STAR Laboratory of Advanced Research on Software Technology

Code Coverage Testing & Tool Support

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Speaker Biographical Sketch

- Professor & Director of International Outreach
  Department of Computer Science
  University of Texas at Dallas
- Guest Researcher
  Computer Security Division
  National Institute of Standards and Technology (NIST)
- Vice President, IEEE Reliability Society
- Secretary, ACM SIGAPP (Special Interest Group on Applied Computing)
- Principal Investigator, NSF TUES (Transforming Undergraduate Education in Science, Technology, Engineering and Mathematics) Project
  - *Incorporating Software Testing into Multiple Computer Science and Software Engineering Undergraduate Courses*
- Founder & Steering Committee co-Chair for the SERE conference (*IEEE International Conference on Software Security and Reliability*) (http://paris.utdallas.edu/sere13)

Our Focus

- We focus on testing programs
  - subsystems or complete systems
  - written in a formal language
  - a large collection of techniques and tools

Testing for Correctness?

- Identify the *input domain* of *P*
  - Input domain of a program *P* is the set of all *valid* inputs that *P* can expect
  - The *size* of an input domain is the number of elements in it
  - An input domain could be finite or infinite
  - Finite input domains might still be very large!
- Execute *P* against *each element* of the input domain
- For each execution of *P*, check if *P* generates the correct output as per its specification *S*
  - This form of testing is also known as *exhaustive testing* as we execute *P* on all elements of the input domain.

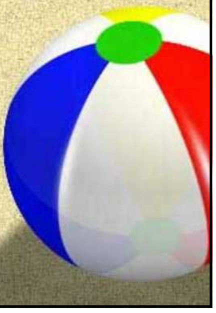
Testing for Correctness? Sorry!

- For most programs *exhaustive testing* is not feasible
  - It will take several *light years* to execute a program on all inputs on the most powerful computers of today!
- What is the alternative?

Confidence in Your Program

- Confidence is a measure of *one's belief* in the correctness of the program.
- It is not measured in binary terms: *a correct or an incorrect program*.
- Instead, it is measured as the *probability* of correct operation of a program when used in various scenarios.
- It can be measured, for example, by *test completeness*
  - The extent to which a program has been tested and errors found have been removed.

How and why does testing improve our confidence in program correctness ?

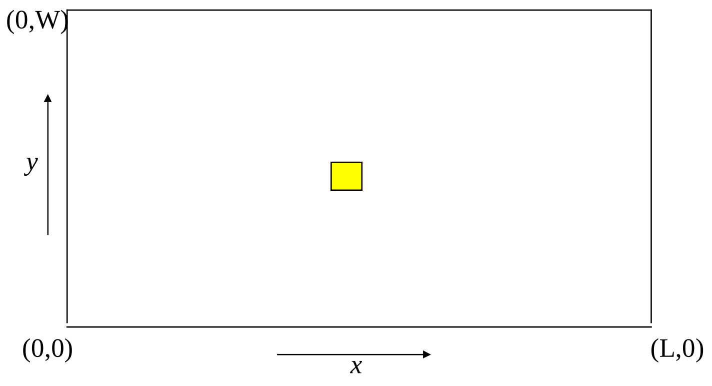


Example: Increase in Confidence

- We consider a non-programming example to illustrate what is meant by "*increase in confidence*."
- Example: A rectangular field has been prepared with respect to certain specifications.
  - One item in the specifications is "*There should be no stones remaining in the field*."

Rectangular Field

- Search for stones inside a rectangular field



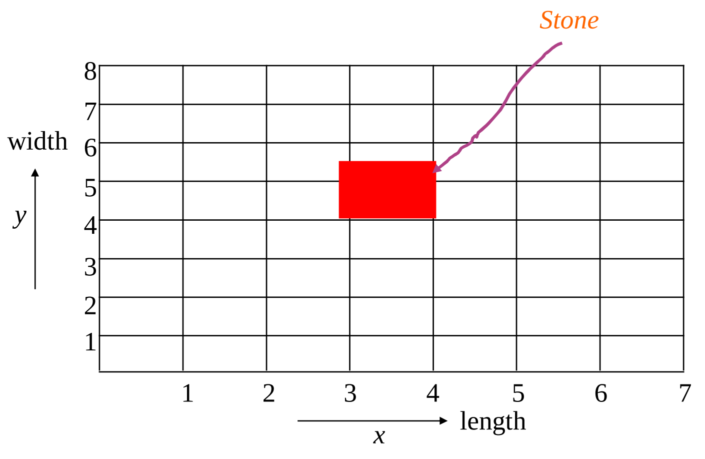
Testing the Rectangular Field

- The field has been prepared and our task is to test it to make sure that it has no stones.
- *How should we organize our search?*

Partitioning the Field

- We divide the entire field into *smaller search rectangles*.
- The length and breadth of each search rectangle is *one half* that of the *smallest* stone.

Partitioning into Search Rectangles



Input Domain

- *Input domain* is the set of all possible inputs to the search process.
- In our example this is the set of all points in the field.
  Thus, the input domain is *infinite*!
- To reduce the size of the input domain we *partition the field into finite size rectangles.*

Rectangle Size

- The length and breadth of each search rectangle is one half that of the smallest stone.
- This ensures that each stone covers at least one rectangle.
- Is this always true?

Constraints

- Testing must be completed in less than $\mathcal{H}$ hours
- Any stone found during testing is removed
- Upon completion of testing the probability of finding a stone must be less than $\mathcal{P}$

Number of Search Rectangles

- Let

L:	length of the field
W:	width of the field
α:	length of the *smallest* stone
β:	width of the *smallest* stone

- Size of each rectangle: $(\alpha/2) * (\beta/2)$
- Number of rectangles: $\mathcal{N} = (L/\alpha)*(W/\beta)*4$
- Assume that L/α and W/β are integers.

Time to Test

- Let t be the time to look inside one rectangle.
  Assume that *no rectangle is examined more than once.*
- Let o be the overhead in moving from one rectangle to another.
- Total time to search $\mathcal{T} = \mathcal{N} * t + (\mathcal{N} - 1) * o$
- Testing with $\mathcal{N}$ rectangles is feasible only if $\mathcal{T} < \mathcal{H}$

Partitioning the Input Domain

- This set consists of all rectangles ($\mathcal{N}$).
- Number of partitions of the input domain is finite ($\mathcal{N}$).
- However, if $\mathcal{T} > \mathcal{H}$ then the number of partitions is too large and scanning each rectangle once is infeasible.
- *What should we do in such a situation?*

Option 1: Do a Limited Search

- Of the $\mathcal{N}$ rectangles we examine only n where n is such that $(t * n + o * (n - 1)) < \mathcal{H}$.
- This limited search will satisfy the *time* constraint.
- Will it satisfy the *probability* constraint?

Distribution of Stones

- To satisfy the probability constraint we must scan enough rectangles so that the probability of finding a stone, after testing, is less than $\mathcal{P}$.
- Let us assume that
  - there are s_i stones remaining after i test cycles.
  - There are $\mathcal{N}_i$ rectangles remaining after i test cycles.
  - Stones are distributed *uniformly* over the field
  - An estimate of the probability of finding a stone in a randomly selected remaining search rectangle is $p_i = s_i \,/\, \mathcal{N}_i$

Probability Constraint

- We will stop looking into rectangles if $p_i \leq \mathcal{P}$
- Can we really apply this test method in practice?

Why Not

- Number of stones in the field is not known in advance.
- Hence we cannot compute the probability of finding a stone after a certain number of rectangles have been examined.
- The best we can do is to *scan* as many rectangles as we can and remove the stones found.

Coverage

- After a rectangle has been scanned for a stone, we say that the rectangle has been *covered.*
- Suppose that *n* rectangles have been scanned from a total of $\mathcal{N}$. Then we say that the coverage is $n / \mathcal{N}$.

Coverage and Confidence

- What happens when coverage increases?
  - *As coverage increases so does our confidence in a "stone-free" field*
- In this particular example, when the coverage reaches 100%, all stones have been found and removed.
- *Can you think of a situation when this might not be true*?

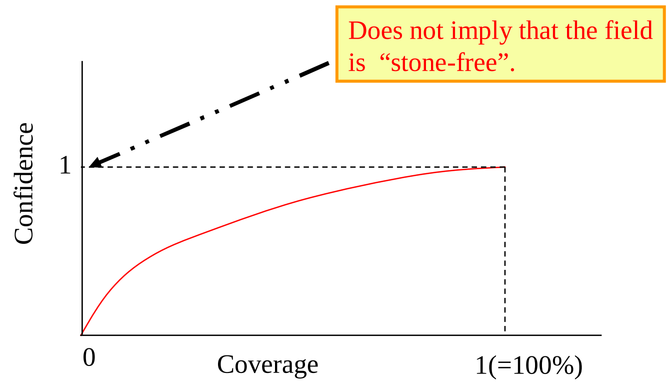
Option 2: Reduce Number of Partitions

- If the number of rectangles to scan is too large, we can increase the size of a rectangle.
  - This reduces the number of rectangles.
- Increasing the size of a rectangle also implies that there might be more than one stone within a rectangle.
  - *Is it good for a tester?*
  - *It also implies . . . .*

Rectangle Size

- As a stone may now be *smaller than a rectangle*, detecting a stone inside a rectangle (by examining only one point) is *not guaranteed*.
- Despite this fact our confidence in a "stone-free" field still increases with coverage.
- However, when the coverage reaches 100% we cannot guarantee a "stone-free" field.

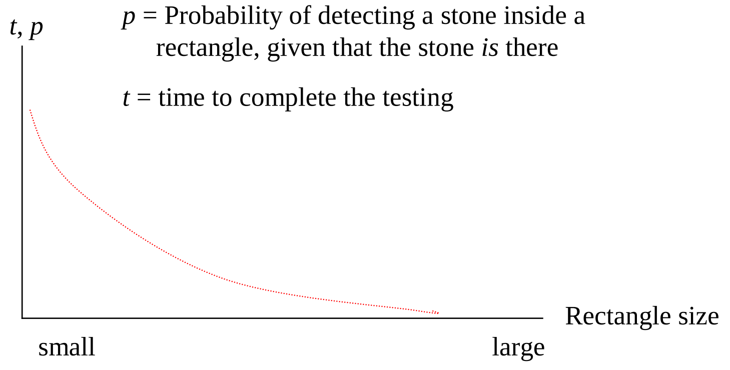
Coverage versus Confidence



Rectangle Size

p = Probability of detecting a stone inside a rectangle, given that the stone *is* there

t = time to complete the testing



Analogy

• Field	Program
• Stone	Error
• Scan a rectangle	Test program on one input
• Remove stone	Remove error
• Partition	Subset of input domain
• Size of stone	Size of an error
• Rectangle size	Size of a partition (wrt "Program")

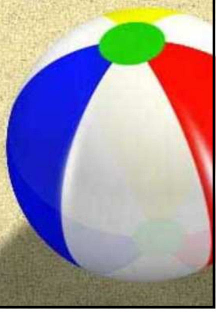
Confidence and Probability

- Increase in coverage increases our confidence in a "stone-free" field.
- It might not increase the probability that the field is "stone-free."

Review Questions

- What is the effect of reducing the partition size on probability of finding errors?
- How does coverage affect our confidence in program correctness?
- Does 100% coverage imply that a program is fault-free?
- Indicate whether the following statements are ***true*** or ***false***
  - The objective of software testing is to *prove the correctness* of the program being tested
  - The reliability of a program *will always increase* as your confidence of the program being correct increases

What is coverage and what role does it play in testing?



Coverage Principle

- The basic idea of coverage testing is that testing is complete when a well-defined set of tests is complete.
  - Example
    - ❑ Pilots use pre-flight check lists
    - ❑ Shoppers use grocery lists

    to assure the correct completion of their tasks
  - In the same way testers can count the completed elements of a test plan
    - ❑ Example
      - ➢ Requirements
      - ➢ Functionalities
      - ➢ Blocks, Decisions (control-flow based)
      - ➢ C-uses, P-uses and All-Uses (dataflow-based)

The Role of Coverage in Testing

- It provides a way of monitoring and measuring the progress of testing against explicit *quantitative* completion criteria
  - Gives a clear measure of the *completion of the testing task*
  - Example, for requirements testing
    - ❑ How many of the requirements have been tested?
    - ❑ How many tests have run per requirement?

Topics

- Code Coverage testing and code inspection
- Code Coverage testing and functional testing
- Controlflow-based testing
- Dataflow-based testing

What is Code Coverage Testing

- It is “White Box Testing”
- Takes into account the structure of the software being tested
- Measures how thoroughly the code has been tested with respect to certain metrics

Code Coverage Testing versus Code Inspection

- Code inspection is a technique whereby the source code is inspected for possible errors
- Code coverage testing is a *dynamic* method, whereas code inspection is a *static* method
- Code coverage testing is a form of code inspection
  - Code that is executed successfully is disregarded for visual inspection
  - Code that is not executed is inspected
  - One is not likely to replace testing by code inspection

Code Coverage Testing versus Functional Testing

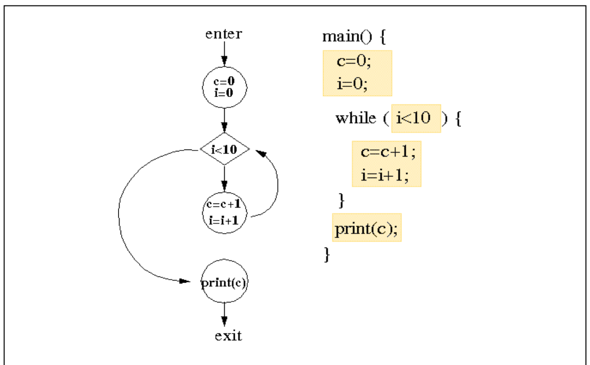
- When test inputs are generated using *program specifications*, we say that we are doing functional testing
  - Functional testing tests how well a program meets the *functionality requirements*
- These two types of testing are complementary
  - Basic functionalities should always be tested
  - The set of tests generated from functional testing provides a good basis for code coverage testing

History of Code Coverage Testing

- Using profiling tools to assess the amount of code coverage during testing (1960's)
- Using t_{cov} to give statement coverage data for C and Fortran programs (1970's)
- Two groups of test criteria
  - Controlflow-based testing (block & decision)
  - Dataflow-based testing (c-use, p-use and all-uses)

Basic Block

- A basic block is a sequence of consecutive statements or expressions, containing no branches except at the end, such that *if one element of the sequence is executed all are.*

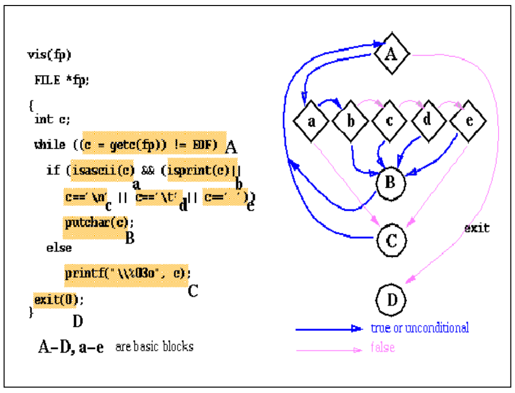


```
main() {
  c=0;
  i=0;
   while ( i<10 ) {
      c=c+1;
      i=i+1;
   }
  print(c);
}
```

A program, its control flowgraph, basic blocks, and decision

Decision

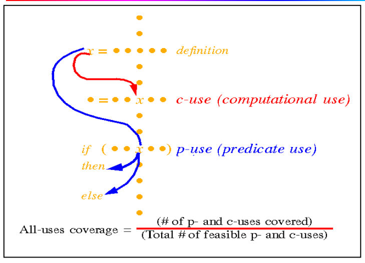
- A decision is a boolean predicate with two possible values, *true* and *false*



```
vis(fp)
 FILE *fp;
{
 int c;
 while ((c = getc(fp)) != EOF) A
   if (isascii(c) && (isprint(c)||
                  a             b
     c=='\n'c || c=='\t'd|| c==' '))
                                  e
     putchar(c);
              B
   else
     printf("\\%03o", c);
                        C
 exit(0);
}
    D
```

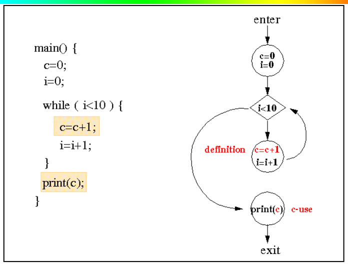
A–D, a–e are basic blocks

C-use & P-use



x = • • • • • definition
• = • • x • • c-use (computational use)
if (• • x • •) p-use (predicate use)
then
else

All-uses coverage = $\frac{\text{(\# of p- and c-uses covered)}}{\text{(Total \# of feasible p- and c-uses)}}$



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main() {
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  while ( i<10 ) {
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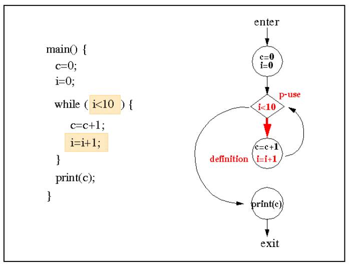
     i=i+1;
  }
  print(c);
}
```

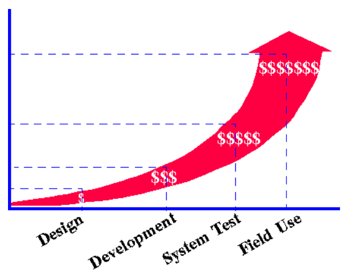


```
main() {
  c=0;
  i=0;

  while ( i<10 ) {
     c=c+1;
     i=i+1;
  }
  print(c);
}
```

Importance of Code Coverage Testing

- In general, a piece of code must be executed before a fault in it can be exposed
- *Helps early fault detection*
  - Are system testers finding faults that should have been found and fixed by developers?
  - Relative cost of fixing a software fault

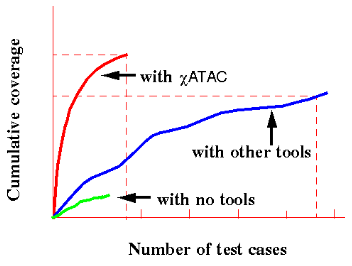


State of Practice

- A published study (ICSE'92)
  - Coverage above 60-70% in system testing is very difficult
- Don Knuth's system testing of TeX (23,000 LOC)
  - 85% block and 72% decision coverage (1992)
- Brian Kernigan's testing of AWK
  - 70% block and 59% decision coverage (1991)

Efficient Coverage Testing (1)

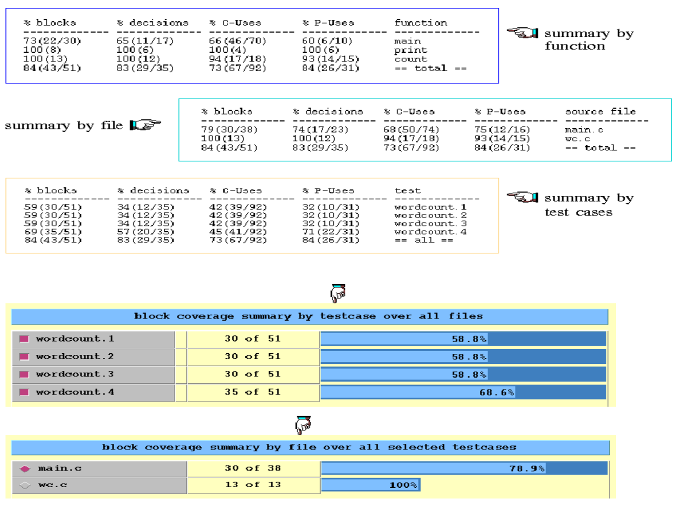
- How much code is currently tested? What is missing?
  - Which statements were exercised?
  - Which paths were traversed?
  - Which def-use associations were exercised?
  - Which functions got invoked from where?
- Need help in creating tests?
  - Which statement should I try to cover next?



Analyzing the controlflow graph of the program to find the dominant blocks, decisions, and def-use pairs.

For example, when a test covers highly dominant blocks it will cover many other blocks.

Efficient Coverage Testing (2)



```
% blocks       % decisions    % C-Uses       % P-Uses       function
------------   ------------   ------------   ------------   ------------
73(22/30)      65(11/17)      66(46/70)      60(6/10)       main
100(8)         100(6)         100(4)         100(6)         print
100(13)        100(12)        94(17/18)      93(14/15)      count
84(43/51)      83(29/35)      73(67/92)      84(26/31)      == total ==
```

summary by function

summary by file

```
% blocks       % decisions    % C-Uses       % P-Uses       source file
------------   ------------   ------------   ------------   ------------
79(30/38)      74(17/23)      68(50/74)      75(12/16)      main.c
100(13)        100(12)        94(17/18)      93(14/15)      wc.c
84(43/51)      83(29/35)      73(67/92)      84(26/31)      == total ==
```

```
% blocks       % decisions    % C-Uses       % P-Uses       test
------------   ------------   ------------   ------------   ------------
59(30/51)      34(12/35)      42(39/92)      32(10/31)      wordcount.1
59(30/51)      34(12/35)      42(39/92)      32(10/31)      wordcount.2
59(30/51)      34(12/35)      42(39/92)      32(10/31)      wordcount.3
69(35/51)      57(20/35)      45(41/92)      71(22/31)      wordcount.4
84(43/51)      83(29/35)      73(67/92)      84(26/31)      == all ==
```

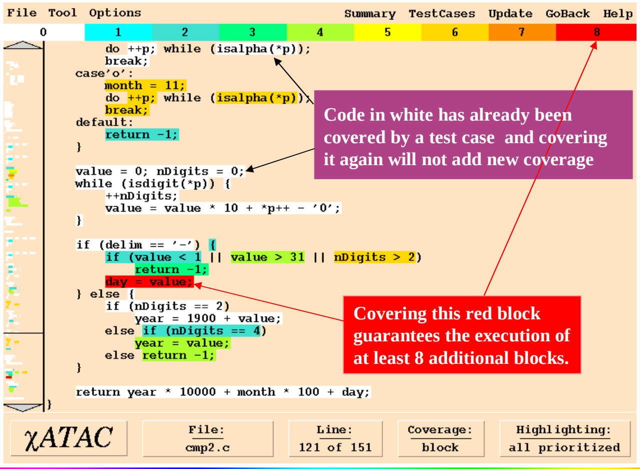
summary by test cases

block coverage summary by testcase over all files		
wordcount.1	30 of 51	58.8%
wordcount.2	30 of 51	58.8%
wordcount.3	30 of 51	58.8%
wordcount.4	35 of 51	68.6%

block coverage summary by file over all selected testcases		
main.c	30 of 38	78.9%
wc.c	13 of 13	100%

Efficient Coverage Testing (3)

- ➢Use *prioritization* and *visualization* to provide hot spots that give the most value in coverage.
- ➢Each color represents a different weight determined by a control flow analysis using the concept of superblocks and dominators.



```
        do ++p; while (isalpha(*p));
        break;
    case'o':
        month = 11;
        do ++p; while (isalpha(*p));
        break;
    default:
        return -1;
    }

    value = 0; nDigits = 0;
    while (isdigit(*p)) {
        ++nDigits;
        value = value * 10 + *p++ - '0';
    }

    if (delim == '-') {
        if (value < 1 || value > 31 || nDigits > 2)
            return -1;
        day = value;
    } else {
        if (nDigits == 2)
            year = 1900 + value;
        else if (nDigits == 4)
            year = value;
        else return -1;
    }

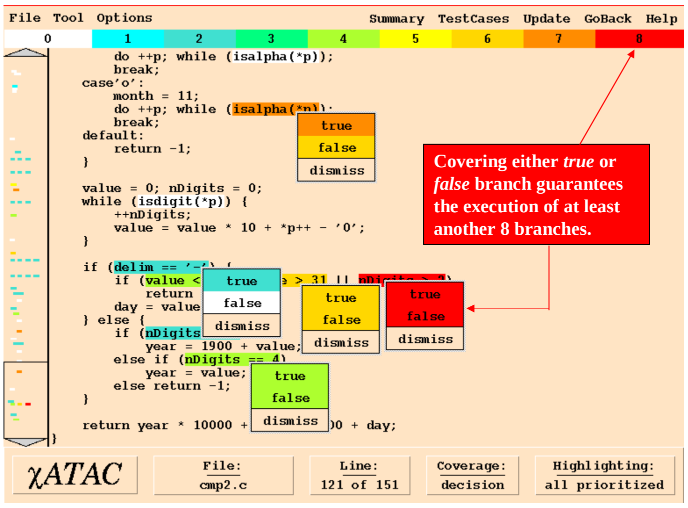
    return year * 10000 + month * 100 + day;
}
```

File: cmp2.c
Line: 121 of 151
Coverage: block
Highlighting: all prioritized

Code in white has already been covered by a test case and covering it again will not add new coverage

Covering this red block guarantees the execution of at least 8 additional blocks.

Efficient Coverage Testing (4)



```
        do ++p; while (isalpha(*p));
        break;
    case'o':
        month = 11;
        do ++p; while (isalpha(*p));
        break;
    default:
        return -1;
    }

    value = 0; nDigits = 0;
    while (isdigit(*p)) {
        ++nDigits;
        value = value * 10 + *p++ - '0';
    }

    if (delim == '-') {
        if (value <                e > 31 || nDigits > 2)
            return
        day = value
    } else {
        if (nDigits
            year = 1900 + value;
        else if (nDigits == 4)
            year = value;
        else return -1;
    }

    return year * 10000 +          00 + day;
}
```

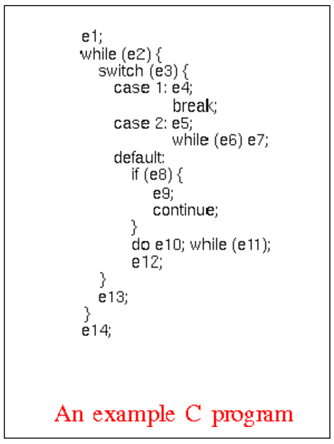
File: cmp2.c
Line: 121 of 151
Coverage: decision
Highlighting: all prioritized

Covering either *true* or *false* branch guarantees the execution of at least another 8 branches.

Dominator & Super Block (1)

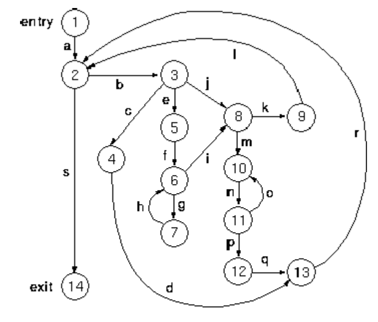
- A super block consists of one or more basic blocks that if one block in the super block is executed all are
  - If any statement in a super block is executed, then all statements in it must be executed, provided the execution terminates on that input
  - A super block needs not be contiguous
- Block *u* dominates block *v* if every path from entry to end, via *v*, contains *u*
  - *u* dominates *v* if covering *v* implies the coverage of *u*
  - Test execution cannot reach *v* without going through *u*
- Given a program, identify a subset of super blocks whose coverage implies that of all super blocks and, in turn, that of all basic blocks

Dominator & Super Block (2)



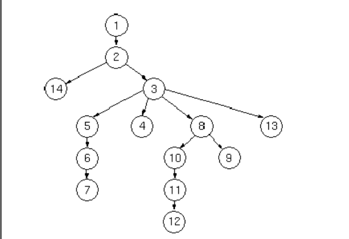
```
e1;
while (e2) {
   switch (e3) {
     case 1: e4;
             break;
     case 2: e5;
             while (e6) e7;
     default:
        if (e8) {
           e9;
           continue;
        }
        do e10; while (e11);
        e12;
   }
   e13;
}
e14;
```

An example C program



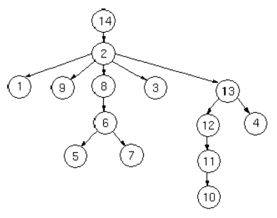
Control Flowgraph

Dominator & Super Block (3)



Predominator tree

u predominates v if every path from the *entry* node to *v* contains *u*.

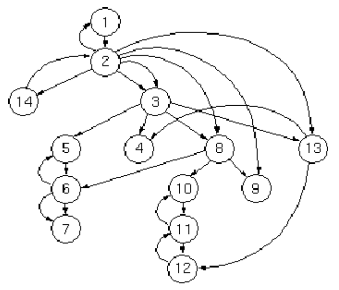


Postdominator tree

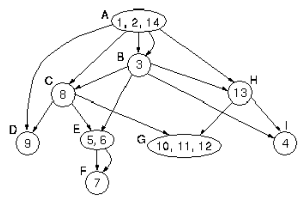
w postdominates v if every path from *v* to the *exit* node contains *w*.

- Quiz: Does node 4 or node 12 predominate node 13? Why?
- Quiz: Does node 9 postdominate node 8? Why?

Dominator & Super Block (4)



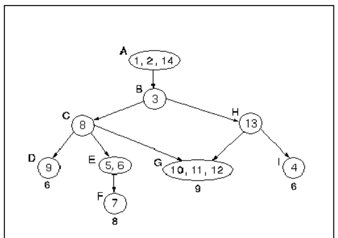
Basic block dominator graph
(union of pre & postdominator trees)



Condensed dominator graph
(Merging strongly connected components)

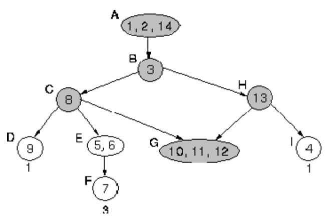
- A *strongly connected component* of a basic block dominator graph has the property that every node in the component dominates all other nodes in that component

Dominator & Super Block (5)



Super block dominator graph with the initial weights associated with the leaves

- Obtained by removing the *composite edges* in the right Figure on the previous slide
- An edge *e* from a node *u* to a node *v* is said to be a composite edge if *v* is also reachable from *u* without going through *e*

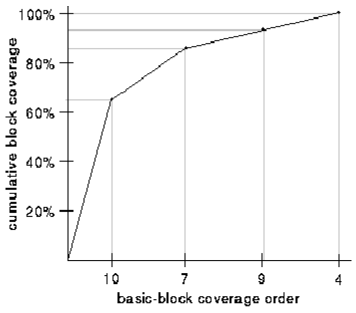


Highlighted blocks show the covered blocks after the initially heaviest leaf is covered. New weights of the remaining leaves are also shown.

- Only need to create test cases that cover basic blocks 4, 7, 9, and 10 – *one from each leaf node* in the super block dominator graph

Dominator & Super Block (6)

- At most four test cases need to be developed to cover all 14 basic blocks



The order in which the targeted basic blocks are covered and the corresponding cumulative coverages achieved.

- An alternative order is 10, 7, 4, and 9

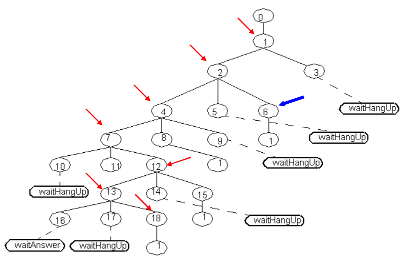
Dominator & Super Block (7)

- Experimental results

program	basic blocks	blocks that need to be covered	
sort	455	138	30%
spiff	1266	361	29%
mgr	3848	1043	27%
ion	4886	1280	26%
atac	8737	2574	29%
odin	9870	2344	24%
xlib	15580	5111	33%
tvo	17680	6267	35%

Weight Re-Computation (1)

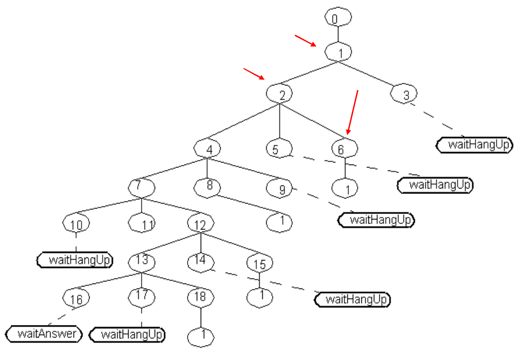
- The weight of a given node is the number of nodes that have not been covered but will be if that node is covered



- To arrive at node 18 requires the execution also go through nodes 1, 2, 4, 7, 12 and 13
- Node 18 is *dominated by* nodes 1, 2, 4, 7,12 and 13
- These nodes will be covered (if they haven't been) by a test execution if that execution covers node 18
- Assuming none of the nodes is covered so far, we say that node 18 has *a weight of 7* because covering it will increase the coverage by at least 7 additional nodes**.**

- Why is it important to take a "conservative" approach?
  - Will node 6 be covered by covering node 18?

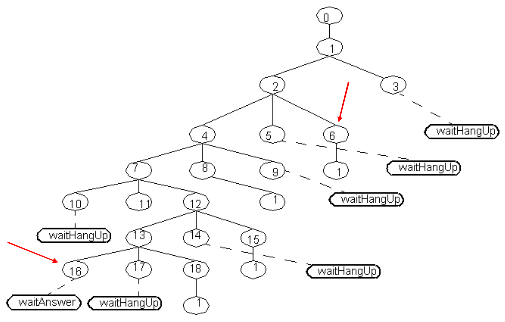
Weight Re-Computation (2)



- Arriving at node 6 requires the execution only goes through nodes 1, and 2
- Assuming none of the nodes is covered so far, we say that node 6 has a weight of 3

Weight Re-Computation (3)

- The execution of certain tests may change the weights of nodes that are not covered by these tests.

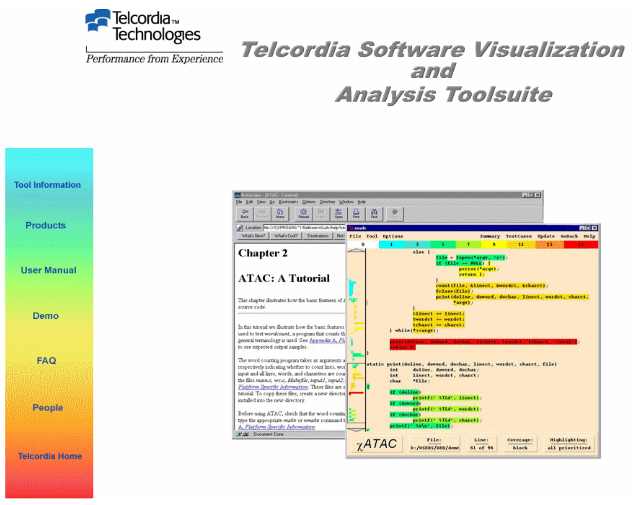


- After a test is executed to cover node 18, the weight (in terms of increasing the coverage) of node 6 is reduced from 3 to 1.

The χSuds Tool Suite

- Telcordia Technologies (formerly Bellcore or Bell Communications Research)
  - χSuds (Software understanding and diagnosis systems): a set of software testing, analysis, and understanding tools for C and C++ programs
    - ❑ χATAC
    - ❑ χSlice
    - ❑ χRegress
    - ❑ χVue
    - ❑ χProf

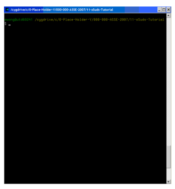
χSuds Home Page

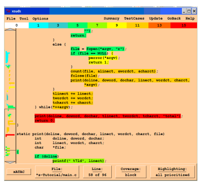

Telcordia Technologies
Performance from Experience

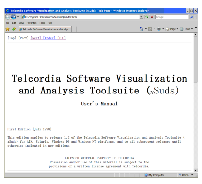
Telcordia Software Visualization and Analysis Toolsuite

http://xsuds.argreenhouse.com

χATAC Demo: Coverage Testing of C Code

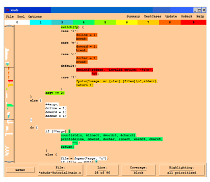

Compile code with χATAC

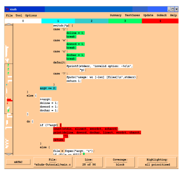

Initial display

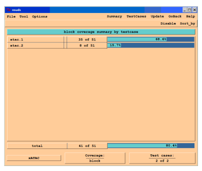

Telcordia Software Visualization
and Analysis Toolsuite (χSuds)

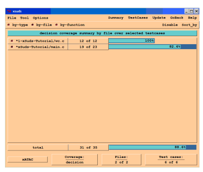
User's Manual

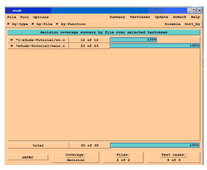
χSuds User's Manual


Source display after executing wordcount.1


Source display after executing wordcount.2


100 % block coverage after executing wordcount.5

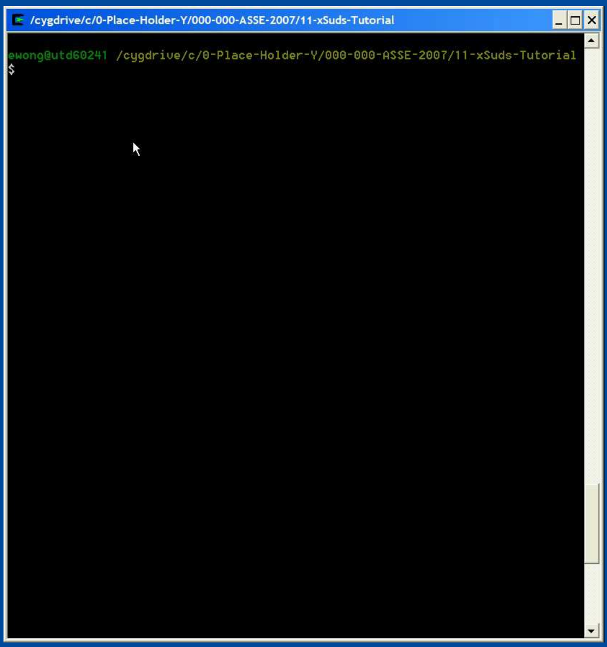

Source display after executing wordcount.6


100 % block & decision coverage after executing wordcount.9

Coverage Testing Tools for Java Code

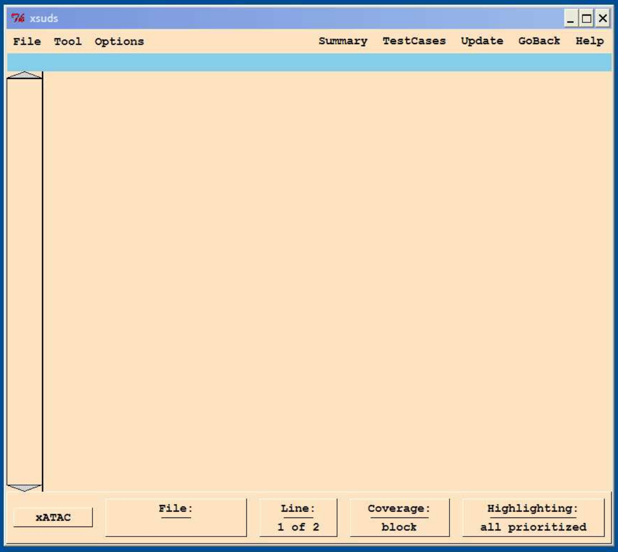
- eXVantage (eXtreme Visual-aid novel testing and generation) *i*
  - A tool suite for code coverage prioritization, test generation, test execution, debugging, and performance profiling of Java, C, and C++ programs
  - Based on the JBT (Java Bytecode Testing) tool suite developed at UTD since 2002
- Clover
- Cobertura
- etc.

The End



/cygdrive/c/0-Place-Holder-Y/000-000-ASSE-2007/11-xSuds-Tutorial

```
ewong@utd60241 /cygdrive/c/0-Place-Holder-Y/000-000-ASSE-2007/11-xSuds-Tutorial
$
```

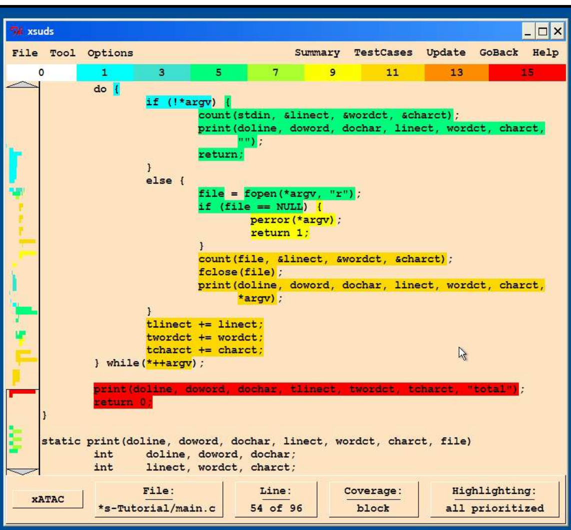


File:

Line: 1 of 2

Coverage: block

Highlighting: all prioritized



```
        do {
                if (!*argv) {
                        count(stdin, &linect, &wordct, &charct);
                        print(doline, doword, dochar, linect, wordct, charct,
                              "");
                        return;
                }
                else {
                        file = fopen(*argv, "r");
                        if (file == NULL) {
                                perror(*argv);
                                return 1;
                        }
                        count(file, &linect, &wordct, &charct);
                        fclose(file);
                        print(doline, doword, dochar, linect, wordct, charct,
                              *argv);
                }
                tlinect += linect;
                twordct += wordct;
                tcharct += charct;
        } while(*++argv);

        print(doline, doword, dochar, tlinect, twordct, tcharct, "total");
        return 0;
}

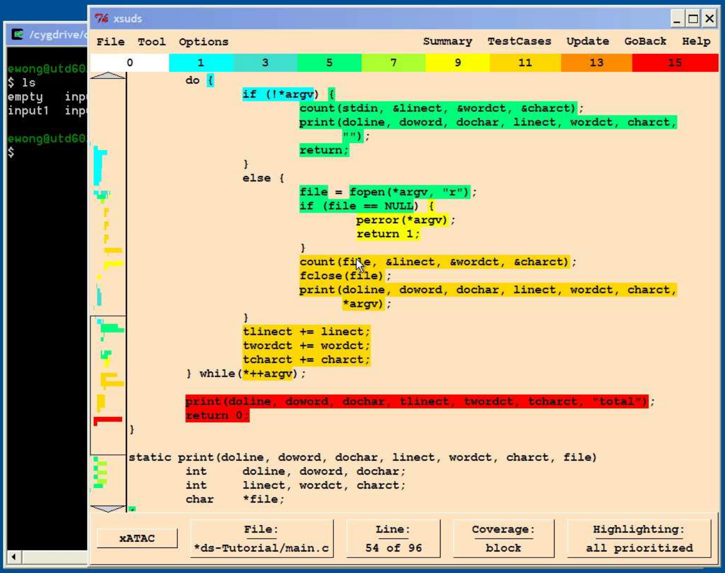
static print(doline, doword, dochar, linect, wordct, charct, file)
        int     doline, doword, dochar;
        int     linect, wordct, charct;
```

File: *s-Tutorial/main.c

Line: 54 of 96

Coverage: block

Highlighting: all prioritized



```
ewong@utd60
$ ls
empty   inp
input1  inp

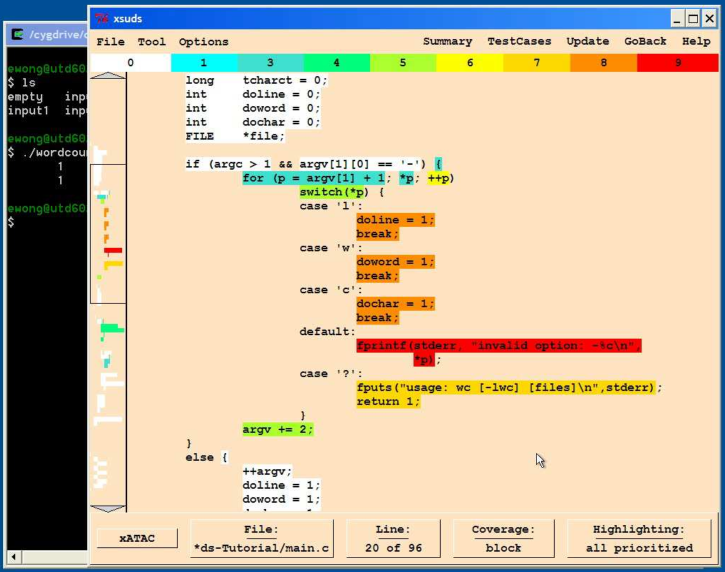
ewong@utd60
$
```

```
        do {
                if (!*argv) {
                        count(stdin, &linect, &wordct, &charct);
                        print(doline, doword, dochar, linect, wordct, charct,
                              "");
                        return;
                }
                else {
                        file = fopen(*argv, "r");
                        if (file == NULL) {
                                perror(*argv);
                                return 1;
                        }
                        count(file, &linect, &wordct, &charct);
                        fclose(file);
                        print(doline, doword, dochar, linect, wordct, charct,
                              *argv);
                }
                tlinect += linect;
                twordct += wordct;
                tcharct += charct;
        } while(*++argv);

        print(doline, doword, dochar, tlinect, twordct, tcharct, "total");
        return 0;
}

static print(doline, doword, dochar, linect, wordct, charct, file)
        int     doline, doword, dochar;
        int     linect, wordct, charct;
        char    *file;
```

xATAC | File: *ds-Tutorial/main.c | Line: 54 of 96 | Coverage: block | Highlighting: all prioritized



```
ewong@utd60
$ ls
empty   inp
input1  inp

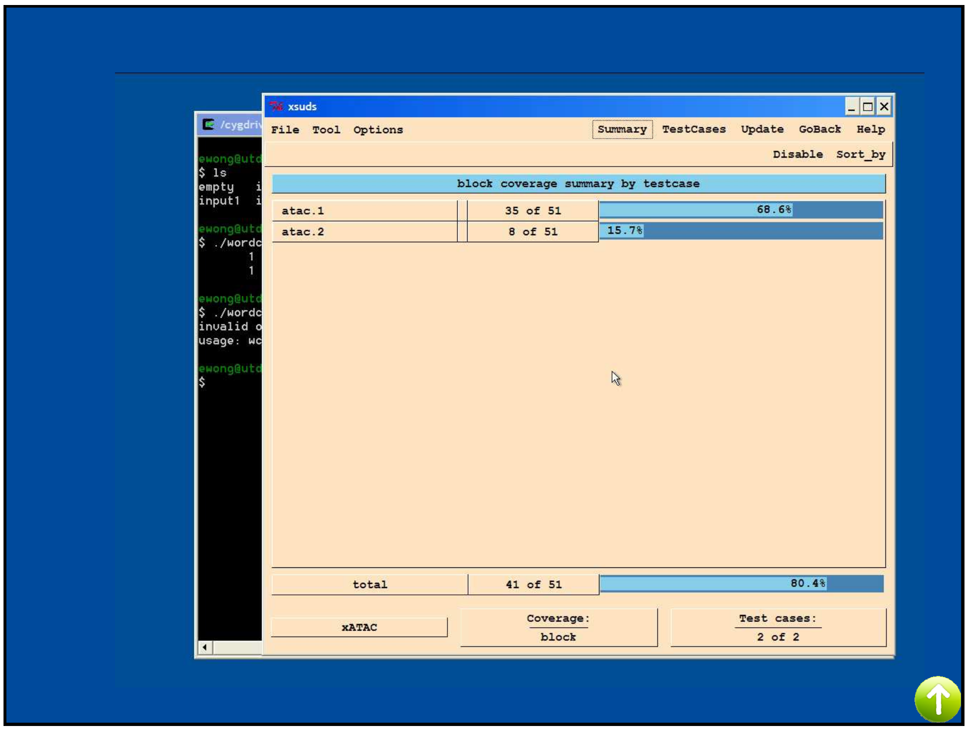
ewong@utd60
$ ./wordcou
        1
        1

ewong@utd60
$
```

```
        long    tcharct = 0;
        int     doline = 0;
        int     doword = 0;
        int     dochar = 0;
        FILE    *file;

        if (argc > 1 && argv[1][0] == '-') {
                for (p = argv[1] + 1; *p; ++p)
                        switch(*p) {
                        case 'l':
                                doline = 1;
                                break;
                        case 'w':
                                doword = 1;
                                break;
                        case 'c':
                                dochar = 1;
                                break;
                        default:
                                fprintf(stderr, "invalid option: -%c\n",
                                        *p);
                        case '?':
                                fputs("usage: wc [-lwc] [files]\n",stderr);
                                return 1;
                        }
                argv += 2;
        }
        else {
                ++argv;
                doline = 1;
                doword = 1;
```

xATAC | File: *ds-Tutorial/main.c | Line: 20 of 96 | Coverage: block | Highlighting: all prioritized



```
block coverage summary by testcase
atac.1        35 of 51   68.6%
atac.2         8 of 51   15.7%

total         41 of 51   80.4%

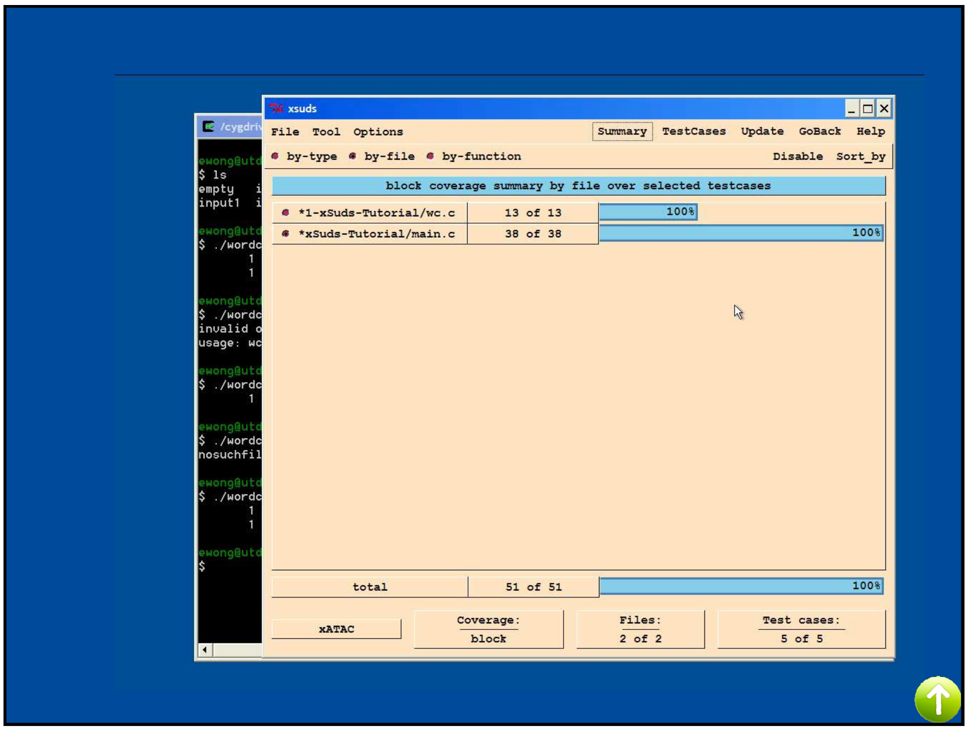
xATAC     Coverage:   Test cases:
          block       2 of 2
```

```
/cygdriv
ewong@utd
$ ls
empty   i
input1  i

ewong@utd
$ ./wordc
        1
        1

ewong@utd
$ ./wordc
invalid o
usage: wc

ewong@utd
$
```


xsuds
File Tool Options
Summary TestCases Update GoBack Help
by-type by-file by-function
Disable Sort_by

```
block coverage summary by file over selected testcases
*1-xSuds-Tutorial/wc.c     13 of 13   100%
*xSuds-Tutorial/main.c     38 of 38   100%

total                      51 of 51   100%

xATAC     Coverage:   Files:   Test cases:
          block       2 of 2   5 of 5
```

```
/cygdriv
ewong@utd
$ ls
empty   i
input1  i

ewong@utd
$ ./wordc
        1
        1

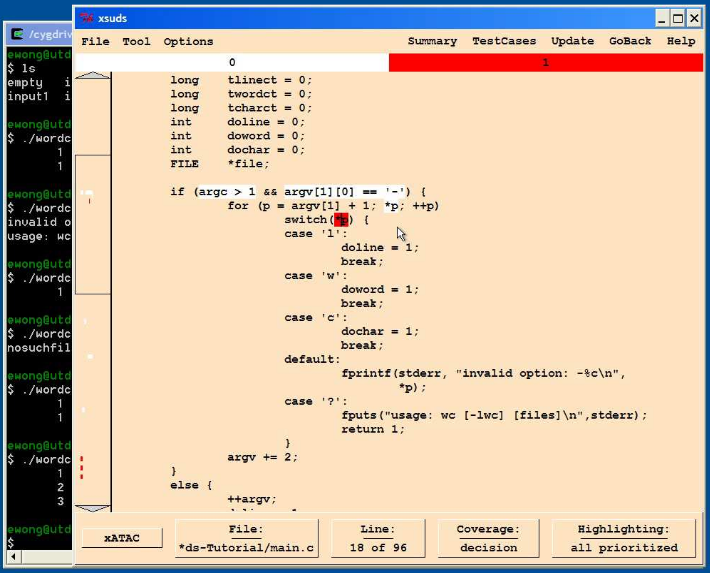
ewong@utd
$ ./wordc
invalid o
usage: wc

ewong@utd
$ ./wordc
        1

ewong@utd
$ ./wordc
nosuchfil

ewong@utd
$ ./wordc
        1
        1

ewong@utd
$
```



```
ewong@utd
$ ls
empty   i
input1  i

ewong@utd
$ ./wordc
        1
        1

ewong@utd
$ ./wordc
invalid o
usage: wc

ewong@utd
$ ./wordc
        1

ewong@utd
$ ./wordc
nosuchfil

ewong@utd
$ ./wordc
        1
        1

ewong@utd
$ ./wordc
        1
        2
        3

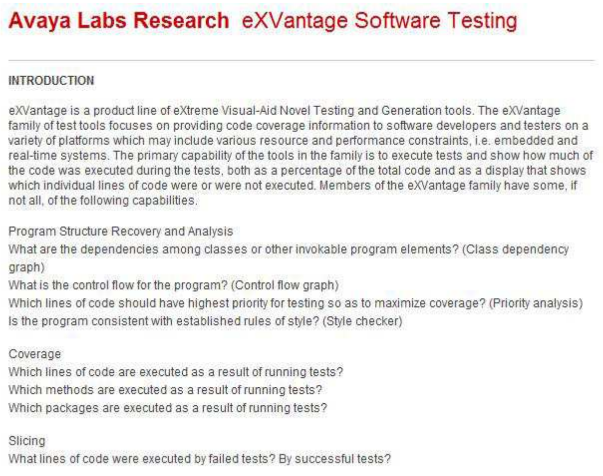
ewong@utd
$
```

```
        long    tlinect = 0;
        long    twordct = 0;
        long    tcharct = 0;
        int     doline = 0;
        int     doword = 0;
        int     dochar = 0;
        FILE    *file;

        if (argc > 1 && argv[1][0] == '-') {
                for (p = argv[1] + 1; *p; ++p)
                        switch(*p) {
                        case 'l':
                                doline = 1;
                                break;
                        case 'w':
                                doword = 1;
                                break;
                        case 'c':
                                dochar = 1;
                                break;
                        default:
                                fprintf(stderr, "invalid option: -%c\n",
                                        *p);
                        case '?':
                                fputs("usage: wc [-lwc] [files]\n",stderr);
                                return 1;
                        }
                argv += 2;
        }
        else {
                ++argv;
```

xATAC	File:	Line:	Coverage:	Highlighting:
	*ds-Tutorial/main.c	18 of 96	decision	all prioritized

eXVantage Home Page



Avaya Labs Research eXVantage Software Testing

INTRODUCTION

eXVantage is a product line of eXtreme Visual-Aid Novel Testing and Generation tools. The eXVantage family of test tools focuses on providing code coverage information to software developers and testers on a variety of platforms which may include various resource and performance constraints, i.e. embedded and real-time systems. The primary capability of the tools in the family is to execute tests and show how much of the code was executed during the tests, both as a percentage of the total code and as a display that shows which individual lines of code were or were not executed. Members of the eXVantage family have some, if not all, of the following capabilities.

Program Structure Recovery and Analysis
What are the dependencies among classes or other invokable program elements? (Class dependency graph)
What is the control flow for the program? (Control flow graph)
Which lines of code should have highest priority for testing so as to maximize coverage? (Priority analysis)
Is the program consistent with established rules of style? (Style checker)

Coverage
Which lines of code are executed as a result of running tests?
Which methods are executed as a result of running tests?
Which packages are executed as a result of running tests?

Slicing
What lines of code were executed by failed tests? By successful tests?

W. Eric Wong and J. Jenny Li, "An Integrated Solution for Testing and Analyzing Java Applications in an Industrial Setting," in *Proceedings of The 12th IEEE Asia-Pacific Software Engineering Conference* (APSEC), pp. 576-583, Taipei, Taiwan, December 2005