Data-Oriented Design and C++

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A bit of background…

What does an “Engine” team do?

Runtime systems

e.g.

- Rendering
- Animation and gestures
- Streaming
- Cinematics
- VFX
- Post-FX
- Navigation
- Localization
- …many, many more!

Development tools

e.g.

- Level creation
- Lighting
- Material editing
- VFX creation
- Animation/state machine editing
- Visual scripting
- Scene painting
- Cinematics creation
- …many, many more!

What’s important to us?

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- Hard deadlines

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- Soft realtime performance requirements (Soft=33ms)

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- Maintenance

What’s important to us?

- Hard deadlines
- Soft realtime performance requirements (Soft=33ms)
- Usability
- Performance
- Maintenance
- Debugability

What languages do we use…?

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- C
- C++
- Asm
- Perl
- Javascript
- C#

What languages do we use…?

- C
- C++ ← ~70%
- Asm
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What languages do we use…?

- C
- C++ ← ~70%
- Asm
- Perl
- Javascript
- C#
- Pixel shaders, vertex shaders, geometry shaders, compute shaders, …

We don’t make games for Mars but…

How are games like the Mars rovers?

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- Exceptions

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- Templates

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- Iostream

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- Multiple inheritance

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- Operator overloading

How are games like the Mars rovers?

- Exceptions
- Templates
- Iostream
- Multiple inheritance
- Operator overloading
- RTTI

How are games like the Mars rovers?

- No STL

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- Custom allocators (lots)

How are games like the Mars rovers?

- No STL
- Custom allocators (lots)
- Custom debugging tools

Is data-oriented even a thing…?

Data-Oriented Design Principles

The purpose of all programs, and all parts of those programs, is to transform data from one form to another.

Data-Oriented Design Principles

If you don’t understand the data you don’t understand the problem.

Data-Oriented Design Principles

Conversely, understand the problem by understanding the data.

Data-Oriented Design Principles

Different problems require different solutions.

Data-Oriented Design Principles

If you have different data, you have a different problem.

Data-Oriented Design Principles

If you don’t understand the cost of solving the problem, you don’t understand the problem.

Data-Oriented Design Principles

If you don’t understand the hardware, you can’t reason about the cost of solving the problem.

Data-Oriented Design Principles

Everything is a data problem. Including usability, maintenance, debug-ability, etc. Everything.

Data-Oriented Design Principles

Solving problems you probably don’t have creates more problems you definitely do.

Data-Oriented Design Principles

Latency and throughput are only the same in sequential systems.

Data-Oriented Design Principles

Latency and throughput are only the same in sequential systems.

Data-Oriented Design Principles

Rule of thumb: Where there is one, there are many. Try looking on the time axis.

Data-Oriented Design Principles

Rule of thumb: The more context you have, the better you can make the solution. Don’t throw away data you need.

Data-Oriented Design Principles

Rule of thumb: NUMA extends to I/O and pre-built data all the way back through time to original source creation.

Data-Oriented Design Principles

Software does not run in a magic fairy aether powered by the fevered dreams of CS PhDs.

Is data-oriented even a thing…?

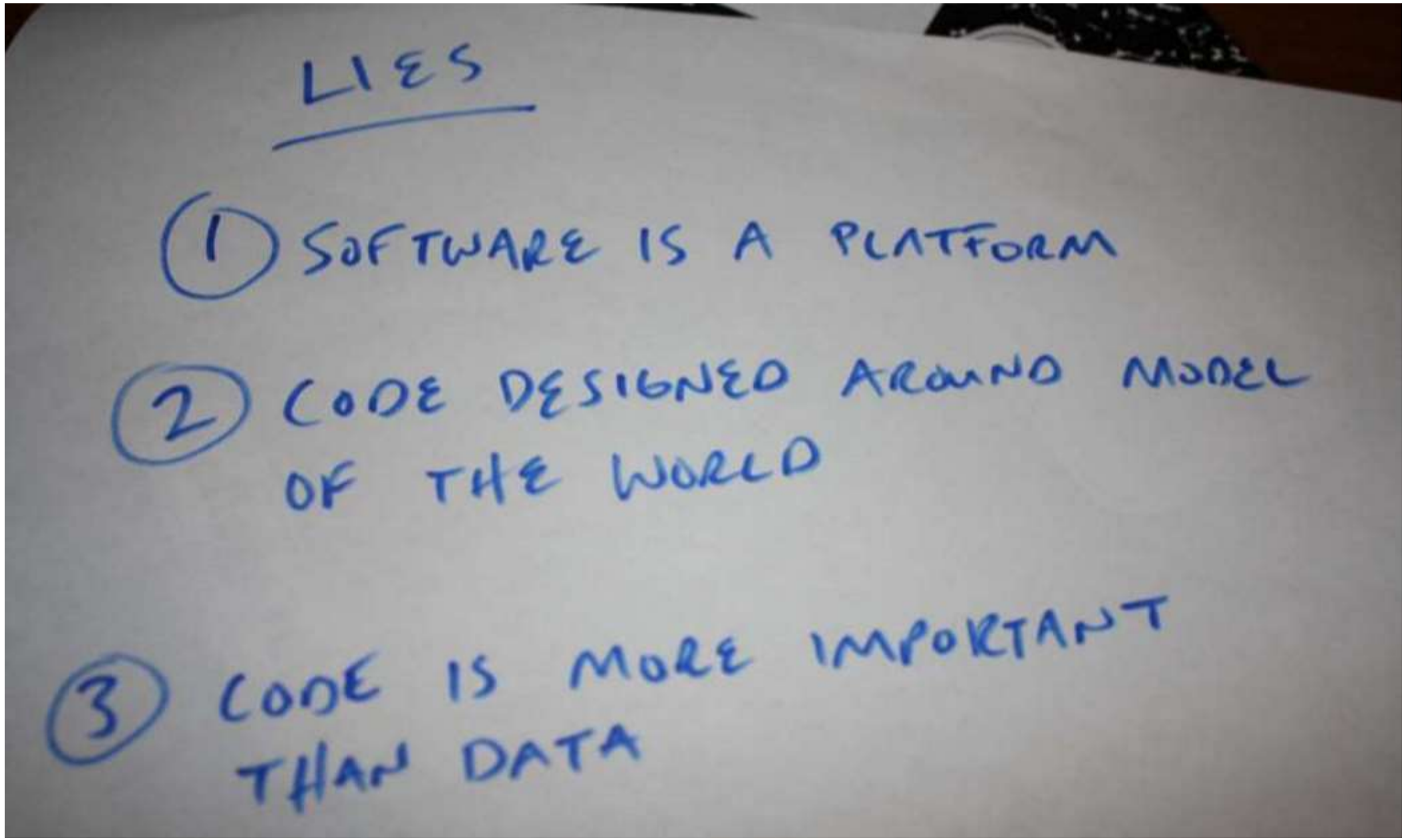
…certainly not new ideas.

…more of a reminder of first principles.

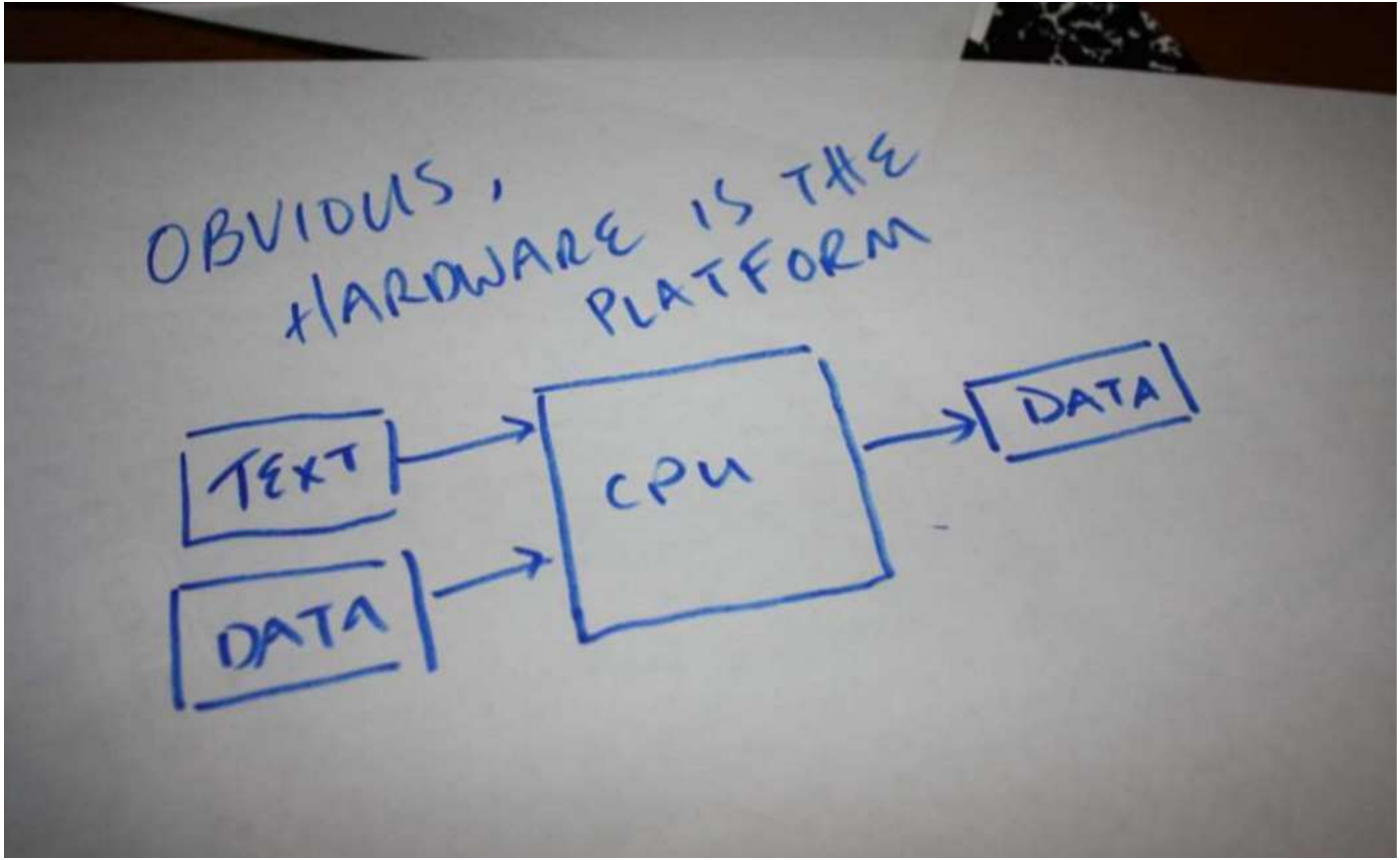
…but it is a response to the culture of C++

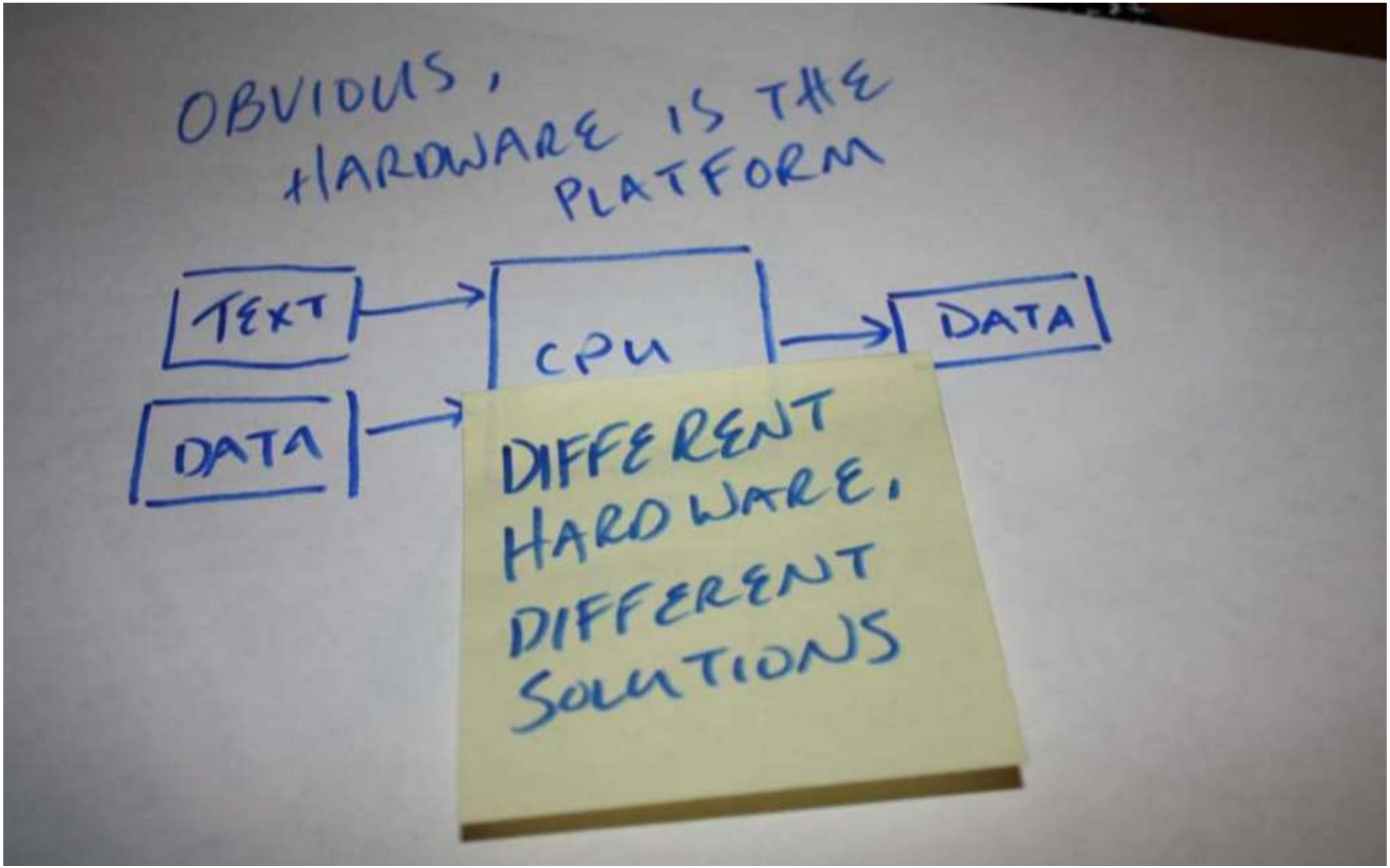
…but it is a response to the culture of C++

…and The Three Big Lies it has engendered

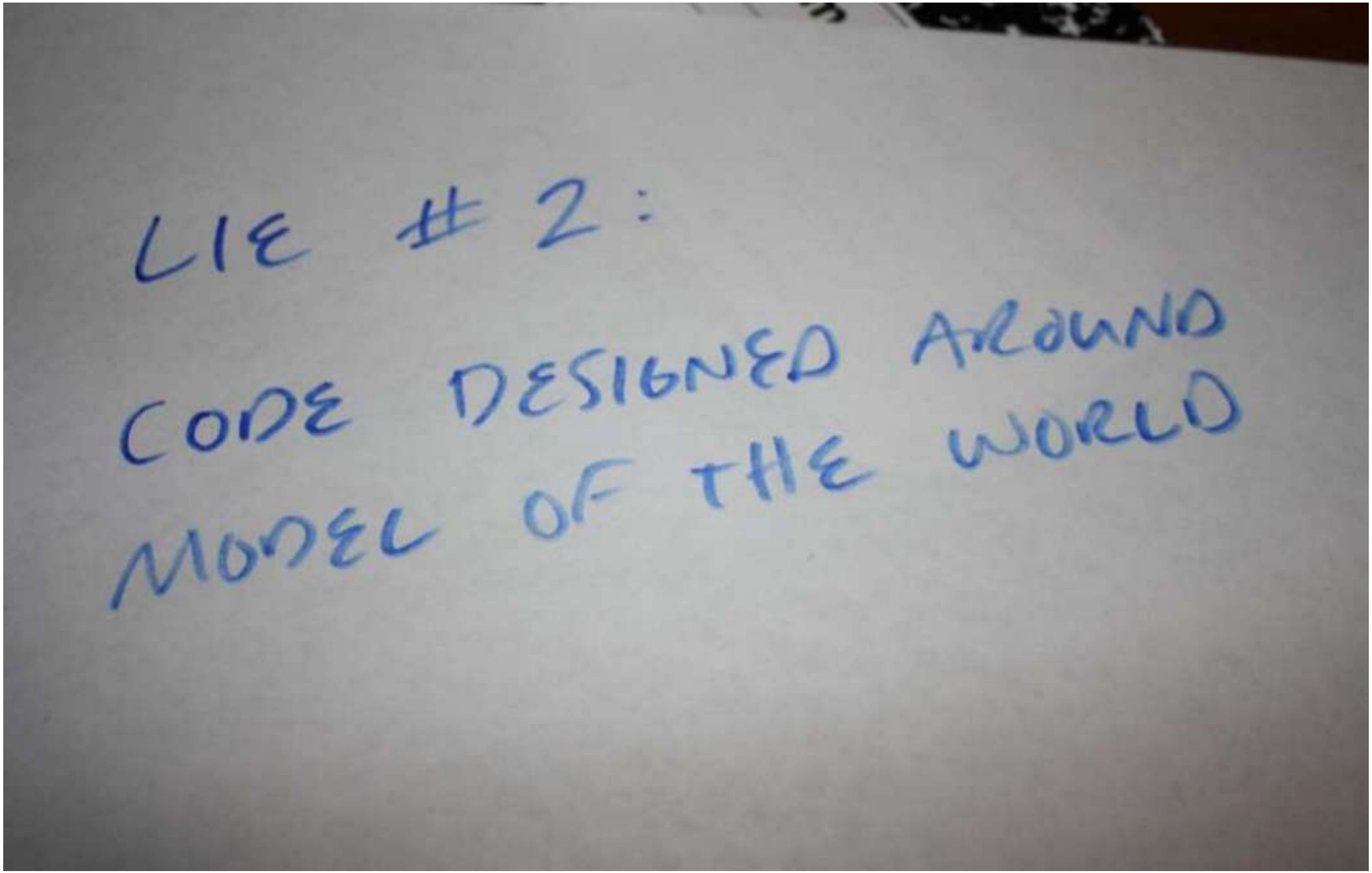

LIES
1 SOFTWARE IS A PLATFORM
2 CODE DESIGNED AROUND MODEL OF THE WORLD
3 CODE IS MORE IMPORTANT THAN DATA

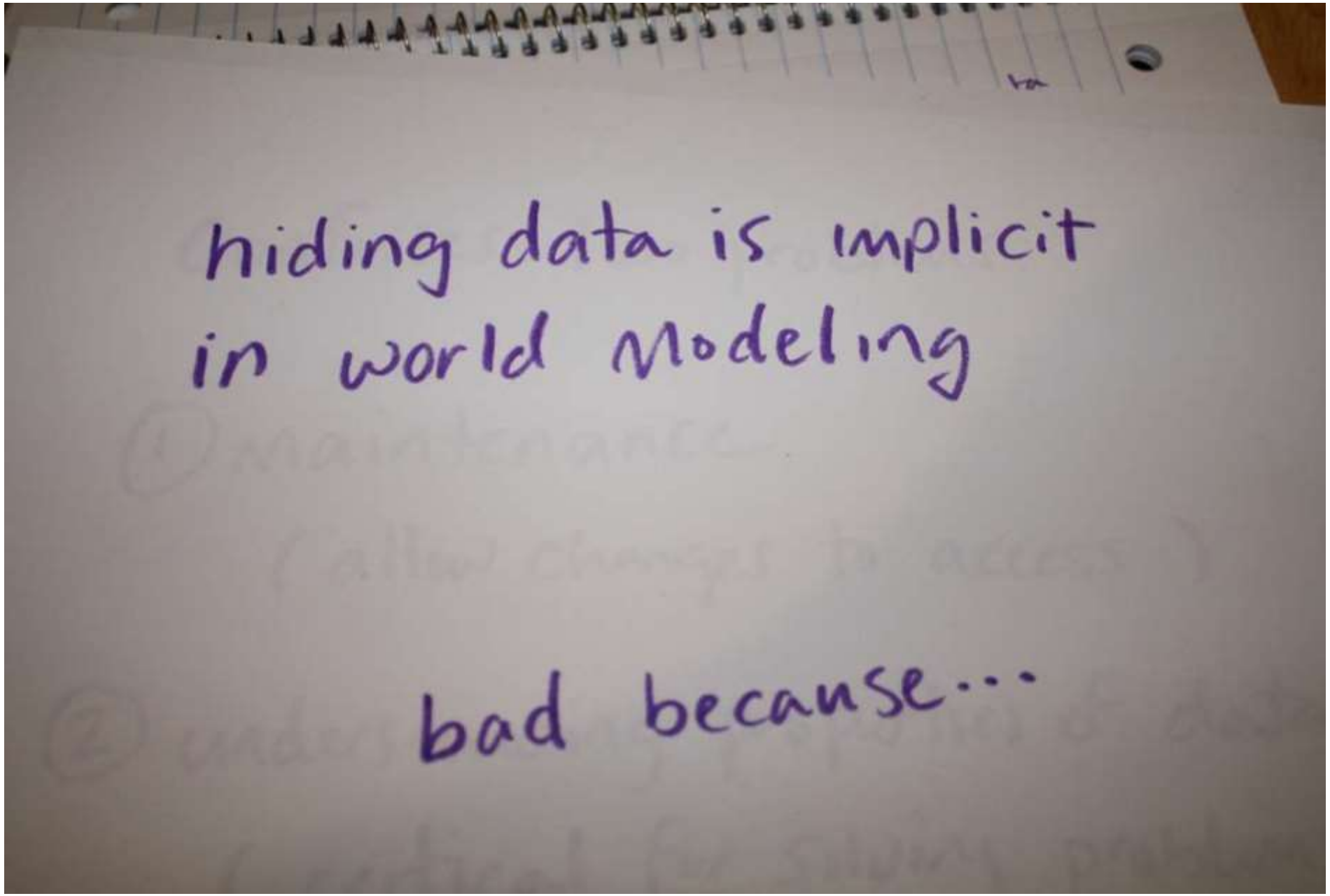

LIE #1:
SOFTWARE IS
A PLATFORM


OBVIOUS,
HARDWARE IS THE PLATFORM
TEXT
DATA
CPU
DATA


OBVIOUS,
+HARDWARE IS THE PLATFORM
TEXT
DATA
CPU
DATA
DIFFERENT HARDWARE, DIFFERENT SOLUTIONS


OBVIOUS,
HARDWARE IS THE PLATFORM
TEXT
DATA
CPU
DATA
DIFFERENT
6502
x86, ARM
CELL, PPC
ATI 5870

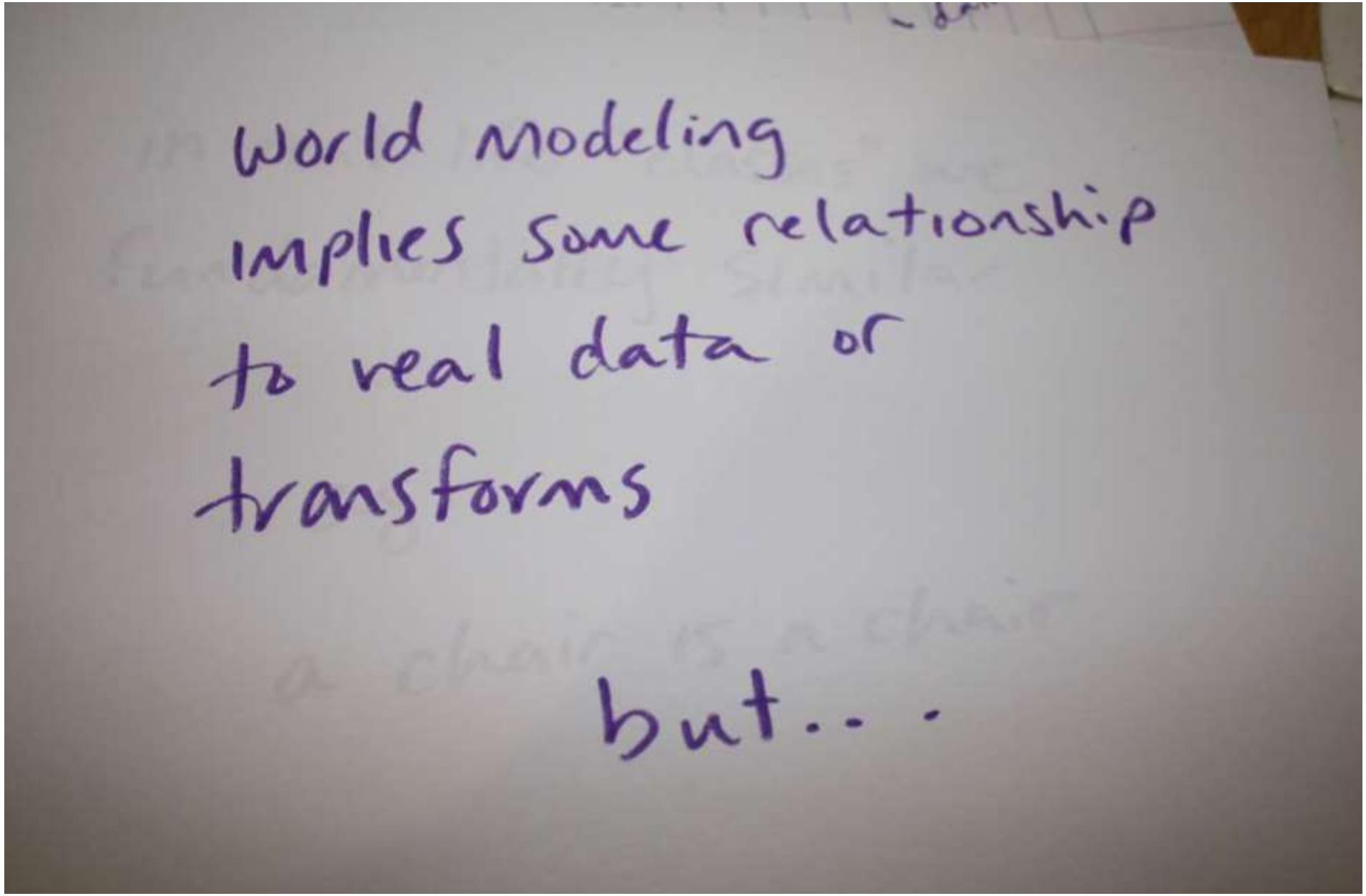

LIE #2:
CODE DESIGNED AROUND
MODEL OF THE WORLD


hiding data is implicit
in world modeling
bad because...

Confuses two problems:

① maintenance
(allow changes to access)

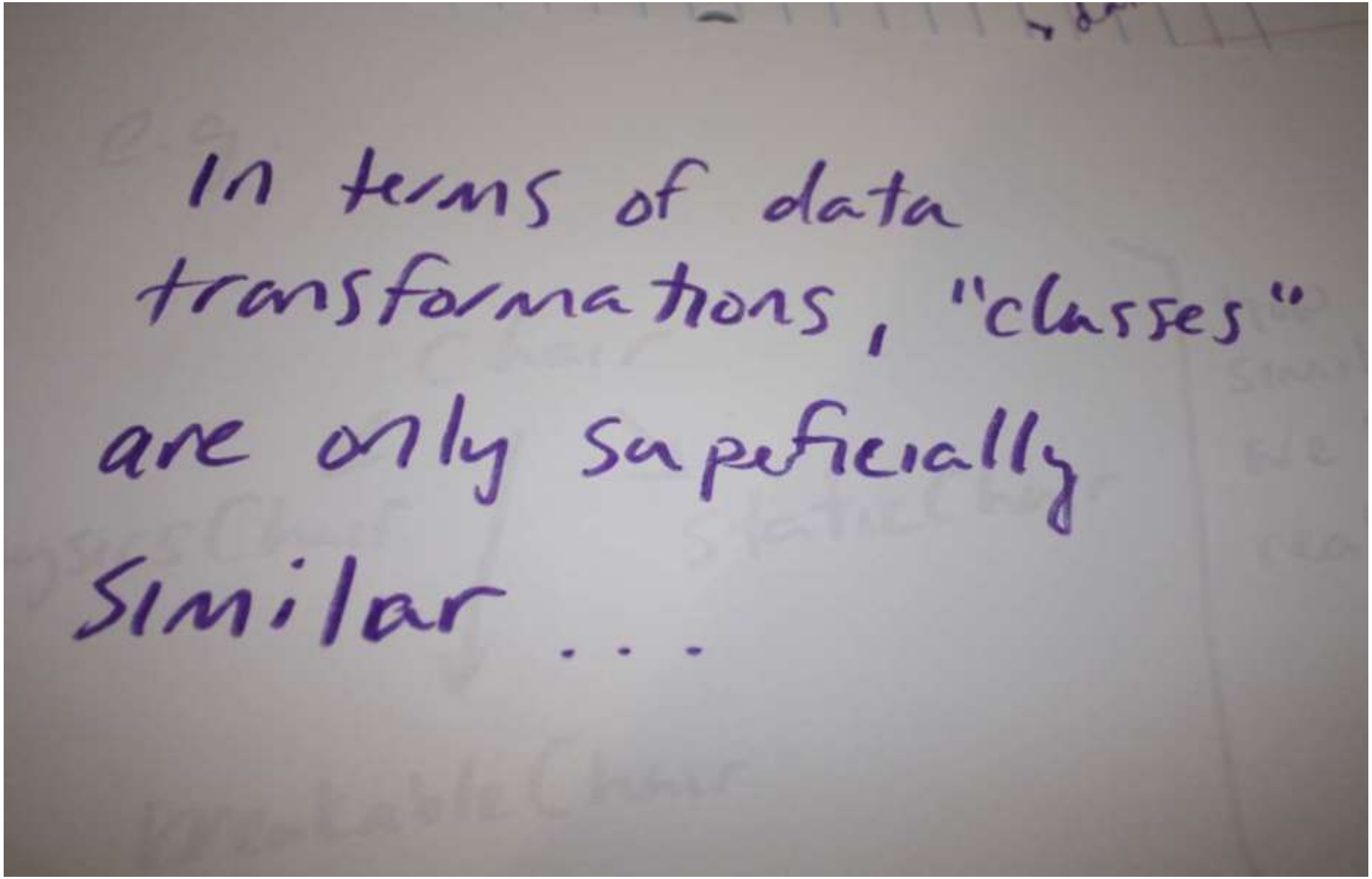
② understanding properties of data
(critical for solving problems)

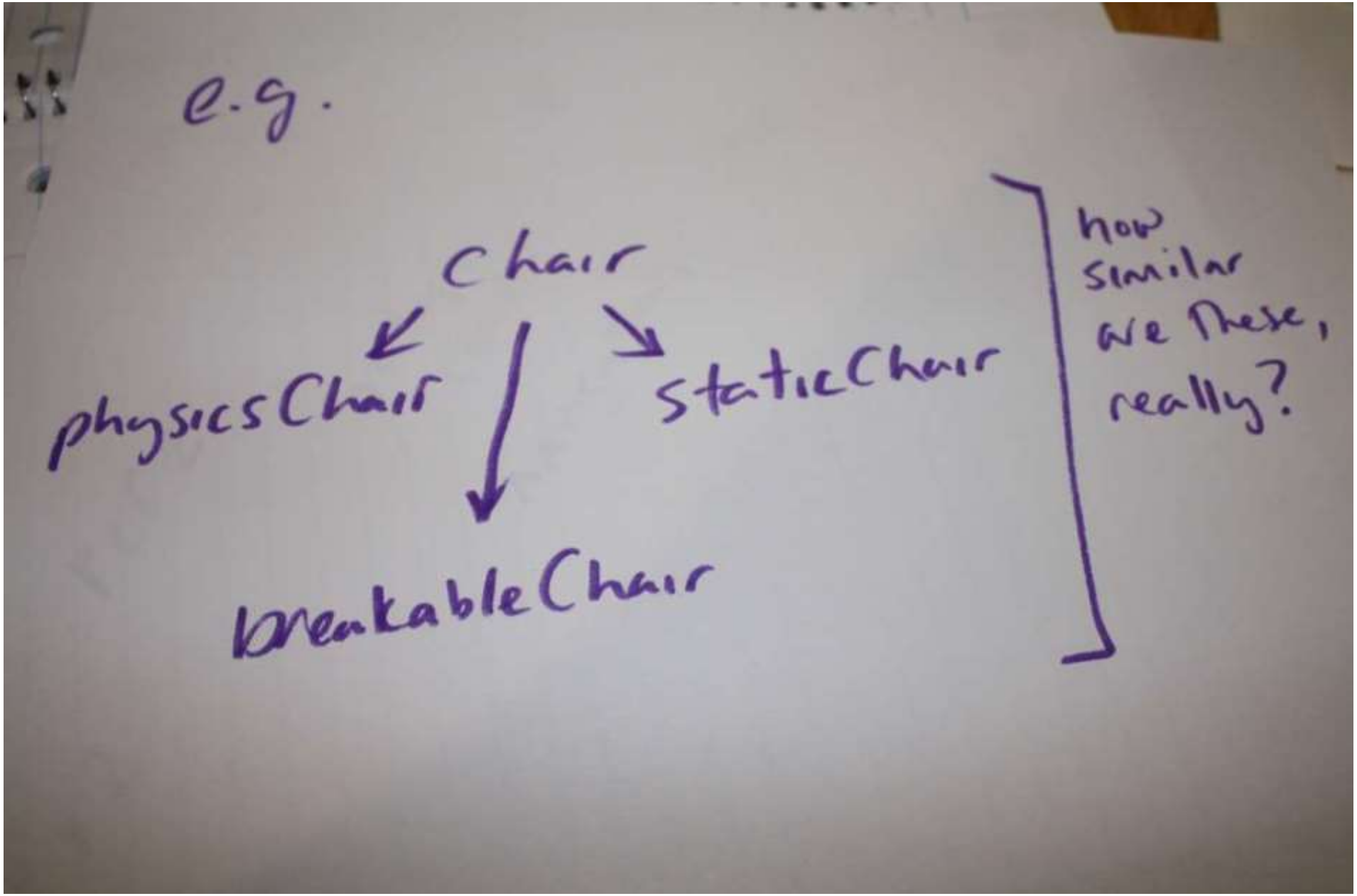

World modeling
implies some relationship
to real data or
transforms
but...

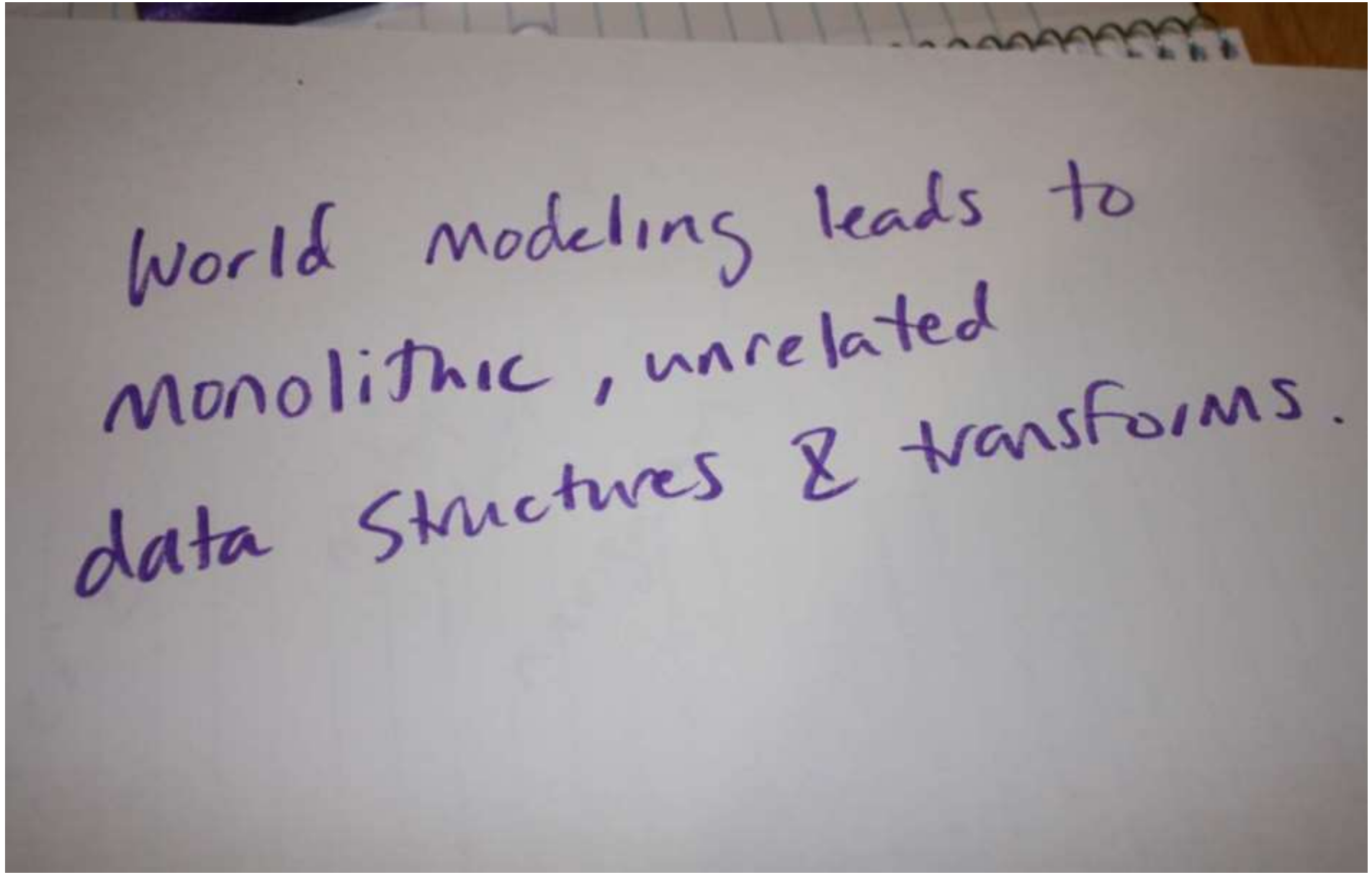
in real life "classes" are fundamentally similar

e.g.

a chair is a chair

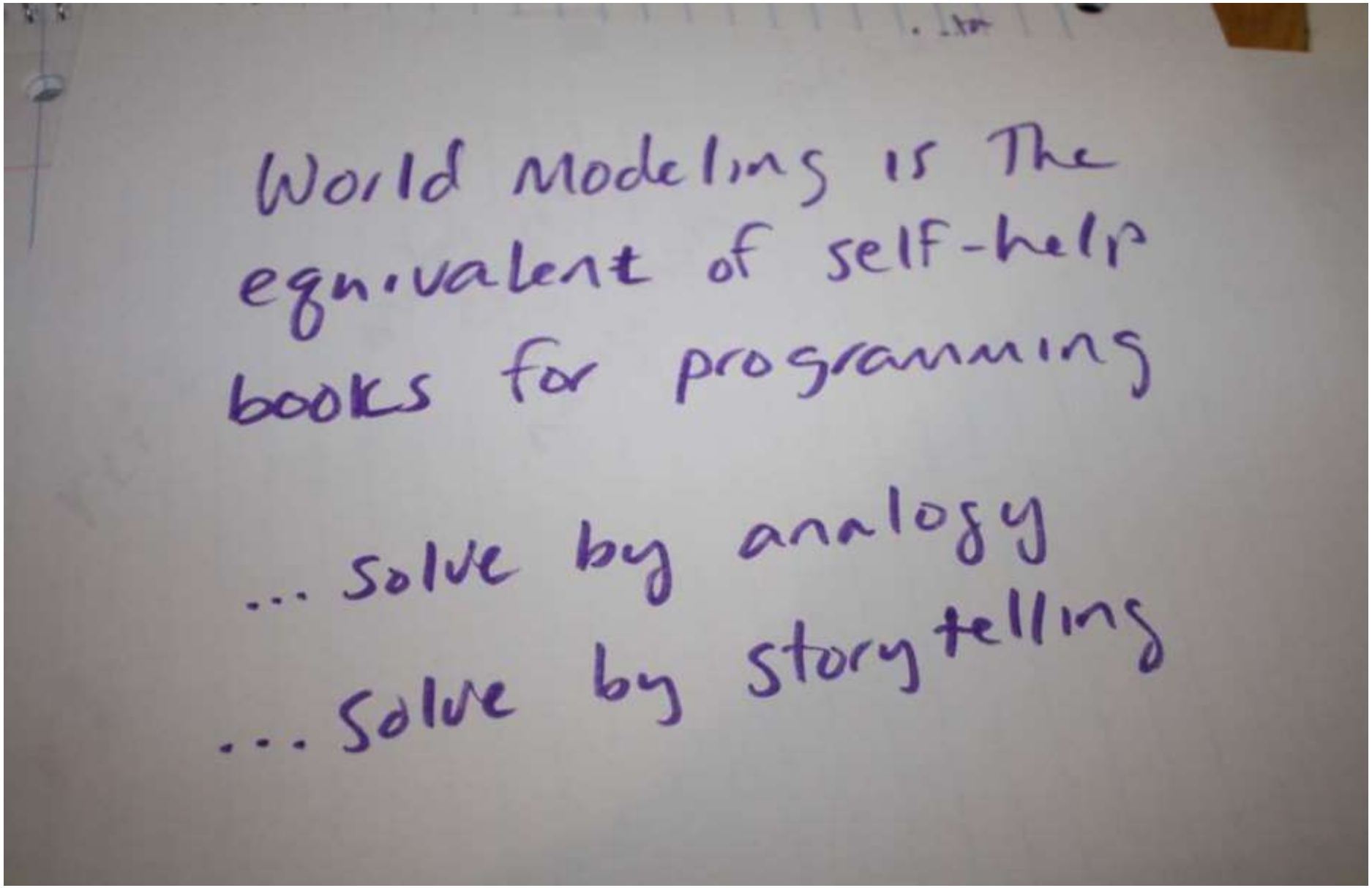

In terms of data
transformations, "classes"
are only superficially
similar . . .

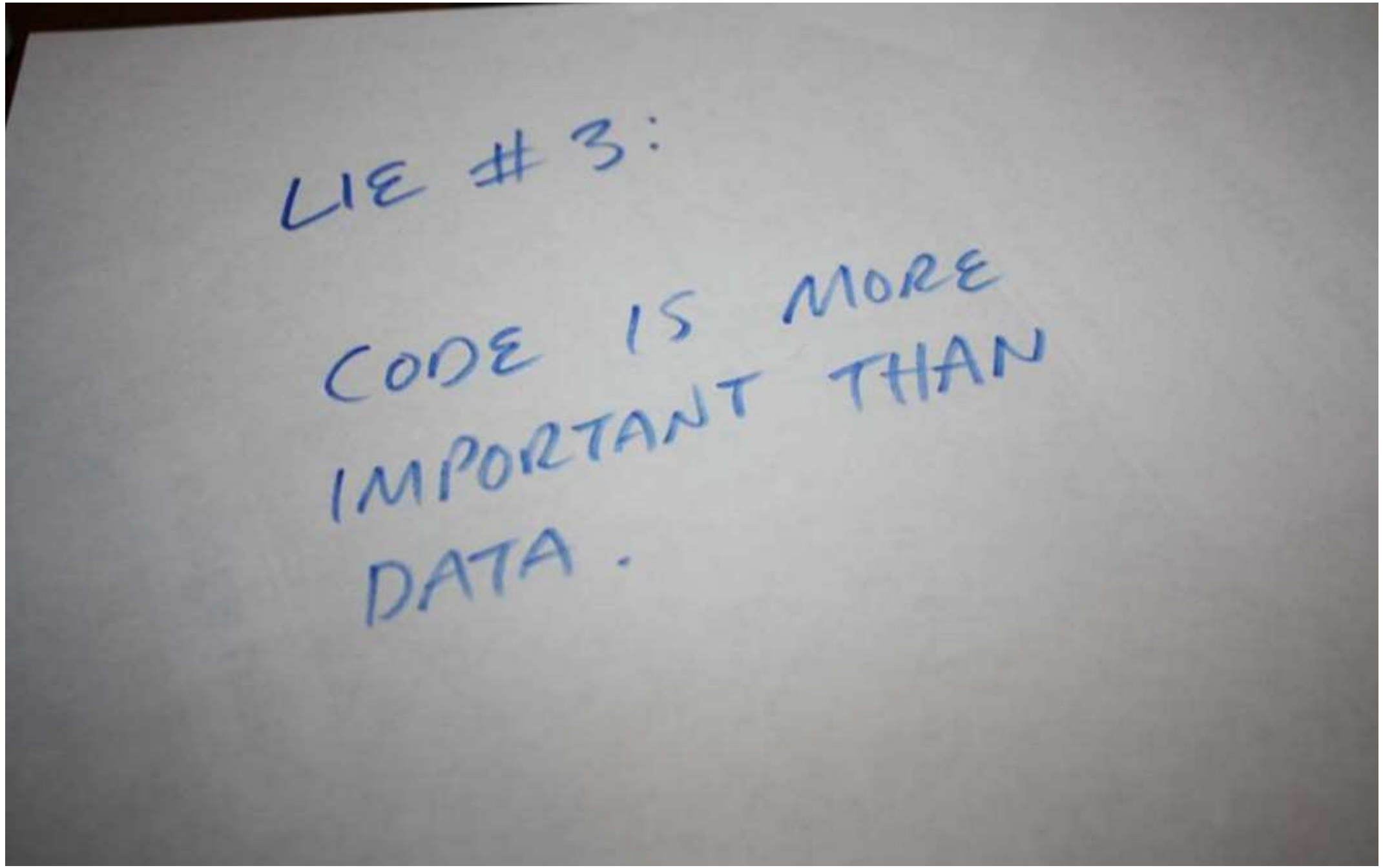

e.g.
Chair
physicsChair
staticChair
breakableChair
how similar are these, really?

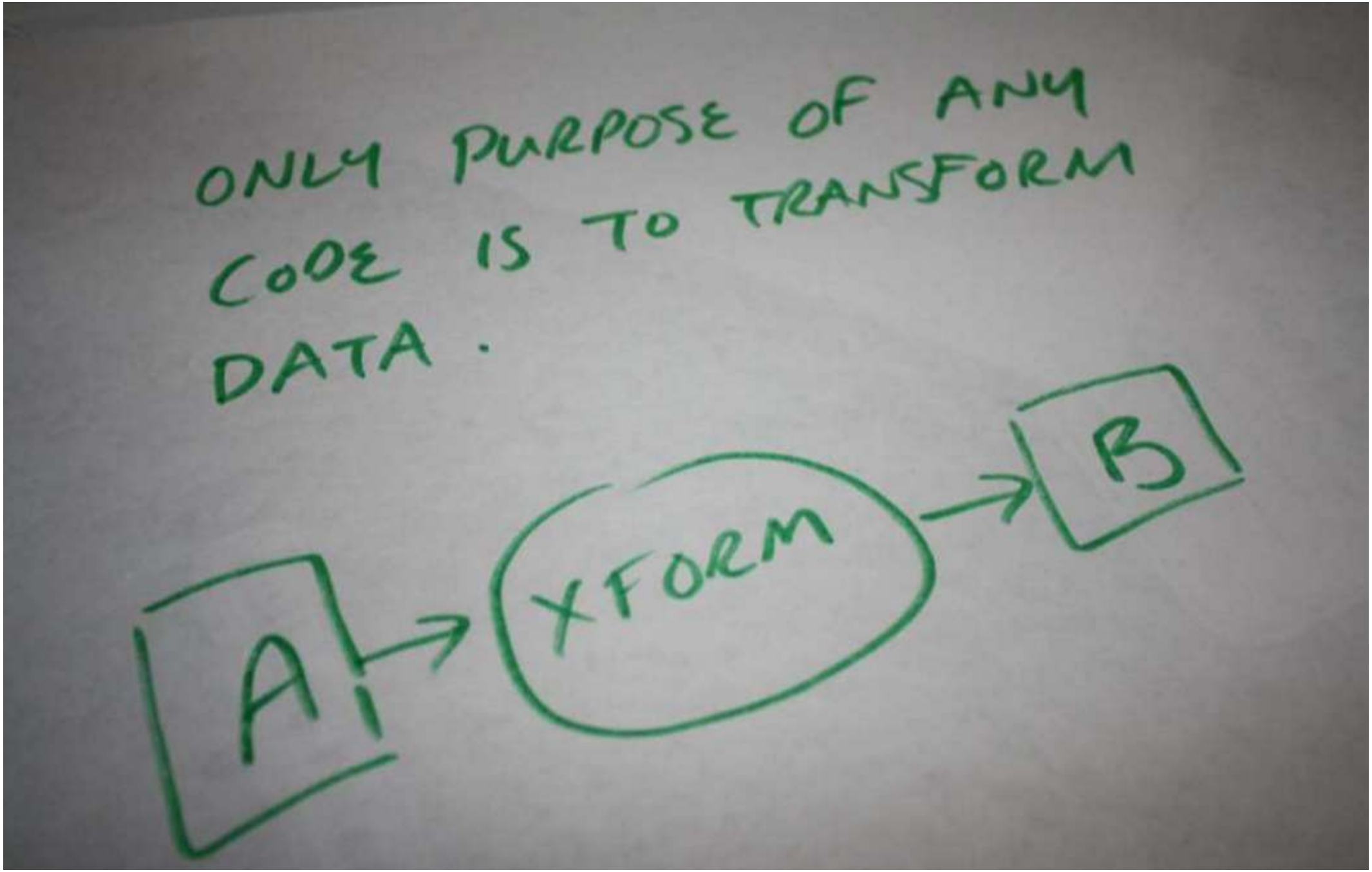

World modeling leads to
monolithic, unrelated
data structures & transforms.

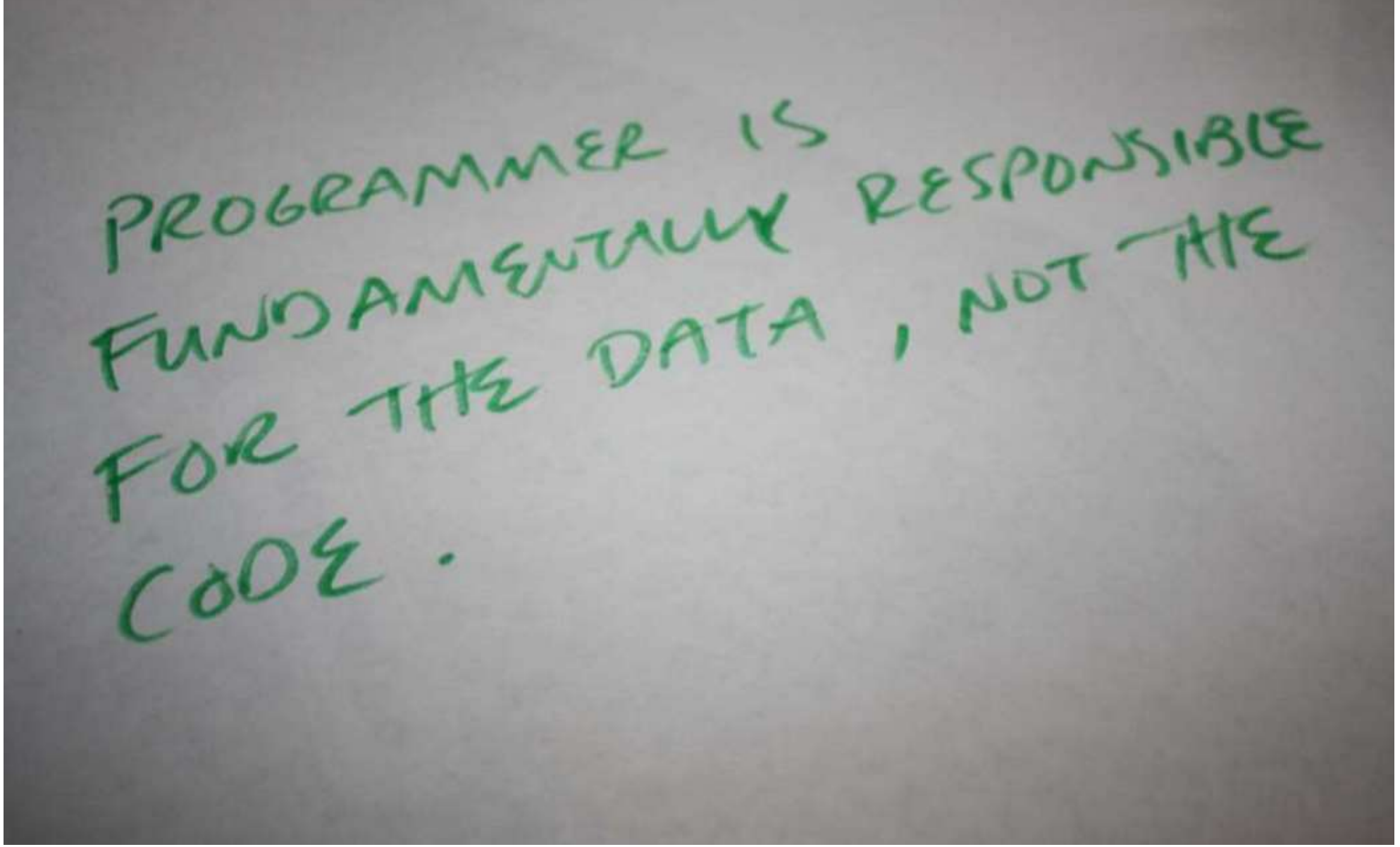
World modeling
tries to idealize the
problem.

(but you can't make a
problem simpler than it is.)


World Modeling is The
equivalent of self-help
books for programming
... solve by analogy
... solve by storytelling


LIE #3:
CODE IS MORE
IMPORTANT THAN
DATA.


ONLY PURPOSE OF ANY CODE IS TO TRANSFORM DATA.
A
XFORM
B

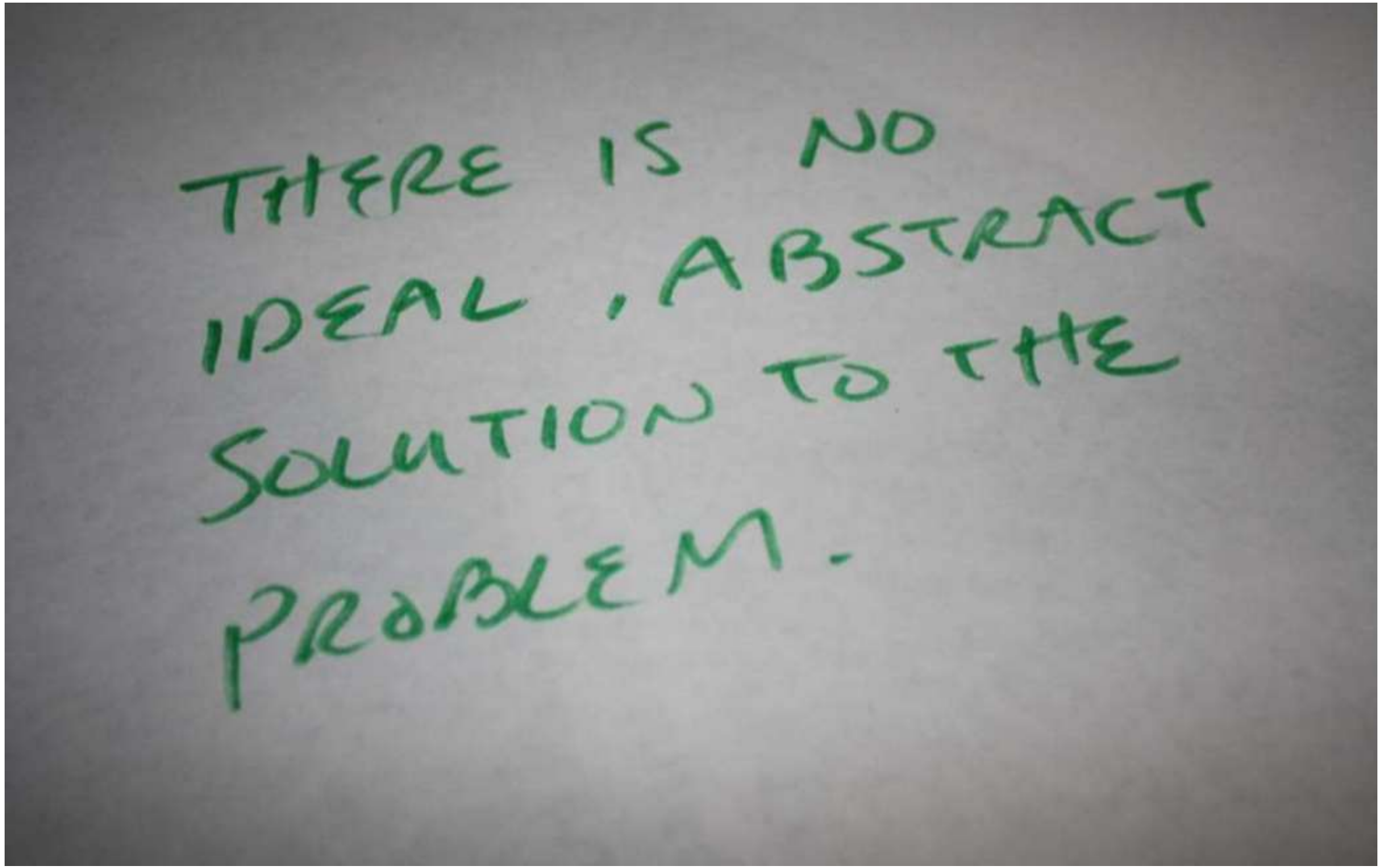


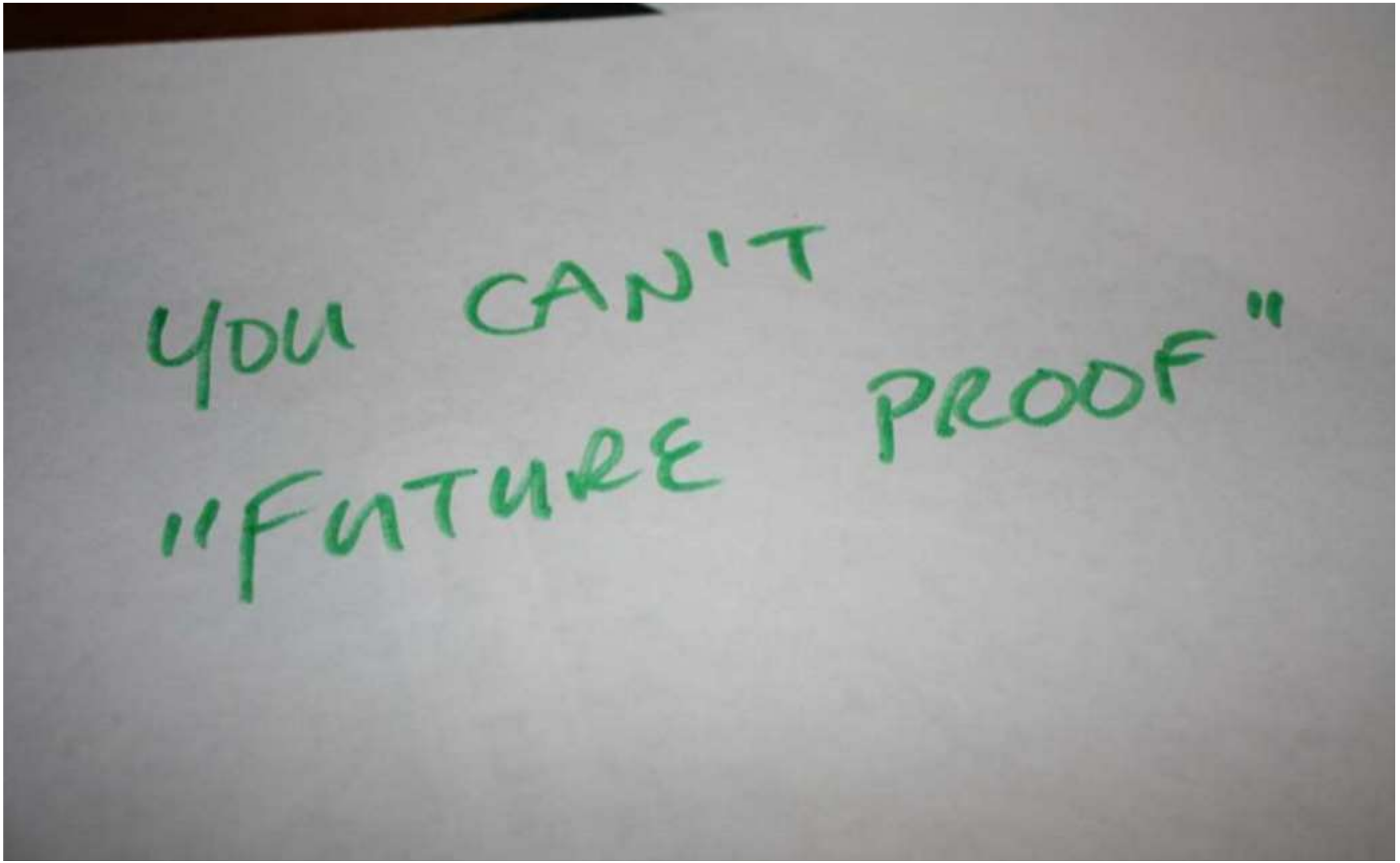
i.e. Programmer's job is NOT to write code;
Programmer's job is to solve (data transformation) problems

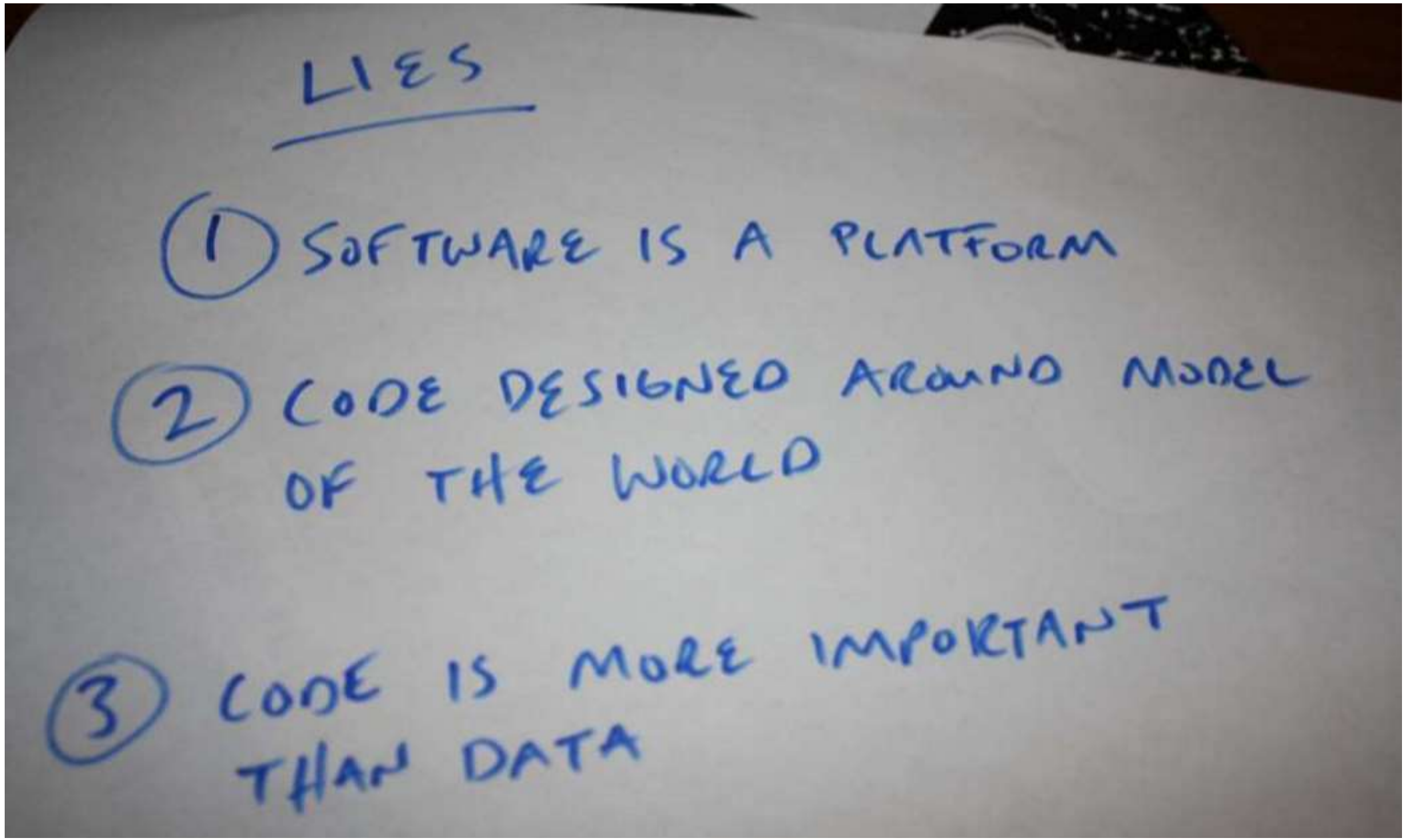
ONLY WRITE CODE THAT
HAS DIRECT, PROVABLE VALUE.

I.e. transforms DATA
IN MEANINGFUL WAY

UNDERSTAND THE DATA
TO UNDERSTAND THE
PROBLEM.


THERE IS NO
IDEAL, ABSTRACT
SOLUTION TO THE
PROBLEM.


YOU CAN'T
"FUTURE PROOF"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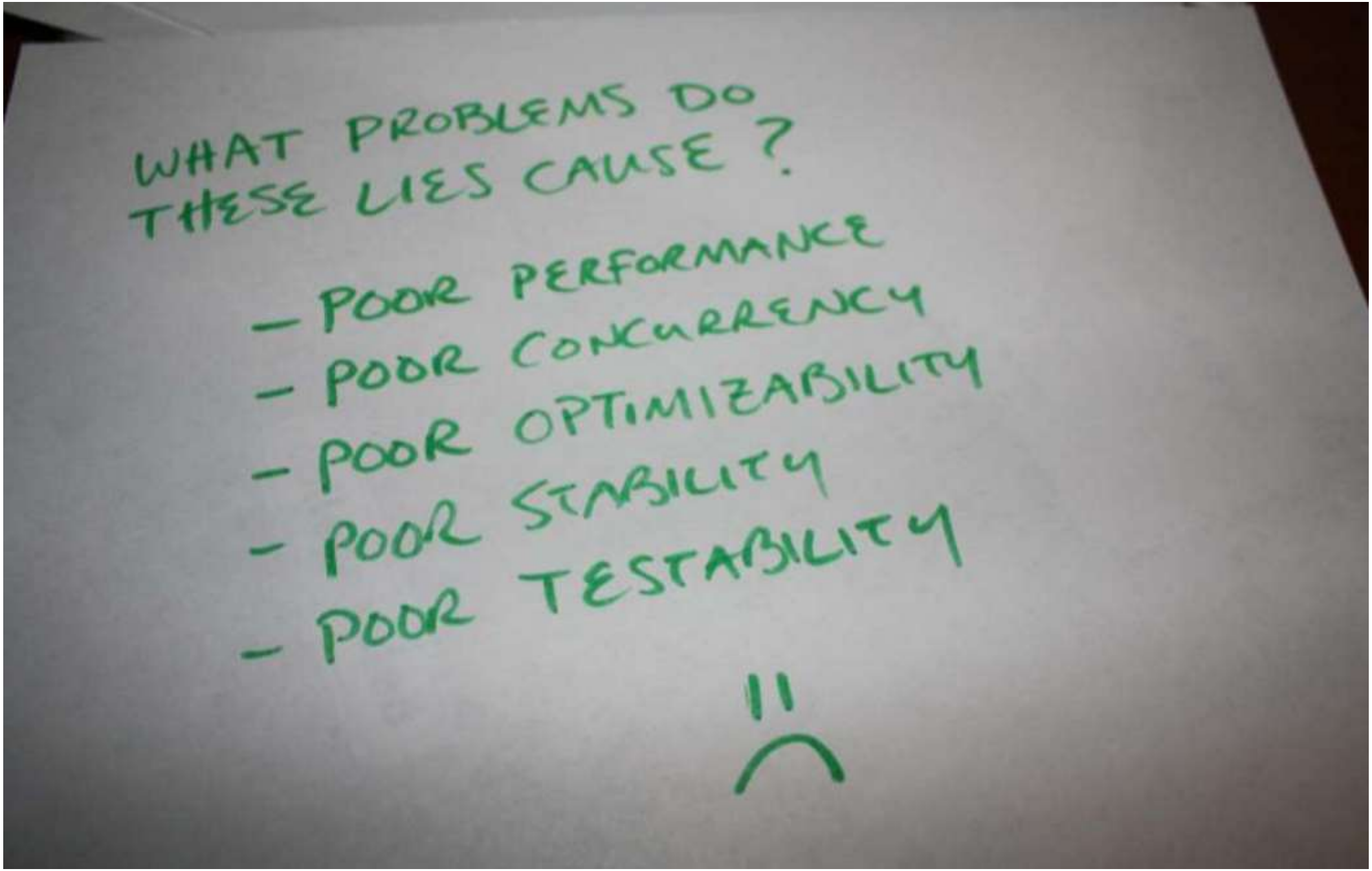
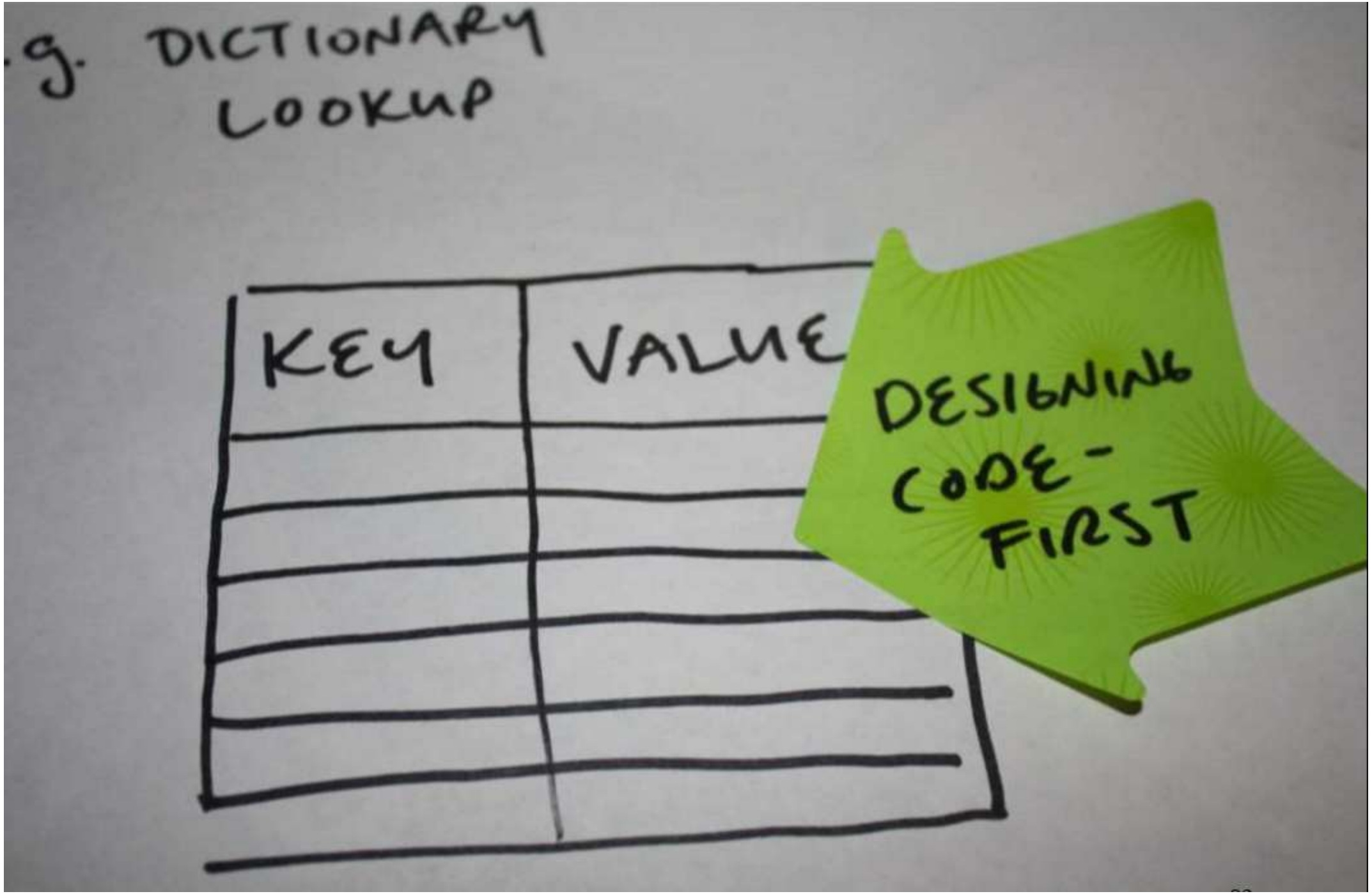

WHAT PROBLEMS DO
THESE LIES CAUSE?
- POOR PERFORMANCE
- POOR CONCURRENCY
- POOR OPTIMIZABILITY
- POOR STABILITY
- POOR TESTABILITY


SOLVE FOR TRANSFORMING
THE DATA YOU HAVE
GIVEN THE CONSTRAINTS OF
THE PLATFORM.
(AND NOTHING ELSE)

A simple example…

e.g. DICTIONARY LOOKUP

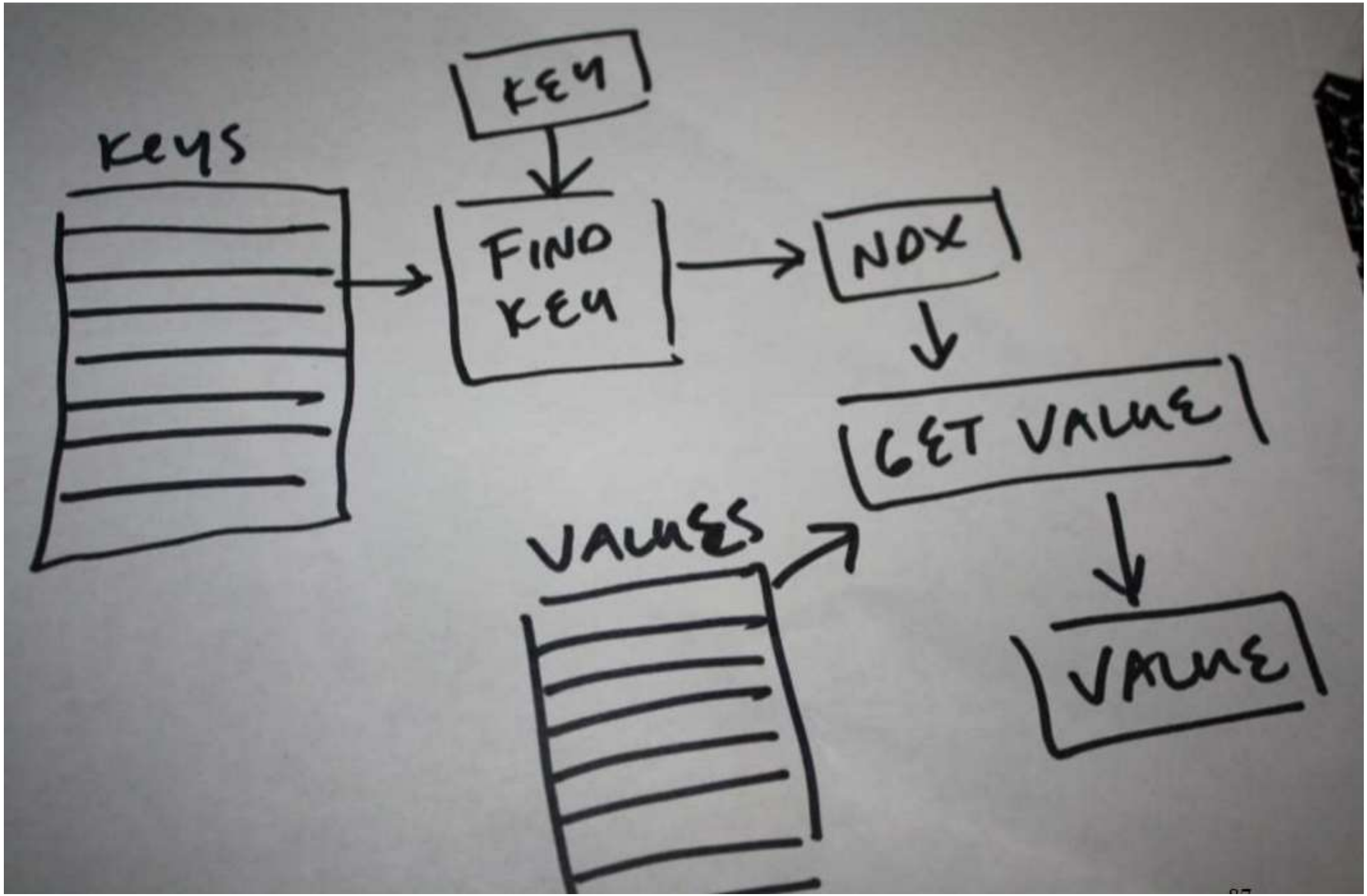

g. DICTIONARY LOOKUP
KEY
VALUE
DESIGNING CODE-FIRST


KEY
VALUE
WHILE SEARCH ON KEYS, WHAT IS STATISTICAL VALUE OF "VALUE"?

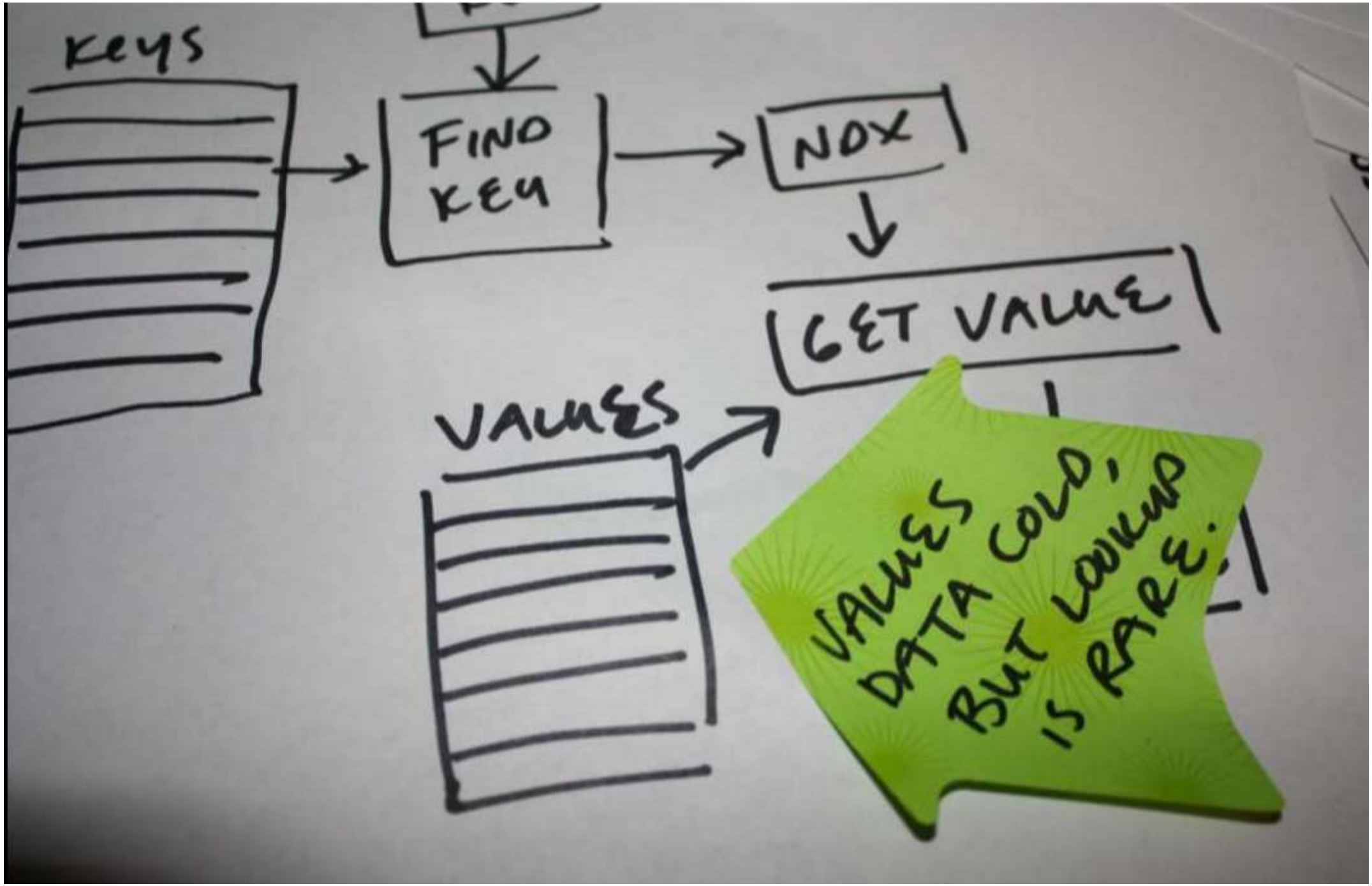

KEY
VALUE
VERY LOW!
(MORE KEYS,
LOWER
VALUE)


KEY
VALUE
SCALES
TOWARD
WORST-
CASE!


KEY
VALUE
DON'T
LOAD
VALUE
INTO
CACHE


KEY
KEYS
FIND KEY
NOX
GET VALUE
VALUES
VALUE


KEY
KEYS
FIND KEY
NOX
CACHE LOADED W/ MOST LIKELY NEEDED


KEYS
FIND KEY
NOX
GET VALUE
VALUES
VALUES DATA COLD, BUT LOOKUP IS RARE.

Solve for the most common case first,
Not the most generic.

“Can’t the compiler do it?”

A little review…

(AMD Piledriver)

Instruction	Latency
SQRTSS/PS	13-15
VSQRTPS	14-15
SQRTSD/PD	24-26
VSQRTPD	24-26

http://www.agner.org/optimize/instruction_tables.pdf

(AMD Piledriver)

Instruction	Latency
FSIN	60-146
FCOS	~154
FSINCOS	86-141
FPTAN	86-204
FPATAN	60-352

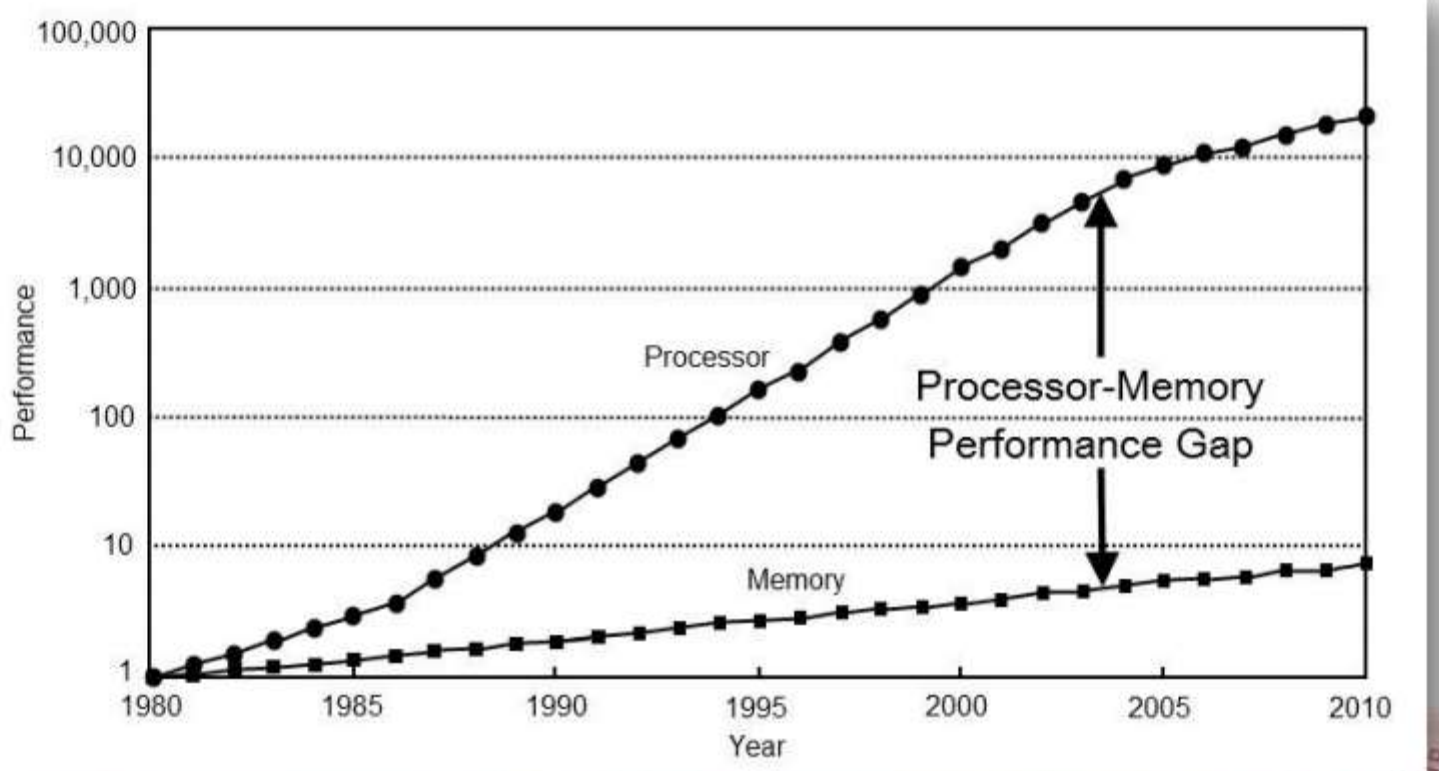
http://www.agner.org/optimize/instruction_tables.pdf

Tony Albrecht – Technical Consultant
Developer Services

LEVEL 4 PUBLIC
Sony Computer Entertainment Europe

SCEE Research & Development

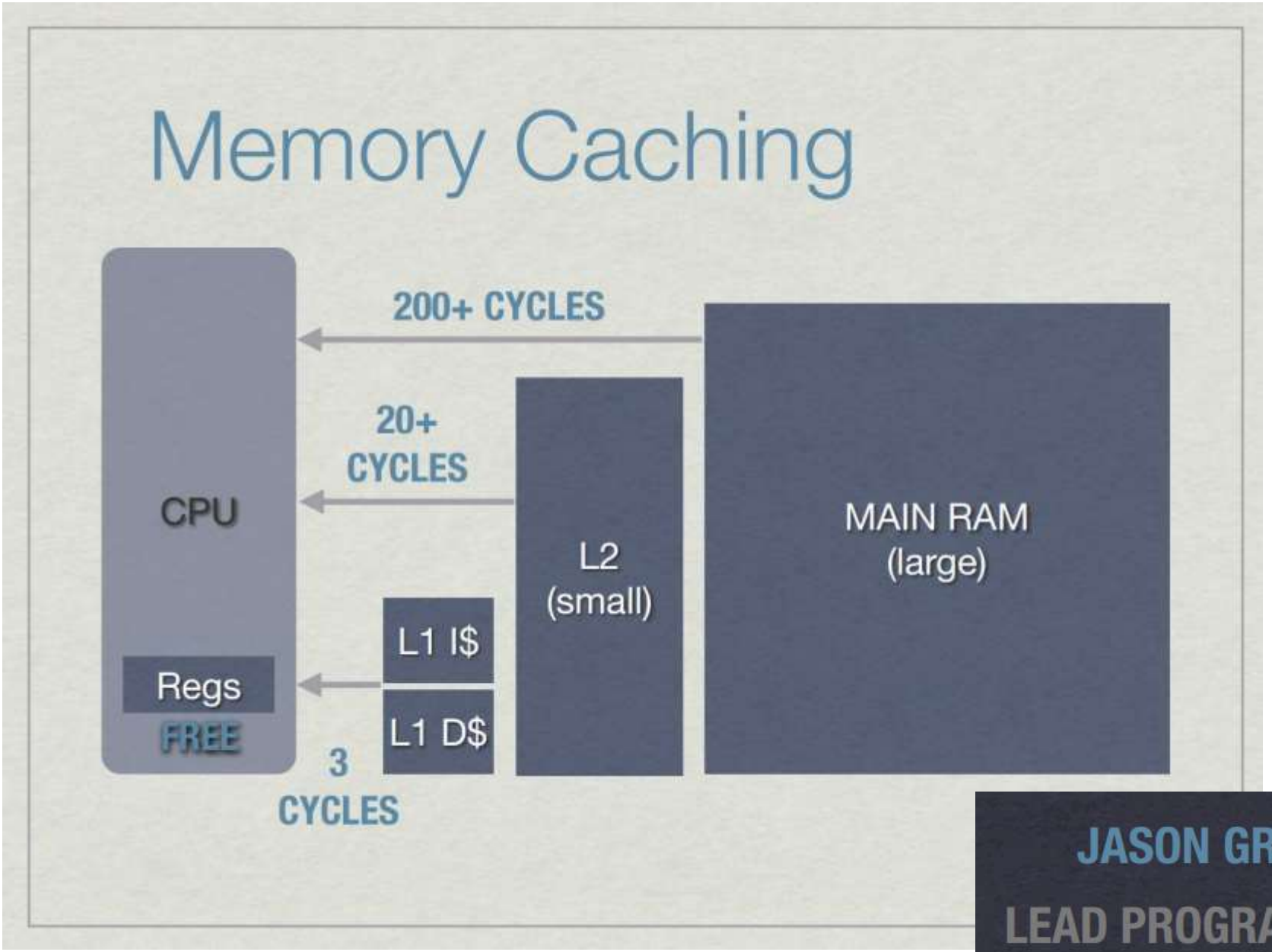
CPU/Memory performance



PS3 PlayStation 3

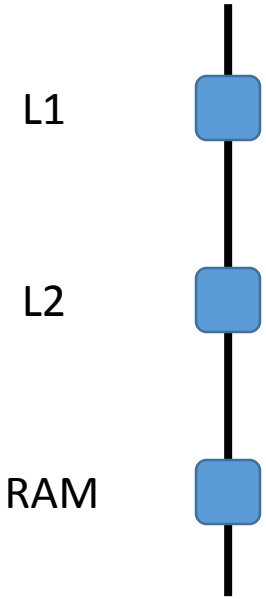
Computer architecture: a quantitative approach
By John L. Hennessy, David A. Patterson, Andrea C. Arpaci-Dusseau

http://research.scee.net/files/presentations/gcapaustralia09/Pitfalls_of_Object_Oriented_Programming_GCAP_09.pdf



http://www.gameenginebook.com/SINFO.pdf

The Battle of North Bridge



L2 cache misses/frame

(Most significant component)

Not even including shared memory modes…

Name	GPU-visible		Cached	GPU Coherent
Heap-cacheable	No		Yes	No
Heap-write-combined	No		No	No
Physical-uncached	?		No	No
GPU-write-combined	Yes		No	No
GPU-write-combined-read-only	Yes		No	No
GPU-cacheable	Yes		Yes	Yes
GPU-cacheable-noncoherent-RO	Yes		Yes	No
Command-write-combined	No		No	No
Command-cacheable	No		Yes	Yes

http://deplinenoise.wordpress.com/2013/12/28/optimizable-code/

```
class GameObject {
  float m_Pos[2];
  float m_Velocity[2];
  char m_Name[32];
  Model* m_Model;
  // ... other members ...
  float m_Foo;

  void UpdateFoo(float f)
  {
    float mag = sqrtf(
      m_Velocity[0] * m_Velocity[0] +
      m_Velocity[1] * m_Velocity[1]);
      m_Foo += mag * f;
  }
};
```

```
_ZN10GameObject9UpdateFooEf:                # @_ZN10GameObject9UpdateFooEf
        .cfi_startproc
# BB#0:
        pushq   %rbx
.Ltmp2:
        .cfi_def_cfa_offset 16
        subq    $16, %rsp
.Ltmp3:
        .cfi_def_cfa_offset 32
.Ltmp4:
        .cfi_offset %rbx, -16
        movss   %xmm0, 12(%rsp)             # 4-byte Spill
        movq    %rdi, %rbx
        movss   8(%rbx), %xmm1
        movss   12(%rbx), %xmm0
        mulss   %xmm1, %xmm1
        mulss   %xmm0, %xmm0
        addss   %xmm1, %xmm0
        callq   sqrtf
        mulss   12(%rsp), %xmm0             # 4-byte Folded Reload
        addss   184(%rbx), %xmm0
        movss   %xmm0, 184(%rbx)
        addq    $16, %rsp
        popq    %rbx
        ret
.Ltmp5:
        .size   _ZN10GameObject9UpdateFooEf, .Ltmp5-_ZN10GameObject9UpdateFooEf
        .cfi_endproc
```

```
_ZN10GameObject9UpdateFooEf:                # @_ZN10GameObject9UpdateFooEf
        .cfi_startproc
# BB#0:
        pushq   %rbx
.Ltmp2:
        .cfi_def_cfa_offset 16
        subq    $16, %rsp
.Ltmp3:
        .cfi_def_cfa_offset 32
.Ltmp4:
        .cfi_offset %rbx, -16
        movss   %xmm0, 12(%rsp)             # 4-byte Spill
        movq    %rdi, %rbx
        movss   8(%rbx), %xmm1
        movss   12(%rbx), %xmm0
        mulss   %xmm1, %xmm1
        mulss   %xmm0, %xmm0
        addss   %xmm1, %xmm0
        callq   sqrtf
        mulss   12(%rsp), %xmm0             # 4-byte Folded Reload
        addss   184(%rbx), %xmm0
        movss   %xmm0, 184(%rbx)
        addq    $16, %rsp
        popq    %rbx
        ret
.Ltmp5:
        .size   _ZN10GameObject9UpdateFooEf, .Ltmp5-_ZN10GameObject9UpdateFooEf
        .cfi_endproc
```

2 x 32bit read; same cache line = ~200

```
_ZN10GameObject9UpdateFooEf:                # @_ZN10GameObject9UpdateFooEf
        .cfi_startproc
# BB#0:
        pushq   %rbx
.Ltmp2:
        .cfi_def_cfa_offset 16
        subq    $16, %rsp
.Ltmp3:
        .cfi_def_cfa_offset 32
.Ltmp4:
        .cfi_offset %rbx, -16
        movss   %xmm0, 12(%rsp)             # 4-byte Spill
        movq    %rdi, %rbx
        movss   8(%rbx), %xmm1
        movss   12(%rbx), %xmm0
        mulss   %xmm1, %xmm1
        mulss   %xmm0, %xmm0
        addss   %xmm1, %xmm0
        callq   sqrtf
        mulss   12(%rsp), %xmm0             # 4-byte Folded Reload
        addss   184(%rbx), %xmm0
        movss   %xmm0, 184(%rbx)
        addq    $16, %rsp
        popq    %rbx
        ret
.Ltmp5:
        .size   _ZN10GameObject9UpdateFooEf, .Ltmp5-_ZN10GameObject9UpdateFooEf
        .cfi_endproc
```

Float mul, add = ~10

```
_ZN10GameObject9UpdateFooEf:                # @_ZN10GameObject9UpdateFooEf
        .cfi_startproc
# BB#0:
        pushq   %rbx
.Ltmp2:
        .cfi_def_cfa_offset 16
        subq    $16, %rsp
.Ltmp3:
        .cfi_def_cfa_offset 32
.Ltmp4:
        .cfi_offset %rbx, -16
        movss   %xmm0, 12(%rsp)             # 4-byte Spill
        movq    %rdi, %rbx
        movss   8(%rbx), %xmm1
        movss   12(%rbx), %xmm0
        mulss   %xmm1, %xmm1
        mulss   %xmm0, %xmm0
        addss   %xmm1, %xmm0
        callq   sqrtf
        mulss   12(%rsp), %xmm0             # 4-byte Folded Reload
        addss   184(%rbx), %xmm0
        movss   %xmm0, 184(%rbx)
        addq    $16, %rsp
        popq    %rbx
        ret
.Ltmp5:
        .size   _ZN10GameObject9UpdateFooEf, .Ltmp5-_ZN10GameObject9UpdateFooEf
        .cfi_endproc
```

Let's assume callq is replaced. Sqrt = ~30

```
_ZN10GameObject9UpdateFooEf:                # @_ZN10GameObject9UpdateFooEf
        .cfi_startproc
# BB#0:
        pushq   %rbx
.Ltmp2:
        .cfi_def_cfa_offset 16
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.Ltmp3:
        .cfi_def_cfa_offset 32
.Ltmp4:
        .cfi_offset %rbx, -16
        movss   %xmm0, 12(%rsp)             # 4-byte Spill
        movq    %rdi, %rbx
        movss   8(%rbx), %xmm1
        movss   12(%rbx), %xmm0
        mulss   %xmm1, %xmm1
        mulss   %xmm0, %xmm0
        addss   %xmm1, %xmm0
        callq   sqrtf
        mulss   12(%rsp), %xmm0             # 4-byte Folded Reload
        addss   184(%rbx), %xmm0
        movss   %xmm0, 184(%rbx)
        addq    $16, %rsp
        popq    %rbx
        ret
.Ltmp5:
        .size   _ZN10GameObject9UpdateFooEf, .Ltmp5-_ZN10GameObject9UpdateFooEf
        .cfi_endproc
```

Mul back to same addr; in L1; = ~3

```
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.Ltmp4:
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        movss   %xmm0, 12(%rsp)             # 4-byte Spill
        movq    %rdi, %rbx
        movss   8(%rbx), %xmm1
        movss   12(%rbx), %xmm0
        mulss   %xmm1, %xmm1
        mulss   %xmm0, %xmm0
        addss   %xmm1, %xmm0
        callq   sqrtf
        mulss   12(%rsp), %xmm0             # 4-byte Folded Reload
        addss   184(%rbx), %xmm0
        movss   %xmm0, 184(%rbx)
        addq    $16, %rsp
        popq    %rbx
        ret
.Ltmp5:
        .size   _ZN10GameObject9UpdateFooEf, .Ltmp5-_ZN10GameObject9UpdateFooEf
        .cfi_endproc
```

Read+add from new line
= ~200

```
_ZN10GameObject9UpdateFooEf:                # @_ZN10GameObject9UpdateFooEf
        .cfi_startproc
# BB#0:
        pushq   %rbx
.Ltmp2:
        .cfi_def_cfa_offset 16
        subq    $16, %rsp
.Ltmp3:
        .cfi_def_cfa_offset 32
.Ltmp4:
        .cfi_offset %rbx, -16
        movss   %xmm0, 12(%rsp)
        movq    %rdi, %rbx
        movss   8(%rbx), %xmm1
        movss   12(%rbx), %xmm0
        mulss   %xmm1, %xmm1
        mulss   %xmm0, %xmm0
        addss   %xmm1, %xmm0
        callq   sqrtf
        mulss   12(%rsp), %xmm0         # 4-byte Folded Reload
        addss   184(%rbx), %xmm0
        movss   %xmm0, 184(%rbx)
        addq    $16, %rsp
        popq    %rbx
        ret
.Ltmp5:
        .size   _ZN10GameObject9UpdateFooEf, .Ltmp5-_ZN10GameObject9UpdateFooEf
        .cfi_endproc
```

Time spent waiting for L2 vs. actual work

~10:1

```
_ZN10GameObject9UpdateFooEf:                # @_ZN10GameObject9UpdateFooEf
        .cfi_startproc
# BB#0:
        pushq   %rbx
.Ltmp2:
        .cfi_def_cfa_offset 16
        subq    $16, %rsp
.Ltmp3:
        .cfi_def_cfa_offset 32
.Ltmp4:
        .cfi_offset %rbx, -16
        movss   %xmm0, 12(%rsp)
        movq    %rdi, %rbx
        movss   8(%rbx), %xmm1
        movss   12(%rbx), %xmm0
        mulss   %xmm1, %xmm1
        mulss   %xmm0, %xmm0
        addss   %xmm1, %xmm0
        callq   sqrtf
        mulss   12(%rsp), %xmm0             # 4-byte Folded Reload
        addss   184(%rbx), %xmm0
        movss   %xmm0, 184(%rbx)
        addq    $16, %rsp
        popq    %rbx
        ret
.Ltmp5:
        .size   _ZN10GameObject9UpdateFooEf, .Ltmp5-_ZN10GameObject9UpdateFooEf
        .cfi_endproc
```

Time spent waiting for L2 vs. actual work

~10:1

This is the compiler's space.

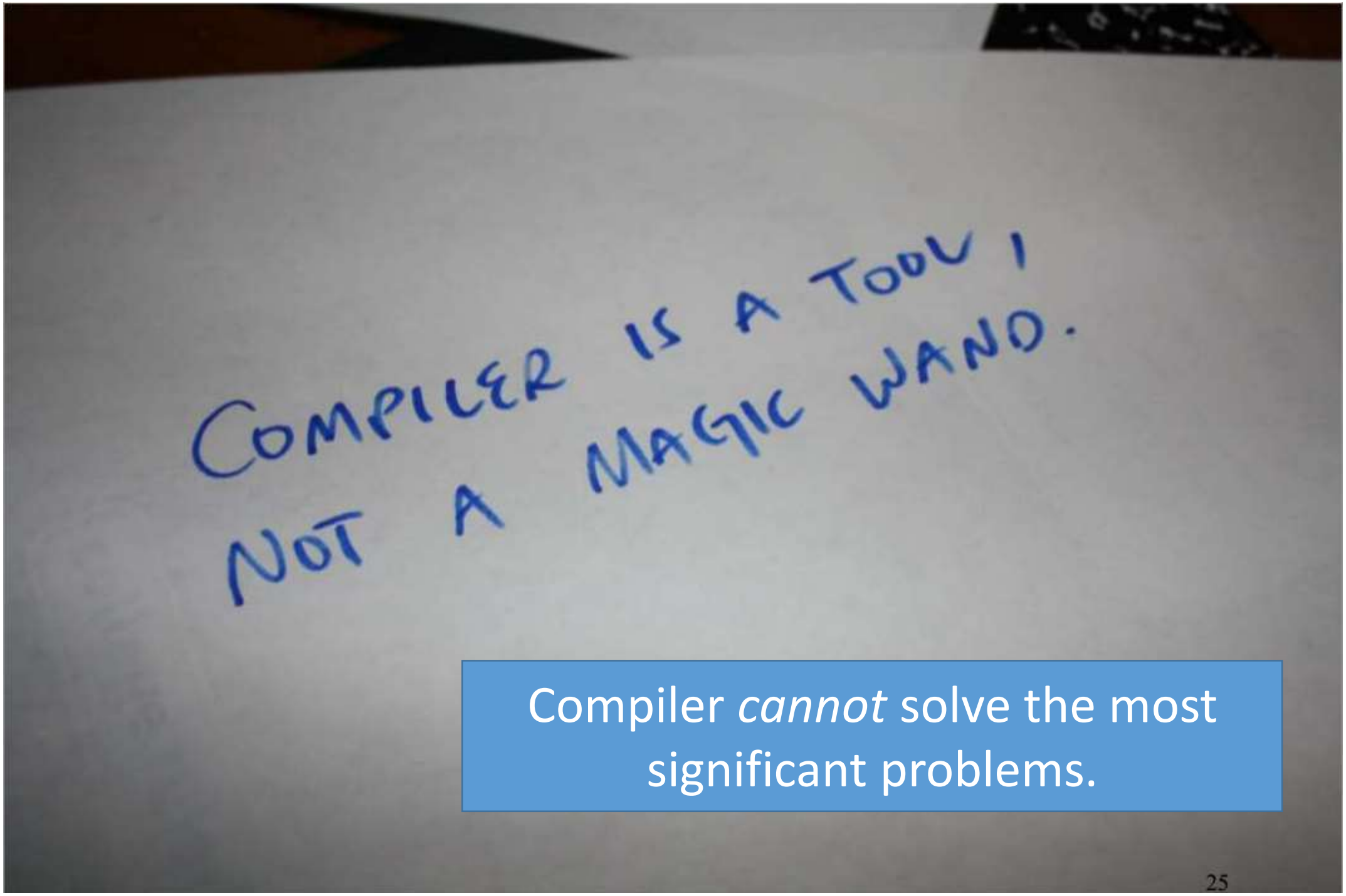
```
_ZN10GameObject9UpdateFooEf:                # @_ZN10GameObject9UpdateFooEf
        .cfi_startproc
# BB#0:
        pushq   %rbx
.Ltmp2:
        .cfi_def_cfa_offset 16
        subq    $16, %rsp
.Ltmp3:
        .cfi_def_cfa_offset 32
.Ltmp4:
        .cfi_offset %rbx, -16
        movss   %xmm0, 12(%rsp)
        movq    %rdi, %rbx
        movss   8(%rbx), %xmm1
        movss   12(%rbx), %xmm0
        mulss   %xmm1, %xmm1
        m
        a
        c
        m
        a
        m
        a
        popq    %rbx
        ret
.Ltmp5:
        .size   _ZN10GameObject9UpdateFooEf, .Ltmp5-_ZN10GameObject9UpdateFooEf
        .cfi_endproc
```

Time spent waiting for L2 vs. actual work

~10:1

This is the compiler's space.

Compiler can solve about 1-10% of the problem space.
i.e. the vast majority of problems are things the compiler can't reason about



Compiler *cannot* solve the most significant problems.

Today's subject:
The 90% of problem space we need to solve that the compiler cannot.

(And how we can help it with the 10% that it can.)

Simple, obvious things to look for
+ Back of the envelope calculations
= Substantial wins

L2 cache misses/frame

(Don’t waste them!)

```
_ZN10GameObject9UpdateFooEf:                # @_ZN10GameObject9UpdateFooEf
        .cfi_startproc
# BB#0:
        pushq   %rbx
.Ltmp2:
        .cfi_def_cfa_offset 16
        subq    $16, %rsp
.Ltmp3:
        .cfi_def_cfa_offset 32
.Ltmp4:
        .cfi_offset %rbx, -16
        movss   %xmm0, 12(%rsp)             # 4-byte Spill
        movq    %rdi, %rbx
        movss   8(%rbx), %xmm1
        movss   12(%rbx), %xmm0
        mulss   %xmm1, %xmm1
        mulss   %xmm0, %xmm0
        addss   %xmm1, %xmm0
        callq   sqrtf
        mulss   12(%rsp), %xmm0             # 4-byte Folded Reload
        addss   184(%rbx), %xmm0
        movss   %xmm0, 184(%rbx)
        addq    $16, %rsp
        popq    %rbx
        ret
.Ltmp5:
        .size   _ZN10GameObject9UpdateFooEf, .Ltmp5-_ZN10GameObject9UpdateFooEf
        .cfi_endproc
```

Waste 56 bytes / 64 bytes

```
_ZN10GameObject9UpdateFooEf:                # @_ZN10GameObject9UpdateFooEf
        .cfi_startproc
# BB#0:
        pushq   %rbx
.Ltmp2:
        .cfi_def_cfa_offset 16
        subq    $16, %rsp
.Ltmp3:
        .cfi_def_cfa_offset 32
.Ltmp4:
        .cfi_offset %rbx, -16
        movss   %xmm0, 12(%rsp)             # 4-byte Spill
        movq    %rdi, %rbx
        movss   8(%rbx), %xmm1
        movss   12(%rbx), %xmm0
        mulss   %xmm1, %xmm1
        mulss   %xmm0, %xmm0
        addss   %xmm1, %xmm0
        callq   sqrtf
        mulss   12(%rsp), %xmm0             # 4-byte Folded Reload
        addss   184(%rbx), %xmm0
        movss   %xmm0, 184(%rbx)
        addq    $16, %rsp
        popq    %rbx
        ret
.Ltmp5:
        .size   _ZN10GameObject9UpdateFooEf, .Ltmp5-_ZN10GameObject9UpdateFooEf
        .cfi_endproc
```

Waste 60 bytes / 64 bytes

```
_ZN10GameObject9UpdateFooEf:                # @_ZN10GameObject9UpdateFooEf
        .cfi_startproc
# BB#0:
        pushq   %rbx
.Ltmp2:
        .cfi_def_cfa_offset 16
        subq    $16, %rsp
.Ltmp3:
        .cfi_def_cfa_offset 32
.Ltmp4:
        .cfi_offset %rbx, -16
        movss   %xmm0, 12(%rsp)
        movq    %rdi, %rbx
        movss   8(%rbx), %xmm1
        movss   12(%rbx), %xmm0
        mulss   %xmm1, %xmm1
        mulss   %xmm0, %xmm0
        addss   %xmm1, %xmm0
        callq   sqrtf
        mulss   12(%rsp), %xmm0         # 4-byte Folded Reload
        addss   184(%rbx), %xmm0
        movss   %xmm0, 184(%rbx)
        addq    $16, %rsp
        popq    %rbx
        ret
.Ltmp5:
        .size   _ZN10GameObject9UpdateFooEf, .Ltmp5-_ZN10GameObject9UpdateFooEf
        .cfi_endproc
```

90% waste!

```
_ZN10GameObject9UpdateFooEf:                # @_ZN10GameObject9UpdateFooEf
        .cfi_startproc
# BB#0:
        pushq   %rbx
.Ltmp2:
        .cfi_def_cfa_offset 16
        subq    $16, %rsp
.Ltmp3:
        .cfi_def_cfa_offset 32
.Ltmp4:
        .cfi_offset %rbx, -16
        movss   %xmm0, 12(%rsp)             #
        movq    %rdi, %rbx
        movss   8(%rbx), %xmm1
        movss   12(%rbx), %xmm0
        mulss   %xmm1, %xmm1
        mulss   %xmm0, %xmm0
        addss   %xmm1, %xmm0
        callq   sqrtf
        mulss   12(%rsp), %xmm0             # 4-byte Folded Reload
        addss   184(%rbx), %xmm0
        movss   %xmm0, 184(%rbx)
        addq    $16, %rsp
        popq    %rbx
        ret
.Ltmp5:
        .size   _ZN10GameObject9                                    Ef
        .cfi_endproc
```

Alternatively,
Only 10% capacity used*

* Not the same as “used well”, but we’ll start here.

```
struct FooUpdateIn {
  float m_Velocity[2];
  float m_Foo;
};

struct FooUpdateOut {
  float m_Foo;
};

void UpdateFoos(const FooUpdateIn* in, size_t count, FooUpdateOut* out, float f)
{
  for (size_t i = 0; i < count; ++i) {
    float mag = sqrtf(
      in[i].m_Velocity[0] * in[i].m_Velocity[0] +
      in[i].m_Velocity[1] * in[i].m_Velocity[1]);
      out[i].m_Foo = in[i].m_Foo + mag * f;
  }
}
```

```
struct FooUpdateIn {
  float m_Velocity[2];
  float m_Foo;
};

struct FooUpdateOut {
  float m_Foo;
};

void UpdateFoos(const FooUpdateIn* in, size_t count, FooUpdateOut* out, float f)
{
  for (size_t i = 0; i < count; ++i) {
    float mag = sqrtf(
      in[i].m_Velocity[0] * in[i].m_Velocity[0] +
      in[i].m_Velocity[1] * in[i].m_Velocity[1]);
      out[i].m_Foo = in[i].m_Foo + mag * f;
  }
}
```

12 bytes x count(5) = 72

```
struct FooUpdateIn {
  float m_Velocity[2];
  float m_Foo;
};
```

12 bytes x count(5) = 72

```
struct FooUpdateOut {
  float m_Foo;
};
```

4 bytes x count(5) = 20

```
void UpdateFoos(const FooUpdateIn* in, size_t count, FooUpdateOut* out, float f)
{
  for (size_t i = 0; i < count; ++i) {
    float mag = sqrtf(
      in[i].m_Velocity[0] * in[i].m_Velocity[0] +
      in[i].m_Velocity[1] * in[i].m_Velocity[1]);
      out[i].m_Foo = in[i].m_Foo + mag * f;
  }
}
```

```
struct FooUpdateIn {
  float m_Velocity[2];
  float m_Foo;
};
```

12 bytes x count(32) = 384 = 64 x 6

```
struct FooUpdateOut {
  float m_Foo;
};
```

4 bytes x count(32) = 128 = 64 x 2

```
void UpdateFoos(const FooUpdateIn* in, size_t count, FooUpdateOut* out, float f)
{
  for (size_t i = 0; i < count; ++i) {
    float mag = sqrtf(
      in[i].m_Velocity[0] * in[i].m_Velocity[0] +
      in[i].m_Velocity[1] * in[i].m_Velocity[1]);
      out[i].m_Foo = in[i].m_Foo + mag * f;
  }
}
```

```
struct FooUpdateIn {
  float m_Velocity[2];
  float m_Foo;
};
```

12 bytes x count(32) = 384 = 64 x 6

```
struct FooUpdateOut {
  float m_Foo;
};
```

4 bytes x count(32) = 128 = 64 x 2

```
void UpdateFoos(const FooUpdateIn* in, size_t count, FooUpdateOut* out, float f)
{
  for (size_t i = 0; i < count; ++i) {
    float mag = sqrtf(
      in[i].m_Velocity[0] * in[i].m_Velocity[0] +
      in[i].m_Velocity[1] * in[i].m_Velocity[1]);
      out[i].m_Foo = in[i].m_Foo + mag * f;
  }
}
```

(6/32) = ~5.33 loop/cache line

```
struct FooUpdateIn {
  float m_Velocity[2];
  float m_Foo;
};
```

12 bytes x count(32) = 384 = 64 x 6

```
struct FooUpdateOut {
  float m_Foo;
};
```

4 bytes x count(32) = 128 = 64 x 2

```
void UpdateFoos(const FooUpdateIn* in, size_t count, FooUpdateOut* out, float f)
{
  for (size_t i = 0; i < count; ++i) {
    float mag = sqrtf(
      in[i].m_Velocity[0] * in[i].m_Velocity[0] +
      in[i].m_Velocity[1] * in[i].m_Velocity[1]);
      out[i].m_Foo = in[i].m_Foo + mag * f;
  }
}
```

(6/32) = ~5.33 loop/cache line

Sqrt + math = ~40 x 5.33 = 213.33 cycles/cache line

```
struct FooUpdateIn {
  float m_Velocity[2];
  float m_Foo;
};
```

12 bytes x count(32) = 384 = 64 x 6

```
struct FooUpdateOut {
  float m_Foo;
};
```

4 bytes x count(32) = 128 = 64 x 2

```
void UpdateFoos(const FooUpdateIn* in, size_t count, FooUpdateOut* out, float f)
{
  for (size_t i = 0; i < count; ++i) {
    float mag = sqrtf(
      in[i].m_Velocity[0] * in[i].m_Velocity[0] +
      in[i].m_Velocity[1] * in[i].m_Velocity[1]);
      out[i].m_Foo = in[i].m_Foo + mag * f;
  }
}
```

(6/32) = ~5.33 loop/cache line
Sqrt + math = ~40 x 5.33 = 213.33 cycles/cache line
+ streaming prefetch bonus

```
struct FooUpdateIn {
  float m_Velocity[2];
  float m_Foo;
};
```

12 bytes x count(32) = 384 = 64 x 6

```
struct FooUpdateOut {
  float m_Foo;
};
```

4 bytes x count(32) = 128 = 64 x 2

```
void UpdateFoos(const FooUpdateIn* in, size_t count, FooUpdateOut* out, float f)
{
  for (size_t i
    float mag =
      in[i].m_Ve
      in[i].m_Ve
      out[i].m_F
  }
}
```

Using cache line to capacity* = 10x speedup

* Used. Still not necessarily as efficiently as possible

(6/32) = ~5.33 loop/cache line
Sqrt + math = ~40 x 5.33 = 213.33 cycles/cache line
+ streaming prefetch bonus

In addition…

1. Code is maintainable
2. Code is debugable
3. Can REASON about cost of change

```
struct FooUpdateIn {
  float m_Velocity[2];
  float m_Foo;
};

struct FooUpdateOut {
  float m_Foo;
};

void UpdateFoos(const FooUpdateIn* in, size_t count, FooUpdateOut* out, float f)
{
  for (size_t i = 0; i < count; ++i) {
    float mag = sqrtf(
      in[i].m_Velocity[0] * in[i].m_Velocity[0] +
      in[i].m_Velocity[1] * in[i].m_Velocity[1]);
      out[i].m_Foo = in[i].m_Foo + mag * f;
  }
}
```

(6/32) = ~5.33 loop/cache line
Sqrt + math = ~40 x 5.33 = 213.33 cycles/cache line
+ streaming prefetch bonus

In addition…

1. Code is maintainable
2. Code is debugable
3. Can REASON about cost of change

Ignoring inconvenient facts is not engineering;
It's dogma.

```
struct FooUpdateIn {
  float m_Velocity[2];
  float m_Foo;
};

struct FooUpdateOut {
  float m_Foo;
};

void UpdateFoos(const FooUpdateIn* in, size_t count, FooUpdateOut* out, float f)
{
  for (size_t i = 0; i < count; ++i) {
    float mag = sqrtf(
      in[i].m_Velocity[0] * in[i].m_Velocity[0] +
      in[i].m_Velocity[1] * in[i].m_Velocity[1]);
      out[i].m_Foo = in[i].m_Foo + mag * f;
  }
}
```

(6/32) = ~5.33 loop/cache line
Sqrt + math = ~40 x 5.33 = 213.33 cycles/cache line
+ streaming prefetch bonus

bools in structs…

(3) Extremely low information density

```
class __attribute__((__packed__)) Foo
{
public:
  uint8_t  a0;
  uint16_t b0;
  uint8_t  c0;
  bool     d0;

  uint8_t  a1;
  uint16_t b1;
  uint8_t  c1;
  bool     d1;

  uint8_t  a2;
  uint16_t b2;
  uint8_t  c2;
  bool     d2;
};
```

```
Foo
{
  a0: 0
  b0: 1
  c0: 3
  d0: 4
  a1: 5
  b1: 6
  c1: 8
  d1: 9
  a2: 10
  b2: 11
  c2: 13
  d2: 14
}
```

bools in structs…

(3) Extremely low information density

How big is your cache line?

```
class __attribute__((__packed__)) Foo
{
public:
  uint8_t  a0;
  uint16_t b0;
  uint8_t  c0;
  bool     d0;

  uint8_t  a1;
  uint16_t b1;
  uint8_t  c1;
  bool     d1;

  uint8_t  a2;
  uint16_t b2;
  uint8_t  c2;
  bool     d2;
};
```

```
Foo
{
  a0: 0
  b0: 1
  c0: 3
  d0: 4
  a1: 5
  b1: 6
  c1: 8
  d1: 9
  a2: 10
  b2: 11
  c2: 13
  d2: 14
}
```

```
class Foo
{
public:
  bool    m_NeedParentUpdate;
  bool    m_NeedChildUpdate;
  bool    m_ParentNotNotified;
  Mat4    m_ObjectWorld;
  bool    m_InheritScale;
  bool    m_InheritOrientation;
};
```

```
Foo
{
  m_NeedParentUpdate:    0
  m_NeedChildUpdate:     1
  m_ParentNotNotified:   2
  m_ObjectWorld:         4
  m_InheritScale:        68
  m_InheritOrientation:  69
}
```

bools in structs…

```
class __attribute__((__packed__)) Foo
{
public:
  uint8_t  a0;
  uint16_t b0;
  uint8_t  c0;
  bool     d0;

  uint8_t  a1;
  uint16_t b1;
  uint8_t  c1;
  bool     d1;

  uint8_t  a2;
  uint16_t b2;
  uint8_t  c2;
  bool     d2;
};
```

```
Foo
{
  a0: 0
  b0: 1
  c0: 3
  d0: 4
  a1: 5
  b1: 6
  c1: 8
  d1: 9
  a2: 10
  b2: 11
  c2: 13
  d2: 14
}
```

(3) Extremely low information density

How big is your cache line?

What's the most commonly accessed data?

```
class Foo
{
public:
  bool    m_NeedParentUpdate;
  bool    m_NeedChildUpdate;
  bool    m_ParentNotNotified;
  Mat4    m_ObjectWorld;
  bool    m_InheritScale;
  bool    m_InheritOrientation;
};
```

```
Foo
{
  m_NeedParentUpdate:    0
  m_NeedChildUpdate:     1
  m_ParentNotNotified:   2
  m_ObjectWorld:         4
  m_InheritScale:        68
  m_InheritOrientation:  69
}
```

64b?

How is it used? What does it generate?

(2) Bools and last-minute decision making

```
int
Foo::Bar( int count )
{
  int value = 0;
  for (int i=0;i<count;i++)
  {
    if ( m_NeedParentUpdate )
    {
      value++;
    }
  }
  return (value);
}
```

MSVC

```
?Bar@Foo@@QEAAHH@Z PROC                 ; Foo::Bar, COMDAT

; 1696 :   int value = 0;

  00000 33 c0        xor     eax, eax

; 1697 :   for (int i=0;i<count;i++)

  00002 85 d2        test    edx, edx
  00004 7e 11        jle     SHORT $LN2@Bar

; 1696 :   int value = 0;

  00006 44 8a 01     mov     r8b, BYTE PTR [rcx]
  00009 8b ca        mov     ecx, edx
$LL9@Bar:

; 1698 :   {
; 1699 :     if ( m_NeedParentUpdate )

  0000b 45 84 c0     test    r8b, r8b
  0000e 74 02        je  SHORT $LN10@Bar

; 1700 :     {
; 1701 :       value++;

  00010 ff c0        inc     eax
$LN10@Bar:

; 1697 :   for (int i=0;i<count;i++)

  00012 48 ff c9     dec     rcx
  00015 75 f4        jne     SHORT $LL9@Bar
$LN2@Bar:

; 1702 :     }
; 1703 :   }
; 1704 :   return (value);
; 1705 : }
```

MSVC

```
?Bar@Foo@@QEAAHH@Z PROC                 ; Foo::Bar, COMDAT

; 1696 :   int value = 0;

  00000 33 c0        xor     eax, eax

; 1697 :   for (int i=0;i<count;i++)

  00002 85 d2        test    edx, edx
  00004 7e 11        jle     SHORT $LN2@Bar

; 1696 :   int value = 0;

  00006 44 8a 01     mov     r8b, BYTE PTR [rcx]
  00009 8b ca        mov     ecx, edx
$LL9@Bar:

; 1698 :   {
; 1699 :     if ( m_NeedParentUpdate )

  0000b 45 84 c0     test    r8b, r8b
  0000e 74 02        je  SHORT $LN10@Bar

; 1700 :     {
; 1701 :       value++;

  00010 ff c0        inc     eax
$LN10@Bar:

; 1697 :   for (int i=0;i<count;i++)

  00012 48 ff c9     dec     rcx
  00015 75 f4        jne     SHORT $LL9@Bar
$LN2@Bar:

; 1702 :     }
; 1703 :   }
; 1704 :   return (value);
; 1705 : }
```

Re-read and re-test…

Increment and loop…

```
?Bar@Foo@@QEAAHH@Z PROC                 ; Foo::Bar, COMDAT

; 1696 :   int value = 0;

  00000 33 c0        xor     eax, eax

; 1697 :   for (int i=0;i<count;i++)

  00002 85 d2        test    edx, edx
  00004 7e 11        jle     SHORT $LN2@Bar

; 1696 :   int value = 0;

  00006 44 8a 01     mov     r8b, BYTE PTR [rcx]
  00009 8b ca        mov     ecx, edx
$LL9@Bar:

; 1698 :   {
; 1699 :     if ( m_NeedParentUpdate )

  0000b 45 84 c0     test    r8b, r8b
  0000e 74 02        je  SHORT $LN10@Bar

; 1700 :     {
; 1701 :       value++;

  00010 ff c0        inc     eax
$LN10@Bar:

; 1697 :   for (int i=0;i<count;i++)

  00012 48 ff c9     dec     rcx
  00015 75 f4        jne     SHORT $LL9@Bar
$LN2@Bar:

; 1702 :     }
; 1703 :   }
; 1704 :   return (value);
; 1705 : }
```

Re-read and re-test…

Increment and loop…

Visual Studio

Why?

Super-conservative aliasing rules…?
Member value might change?

What about something more aggressive…?


```
        .type   _ZN3Foo3BarEi,@function
_ZN3Foo3BarEi:                          # @_ZN3Foo3BarEi
        .cfi_startproc
# BB#0:
        xorl    %eax, %eax
        testl   %esi, %esi
        jle     .LBB1_2
# BB#1:                                 # %.lr.ph
        movzbl  (%rdi), %eax
        negl    %eax
        andl    %esi, %eax
.LBB1_2:
        ret
.Ltmp3:
        .size   _ZN3Foo3BarEi, .Ltmp3-_ZN3Foo3BarEi
        .cfi_endproc
```

What about something more aggressive…?


```
        .type   _ZN3Foo3BarEi,@function
_ZN3Foo3BarEi:                          # @_ZN3Foo3BarEi
        .cfi_startproc
# BB#0:
        xorl    %eax, %eax
        testl   %esi, %esi
        jle     .LBB1_2
# BB#1:                                 # %.lr.ph
        movzbl  (%rdi), %eax
        negl    %eax
        andl    %esi, %eax
.LBB1_2:
        ret
.Ltmp3:
        .size   _ZN3Foo3BarEi, .Ltmp3-_ZN3Foo3BarEi
        .cfi_endproc
```

Test once and return…

Okay, so what about…

```
int
Foo::Bar( int count )
{
  int value = 0;
  for (int i=0;i<count;i++)
  {
    if ( m_NeedParentUpdate )
    {
      value++;
    }
  }
  return (value);
}

int
Foo::Baz( int count )
{
  int value = 0;
  for (int i=0;i<count;i++)
  {
    if ( Bar(count) > 0 )
    {
      value++;
    }
  }
  return (value);
}
```

```
clang version 3.4 (tags/RELEASE_34/final)
Target: x86_64-unknown-linux-gnu
Thread model: posix
```

…well at least it inlined it?

```
        .type   _ZN3Foo3BazEi,@function
_ZN3Foo3BazEi:                          # @_ZN3Foo3BazEi
        .cfi_startproc
# BB#0:
        xorl    %eax, %eax
        testl   %esi, %esi
        jle     .LBB2_7
# BB#1:                                 # %.lr.ph
        xorl    %eax, %eax
        movl    %esi, %r8d
        andl    $-2, %r8d
        je      .LBB2_2
# BB#3:
        movl    %r8d, %ecx
        xorl    %r9d, %r9d
        .align  16, 0x90
.LBB2_4:                                # %vector.body
                                        # =>This Inner Loop Header: Depth=1
        movzbl  (%rdi), %edx
        negl    %edx
        testl   %esi, %edx
        setg    %dl
        movzbl  %dl, %edx
        addl    %edx, %eax
        addl    %edx, %r9d
        addl    $-2, %ecx
        jne     .LBB2_4
        jmp     .LBB2_5
.LBB2_2:
        xorl    %r8d, %r8d
        xorl    %r9d, %r9d
.LBB2_5:                                # %middle.block
        addl    %r9d, %eax
        cmpl    %esi, %r8d
        je      .LBB2_7
        .align  16, 0x90
.LBB2_6:                                # %._ZN3Foo3BarEi.exit
                                        # =>This Inner Loop Header: Depth=1
        movzbl  (%rdi), %ecx
        negl    %ecx
        testl   %esi, %ecx
        setg    %cl
        movzbl  %cl, %ecx
        addl    %ecx, %eax
        incl    %r8d
        cmpl    %r8d, %esi
        jne     .LBB2_6
.LBB2_7:                                # %._crit_edge
        ret
.Ltmp4:
```

```
  00000 33 c0        xor     eax, eax

; 1711 :   for (int i=0;i<count;i++)

  00002 85 d2        test    edx, edx
  00004 7e 25        jle     SHORT $LN2@Baz

  00006 44 8a 11     mov     r10b, BYTE PTR [rcx]
  00009 44 8b ca     mov     r9d, edx
  0000c 44 8b c2     mov     r8d, edx
$LL4@Baz:

  0000f 33 c9        xor     ecx, ecx
  00011 49 8b d1     mov     rdx, r9
$LL17@Baz:

; 1699 :     if ( m_NeedParentUpdate )

  00014 45 84 d2     test    r10b, r10b
  00017 74 02        je  SHORT $LN18@Baz

; 1701 :       value++;

  00019 ff c1        inc     ecx
$LN18@Baz:

; 1697 :   for (int i=0;i<count;i++)

  0001b 48 ff ca     dec     rdx
  0001e 75 f4        jne     SHORT $LL17@Baz

; 1713 :     if ( Bar(count) )

  00020 85 c9        test    ecx, ecx
  00022 74 02        je  SHORT $LN3@Baz

; 1715 :       value++;

  00024 ff c0        inc     eax
$LN3@Baz:

; 1711 :   for (int i=0;i<count;i++)

  00026 49 ff c8     dec     r8
  00029 75 e4        jne     SHORT $LL4@Baz
$LN2@Baz:
```

MSVC doesn’t fare any better…

```
int
Foo::Bar( int count )
{
  int  value       = 0;
  bool need_update = m_NeedParentUpdate;
  for (int i=0;i<count;i++)
  {
    if ( need_update )
    {
      value++;
    }
  }
  return (value);
}

int
Foo::Baz( int count )
{
  int  value       = 0;
  bool need_update = Bar(count) > 0;
  for (int i=0;i<count;i++)
  {
    if ( need_update )
    {
      value++;
    }
  }
  return (value);
}
```

(4) Ghost reads and writes

Don’t re-read member values or re-call functions when you *already* have the data.

```
clang version 3.4 (tags/RELEASE_34/final)
Target: x86_64-unknown-linux-gnu
Thread model: posix
```

BAM!

```
_ZN3Foo3BazEi:                          # @_ZN3Foo3BazEi
        .cfi_startproc
# BB#0:
        xorl    %eax, %eax
        testl   %esi, %esi
        jle     .LBB2_2
# BB#1:                                 # %.lr.ph
        movzbl  (%rdi), %ecx
        negl    %ecx
        xorl    %eax, %eax
        testl   %esi, %ecx
        cmovgl  %esi, %eax
.LBB2_2:                                # %_ZN3Foo3BarEi.exit
        ret
```

```
; 1697 :   bool need_update = m_NeedParentUpdate;
  00000 44 8a 09     mov     r9b, BYTE PTR [rcx]
  00003 33 c0        xor     eax, eax
  00005 45 33 c0     xor     r8d, r8d

; 1698 :   for (int i=0;i<count;i++)
  00008 85 d2        test    edx, edx
  0000a 7e 0f        jle     SHORT $LN8@Baz

; 1711 :   int  value       = 0;
  0000c 8b ca        mov     ecx, edx
$LL10@Baz:

; 1700 :     if ( need_update )
  0000e 45 84 c9     test    r9b, r9b
  00011 74 03        je  SHORT $LN9@Baz
  00013 41 ff c0     inc     r8d
$LN9@Baz:

; 1698 :   for (int i=0;i<count;i++)
  00016 48 ff c9     dec     rcx
  00019 75 f3        jne     SHORT $LL10@Baz
$LN8@Baz:

; 1712 :   bool need_update = Bar(count) > 0;
  0001b 45 85 c0     test    r8d, r8d
  0001e 41 0f 9f c0  setg    r8b

; 1713 :   for (int i=0;i<count;i++)
  00022 85 d2        test    edx, edx
  00024 7e 0e        jle     SHORT $LN2@Baz
  00026 8b ca        mov     ecx, edx
$LL4@Baz:

; 1715 :     if ( need_update )
  00028 45 84 c0     test    r8b, r8b
  0002b 74 02        je  SHORT $LN3@Baz
  0002d ff c0        inc     eax
$LN3@Baz:

; 1713 :   for (int i=0;i<count;i++)
  0002f 48 ff c9     dec     rcx
  00032 75 f4        jne     SHORT $LL4@Baz
$LN2@Baz:

; 1720 :   return (value);
```

:(

```
int
Foo::Bar( int count )
{
  int value       = 0;
  bool need_update = m_NeedParentUpdate;
  if ( need_update )
  {
    for (int i=0;i<count;i++)
    {
      value++;
    }
  }
  return (value);
}

int
Foo::Baz( int count )
{
  int value       = 0;
  bool need_update = Bar(count) > 0;
  if ( need_update )
  {
    for (int i=0;i<count;i++)
    {
      value++;
    }
  }
  return (value);
}
```

(4) Ghost reads and writes

Don’t re-read member values or re-call functions when you *already* have the data.

Hoist all loop-invariant reads and branches. Even super-obvious ones that should already be in registers.

```
?Baz@Foo@@QEAAHH@Z PROC                ; Foo::Baz, COMDAT

; 1711 :   int  value       = 0;

  00000 33 c0        xor     eax, eax

; 1698 :   if ( need_update )

  00002 38 01        cmp     BYTE PTR [rcx], al
  00004 74 07        je  SHORT $LN3@Baz

; 1699 :   {
; 1700 :     for (int i=0;i<count;i++)

  00006 85 d2        test    edx, edx
  00008 7e 03        jle     SHORT $LN3@Baz

; 1712 :   bool need_update = Bar(count) > 0;
; 1713 :   if ( need_update )

  0000a 0f 4f c2     cmovg   eax, edx
$LN3@Baz:

; 1714 :   {
; 1715 :     for (int i=0;i<count;i++)
; 1716 :     {
; 1717 :       value++;
; 1718 :     }
; 1719 :   }
; 1720 :   return (value);
; 1721 : }

  0000d c3       ret     0
?Baz@Foo@@QEAAHH@Z ENDP                ; Foo::Baz
```

:)

:)

```
?Baz@Foo@@QEAAHH@Z PROC                 ; Foo::Baz, COMDAT

; 1711 :   int  value       = 0;

  00000 33 c0        xor     eax, eax

; 1698 :   if ( need_update )

  00002 38 01        cmp     BYTE PTR [rcx], al
  00004 74 07        je  SHORT $LN3@Baz

; 1699 :   {
; 1700 :     for (int i=0;i<count;i++)

  00006 85 d2        test    edx, edx
  00008 7e 03        jle     SHORT $LN3@Baz

; 1712 :   bool need_update = Bar(count) > 0;
; 1713 :   if ( need_update )

  0000a 0f 4f c2     cmovg   eax, edx
$LN3@Baz:

; 1714 :   {
; 1715 :     for (int i=0;i<count;i++)
; 1716 :     {
; 1717 :       value++;
; 1718 :     }
; 1719 :   }
; 1720 :   return (value);
; 1721 : }

  0000d c3       ret     0
?Baz@Foo@@QEAAHH@Z ENDP                 ; Foo::Baz
```

A bit of unnecessary branching, but more-or-less equivalent.

```
int
Foo::Bar( int count )
{
  int  value        = 0;
  bool need_update = m_NeedParentUpdate;
  if ( need_update )
  {
    for (int i=0;i<count;i++)
    {
      value++;
    }
  }
  return (value);
}

int
Foo::Baz( int count )
{
  int  value        = 0;
  bool need_update = Bar(count) > 0;
  if ( need_update )
  {
    for (int i=0;i<count;i++)
    {
      value++;
    }
  }
  return (value);
}
```

(4) Ghost reads and writes

Don’t re-read member values or re-call functions when you *already* have the data.

Hoist all loop-invariant reads and branches. Even super-obvious ones that should already be in registers.

Applies to any member fields especially.
(Not particular to bools)

(3) Extremely low information density

```
void
Foo::Update()
{
  float choose    = RandFloat();
  bool  is_spawn = (choose < m_SpawnChance);
  if (is_spawn)
  {
    Spawn();
    m_SpawnChance = 0.0f;
  }
  else
  {
    m_SpawnChance += kFooSpawnChanceIncrease;
  }
}
```

(3) Extremely low information density

```
void
Foo::Update()
{
  float choose    = RandFloat();
  bool  is_spawn  = (choose < m_SpawnChance);
  if (is_spawn)
  {
    Spawn();
    m_SpawnChance = 0.0f;
  }
  else
  {
    m_SpawnChance += kFooSpawnChanceIncrease;
  }
}
```

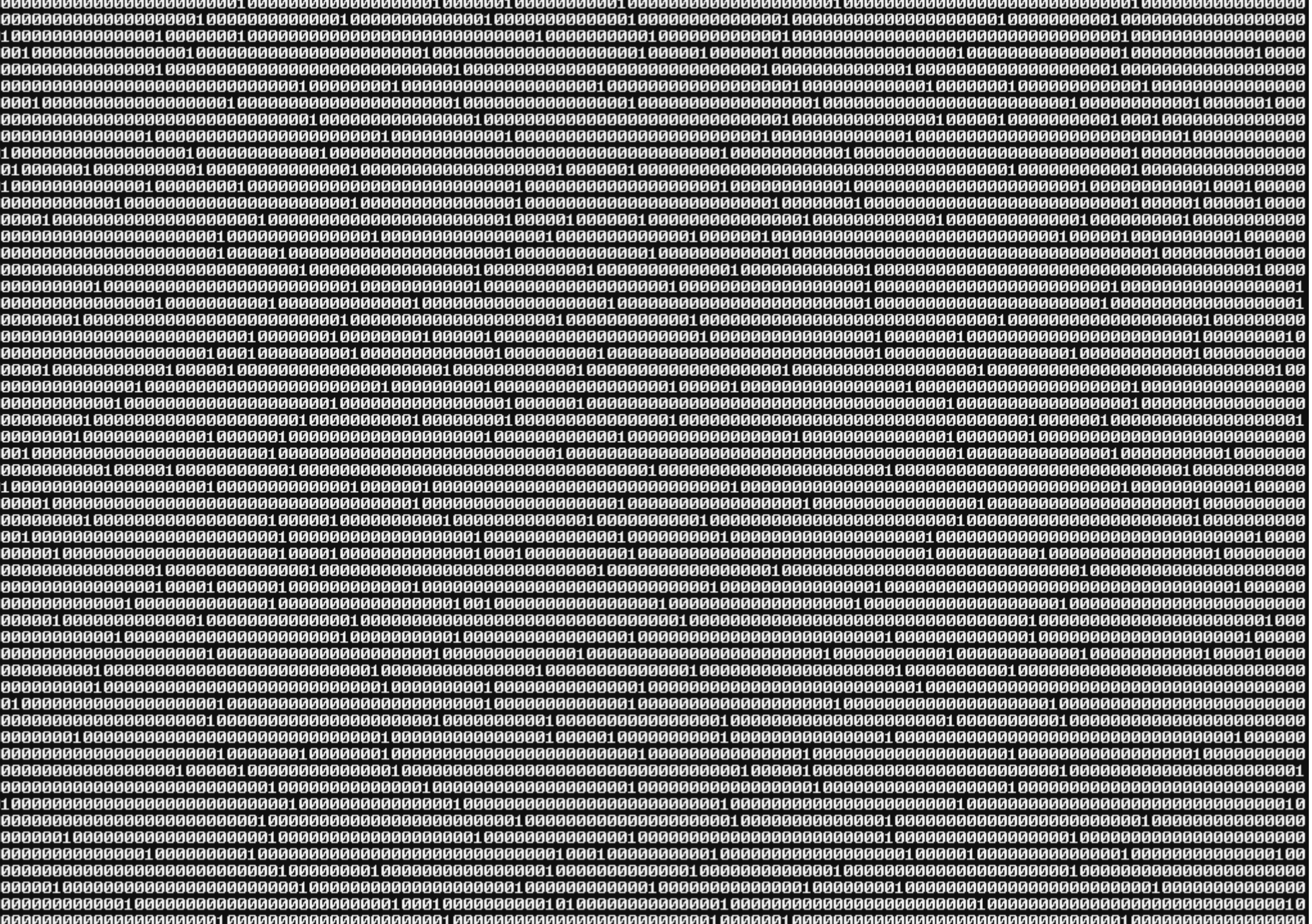
What is the information density for is_spawn over time?

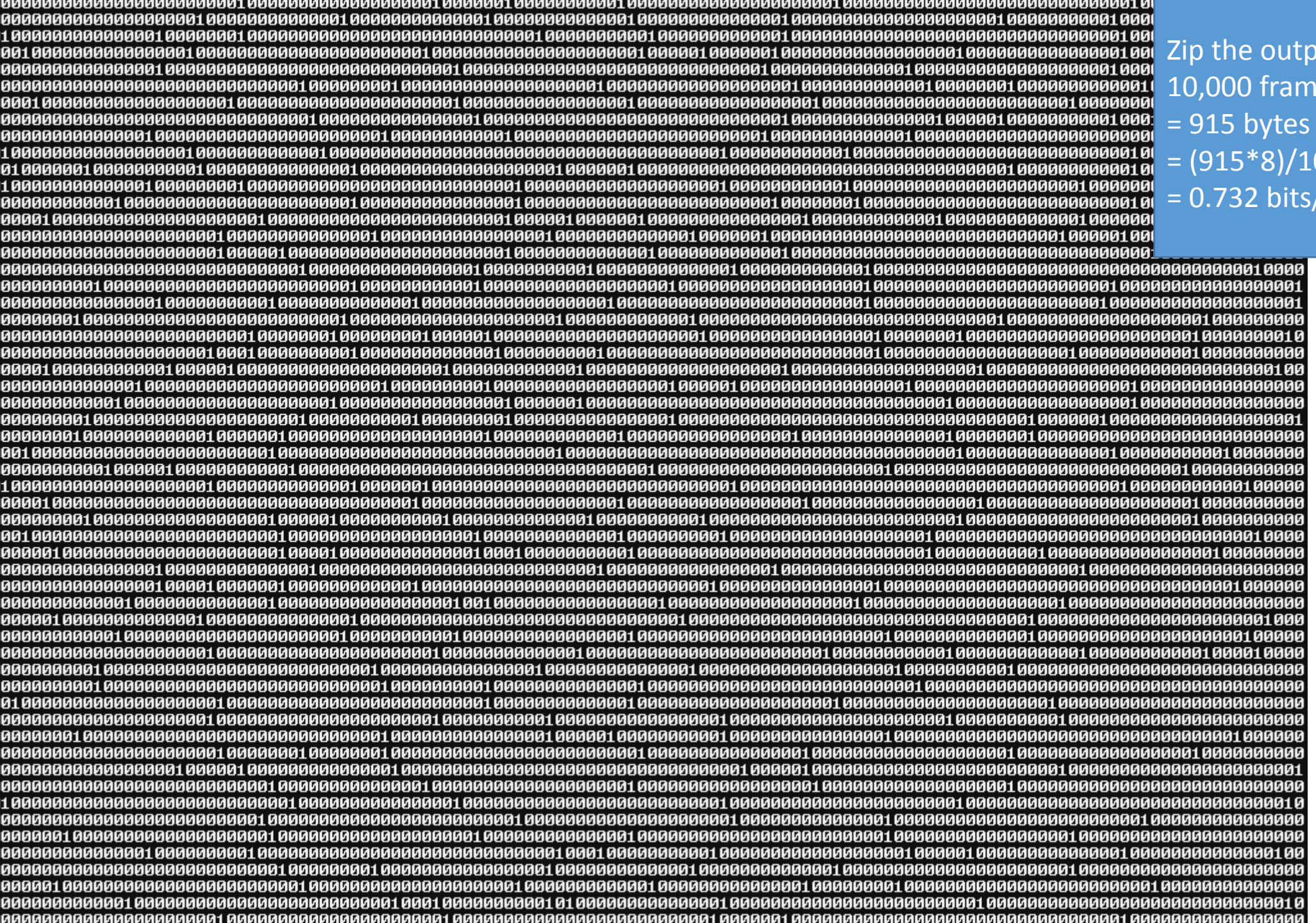
(3) Extremely low information density

```
void
Foo::Update()
{
  float choose    = RandFloat();
  bool  is_spawn  = (choose < m_SpawnChance);
  printf("%d",is_spawn?1:0);
  if (is_spawn)
  {
    Spawn();
    m_SpawnChance = 0.0f;
  }
  else
  {
    m_SpawnChance += kFooSpawnChanceIncrease;
  }
}
```

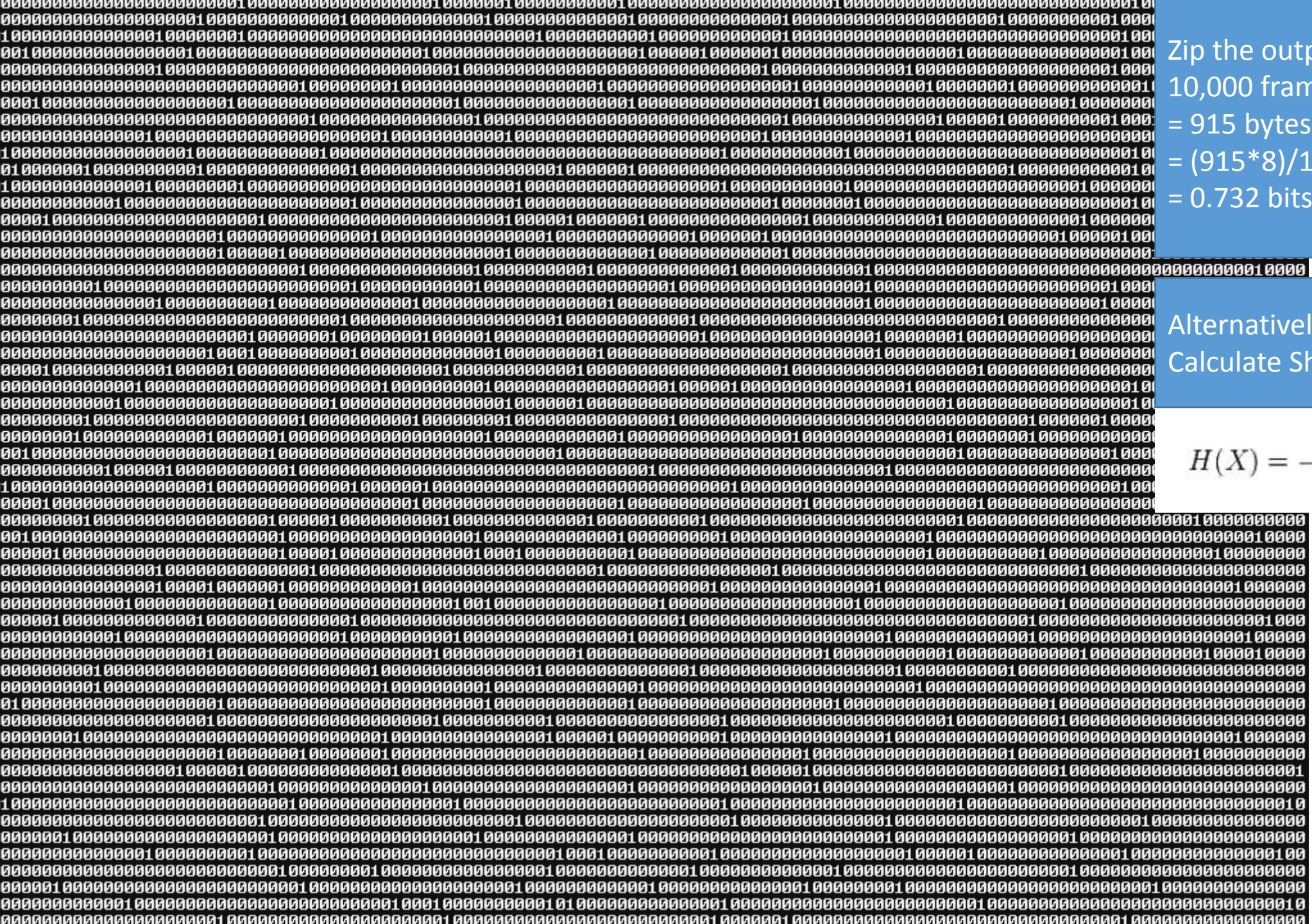
What is the information density for is_spawn over time?

The easy way.





Zip the output
10,000 frames
= 915 bytes
= (915*8)/10,000
= 0.732 bits/frame



Zip the output
10,000 frames
= 915 bytes
= (915*8)/10,000
= 0.732 bits/frame

Alternatively,
Calculate Shannon Entropy:

$$H(X) = -\sum_{i=1}^{n} p(x_i) \log_b p(x_i)$$

(3) Extremely low information density

```
void
Foo::Update()
{
  float choose    = RandFloat();
  bool  is_spawn = (choose < m_SpawnChance);
  if (is_spawn)
  {
    Spawn();
    m_SpawnChance = 0.0f;
  }
  else
  {
    m_SpawnChance += kFooSpawnChanceIncrease;
  }
}
```

What does that tell us?

(3) Extremely low information density

```
void
Foo::Update()
{
  float choose    = RandFloat();
  bool  is_spawn = (choose < m_SpawnChance);
  if (is_spawn)
  {
    Spawn();
    m_SpawnChance = 0.0f;
  }
  else
  {
    m_SpawnChance += kFooSpawnChanceIncrease;
  }
}
```

What does that tell us?

Figure (~2 L2 misses each frame) x 10,000
If each cache line = 64b,
128b x 10,000 = 1,280,000 bytes

(3) Extremely low information density

```
void
Foo::Update()
{
  float choose    = RandFloat();
  bool  is_spawn = (choose < m_SpawnChance);
  if (is_spawn)
  {
    Spawn();
    m_SpawnChance = 0.0f;
  }
  else
  {
    m_SpawnChance += kFooSpawnChanceIncrease;
  }
}
```

What does that tell us?

Figure (~2 L2 misses each frame) x 10,000
If each cache line = 64b,
128b x 10,000 = 1,280,000 bytes

If avg information content = 0.732bits/frame
X 10,000 = 7320 bits
/ 8 = 915 bytes

(3) Extremely low information density

```
void
Foo::Update()
{
  float choose    = RandFloat();
  bool  is_spawn  = (choose < m_SpawnChance);
  if (is_spawn)
  {
    Spawn();
    m_SpawnChance = 0.0f;
  }
  else
  {
    m_SpawnChance += kFooSpawnChanceIncrease;
  }
}
```

What does that tell us?

Figure (~2 L2 misses each frame) x 10,000
If each cache line = 64b,
128b x 10,000 = 1,280,000 bytes

If avg information content = 0.732bits/frame
X 10,000 = 7320 bits
/ 8 = 915 bytes

Percentage waste (Noise::Signal) =
(1,280,000-915)/1,280,000

0.99928515625

What’re the alternatives?

(1) Per-frame…

(1) Per-frame… (decision table)

1 of 512 (8*64) bits used…

(1) Per-frame… (decision table)

1 of 512 (8*64) bits used…

(a) Make same decision x 512

(1) Per-frame… (decision table)

1 of 512 (8*64) bits used…

(a) Make same decision x 512

(b) Combine with other reads / xforms

(1) Per-frame… (decision table)

1 of 512 (8*64) bits used…

(a) Make same decision x 512

(b) Combine with other reads / xforms

Generally simplest.

- But things cannot exist in abstract bubble.
- Will require context.

(2) Over-frames…

(2) Over-frames…

i.e. Only read when needed

Arrays of command buffers for future frames…

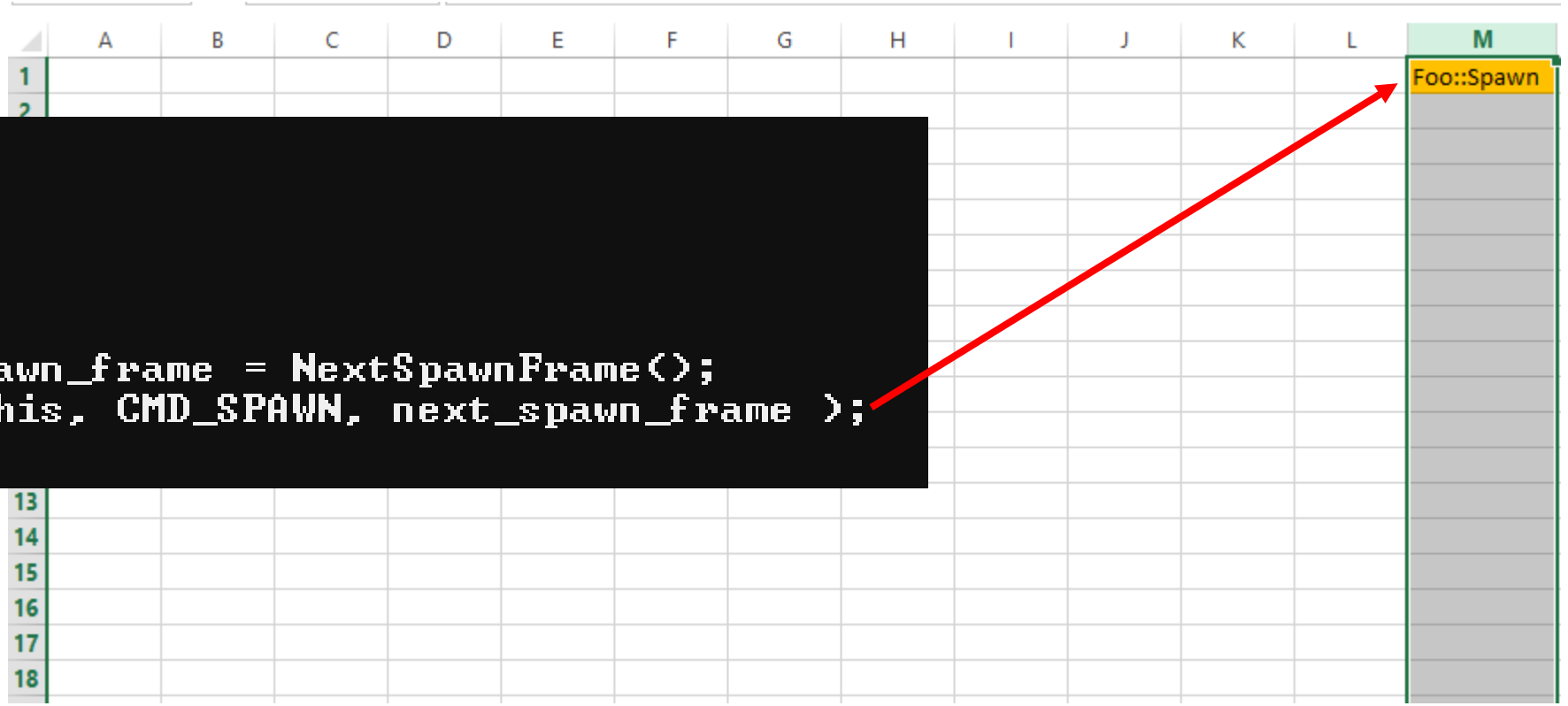
(2) Over-frames…

i.e. Only read when needed

e.g.

```
void
Foo::Spawn()
{
  ...

  uint32_t next_spawn_frame = NextSpawnFrame();
  InsertCommand( this, CMD_SPAWN, next_spawn_frame );
}
```



Let’s review some code…

default | ogre / OgreMain / src / OgreNode.cpp

569ec69 2013-10-15 | Full commit

```
1  /*
2  -----------------------------------------------------------------------------
3  This source file is part of OGRE
4      (Object-oriented Graphics Rendering Engine)
5  For the latest info, see http://www.ogre3d.org/
6
7  Copyright (c) 2000-2013 Torus Knot Software Ltd
```

Mike Acton reviewed the 1.9 version. Perhaps it would've been more interesting to see a review of the 2.0 file which has been refactored to better fit Data Oriented Design principles (and I'm sure there are things I wrote to criticize). Many of the things he criticizes of 1.9 have been fixed. Nevertheless there are things we can learn. Note that if he weren't right, then it would be hard to explain why there was a 5x performance increase between 1.9 and 2.0.

http://yosoygames.com.ar/wp/2013/11/on-mike-actons-review-of-ogrenode-cpp/

```
namespace Ogre {

    NameGenerator Node::msNameGenerator("Unnamed_");
        Node::QueuedUpdates Node::msQueuedUpdates;
    //-----------------------------------------------------------------------
    Node::Node()
                :mParent(0),
                mNeedParentUpdate(false),
                mNeedChildUpdate(false),
                mParentNotified(false),
        mQueuedForUpdate(false),
                mOrientation(Quaternion::IDENTITY),
                mPosition(Vector3::ZERO),
                mScale(Vector3::UNIT_SCALE),
        mInheritOrientation(true),
                mInheritScale(true),
                mDerivedOrientation(Quaternion::IDENTITY),
                mDerivedPosition(Vector3::ZERO),
                mDerivedScale(Vector3::UNIT_SCALE),
                mInitialPosition(Vector3::ZERO),
                mInitialOrientation(Quaternion::IDENTITY),
                mInitialScale(Vector3::UNIT_SCALE),
                mCachedTransformOutOfDate(true),
                mListener(0),
                mDebug(0)
    {
        // Generate a name
        mName = msNameGenerator.generate();

        needUpdate();

    }
```

```
45  namespace Ogre {
46
47      NameGenerator Node::msNameGenerator("Unnamed_");
48          Node::QueuedUpdates Node::msQueuedUpdates;
49      //-----------------------------------------------------------------
50      Node::Node()
51                  :mParent(0),
52                  mNeedParentUpdate(false),
53                  mNeedChildUpdate(false),
54                  mParentNotified(false),
55          mQueuedForUpdate(false),
56                  mOrientation(Quaternion::IDENTITY),
57                  mPosition(Vector3::ZERO),
58                  mScale(Vector3::UNIT_SCALE),
59          mInheritOrientation(true),
60                  mInheritScale(true),
61                  mDerivedOrientation(Quaternion::IDENTITY),
62                  mDerivedPosition(Vector3::ZERO),
63                  mDerivedScale(Vector3::UNIT_SCALE),
64                  mInitialPosition(Vector3::ZERO),
65                  mInitialOrientation(Quaternion::IDENTITY),
66                  mInitialScale(Vector3::UNIT_SCALE),
67                  mCachedTransformOutOfDate(true),
68                  mListener(0),
69                  mDebug(0)
70      {
71          // Generate a name
72          mName = msNameGenerator.generate();
73
74          needUpdate();
75
76      }
```

(1) Can’t re-arrange memory (much)

Limited by ABI

Can’t limit unused reads

Extra padding

(2) Bools and last-minute decision making

```
45  namespace Ogre {
46
47      NameGenerator Node::msNameGenerator("Unnamed_");
48          Node::QueuedUpdates Node::msQueuedUpdates;
49      //-----------------------------------------------------------------
50      Node::Node()
51                  :mParent(0),
52                  mNeedParentUpdate(false),
53                  mNeedChildUpdate(false),
54                  mParentNotified(false),
55          mQueuedForUpdate(false),
56                  mOrientation(Quaternion::IDENTITY),
57                  mPosition(Vector3::ZERO),
58                  mScale(Vector3::UNIT_SCALE),
59          mInheritOrientation(true),
60                  mInheritScale(true),
61                  mDerivedOrientation(Quaternion::IDENTITY),
62                  mDerivedPosition(Vector3::ZERO),
63                  mDerivedScale(Vector3::UNIT_SCALE),
64                  mInitialPosition(Vector3::ZERO),
65                  mInitialOrientation(Quaternion::IDENTITY),
66                  mInitialScale(Vector3::UNIT_SCALE),
67                  mCachedTransformOutOfDate(true),
68                  mListener(0),
69                  mDebug(0)
70      {
71          // Generate a name
72          mName = msNameGenerator.generate();
73
74          needUpdate();
75
76      }
```

```
45  namespace Ogre {
46
47      NameGenerator Node::msNameGenerator("Unnamed_");
48          Node::QueuedUpdates Node::msQueuedUpdates;
49      //-----------------------------------------------------------------------
50      Node::Node()
51                  :mParent(0),
52                  mNeedParentUpdate(false),
53                  mNeedChildUpdate(false),
54                  mParentNotified(false),
55          mQueuedForUpdate(false),
56                  mOrientation(Quaternion::IDENTITY),
57                  mPosition(Vector3::ZERO),
58                  mScale(Vector3::UNIT_SCALE),
59          mInheritOrientation(true),
60                  mInheritScale(true),
61                  mDerivedOrientation(Quaternion::IDENTITY),
62                  mDerivedPosition(Vector3::ZERO),
63                  mDerivedScale(Vector3::UNIT_SCALE),
64                  mInitialPosition(Vector3::ZERO),
65                  mInitialOrientation(Quaternion::IDENTITY),
66                  mInitialScale(Vector3::UNIT_SCALE),
67                  mCachedTransformOutOfDate(true),
68                  mListener(0),
69                  mDebug(0)
70      {
71          // Generate a name
72          mName = msNameGenerator.generate();
73
74          needUpdate();
75
76      }
```

Are we done with the constructor?

(5) Over-generalization

```
45  namespace Ogre {
46
47      NameGenerator Node::msNameGenerator("Unnamed_");
48          Node::QueuedUpdates Node::msQueuedUpdates;
49      //-----------------------------------------------------------------------
50      Node::Node()
51                  :mParent(0),
52                  mNeedParentUpdate(false),
53                  mNeedChildUpdate(false),
54                  mParentNotified(false),
55          mQueuedForUpdate(false),
56                  mOrientation(Quaternion::IDENTITY),
57                  mPosition(Vector3::ZERO),
58                  mScale(Vector3::UNIT_SCALE),
59          mInheritOrientation(true),
60                  mInheritScale(true),
61                  mDerivedOrientation(Quaternion::IDENTITY),
62                  mDerivedPosition(Vector3::ZERO),
63                  mDerivedScale(Vector3::UNIT_SCALE),
64                  mInitialPosition(Vector3::ZERO),
65                  mInitialOrientation(Quaternion::IDENTITY),
66                  mInitialScale(Vector3::UNIT_SCALE),
67                  mCachedTransformOutOfDate(true),
68                  mListener(0),
69                  mDebug(0)
70      {
71          // Generate a name
72          mName = msNameGenerator.generate();
73
74          needUpdate();
75
76      }
```

Are we done with the constructor?

(5) Over-generalization

Complex constructors tend to imply that…

- Reads are unmanaged (one at a time…)

```
45  namespace Ogre {
46
47      NameGenerator Node::msNameGenerator("Unnamed_");
48          Node::QueuedUpdates Node::msQueuedUpdates;
49      //-----------------------------------------------------------------------
50      Node::Node()
51                  :mParent(0),
52                  mNeedParentUpdate(false),
53                  mNeedChildUpdate(false),
54                  mParentNotified(false),
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56                  mOrientation(Quaternion::IDENTITY),
57                  mPosition(Vector3::ZERO),
58                  mScale(Vector3::UNIT_SCALE),
59          mInheritOrientation(true),
60                  mInheritScale(true),
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62                  mDerivedPosition(Vector3::ZERO),
63                  mDerivedScale(Vector3::UNIT_SCALE),
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70      {
71          // Generate a name
72          mName = msNameGenerator.generate();
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```

Are we done with the constructor?

(5) Over-generalization

Complex constructors tend to imply that…

- Reads are unmanaged (one at a time…)
- Unnecessary reads/writes in destructors

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Complex constructors tend to imply that…

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- Unmanaged icache (i.e. virtuals)

=> unmanaged reads/writes

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Complex constructors tend to imply that…

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- Unmanaged icache (i.e. virtuals)
  => unmanaged reads/writes
- Unnecessarily complex state machines (back to bools)
  - E.g. 2^7 states

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Are we done with the constructor?

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Complex constructors tend to imply that…

- Reads are unmanaged (one at a time…)
- Unnecessary reads/writes in destructors
- Unmanaged icache (i.e. virtuals)
  => unmanaged reads/writes
- Unnecessarily complex state machines (back to bools)
  - E.g. 2^7 states

Rule of thumb:
Store each state type separately
Store same states together
(No state value needed)

```
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50      Node::Node()
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57                  mPosition(Vector3::ZERO),
58                  mScale(Vector3::UNIT_SCALE),
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Are we done with the constructor?

(5) Over-generalization

(6) Undefined or under-defined constraints

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Imply more (wasted) reads because pretending you don’t know what it could be.

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e.g. Strings, generally. Filenames, in particular.

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Imply more (wasted) reads because pretending you don't know what it could be.

e.g. Strings, generally. Filenames, in particular.

Rule of thumb:
The best code is code that doesn't need to exist.
Do it offline. Do it once.
e.g. precompiled string hashes

```
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Are we done with the constructor?

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(7) Over-solving (computing too much)

Compiler doesn't have enough context to know how to simplify your problems for you.

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Compiler doesn't have enough context to know how to simplify your problems for you.

But you can make simple tools that do…

- E.g. Premultiply matrices

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But you can make simple tools that do…

- E.g. Premultiply matrices

Work with the (actual) data you have.

- E.g. Sparse or affine matrices

How do we approach “fixing” it?

```
439     //-----------------------------------------------------------------------
440     void Node::translate(const Vector3& d, TransformSpace relativeTo)
441     {
442         switch(relativeTo)
443         {
444         case TS_LOCAL:
445             // position is relative to parent so transform downwards
446             mPosition += mOrientation * d;
447                 break;
448         case TS_WORLD:
449             // position is relative to parent so transform upwards
450             if (mParent)
451             {
452                 mPosition += (mParent->_getDerivedOrientation().Inverse() * d)
453                     / mParent->_getDerivedScale();
454             }
455             else
456             {
457                 mPosition += d;
458             }
459                 break;
460         case TS_PARENT:
461             mPosition += d;
462             break;
463         }
464         needUpdate();
465 
466     }
```

(2) Bools and last-minute decision making

```
439     //-----------------------------------------------------------------------
440     void Node::translate(const Vector3& d, TransformSpace relativeTo)
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453                     / mParent->_getDerivedScale();
454             }
455             else
456             {
457                 mPosition += d;
458             }
459                 break;
460         case TS_PARENT:
461             mPosition += d;
462             break;
463         }
464         needUpdate();
465
466     }
```

```
void
NodesTranslateLocal( Node* nodes, int count, const Vector3& d )
{
  for (int i=0;i<count;i++)
  {
    Node* node = &nodes[i];
    node->m_Position += node->m_Orientation * d;
  }
}

void
NodesTranslateWorld( Node* nodes, int count, const Vector3& d )
{
  for (int i=0;i<count;i++)
  {
    Node* node = &nodes[i];
    if ( node->m_Parent )
    {
      node->m_Position += ( node->m_Parent->_getDerivedOrientation().Inverse() * d );
                          / node->m_Parent->_getDerivedScale();
    }
    else
    {
      node->m_Position += d;
    }
  }
}

void
NodesTranslateParent( Node* nodes, int count, const Vector3& d )
{
  for (int i=0;i<count;i++)
  {
    Node* node = &nodes[i];
    node->m_Position += d;
  }
}
```

Step 1: organize

Separate states so you can reason about them

```
void
NodesTranslateLocal( Node* nodes, int count, const Vector3& d )
{
  for (int i=0;i<count;i++)
  {
    Node* node = &nodes[i];
    node->m_Position += node->m_Orientation * d;
  }
}

void
NodesTranslateWorld( Node* nodes, int count, const Vector3& d )
{
  for (int i=0;i<count;i++)
  {
    Node* node = &nodes[i];
    if ( node->m_Parent )
    {
      node->m_Position += ( node->m_Parent->_getDerivedOrientation().Inverse() * d );
                          / node->m_Parent->_getDerivedScale();
    }
    else
    {
      node->m_Position += d;
    }
  }
}

void
NodesTranslateParent( Node* nodes, int count, const Vector3& d )
{
  for (int i=0;i<count;i++)
  {
    Node* node = &nodes[i];
    node->m_Position += d;
  }
}
```

Step 1: organize
Separate states so you can reason about them

Step 2: triage
What are the relative values of each case
i.e. p(call) * count

```
void
NodesTranslateLocalEach( Node* nodes, int count, const Vector3* t )
{
  for (int i=0;i<count;i++)
  {
    Node* node = &nodes[i];
    Vec3& d    = *t[i];
    node->m_Position += node->m_Orientation * d;
  }
}

void
NodesTranslateWorldEach( Node* nodes, int count, const Vector3* t )
{
  for (int i=0;i<count;i++)
  {
    Node* node = &nodes[i];
    Vec3& d    = *t[i];
    if ( node->m_Parent )
    {
      node->m_Position += ( node->m_Parent->_getDerivedOrientation().Inverse() * d );
                          / node->m_Parent->_getDerivedScale();
    }
    else
    {
      node->m_Position += d;
    }
  }
}

void
NodesTranslateParentEach( Node* nodes, int count, const Vector3* t )
{
  for (int i=0;i<count;i++)
  {
    Node* node = &nodes[i];
    Vec3& d    = *t[i];
    node->m_Position += d;
  }
}
```

Step 1: organize
Separate states so you can reason about them

Step 2: triage
What are the relative values of each case
i.e. p(call) * count

e.g. in-game vs. in-editor

```
void
NodesTranslateLocal( Node* nodes, int count, const Vector3& d )
{
  for (int i=0;i<count;i++)
  {
    Node* node = &nodes[i];
    node->m_Position += node->m_Orientation * d;
  }
}

void
NodesTranslateWorld( Node* nodes, int count, const Vector3& d )
{
  for (int i=0;i<count;i++)
  {
    Node* node = &nodes[i];
    if ( node->m_Parent )
    {
      node->m_Position += ( node->m_Parent->_getDerivedOrientation().Inverse() * d );
                          / node->m_Parent->_getDerivedScale();
    }
    else
    {
      node->m_Position += d;
    }
  }
}

void
NodesTranslateParent( Node* nodes, int count, const Vector3& d )
{
  for (int i=0;i<count;i++)
  {
    Node* node = &nodes[i];
    node->m_Position += d;
  }
}
```

Step 1: organize
Separate states so you can reason about them

Step 2: triage
What are the relative values of each case
i.e. p(call) * count

Step 3: reduce waste

```
void
NodesTranslateLocal( Node* nodes, int count, const Vector3& d )
{
  for (int i=0;i<count;i++)
  {
    node->m_Position += m_Orientation * d;
  }
}
```

(back of the envelope read cost)

~200 cycles x 2 x count

```
void
NodesTranslateLocal( Node* nodes, int count, const Vector3& d )
{
  for (int i=0;i<count;i++)
  {
    node->m_Position += m_Orientation * d;
  }
}
```

(back of the envelope read cost)

~200 cycles x 2 x count

```
struct NodeTranslate
{
  Vec3 m_Position;
  Quat m_Orientation;
};

void
NodesTranslateLocal( NodeTranslate* nodes, int count, const Vector3& d )
{
  for (int i=0;i<count;i++)
  {
    node->m_Position += node->m_Orientation * d;
  }
}
```

~2.28 count per 200 cycles
= ~88

```
void
NodesTranslateLocal( Node* nodes, int count, const Vector3& d )
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  for (int i=0;i<count;i++)
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  }
}
```

~2.28 count per 200 cycles
= ~88

```
t = 2 * cross(q.xyz, v)
v' = v + q.w * t + cross(q.xyz, t)
```

```
void
NodesTranslateLocal( Node* nodes, int count, const Vector3& d )
{
  for (int i=0;i<count;i++)
  {
    node->m_Position += m_Orientation * d;
  }
}
```

(back of the envelope read cost)

~200 cycles x 2 x count

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void
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  for (int i=0;i<count;i++)
  {
    node->m_Position += node->m_Orientation * d;
  }
}
```

~2.28 count per 200 cycles
= ~88

(close enough to dig in and measure)

```
t = 2 * cross(q.xyz, v)
v' = v + q.w * t + cross(q.xyz, t)
```

Apply the same steps recursively…

```
void
NodesTranslateWorldEach( Node* nodes, int count, const Vector3* t )
{
  for (int i=0;i<count;i++)
  {
    Node* node = &nodes[i];
    Vec3& d    = t[i];
    if ( node->m_Parent )
    {
      node->m_Position += ( node->m_Parent->_getDerivedOrientation().Inverse() * d );
                          / node->m_Parent->_getDerivedScale();
    }
    else
    {
      node->m_Position += d;
    }
  }
}
```

Apply the same steps recursively…

```
void
NodesTranslateWorldEach( Node* nodes, int count, const Vector3* t )
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    if ( node->m_Parent )
    {
      node->m_Position += ( node->m_Parent->_getDerivedOrientation().Inverse() * d );
                          / node->m_Parent->_getDerivedScale();
    }
    else
    {
      node->m_Position += d;
    }
  }
}
```

Step 1: organize

Separate states so you can reason about them

Root or not; Calling function with context can distinguish

Apply the same steps recursively…

```
void
NodesTranslateWorldEach( Node* nodes, int count, const Vector3* t )
{
  for (int i=0;i<count;i++)
  {
    Node* node = &nodes[i];
    Vec3& d    = t[i];
    if ( node->m_Parent )
    {
      node->m_Position += ( node->m_Parent->_getDerivedOrientation().Inverse() * d );
                          / node->m_Parent->_getDerivedScale();
    }
    else
    {
      node->m_Position += d;
    }
  }
}
```

Step 1: organize

Separate states so you can reason about them

Root or not; Calling function with context can distinguish

Apply the same steps recursively…

```
void
NodesTranslateWorldEachRoot( Node* nodes, int count, const Vector3* t )
{
  for (int i=0;i<count;i++)
  {
    Node* node = &nodes[i];
    Vec3& d    =  t[i];
    node->m_Position += d;
  }
}

void
NodesTranslateWorldEachWithParent( Node* nodes, int count, const Vector3* t )
{
  for (int i=0;i<count;i++)
  {
    Node* node = &nodes[i];
    Vec3& d    =  t[i];
    node->m_Position += ( node->m_Parent->_getDerivedOrientation().Inverse() * d );
                      / node->m_Parent->_getDerivedScale();
  }
}
```

Step 1: organize

Separate states so you can reason about them

Apply the same steps recursively…

```
void
NodesTranslateWorldEachRoot( Node* nodes, int count, const Vector3* t )
{
  for (int i=0;i<count;i++)
  {
    Node* node = &nodes[i];
    Vec3& d    =  t[i];
    node->m_Position += d;
  }
}

void
NodesTranslateWorldEachWithParent( Node* nodes, int count, const Vector3* t )
{
  for (int i=0;i<count;i++)
  {
    Node* node = &nodes[i];
    Vec3& d    =  t[i];
    node->m_Position += ( node->m_Parent->_getDerivedOrientation().Inverse() * d );
                      / node->m_Parent->_getDerivedScale();
  }
}
```

Step 1: organize

Separate states so you can reason about them

Can’t reason well about the cost from…

```
// NodeParent
//    Quat       DerivedOrientationInverse
//    float      DerivedScale
//    uint32_t   ChildCount
//    Vector3    ChildPosition[]

void
NodesTranslateWorldEachWithParent( char* nodes, int parentCount, const Vector3* t )
{
  int k=0;
  for (int i=0;i<parentCount;i++)
  {
    Quat*    derivedOrientationInverse = (Quat*)nodes;
    nodes += sizeof(Quat);

    float    derivedScale              = *(float*)nodes;
    nodes += sizeof(float);

    uint32_t childCount                = *(uint32_t*)nodes;
    nodes += sizeof(uint32_t)

    for (int j=0;j<childCount;j++,k++)
    {
      Vector3& d             = t[k];
      Vector3& childPosition = *(Vector3*)nodes;
      nodes += sizeof(Vector3);

      childPosition += (derivedOrientationInverse * d) / derivedScale;
    }
  }
}
```

Step 1: organize

Separate states so you can reason about them

```
// NodeParent
//    Quat       DerivedOrientationInverse
//    float      DerivedScale
//    uint32_t   ChildCount
//    Vector3    ChildPosition[]

void
NodesTranslateWorldEachWithParent( char* nodes, int parentCount, const Vector3* t )
{
  int k=0;
  for (int i=0;i<parentCount;i++)
  {
    Quat*    derivedOrientationInverse = (Quat*)nodes;
    nodes += sizeof(Quat);

    float    derivedScale              = *(float*)nodes;
    nodes += sizeof(float);

    uint32_t childCount                = *(uint32_t*)nodes;
    nodes += sizeof(uint32_t)

    for (int j=0;j<childCount;j++,k++)
    {
      Vector3& d             = t[k];
      Vector3& childPosition = *(Vector3*)nodes;
      nodes += sizeof(Vector3);

      childPosition += (derivedOrientationInverse * d) / derivedScale;
    }
  }
}
```

Step 1: organize
Separate states so you can reason about them

Step 2: triage
What are the relative values of each case
i.e. p(call) * count

Step 3: reduce waste

Good News:
Most problems are
easy to see.

Good News:
Side-effect of solving the 90% well, compiler can solve the 10% better.

Good News:
Organized data makes maintenance, debugging and concurrency much easier

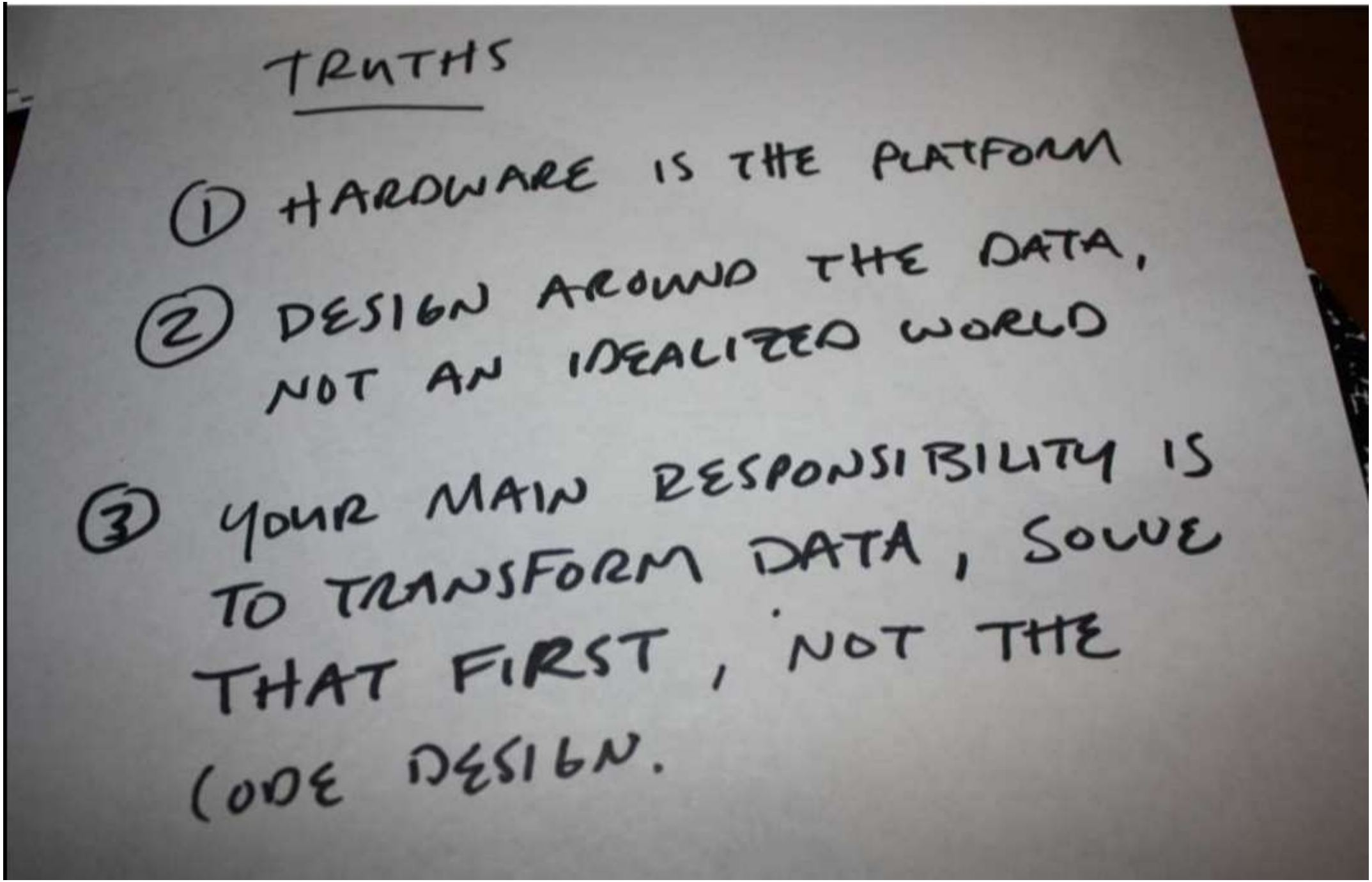
Bad News:
Good programming is hard.
Bad programming is easy.

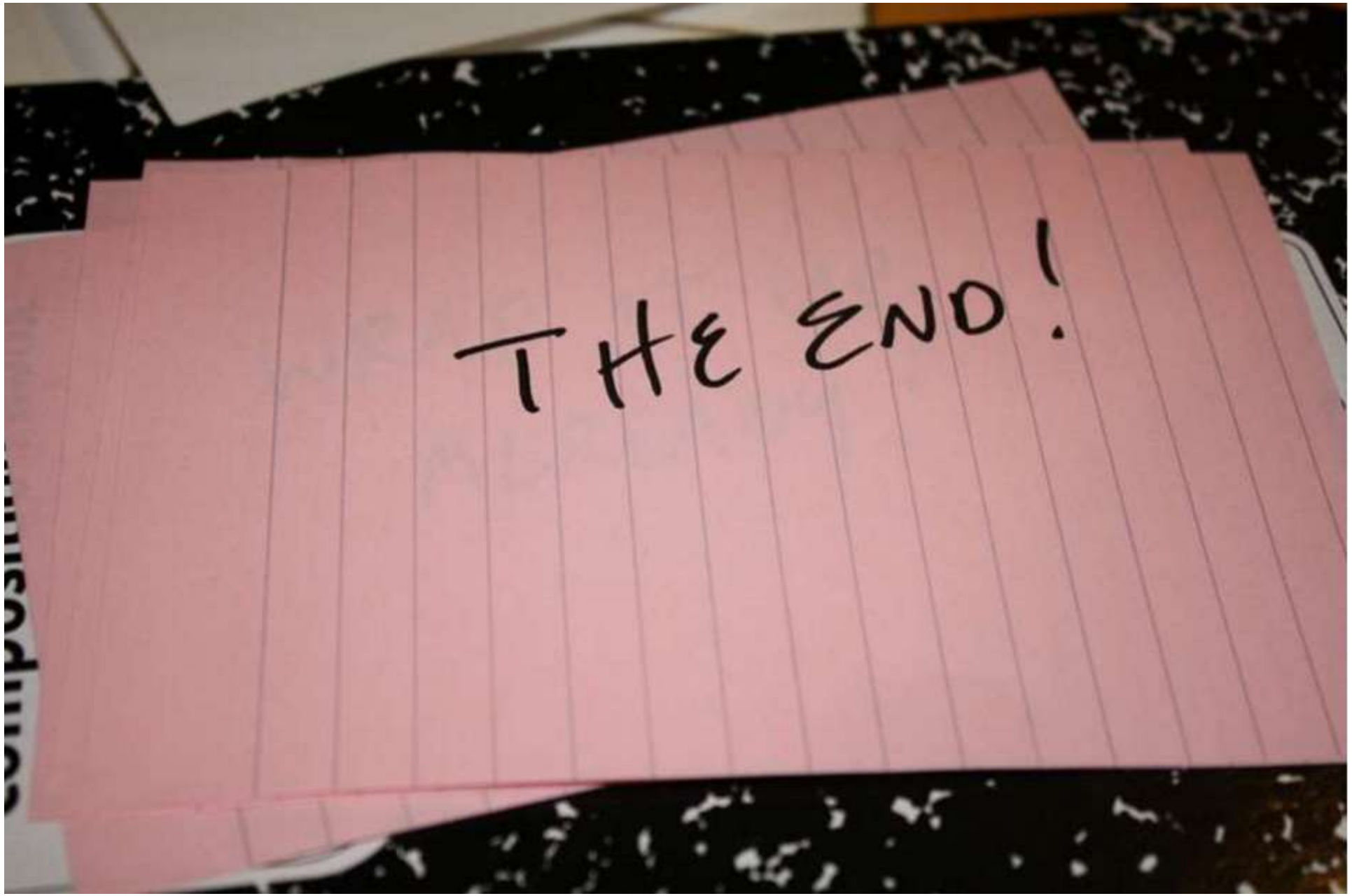
While we're on the subject…
DESIGN PATTERNS:

> "Design patterns are spoonfeed material for brainless programmers incapable of independent thought, who will be resolved to producing code as mediocre as the design patterns they use to create it.

http://realtimecollisiondetection.net/blog/?p=81

http://realtimecollisiondetection.net/blog/?p=44


TRUTHS
① HARDWARE IS THE PLATFORM
② DESIGN AROUND THE DATA, NOT AN IDEALIZED WORLD
③ YOUR MAIN RESPONSIBILITY IS TO TRANSFORM DATA, SOLVE THAT FIRST, NOT THE CODE DESIGN.


THE END!