## 4 Main Steps of Concolic Testing

1. Instrumentation of a target program
   - To insert probes to build symbolic path formula
2. Transform a constructed symbolic path formula to SMT-compatible format
   - SMT solvers can solve simple formula only
3. Select one branch condition to negate
   - Core technique impacting both effectiveness and efficiency
4. Invoking SMT solvers on the SPF SMT formula
   - Selection of a SMT solver and proper configuration parameters

## 4 Main Tasks of Human Engineers

1. Adding proper assert() statements
   - W/o assert(), no test results obtained
2. Selection of symbolic variables in a target program
   - Identify which parts of a target program are most important
3. Construction of symbolic external environment
   - To detect real bugs
4. Performance tuning and debugging
   - To obtain better concolic testing results

## Busybox Overview

- We test a busybox by using CROWN.
  - BusyBox is a one-in-all command-line utilities providing a fairly complete programming/debugging environment
  - It combines tiny versions of ~300 UNIX utilities into a single small executable program suite.
  - Among those 300 utilities, we focused to test the following 10 utilities
    - **`grep, vi, cut, expr, od , printf, tr, cp, ls, mv.`**
    - We selected these 10 utilities, because their behavior is easy to understand so that it is clear what variables should be declared as symbolic

## Experiment overview

- Experimental environments
  - HW: Core(TM)2 E8400@3GHz, 4GB memory
  - OS: fc8 32bit

- Target program: **busybox 1.17.0**

- Strategies: 4 different strategies are used in our experiment.

|  |  |
|---|---|
| **dfs**: | explore path space by (reverse) Depth-First Search |
| **cfg**: | explore path space by Control-Flow Directed Search |
| **random**: | explore path space by Random Branch Search |
| **random_input**: | testing target program by randomly generating input |

- In addition, a port-polio approach is applied (i.e., merging the test cases generated by all four above strategies).

## Target description -- `printf`

- Description: print ARGUMENT(s) according to FORMAT, where FORMAT controls the output exactly as in C printf.
- Usage: printf FORMAT [ARGUMENT]...
- Example :
  - input: ./busybox printf ‘%s is coming' 'autumn‘
  - output: autumn is coming

## Target program setting -- `printf`

- Experiment Setting :
  - Target utilities: **busybox printf**
  - Usage: **printf FORMAT [ARGUMENT]...**
  - Symbolic variables setting:
    1. Set **FORMAT** as symbolic value.
       - Type of FORMAT is string. Restrict **5** symbolic characters as input of FORMAT.
    2. Set **ARGUMENT** as symbolic value.
       - Type of ARGUMENT is array of string. Restrict ARGUMENT to **1** length, **10** symbolic characters for each string.
    3. Replace library function by source code: **`strchr().`**
  - We perform experiments in the following approach:
    1. run experiment by various strategies.

## Result -- `printf`

Experiment setting:

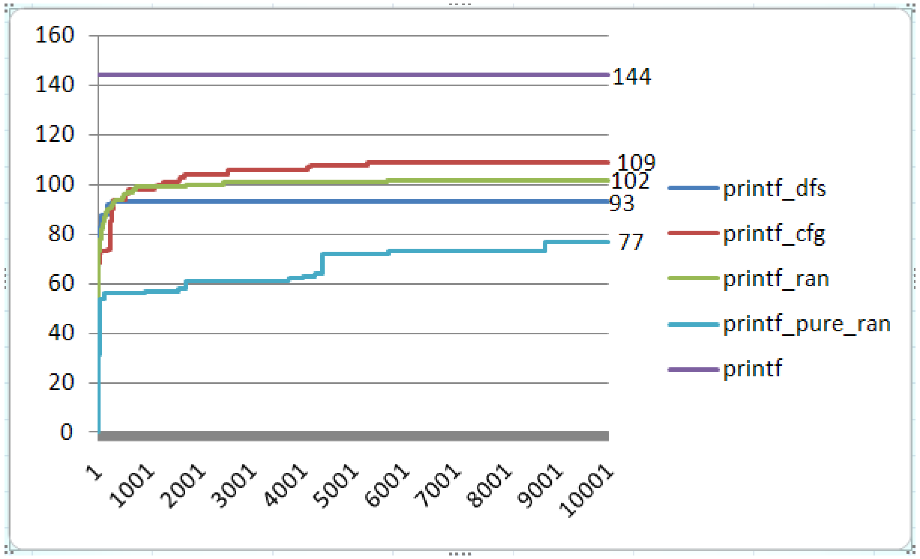
Iterations: 10,000

branches in `printf.c` : 144

Execution command:

Command-line arguements are just place holders (i.e., their content will be replaced by symbolic values)

```
run_crown './busybox printf '%d123' 0123456789' 10000 -dfs
run_crown './busybox printf '%d123' 0123456789' 10000 -cfg
run_crown './busybox printf '%d123' 0123456789' 10000 -random
run_crown './busybox printf '%d123' 0123456789' 10000 -random_input
```



| Strategy | Time cost (s) |
|---|---|
| Dfs | 84 |
| Cfg | 41 |
| Random | 40 |
| Pure_random | 30 |

## Symbolic setup in source code for `printf`

- Two main instruments in busybox printf.c.
  - Set 2 symbolic inputs: `FORMAT`, `ARGUMENT`.
  - Replace library function `strchr()` by source code.

```
static void print_direc(char *format, unsigned fmt_length,
        int field_width, int precision,
        const char *argument)
{
//......
#ifndef CROWN
    have_width = strchr(format, '*');
#else
    have_width = sym_strchr(format, '*');
#endif
//......
}
//......
int printf_main(int argc UNUSED_PARAM, char **argv)
{
    int conv_err;
    char *format;
    char **argv2;
//......
    format = argv[1];
    argv2 = argv + 2;
    int i;
    int argcc=strlen(format);
#ifdef CROWN
    for( i=0 ; i<argcc ; i++){// argcc = 5 due to the fixed input
        SYM_char(format[i]);
    }
    for(i= 0 ; i<10 ; i++){
        SYM_char(argv2[0][i]);
    }
#endif
//......
}

static char *sym_strchr(const char *str, char ch){

    while (*str && *str != ch)
        str++;

    if (*str == ch)
        return str;

    return(NULL);

}
```

## Target description -- grep

- Description: Search for PATTERN in FILEs (or stdin).
- Usage: `grep [OPTIONS] PATTERN [FILE]`
  - OPTIONS includes

  [-1nqvscFiHhf:Lorm:wA:B:C:EaI] (option followed by ":" means one argument is required.)
- Example :
  - `test_grep.dat` contains

```
define
enifed
what is defined?
def ine
```

  - input: `busybox grep define test_grep.dat`
  - output:

```
define
what is defined?
```

Options:

| | |
|---|---|
| -H | Add 'filename:' prefix |
| -h | Do not add 'filename:' prefix |
| -n | Add 'line_no:' prefix |
| -l | Show only names of files that match |
| -L | Show only names of files that don't match |
| -c | Show only count of matching lines |
| -o | Show only the matching part of line |
| -q | Quiet. Return 0 if PATTERN is found, 1 otherwise |
| -v | Select non-matching lines |
| -s | Suppress open and read errors |
| -r | Recurse |
| -i | Ignore case |
| -w | Match whole words only |
| -F | PATTERN is a literal (not regexp) |
| -E | PATTERN is an extended regexp |
| -m N | Match up to N times per file |
| -A N | Print N lines of trailing context |
| -B N | Print N lines of leading context |
| -C N | Same as '-A N -B N' |
| -f FILE | Read pattern from file |

## Symbolic Variable Declaration for `grep`

- PATTERN was not declared as symbolic variables, since grep.c handles PATTERN using external binary libraries
  - CROWN would not generate new test cases for symbolic PATTERN
  - We used a concrete pattern "`define`"
- We use a concrete file `test_grep.dat` as a FILE parameter
- **Set options as symbolic input (i.e. an array of symbolic characters)**
  - **23** different options can be given.
    - Specified options are represented by **`option_mask32`**, an `uint32_t` value, of which each bit field indicates a corresponding option is ON/OFF.
    - Function `getopt32(char **argv, const char *applet_opts, …)` is used to generate a bit array `option_mask32` which indicates specified options from command line input.
- Set 4 parameters to options as symbolic variables
  - `Copt, max_matches, lines_before, lines_after.`
  - Option argument `fopt` for option `-f` (read a pattern from a file) is ignored, since it is hard to set a file name as a symbolic value.

## Instrumentation in grep.c

```
…
uint32_t option_mask32;
...
int grep_main (int argc UNUSED_PARAM,
char **argv)
{
      getopt32(argv, OPTSTR_GREP,
        &pattern_head, &fopt,
        &max_matches, &lines_after,
        &lines_before,&Copt);
       #ifdef CROWN
       SYM_int(max_matches);
       SYM_int(lines_after);
       SYM_int(lines_before);
       SYM_int(Copt);

       #endif
       //……
       #ifdef CROWN
       SYM_int(option_mask32);
       #endif
       if (option_mask32 & OPT_m) {
```

## Result of Busybox `grep`

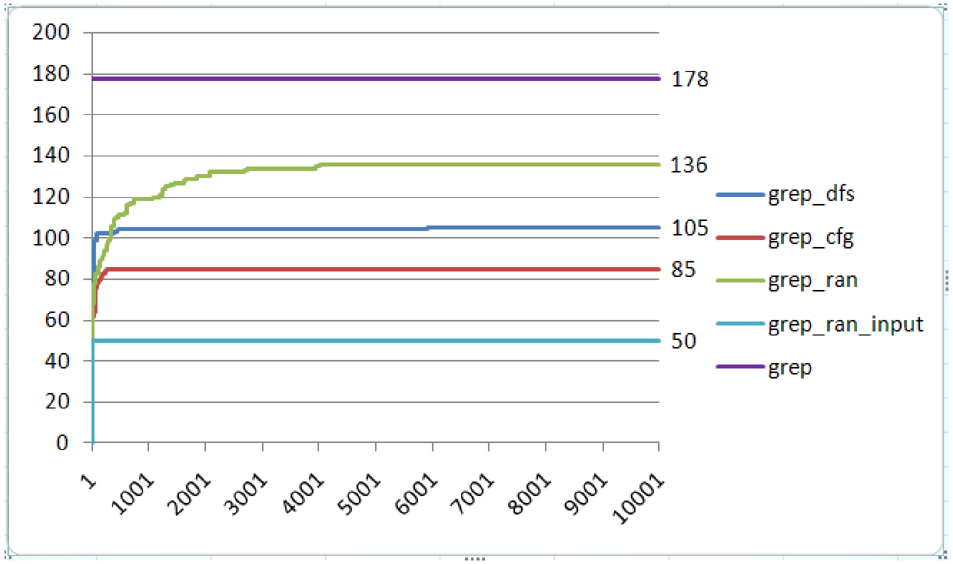
Experiment 1:

Iterations: 10, 000

branches in `grep.c` : 178

Execution Command:

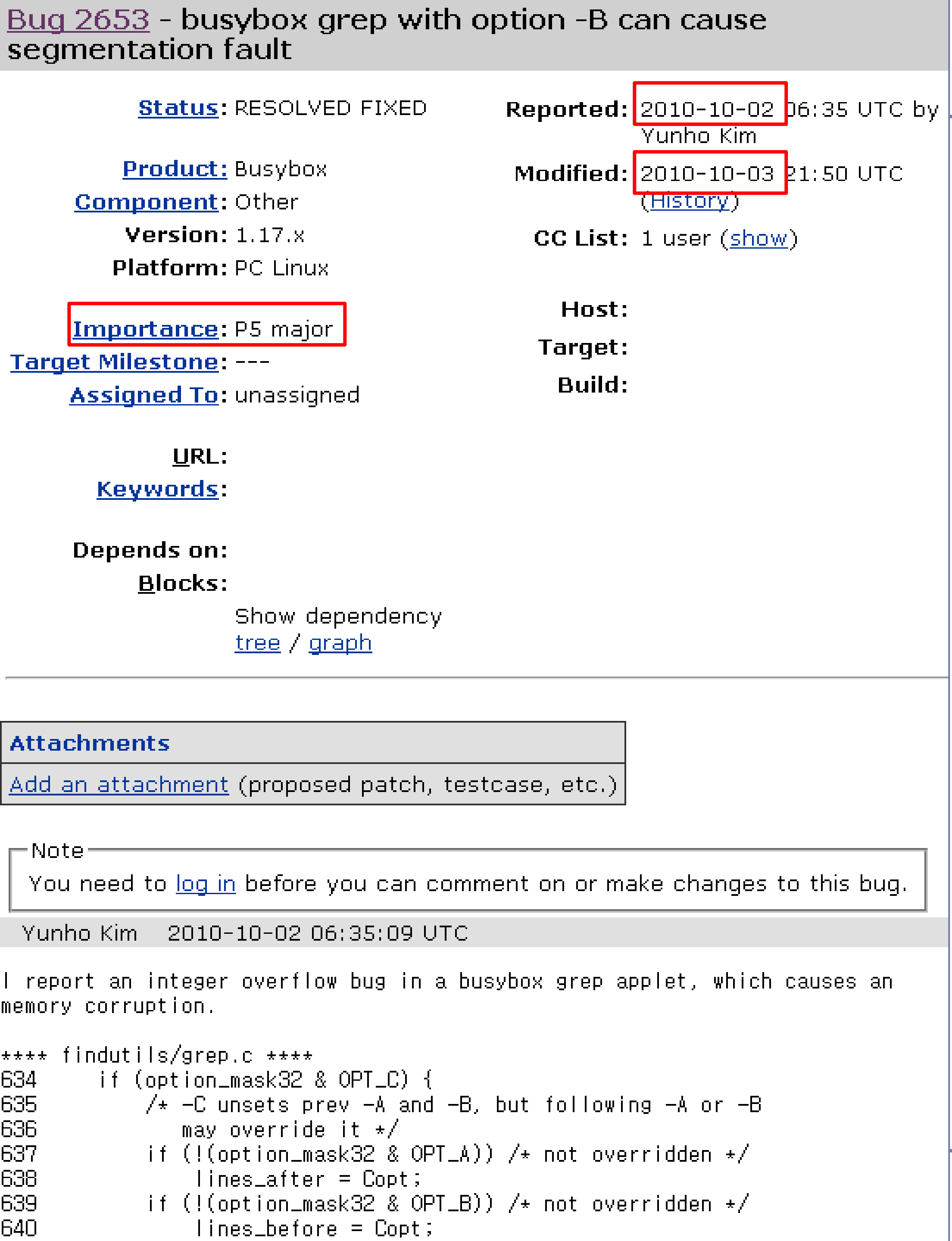
```
run_crown './busybox grep "define" test_grep.dat' 10000 -dfs
run_crown './busybox grep "define" test_grep.dat' 10000 -cfg
run_crown './busybox grep "define" test_grep.dat' 10000 -random
run_crown './busybox grep "define" test_grep.dat' 10000 -random_input
```



| Strategy | Time cost (s) |
|---|---|
| Dfs | 2758 |
| Cfg | 56 |
| Random | 85 |
| Pure_random | 45 |

## Test Oracles

- In the busybox testing, we do not use any explicit test oracles
  - Test oracle is an orthogonal issue to test case generation
  - However, still violation of runtime conformance (i.e., no segmentation fault, no divide-by-zero, etc) can be checked
- Segmentation fault due to integer overflow detected at grep 2.0
  - This bug was detected by test cases generated using DFS
  - The bug causes segmentation fault when
    - -B 1073741824 (i.e. 2^32/4)
    - PATTERN should match line(s) after the 1st line
    - Text file should contain at least two lines
  - Bug scenario
    - Grep tries to dynamically allocate memory for buffering matched lines (-B option).
    - But due to integer overflow (# of line to buffer * sizeof(pointer)), memory is allocated in much less amount
    - Finally grep finally accesses illegal memory area


Bug 2653 - busybox grep with option -B can cause segmentation fault

| | | | |
|---|---|---|---|
| Status: | RESOLVED FIXED | Reported: | 2010-10-02 06:35 UTC by Yunho Kim |
| Product: | Busybox | Modified: | 2010-10-03 21:50 UTC (History) |
| Component: | Other | CC List: | 1 user (show) |
| Version: | 1.17.x | | |
| Platform: | PC Linux | | |
| Importance: | P5 major | Host: | |
| Target Milestone: | --- | Target: | |
| Assigned To: | unassigned | Build: | |
| URL: | | | |
| Keywords: | | | |
| Depends on: | | | |
| Blocks: | | | |
| | Show dependency tree / graph | | |

Attachments

Add an attachment (proposed patch, testcase, etc.)

Note

You need to log in before you can comment on or make changes to this bug.

Yunho Kim 2010-10-02 06:35:09 UTC

```
I report an integer overflow bug in a busybox grep applet, which causes an
memory corruption.

**** findutils/grep.c ****
634     if (option_mask32 & OPT_C) {
635         /* -C unsets prev -A and -B, but following -A or -B
636            may override it */
637         if (!(option_mask32 & OPT_A)) /* not overridden */
638             lines_after = Copt;
639         if (!(option_mask32 & OPT_B)) /* not overridden */
640             lines_before = Copt;
```

- Bug patch was immediately made in 1 day, since this bug is critical one
  - Importance: P5 major
    - major loss of function
  - Busybox 1.18.x will have fix for this bug

## Target description -- `vi`

- Description: Edit FILE

- Usage: vi [OPTIONS] [FILE] …
- Options:
  - -c Initial command to run ($EXINIT also available)
  - -R Read-only
  - -H Short help regarding available features
- Example :
  - input: cat read_vi.dat

```
test for initial command
```

  - input: cat test_vi.dat

```
this is the test for vi

@#$%&*vi?
```

  - input: ./busybox vi -c ":read read_vi.dat" test_vi.dat
  - output:

```
this is the test for vi
test for initial command

@#$%&*vi?
```

## Symbolic Variable Declaration for `vi`

- We declared a key stroke by a user as a symbolic input character
  - Restrict user key input to **50** symbolic characters.
    - **We modified vi source code so that vi exits after testing 50th key stroke.**
- Set initial command as symbolic input (initial command is only used when option `-c` is specified).
  - Type of initial command is a string (i.e., an array of 17 characters)
- Replace *4* library functions with source code: **`strncmp()`, `strchr()`, `strcpy()`, `memchr()`.**
- We used a concrete file `test_vi.dat`

## Symbolic Key-stroke Setting

```
static int readit(void){
    //……
    #ifndef CROWN
    c = read_key(STDIN_FILENO, readbuffer, -2);
    #else
    if(count<50){
        char ch;
        SYM_char(ch);
        putc(ch, finput);
        c=(int)ch;
        count++;
    }else {
        fclose(finput);
        exit(0);
    }
    #endif
     //……
}
```

## 4 Functions Added

```
static int sym_strncmp (const char *first,const char *last,int count)
{
  if (!count)
    return(0);

  while (--count && *first && *first == *last){
      first++;
      last++;
   }
  return( *(unsigned char *)first - *(unsigned char *)last );
}

static char *sym_strchr(const char *str, char ch){

  while (*str && *str != ch)
      str++;

  if (*str == ch)
      return str;

  return(NULL);

}

static char *sym_strcpy(char *to, const char *from)
{
      char *save = to;

      for (; (*to = *from) != '\0'; ++from, ++to);
      return(save);
}

void *sym_memchr(const void* src, int c, size_t count)
{
     assert(src!=NULL);
     char *tempsrc=(char*)src;
     while(count&&*tempsrc!=(char)c)
     {
        count--;
        tempsrc++;
      }
      if(count!=0)
          return tempsrc;
      else
          return NULL;
}
```

## Result of `vi`

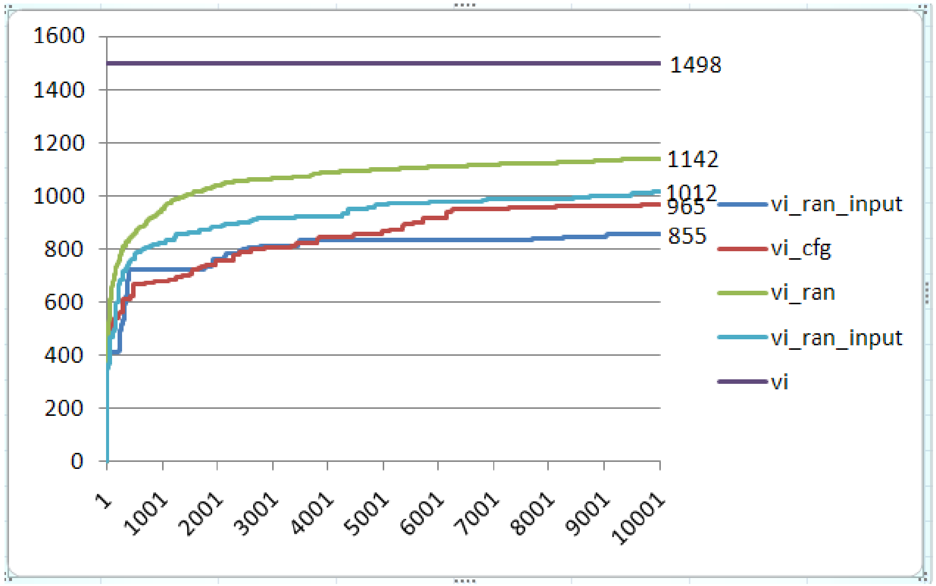
Experiment 1:

Iterations: 10,000

Branches in `vi.c` : 1498

Execution Command:

```
run_crown './busybox -c ":read read_vi.dat" test_vi.dat' 10000 -dfs
run_crown './busybox -c ":read read_vi.dat" test_vi.dat' 10000 -cfg
run_crown './busybox -c ":read read_vi.dat" test_vi.dat' 10000 -random
run_crown './busybox -c ":read read_vi.dat" test_vi.dat' 10000 -random_input
```



| Strategy | Time cost (s) |
|---|---|
| Dfs | 1495 |
| Cfg | 1306 |
| Random | 723 |
| Pure_random | 463 |