CPU Toolchain Launch Postmortem

Greg Bedwell

x86-64 AMD “Jaguar”
8-core CPU

1.84 TFLOPS AMD Radeon™
based GPU

8GB GDDR5 RAM

http://llvm.org/devmtg/2013-11/

postmortem *noun*

“an analysis or discussion of an event after it is over”

Now that we have successfully launched PlayStation®4 it is a good time to look back on our initial period of development up to that point

http://www.merriam-webster.com/dictionary/postmortem

condensed

First, some history...

SN Systems Ltd. was founded in 1988 to provide development tools for the games industry

1990 *Psy-Q*

16-bit home systems

Psy-Q included a version of GCC that was highly customized for the needs of game developers

1994 *Psy-Q*

PlayStation®

Continued to provide GCC but started researching a proprietary compiler technology – “SNC”

2000 *ProDG*

PlayStation®2

Provided SNC as part of the ProDG suite of tools although GCC was also available

2004 *ProDG*

PSP®

(PlayStation®Portable)

Sony Computer Entertainment Inc. acquired SN Systems in 2005

Provided SNC as part of the ProDG suite of tools although GCC was also available

2006 *ProDG*

PlayStation®3

CPU Compiler is SNC

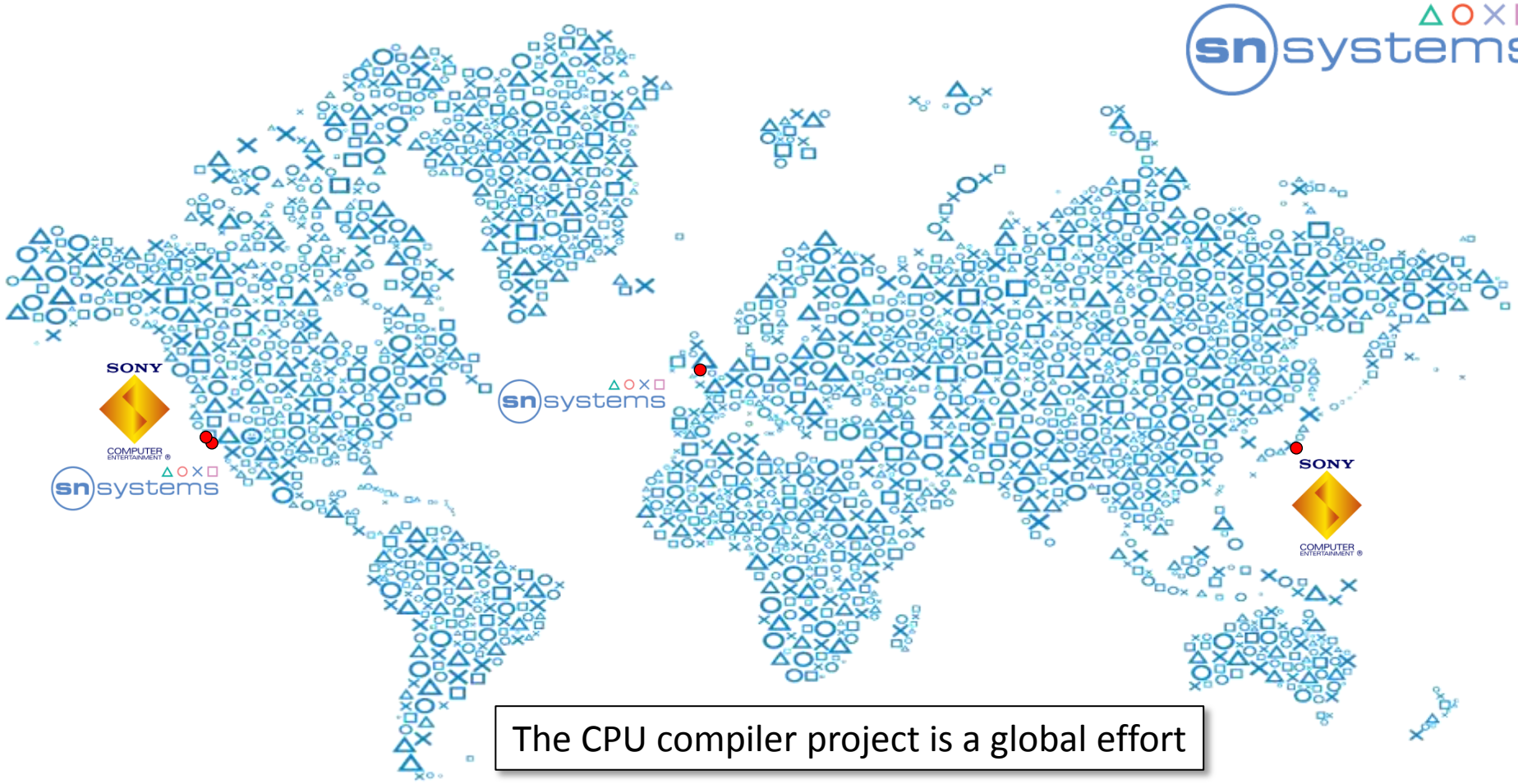
2011

PlayStation®Vita

CPU Compiler is Clang

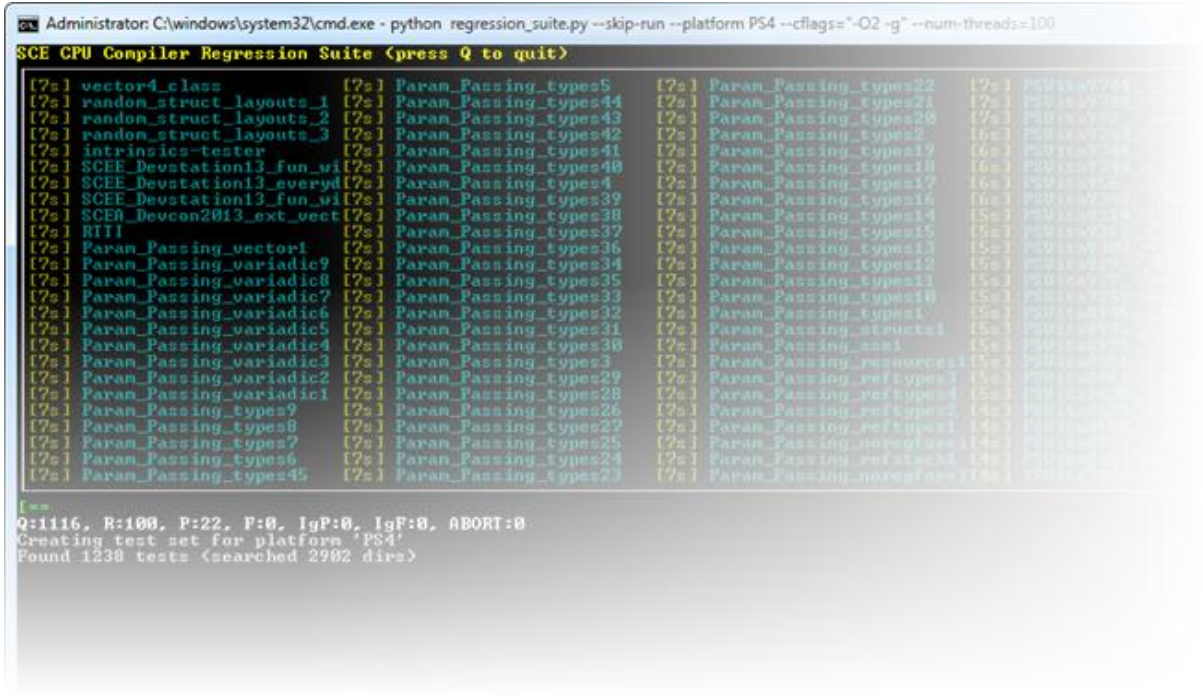
2013

PlayStation®4


sn systems
SONY
COMPUTER ENTERTAINMENT
sn systems
sn systems
SONY
COMPUTER ENTERTAINMENT
The CPU compiler project is a global effort

Builds and build systems

(and test systems)

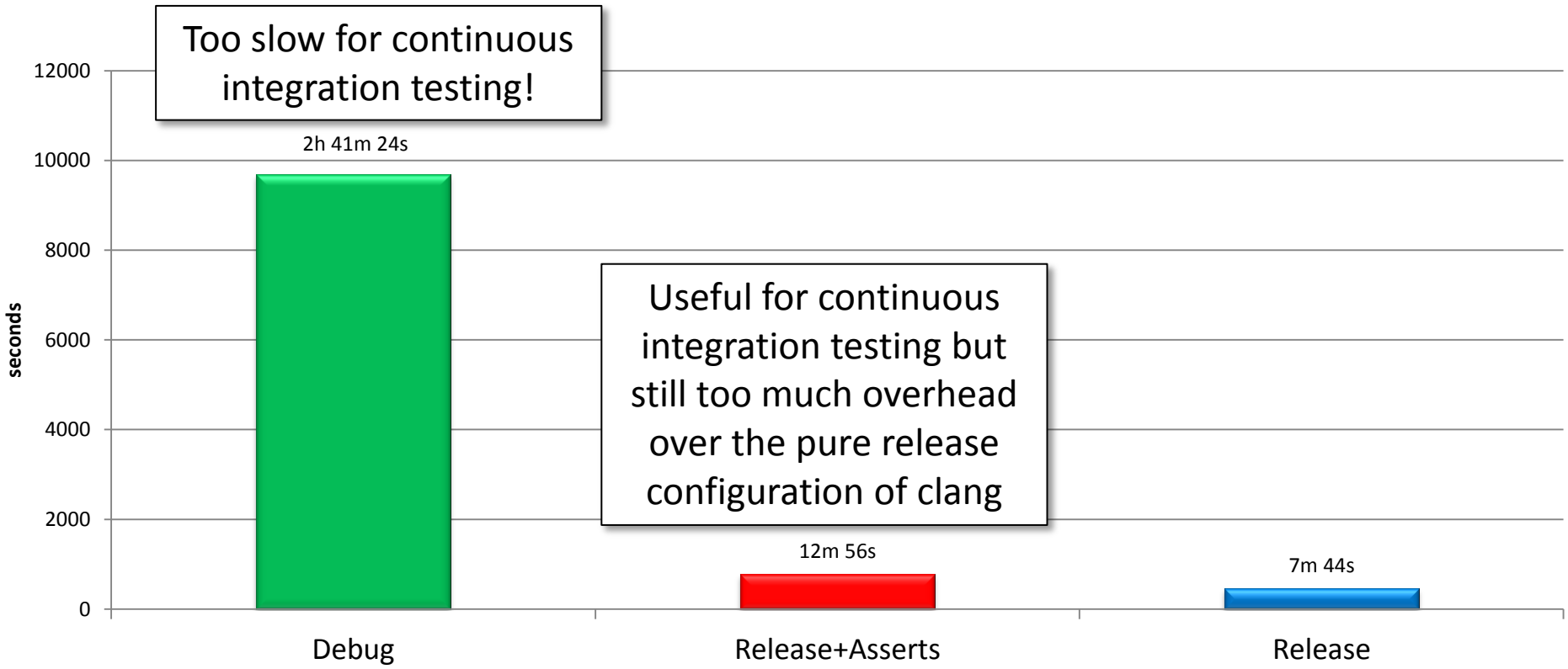


We wanted to make use of all of our pre-existing test suites and test systems, which are shared across all targets

	Optimized	Assertions	Debug Info
Debug	✗	✓	✓
MinSizeRel	✓	✗	✗
Release	✓	✗	✗
RelWithDebInfo	✓	✗	✓

	Optimized	Assertions	Debug Info
Debug	✗	✓	✓
MinSizeRel	✓	✗	✗
Release	✓	✗	✗
RelWithDebInfo	✓	✗	✓

Clang configuration effect on game build time



	Optimized	Assertions	Debug Info
Debug	✗	✓	✓
Checking	✓	✓	✗
Release	✓	✗	✗

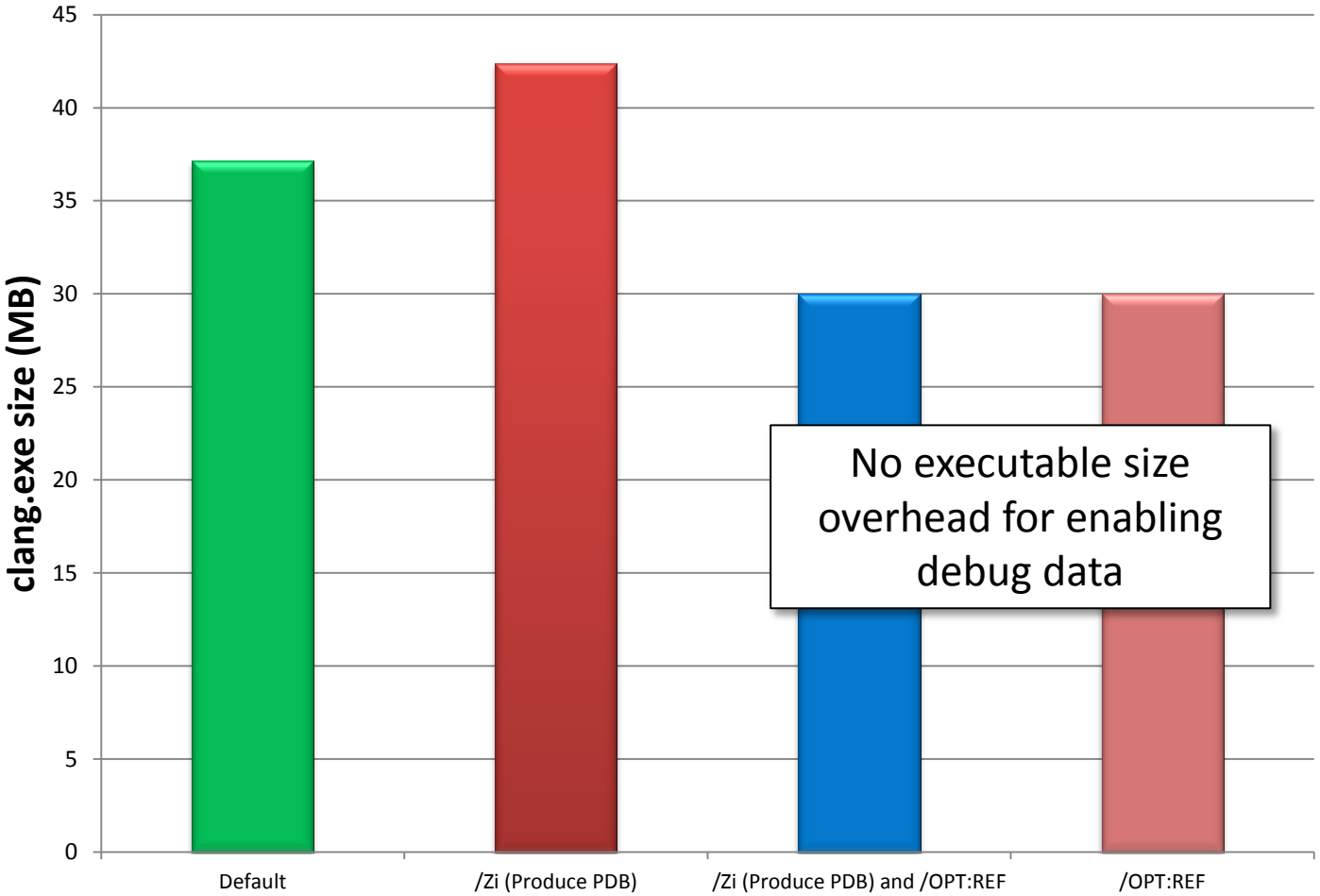
The same set of build configurations as we use for SNC

“Debug” for debugging

“Release” for releasing

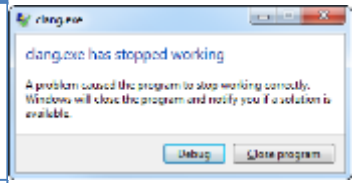
“Checking” (Release+Asserts) for continuous integration testing

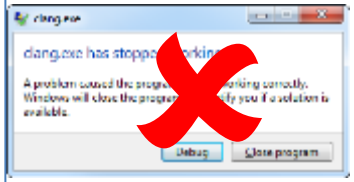
	Optimized	Assertions	Debug Info
Debug	✗	✓	✓
Checking	✓	✓	✗
Release	✓	✗	✗

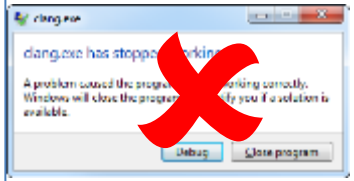

clang.exe size (MB)
45
40
35
30
25
20
15
10
5
0
Default
/Zi (Produce PDB)
/Zi (Produce PDB) and /OPT:REF
/OPT:REF
No executable size overhead for enabling debug data

	Optimized	Assertions	Debug Info
Debug	✗	✓	✓
Checking	✓	✓	✓
Release	✓	✗	✓

	Optimized	Assertions	Debug Info
Debug	✗	✓	✓
Checking	✓	✓	✓
Release	✓	✗	✓







Suppress Windows crash dialog box for Checking and Release builds

Improving test coverage

Things we know

Game code is usually

BIG

For a new platform, the amount of code that exists is

small

Things we know

Users value

CORRECTNESS

over all else

*Why write **tests***

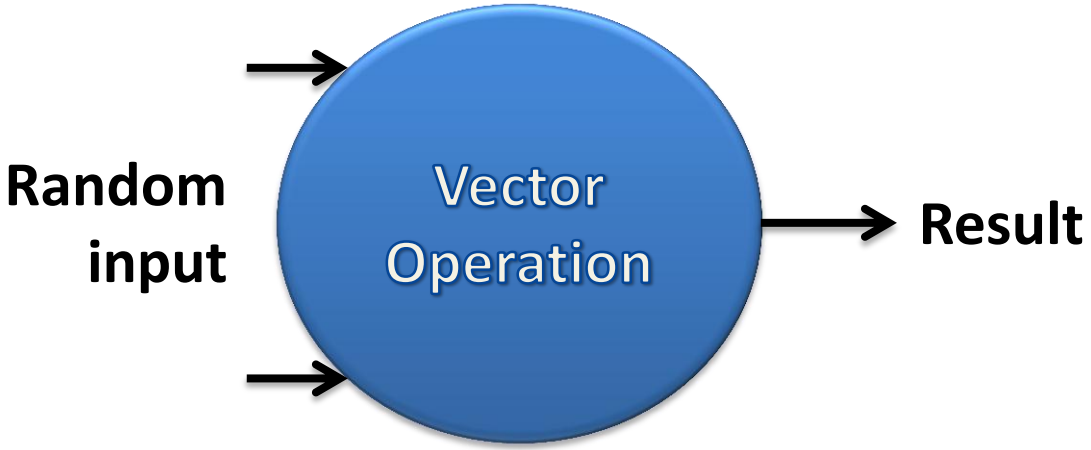
*when I can write a **test generator**?*

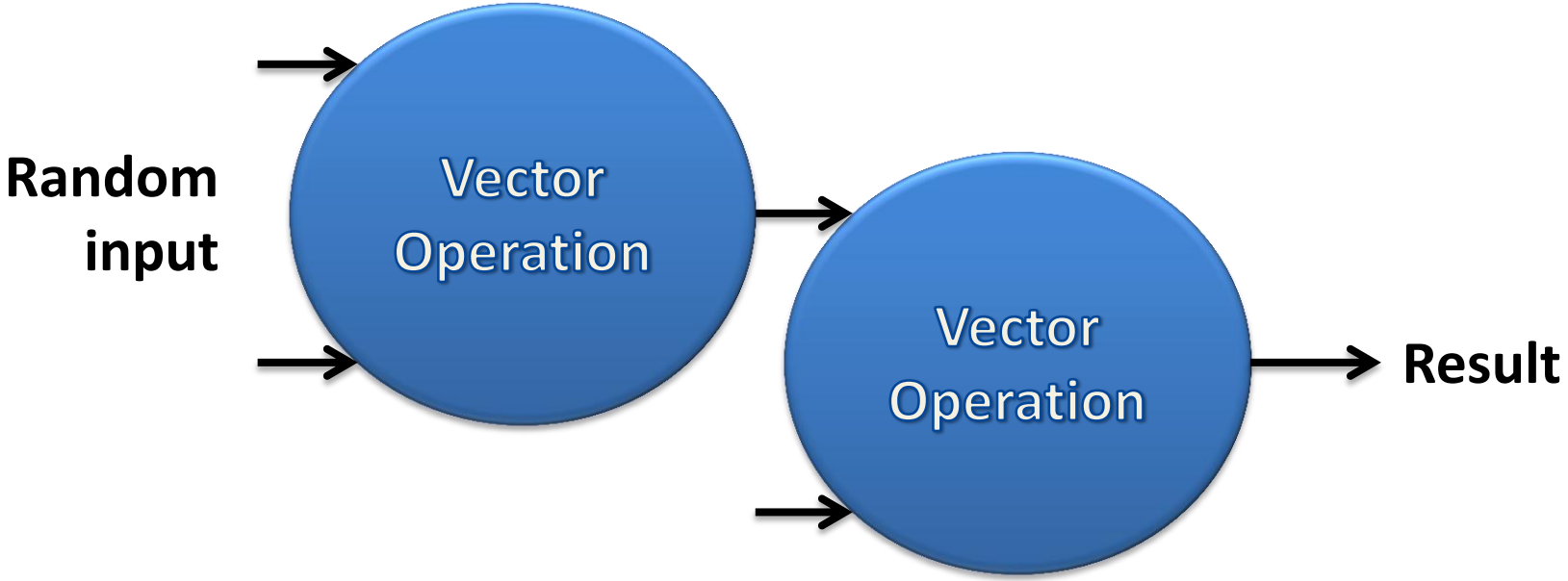
Why write ***tests***

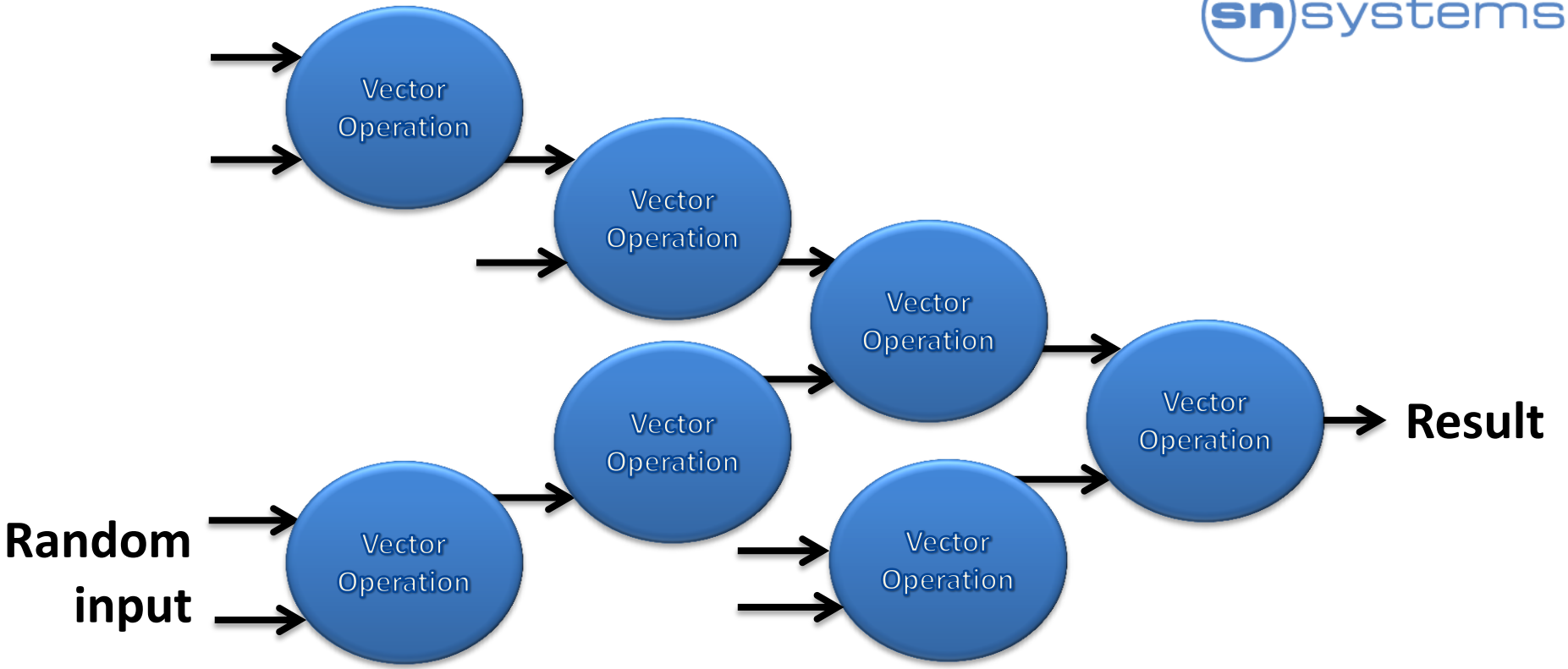
when I ~~can write~~ a ***test generator****?*

already have

Generate random C++ tests using SIMD language extensions and intrinsics to increase test coverage




Random input
Vector Operation
Vector Operation
Result


Vector Operation
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Vector Operation
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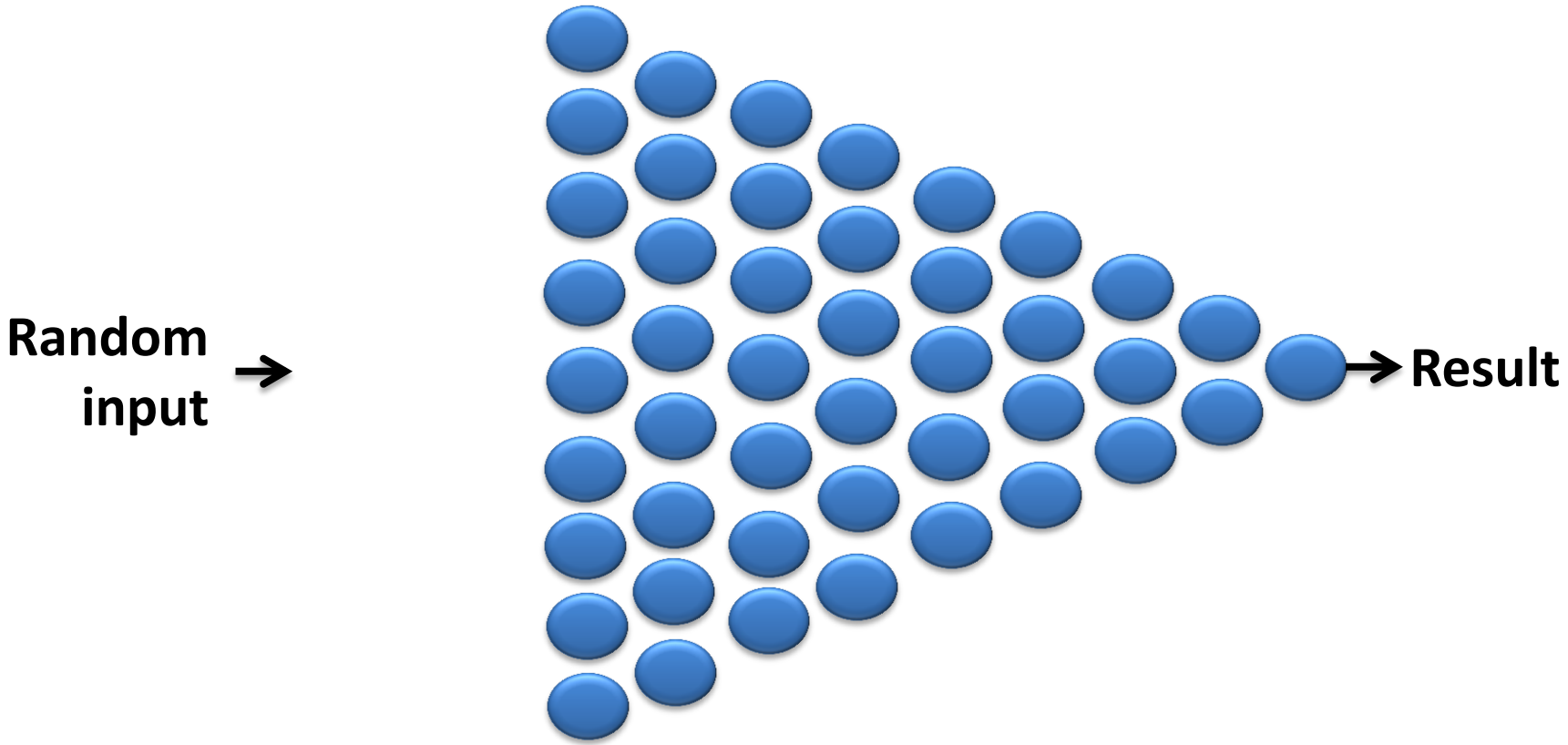
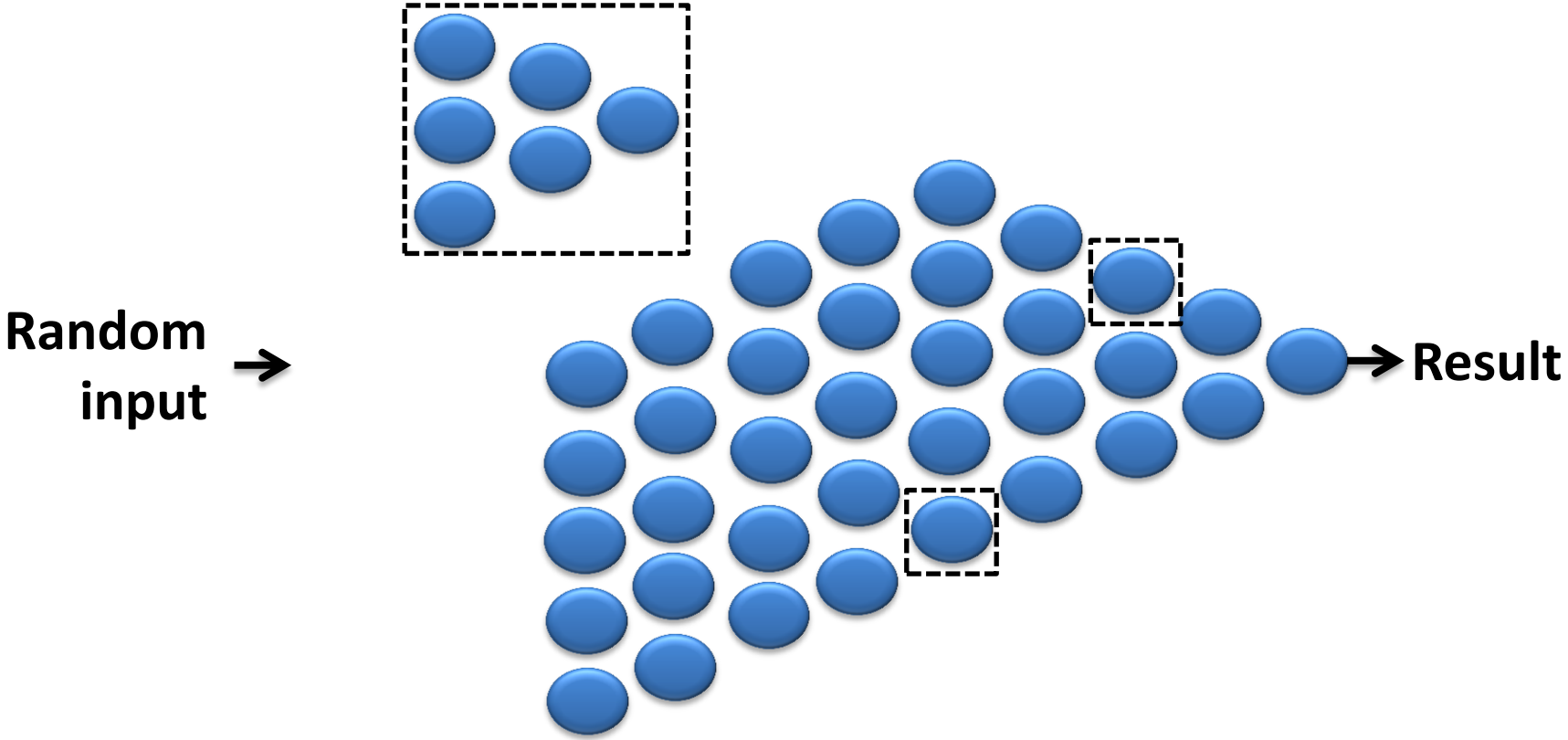
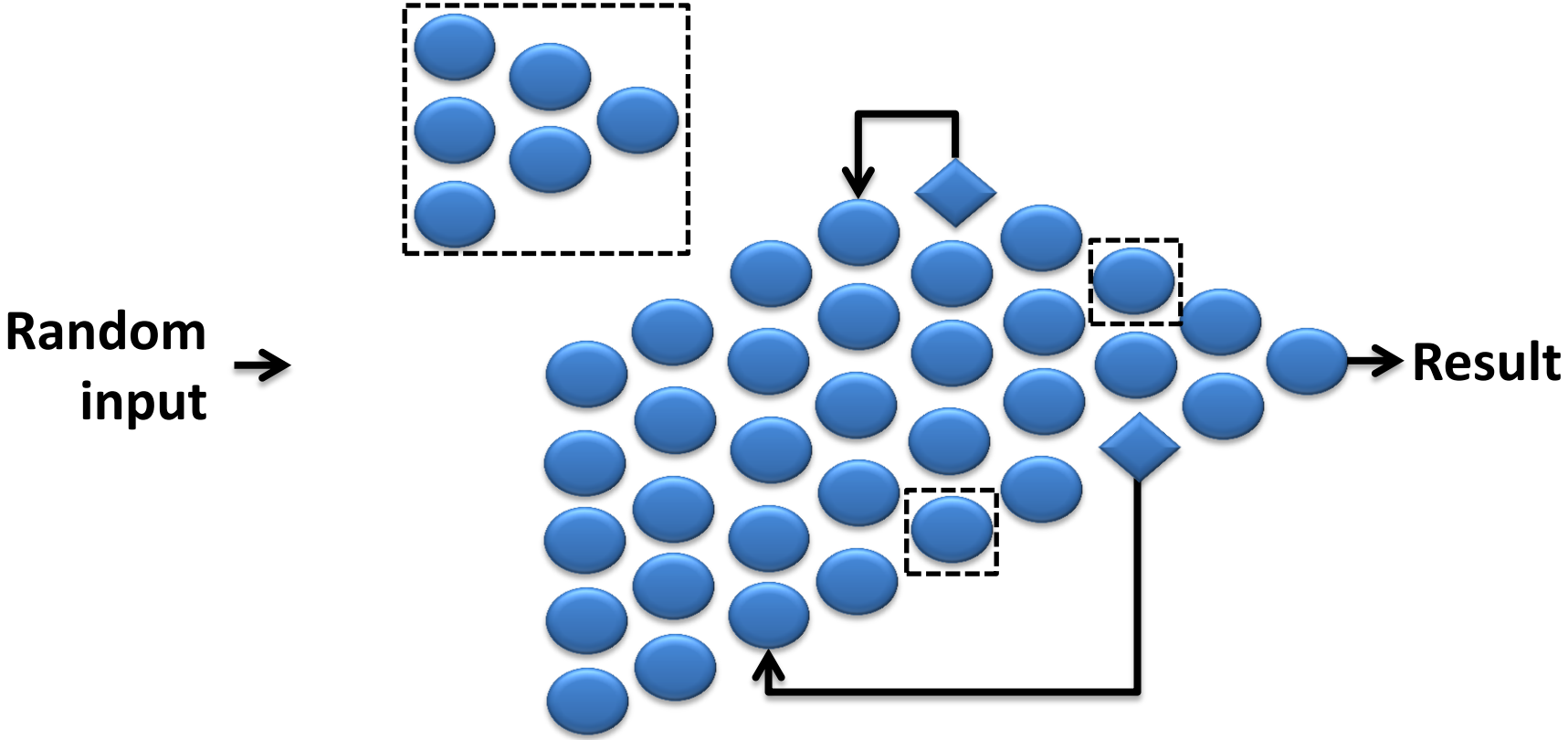
Random input


Random input
Result


Random input
Result


Random
input
Result

Undefined behaviour makes runtime-behaviour random testing hard!

Solution: Use a ‘safe’ wrapper to make all undefined behaviour defined for the purpose of the test

Reducing optimization bugs

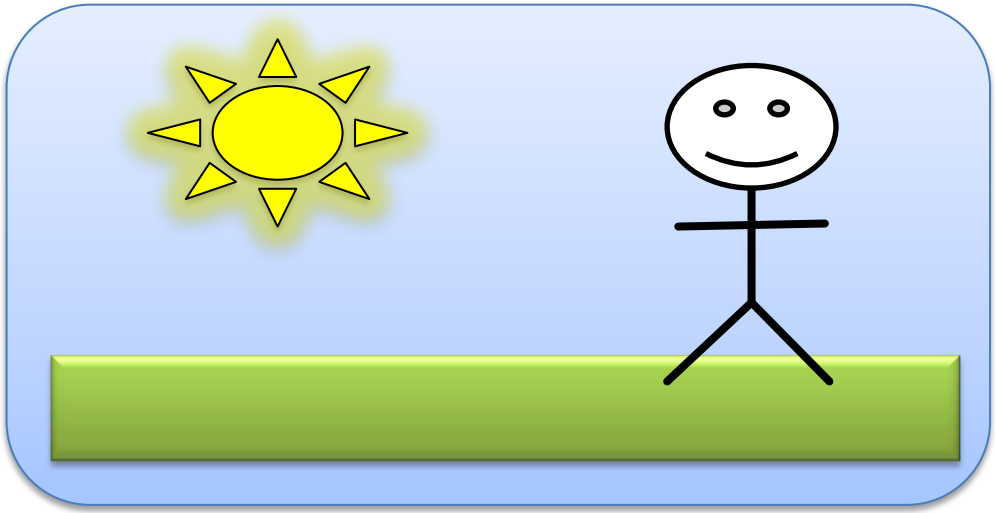
bugpoint

Windows

Clang integration

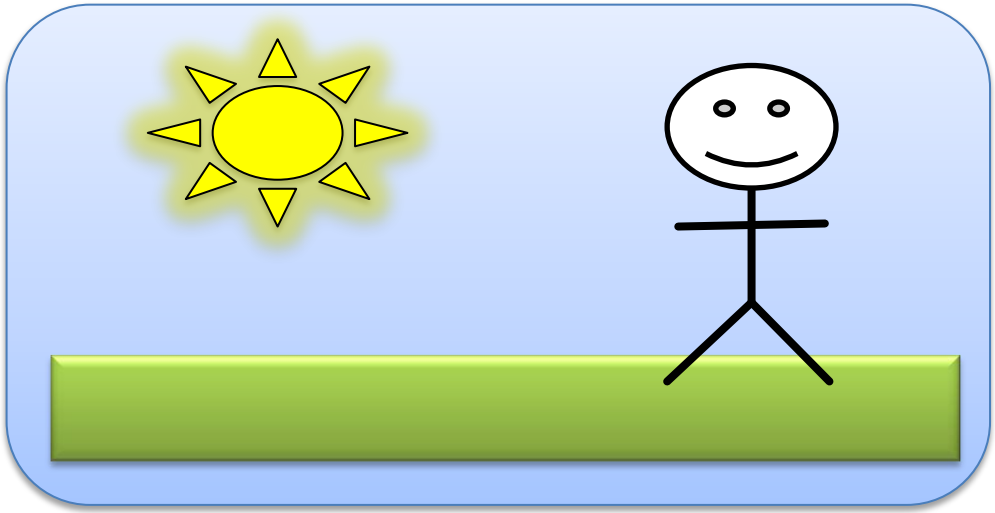
An alternative approach

SNC's max_opts

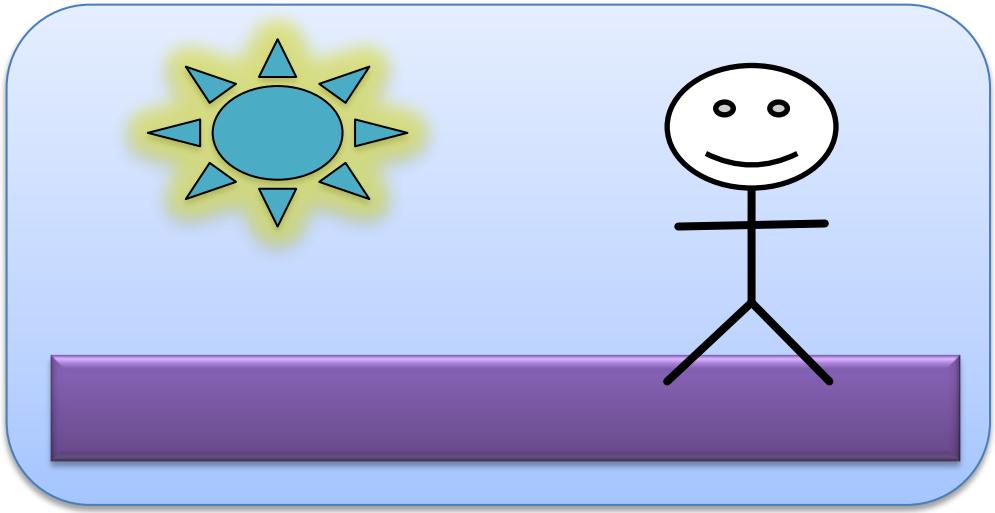


*Not representative of actual visuals

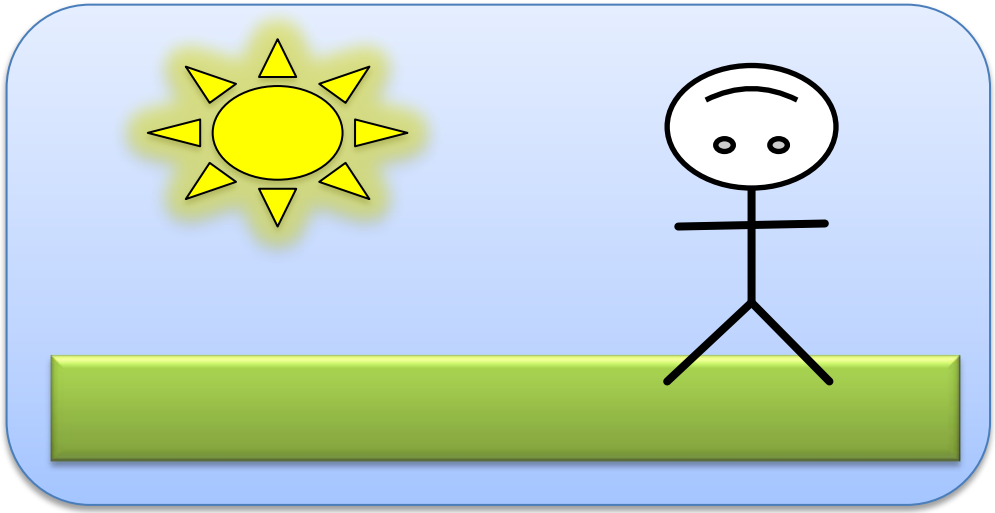
SNC's max_opts



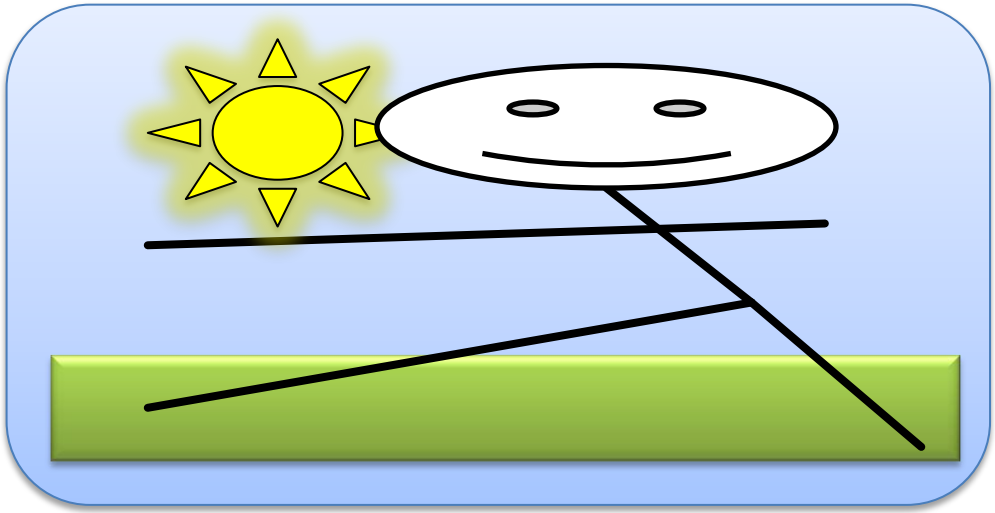
SNC's max_opts



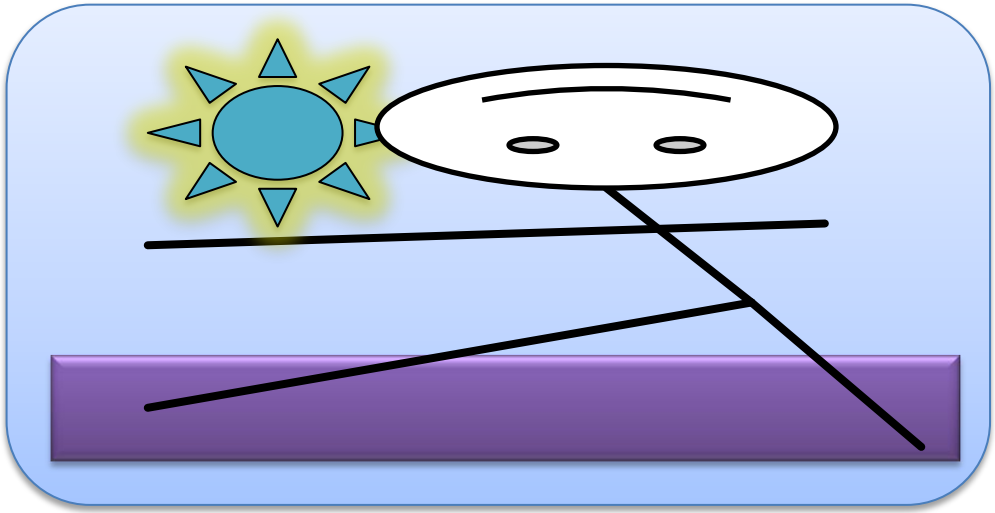
SNC's max_opts



SNC's max_opts



SNC's max_opts



SNC's max_opts

SNC optimizer

SSA Form

Rule Based

Every transformation is guarded by a specific check

SNC keeps an internal counter of the number of transformations it performs

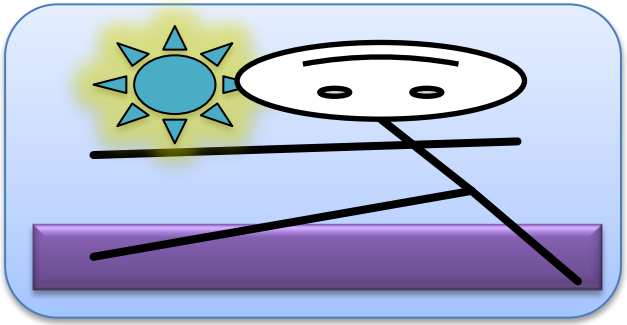
```
if (/* conditions match */ &&
    Opt_Enabled(permute_converted_to_opscalartovector))
{
  Trace_Opt(permute_converted_to_opscalartovector);
  /* Perform optimization */
}
```

Allows the user to specify a limit on the command line after which no further transformations can be performed

SNC's max_opts

"Autochop" harness

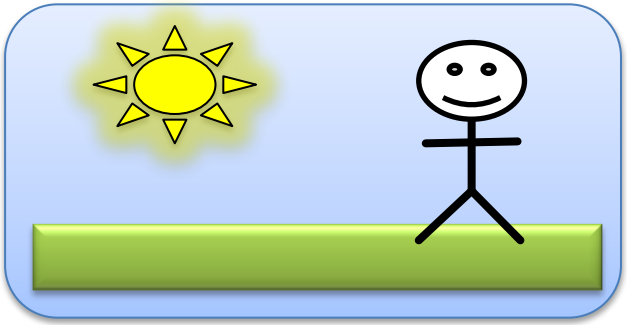
-O2



SNC's max_opts

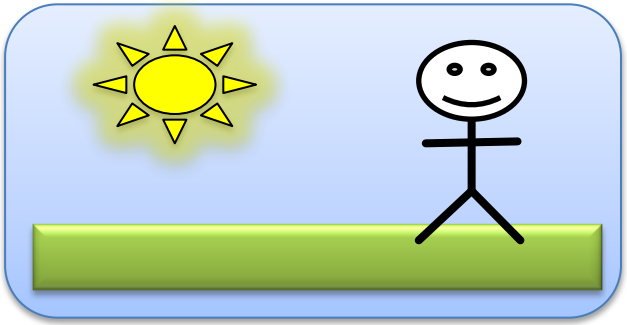
"Autochop" harness

-O0



SNC's max_opts

"Autochop" harness

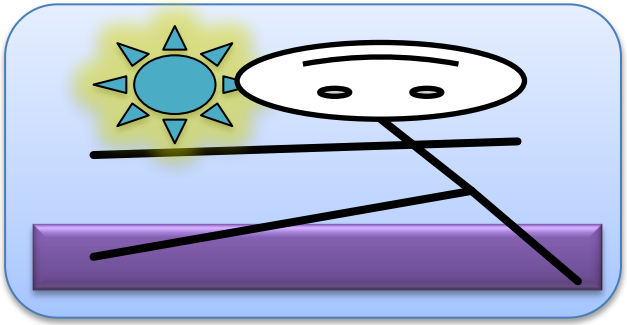


SNC's max_opts

"Autochop" harness

-O0

-O2



SNC's max_opts

"Autochop" harness

-O0

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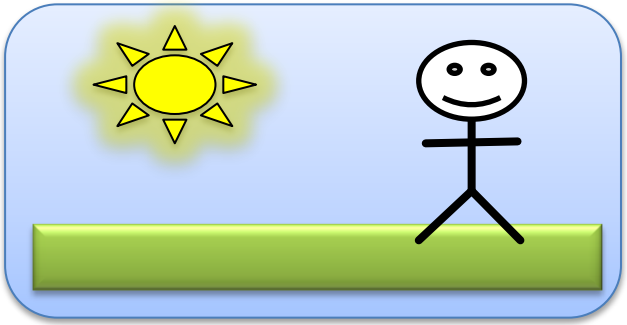
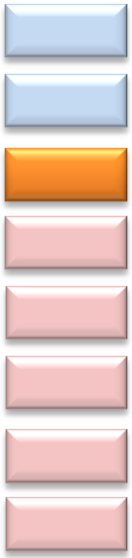


SNC's max_opts

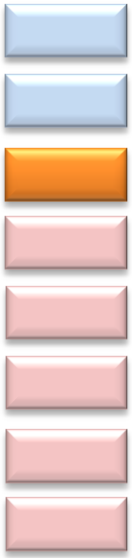
"Autochop" harness



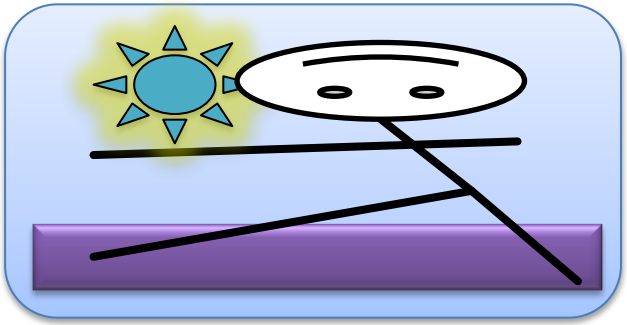
We've found the game source file with the bad transformation

SNC's max_opts

"Autochop" harness

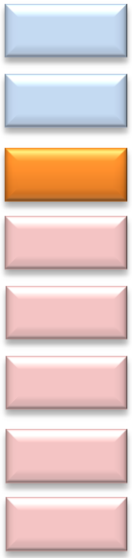


-Xmax_opts=2048

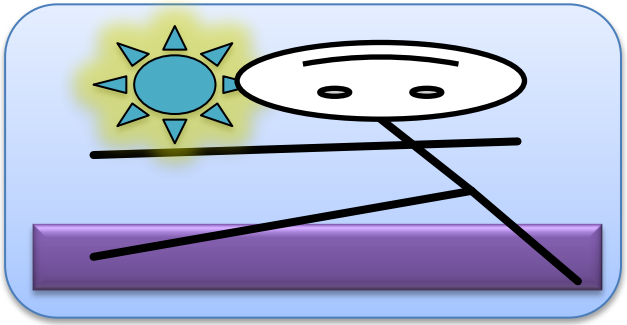


SNC's max_opts

"Autochop" harness

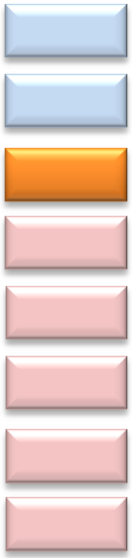


-Xmax_opts=1024

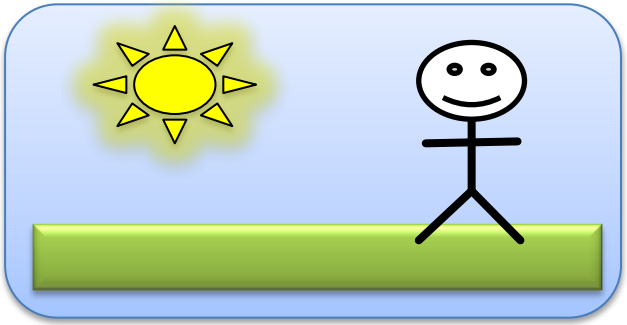


SNC's max_opts

"Autochop" harness

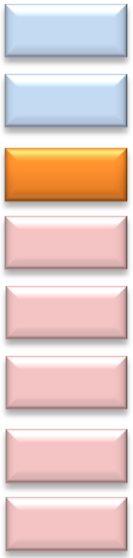


-Xmax_opts=512

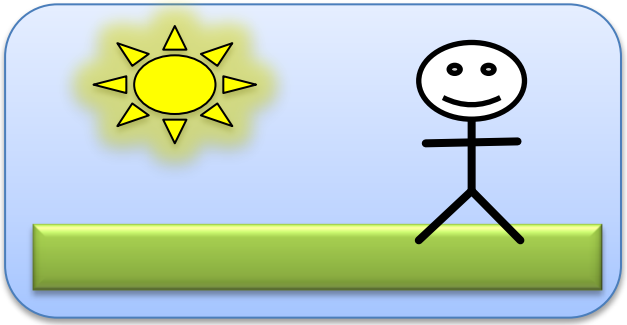


SNC's max_opts

"Autochop" harness

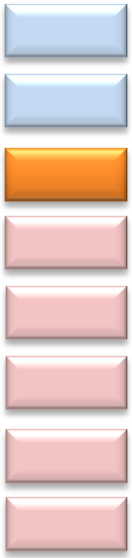


-Xmax_opts=988

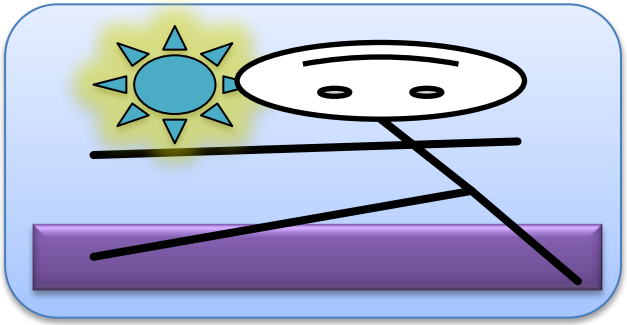


SNC's max_opts

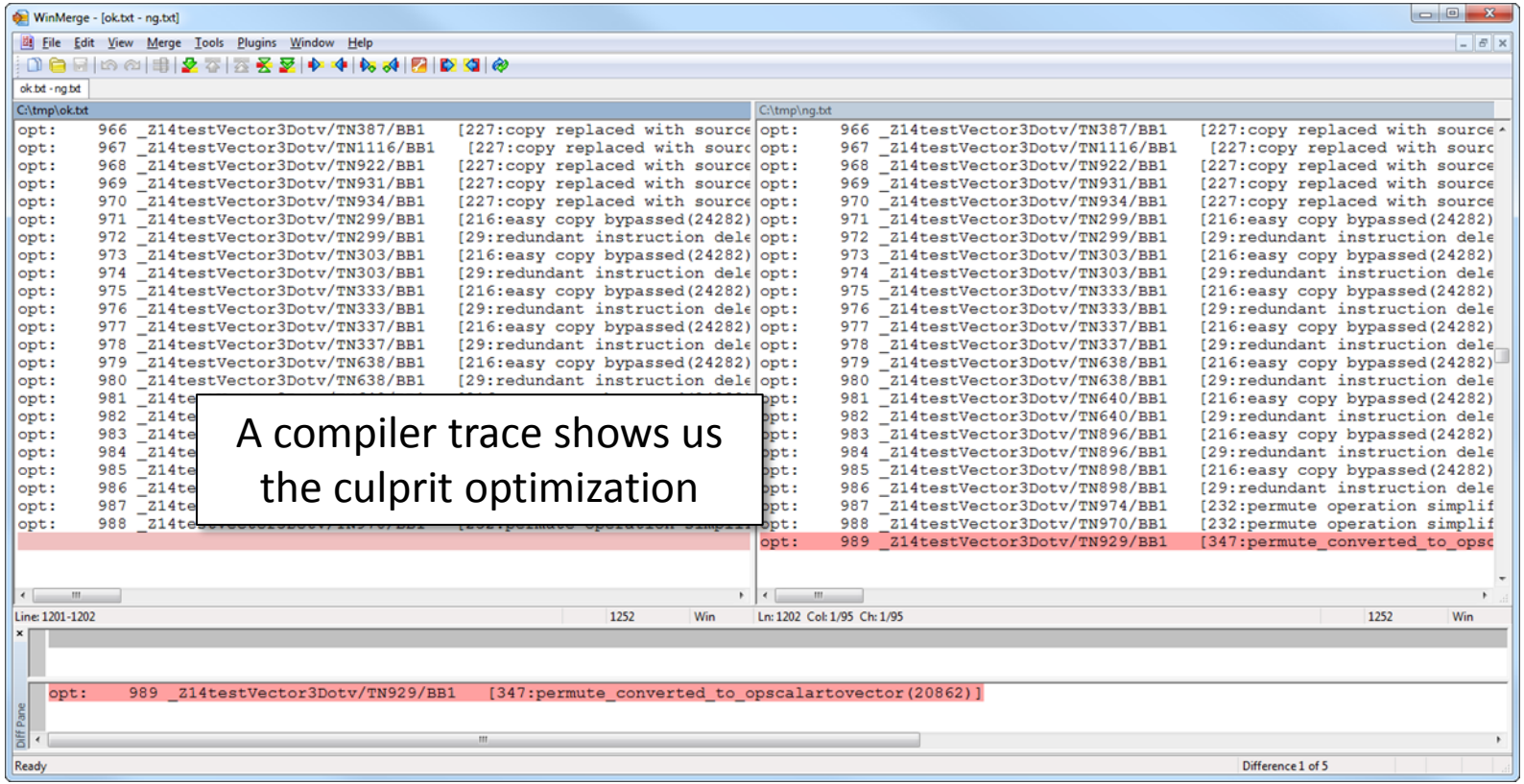
"Autochop" harness



-Xmax_opts=989



Now we've found the specific transformation causing the miscompile


WinMerge - [ok.txt - ng.txt]
File Edit View Merge Tools Plugins Window Help
ok.txt - ng.txt
C:\tmp\ok.txt
C:\tmp\ng.txt
opt: 966 _Z14testVector3Dotv/TN387/BB1 [227:copy replaced with source
opt: 967 _Z14testVector3Dotv/TN1116/BB1 [227:copy replaced with sourc
opt: 968 _Z14testVector3Dotv/TN922/BB1 [227:copy replaced with source
opt: 969 _Z14testVector3Dotv/TN931/BB1 [227:copy replaced with source
opt: 970 _Z14testVector3Dotv/TN934/BB1 [227:copy replaced with source
opt: 971 _Z14testVector3Dotv/TN299/BB1 [216:easy copy bypassed(24282)
opt: 972 _Z14testVector3Dotv/TN299/BB1 [29:redundant instruction dele
opt: 973 _Z14testVector3Dotv/TN303/BB1 [216:easy copy bypassed(24282)
opt: 974 _Z14testVector3Dotv/TN303/BB1 [29:redundant instruction dele
opt: 975 _Z14testVector3Dotv/TN333/BB1 [216:easy copy bypassed(24282)
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opt: 985 _Z14testVector3Dotv/TN898/BB1 [216:easy copy bypassed(24282)
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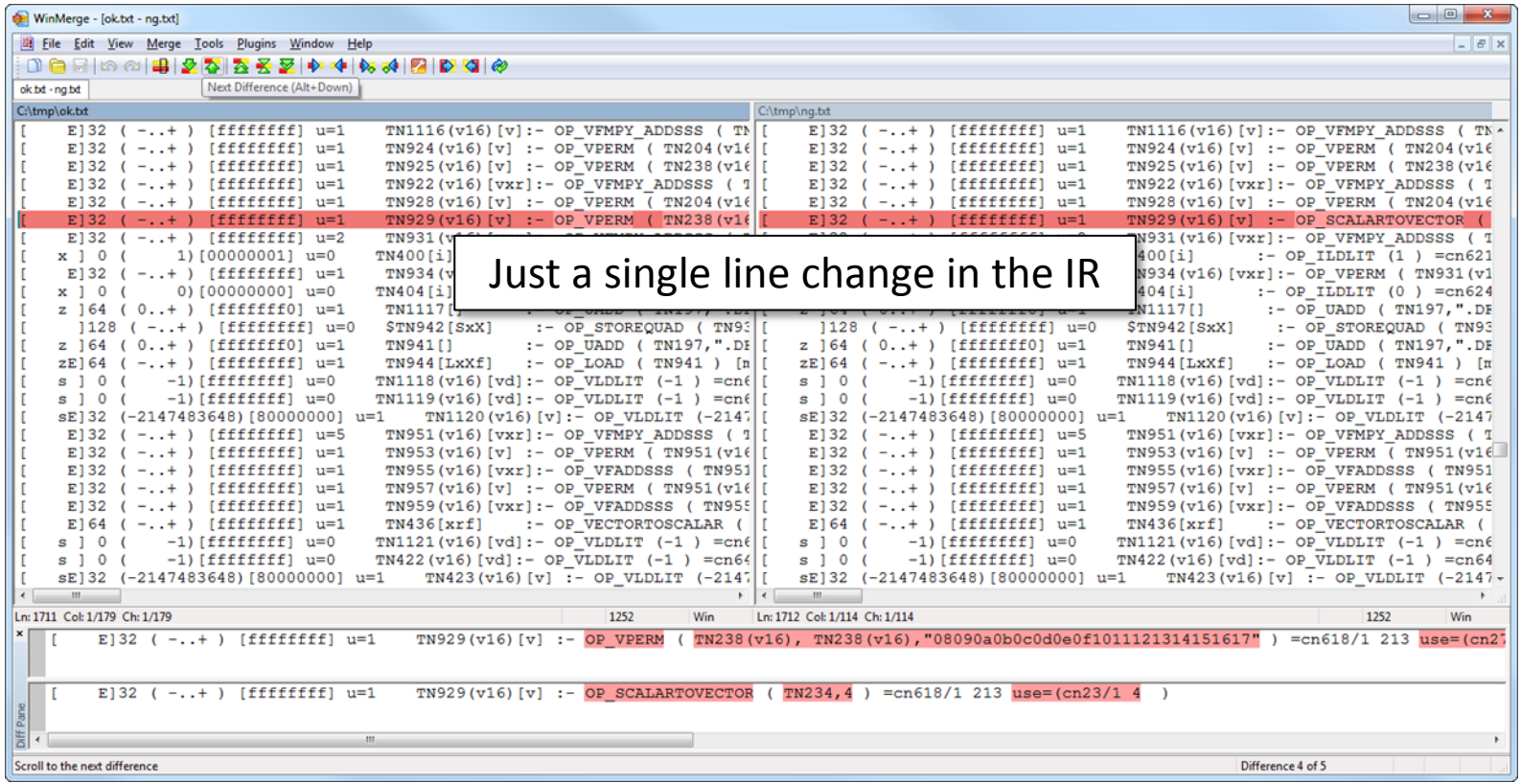
opt: 987 _Z14testVector3Dotv/TN974/BB1 [232:permute operation simplif
opt: 988 _Z14testVector3Dotv/TN970/BB1 [232:permute operation simplif
opt: 989 _Z14testVector3Dotv/TN929/BB1 [347:permute_converted_to_opsc
A compiler trace shows us the culprit optimization
Line: 1201-1202 1252 Win
Ln: 1202 Col: 1/95 Ch: 1/95 1252 Win
Diff Pane
opt: 989 _Z14testVector3Dotv/TN929/BB1 [347:permute_converted_to_opscalartovector(20862)]
Ready
Difference 1 of 5

Narrowed down to a single difference in IR



SNC's max_opts

A question for the community:

Would this work in LLVM/Clang?

(even if just at pass level)

The release process

Docs

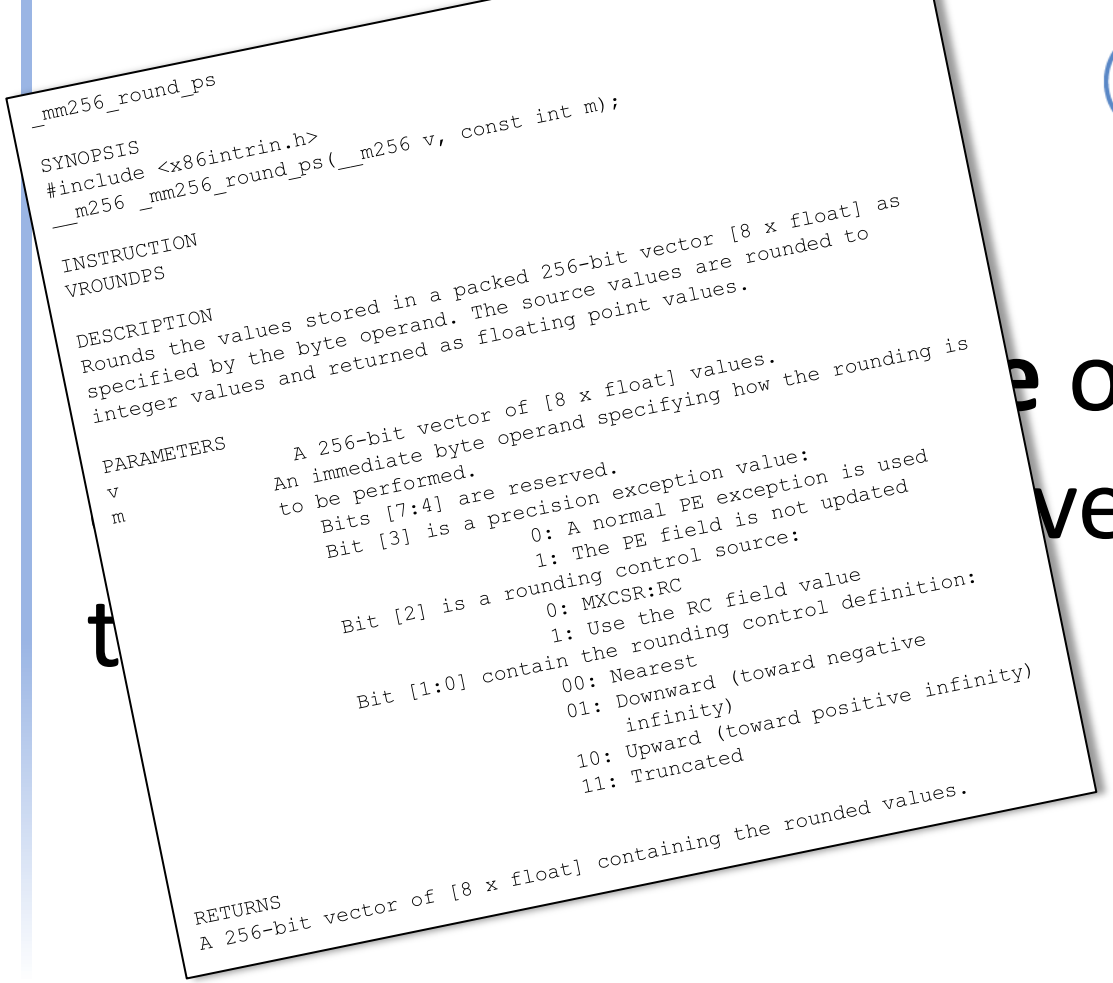
End-user documentation is lacking

Release notes aimed at Clang/LLVM developers, not users

Docs

We plan to **contribute** our documentation improvements to the **community**

Docs



```
_mm256_round_ps

SYNOPSIS
#include <x86intrin.h>
__m256 _mm256_round_ps(__m256 v, const int m);

INSTRUCTION
VROUNDPS

DESCRIPTION
Rounds the values stored in a packed 256-bit vector [8 x float] as
specified by the byte operand. The source values are rounded to
integer values and returned as floating point values.

PARAMETERS
v          A 256-bit vector of [8 x float] values.
m          An immediate byte operand specifying how the rounding is
           to be performed.
             Bits [7:4] are reserved.
             Bit [3] is a precision exception value:
               0: A normal PE exception is used
               1: The PE field is not updated
             Bit [2] is a rounding control source:
               0: MXCSR:RC
               1: Use the RC field value
             Bit [1:0] contain the rounding control definition:
               00: Nearest
               01: Downward (toward negative
                   infinity)
               10: Upward (toward positive infinity)
               11: Truncated

RETURNS
A 256-bit vector of [8 x float] containing the rounded values.
```

t e our

vements

Forward compatibility

ABI

v3.x

v3.x

System libraries

ABI

v3.x

v4.x

System libraries

ABI

v3.x

v5.x

System libraries

ABI

v3.x

v6.x

System libraries

ABI

v3.x

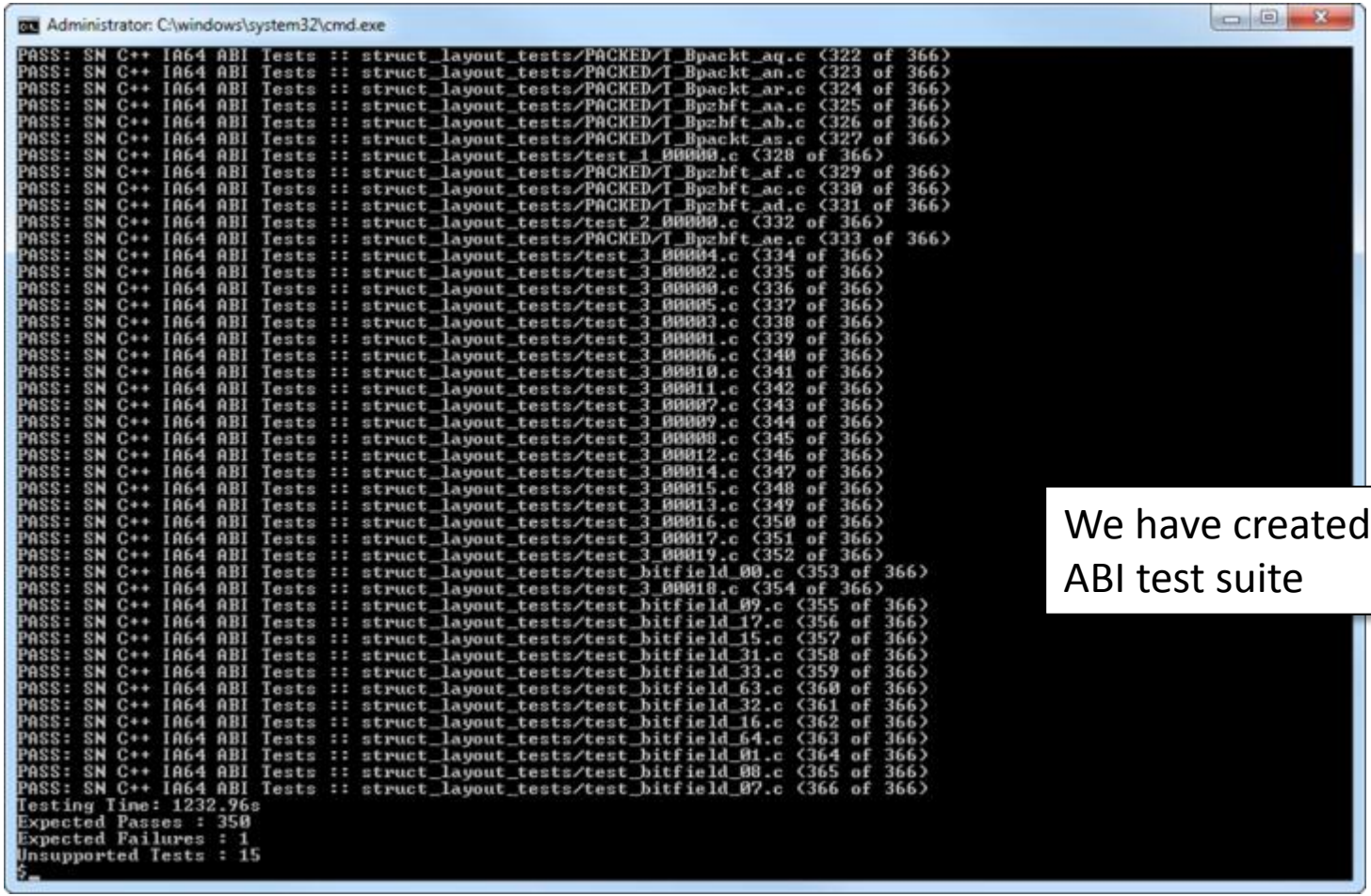
v13.x

System libraries

Maintaining a stable ABI is a

MUST

(including maintaining existing ABI bugs)



We have created a full IA64 ABI test suite

ABI TEST SUITE

We hope to **contribute** our test suite to the **community**

(some logistics still to be worked out)

Developer reaction

Developer Toolchain for PS4™

Paul T. Robinson
Sony Computer Entertainment
LLVM Dev Meeting, 7 Nov 2013

snsystems

Game Developers Love It!

"Toolchain is really nice, **link time is ~10 seconds, versus 2-4 minutes** on PC."
--Sammy Fatnassi, Eidos Montreal

"The quality of diagnostics is also incredible! It's **as pretentious as Google Search** when it comes to **correcting typos** for us and that's a good thing."
--Jean-François Marquis, Ubisoft

Game Developers Love It!

Quotes from 3rd-party studios (not SCE):

"Clang for PS4™ is a **huge improvement over GCC** for PS3™. The **same codebase** (more or less) on the same hardware **went from ~25 minutes to ~1.5 minutes.** Clang's **improved warning and error messages** also pointed us to some very questionable legacy stuff."
--Steven Houchard, Gearbox

But…

#pragma optimize

Most requested feature by an

order of magnitude

and already supported by all the other major compilers

#pragma optimize

This is the most common use-case:

```
void CriticalToPerformance() {
    ....
}

void MaybeHasABugInIt() {
    ....
}

void AlsoCriticalToPerformance() {
    ....
}
```

Game runs too slowly at –O0, but is very hard to debug at –O2

#pragma optimize

```
void CriticalToPerformance() {
    ....
}

#pragma optimize off
void MaybeHasABugInIt() {
    ....
}
#pragma optimize on

void AlsoCriticalToPerformance() {
    ....
}
```

Solution: use a pragma to selectively disable optimization on a small set of functions to be debugged

We proposed this on the mailing lists, but it is a major change and we got a limited response

#pragma optimize

```
void CriticalToPerformance() {
    ....
}

__attribute__((optnone))
void MaybeHasABugInIt() {
    ....
}


void AlsoCriticalToPerformance() {
    ....
}
```

Short term solution: function level attribute to disable optimization

Not user-friendly for more than a very small number of functions at a time!

#pragma optimize

```
#if SNC
    #define OPT_OFF ...
    #define OPT_ON ...
#elif GCC
    #define OPT_OFF ...
    #define OPT_ON ...
#elif MSVC
    #define OPT_OFF ...
    #define OPT_ON ...
#elif CLANG
    ;,-(
#endif
```

Many of our users abstract this away behind a compiler-independent interface. Function attribute does not fit this model!

We still need a range-based solution

In summary

Our initial experience with Clang and LLVM has been **very positive**

Thanks to all of you who helped make Clang and LLVM great!

There are still **improvements** that can be made…

We will be working alongside you to make them