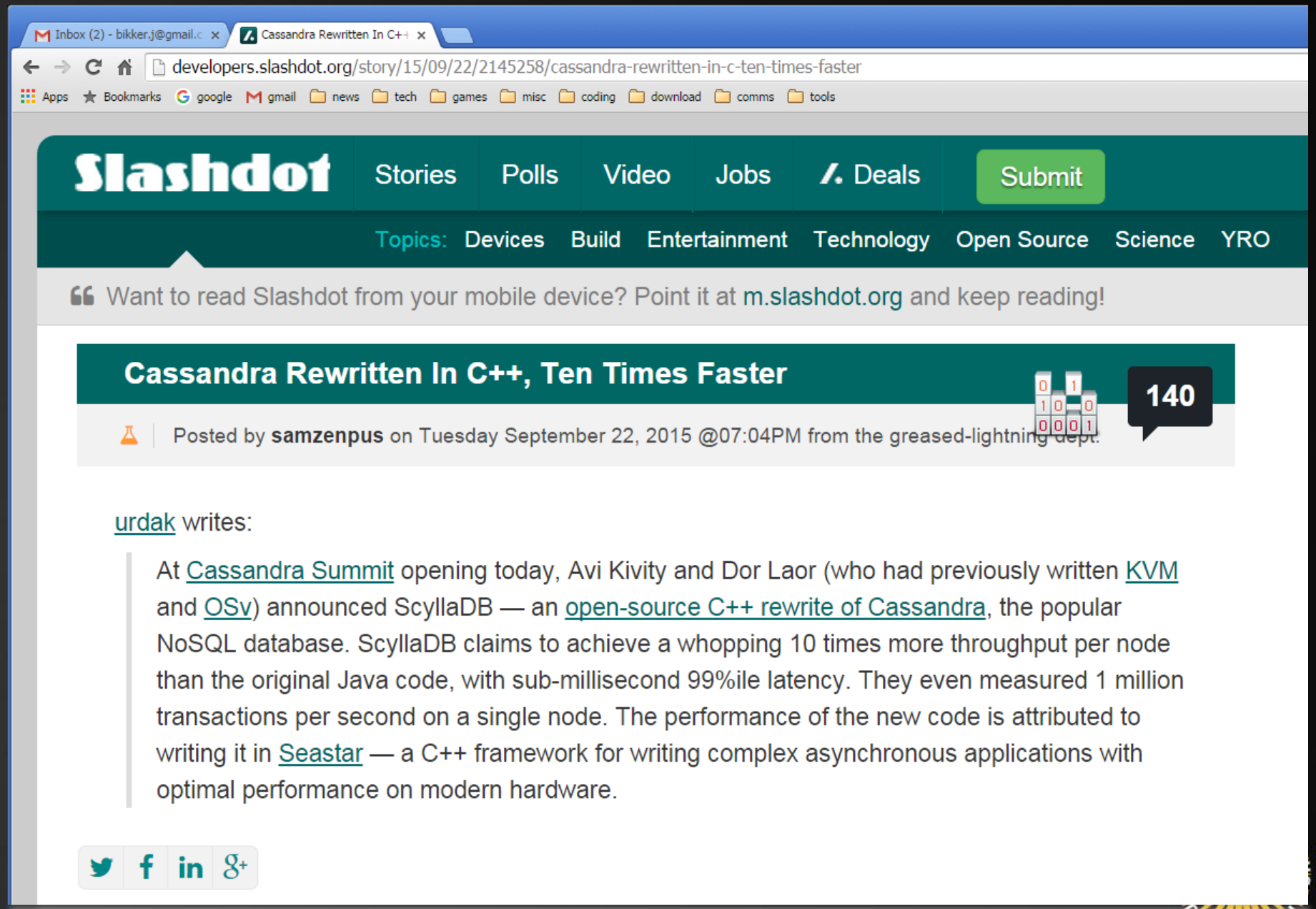
/INFOMOV/

Optimization & Vectorization

J. Bikker - Sep-Nov 2016 - Lecture 6: “SIMD (1)”

Welcome!

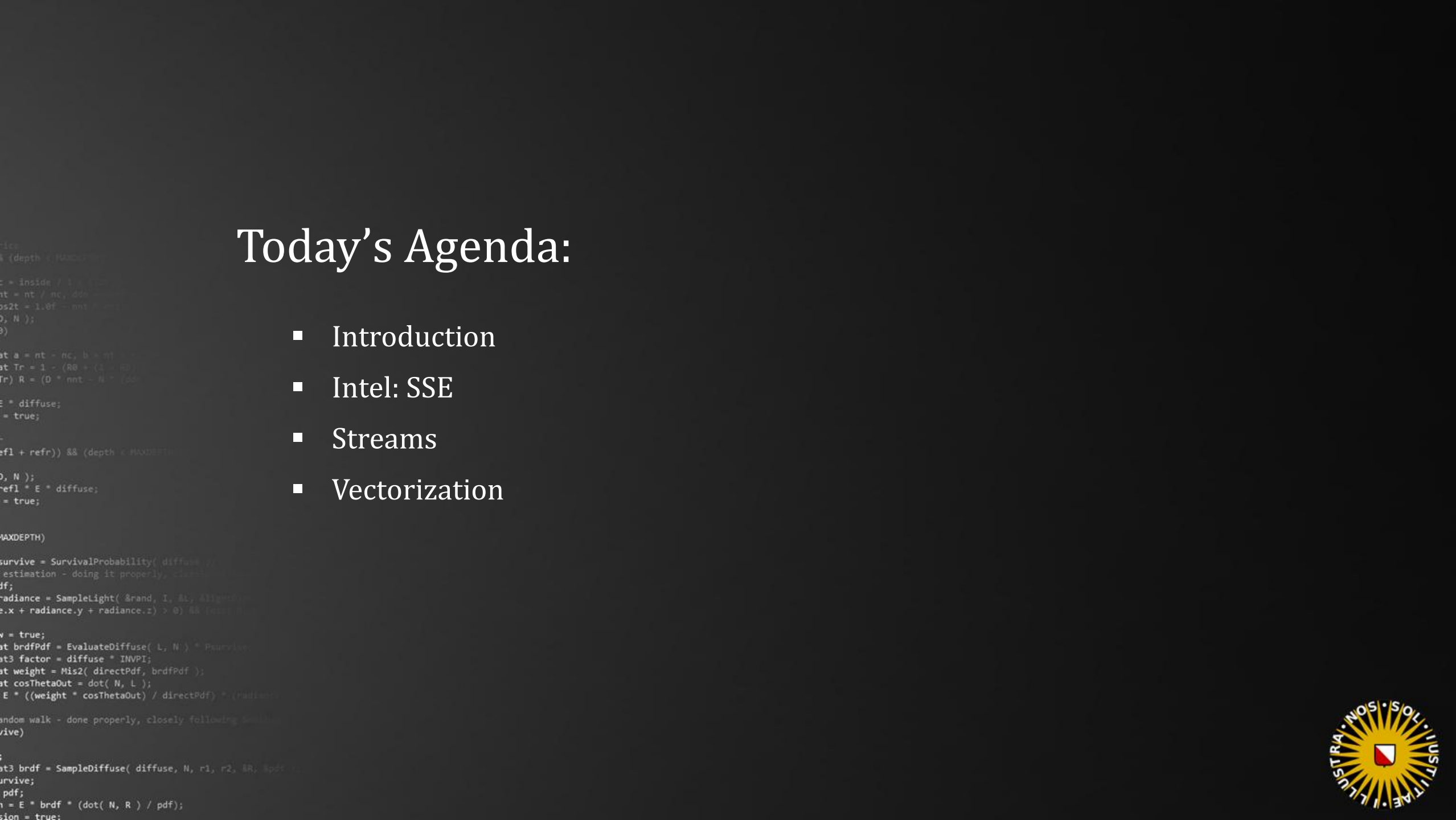
Meanwhile, on \.



Meanwhile, on Tweakers

Today's Agenda:

- Introduction
- Intel: SSE
- Streams
- Vectorization



Introduction

S.I.M.D.

Single Instruction Multiple Data:
Applying the same instruction to several input elements.

In other words: if we are going to apply the same sequence of instructions to a large input set, this allows us to do this in parallel (and thus: faster).

SIMD is also known as *instruction level parallelism*.

Examples:

```
union { uint a4; unsigned char a[4]; };
do
{
   GetFourRandomValues( a );
}
while (a4 != 0);
```

```
unsigned char a[4] = { 1, 2, 3, 4 };
unsigned char b[4] = { 5, 5, 5, 5 };
unsigned char c[4];
*(uint*)c = *(uint*)a + *(uint*)b;
// c is now { 6, 7, 8, 9 }.
```

Introduction

uint = unsigned char[4]

Pinging google.com yields: 74.125.136.101
Each value is an unsigned 8-bit value (0..255).
Combing them in one 32-bit integer:

101 +
256 * 136 +
256 * 256 * 125 +
256 * 256 * 256 * 74 = 1249740901.

Browse to: http://1249740901 (works!)

Evil use of this:

We can specify a user name when visiting a website, but any username will be accepted by google. Like this:

http://infomov@google.com

Or:

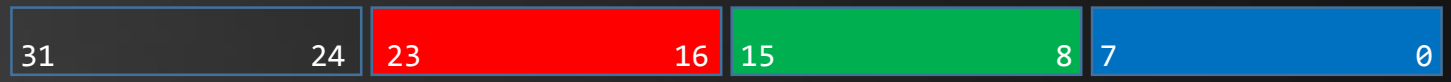
http://www.ing.nl@1249740901

Replace the IP address used here by your own site which contains a copy of the ing.nl site to obtain passwords, and send the link to a ‘friend’.

Introduction

Example: color scaling

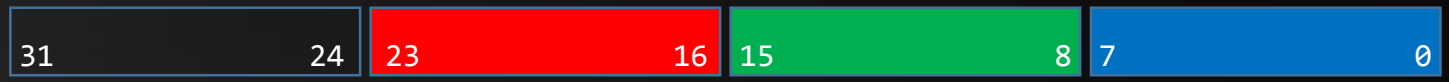
Assume we represent colors as 32-bit ARGB values using unsigned ints:



To scale this color by a specified percentage, we use the following code:

```
uint ScaleColor( uint c, float x ) // x = 0..1
{
    uint red = (c >> 16) & 255;
    uint green = (c >> 8) & 255;
    uint blue = c & 255;
    red = red * x, green = green * x, blue = blue * x;
    return (red << 16) + (green << 8) + blue;
}
```

Introduction



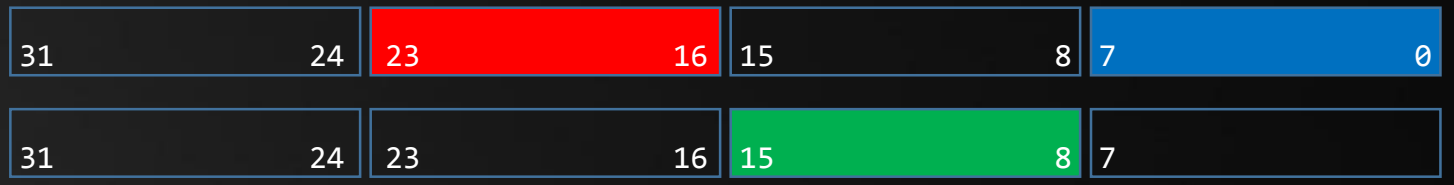
Example: color scaling

```
uint ScaleColor( uint c, float x ) // x = 0..1
{
    uint red = (c >> 16) & 255, green = (c >> 8) & 255, blue = c & 255;
    red = red * x, green = green * x, blue = blue * x;
    return (red << 16) + (green << 8) + blue;
}
```

Improved:

```
uint ScaleColor( uint c, uint x ) // x = 0..255
{
    uint red = (c >> 16) & 255, green = (c >> 8) & 255, blue = c & 255;
    red = (red * x) >> 8;
    green = (green * x) >> 8;
    blue = (blue * x) >> 8;
    return (red << 16) + (green << 8) + blue;
}
```

Introduction



Example: color scaling

```
uint ScaleColor( uint c, uint x ) // x = 0..255
{
    uint red = (c >> 16) & 255, green = (c >> 8) & 255, blue = c & 255;
    red = (red * x) >> 8, green = (green * x) >> 8, blue = (blue * x) >> 8;
    return (red << 16) + (green << 8) + blue;
}
```

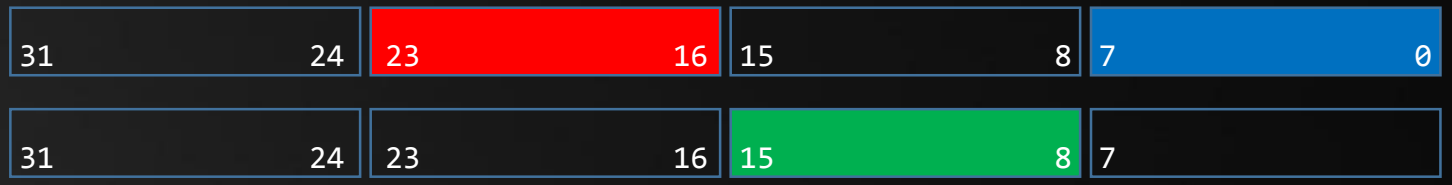
7 shifts, 3 ands, 3 muls, 2 adds

Improved:

```
uint ScaleColor( const uint c, const uint x ) // x = 0..255
{
    uint redblue = c & 0x00FF00FF;
    uint green   = c & 0x0000FF00;
    redblue = ((redblue * x) >> 8) & 0x00FF00FF;
    green = ((green * x) >> 8) & 0x0000FF00;
    return redblue + green;
}
```

2 shifts, 4 ands, 2 muls, 1 add

Introduction



Example: color scaling

```
uint ScaleColor( uint c, uint x ) // x = 0..255
{
    uint red = (c >> 16) & 255, green = (c >> 8) & 255, blue = c & 255;
    red = (red * x) >> 8, green = (green * x) >> 8, blue = (blue * x) >> 8;
    return (red << 16) + (green << 8) + blue;
}
```

7 shifts, 3 ands, 3 muls, 2 adds (15 ops)

Further improved:

```
uint ScaleColor( const uint c, const uint x ) // x = 0..255
{
    uint redblue = c & 0x00FF00FF;
    uint green   = c & 0x0000FF00;
    redblue = (redblue * x) & 0xFF00FF00;
    green = (green * x) & 0x00FF0000;
    return (redblue + green) >> 8;
}
```

1 shift, 4 ands, 2 muls, 1 add (8 ops)

Introduction

Other Examples

Rapid string comparison:

```
char a[] = “optimization skills rule”;
char b[] = “optimization is so nice!”;
bool equal = true;
int l = strlen( a );
for ( int i = 0; i < l; i++ )
{
  if (a[i] != b[i])
  {
    equal = false;
    break;
  }
}
```

```
char a[] = “optimization skills rule”;
char b[] = “optimization is so nice!”;
bool equal = true;
int q = strlen( a ) / 4;
for ( int i = 0; i < q; i++ )
{
  if (((int*)a)[i] != ((int*)b)[i])
  {
    equal = false;
    break;
  }
}
```

Likewise, we can copy byte arrays faster.

Introduction

SIMD using 32-bit values - Limitations

Mapping four chars to an int value has a number of limitations:

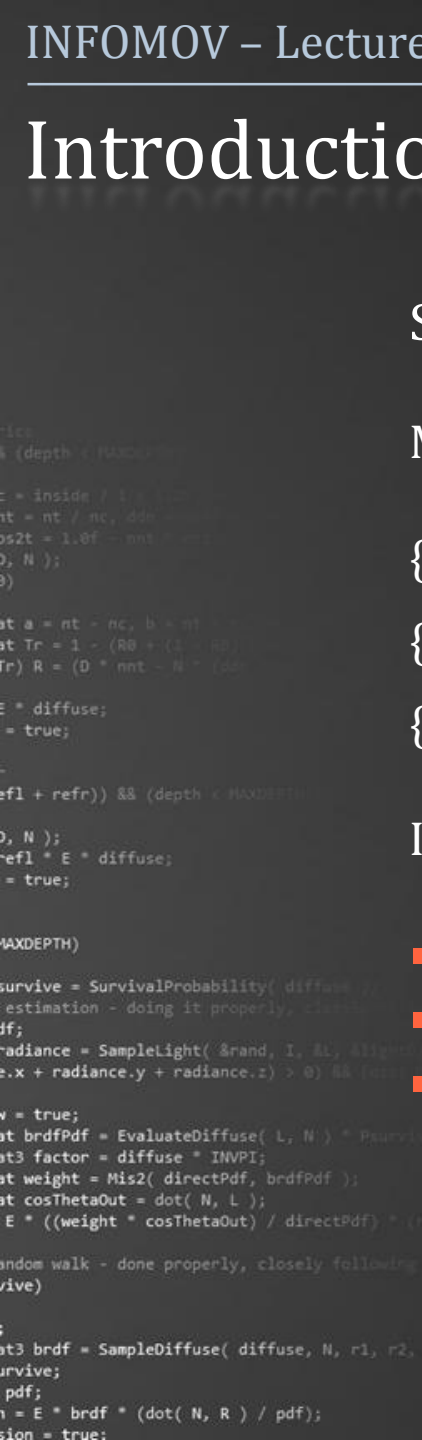
{ 100, 100, 100, 100 } + { 1, 1, 1, 200 } = { 101, 101, 102, 44 }

{ 100, 100, 100, 100 } * { 2, 2, 2, 2 } = { … }

{ 100, 100, 100, 200 } * 2 = { 200, 200, 201, 144 }

In general:

- Streams are not separated (prone to overflow into next stream);
- Limited to small unsigned integer values;
- Hard to do multiplication / division.



Introduction

SIMD using 32-bit values - Limitations

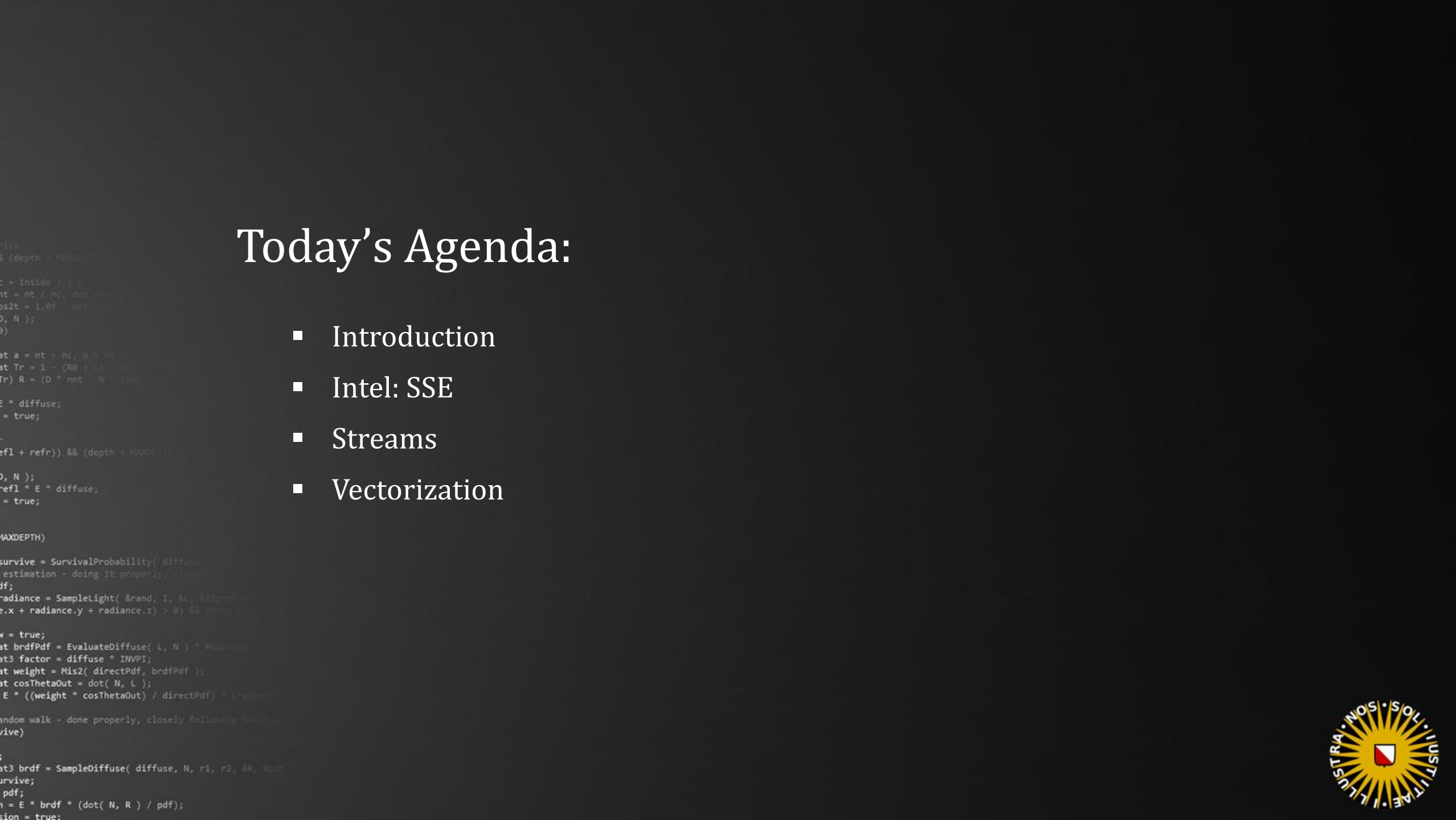
Ideally, we would like to see:

- Isolated streams
- Support for more data types (char, short, uint, int, float, double)
- An easy to use approach

Meet SSE!

Today's Agenda:

- Introduction
- Intel: SSE
- Streams
- Vectorization



SSE

A Brief History of SIMD

Early use of SIMD was in vector supercomputers such as the CDC Star-100 and TI ASC (image).

Intel’s MMX extension to the x86 instruction set (1996) was the first use of SIMD in commodity hardware, followed by Motorola’s AltiVec (1998), and Intel’s SSE (P3, 1999).

SSE:

- 70 assembler instructions
- Operates on 128-bit registers
- Operates on vectors of 4 floats.

SSE

SIMD Basics

C++ supports a 128-bit vector data type: __m128
Henceforth, we will pronounce to this as ‘quadfloat’. ☺

__m128 literally is a small array of floats:

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

Alternatively, you can use the integer variety __m128i:

```
union { __m128i a4; int a[4]; };
```

SSE

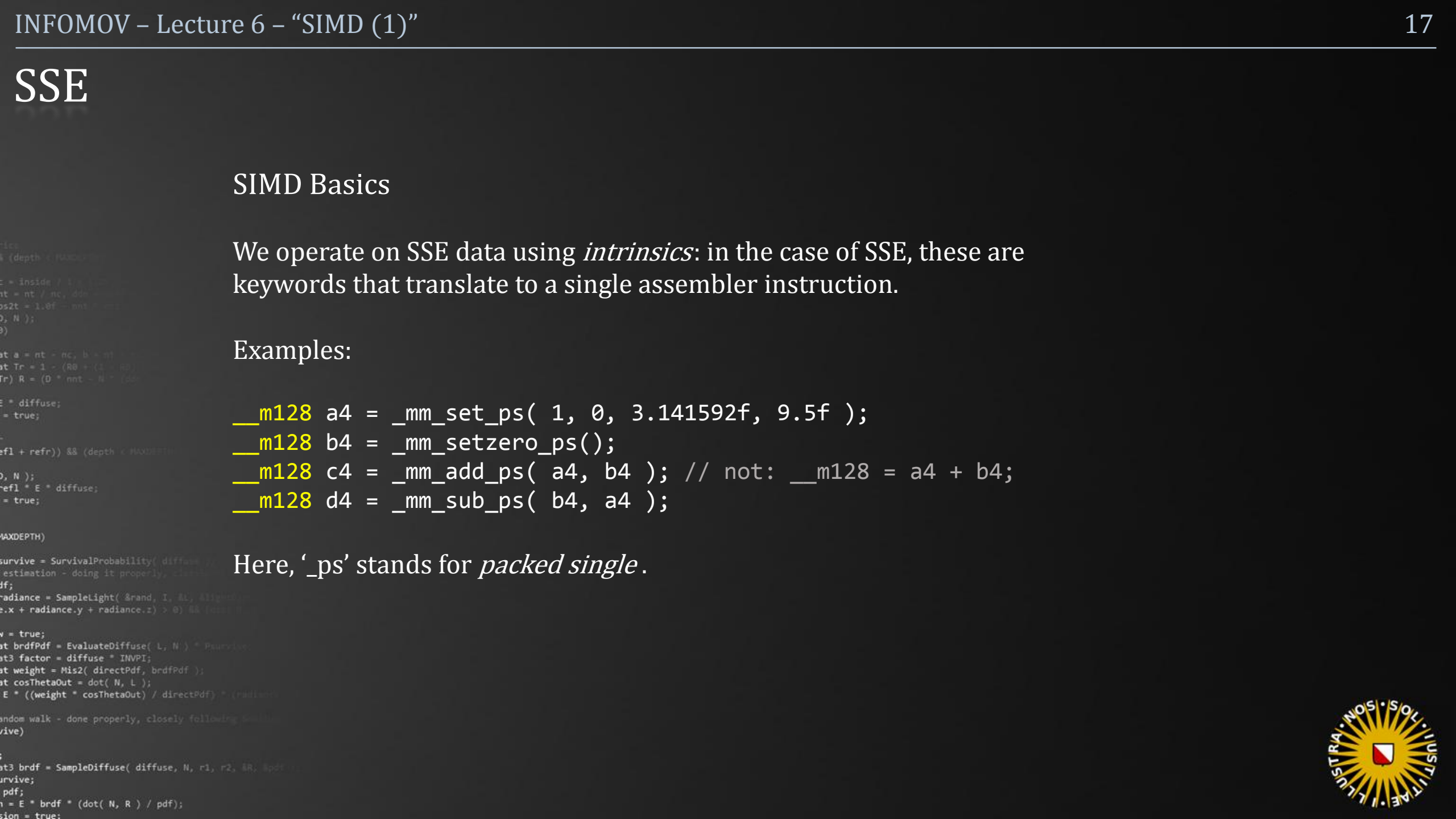
SIMD Basics

We operate on SSE data using *intrinsics*: in the case of SSE, these are keywords that translate to a single assembler instruction.

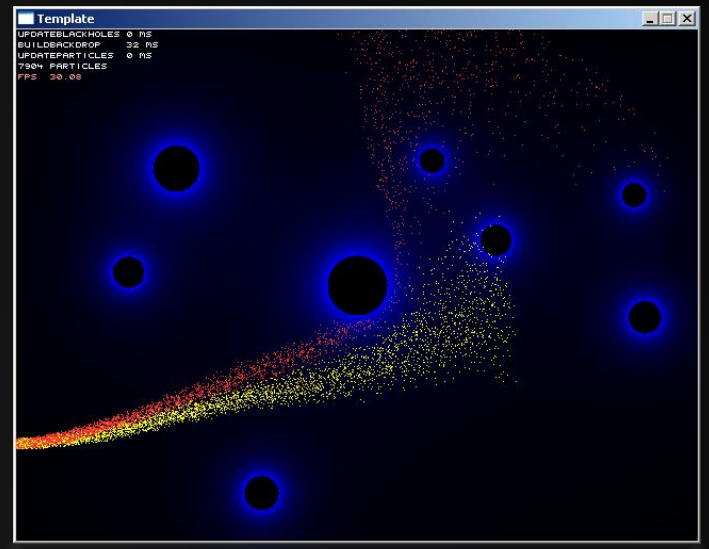
Examples:

```
__m128 a4 = _mm_set_ps( 1, 0, 3.141592f, 9.5f );
__m128 b4 = _mm_setzero_ps();
__m128 c4 = _mm_add_ps( a4, b4 ); // not: __m128 = a4 + b4;
__m128 d4 = _mm_sub_ps( b4, a4 );
```

Here, ‘_ps’ stands for *packed single*.



SSE



SIMD Basics

Other instructions:

```
__m128 c4 = _mm_div_ps( a4, b4 ); // component-wise division
__m128 d4 = _mm_sqrt_ps( a4 );    // four square roots
__m128 d4 = _mm_rcp_ps( a4 );     // four reciprocals
__m128 d4 = _mm_rsqrt_ps( a4 );   // four reciprocal square roots (!)

__m128 d4 = _mm_max_ps( a4, b4 );
__m128 d4 = _mm_min_ps( a4, b4 );
```

CODING TIME

Keep the assembler-like syntax in mind:

```
__m128 d4 = dx4 * dx4 + dy4 * dy4;

__m128 d4 = _mm_add_ps(
                _mm_mul_ps( dx4, dx4 ),
                _mm_mul_ps( dy4, dy4 )
            );
```

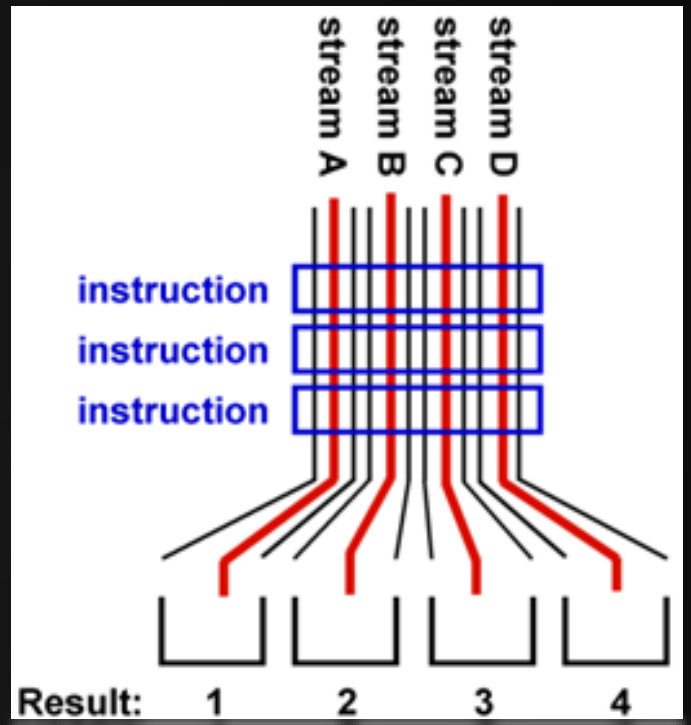
SSE

SIMD Basics

In short:

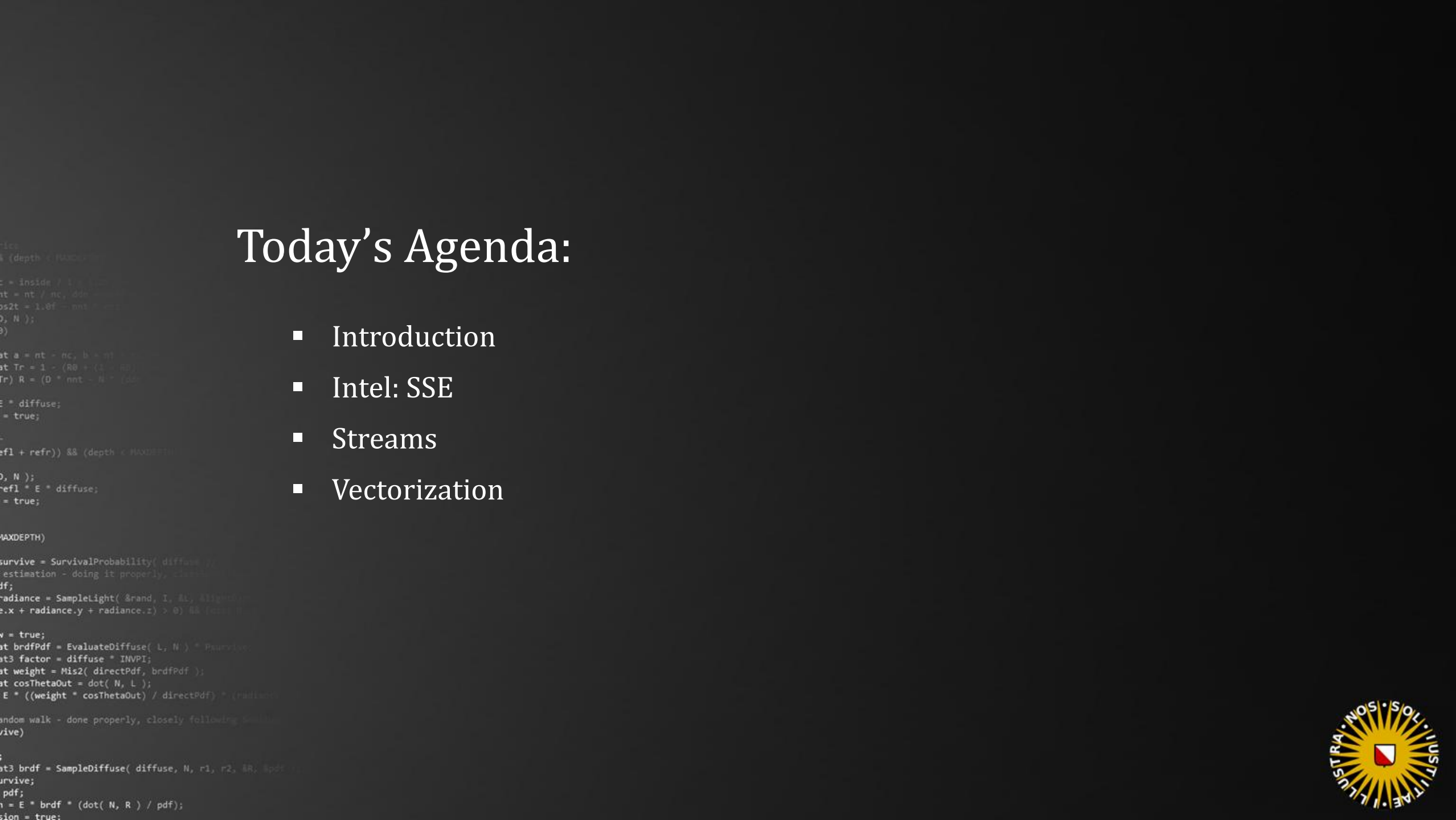
- Four times the work at the price of a single scalar operation (if you can feed the data fast enough)
- Potentially even better performance for min, max, sqrt, rsqrt
- Requires four independent streams.

And, with AVX we get __m256…



Today's Agenda:

- Introduction
- Intel: SSE
- Streams
- Vectorization



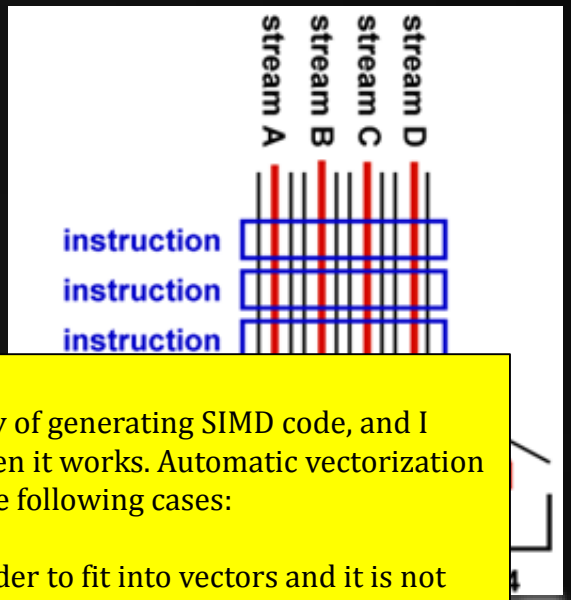
Streams

SIMD According To Visual Studio

```
vec3 image[256][256];
vec3 sum( 0, 0, 0 );
for( int y = 0; y < 16; y++ ) for( int x = 0; x < 16; x++ )
{
    sum += image[y][x];
}
blurred[y][x] = sum / 256.0f;
```

The compiler will notice that we are adding 3-compo
use an SSE instruction to speed up this single line. Th
speedup. Note that one lane is never used at all.

To get maximum throughput, we want four independ
parallel.



Agner Fog:
“Automatic vectorization is the easiest way of generating SIMD code, and I would recommend to use this method when it works. Automatic vectorization may fail or produce suboptimal code in the following cases:

- when the algorithm is too complex.
- when data have to be re-arranged in order to fit into vectors and it is not obvious to the compiler how to do this or when other parts of the code needs to be changed to handle the re-arranged data.
- when it is not known to the compiler which data sets are bigger or smaller than the vector size.
- when it is not known to the compiler whether the size of a data set is a multiple of the vector size or not.
- when the algorithm involves calls to functions that are defined elsewhere or cannot be inlined and which are not readily available in vector versions.
- when the algorithm involves many branches that are not easily vectorized.
- when floating point operations have to be reordered or transformed and it is not known to the compiler whether these transformations are permissible with respect to precision, overflow, etc.
- when functions are implemented with lookup tables.

Streams

SIMD Friendly Data Layout

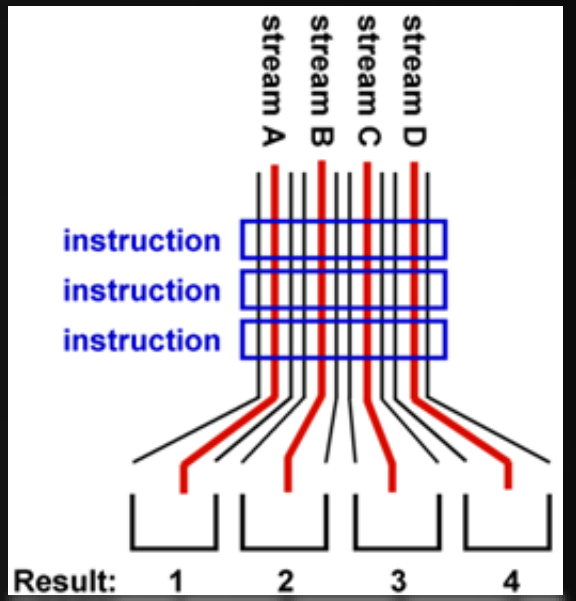
Consider the following data structure:

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

AoS

```
union { float x[512];  __m128 x4[128]; };
union { float y[512];  __m128 y4[128]; };
union { float z[512];  __m128 z4[128]; };
union { int mass[512]; __m128i mass4[128]; };
```

SoA



Streams

SIMD Data Naming Conventions

```
union { float x[512];  __m128 x4[128]; };
union { float y[512];  __m128 y4[128]; };
union { float z[512];  __m128 z4[128]; };
union { int mass[512]; __m128i mass4[128]; };
```

Notice that SoA is breaking our OO...

Consider adding the struct name to the variables:

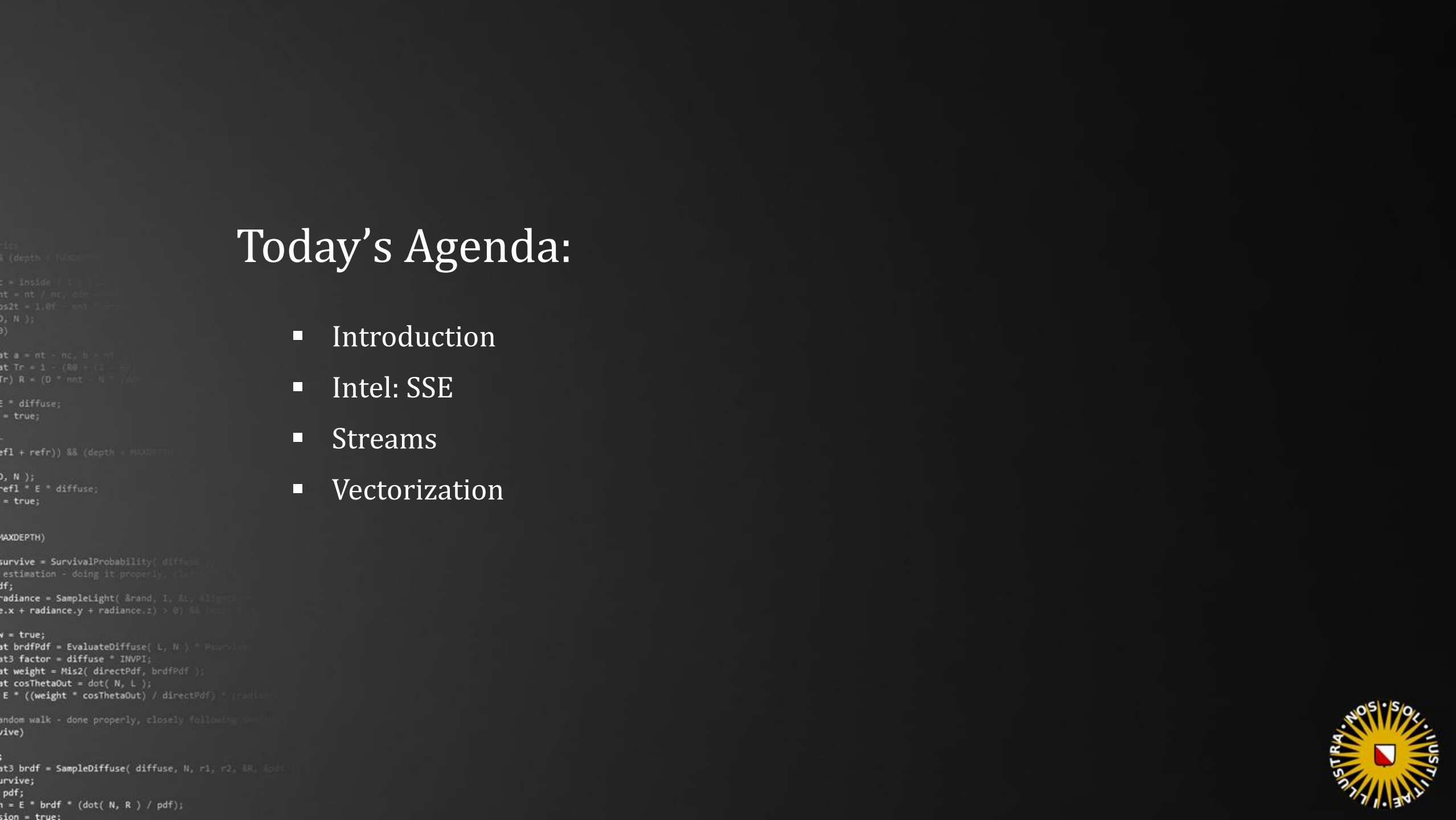
```
float particle_x[512];
```

Or put an amount of particles in a struct.

Also note the convention of adding ‘4’ to any SSE variable.

Today's Agenda:

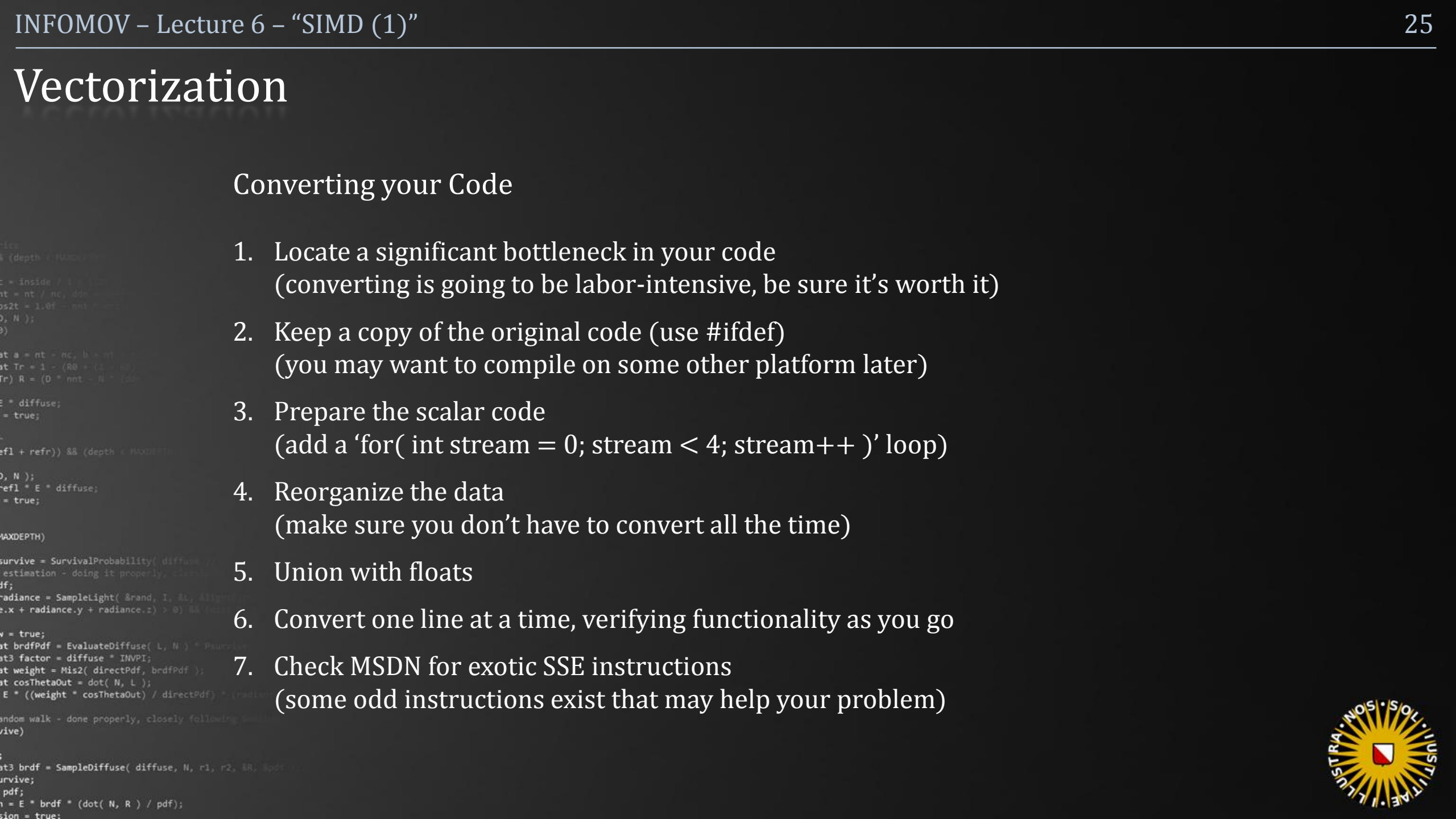
- Introduction
- Intel: SSE
- Streams
- Vectorization



Vectorization

Converting your Code

1. Locate a significant bottleneck in your code
   (converting is going to be labor-intensive, be sure it’s worth it)
2. Keep a copy of the original code (use #ifdef)
   (you may want to compile on some other platform later)
3. Prepare the scalar code
   (add a ‘for(int stream = 0; stream < 4; stream++)’ loop)
4. Reorganize the data
   (make sure you don’t have to convert all the time)
5. Union with floats
6. Convert one line at a time, verifying functionality as you go
7. Check MSDN for exotic SSE instructions
   (some odd instructions exist that may help your problem)



/INFOMOV/

END of “SIMD (1)”

next lecture: “SIMD (2)”