/INFOMOV/

Optimization & Vectorization

J. Bikker - Sep-Nov 2016 - Lecture 8: “Data-Oriented Design”

Welcome!

2016, P2:
Avg. ?

a few remarks on
GRADING P1

2015:
Avg.7.9

2016:
Avg.9.0

2017:
Avg.7.5

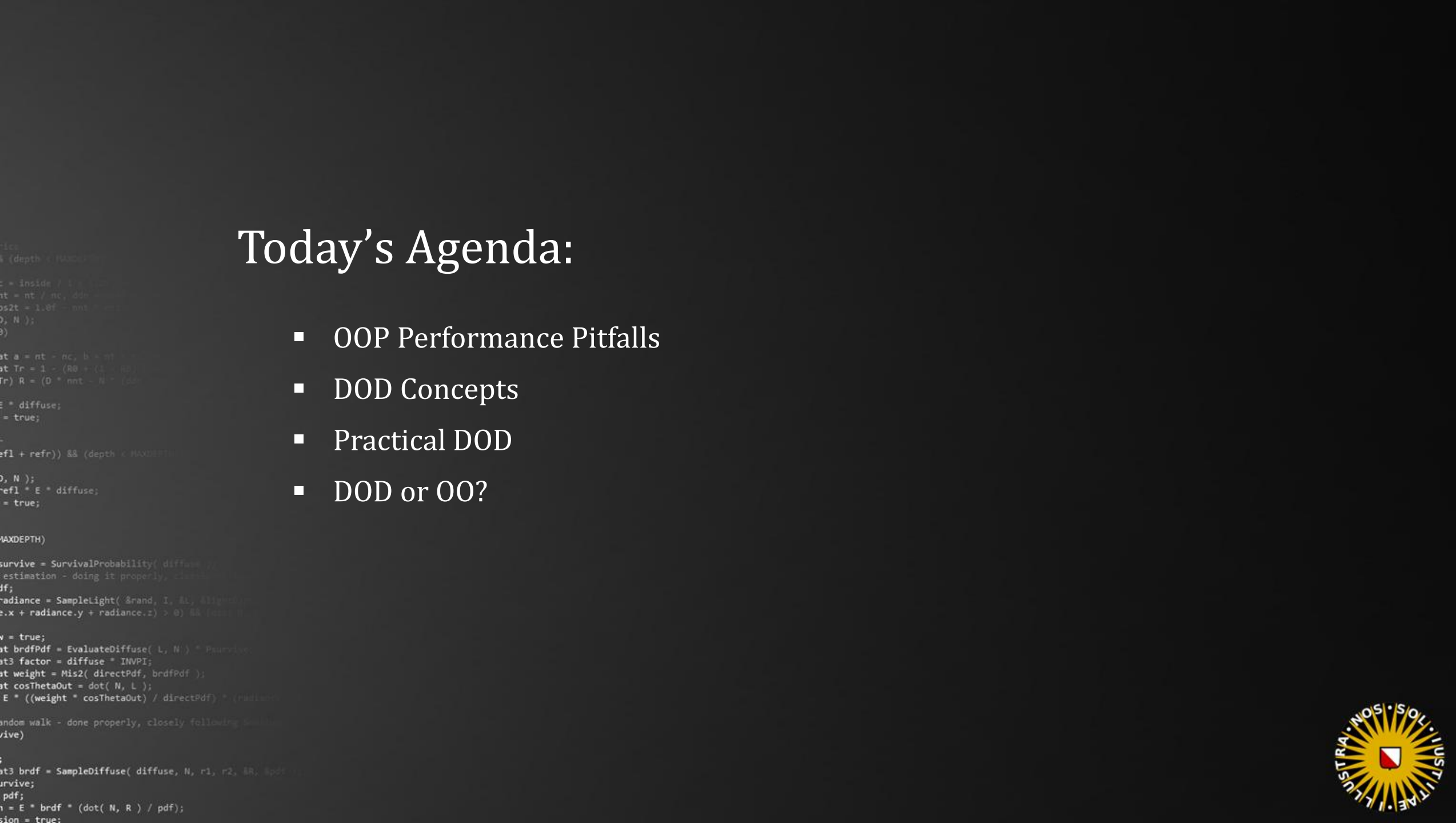
Learn about caches

Performance feedback

Reward / distinction

Today’s Agenda:

- OOP Performance Pitfalls
- DOD Concepts
- Practical DOD
- DOD or OO?

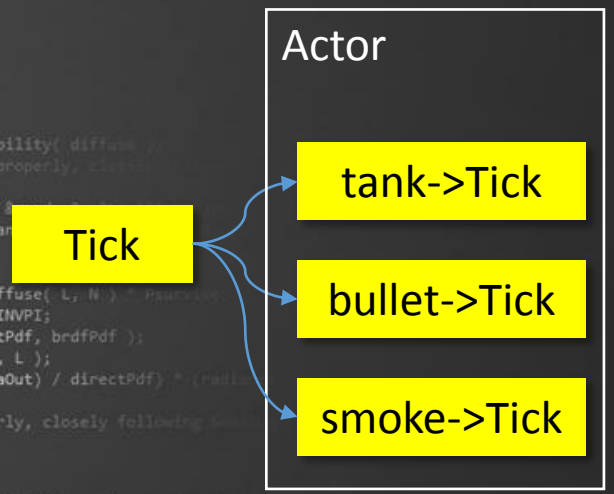


OOP

“Death by a Thousand Paper Cuts”

Object Oriented Programming:

- Objects
  - Data
  - Methods
  - Instances



Cost of a virtual function call:

1. Virtual Function Table
2. No inlining

…

Calling such a function:

cache miss
cache miss
branch

1. Read pointer to VFT of base class
2. Add function offset
3. Read function address from VFT
4. Load address in PC (jump)

But, that isn’t realistic, right?

It is, if we use OO for what it was designed for: operating on heterogeneous objects.

OOP

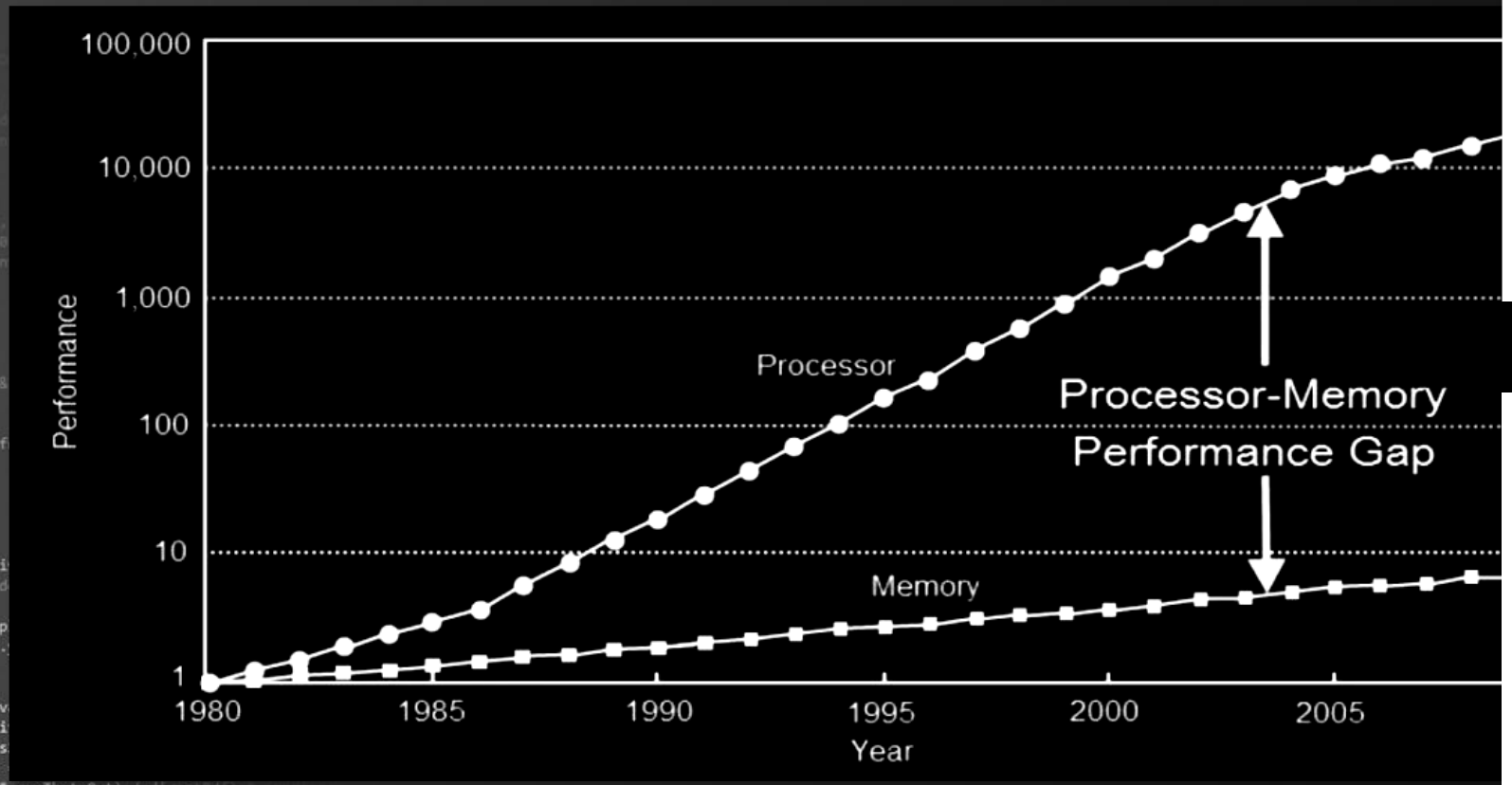
“Death by a Thousand Paper Cuts”

Characteristics of OO:

- Virtual calls
- Scattered individual objects

OOP

"Death by a Thousand Paper Cuts"



Reading memory: 40 cycles @ 300Mhz

Reading memory: 600 cycles @ 3.2Ghz

OOP

“Death by a Thousand Paper Cuts”

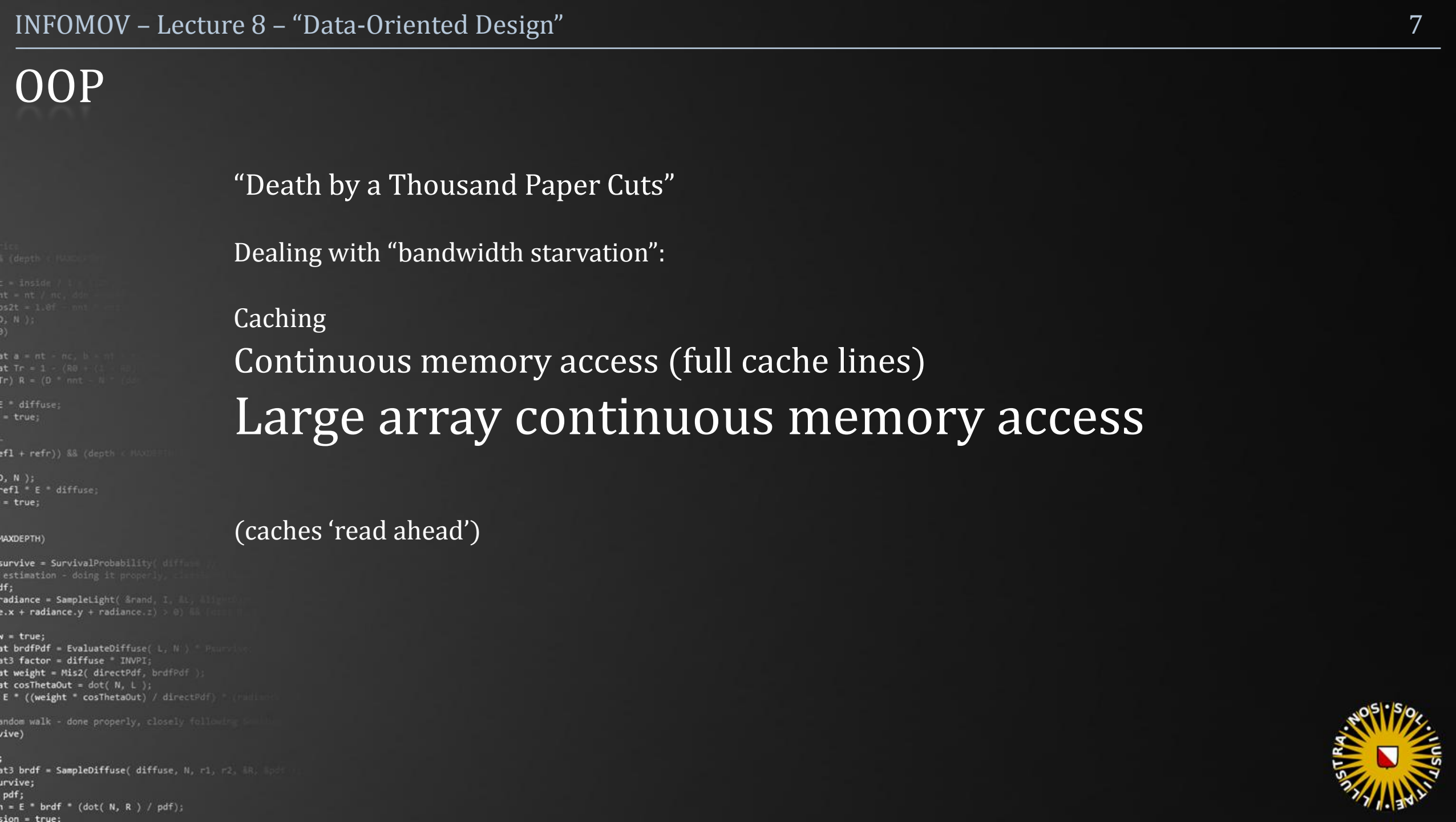
Dealing with “bandwidth starvation”:

Caching

Continuous memory access (full cache lines)

Large array continuous memory access

(caches ‘read ahead’)



OOP

“Death by a Thousand Paper Cuts”

Code performance is typically bound by memory access.

“The ideal data is in a format that we can use with the least amount of effort.”

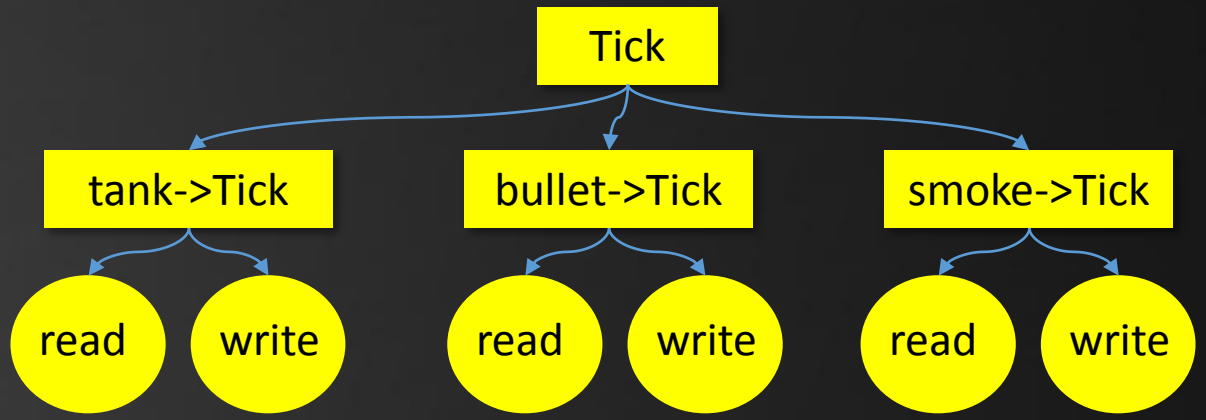
➔ Effort = CPU-effort.

“You cannot be fast without knowing how data is touched.”

OOP

“Death by a Thousand Paper Cuts”

Parallel processing typically requires synchronization.

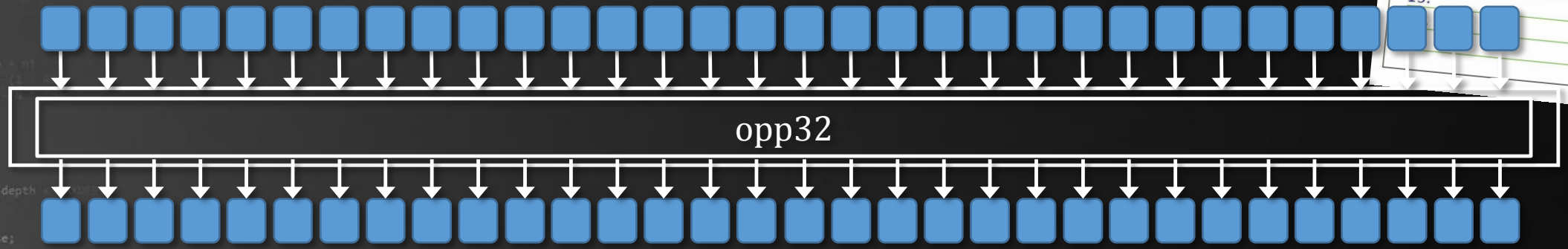


“You cannot multi-thread without knowing how data is touched.”

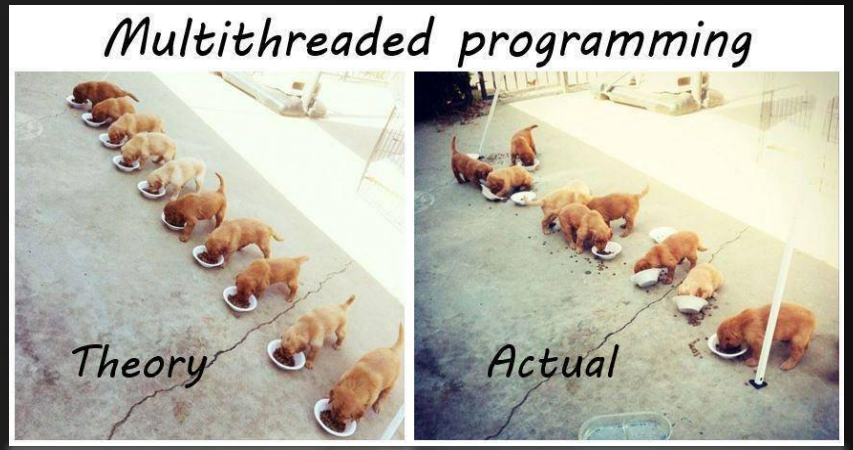
OOP

“Death by a Thousand Paper Cuts”

Parallel processing requires coherent program flow.



“You cannot multi-thread without knowing how data is touched.”



OOP

“Death by a Thousand Paper Cuts”

```
class Bot : public Enemy
{
    ...
    vec3 m_position;
    ...
    float m_mod;
    ...
    float m_aimDirection;
    ...
    virtual void updateAim( vec3 target )
    {
        m_aimDirection = dot3( m_position, target ) * m_mod;
    }
}
```

cached but not used

cached but not used

branch

cache miss

cache miss

cache miss

cache miss

cache miss

OOP

“Death by a Thousand Paper Cuts”


```
void updateAims(
    float* aimDir,
    const AimingData* aim,
    vec3 target,
    uint count
)
{
   for (uint i = 0; i < count; ++i)
   {
      aimDir[i] = dot3(aim->positions[i],target) * aim->mod[i];
   }
}
```

only reads data that is actually needed to cache

writes to linear array

actual functionality is unchanged

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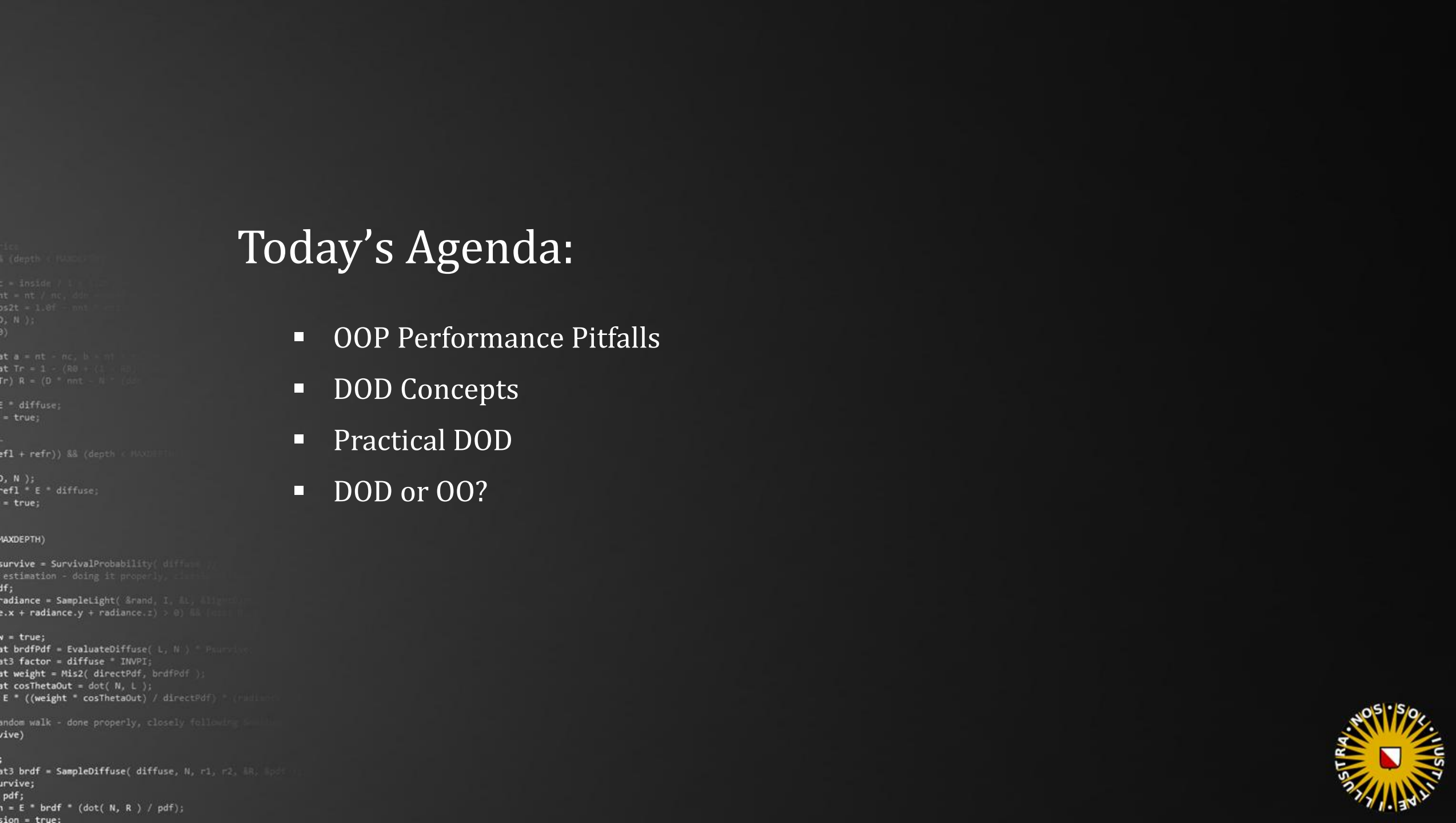


DOD

Data Oriented Design*

Origin: low-level game development.

Core idea: *focus software design on CPU- and cache-aware data layout*.

Take into account:

- Cache line size
- Data alignment
- Data size
- Access patterns
- Data transformations

Strive for a simple, linear access pattern as much as possible.

*: Nikos Drakos, “Data Oriented Design”, 2008. http://www.dataorienteddesign.com/dodmain

DOD

Bad Access Patterns: Linked List

The Perfect LinkedList™:

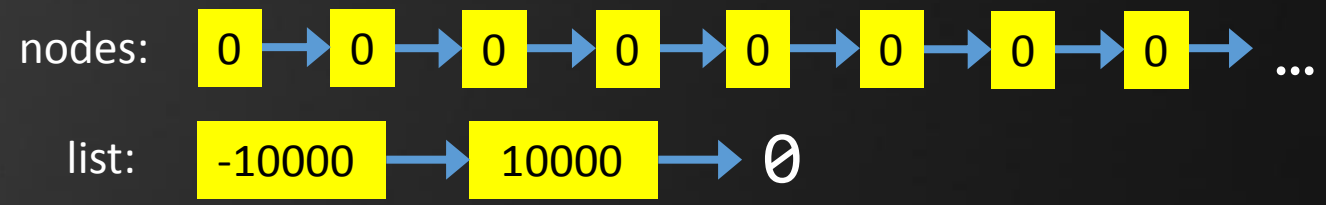
```
struct LLNode
{
   LLNode* next;
   int value;
};

nodes = new LLNode[…];

for( int i = 0; i < ...; i++ )
   nodes[i].next = &nodes[i + 1];
```

```
LLNode* NewNode( int value )
{
   LLNode* retval = pool;
   pool = pool->next;
   retval->value = value;
   return retval;
}

list = NewNode( -10000 );
list->next = NewNode( 10000 );
list->next->next = 0;
```



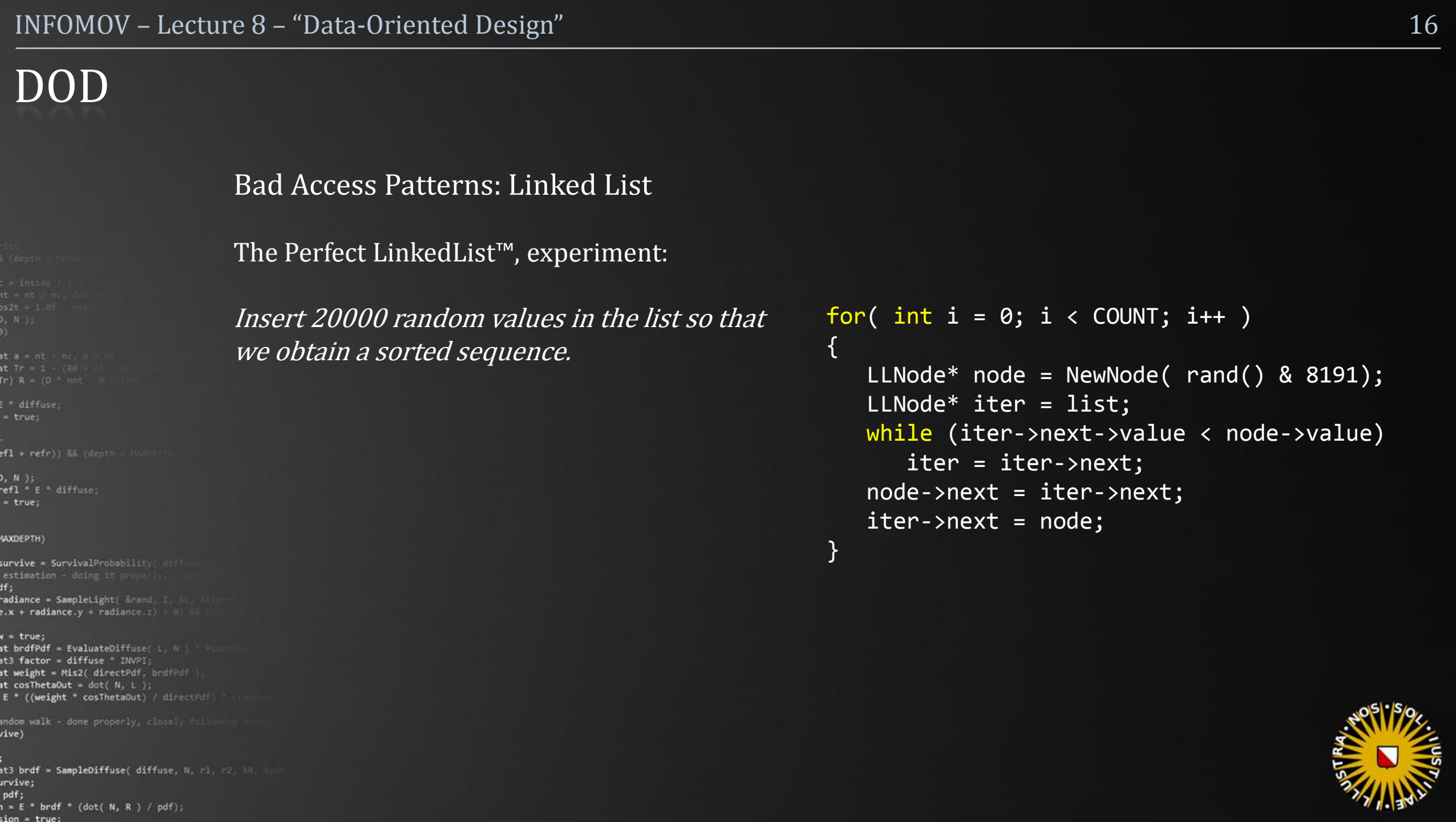
DOD

Bad Access Patterns: Linked List

The Perfect LinkedList™, experiment:

Insert 20000 random values in the list so that we obtain a sorted sequence.

```
for( int i = 0; i < COUNT; i++ )
{
   LLNode* node = NewNode( rand() & 8191);
   LLNode* iter = list;
   while (iter->next->value < node->value)
      iter = iter->next;
   node->next = iter->next;
   iter->next = node;
}
```



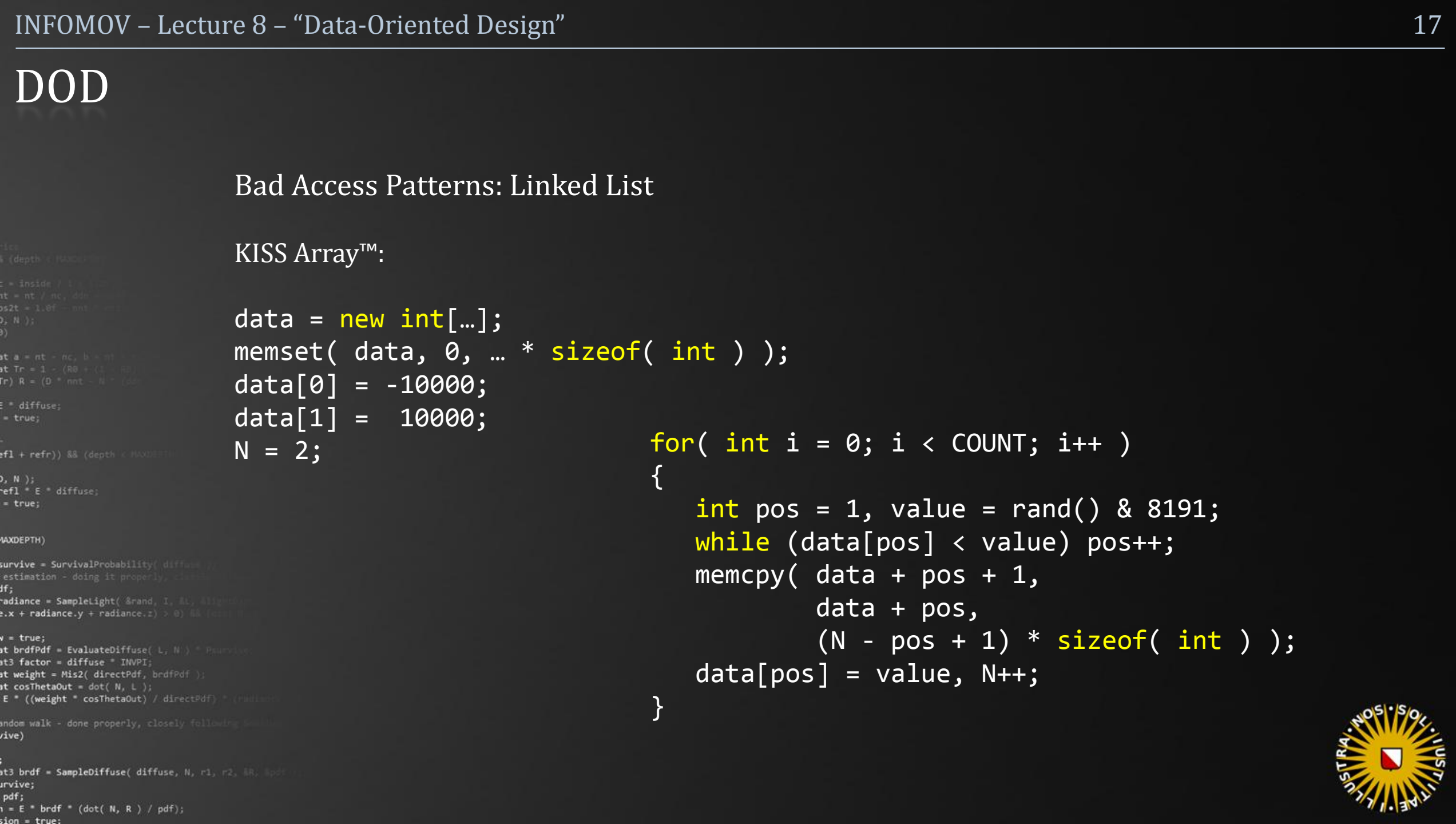
DOD

Bad Access Patterns: Linked List

KISS Array™:

```
data = new int[…];
memset( data, 0, … * sizeof( int ) );
data[0] = -10000;
data[1] =  10000;
N = 2;
```

```
for( int i = 0; i < COUNT; i++ )
{
   int pos = 1, value = rand() & 8191;
   while (data[pos] < value) pos++;
   memcpy( data + pos + 1,
           data + pos,
           (N - pos + 1) * sizeof( int ) );
   data[pos] = value, N++;
}
```



DOD


```
for( int i = 0; i < COUNT; i++ )
{
   LLNode* node = NewNode( rand() & 8191);
   LLNode* iter = list;
   while (iter->next->value < node->value)
      iter = iter->next;
   node->next = iter->next;
   iter->next = node;
}
```

```
for( int i = 0; i < COUNT; i++ )
{
   int pos = 1, value = rand() & 8191;
   while (data[pos] < value) pos++;
   memcpy( data + pos + 1, data + pos,
           (N - pos + 1) * sizeof( int ) );
   data[pos] = value, N++;
}
```

DOD

Bad Access Patterns: Linked List*

Inserting elements in an array by shifting the remainder of the array is *significantly faster* than using an optimized linked list.

Why?

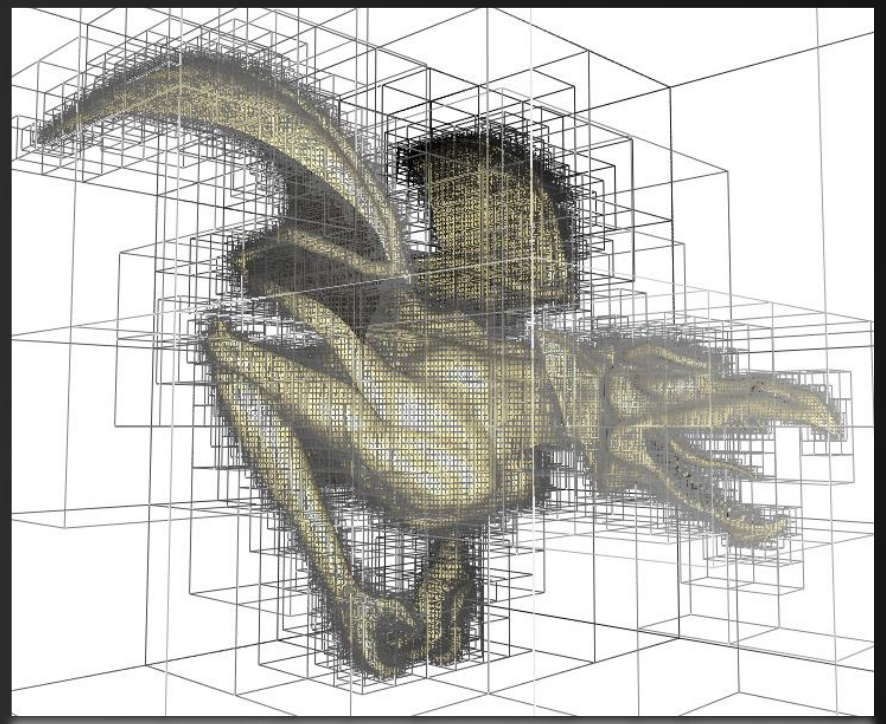
- Finding the location in the array: pure linear access
- Shifting the remainder: pure linear access.

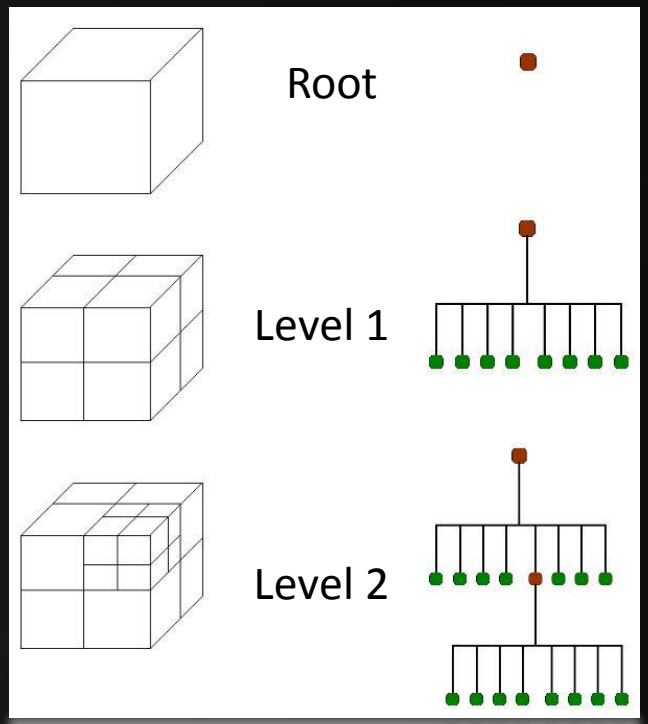
➔ Even though the amount of transferred memory is huge, this approach wins.

*: Also see: Nathan Reed, Data Oriented Hash Table, 2015.
http://www.reedbeta.com/blog/data-oriented-hash-table

DOD

Bad Access Patterns: Octree

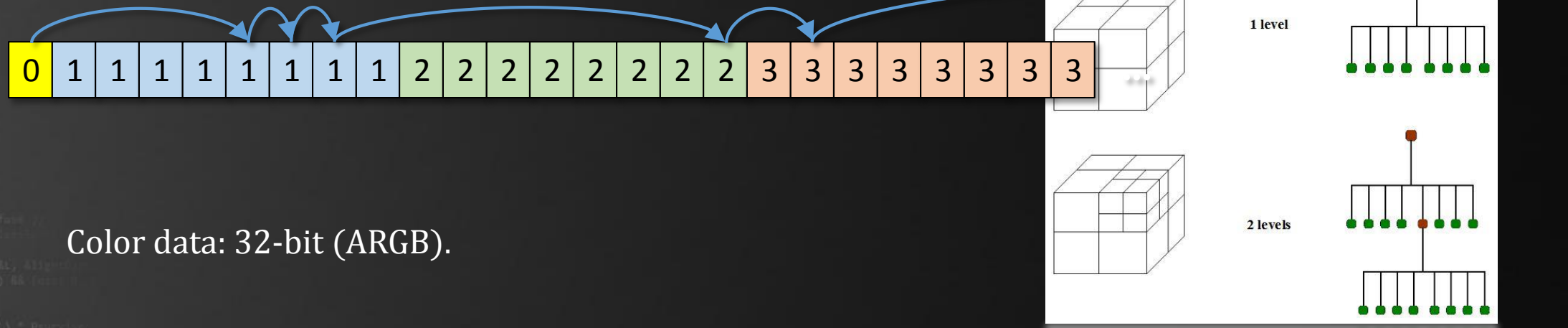




DOD

Bad Access Patterns: Octree

Query: find the color of a voxel visible through pixel (x,y).
Operation: ‘3DDDA’ (basically: Bresenham).
Data layout:



Color data: 32-bit (ARGB).

DOD

Bad Access Patterns: Octree

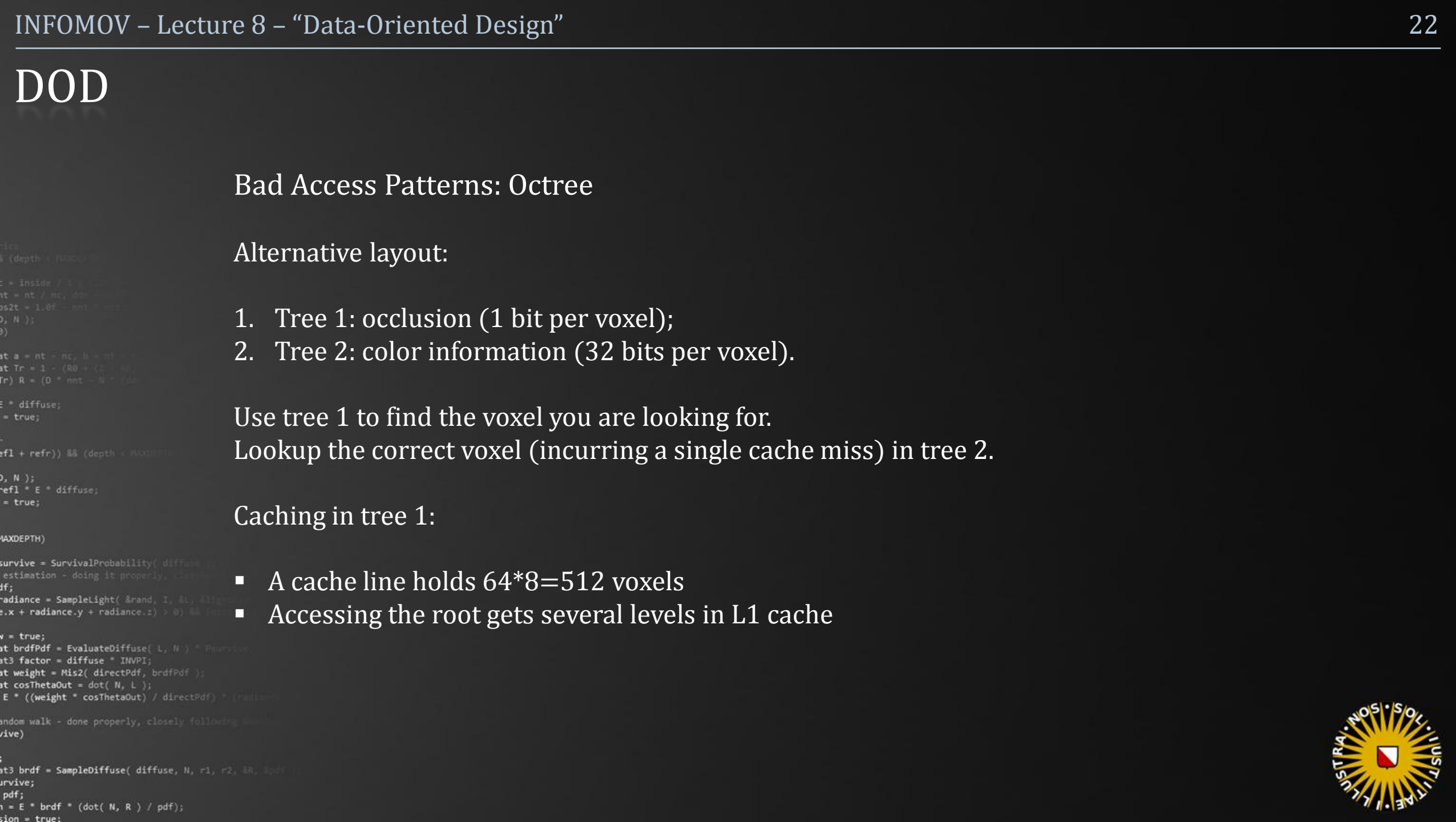
Alternative layout:

1. Tree 1: occlusion (1 bit per voxel);
2. Tree 2: color information (32 bits per voxel).

Use tree 1 to find the voxel you are looking for.
Lookup the correct voxel (incurring a single cache miss) in tree 2.

Caching in tree 1:

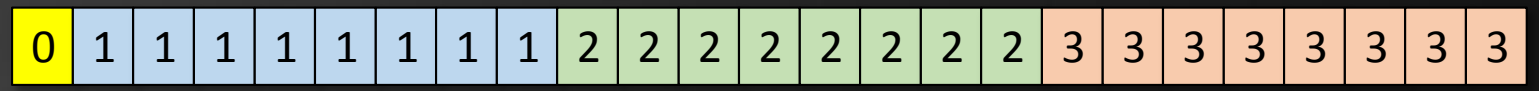
- A cache line holds 64*8=512 voxels
- Accessing the root gets several levels in L1 cache



DOD

Bad Access Patterns: Octree

Alternative layout (part 2):

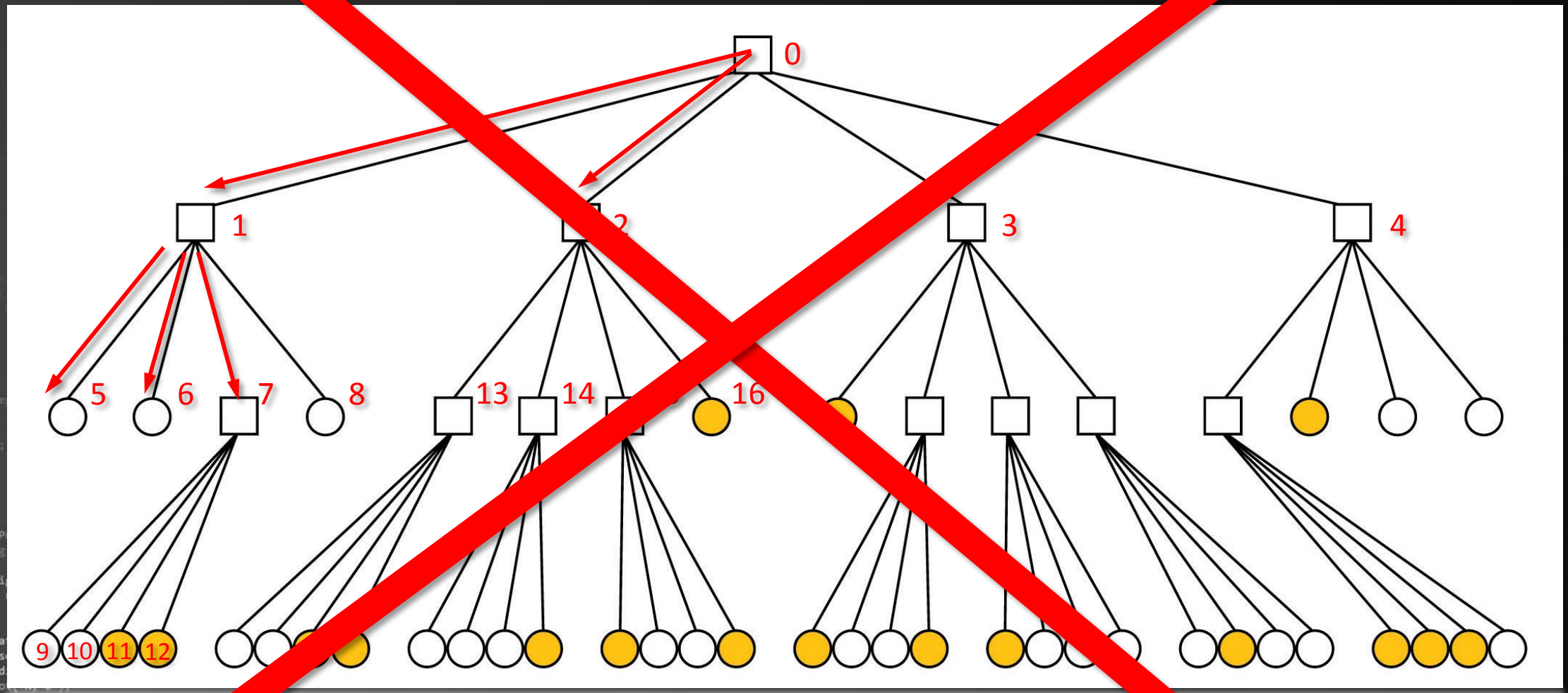


Trees are typically generated by a divide-and-conquer algorithm, in a depth-first fashion.

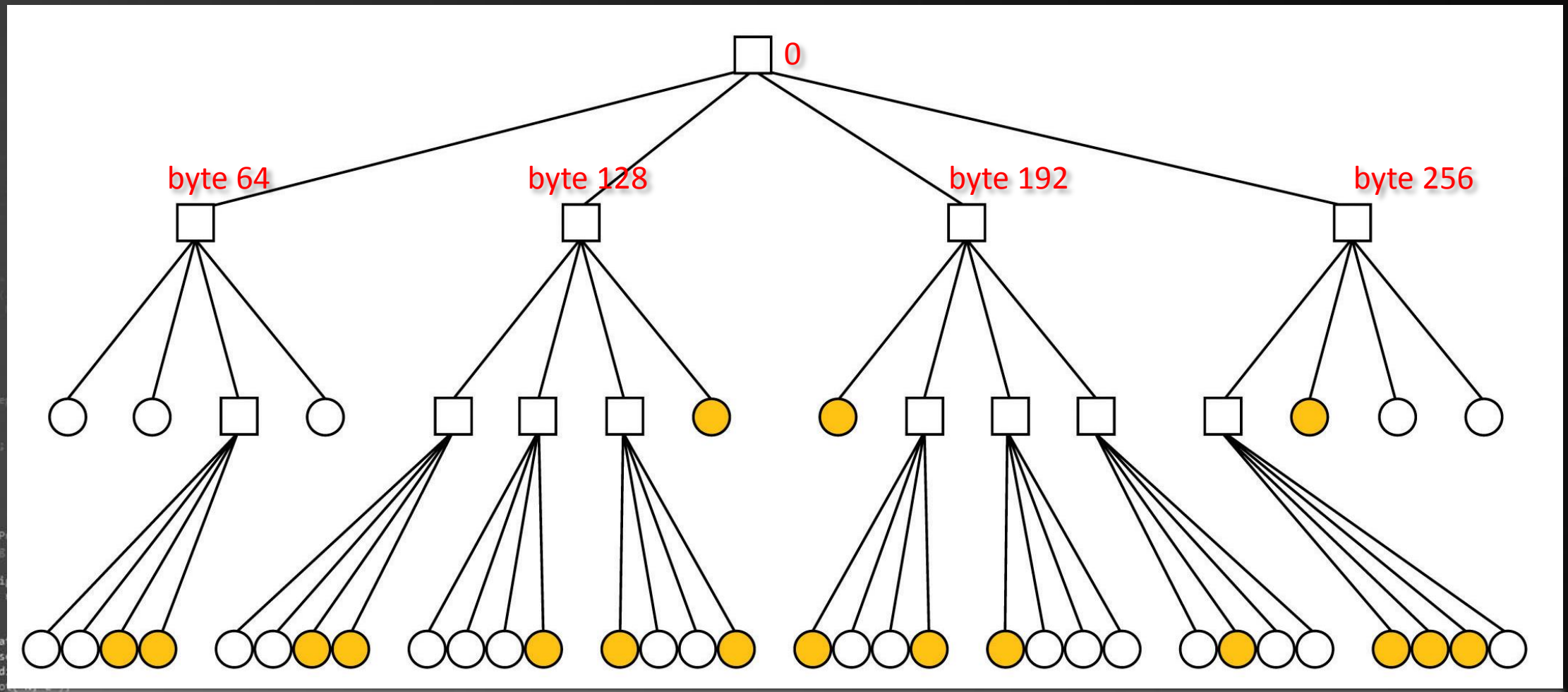
Compact storage:

```
struct OTNode
{
    int firstChild;
    // bit 31: empty
    // bit 30: leaf
};
```

DOD



DOD



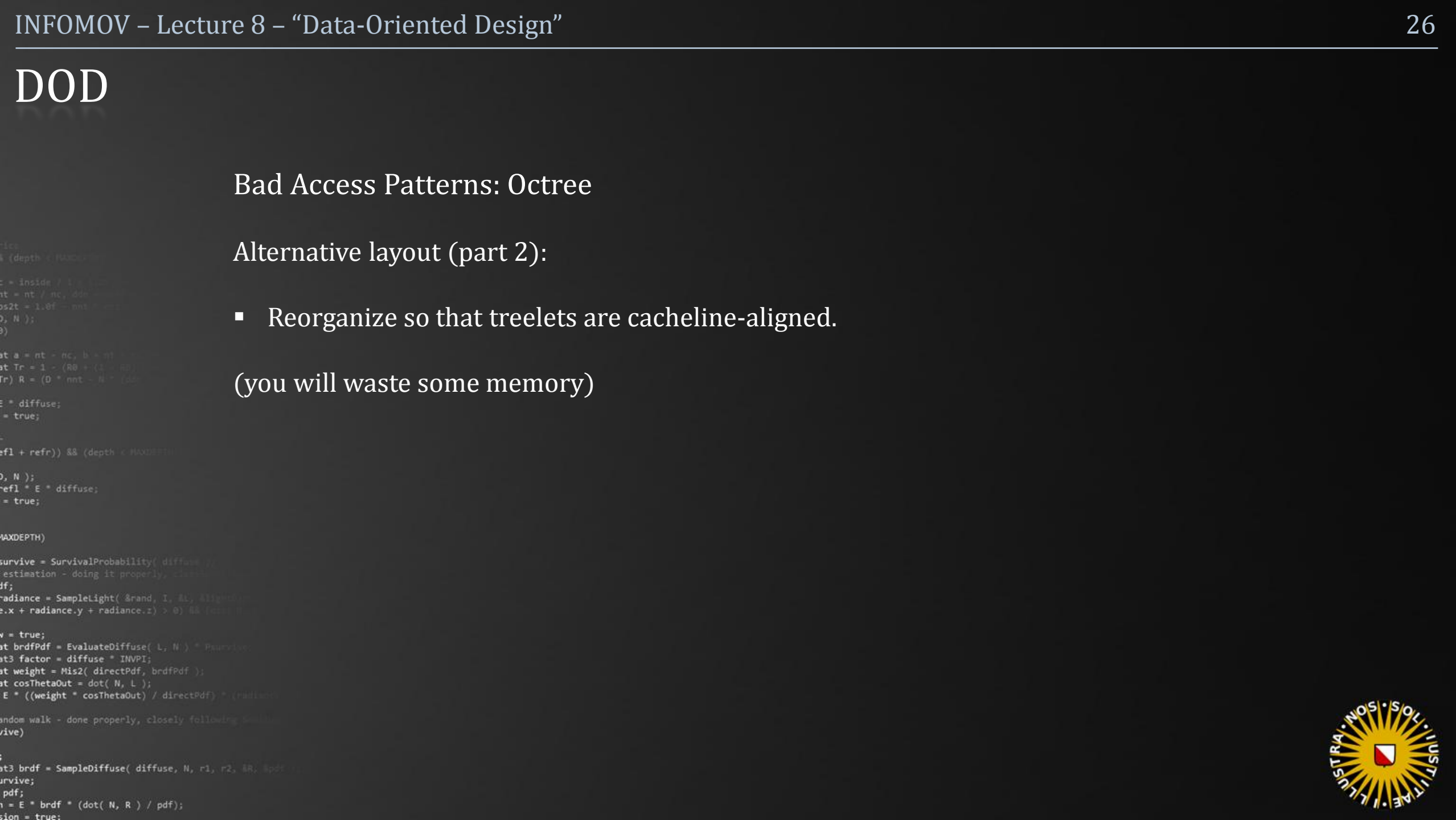
DOD

Bad Access Patterns: Octree

Alternative layout (part 2):

- Reorganize so that treelets are cacheline-aligned.

(you will waste some memory)



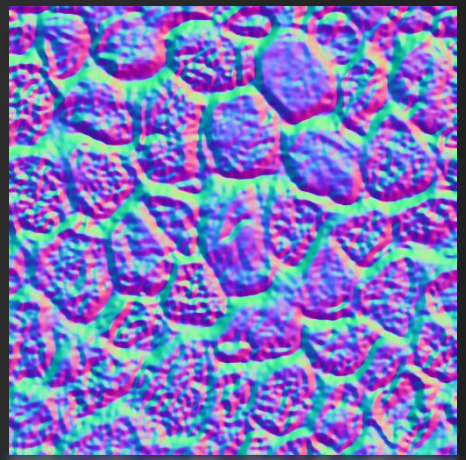
DOD

Bad Access Patterns: Textures in a Ray Tracer

Typical process for tracing a ray:

- Traverse a tree (multiple kilobytes)
- Intersect triangles in the leaf nodes (quite a few bytes)
- If a hit is found, fetch texture.

This is almost always a cache miss.



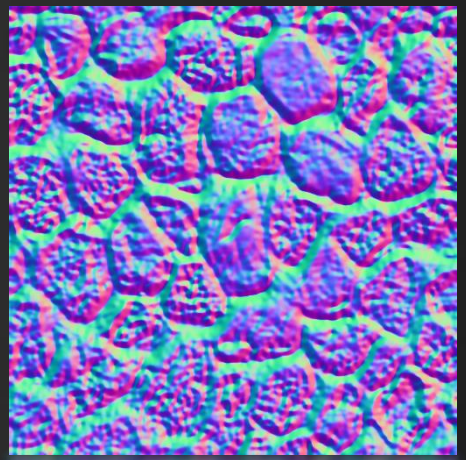
DOD

Bad Access Patterns: Textures in a Ray Tracer

We suffer the cache miss *twice:*

- Once for the texture;
- Once for the normal map.

Note: both values are 32-bit.

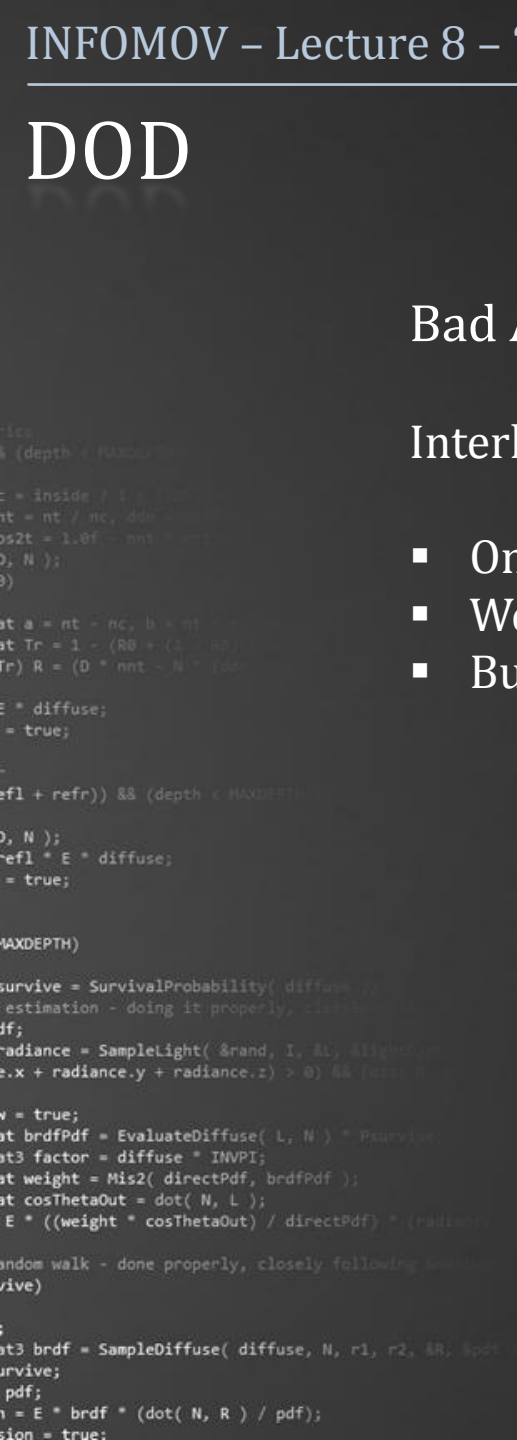



DOD

Bad Access Patterns: Textures in a Ray Tracer

Interleaved texture / normal:

- One value now becomes 64-bit and contains the normal and the color.
- We still suffer a cache miss –
- But only once.



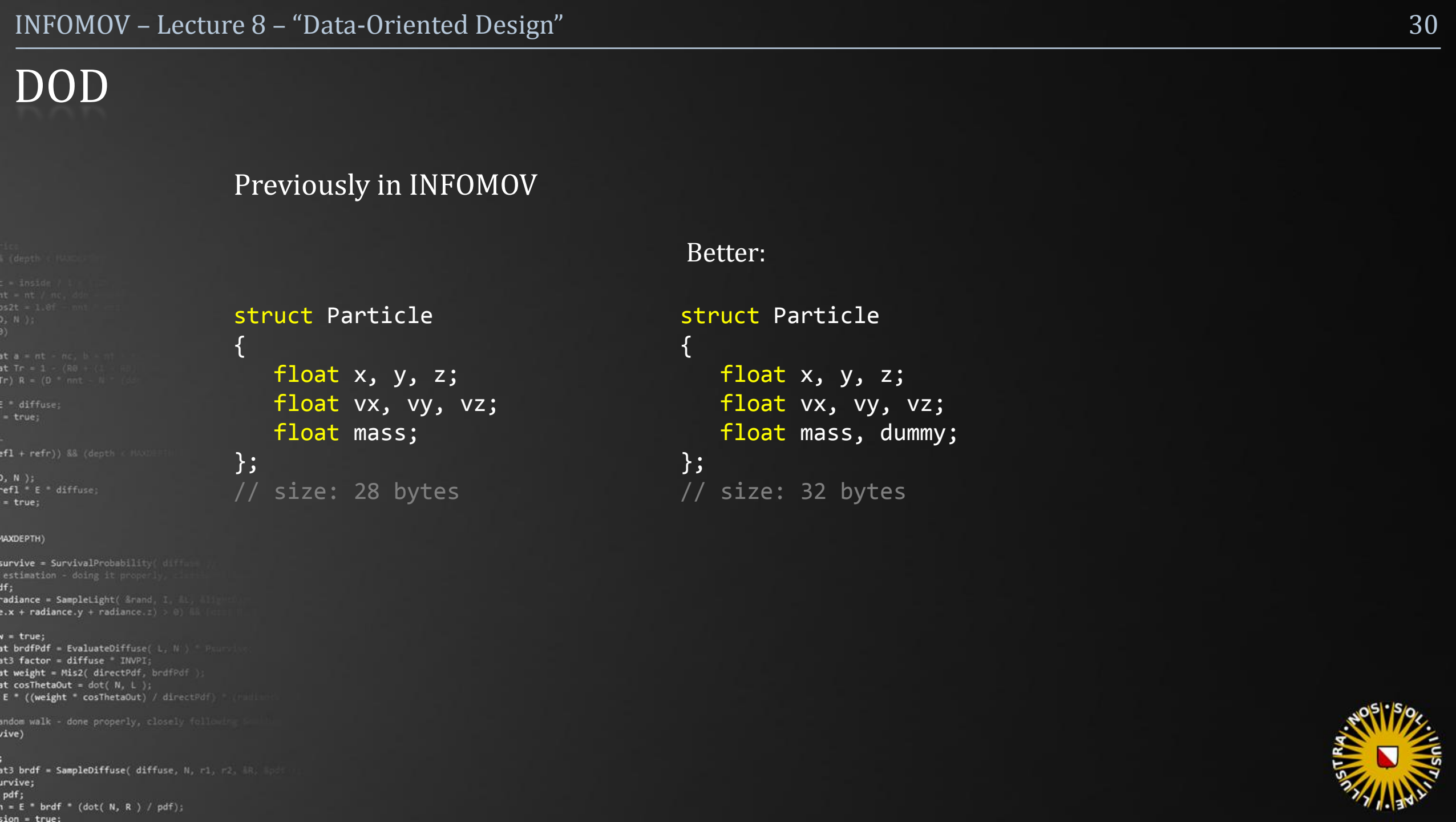
DOD

Previously in INFOMOV

```
struct Particle
{
   float x, y, z;
   float vx, vy, vz;
   float mass;
};
// size: 28 bytes
```

Better:

```
struct Particle
{
   float x, y, z;
   float vx, vy, vz;
   float mass, dummy;
};
// size: 32 bytes
```



DOD

Previously in INFOMOV

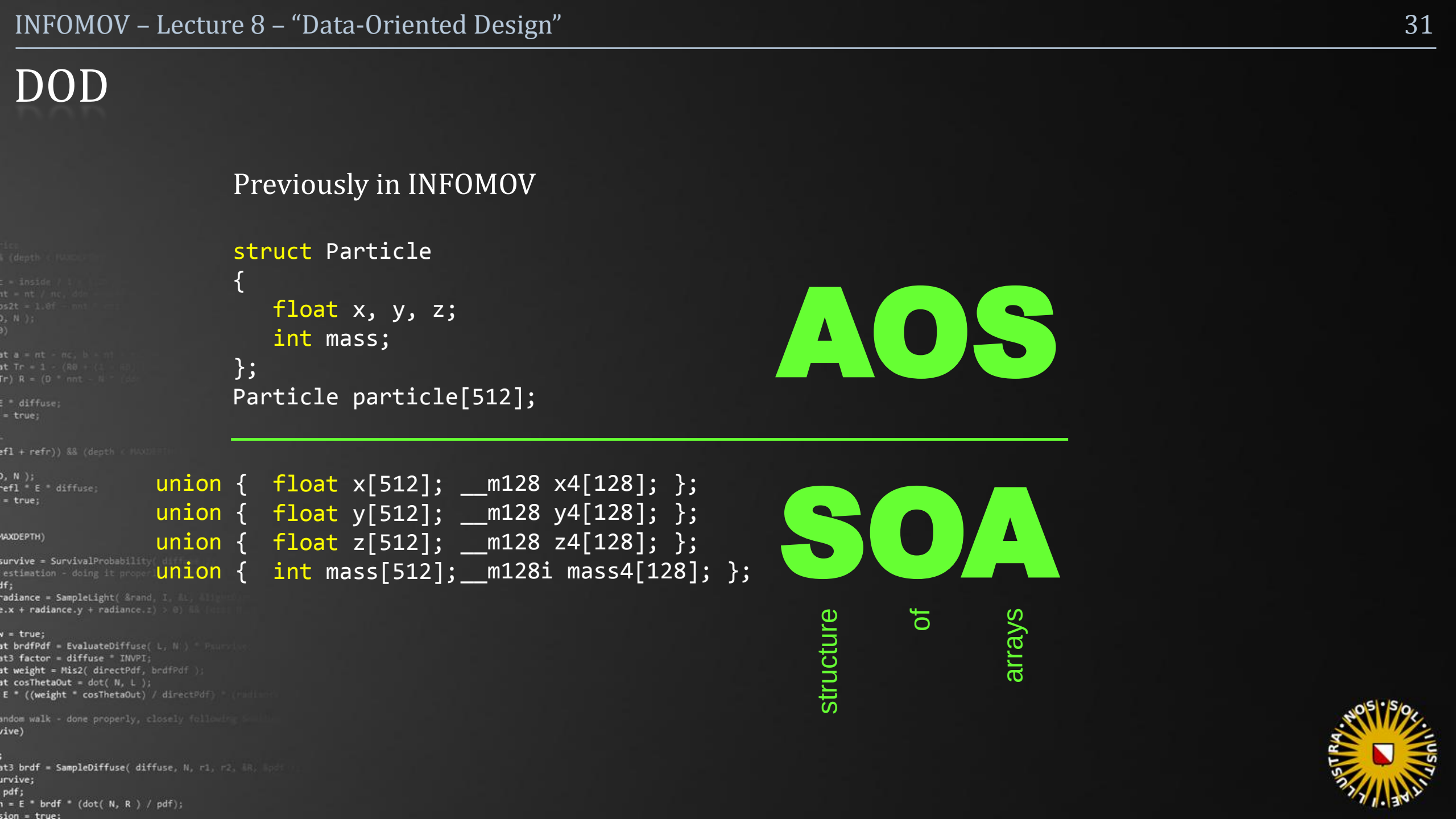
```
struct Particle
{
   float x, y, z;
   int mass;
};
Particle particle[512];
```

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]; };
```

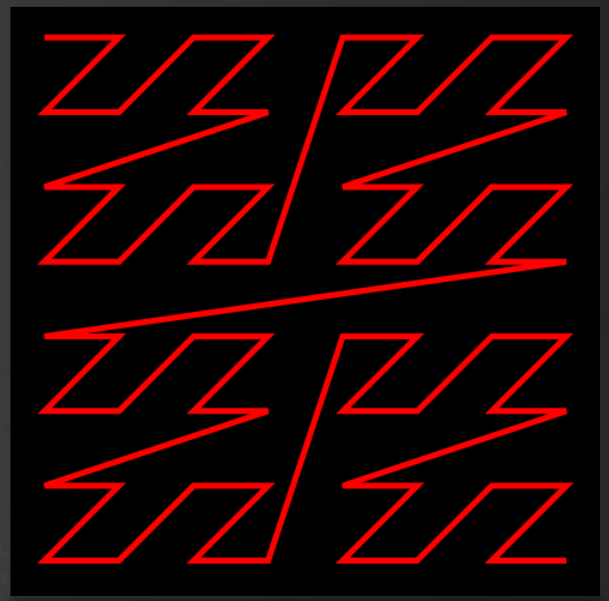
SOA

structure of arrays



DOD

Previously in INFOMOV



Method:

```
X =  1 1 0 0 0 1 0 1 1 0 1 1 0 1

Y = 1 0 1 1 0 1 1 0 1 0 1 1 1 0

--------------------------------

M = 11011010001110011100111111001
```

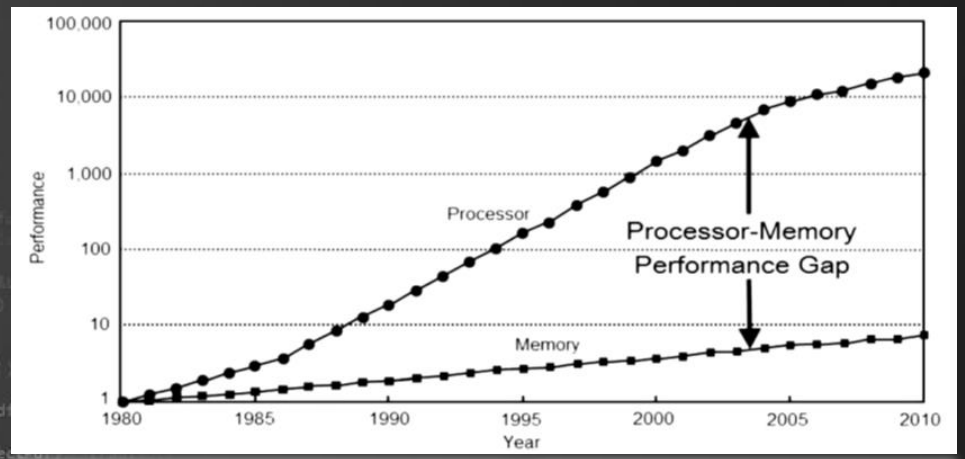
DOD

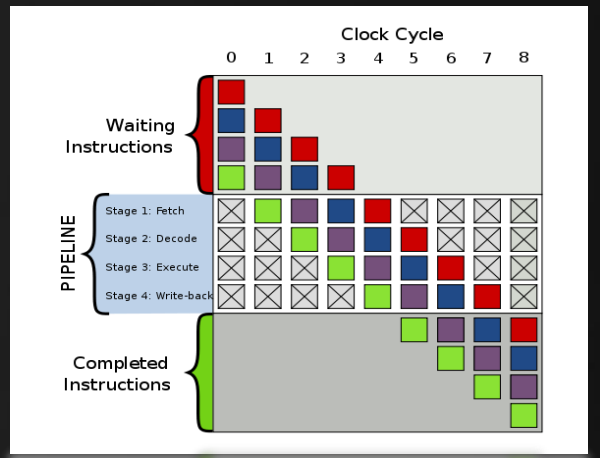
Algorithm Performance Factors

Estimating algorithm cost:

t

1. Algorithmic Complexity : $O(N)$, $O(N^2)$, $O(N \log N)$, …
2. Cyclomatic Complexity* (or: Conditional Complexity)
3. Amdahl’s Law / Work-Span Model
4. Cache Effectiveness





*: McCabe, A Complexity Measure, 1976.

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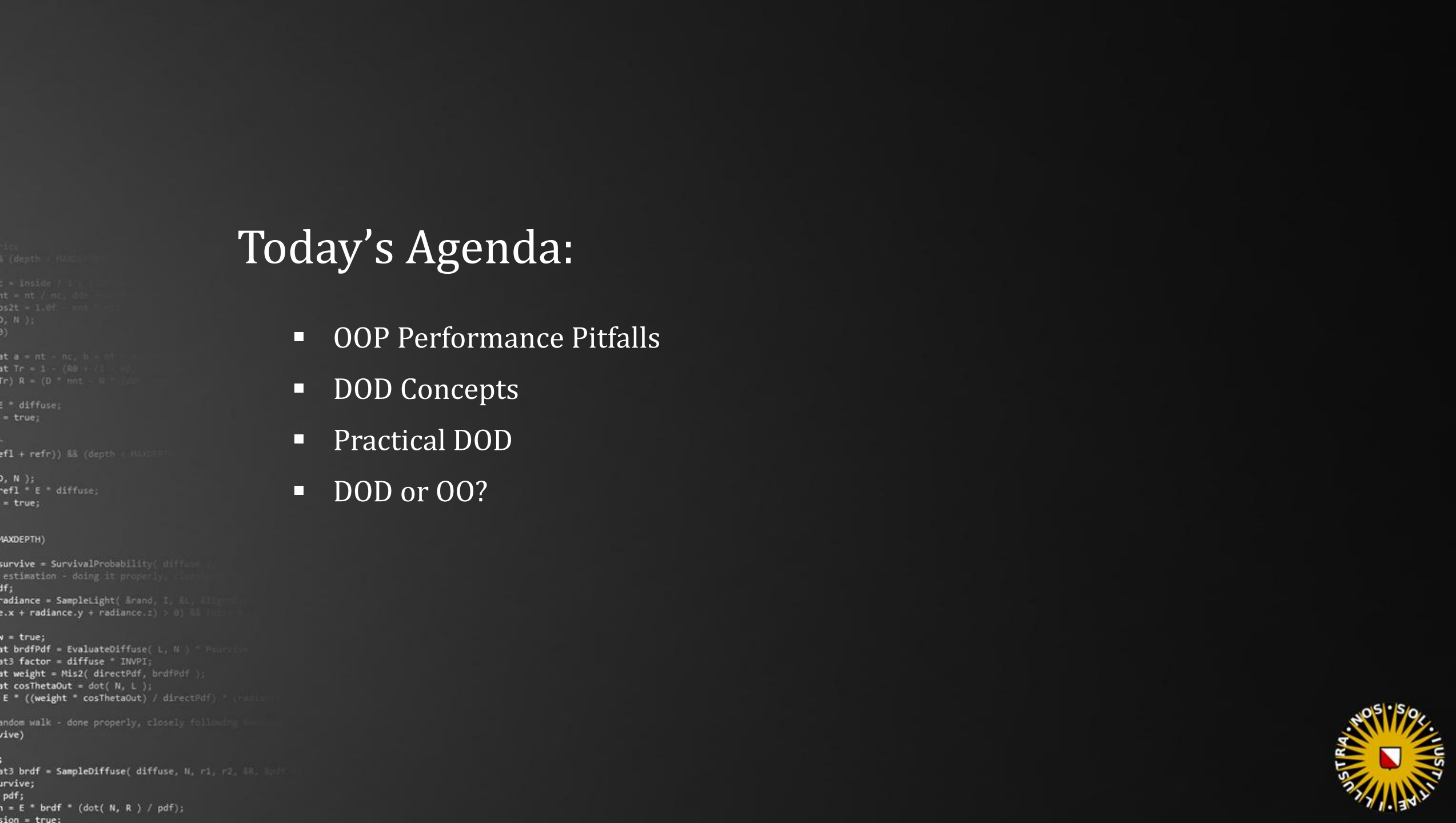

P2

Data-Oriented Optimization: P2

How many tanks fit in a grid cell?
How many tanks do we want to fit in a grid cell? ☺
How many cache lines is a grid cell?
How far away are the neighbors?
Can we fit more tanks in a grid cell without using more memory?
How can we efficiently point to a tank?
…

Profiler: does this stuff matter?

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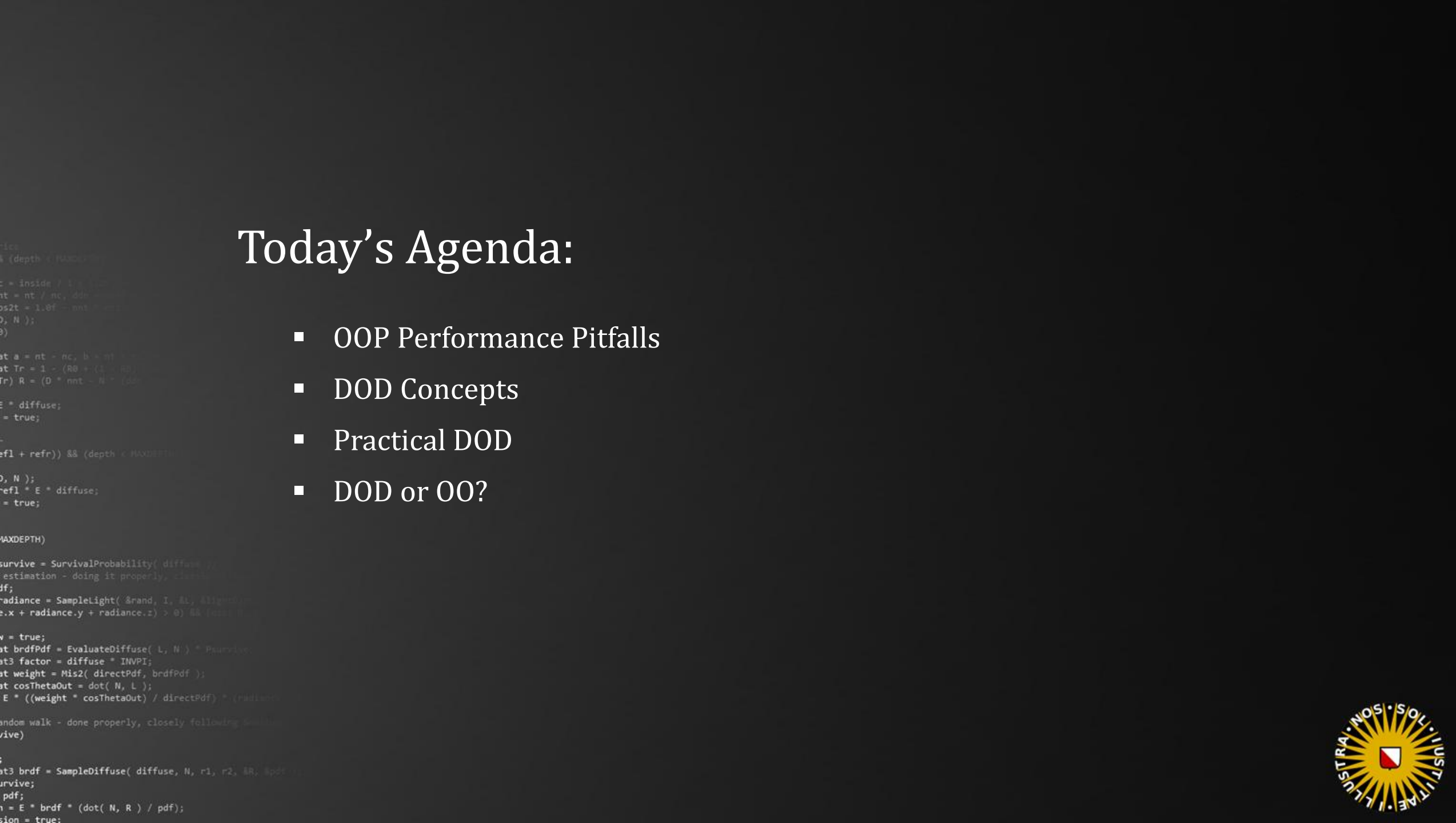

2B|~2B

OO = Evil, DO = Good?

10% of your code runs 90% of the time. DO is good for this 10%.

For all other code, please:

- Use STL
- Apply OO
- Program in C#
- Use event handling
- Check return values
- Focus on productivity

/INFOMOV/

END of “Data-Oriented Design”

next lecture: “Fixed Point”