Welcome!
Today's Agenda:

- Recap
- Flow Control
- AVX, Larrabee, GPGPU
Recap

**SSE: Four Floats**

```c
union {
  __m128 a4;
  float a[4];
};

a4 = _mm_sub_ps( val1, val2 );
__m128 b4 = _mm_sqrt_ps( a4 );
__m128 m4 = _mm_max_ps( a4, b4 );
```
Recap

SSE: Four Floats

Actually...

_mm_mul_epi32 does exist. However, it produces 2 64-bit numbers, not 4 32-bit numbers.

Actually...

Intel’s ‘short vector math lib’ (SVML) has the _mm_div_epi32 instruction. However, as they note:
1. It’s a ‘sequence of instructions’;
2. “Many routines in the SVML are ‘more optimized’ for Intel CPUs.” (read: are deliberately crippled for AMD)
Recap

SSE: Four Floats

AOS

SOA
Recap

SSE: Four Floats

```c
struct Particle {
    float x, y, z;
    int mass;
};
Particle particle[512];
```

AOS

<table>
<thead>
<tr>
<th>union</th>
</tr>
</thead>
<tbody>
<tr>
<td>x[512]; _m128 x4[128];</td>
</tr>
</tbody>
</table>

SOA

<table>
<thead>
<tr>
<th>union</th>
</tr>
</thead>
<tbody>
<tr>
<td>y[512]; _m128 y4[128];</td>
</tr>
<tr>
<td>z[512]; _m128 z4[128];</td>
</tr>
<tr>
<td>mass[512]; _m128i mass4[128];</td>
</tr>
</tbody>
</table>

structure of arrays

- AOS: Access to fields as an array of structures
- SOA: Access to fields as a structure of arrays
Recap

Vectorization:

"The Art of rewriting your algorithm so that it operates in four separate streams, rather than one."

Note: compilers will apply SSE2/3/4 for you as well:

```cpp
vector3f A = { 0, 1, 2 };
vector3f B = { 5, 5, 5 };
A += B;
```

This will marginally speed up one line of your code; manual vectorization is much more fundamental.
Recap

```cpp
void Game::BuildBackdrop()
{
    Pixel* dst = m_Surface->GetBuffer();
    float fy = 0;
    for (unsigned int y = 0; y < SCRHEIGHT; y++, fy++)
    {
        float fx = 0;
        for (unsigned int x = 0; x < SCRWIDTH; x++, fx++)
        {
            float g = 0;
            for (unsigned int i = 0; i < HOLES; i++)
            {
                float dx = m_Hole[i] -> x - fx, dy = m_Hole[i] -> y - fy;
                float squareddist = (dx * dx + dy * dy);
                g += (250.0f * m_Hole[i] -> g) / squareddist;
            }
            if (g > 1) g = 0;
            *dst++ = (int)(g * 255.0f);
        }
        dst += m_Surface -> GetPitch() - m_Surface -> GetWidth();
    }
}
```
Recap

void Game::BuildBackdrop()
{
    Pixel* dst = m_Surface->GetBuffer();
    float fy = 0;
    for ( unsigned int y = 0; y < SCRHEIGHT; y++, fy++ )
    {
        float fx = 0;
        for ( unsigned int x = 0; x < SCRWIDTH; x++, fx++ )
        {
            float g = 0;
            for ( unsigned int i = 0; i < HOLES / 4; i++ )
            {
                float dx = m_Hole[i]->x - fx, dy = m_Hole[i]->y - fy;
                float squaredist = ( dx * dx + dy * dy );
                g += (250.0f * m_Hole[i]->g) / squaredist;
            }
            if (g > 1) g = 0;
            *dst++ = (int)(g * 255.0f);
        }
    dst += m_Surface->GetPitch() - m_Surface->GetWidth();
}
Recap

```cpp
void Game::BuildBackdrop()
{
    Pixel* dst = m_Surface->GetBuffer();
    float fy = 0;
    for ( unsigned int y = 0; y < SCRHEIGHT; y++, fy++ )
    {
        float fx = 0;
        for ( unsigned int x = 0; x < SCRWIDTH; x++, fx++ )
        {
            float g = 0; __m128 g4 = _mm_setzero_ps();
            for ( unsigned int i = 0; i < HOLES / 4; i++ )
            {
                __m128 dx4 = _mm_sub_ps( bhx4[i], fx4 );
                __m128 dy4 = _mm_sub_ps( bhy4[i], fy4 );
                __m128 sq4 = _mm_add_ps( _mm_mul_ps( dx4, dx4 ), _mm_mul_ps( dy4, dy4 ) );
                __m128 mulresult4 = _mm_mul_ps( _mm_set1_ps( 250.0f ), bhg4[i] );
                g4 = _mm_add_ps( g4, _mm_div_ps( mulresult4, sq4 ) );
            }
            if (g > 1) g = 0;
            *dst++ = (int)(g * 255.0f);
        }
        dst += m_Surface->GetPitch() - m_Surface->GetWidth();
    }
}
```
Recap

```cpp
void Game::BuildBackdrop()
{
    Pixel* dst = m_Surface->GetBuffer();
    float fy = 0;
    for ( unsigned int y = 0; y < SCRHEIGHT; y++, fy++ )
    {
        float fx = 0;
        for ( unsigned int x = 0; x < SCRWIDTH; x++, fx++ )
        {
            float g = 0; __m128 g4 = _mm_setzero_ps();
            for ( unsigned int i = 0; i < HOLES / 4; i++ )
            {
                __m128 dx4 = _mm_sub_ps( bhx4[i], fx4 );
                __m128 dy4 = _mm_sub_ps( bhy4[i], fy4 );
                __m128 sq4 = _mm_add_ps( _mm_mul_ps( dx4, dx4 ), _mm_mul_ps( dy4, dy4 ) );
                __m128 mulresult4 = _mm_mul_ps( _mm_set1_ps( 250.0f ), bhg4[i] );
                g4 = _mm_add_ps( g4, _mm_div_ps( mulresult4, sq4 ) );
            }
            g += g[0] + g[1] + g[2] + g[3];
            if (g > 1) g = 0;
            *dst++ = (int)(g * 255.0f);
        }
        dst += m_Surface->GetPitch() - m_Surface->GetWidth();
    }
}
```
Today’s Agenda:

- Recap
- Flow Control
- AVX, Larrabee, GPGPU
for ( uint i = 0; i < PARTICLES; i++ ) if (m_Particle[i]->alive)
{
    m_Particle[i]->x += m_Particle[i]->vx;
    m_Particle[i]->y += m_Particle[i]->vy;
    if (!((m_Particle[i]->x < (2 * SCRWIDTH)) && (m_Particle[i]->x > -SCRWIDTH) &&
         (m_Particle[i]->y < (2 * SCRHEIGHT)) && (m_Particle[i]->y > -SCRHEIGHT)))
    {
        SpawnParticle( i );
        continue;
    }
}
for ( uint h = 0; h < HOLES; h++ )
{
    float dx = m_Hole[h]->x - m_Particle[i]->x;
    float dy = m_Hole[h]->y - m_Particle[i]->y;
    float sd = dx * dx + dy * dy;
    float dist = 1.0f / sqrtf( sd );
    dx *= dist, dy *= dist;
    float g = (250.0f * m_Hole[h]->g * m_Particle[i]->m) / sd;
    if (g >= 1) { SpawnParticle( i ); break; }
    m_Particle[i]->vx += 0.5f * g * dx;
    m_Particle[i]->vy += 0.5f * g * dy;
}
int x = (int)m_Particle[i]->x, y = (int)m_Particle[i]->y;
if (((x >= 0) && (x < SCRWIDTH) && (y >= 0) && (y < SCRHEIGHT))
    m_Surface->GetBuffer()[x + y * m_Surface->GetPitch()] = m_Particle[i]->c;
Flow Control

Broken Streams

```cpp
bool respawn = false;
for ( uint h = 0; h < HOLES; h++ )
{
    float dx = m_Hole[h] - x - m_Particle[i] - x;
    float dy = m_Hole[h] - y - m_Particle[i] - y;
    float sd = dx * dx + dy * dy;
    float dist = 1.0f / sqrtf( sd );
    dx *= dist,
    dy *= dist;
    float g = (250.0f * m_Hole[h] - g * m_Particle[i] - m) / sd;
    if (g >= 1) {
        SpawnParticle( i );
        break; }
    respawn = true;
    m_Particle[i] - vx += 0.5f * g * dx;
    m_Particle[i] - vy += 0.5f * g * dy;
}
if (respawn) SpawnParticle( i );
```

**Masking** allows us to run code unconditionally, without consequences.
Flow Control

Broken Streams

```c
char a[4] = { 6, 7, 8, 9 };  
char c[4];  
*(uint*)c = *(uint*)a + *(uint*)b;
```

Masked addition:

```c
char a[4] = { 6, 7, 8, 9 };  
char mask[4] = { 255, 0, 255, 255 };  
char c[4];  
*(uint*)c = *(uint*)a + (*(uint*)mask & *(uint*)b);
```

```c
char a[4] = { 6, 7, 8, 9 };  
uint mask4 = 0xFFFF00FF;  
char c[4];  
*(uint*)c = *(uint*)a + (*(uint*)b & mask4);
```
Flow Control

Broken Streams

```
_mm_cmpeq_ps ==
_mm_cmplt_ps <
_mm_cmpgt_ps >
_mm_cmple_ps <=
_mm_cmpge_ps >=
_mm_cmpne_ps !=
```
Flow Control

Broken Streams – Flow Divergence

Like other instructions, comparisons between vectors yield a vector of booleans.

\[
\text{__m128 mask = _mm_cmpeq_ps( v1, v2 );}
\]

The mask contains a bitfield: 32 x ‘1’ for each TRUE, 32 x ‘0’ for each FALSE.

The mask can be converted to a 4-bit integer using _mm_movemask_ps:

\[
\text{int result = _mm_movemask_ps( mask );}
\]

Now we can use regular conditionals:

```c
if (result == 0) { /* false for all streams */ }
if (result == 15) { /* true for all streams */ }
if (result < 15) { /* not true for all streams */ }
if (result > 0) { /* not false for all streams */ }
```
Flow Control

Streams – Masking

More powerful than ‘any’, ‘all’ or ‘none’ via movemask is masking.

```c
if (x >= 1 && x < PI) x = 0;
```

Translated to SSE:

```c
__m128 mask1 = _mm_cmpge_ps( x4, ONE4 );
__m128 mask2 = _mm_cmplt_ps( x4, PI4 );
__m128 fullmask = _mm_and_ps( mask1, mask2 );
x4 = _mm_andnot_ps( fullmask, x4 );
```

(_mm_andnot_ps inverts the first argument.)
Flow Control

Streams – Masking

```c
float a[4] = { 1, -5, 3.14f, 0 };  
if (a[0] < 0) a[0] = 999;  
if (a[1] < 0) a[1] = 999;  
```

in SSE:

```c
__m128 a4 = _mm_set_ps( 1, -5, 3.14f, 0 );  
__m128 nine4 = _mm_set_ps1( 999 );  
__m128 zero4 = _mm_setzero_ps();  
__m128 mask = _mm_cmplt_ps( a4, zero4 );
```
Flow Control

Streams – Masking

```c
__m128 a4 = _mm_set_ps( 1, -5, 3.14f, 0 );
__m128 nine4 = _mm_set_ps1( 999 );
__m128 zero4 = _mm_setzero_ps();
__m128 mask = _mm_cmplt_ps( a4, zero4 );
__m128 part1 = _mm_and_ps( mask, nine4 );
// yields: { 0, 999, 0, 0 }
__m128 part2 = _mm_andnot_ps( mask, a4 );
// yields: { 1, 0, 3.14, 0 }
a4 = _mm_or_ps( part1, part2 );
// yields: { 1, 999, 3.14, 0 }
```

or simply:
```
a4 = _mm_blendv_ps( a4, nine4, mask );
```
Streams – Masking

Take-away:

- In vectorized code, stream divergence is not possible.
- We solve this by keeping all lanes alive.
- ‘Inactive lanes’ use masking to nullify actions.

This approach is used in SSE/AVX, as well as on GPUs.
Flow Control

Streams – Masking
Flow Control

```c
static union { float px[PARTICLES]; __m128 px4[PARTICLES / 4]; };  
static union { float py[PARTICLES]; __m128 py4[PARTICLES / 4]; };  
static union { float pvx[PARTICLES]; __m128 pvx4[PARTICLES / 4]; };  
static union { float pvy[PARTICLES]; __m128 pvy4[PARTICLES / 4]; };  
static union { float pm[PARTICLES]; __m128 pm4[PARTICLES / 4]; };  
static union { uint pc[PARTICLES]; __m128i pc4[PARTICLES / 4]; };  

declare SoA for (int i = 0; i < PARTICLES; i++) {
    px[i] = m_Particle[i]->x;  
    py[i] = m_Particle[i]->y;  
    pvx[i] = m_Particle[i]->vx;  
    pvy[i] = m_Particle[i]->vy;  
    pa[i] = m_Particle[i]->alive;  
    pc[i] = m_Particle[i]->c;  
    pm[i] = m_Particle[i]->m;
}
```
Today's Agenda:

- Recap
- Flow Control
- AVX, Larrabee, GPGPU
INFOMOV – Lecture 5 – “SIMD (2)”

Beyond SSE

AVX*

`__m256`  
`_mm256_add_ps`  
`_mm256_sqrt_ps`  
...etc.

Beyond SSE

**AVX2**

Extension to AVX: adds broader __mm256i support, and FMA:

\[
\text{r8} = \text{c8} + (a8 \times b8)
\]

\[
\text{__m256 r8 = _mm256_fmadd_ps( a8, b8, c8 );}
\]

Emulate on AVX:

\[
\text{r8} = \_mm256_add_ps( \_mm256_mul_ps( a8, b8 ), c8 );
\]

Benefits of *fused multiply and add*:

- Even more work done for a single 'fetch-decode'
- Better precision: rounding doesn’t happen between multiply and add

AVX512*

16-wide SIMD, with 32 512-bit registers (__m512, __m512i).

Most AVX512 instructions can be masked:

```c
__m512 __mm512_maskz_add_ps( __mmask16 k, __m512 a, __m512 b )
```

"Add packed single-precision (32-bit) floating-point elements in a and b, and store the results in dst using zeromask k (elements are zeroed out when the corresponding mask bit is not set)."

For a full list of instructions, see: [https://software.intel.com/sites/landingpage/IntrinsicsGuide](https://software.intel.com/sites/landingpage/IntrinsicsGuide)

GPU Model

```c
__kernel void main( write_only image2d_t outimg )
{
    int column = get_global_id( 0 );
    int line = get_global_id( 1 );
    float red = column / 800.;
    float green = line / 480.;
    float4 color = { red, green, 0, 1 };
    write_imagef( outimg, (int2)(column, line), color );
}
```
GPU Model

```c
__kernel void main( write_only image2d_t outimg )
{
    int column = get_global_id( 0 );
    int line = get_global_id( 1 );
    float red, green, blue;
    if (column & 1)
    {
        red = column / 800.0;
        green = line / 480.0;
        color = { red, green, 0, 1 };
    }
    else
    {
        red = green = blue = 0;
    }
    write_imagef( outimg, (int2)(column, line), color );
}
```
Today's Agenda:

- Recap
- Flow Control
- AVX, Larrabee, GPGPU
END of “SIMD (2)”

next lecture: “GPGPU (3)”