Compiler Verification, More Necessary than Ever

Marcel Beemster, CTO

Solid Sands

Selection of our Customers

WIND™
AN INTEL COMPANY

DENSO

SILEXICA

HIGHTEC

ARM®

NVIDIA

SYNOPSYS®
Silicon to Software™

QUALCOMM®

Green Hills®
SOFTWARE

TEXAS INSTRUMENTS

cadence®

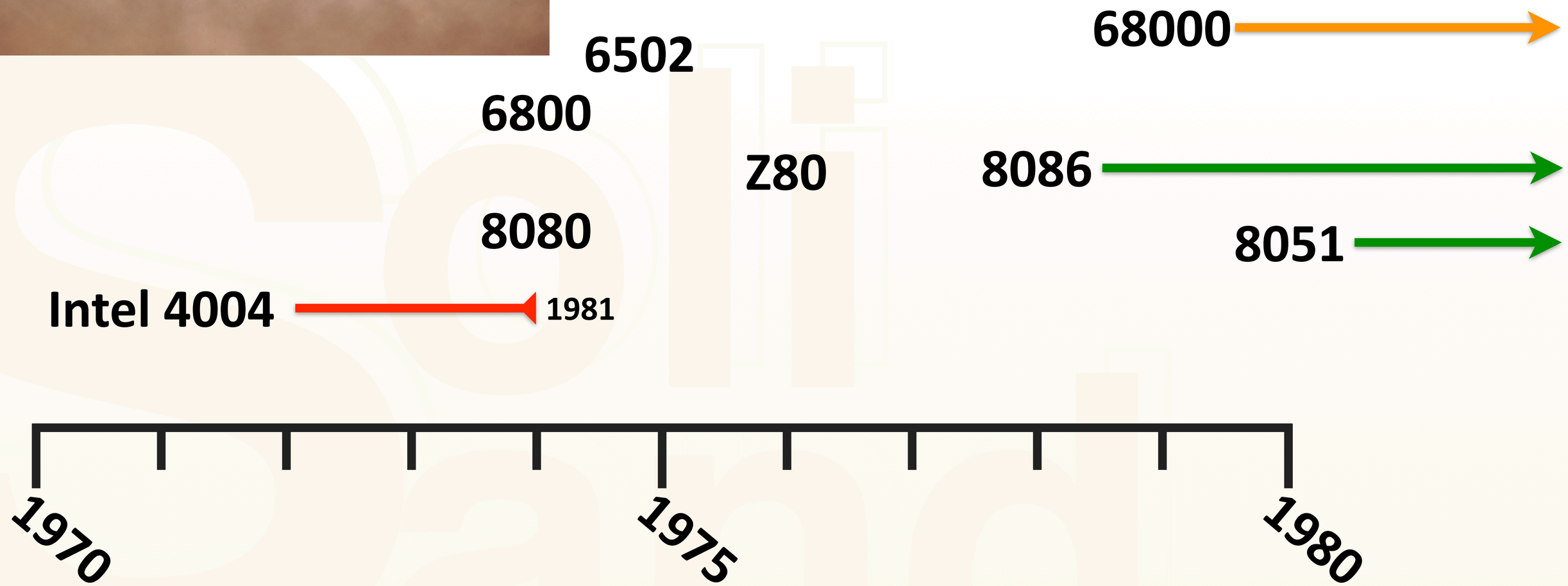
ERICSSON

Sony
Interactive
Entertainment

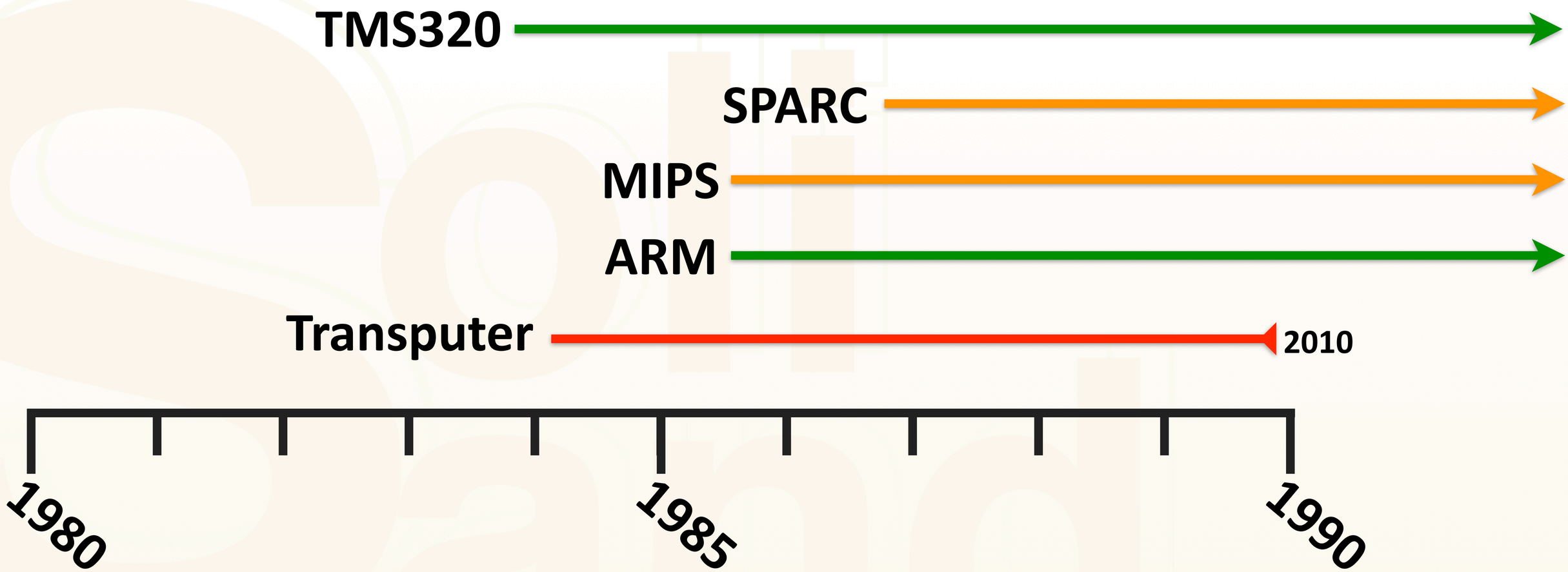
ANALOG DEVICES

CEVA®

The Seventies - CISC



The Eighties - RISC



The Nineties - DSP

StarCore

MMDSP+

REAL

SHARC

1990

1995

2000

The 2000s - VLIW/SIMD

Solid Sands

Hexagon

Itanium

2017

Trimedia

2010

GPU

2000

2005

iPhone

Crisis

2010

The 2010s

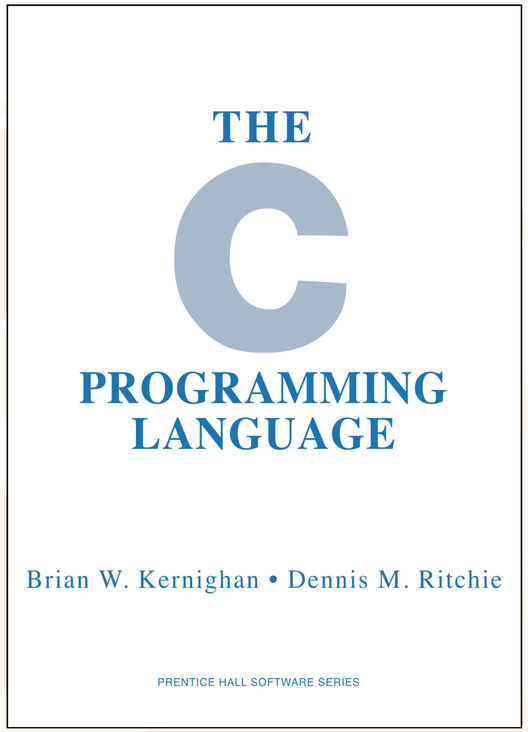
AI/ADAS
ASIP

RISC-V

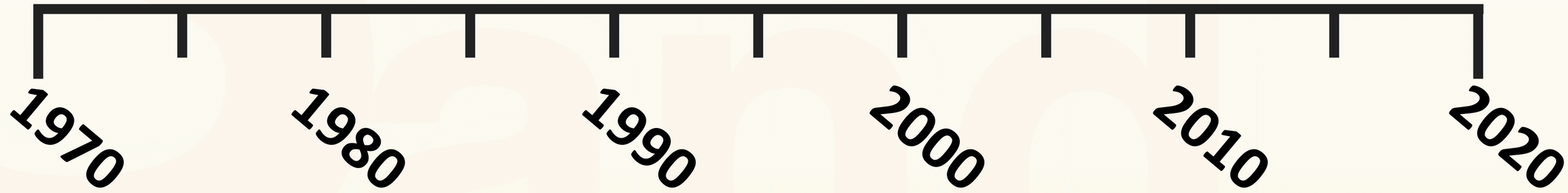
AArch64

2010 2015 2020

Constants of the IT Industry
(The Porsche 911s of Computing?)



- Moore's law
- Battery power is limited
- The C programming language



So, When is my Compiler Finished?

GCC 7.5	November 14, 2019
GCC 9.2	August 12, 2019
GCC 9.1	May 3, 2019
GCC 8.3	February 22, 2019
GCC 7.4	December 6, 2018
GCC 6.5	October 26, 2018
GCC 8.2	July 26, 2018
GCC 8.1	May 2, 2018
GCC 7.3	January 25, 2018
GCC 5.5	October 10, 2017
GCC 7.2	August 14, 2017
GCC 6.4	July 4, 2017
GCC 7.1	May 2, 2017
GCC 6.3	December 21, 2016
GCC 6.2	August 22, 2016
GCC 4.9.4	August 3, 2016
GCC 5.4	June 3, 2016
GCC 6.1	April 27, 2016
GCC 5.3	December 4, 2015
GCC 5.2	July 16, 2015
GCC 4.9.3	June 26, 2015
GCC 4.8.5	June 23, 2015
GCC 5.1	April 22, 2015
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GCC 4.9.1	July 16, 2014
GCC 4.7.4	June 12, 2014
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GCC 4.9.0	April 22, 2014
GCC 4.8.2	October 16, 2013
GCC 4.8.1	May 31, 2013
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1.4	June 13, 1987
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1.2	June 1, 1987
1.1	May 24, 1987
1.0	May 23, 1987
0.9	March 22, 1987

NEVER!

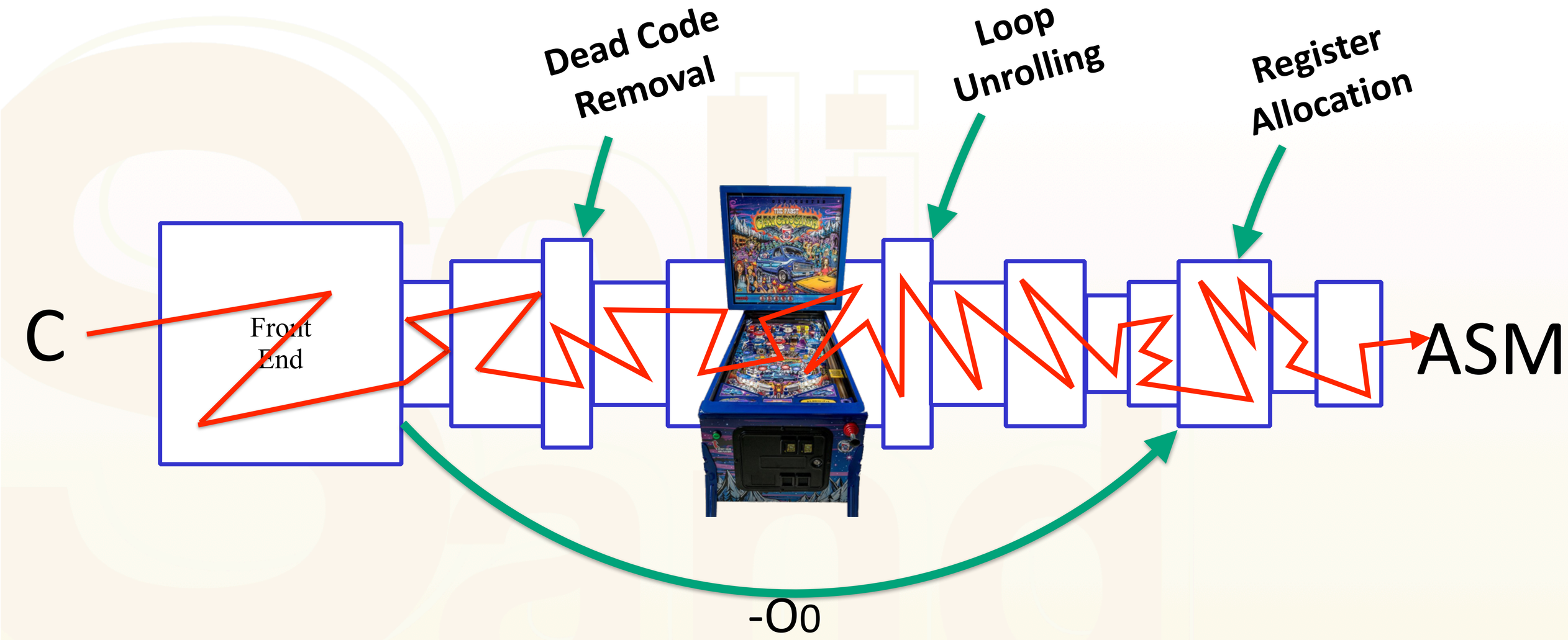
Compilers: Easy to Test in Principle, Hard to Develop

- Well defined and stable specs: ISO C/C++ std
- Single input, single out & deterministic

But need rigorous testing:

- Unstable (Pinball Effect)
- Huge in size, dev team, time-span
- Never finished
- Non-functional reqs

The Internal Structure of a Compiler



Solid Sands

cc -O1

Solid Sands

```
cc -O1
```

Solid Sands

cc -Ofast

Solid Sands

```
cc -Ofast
```

Run-Time Optimization Error SuperTest 3/5/7/tspr2388.c

```
s[0] = 42;
*(sp[0]) = -1;      /* *(sp[0]) is an alias of s[0] */
if( s[0] == 42 )    /* Incorrectly yields true */
```

- This is REALLY BAD!
- Because no optimization was specified and there is no option to turn this off
- Because it is not linked to a specific syntactical feature

Optimization Testing

```
int f(int n) {
    int total = 0;
    for (int i=0; i<n; i++){
        total += i & n;
    }
    return total;
}
```

Compile at -O2:
About 80% structural coverage at assembly with unit test:
f(999)

Needs 5 tests for maximal coverage.
Full branch coverage not possible

```
+:  test   %edi,%edi
v:  jle    0x400552 <loop+0x12>
+:  xor    %edx,%edx
+:  cmp    $0x7,%edi
>:  ja     0x400555 <loop+0x15>
-:  xor    %eax,%eax
-:  jmpq   0x400660 <loop+0x120>
-:  xor    %eax,%eax
-:  retq
+:  mov    %edi,%ecx
+:  and    $0xfffffff8,%ecx
+:  mov    $0x0,%eax
v:  je     0x400660 <loop+0x120>
+:  movd   %edi,%xmm0
+:  pshufd $0x0,%xmm0,%xmm0
+:  lea    -0x8(%rcx),%edx
+:  mov    %edx,%eax
+:  shr    $0x3,%eax
+:  bt     $0x3,%edx
>:  jb     0x4005aa <loop+0x6a>
-:  movdqa 0x17c(%rip),%xmm1
-:  pand   %xmm0,%xmm1
-:  movdqa 0x180(%rip),%xmm3
-:  pand   %xmm0,%xmm3
-:  movdqa 0x184(%rip),%xmm5
-:  mov    $0x8,%edx
-:  test   %eax,%eax
```

```
-:  jne    0x4005c0 <loop+0x80>
-:  jmpq   0x400637 <loop+0xf7>
+:  pxor   %xmm1,%xmm1
+:  movdqa 0x14a(%rip),%xmm5
+:  xor    %edx,%edx
+:  pxor   %xmm3,%xmm3
+:  test   %eax,%eax
v:  je     0x400637 <loop+0xf7>
+:  mov    %ecx,%eax
+:  sub    %edx,%eax
+:  movdqa 0x163(%rip),%xmm8
+:  movdqa 0x16a(%rip),%xmm9
+:  movdqa 0x172(%rip),%xmm6
+:  movdqa 0x17a(%rip),%xmm7
+:  nopw   %cs:0x0(%rax,%rax,1)
+:  movdqa %xmm5,%xmm2
+:  paddd  %xmm8,%xmm2
+:  movdqa %xmm5,%xmm4
+:  pand   %xmm0,%xmm4
+:  pand   %xmm0,%xmm2
+:  paddd  %xmm1,%xmm4
+:  paddd  %xmm3,%xmm2
+:  movdqa %xmm5,%xmm1
+:  paddd  %xmm9,%xmm1
+:  movdqa %xmm5,%xmm3
+:  paddd  %xmm6,%xmm3
+:  pand   %xmm0,%xmm1
```

```
+:  pand   %xmm0,%xmm3
+:  paddd  %xmm4,%xmm1
+:  paddd  %xmm2,%xmm3
+:  paddd  %xmm7,%xmm5
+:  add    $0xfffffff0,%eax
+:  jne    0x4005f0 <loop+0xb0>
+:  paddd  %xmm3,%xmm1
+:  pshufd $0x4e,%xmm1,%xmm0
+:  paddd  %xmm1,%xmm0
+:  pshufd $0xe5,%xmm0,%xmm1
+:  paddd  %xmm0,%xmm1
+:  movd   %xmm1,%eax
+:  cmp    %edi,%ecx
+:  mov    %ecx,%edx
v:  je     0x40066c <loop+0x12c>
+:  nopw   0x0(%rax,%rax,1)
+:  mov    %edx,%ecx
+:  and    %edi,%ecx
+:  add    %ecx,%eax
+:  inc    %edx
+:  cmp    %edx,%edi
+:  jne    0x400660 <loop+0x120>
+:  retq
```

Floating Point Fail on Linux Subsystem for Windows on x86


```
long double ldVar = 1.3L
assert ( ldVar + LDBL_EPSILON >= ldVar );
```

- Compiler is OK
- Windows is OK
- But integration (use case) fails

Compiler Verification, More Necessary than Ever!

- As long as there is technological progress, or new application areas, there will be new compilers
- Compilers are fundamentally unstable
- SuperTest is the best test-suite for C and C++ compilers and libraries

Thank You!

Marcel Beemster
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