Light-weight Bounds Checking

Niranjan Hasabnis, Ashish Misra, and R. Sekar

Stony Brook University

International Symposium on Code Generation and Optimization (**CGO**)
San Jose, CA, March 31-April 4, 2012

Memory Errors

2003

Lock IT Down: Sapphire/Slammer worm attacks SQL Server and the Internet

By John McCormick
January 28, 2003, 8:00am PST

2005

Linux introduced ASLR. Other OS followed it later.

2010

Adobe PDF exploits using signed certificates, bypasses ASLR/DEP

By Ryan Naraine | September 9, 2010, 11:54am PDT

2012


Sponsored by DHS National Cyber Security Division/US-CERT
NIST National Institute of Standards and Technology
National Vulnerability Database
automating vulnerability management, security measurement, and compliance checking
Vulnerabilities | Checklists | 800-53/800-53A
Home | SCAP | SCAP Validated Tools
Mission and Overview
NVD is the U.S. government repository of standards based
Search Results (Refine Search)
There are 530 matching records. Displaying matches 1 through 20.

ASLR: Problem

It is a probabilistic defense!

To overcome this challenge, we need deterministic and prompt defense.

Research Efforts

- Debugging techniques
  - Purify [Hastings et al 92]
  - Valgrind [Nethercote et al 07]

- Type-safe C dialects
  - Cyclone [Morrisett et al 02]
  - CCured [Necula et al 05]

- Bounds checking
  - Backwards-compatible bounds checking for arrays and pointers in C programs [Jones et al 97]
  - CRED [Ruwase et al 04]
  - Baggy bounds [Akritidis et al 09]

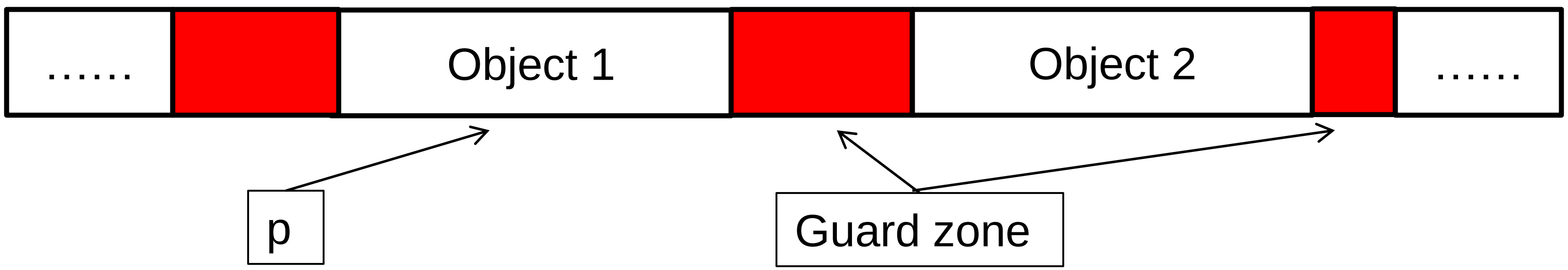
Why Do We Need A New Method?

Most existing solutions are not widely deployed!

- Performance
  - Fastest previous bounds checker: 60% runtime overhead
- Compatibility
  - Breaks some programs
  - Checks pointer *arithmetic*
    - Problems when
      - pointers are cast into integers
      - invalid pointers are created but not used

Check pointer dereference and not arithmetic!

Our Approach: LBC




```
*p   →   if (p is pointing to guard zone)
            flag_error()
         else
            *p
```

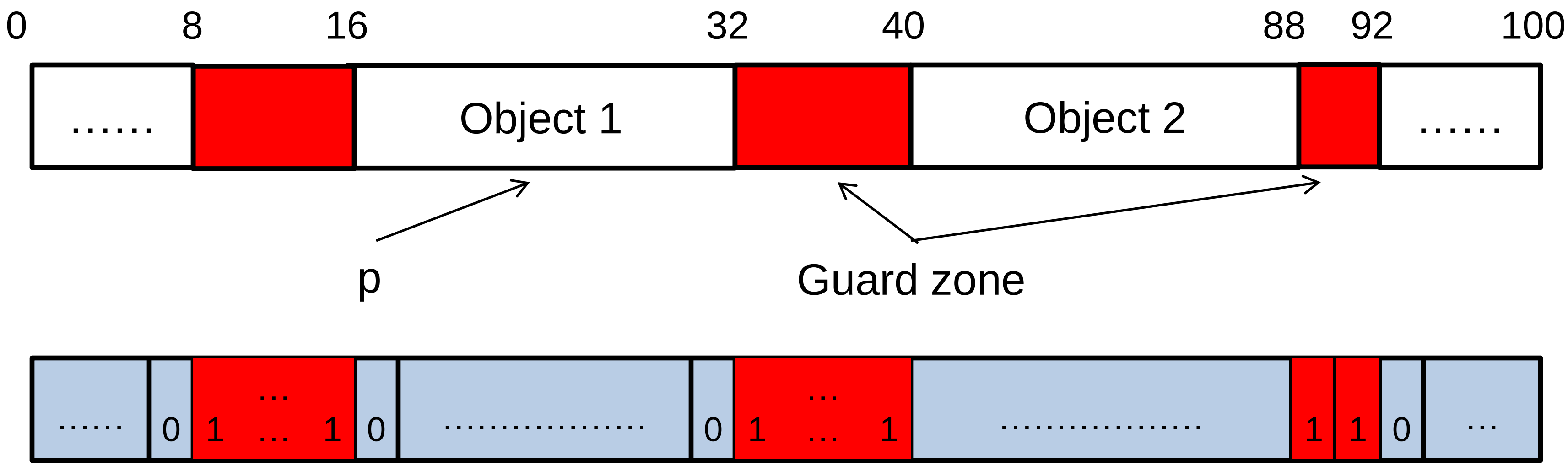
- Limitation: jumping past guardzones
- Challenge: how to make it efficient

Contributions

- Light-weight Bounds Checking is a source-to-source transformation based memory error detection technique
  - Efficient:
    - runtime overhead: 23% (half of fastest previous bounds checker)
    - space overhead: 8.5%
  - Compatible: compiled 7M LOC

- Allows arbitrary pointer manipulations, but checks pointer dereferences

Achieving Efficiency And Compatibility: Attempt 1

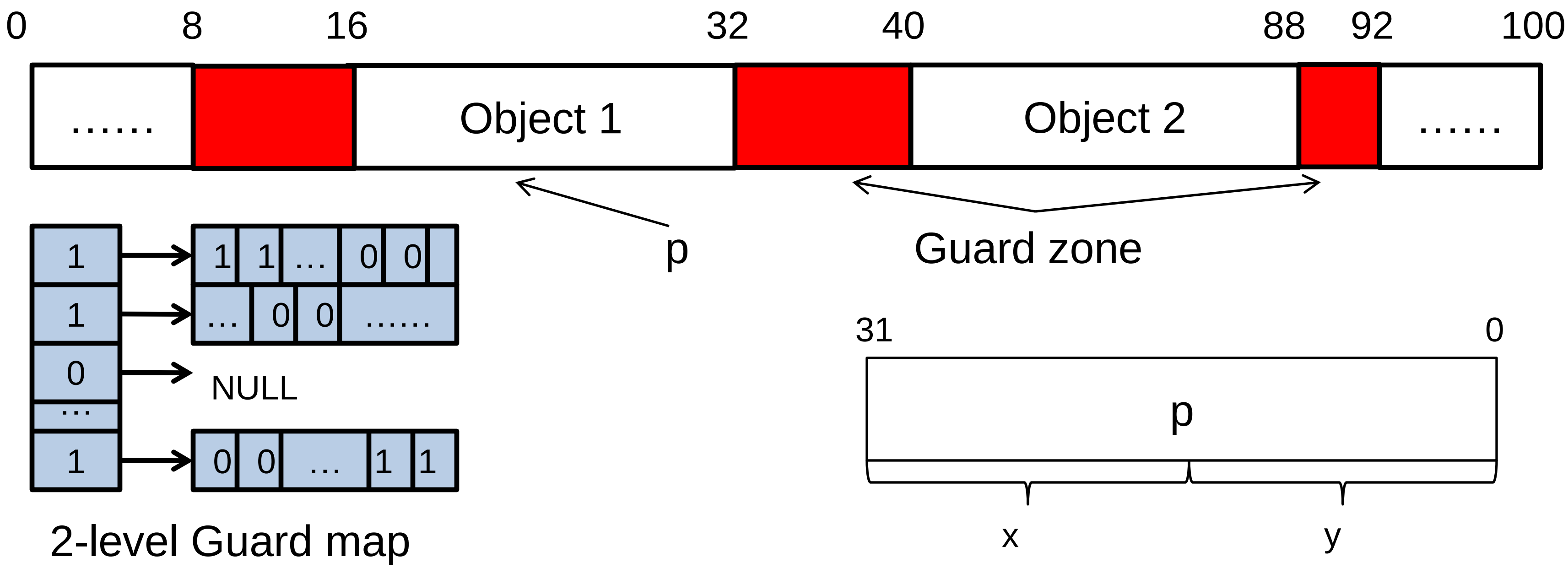


Guard map

```
if (guardmap[p] == 1)
   flag_error()
else
   *p
```

Incompatible!

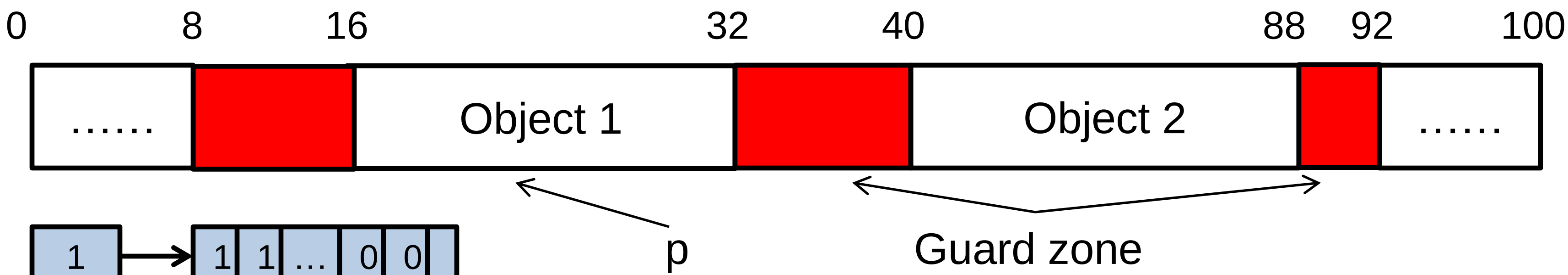
Achieving Efficiency And Compatibility: Attempt 2

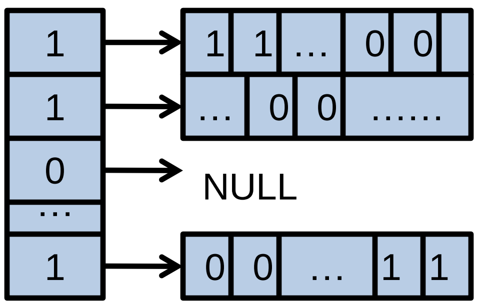



```
if (guardmap[x][y] == 1)
   flag_error()
else
    *p
```

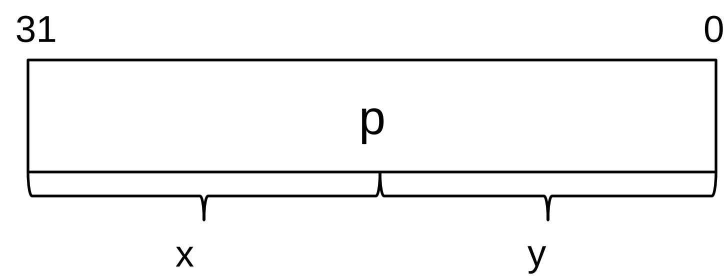
Compatible but too slow!

Achieving Efficiency And Compatibility: Attempt 3





2-level Guard map




```
if (*p == guard_zone_value)
 if (guardmap[x][y] == 1)
   flag_error()
else
   *p
```

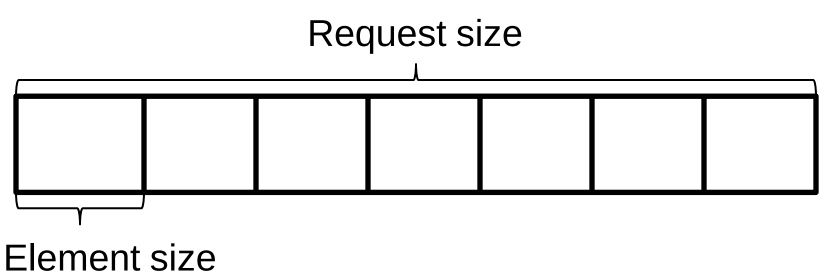
Compatible and efficient!

Guardzone Size

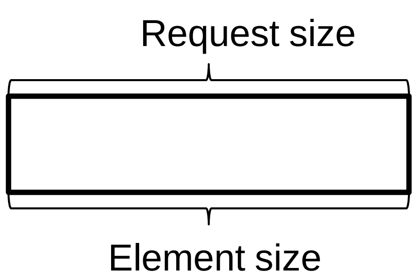
- Tradeoff between security and performance

k, n: configurable

```
max (k * element_size, request_size / n)
```



Arrays



Non-arrays

Getting Even More Efficiency: Optimizations

Optimization (1): Compiler Optimizations

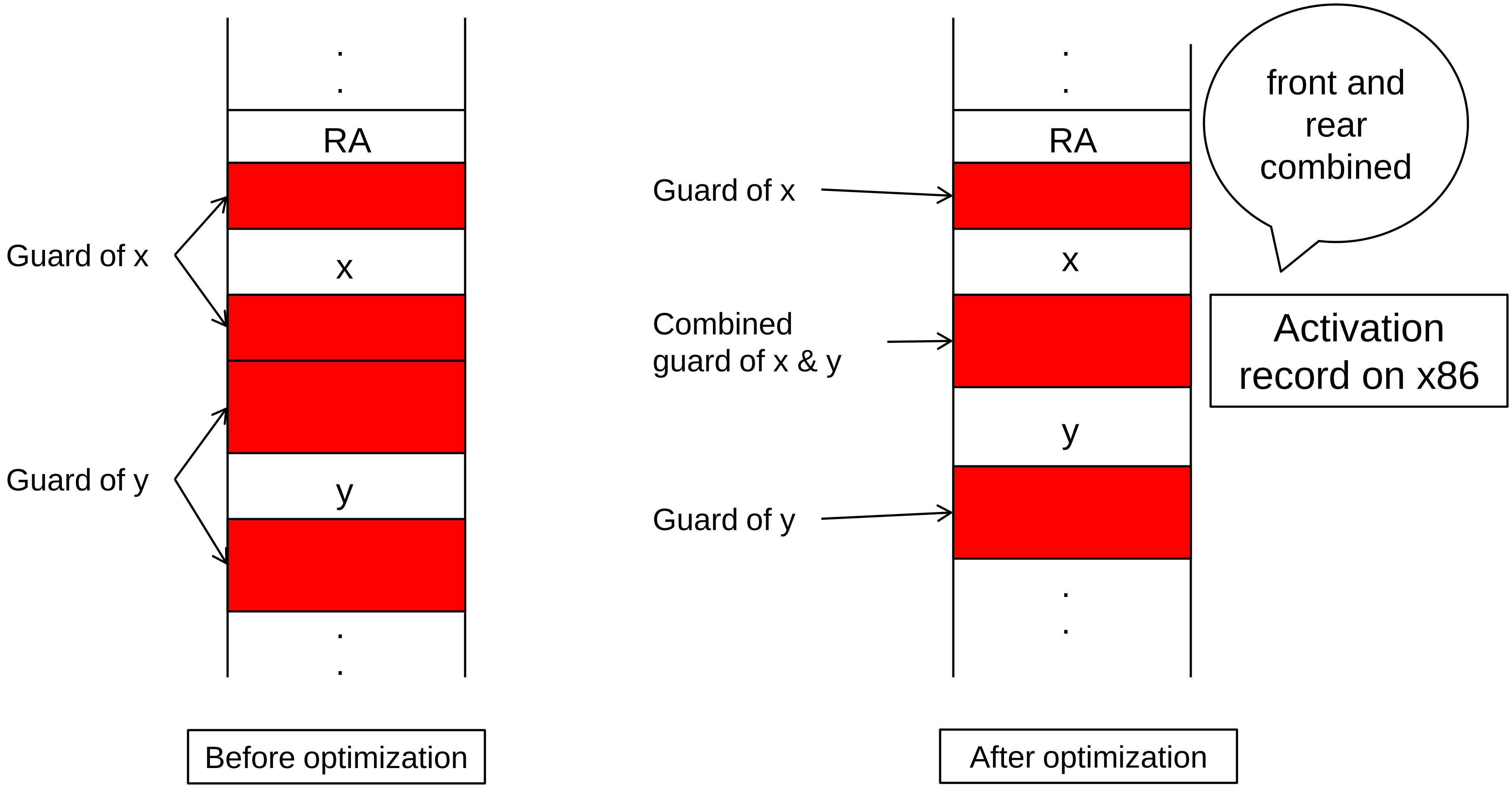
- Remove check for "safe" variables
  - Variable whose address is not taken cannot be involved in overflow (array is exception)

- All compiler-supported optimizations
  - CSE

```
p->q->r = p->q->r + p->q->s;
```

Lots of optimizations from compiler … for FREE!

Optimization (2): Guard zone Placement



Optimization (3): Lock Optimization For Multi-threaded Programs

- Naïve approach is to use lock for all concurrent accesses to guard map.

Develop an approach to reason
about the cases when lock is not needed.
Prove correctness.

Optimization (4): Static Analysis

- Observation
  - Most pointers are not involved in arithmetic.
  - Guard zone checks can be eliminated for such pointers.

- Approach
  - Classify pointers into
    - SAFE (cannot cause overflow)
    - UNSAFE (may cause overflow)

Static Analysis …

- CCured [Necula et al 05]
  - SAFE: not involved in arithmetic and unsafe typecasting

- LBC SAFE = CCured SAFE

Don’t check SAFE pointers and SAFE objects.

Static Analysis …

But we made an important change to CCured's algorithm.

```
int main()
{
    int a[2] = {100, 200};
    int* q = &a[0];

    for (int j = 0; j < 2; j++)
      q++;

    int* p = q;   /* Line 36 */

    return 0;
}
```

```
Failure UBOUND at eager.c:36:
main(): Ubound
Aborted
```

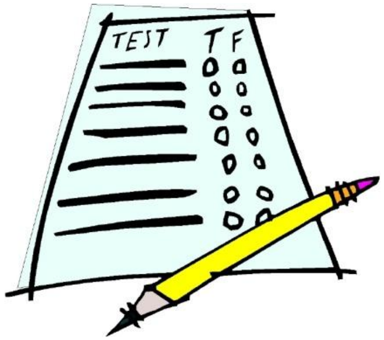
No assignment from UNSAFE pointer to SAFE pointer.

Implementation

- Package
  - Source-to-source transformer:
    - OCaml (5KLOC) + CIL [McPeak et al 02]
  - Runtime support library: C (1KLOC)
- Supports 32-bit Linux
  - 64-bit release is on the way

http://seclab.cs.sunysb.edu/download.html

Evaluation



- Compatibility
- Security: effectiveness in stopping exploits
- Runtime and Space overhead
- Effectiveness of optimizations

Compatibility

7 Million

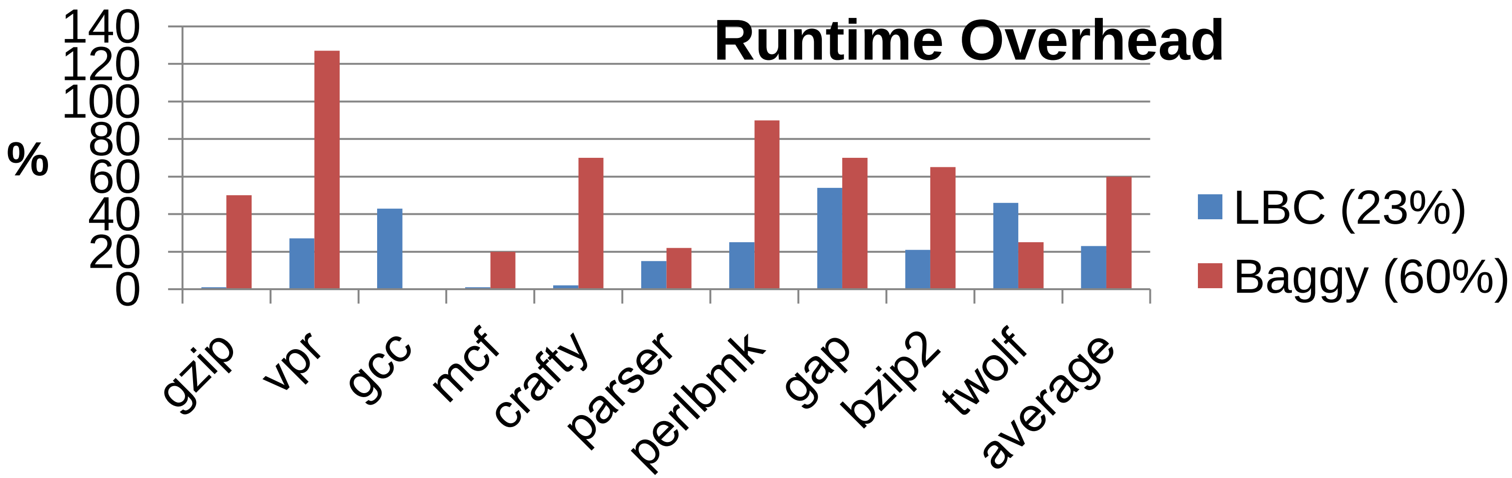
Detecting Memory Errors And Stopping Exploits

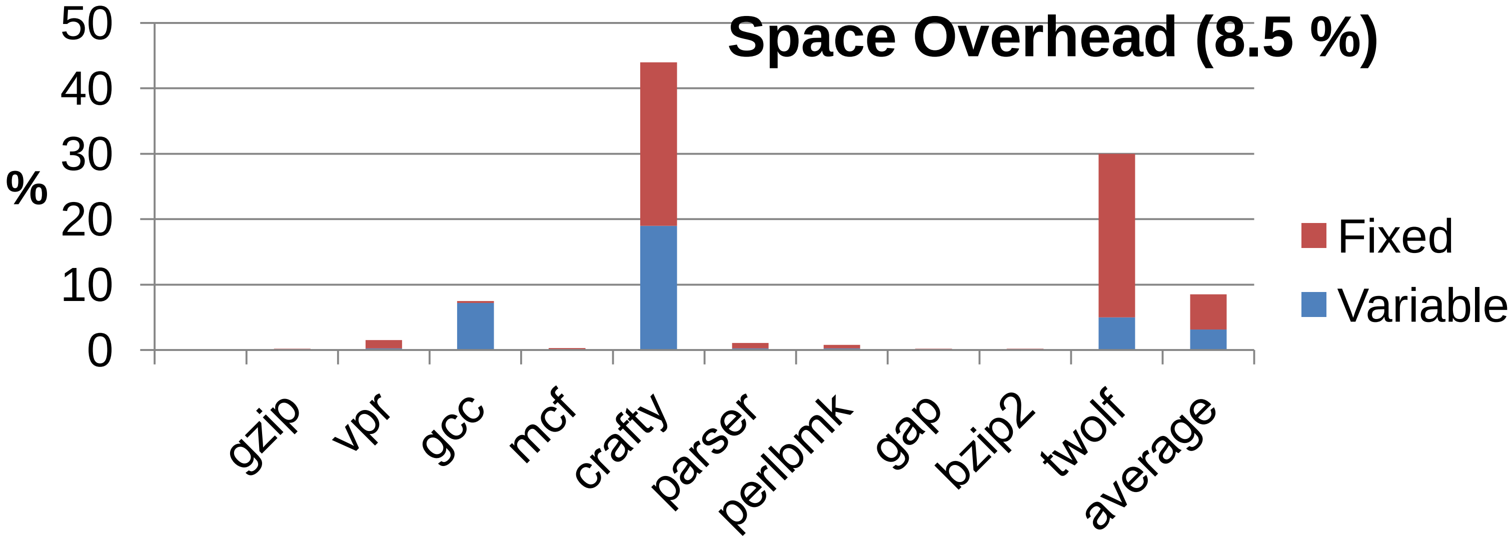
- Bugbench [Lu et al 2005]
  - Overflows in bc, man, polymorph, gzip, ncompress
  - LBC detected and prevented all the overflows.
  - cvs, mysql1, mysql2, mysql3 contain other kinds of bugs which are not bounds errors.

- RIPE [Wilander et al 2011]
  - 850 different attacks
  - 4 attack areas: stack, heap, data, bss
  - 5 target code pointers (return address, base pointer, etc)
  - multiple overflow techniques: direct, indirect
  - …

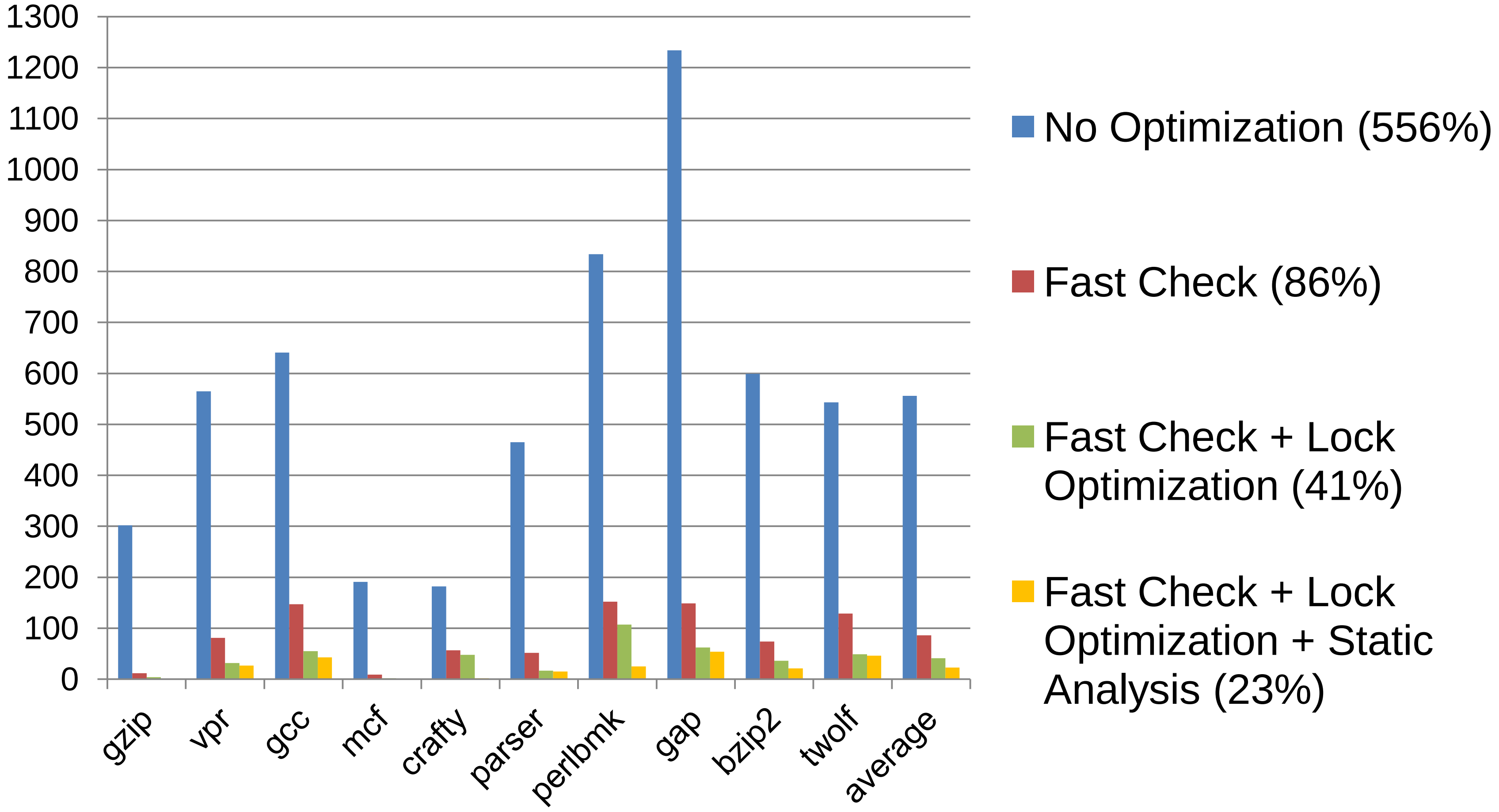
LBC detected and prevented 770 attacks.
It missed 80 which are intra-object overflows.

Runtime And Space Overhead For SPECINT 2000





Effectiveness Of Optimizations



Related Work

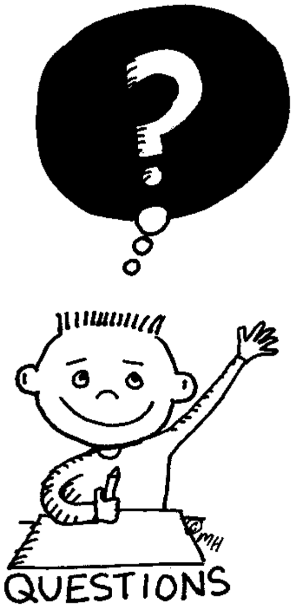
- Debugging techniques
  - Purify [Hastings et al 92]
  - Valgrind [Nethercote et al 07]
- Comprehensive memory error detection
  - RTCC [Steffen et al 92]
  - CCured [Necula et al 05]
- Bounds checking
  - Backwards-compatible bounds checking for arrays and pointers in C programs [Jones et al 97]
  - Baggy bounds checking [Akritidis et al 09]
- Security-targeted techniques
  - ASLR [PaX group 00]
  - Write-integrity testing (WIT) [Akritidis et al 08]

Conclusion

- Light-weight backwards compatible memory error detection technique
  - Runtime overhead: 23% (half of fastest previous bounds checking technique)
  - Compatibility: compiled 7 Million lines of code

- Favorable factors for easy deployment

Thank You



nhasabni@cs.stonybrook.edu

http://seclab.cs.sunysb.edu/download.html

Backup Slides

Compatibility

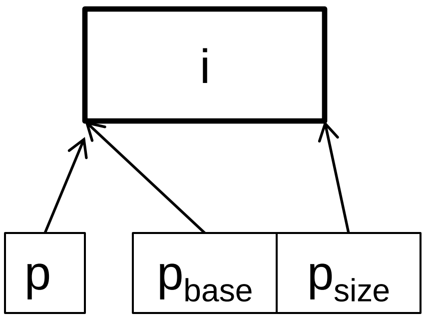
```
struct S {
  int* p;
} *q;

q-> p = &i;
foo (q);
```

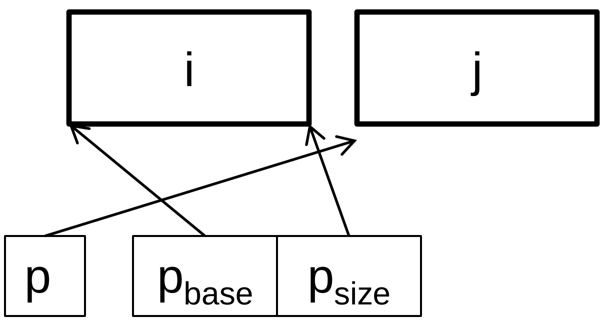
$q \texttt{ >= } q_{base} \texttt{ \&\& (char*) q + sizeof(q) <= } q_{size}$

$q\texttt{->}p \texttt{ >= } p_{base} \texttt{ \&\& (char*) q->p + sizeof(*q->p) <= } p_{size}$

```
*q->p
```

```
void foo (struct S* q) {
   static int j;
   q->p = &j;
}
```





False positives cause compatibility issues

Static Analysis

- But … CCured works in “merged mode” ..
- For compatibility, we support “separate compilation” also, and for that we must do conservative analysis.

All pointers, by default, are WILD. A pointer is made SAFE iff it is not assigned from WILD, and not involved in arithmetic and unsafe cast.

Instrumentation

Original Program

```
void f() {
  int x;

  int* y;

  y = &x;
  *y = 100;

}
```

LBC-Transformed Program

```
void f() {
  struct x_type {
    char front[24];
    int  orig;
    char rear[24];
  } x_gz;

  int* y;

  init_guardzone(x_gz);
  init_guardmap(x_gz);

  y = &x_gz.orig;

  if (*y == guard_zone_value)
    if (slowcheck(y))
      flag_error();

  *y = 100;

  uninit_guardmap(x_gz);
}
```