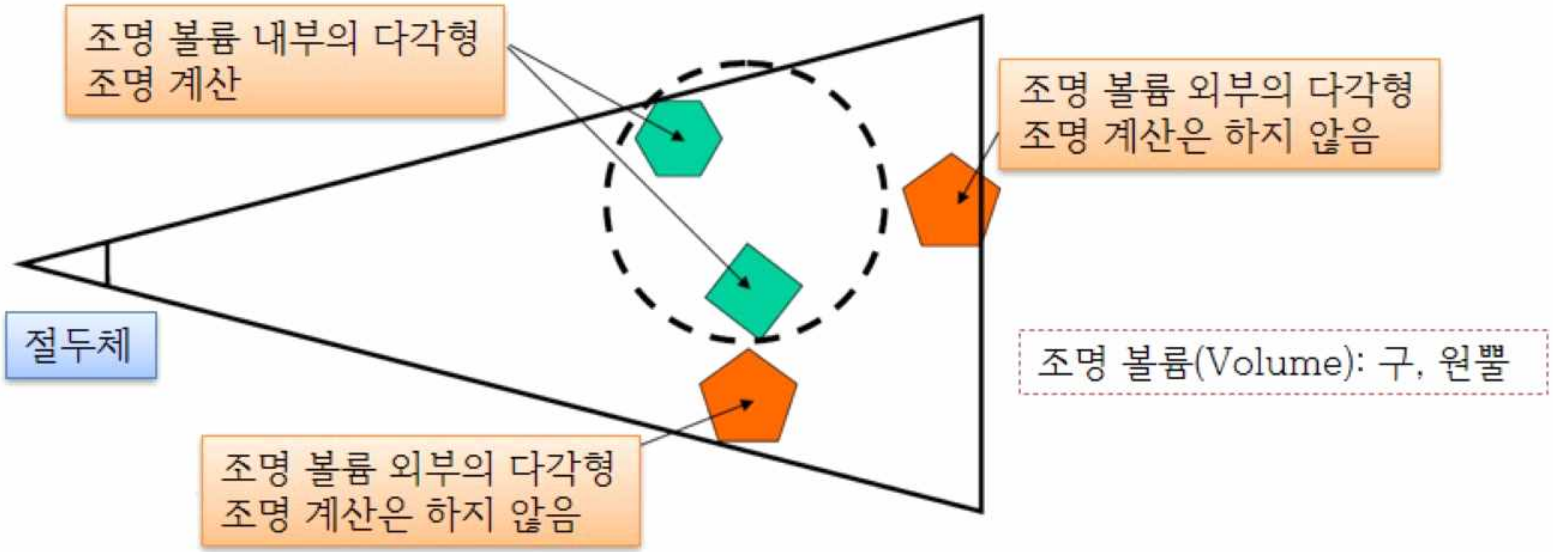
Game Programming with DirectX

지연 조명
(Deferred Shading)

조명 처리(Lighting)

- **조명 처리의 최적화**
  - 조명 볼륨 내부의 표면을 쉐이딩(최적화)



  - 스텐실 컬링(Stencil Culling)
    첫번째 단계는 계산량이 많지 않으므로 색상을 출력하지 않으면서 렌더링

D3D12_DEPTH_STENCIL_DESC

1. 색상 출력(Color Write)을 비활성화하여 조명 볼륨을 렌더링
   DepthFunc = D3D12_COMPARISON_FUNC_**LESS**;
   FrontFace.StencilFunc = D3D12_COMPARISON_FUNC_**ALWAYS**;
   FrontFace.**StencilDepthFailOp** = D3D12_STENCIL_OP_**REPLACE**; //참조값(a)
   나머지 스텐실 연산: D3D12_STENCIL_OP_KEEP;
2. 조명 계산 쉐이더를 사용하여 출력
   DepthFunc = D3D12_COMPARISON_FUNC_ALWAYS;
   FrontFace.StencilFunc = D3D12_COMPARISON_FUNC_**EQUAL**; //참조값(a)
   조명이 영향을 주지 않는 픽셀은 컬링됨(스텐실 값이 참조값과 일치하지 않으므로)

지연 쉐이딩(Deferred Shading)

- **조명(Lighting)**
  - 많은 조명과 많은 객체들을 렌더링하는 경우 계산량이 많음
  - 단일-패스, 다중-패스, 지연 쉐이딩
- **단일-패스 조명(Single-Pass Lighting)**

```
For each object:
    Render object(Apply all lighting in one shader)
```

O(Objects*Lights*ScreenPixels)

  - 가려진 표면들에 대한 조명 효과는 화면에 나타나지 않음(낭비: Overdraw)
  - 여러 조명을 관리하기 어렵고 그림자(Shadow)와 통합하기 어려움
- **다중-패스 조명(Multi-Pass Lighting)**

Bidirectional **R**eflectance **D**istribution **F**unction

```
For each light:
    For each object affected by light
        FrameBuffer += BRDF(object, light)
```

깊이 검사 (Depth Test)

  - 가려진 표면들에 대한 조명 효과는 화면에 나타나지 않음(낭비)
- **지연 조명(Deferred Shading)**

```
For each object:
    Render lighting(material) properties into "G-buffer"
For each light:
    FrameBuffer += BRDF(G-buffer, light)
```

O((Objects+Lights)*ScreenPixels)

  - 픽셀에 대한 조명 계산을 하지 않고 정보를 모아 나중에 조명 효과를 계산

지연 쉐이딩(Deferred Shading)

- **지연 쉐이딩(Deferred Shading)**
  - 화면-좌표계의 쉐이딩(조명 처리) 기법
  - 정점 쉐이더 또는 픽셀 쉐이더에서 쉐이딩(조명 처리)을 두 단계로 수행함
    - 첫 번째 단계
      쉐이딩을 먼저 수행하지 않고 보이는 픽셀에 대한 조명 처리 데이터를 수집
      각 표면(픽셀)을 위한 위치 벡터, 법선 벡터, 재질 등을 일련의 텍스쳐로 렌더링
      이러한 일련의 텍스쳐를 기하 버퍼(**G-Buffer**: Geometry Buffer)라고 함
    - 두 번째 단계
      각 픽셀에 대하여 **화면 좌표계(Screen Space)**에서 조명 효과를 계산함
  - 씬과 조명을 분리
    각 조명의 효과는 화면의 각 픽셀에 대하여 한번만 계산함
    조명이 많은 경우 성능 저하의 문제없이 렌더링할 수 있음
    조명 관리를 쉽게 할 수 있음
    투명 효과를 처리할 수 없음(투명한 객체들은 따로 렌더링)
    여러 재질을 사용하는 경우 어려움이 있음
  - G-버퍼
    실수 텍스쳐(위치 벡터 등을 저장할 수 있어야 함)
  - 다중 렌더 타겟(MRT: Multiple Render Targets)
    단일 패스로 모든 G-버퍼 속성을 출력

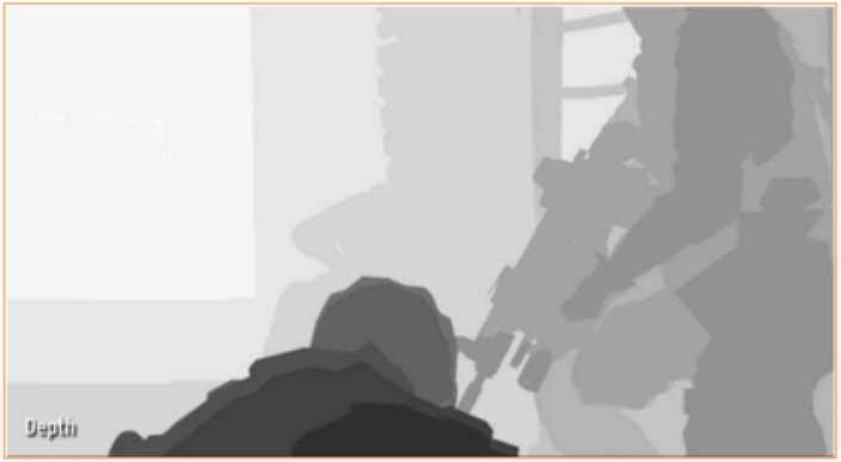
O(Lights*Triangles) → **O(Lights) + O(Triangles)**

지연 쉐이딩(Deferred Shading)

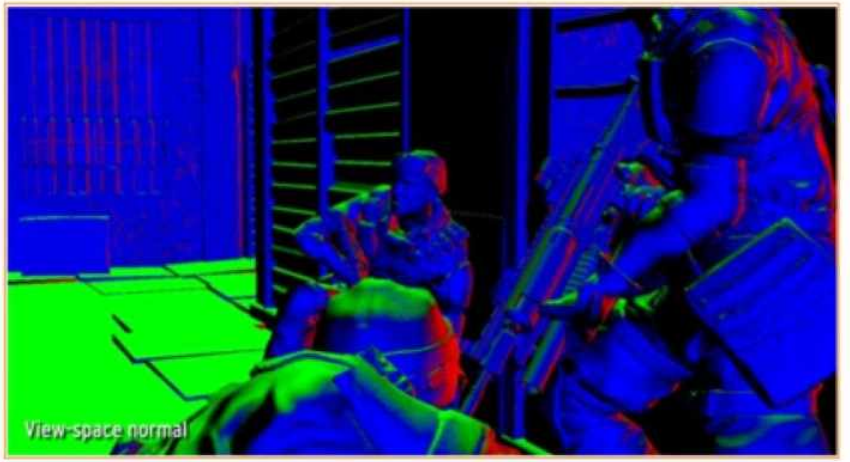
- 지연 쉐이딩(Deferred Shading): Killzone 2
  - http://www.guerrilla-games.com/

지연 쉐이딩(Deferred Shading)

- 지연 쉐이딩(Deferred Shading): Killzone 2



깊이값(Depth)



법선 벡터(Normal)

스펙큘러(Specular Intensity)

스펙큘러(Specular Power)

지연 쉐이딩(Deferred Shading)

- 지연 쉐이딩(Deferred Shading): Killzone 2

화면좌표계 2D 모션 벡터(Motion Vector)

색상(Albedo: Texture Color)

지연 결합(Deferred Composition)

후처리(Post Processing)

지연 쉐이딩(Deferred Shading)

- **지연 쉐이딩(Deferred Shading)**: Killzone 2
  - G-Buffer(Killzone 2)
    4 * R8G8B8A8 + (24-Bit Depth + 8-Bit Stencil) ≒ 36MB

R8	G8	B8	A8	Buffer
Depth 24-Bit			Stencil 8-Bit	Depth Stencil
Lighting Accumulation RGB 24-Bit			Intensity 8-Bit	Render Target 0
Normal X (Floating Point) 16-Bit		Normal Y (Floating Point) 16-Bit		Render Target 1
Motion Vector XY 16-Bit		Specular Power	Specular Intensity	Render Target 2
Diffuse Albedo RGB 24-Bit			Occlusion	Render Target 3

  - G-Buffer(Battlefield 3)

R8	G8	B8	A8	Buffer
Depth 24-Bit			Stencil 8-Bit	Depth Stencil
Lighting Accumulation RGB 24-Bit			Intensity 8-Bit	Render Target 0
Normal X (Floating Point) 16-Bit		Normal Y (Floating Point) 16-Bit		Render Target 1
Motion Vector XY 16-Bit		Specular Power	Specular Intensity	Render Target 2
Diffuse Albedo RGB 24-Bit			Occlusion	Render Target 3

지연 쉐이딩(Deferred Shading)

- **지연 렌더링(Deferred Rendering)**
  - ① 기하 버퍼(GBuffer) 생성 단계
    씬을 텍스쳐(GBuffer) 로 렌더링(조명 계산을 하지 않음)
    - 법선 벡터
    - 디퓨즈 반사
    - 스펙큘러 반사
    - 위치 벡터
    - …
  - ② 조명 계산 단계
    화면 전체 크기의 사각형 렌더링(조명 계산)
    조명 정보는 텍스쳐(GBuffer)에서 로드(샘플링)

```
struct VS_GB_INPUT
{
    float4 position : POSITION;
    float2 uv : TEXCOORD;
    float3 normal : NORMAL;
    float3 tangent : TANGENT;
};
```

```
struct VS_GB_OUTPUT
{
    float4 position : SV_Position;
    float2 uv : TEXCOORD;
    float3 normalW : NORMALW;
    float3 position : POSITIONW;
    float3 tangent : TANGENTW;
    float3 bitangentW : BITANGENTW;
};
```

```
VS_GB_OUTPUT VSDeferredLighting(VS_GB_INPUT input)
{
    VS_GB_OUTPUT output;

    output.position = mul(input.position, gmtxWorld);
    output.positionW = output.position.xyz;
    output.position = mul(output.position, gmtxView);
    output.position = mul(output.position, gmtxProjection);
    output.normalW = normalize(mul(input.normal, (float3x3)gmtxWorld));
    output.tangentW = normalize(mul(input.tangent.xyz, (float3x3)gmtxWorld));
    output.bitangentW = normalize(cross(output.normalW, output.tangentW));
    output.uv = input.uv;
    return(output);
}
```

지연 쉐이딩(Deferred Shading)

- 지연 렌더링(Deferred Rendering)

① GBuffer 생성 단계

```
[earlydepthstencil]
PS_GB_OUTPUT PSDeferredLighting(VS_GB_OUTPUT input)
{
   PS_GB_OUTPUT output;
   float3 T = normalize(input.tangentW);
   float3 B = normalize(input.bitangentW);
   float3 N = normalize(input.normalW);
   float3x3 TBN = float3x3(T, B, N);
   float3 normal = normalize(gtxtNormalMap.Sample(gssNormalMap, input.uv).rgb * 2.0f - 1.0f);
   output.normal = float4(mul(normal, TBN), 1.0f);
   float3 diffuseAlbedo = gtxtTextureMap.Sample(gssDiffuseMap, input.uv).rgb;
   //매핑할 텍스쳐의 색상을 디퓨즈 반사 색상으로 사용하기도 함
   output.diffuseAlbedo = float4(diffuseAlbedo, 1.0f);
   output.specularAlbedo = float4(0.7f, 0.7f, 0.7f, 64.0f / 255.0f);
   //output.specularAlbedo = gcMaterialSpecular; //power : (0~255) → (0 ~ 1.0)
   output.position = float4(input.positionW, 1.0f);
   return(output);
}
```

```
Texture2D gtxtDiffuseMap : register(t0);
SamplerState gssDiffuseMap : register(s0);

Texture2D gtxtNormalMap : register(t1);
SamplerState gssNormalMap : register(s1);
```

```
cbuffer cbMaterial : register(b1)
{
   float4 gcMaterialDiffuse;
   float4 gcMaterialAmbient;
   float4 gcMaterialSpecular; //(r, g, b, power)
   float4 gcMaterialEmissive;
};
```

```
struct PS_GB_OUTPUT
{
   float4 normal : SV_Target0;
   float4 diffuseAlbedo : SV_Target1;
   float4 specularAlbedo : SV_Target2;
   float4 position : SV_Target3;
};
```

```
float4 Lighting(float3 vPosition, float3 vNormal);
```

지연 쉐이딩(Deferred Shading)

- **지연 렌더링(Deferred Rendering)**
  ② 조명 계산 단계(화면 전체 크기의 사각형 렌더링)

```
VS_OUTPUT VS(in VS_INPUT input)
{
   VS_OUTPUT output;
   output.position = input.position;
   return(output);
}
```

```
struct VS_INPUT
{
   float4 position : POSITION;
};
```

```
struct VS_OUTPUT
{
   float4 position : SV_Position;
};
```

```
Texture2D gtxtNormal : register(t0);
Texture2D gtxtDiffuseAlbedo : register(t1);
Texture2D gtxtSpecularAlbedo : register(t2);
Texture2D gtxtPosition : register(t3);

Texture2D gtxtDepth : register(t4);
```

```
ret Object.Load(
   int# Location, //배열 인덱스(u, v, mip)
   [int SampleIndex, ][int Offset]
);
```

```
void Object.GetDimensions(
   [in] UINT MipLevel,
   [out] UINT Width, UINT Height,
   [out] UINT NumberOfLevels
);
```

```
float4 PS(VS_OUTPUT input) : SV_Target
{
   int3 uvm = int3(input.position.xy, 0); //(u, v, mipmap level)
   float3 normal = gtxtNormal.Load(uvm).xyz; //gtxtNormal[uvm]
   float3 position = gtxtPosition.Load(uvm).xyz;
   float3 diffuseAlbedo = gtxtDiffuseAlbedo.Load(uvm).xyz;
   float4 specular = gtxtSpecularAlbedo.Load(uvm);
   float4 cIllumination = Lighting(position, normal, diffuseAlbedo, specular.xyz, specular.w*255.0f);
   return(cIllumination);
}
```

지연 쉐이딩(Deferred Shading)

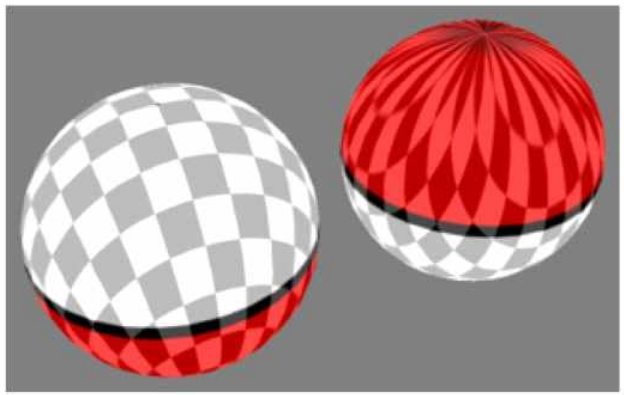
- **지연 렌더링(Deferred Rendering)**
  - 법선 벡터의 인코딩(Encoding Normal Vector)
    - 법선 벡터 $\boldsymbol{n} = (x, y, z)$는 구 표면의 점으로 취급할 수 있음
    - XYZ

      $\boldsymbol{n} = (x, y, z) \rightarrow \boldsymbol{c} = 0.5 * \boldsymbol{n} + 0.5 \qquad \boldsymbol{c} = (r, g, b) \rightarrow \boldsymbol{n} = 2.0 * \boldsymbol{c} - 1.0$
    - LAEAP(Lambert Azimuthal Equal-Area Projection)

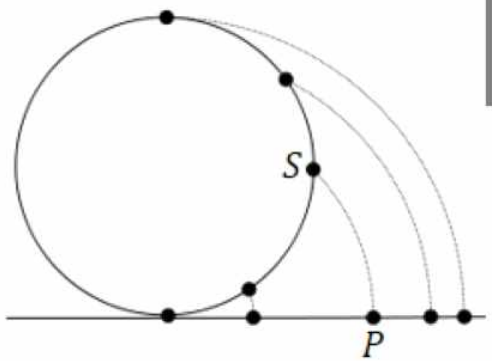
      구의 방정식: $x^2 + y^2 + z^2 = 1$

      $$(X, Y) = \left(\sqrt{\frac{2}{1-z}}x, \sqrt{\frac{2}{1-z}}y\right)$$

      $$(x, y, z) = \left(\sqrt{1 - \frac{X^2+Y^2}{4}}X, \sqrt{1 - \frac{X^2+Y^2}{4}}Y, -1 + \frac{X^2+Y^2}{2}\right)$$



$$x^2 + y^2 + z^2 = 1$$
$$z^2 = 1 - (x^2 + y^2)$$
$$z = \pm\sqrt[2]{1 - (x^2 + y^2)}$$



Compact Normal Storage for small G-Buffers
Survey of Efficient Representations for Independent Unit Vectors
Octahedron normal vector encoding

지연 쉐이딩(Deferred Shading)

- **지연 렌더링(Deferred Rendering)**
  - 법선 벡터의 인코딩(Encoding Normal Vector)
    - 구면 좌표계(Spherical Coordinates)
      단위벡터의 길이를 알고 있으므로 2개의 각도만 저장
      일반적인 법선벡터들의 인코딩에 적합

$$\boldsymbol{f} = float2(atan2(y, x) * \frac{1}{\pi}, z)$$

$$angle = 2.0 * \boldsymbol{f} - 1.0 \qquad s\theta = sin(angle.x * \pi) \qquad c\theta = cos(angle.x * \pi)$$

$$s\varphi = sqrt(1.0 - angle.y * angle.y) \qquad c\varphi = angle.y$$

$$\boldsymbol{n} = (c\theta * s\varphi, s\theta * s\varphi, c\varphi)$$

```
#define PI 3.1415926536f

float4 Encode(float3 n)
{
   return(float4((float2(atan2(n.y, n.x) / PI, n.z) + 1.0) * 0.5, 0, 0));
}
```

```
float3 Decode(float2 enc)
{
   float2 ang = enc * 2.0 – 1.0;
   float2 scth;
   sincos(ang.x * PI, scth.x, scth.y);
   float2 scphi = float2(sqrt(1.0 - ang.y * ang.y), ang.y);
   return(float3(scth.y * scphi.x, scth.x * scphi.x, scphi.y));
}
```

지연 쉐이딩(Deferred Shading)

- **지연 렌더링(Deferred Rendering)**
  - 법선 벡터의 인코딩(Encoding Normal Vector)

- **Store X&Y, Reconstruct Z (Killzone 2)**

간단하게 인코딩/디코딩

```
float2 Encode(float3 n)
{
   return(float2(n.xy * 0.5 + 0.5));
}
```

```
float3 Decode(float2 enc)
{
   float2 dec = enc * 2 – 1;
   return(float3(dec, sqrt(1 - dot(dec, dec))));
}
```

- **Spheremap Transform (Cry Engine 3)**

구를 원으로 매핑

```
float2 Encode(float3 n)
{
   float2 enc = normalize(n.xy) * (sqrt(-n.z * 0.5 + 0.5));
   return(enc * 0.5 + 0.5);
}
```

```
float3 Decode(float2 enc)
{
   float4 nn = float4(enc, 0, 0) * float4(2.0, 2.0, 0, 0) + float4(-1.0, -1.0, -1.0, -1.0);
   float f = dot(nn.xyz, -nn.xyw);
   nn.xy *= sqrt(f);
   return(float3(nn.xy, f) * 2.0) + float3(0, 0, -1.0));
}
```

지연 쉐이딩(Deferred Shading)

- **지연 렌더링(Deferred Rendering)**
  - 법선 벡터의 인코딩(Encoding Normal Vector)

- **Lambert Azimuthal Equal-Area Projection**

```
float2 Encode(float3 n)
{
   return(n.xy / sqrt(8.0 * n.z + 8.0) + 0.5);
}
```

```
float3 Decode(float2 enc)
{
   float2 fenc = enc * 4.0 – 2.0;
   float f = dot(fenc, fenc);
   return(float3(fenc * sqrt(1 – (f / 4.0)), 1.0 – (f / 2.0)));
}
```

- **Octahedron-Normal Vectors**

```
float2 Encode(float3 n)
{
    n /= (abs(n.x) + abs(n.y) + abs(n.z));
    n.xy = (n.z >= 0.0) ? n.xy : OctWrap(n.xy);
    n.xy = n.xy * 0.5 + 0.5;
    return(n.xy);
}
```

```
float2 OctWrap(float2 v)
{
   return((1.0 - abs(v.yx)) * (v.xy >= 0.0) ? 1.0 : -1.0);
}
```

```
float3 Decode(float2 f)
{
    f = f * 2.0 - 1.0;
    float3 n = float3(f.x, f.y, 1.0 - abs(f.x) - abs(f.y));
    float t = saturate(-n.z);
    n.xy += (n.xy >= 0.0) ? -t : t;
    return(normalize(n));
}
```

지연 쉐이딩(Deferred Shading)

- **지연 렌더링(Deferred Rendering)**
  - 법선 벡터의 인코딩(Encoding Normal Vector)
    - **Crytek Spheremap Transform**

```
G.xy = normalize(normal.xy) * (sqrt(normal.z * 0.5f + 0.5f));
```

```
G.xy = normalize(normal.xy) * (sqrt(-normal.z * 0.5f + 0.5f));
```

```
G.xy = normalize(normal.xy) / sqrt(8.0f * normal.z + 8.0f) + 0.5f;
```

```
uint nPackedG = (f32tof16(G.y) << 16) | f32tof16(G.x);
```

```
float2 G = float2(f16tof32(nPackedG), f16tof32(nPackedG >> 16));
```

```
normal.z = length(G.xy) * 2.0f – 1.0f;
normal.xy = normalize(G.xy) * sqrt(1.0f - normal.z * normal.z);
```

$$(X, Y) = \left(\frac{x}{\sqrt{x^2+y^2}}, \frac{y}{\sqrt{x^2+y^2}}\right)\sqrt{z*0.5+0.5} = \left(\frac{x\sqrt{z*0.5+0.5}}{\sqrt{x^2+y^2}}, \frac{y\sqrt{z*0.5+0.5}}{\sqrt{x^2+y^2}}\right)$$

$$X^2+Y^2 = \left(\frac{x\sqrt{z*0.5+0.5}}{\sqrt{x^2+y^2}}\right)^2 + \left(\frac{y\sqrt{z*0.5+0.5}}{\sqrt{x^2+y^2}}\right)^2 = \frac{(x^2+y^2)}{(x^2+y^2)}(z*0.5+0.5) = z*0.5+0.5 = \frac{(z+1)}{2}$$

$$z = 2(X^2+Y^2)-1 = 2\frac{(z+1)}{2}-1 = z$$

$$(x, y) = \left(\frac{X}{\sqrt{X^2+Y^2}}, \frac{Y}{\sqrt{X^2+Y^2}}\right)\sqrt{1.0-z*z} = \frac{1}{\sqrt{X^2+Y^2}}\left(\frac{x\sqrt{z*0.5+0.5}}{\sqrt{x^2+y^2}}, \frac{y\sqrt{z*0.5+0.5}}{\sqrt{x^2+y^2}}\right)\sqrt{1.0-z*z}$$

$$= \frac{1}{\sqrt{\frac{(z+1)}{2}}}\sqrt{\frac{(z+1)}{2}}\left(\frac{x}{\sqrt{x^2+y^2}}, \frac{y}{\sqrt{x^2+y^2}}\right)\sqrt{1.0-z^2} == \frac{1}{\sqrt{\frac{(z+1)}{2}}}\sqrt{\frac{(z+1)}{2}}\left(\frac{x}{\sqrt{x^2+y^2}}, \frac{y}{\sqrt{x^2+y^2}}\right)\sqrt{x^2+y^2} = (x, y)$$

$$\text{length}(G.xy) = \sqrt{X^2+Y^2}$$

$$x^2+y^2+z^2 = 1$$
$$z^2 = 1-(x^2+y^2)$$
$$z = \pm\sqrt[2]{1-(x^2+y^2)}$$
$$1-z^2 = (x^2+y^2)$$

지연 쉐이딩(Deferred Shading)

- 지연 렌더링(Deferred Rendering)
  - 최적화된 GBuffer 생성 단계

```
VS_GB_OUTPUT VSOptimizedDeferredLighting(in VS_GB_INPUT input)
{
   VS_GB_OUTPUT output;

   matrix mtxWorldView = mul(gmtxWorld, gmtxView);
   output.position = mul(input.position, mtxWorldView);
   output.position = mul(output.position, gmtxProjection);

   output.normal = normalize(mul(input.normal, (float3x3)mtxWorldView));
   output.tangent = normalize(mul(input.tangent.xyz, (float3x3)mtxWorldView));
   output.bitangent = normalize(cross(output.normal, output.tangent));

   output.uv = input.uv;

   return(output);
}
```

```
struct VS_GB_INPUT
{
   float4 position : POSITION;
   float2 uv : TEXCOORD;
   float3 normal : NORMAL;
   float3 tangent : TANGENT;
};
```

```
struct VS_GB_OUTPUT
{
   float4 position : SV_Position;
   float2 uv : TEXCOORD;
   float3 normal : NORMAL;
   float3 tangent : TANGENT;
   float3 bitangent : BITANGENT;
};
```

지연 쉐이딩(Deferred Shading)

- **지연 렌더링(Deferred Rendering)**
  - 최적화된 GBuffer 생성 단계

```
PS_GB_OUTPUT PSOptimizedDeferredLighting(in VS_GB_OUTPUT input)
{
    PS_GB_OUTPUT output;
    float3 T = normalize(input.tangent);
    float3 B = normalize(input.bitangent);
    float3 N = normalize(input.normal);
    float3x3 TBN = float3x3(T, B, N);
    float3 normal = normalize(gtxtNormalMap.Sample(gssNormalMap, input.uv).rgb * 2.0f - 1.0f);
    normal = normalize(mul(normal, TBN));
    output.normal = normal.xy * (sqrt(-normal.z * 0.5f + 0.5f)); //Encode Azimuthal
    float3 diffuseAlbedo = gtxtDiffuseMap.Sample(gssDiffuseMap, input.uv).rgb;
    output.diffuseAlbedo = float4(diffuseAlbedo, 1.0f);
    output.specularAlbedo = gcMaterialSpecular; //power : (0~255) → (0 ~ 1.0)

    return(output);
}
```

```
Texture2D gtxtDiffuseMap : register(t0);
SamplerState gssDiffuseMap : register(s0);

Texture2D gtxtNormalMap : register(t1);
SamplerState gssNormalMap : register(s1);
```

```
normal.xy / sqrt(8.0f * normal.z + 8.0f) + 0.5f;
```

```
cbuffer cbMaterial : register(b1)
{
    float4 gcMaterialDiffuse;
    float4 gcMaterialAmbient;
    float4 gcMaterialSpecular;
    float4 gcMaterialEmissive;
};
```

```
struct PS_GB_OUTPUT
{
    float2 normal : SV_Target0;
    float4 diffuseAlbedo : SV_Target1;
    float4 specularAlbedo : SV_Target2;
};
```

```
float4 Lighting(float3 vPosition, float3 vNormal);
```

지연 쉐이딩(Deferred Shading)

- **지연 렌더링(Deferred Rendering)**
  - 최적화된 GBuffer를 사용한 조명 계산 단계

```
VS_OUTPUT VS(in VS_INPUT input)
{
   VS_OUTPUT output;
   output.position = input.position; //투영 좌표계
   float3 positionCS = mul(input.position, gmtxInvProjection).xyz;
   output.positionCS = float3(positionCS.xy / positionCS.z, 1.0f);
   return(output);
}
```

```
struct VS_INPUT
{
   float4 position : POSITION;
};
```

```
struct VS_OUTPUT
{
   float4 position : SV_Position;
   float3 positionCS : POSITION;
};
```

```
Texture2D gtxtNormal : register(t0);
Texture2D gtxtDiffuseAlbedo : register(t1);
Texture2D gtxtSpecularAlbedo : register(t2);
Texture2D gtxtDepth : register(t3);
```

```
cbuffer cbCamera : register(b1)
{
   ...
   matrix gmtxInvProjection;
};
```

```
float4 PS(VS_OUTPUT input, uint coverage : SV_Coverage) : SV_Target
{
   int3 uvm = int3(input.position.xy, 0); //(u, v, mipmap level)
   float3 position = PositionFromDepth(gtxtDepth.Load(uvm).x, input.positionCS);
   float3 normal = SphereMapDecode(gtxtNormal.Load(uvm).xy);
   float3 diffuseAlbedo = gtxtDiffuseAlbedo.Load(uvm).xyz;
   float4 specular = gtxtSpecularAlbedo.Load(uvm);
   float4 cIllumination = Lighting(position, normal, diffuseAlbedo, specular.xyz, specular.w*255.0f);
   return(cIllumination);
}
```

지연 쉐이딩(Deferred Shading)

- **지연 렌더링(Deferred Rendering)**
  - 최적화된 GBuffer를 사용한 조명 계산 단계

```
float3 PositionFromDepth(float depth, float3 positionCS)
{
   float fz = gmtxProjection[3][2] / (depth - gmtxProjection[2][2]);
   return(positionCS * fz);
}
```

$$(x, y, z, 1) * PM = (x * xScale, y * yScale, \frac{(z - z_n) * z_f}{(z_f - z_n)}, z)$$

$$\begin{pmatrix} xScale & 0 & 0 & 0 \\ 0 & yScale & 0 & 0 \\ 0 & 0 & \frac{z_f}{(z_f - z_n)} & 1 \\ 0 & 0 & \frac{-z_n * z_f}{(z_f - z_n)} & 0 \end{pmatrix}$$

$$d = \frac{(z - z_n) * z_f}{(z_f - z_n)} * \frac{1}{z}$$

$$d * z = \frac{(z - z_n) * z_f}{(z_f - z_n)}$$

$$d * z * (z_f - z_n) = (z - z_n) * z_f$$

$$d * z * (z_f - z_n) - z * z_f = -z_n z_f$$

$$z * \{d * (z_f - z_n) - z_f\} = -z_n z_f$$

$$z = \frac{-z_n z_f}{d * (z_f - z_n) - z_f} = \frac{\frac{-z_n * z_f}{(z_f - z_n)}}{d - \frac{z_f}{z_f - z_n}}$$

```
float3 PositionFromDepth(float2 uv)
{
   float z = gtxtDepth.Sample(gssDefault, uv);
   float x = uv.x * 2.0f – 1.0f;
   float y = uv.y * 2.0f – 1.0f;
   float4 posPS = float4(x, y, z, 1.0f);
   float4 posCS = mul(posPS, gmtxInvProjection);
   return(posCS.xyz / posCS.w);
}
```

지연 쉐이딩(Deferred Shading)

- **지연 렌더링(Deferred Rendering)**
  - 최적화된 GBuffer를 사용한 조명 계산 단계

```
float3 SphereMapDecode(float2 enc)
{
   float4 nn = float4(enc, 1.0f, -1.0f);
   float l = dot(nn.xyz, -nn.xyw);
   nn.z = l;
   nn.xy *= sqrt(l);
   return(nn.xyz * 2.0f + float3(0.0f, 0.0f, -1.0f));
}
```

```
output.normal = normal.xy * (sqrt(-normal.z * 0.5f + 0.5f));
```

```
float2 Encode(float3 n)
{
   float2 e = normalize(n.xy) * sqrt(-n.z * 0.5f + 0.5f);
   return(e * 0.5f + 0.5f);
}
```

```
float2 Encode(float3 n)
{
   return(n.xy / sqrt(8.0f * n.z + 8.0f) + 0.5f);
}
```

```
float3 Decode(float4 e)
{
   float4 nn = e * float4(2, 2, 0, 0) + float4(-1, -1, 1, -1);
   nn.z = dot(nn.xyz, -nn.xyw);
   nn.xy *= sqrt(nn.z);
   return(nn.xyz * 2 + float3(0, 0, -1));
}
```

```
float3 Decode(float2 e)
{
   float2 fe = (e * 4.0f) – 2.0f;
   float f = dot(fe, fe);
   float3 n;
   n.xy = fe * sqrt(1.0f – (f / 4.0f));
   n.z = 1.0f – (f / 2.0f);
   return(n);
}
```