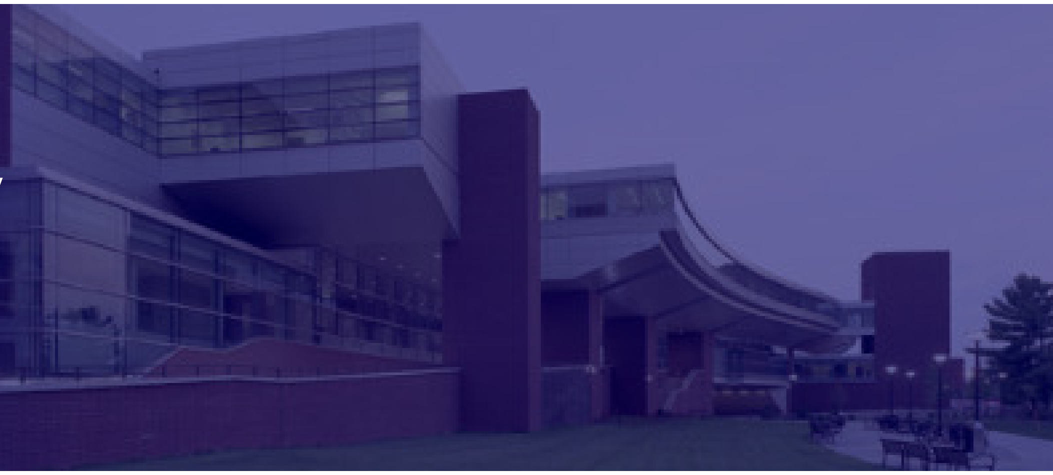

CCured: Type-safe Retrofitting of Legacy Code

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Presented By: Philip Koshy

Background

- Circa the 1970s, writing fast code was important
  - This generally required writing assembly code
- UNIX was first written in assembly.
  - They realized they needed something fast and portable.
- C was created by Ken Thompson and Dennis Ritchie as an alternative to assembly
- UNIX was eventually rewritten in C
  - The rest is history

Ken Thompson & Dennis Ritchie

National Medal of Technology,1999

“For co-inventing UNIX and the C programming language”

Why C matters today

- Although application development today is largely done in type safe languages (e.g., Java/C#), there are many legacy C applications and libraries.

- Kernels are still largely written in C.
  - ➢ Linux, Unix, Solaris, Windows

- C code is the foundation for
  - ➢ Billions of dollars of software
    - ➢ Linux kernel is estimated to be worth $700 million in programmer productivity
  - ➢ Millions of lines of code.
    - ➢ Linux kernel has more than 10 million lines of code

What's wrong with C?

- This enormous codebase implicitly comes with all of C's strengths and weaknesses…
- As a design decision in the 1970s, type safety was intentionally sacrificed for flexibility/performance.
  - ➢ At the time, C still needed to win the hearts and minds of assembly programmers.
- The paper says that 50% of CERT advisories (in 2002), were caused by avoidable type safety issues:
  - E.g., Array out-of-bounds, buffer overruns, etc.
- Incorrect pointer usage is at the heart of the problem

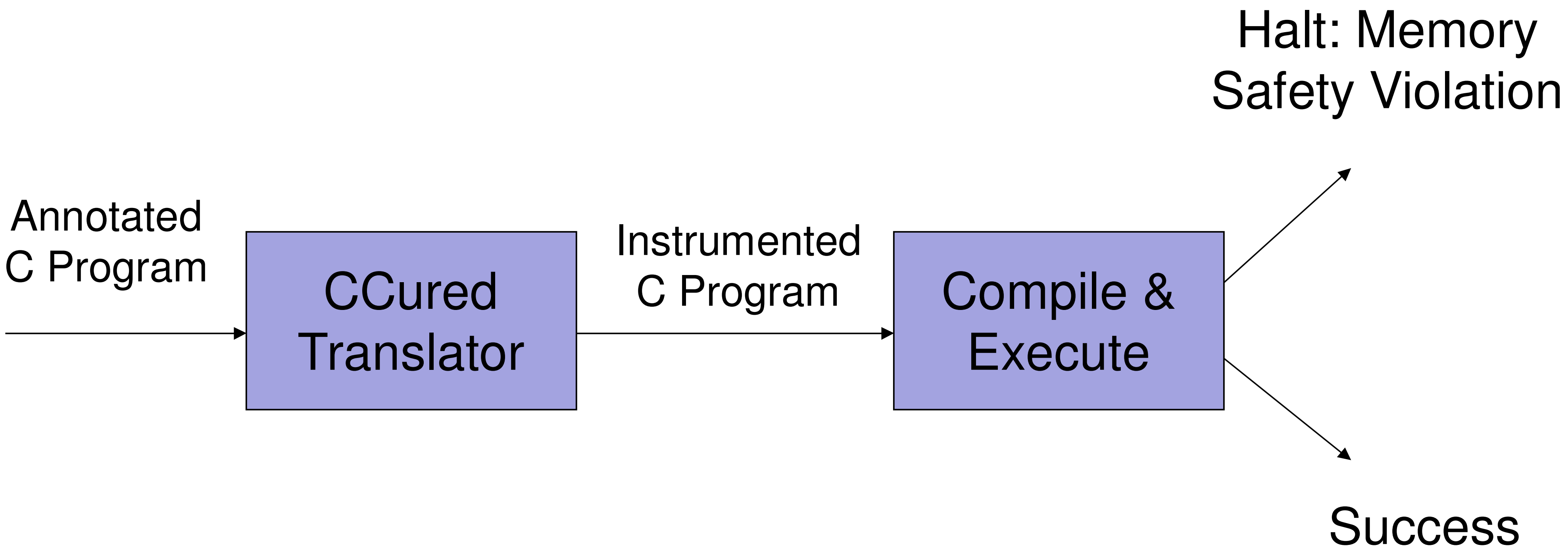
CCured Solution

- Assumption # 1: The majority of pointers in C are used in safe ways, and thus, large portions of legacy programs should be verifiably safe at compile-time.
- With CCured, pointer usage is statically analyzed at compile-time and verified to be type safe.
- For situations where safety cannot be determined at compile time, run-time checks are inserted.

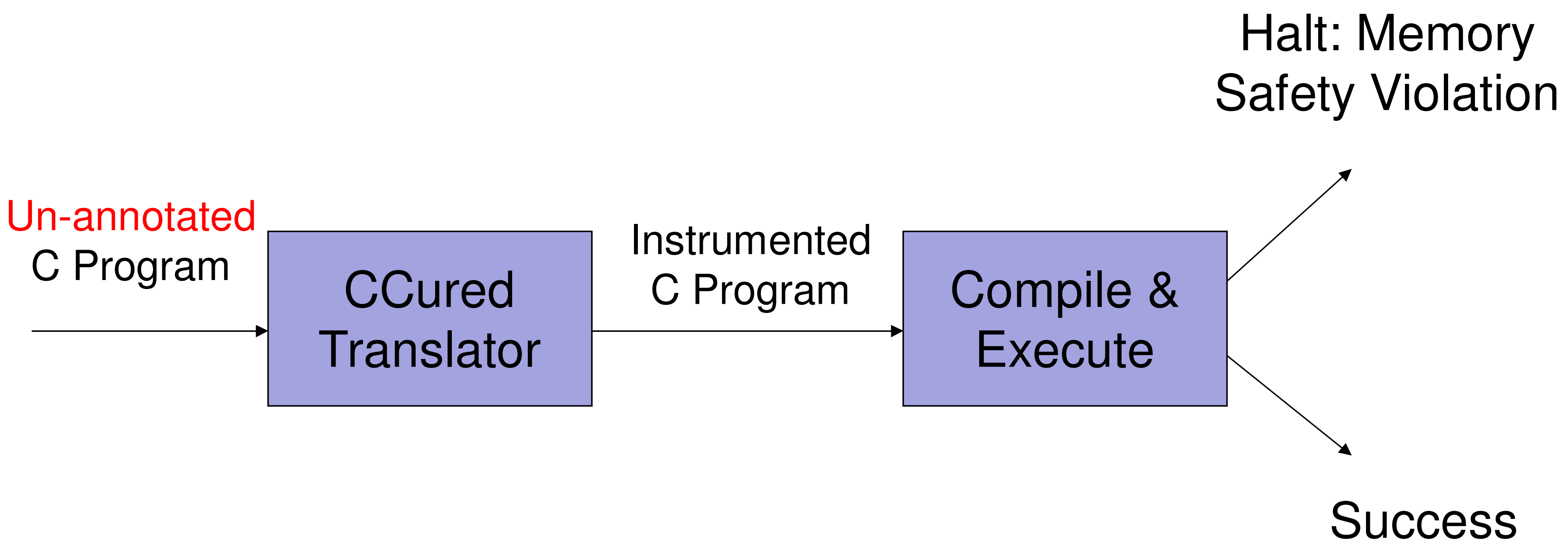
CCured Solution

- Assumption #2: For many, non-critical applications, performance penalties (due to run-time checks) are probably acceptable.
- In performance tests, CCured was between 0 to 150% slower.
  - That’s certainly a wide spread…
  - Is this really acceptable?

Idealized CCured Workflow



Realistic CCured Workflow



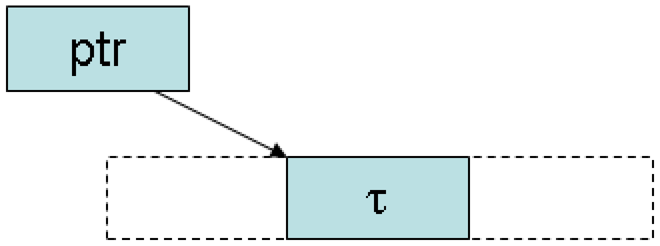
Pointer Usage

Most pointer usage is ‘safe.’ These just need to be checked before dereferencing:

```
int* p = (int*)malloc( sizeof(int) ); // // What if malloc() fails?

if( p == NULL )
          return -1;

*p = 3;

printf( "p is %d\n", *p );
```

SAFE Pointers

SAFE pointer to type τ



Check if the pointer is NULL

If the pointer != NULL, we can dereference it.

This check can be performed statically with CCured.

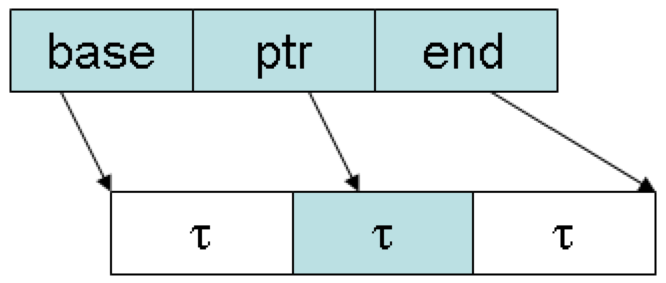
Pointer Usage

It’s possible to perform arithmetic operations on a pointer before dereferencing.

```
int i;
int* array = (int*)malloc( 5 * sizeof(int) );

if( array == NULL )
        return -1;

for( i = 0; i < 5; i++ )
        array[i] = i;

printf( "array[2] is %d\n", *(array + 2) );  // What if we accidently
                                             // step out of bounds?
```

SEQuence Pointers

SEQ pointer to type τ



- In addition to checking if pointer != NULL:
- A "SEQuence" pointer is checked to make sure arithmetic expressions do not move outside an expected bound.
- This check can also be performed statically with CCured.
- The bounds data ('base' and 'end') is stored as metadata alongside the pointer. This creates "fat pointers."

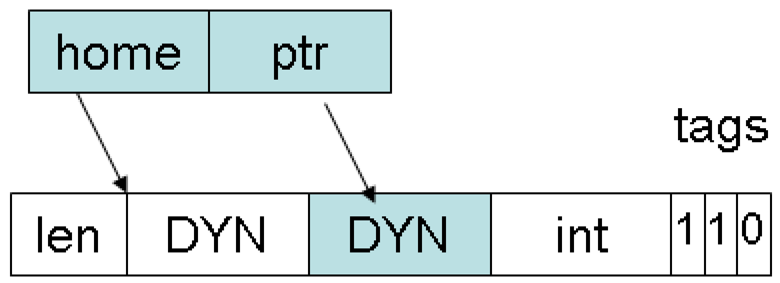
Pointer Usage

We can cast pointers to other types of pointers!

```
int* testValue = (int*)malloc( sizeof(int) );
*testValue = 1;

char* lsb = (char*)testValue; // On the rhs, we cast an int* to a char*
                              // The statically declared type of the lhs
                              // is misleading, due to this cast.
if( *lsb == 1 )
        printf("This is a little-endian system\n");
else
        printf("This is a big-endian system\n");
```

DYNamic (aka WILD) Pointers

DYN pointer



- Any pointer that can point to a heterogeneous type is considered WILD.
- Any pointer obtained through a WILD pointer (either through assignment or deference) must be inferred as WILD.
- This check is be performed at run-time with CCured.
- Note the additional metadata.

A contrived example

```
int *_1 *_2 a;                      // array
int i;                              // index
int acc;                            // accumulator
int *_3 *_4 p;                      // elem ptr
int *_5 e;                          // unboxer
acc = 0;
for (i=0; i<100; i++) {
   p = a + i;                       // ptr arith
   e = *p;                          // read elem
   while ((int) e % 2 == 0) {       // check tag
      e = * (int *_6 *_7) e;        // unbox
   }
   acc += ((int)e >> 1);            // strip tag
}
```

A contrived example

```
1  int *_1 *_2 a;                      // array
2  int i;                              // index
3  int acc;                            // accumulator
4  int *_3 *_4 p;                      // elem ptr
5  int *_5 e;                          // unboxer
6  acc = 0;
7  for (i=0; i<100; i++) {
8      p = a + i;                      // ptr arith
9      e = *p;                         // read elem
10     while ((int) e % 2 == 0) {      // check tag
11         e = * (int *_6 *_7) e;      // unbox
12     }
13     acc += ((int)e >> 1);           // strip tag
14 }
```

a = SEQ

Pointer arithmetic on Line 8

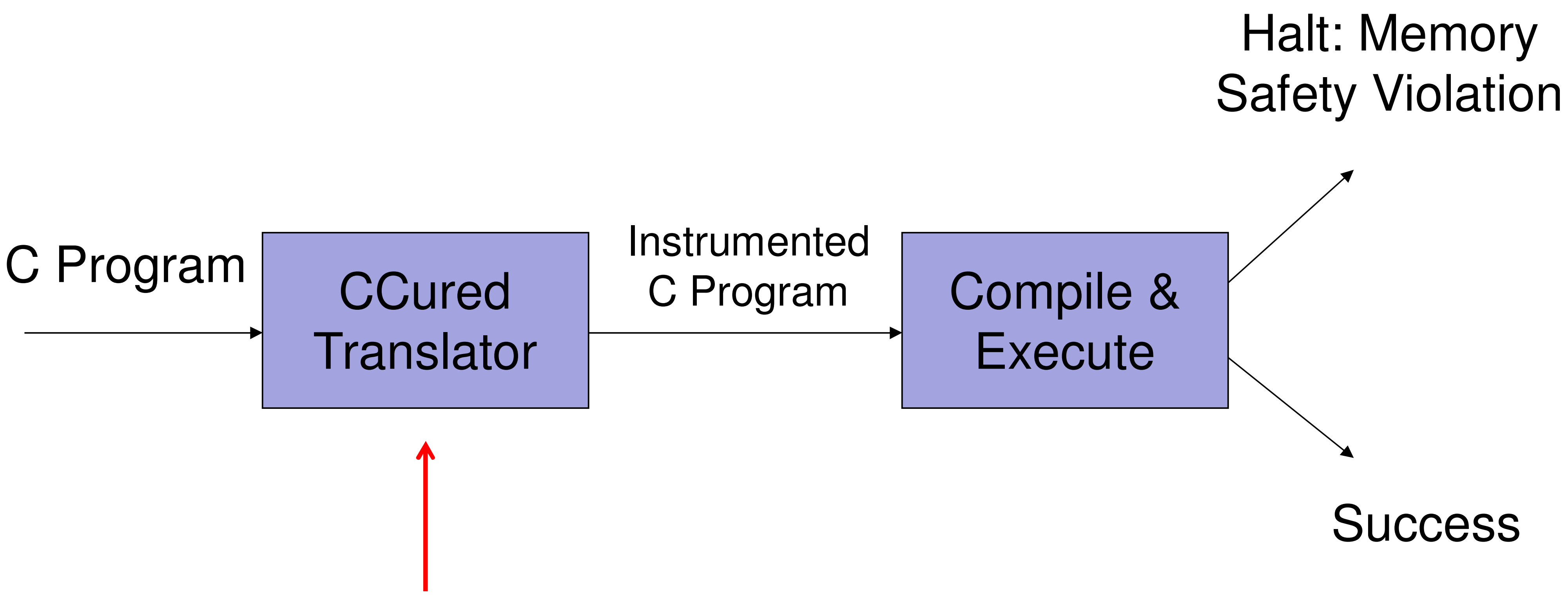
p = SAFE

Simple dereference on line 9

e = WILD

Line 5 says it declared as type (int*) but it is cast in Line 11 as (int**)

Realistic CCured Workflow

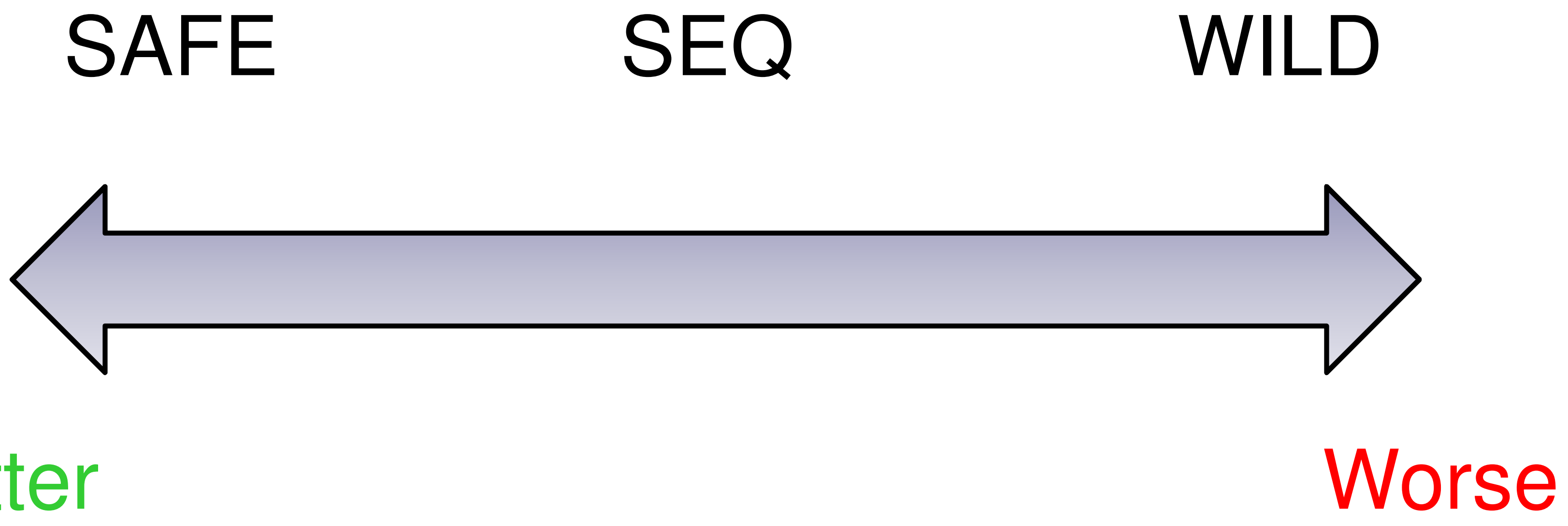


How does CCured infer the pointer type at this stage?

Inference Algorithm

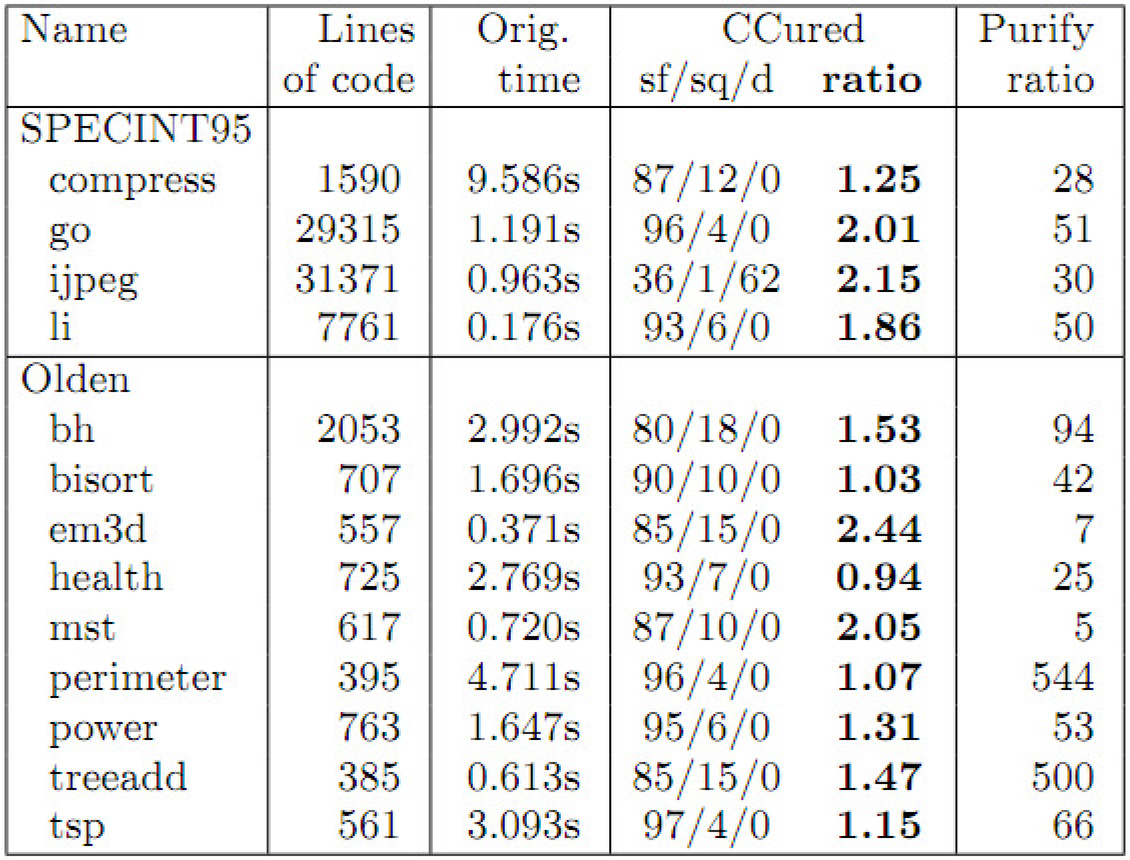
- Inference involves solving a constraint problem
- Any pointer obtained through a WILD pointer (either through assignment or deference) must be inferred as WILD.
  - WILD pointers propagate quickly through programs in this way.
- Otherwise, it is either SEQ or SAFE.
  - If the pointer under consideration is involved in any pointer arithmetic, it is SEQ
  - Otherwise, it is SAFE.

Performance Characteristics



This inference algorithm attempts to maximize the number of SAFE and SEQ pointers.

Performance Results



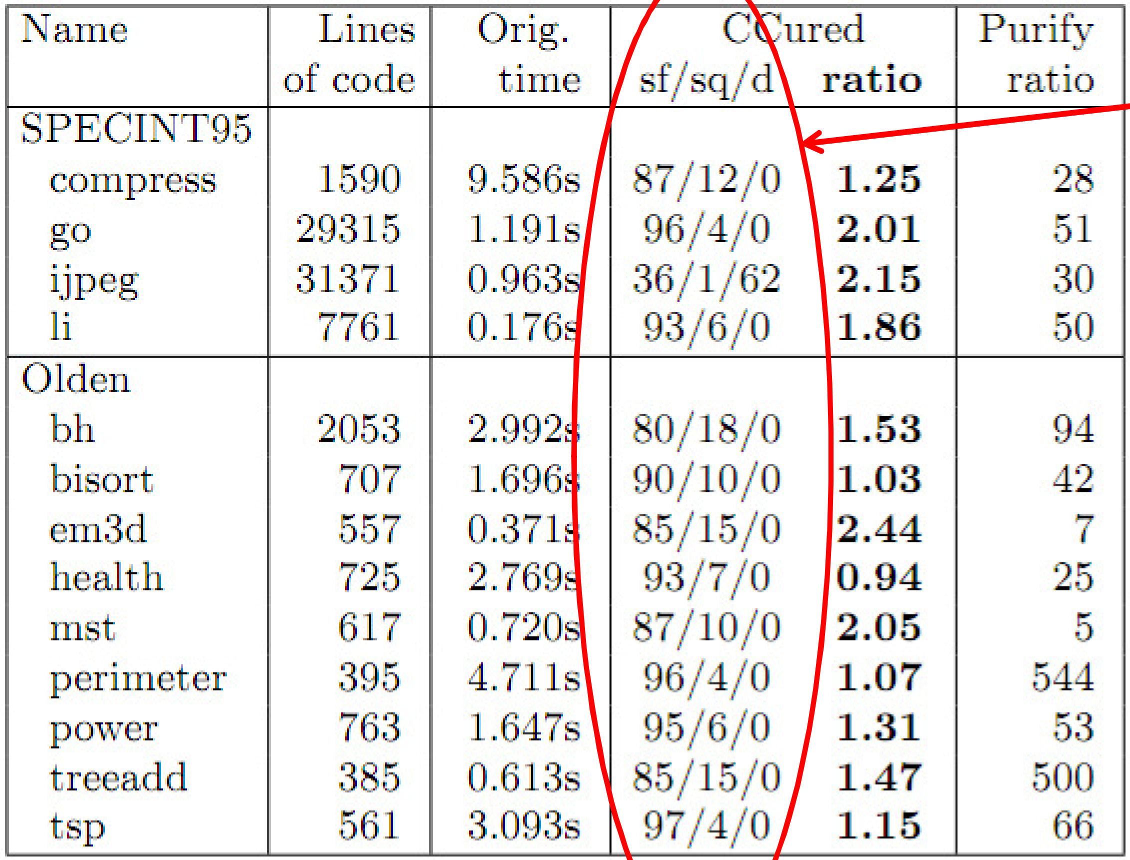
Name	Lines of code	Orig. time	CCured sf/sq/d	CCured **ratio**	Purify ratio
SPECINT95					
compress	1590	9.586s	87/12/0	**1.25**	28
go	29315	1.191s	96/4/0	**2.01**	51
ijpeg	31371	0.963s	36/1/62	**2.15**	30
li	7761	0.176s	93/6/0	**1.86**	50
Olden					
bh	2053	2.992s	80/18/0	**1.53**	94
bisort	707	1.696s	90/10/0	**1.03**	42
em3d	557	0.371s	85/15/0	**2.44**	7
health	725	2.769s	93/7/0	**0.94**	25
mst	617	0.720s	87/10/0	**2.05**	5
perimeter	395	4.711s	96/4/0	**1.07**	544
power	763	1.647s	95/6/0	**1.31**	53
treeadd	385	0.613s	85/15/0	**1.47**	500
tsp	561	3.093s	97/4/0	**1.15**	66

Figure 8: CCured versus original performance. The measurements are presented as ratios, where 2.00 means the program takes twice as long to run when instrumented with CCured. The "sf/sq/d" column show the percentage of (static) pointer declarations which were inferred `SAFE`, `SEQ` and `DYNAMIC`, respectively.

Before performing these tests, the authors applied CCured to the actual test suite (SPECINT95).

They found and fixed several previously undetected bugs.

Performance Results



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Their initial assumption that most pointers are used in a 'safe' way seem to be validated here.

CCured breaks legitimate code

- Due to metadata being stored in “fat pointers,” programmer assumptions about memory may be invalidated.
  - ➢ E.g., sizeof() will no longer works as expected on pointers
- CCured uses its own garbage collection
  - ➢ free()’s are ignored
- Will not work with libraries unless they are recompiled with CCured
  - ➢ If we are dealing with legacy code/libraries, can we assume we have the source code?

CCured breaks legitimate code

```
int* a = (int*)malloc( sizeof(int) );
*a = 5;

// Store the address of ‘a’ into a regular variable
unsigned long addressOfA = (unsigned long)a;

// Cast the variable back to an address and then dereference
int b = *((int*)addressOfA);

printf( "b is %d\n", b );
```