Tiled resource in DX11.2
  - Our current min-spec is DX11.1 ☹
  - Revisit later in development

Scale Issues



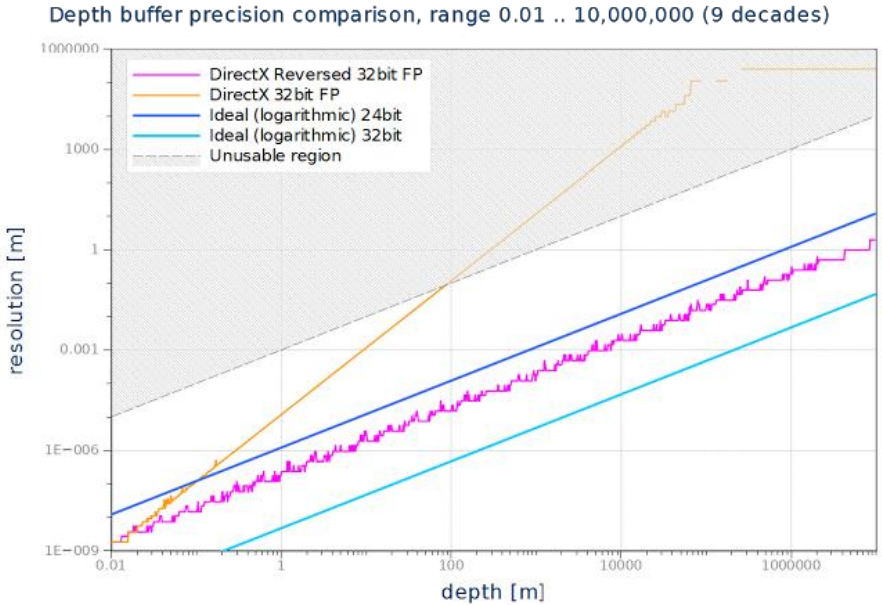
Scale Issues

- Enormous scale
  - No ‘faked’ UI or FPS arms/body
  - Everything is ‘in the world’
  - UI is ~3cm from camera
  - Ships up to a mile long with ~100 rooms
  - Planets are hundreds/thousands of miles wide
  - Inter-planetary travel

Scale Issues

- Quickly reached 32bit precision issues
- Upgraded CryEngine to 64bit transforms
- Renderer stays 32bit camera-relative
- Depth buffer changed to inverted 32f
  - No performance hit on modern hardware

Scale Issues

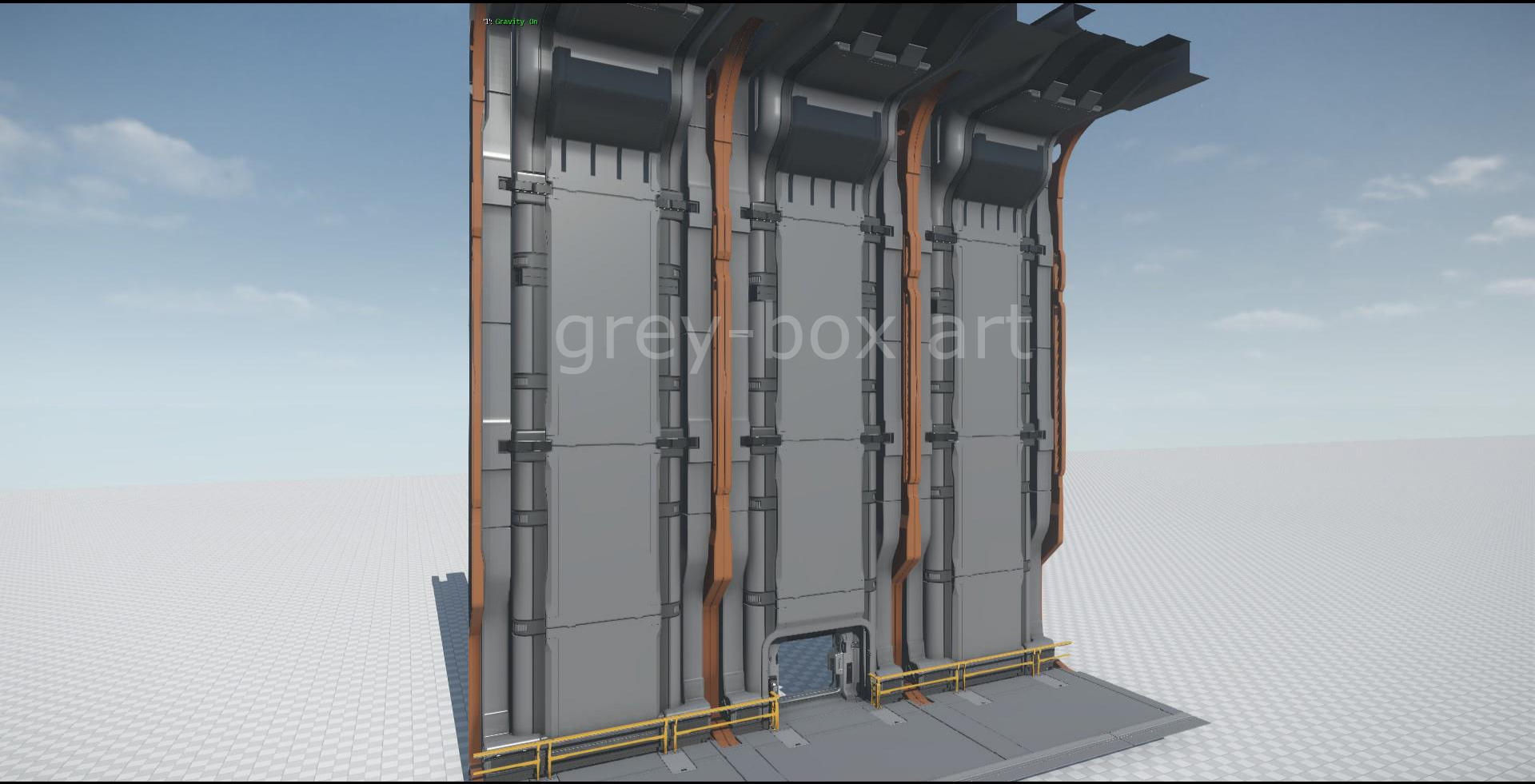


Brano Kemen - http://outerra.blogspot.co.uk/2012/11/maximizing-depth-buffer-range-and.html

Environments

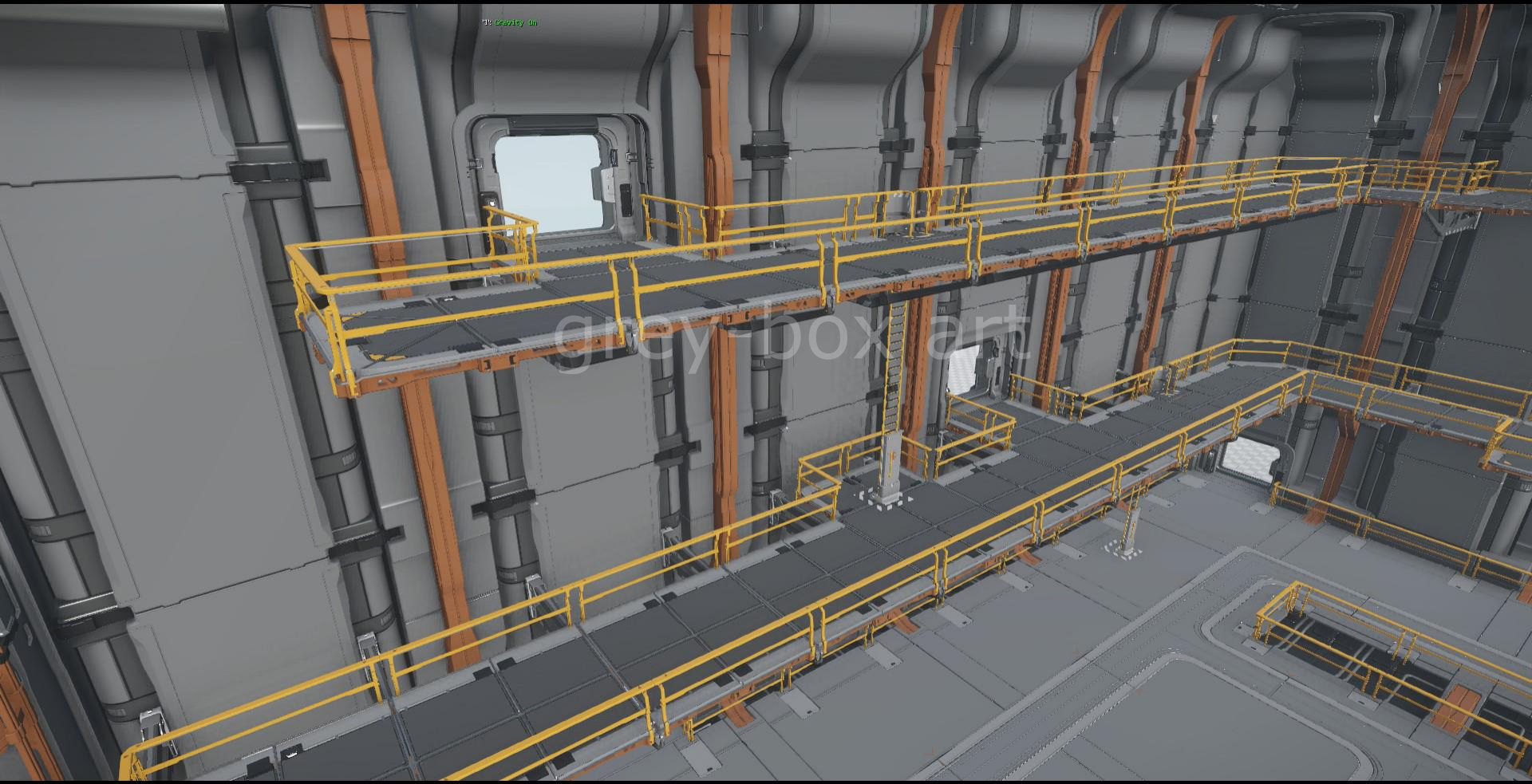
- Due to the MMO part of the game we require a LOT of environments and so opted for a modular approach
- Modular ‘kits’ are built that easily snap together
- Simplifies art pipeline (e.g. out-sourcing)
- Very flexible for level designers

Individual Components



Small Configuration

Shubin Interstellar
INTERIOR BUILDING SET



Large Configuration

Shubin Interstellar
INTERIOR BUILDING SET

Close up shot

Shubin Interstellar
Greybox

Mid shot

Shubin Interstellar
Greybox

Far shot

Shubin Interstellar
Greybox

Wide shot

Shubin Interstellar
Greybox

Environments

- We immediately hit many performance issues
  - Poly count due to desired fidelity
  - Texel density too high for baking textures
  - Tiling textures means many draw calls per mesh
  - Lots of meshes to build a room
  - Even more meshes for a space-station!
  - LOTS of draw calls

Environments

- Texture arrays are a potential solution
  - Resolution limitation means streaming is difficult
  - Instead use low-resolution texture arrays just for LODs
  - No need to stream individual textures – entire texture array at 256x256 for a level is < 15Mb
- Can now render LODs with a single draw call! ☺
  - Vertex buffers sorted by material ID so can still use high-res textures if required

Environments

- Mesh merging solution similar to KillZone
- Build LODs for each individual modular asset
- Iterative heuristic algorithm to combine LODs to build a hierarchy with min draw calls and memory
- Relies on aggressive LODs but can drastically reduce draw calls with no manual artist work

Future

- That’s just a tiny sub-set of what we’re doing, there’s lots more to come…
  - Gas-clouds
  - Asteroid fields
  - Stars
  - Planets
  - Worm-holes

Thanks

- Thanks for listening!

- Special thanks to our awesome team at CIG, especially these lot:

Nicolas Thibieroz, Chris Roberts, Erin Roberts, Neil McKnight, Bjorn Seinstra, Nathan Dearsley, Okka Kyaw, Geoff Birch, Muhammad Ahmad, Matt Intrieri, Mark Abent

Obligatory “We’re Hiring” Slide

https://cloudimperiumgames.com/jobs
Manchester (UK) + Frankfurt + Santa Monica

Questions?

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- Making of Killzone 3
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  - http://outerra.blogspot.co.uk/2012/11/maximizing-depth-buffer-range-and.html
- Bump Mapping Unparametrized Surfaces on the GPU - Morten S. Mikkelsen
  - https://dl.dropboxusercontent.com/u/55891920/papers/mm_sfgrad_bump.pdf

Unofficial Trailer

Fan Trailer…

Watch on YouTube