Debugging and Optimization of Scientific Applications
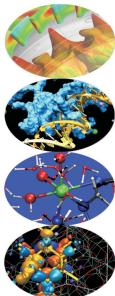
P. Lanucara V. Ruggiero

CINECA Rome - SCAI Department

Rome, 19-21 April 2017

AGENDA

19th April 2017

9.00-9.30 Registration
9.30-10.30 Architectures
10.30-13.00 Cache and Memory System
14.00-15.00 Pipelines
15.00-17.00 Profilers

20th april 2017

9.30-13.00 Compilers
14.00-15.30 Scientific Libraries
15.00-17.00 Makefile

21st april 2017

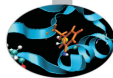9.30-13.00 Debugging
14.00-17.00 Final hands-on

Bugs, Prevention and Testing

Static analysis

Run-time analysis

Debugging

Conclusions

As soon as we started programming, we found to our surprise that it wasn't as easy to get programs right as we had thought. Debugging had to be discovered. I can remember the exact instant when I realized that a large part of my life from then on was going to be spent in finding mistakes in my own programs.!

Maurice Wilkes discovers debugging, 1949.

- TESTING: finds errors.
- DEBUGGING: localizes and repairs them.

TESTING DEBUGGING CYCLE:
we test, then debug, then repeat.

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Program testing can be used to show the presence of bugs, but never to show their absence!
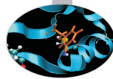Edsger Dijkstra

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▶ Defect: An incorrect program code $\implies$ a bug in the code.

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Defect

- The programmer creates a defect in the program code (also known as bug or fault).

Defect $\Longrightarrow$ Infection

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$$\boxed{\text{Defect} \implies \text{Infection} \implies \text{Failure}}$$

▶ The programmer creates a defect in the program code (also known as bug or fault).

▶ The defect causes an in infection in the program state.

▶ The infection creates a failure - an externally observable error.

Failure

- A Failure is visible to the end user of a program. For example, the program prints an incorrect output.

$$\text{Infection} \Longleftarrow \text{Failure}$$

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- ▶ Infection is the underlying state of the program at runtime that leads to a Failure. For example, the program might display the incorrect output because the wrong value is stored in avariable.

Defect $\Longleftarrow$ Infection $\Longleftarrow$ Failure

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▶ Infection is the underlying state of the program at runtime that leads to a Failure. For example, the program might display the incorrect output because the wrong value is stored in a variable.

▶ A Defect is the actual incorrect fragment of code that the programmer wrote; this is what must be changed to fix the problem.

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TO MAKE NO MISTAKES

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TO MAKE NO MISTAKES**

► Preventing bugs.

► Detecting/locating bugs.
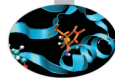
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Ca. 80 percent of software development costs spent on identifying and correcting defects.

It is much more expensive (in terms of time and effort) to detect/locate exisising bugs, than prevent them in the first place.

www.ifsq.org

IfSQ Institute for Software Quality

www.ifsq.org

- ▶ We have an agreed common goal: to raise the standard of software (and software development) around the world by promoting Code Inspection as a prerequisite to Software Testing in the production and delivery cycle.
- ▶ Our strong hope is that eventually the idea of inspecting code before testing will be as self-evident as testing software before using it.

How can I prevent Bugs?

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- ► Design.

- ► Good writing.

- ► Self-checking code.

- ► Test scaffolding.

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It's a creative act, not mechanical code generation.

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▶ Good modularization.

▶ Strong encapsulation/information hiding.

▶ Clear,simple pre- and post-processing.

▶ Requirements of operations should testable.

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- The smaller the component, the easier it is to understand.

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  A study showed that when routines averaged 100 to 150 lines each, code was more stable and required less changes.

- reduces complexity
- avoids duplicate code
- facilitates reusable code
- limits effects of the changes
- facilitates test
- results in easier implementation

- ▶ The principle of information hiding suggests that modules be characterized by design decisions that each hides from all others.
- ▶ The information contained within a module is inaccesible to other modules that have no need for such information.
- ▶ Hiding implies that effective modularity can be achieved by defining a set of independent modules that communicate with one another only that information necessary to achieve software function.
- ▶ Because most data and procedure are hidden from other parts of software , inadvertent errors introduced during modification are less likely to propagate to other locations within the software.

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- As a general rule, you should always aim to create modules that have strong cohesion and weak coupling.
- The routines with the highest coupling-to-cohesion ratios had 7 times more errors than those with the lowest ratios.

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    Spaghetti code is characterized by very strong coupling.

- Clarity is more important than efficiency: clarity of writing and style.
    - Use simple expressions, not complex
    - Use meaningful names
    - Clarity of purpose for:
        - Functions.
        - Loops.
        - Nested constructs.

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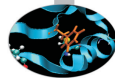   Studies have shown that few people can understand nesting of conditional statements to more than 3 levels.
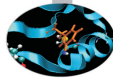
Preventing bugs via good writing

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- Comments,comments,comments.

- Small size of functions,routines.
A study at IBM found that the most error-prone routines were those larger than 500 lines of code.

- ▶ Use the smallest acceptable scope for:
  - ▶ Variable names.
  - ▶ Static/local functions.
- ▶ Use named intermediate values.
- ▶ Avoid "Magic numbers".
- ▶ Generalize your code.
- ▶ Document your program.
- ▶ Write standard language.

- ▶ Checking assumptions.
- ▶ "assert" macro.
- ▶ Custom "assert" macros.
- ▶ Assertions about intermediate values.
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  Defensive programming.

- ▶ That an input parameter's value falls within its expected range (or an output parameters' value does)
- ▶ That the value of an input-only variable is not changed by a routine.
- ▶ That a pointer is non-NULL.
- ▶ That an array or other container passed into a routine can contain at least X data number of data elements.
- ▶ That a table has been initialized to contain real values.
- ▶ Etc.

- An assertion is a code (usually routine or macro) that allows a program to check itself as runs.
- When an assertion is true, that means everything is operating as expected
- When it's false, that means it has detected an unexpected error in the code.
- Use error handling code for conditions you expected to occur.
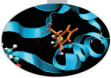
- Return a neutral value.
- Substitute the closest legal value.
- Log a warning message to a file.
- Return an error code.
  - Set a value of a status variable.
  - Return status as the function's return value.
  - Throw an exception using the language's build-in exception mechanism.
- Display an error message wherever the error is encountered.
- Handle the error in whatever way works best locally.
- Shutdown.

Input

Read three integer values from the command line.
The three values represent the lengths of the sides of a triangle.

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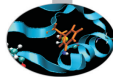Tell whether the triangle is:
Scalene
Isosceles
Equilater.

Create a set of test cases for this program.
("The art of sotware testing" G.J. Myers)

Q:1 Do you have a test case with three integers greater than zero such that the sum of two of the numbers is less than the third ?

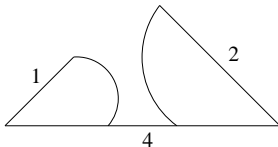Q:1 Do you have a test case with three integers greater than zero such that the sum of two of the numbers is less than the third ?

(4,1,2) is an invalid triangle.

(a,b,c) with a $>$ b+c

Define valide triangles $a < b + c$

Q:2 Do you have a test case with some permutations of previous test?

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(1,4,2) (4,1,2)

Fulfill above definition, but are still invalid.

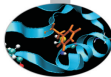Patch definition of valid triangles:
$a < b + c$
$b < a + c$
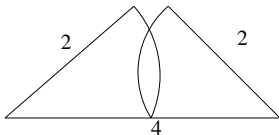$c < a + b$

Q:3 Do you have a test case with three integers greater than zero such that the sum of two numbers is equal to the third?

Q:3 Do you have a test case with three integers greater than zero such that the sum of two numbers is equal to the third? (4,2,2) is invalid triangle with equal sum.

Fulfill above definition, but is invalid:

a $<$ b+c

b $<$ a+c

c $<$ a+b

Testing: a simple program

Do you have a test case:

4. with some permutations of previous test? (2,4,2) (2,2,4)

5. that represents a valid scalene triangle? (3,4,5)

6. that represents a valid equilateral triangle? (3,3,3)

7. that represents a valid isosceles triangle? (4,3,3)

8. with some permutations of previous test? (3,4,3) (3,3,4)

9. in which one side has a zero value? (0,4,3)

10. in which one side has a negative value? (-1,4,3)

11. in which all sides are zero? (0,0,0)

12. specifying at least one noninteger value? (2,2.5,4)

13. specifying the wrong number of values? (2,3) or (2,3,5,4)

14. For each test case did you specify the expected output from the program in addition to the input values?

- A set of test case that satisfies these conditions does not guarantee that all possibile errors would be found.
- An adeguate test of this program should expose at least these errors.
- Higly qualified professional programmers score, on the average, 7.8 out of a possibile 14.

Syntax

- **Definition**: errors in grammar (violations of the "rules" for forming legal language statements).
- **Examples**: undeclared identifiers, mismatched parentheses in an expression, an opening brace without a matching closing brace, etc.
- **Occur**: an error that is caught in the process of compiling the program.

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- **Occur**: an error that is caught in the process of compiling the program.
  The easiest errors to spot by a compiler or some aid in checking the syntax.
  As you get more practice using a language, you naturally make fewer errors, and will be able to quickly correct those that do occur.

Runtime

- Definition: "Asking the computer to do the impossible!"
- Examples: division by zero, taking the square root of a negative number, referring to the 101th on a list of only 100 items, deferencing a null pointer, etc.
- Occur: an error that is not detected until the program is executed, and then causes a processing error to occur.

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- **Occur**: an error that is not detected until the program is executed, and then causes a processing error to occur.
  They are not easy to spot because they are not syntax or grammar errors, they are subtle errors and develop in the course of program's execution.
  Avoiding exceptions and correcting program behaviour is also largely a matter of experience.
  To prevent use defensive programming.

Logic (semantic, meaning)

▶ Definition: the program compiles (no syntax errors) and runs to a normal completion (no runtime erros), but the output is wrong. A statement may be syntactically correct, but mean something other than what we intended. Therefore it has a different effect, causing the program output to be wrong.

▶ Examples: improper initialization of variables, performing arithmetic operations in the wrong order, using an incorrect formula to compute a value, etc.

▶ Occur: an error that affect how the code works.

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- **Examples**: improper initialization of variables, performing arithmetic operations in the wrong order, using an incorrect formula to compute a value, etc.

- **Occur**: an error that affect how the code works.
  It is a type of error that only the programmer can recognize.Finding and correcting logic errors in a program is known as debugging.

Bugs, Prevention and Testing

Static analysis
    Compiler options
    Static analyzer

Run-time analysis

Debugging

Conclusions

Static analysis refers to a method of examinig software that allows developers to discover dangerous programming pratices or potential errors in source code, without actually run the code.

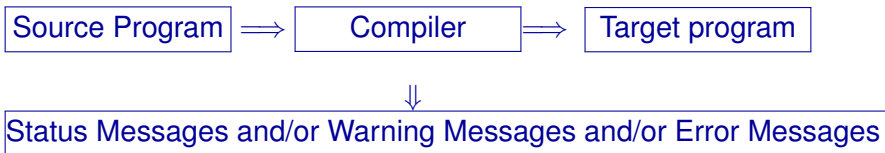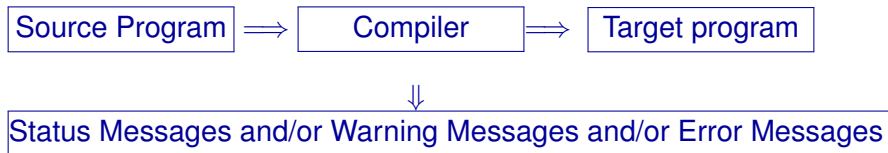Static analysis refers to a method of examinig software that allows developers to discover dangerous programming pratices or potential errors in source code, without actually run the code.

► Using compiler options.
► Using static analyzer.

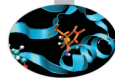Source Program $\Longrightarrow$ Compiler $\Longrightarrow$ Target program

$\Downarrow$

Status Messages and/or Warning Messages and/or Error Messages

Source Program $\Longrightarrow$ Compiler $\Longrightarrow$ Target program

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Status Messages and/or Warning Messages and/or Error Messages

Compiler checks:

► Syntax.

► Semantic.

- Characters in the source that aren't in the alphabet of the language.

- Words in the source that aren't in the vocabulary of the language.

- Comment delimiters that have been put in wrong place or omitted.
- Literal delimiters that have been put in wrong place or omitted.
- Keywords that have been misspelled.
- Required punctuation that is missing.
- Construct delimiters such as parentheses or braces that have been missplaced.
- Blank or tab characters that are missing.
- Blank or tab characters that shouldn't occur where they're found.

- Names that aren't declared.
- Operands of the wrong type for the operator they're used with.
- Values that have the wrong type for the name to which they're assigned.
- Procedures that are invoked with the wrong number of arguments.
- Procedures that are invoked with the wrong type of arguments.
- Function return values that are the wrong type for the context in which they're used.

- Code blocks that are unreachable.
- Code blocks that have no effect.
- Local variables that are used before being initialized or assigned.
- Local variables that are initialized or assigned but not used.
- Procedures that are never invoked.
- Procedures that have no effect.
- Global variables that are used before being initialized or assigned.
- Global variables that are initialized or assigned, but not used.

► Not all compilers find the same defects.

► The more information a compilers has, the more defects it can find.

► Some compilers operate in "forgiving" mode but have "strict" or "pedantic" mode, if you request it.

```
1  #include <stdio.h>
2  int main (void)
3  {
4    printf ("Two plus two is %f\n", 4);
5    return 0;
6  }
```

```c
#include <stdio.h>
int main (void)
{
  printf ("Two plus two is %f\n", 4);
  return 0;
}
```
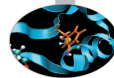
```
<ruggiero@shiva ~/CODICI>gcc bad.c
```

```
<ruggiero@shiva ~/CODICI>./a.out
```

```
Two plus two is 0.000000
```

```
<ruggiero@shiva ~/CODICI>gcc –Wall bad.c
```

```
bad.c: In function main:
bad.c:4: warning: format '%f' expects type 'double',
but argument 2 has type 'int'
```
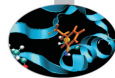
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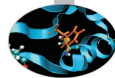
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-Wall

turns on the most commonly-used compiler warnings option

-Waddress -Warray-bounds (only with -O2) -Wc++0x-compat -Wchar-subscripts

-Wimplicit-int -Wimplicit-function-declaration -Wcomment -Wformat -Wmain (only for

C/ObjC and unless -ffreestanding) -Wmissing-braces -Wnonnull -Wparentheses

-Wpointer-sign -Wreorder -Wreturn-type -Wsequence-point -Wsign-compare (only in

C++) -Wstrict-aliasing -Wstrict-overflow=1 -Wswitch -Wtrigraphs -Wuninitialized

-Wunknown-pragmas -Wunused-function -Wunused-label -Wunused-value

-Wunused-variable -Wvolatile-register-var

```
[ruggiero@matrix1 ~]$ pgcc bad.c
```

```
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```
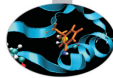
```
[ruggiero@matrix1 ~]$ icc bad.c
```

bad.c(4): warning #181: argument is incompatible
with corresponding format string conversion
    printf ("Two plus two is %f\n", 4);
                                    ^

```
1   #include <stdio.h>
2
3   int main (void)
4   {
5            return 0;
6   }
7   void checkVal(unsigned int n) {
8            if (n < 0) {
9                       /* Do something... */
10                     }
11              else if (n >= 0) {
12                       /* Do something else... */
13                     }
14  }
```

```
<ruggiero@shiva:~> gcc –Wall check.c
```

<ruggiero@shiva:~> gcc –Wall check.c

<ruggiero@shiva:~> gcc –Wall –Wextra check.c

check.c: In function ?checkVal?:
check.c:8: warning: comparison of unsigned expression < 0 is always false
check.c:11: warning: comparison of unsigned expression >= 0 is always true
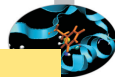
-Wextra (-W)
reports the most common programming errors and less-serious but potential problem

```
-Wclobbered -Wempty-body
-Wignored-qualifiers -Wmissing-field-initializers
-Wmissing-parameter-type (C only) -Wold-style-declaration (C only)
-Woverride-init -Wsign-compare
-Wtype-limits -Wuninitialized (only with -O1 and above)
-Wunused-parameter (only with -Wunused or -Wall)
```

```
1    #include <stdio.h>
2     int main (void)
3     {
4             double x = 10.0;
5             double y = 11.0;
6             double z = 0.0;
7             if (x == y) {
8                     z = x * y;
9             }
10              return 0;
11    }
```
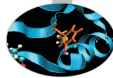
```
1   #include <stdio.h>
2    int main (void)
3    {
4           double x = 10.0;
5           double y = 11.0;
6           double z = 0.0;
7           if (x == y) {
8                       z = x * y;
9           }
10            return 0;
11   }
```

```
<ruggiero@shiva:~> gcc -Wall -Wextra  check1.c
```

```
<ruggiero@shiva:~> gcc -Wall -Wextra -Wfloat-equal check1.c
```

```
check1.c: In function main:
check1.c:8: warning: comparing  floating point
with == or != is unsafe
```

-Wno-div-by-zero -Wsystem-headers -Wfloat-equal -Wtraditional (C only)

-Wdeclaration-after-statement (C only) -Wundef -Wno-endif-labels -Wshadow

-Wlarger-than-len -Wpointer-arith -Wbad-function-cast (C only) -Wcast-align

-Wwrite-strings -Wconversion -Wsign-compare -Waggregate-return -Wstrict-prototypes

(C only) -Wold-style-definition (C only) -Wmissing-prototypes (C only)

-Wmissing-declarations (C only) -Wcast-qual -Wmissing-field-initializers

-Wmissing-noreturn -Wmissing-format-attribute -Wno-multichar

-Wno-deprecated-declarations -Wpacked -Wpadded -Wredundant-decls

-Wnested-externs (C only) -Wvariadic-macros -Wunreachable-code -Winline

-Wno-invalid-offsetof (C++ only) -Winvalid-pch -Wlong-long -Wdisabled-optimization

-Wno-pointer-sign

```c
int main() {
        int v[16];
        int i,j,k;
        j=i;
        v[i]= 42;
        return 0 ;
}
```

```
1  int main() {
2          int v[16];
3          int i,j,k;
4          j=i;
5          v[i]= 42;
6          return 0 ;
7  }
```

```
ruggiero@shiva:~> gcc -Wall -Wextra testinit.c
```

```
1  int main() {
2          int v[16];
3          int i,j,k;
4          j=i;
5          v[i]= 42;
6          return 0 ;
7  }
```

```
ruggiero@shiva:~> gcc –Wall –Wextra testinit.c
```

```
ruggiero@shiva:~> gcc –O1 –Wall –Wextra –Wuninitialized testinit.c
```

```
testinit.c: In function main
testinit.c:4: warning: unused variable k
testinit.c:5: warning: i is used uninitialized
in this function
```

```
1   int main() {
2           int v[16];
3           int i,j,k;
4           j=i;
5           v[i]= 42;
6           return 0 ;
7   }
```

```
ruggiero@shiva:~> gcc –Wall –Wextra testinit.c
```

```
ruggiero@shiva:~> gcc –O1 –Wall –Wextra –Wuninitialized testinit.c
```

testinit.c: In function main
testinit.c:4: warning: unused variable k
testinit.c:5: warning: i is used uninitialized
in this function

```
[ruggiero@matrix1 ~]$ icc testinit.c
```

testinit.c(5): warning #592: variable "i" is used
                before its value is set j=i;

```fortran
program par
implicit none
integer,parameter  :: hacca=10

call sub(hacca)

end

subroutine sub(hacca)
implicit none
integer hacca

hacca=hacca+1
write(*,*) hacca

return

end
```
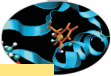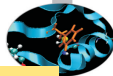
```
> xlf par.f -o par.x
```
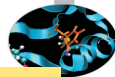
```
> ./par.x
```

11

```
> xlf par.f -o par.x
```

```
> ./par.x
```

11

```
<ruggiero@ife2 ~>ifort par.f -o par.x
```

Compilation: default options

```
> xlf par.f –o par.x
```

```
> ./par.x
```

11

```
<ruggiero@ife2 ~>ifort par.f –o par.x
```

```
<ruggiero@ife2 ~> ./par.x
```

```
forrtl: severe (174): SIGSEGV, segmentation fault occurred
Image              PC                 Routine      Line      Source
par.x              0000000000402688   Unknown      Unknown   Unknown
par.x              0000000000402670   Unknown      Unknown   Unknown
par.x              000000000040262A   Unknown      Unknown   Unknown
libc.so.6          00000036FF81C40B   Unknown      Unknown   Unknown
par.x              000000000040256A   Unknown      Unknown   Unknown
```

<ruggiero@ife2 ~> man ifort

? -assume noprotect_constants

Tells the compiler to pass a copy of a constant actual argument.
This copy can be modified by the called routine, even though
the Fortran standard prohibits such modification. The calling
routine does not see any modification to the constant. The default
is -assume protect_constants, which passes the constant actual
argument. Any attempt to modify it results in an error.

Compilation: default options

? -assume noprotect_constants

Tells the compiler to pass a copy of a constant actual argument. This copy can be modified by the called routine, even though the Fortran standard prohibits such modification. The calling routine does not see any modification to the constant. The default is -assume protect_constants, which passes the constant actual argument. Any attempt to modify it results in an error.

<ruggiero@ife2 ~>ifort par.f -assume noprotect_constants -o par.x

Compilation: default options

```
<ruggiero@ife2 ~> man ifort
```

? -assume noprotect_constants

Tells the compiler to pass a copy of a constant actual argument.
This copy can be modified by the called routine, even though
the Fortran standard prohibits such modification. The calling
routine does not see any modification to the constant. The default
is -assume protect_constants, which passes the constant actual
argument. Any attempt to modify it results in an error.

```
<ruggiero@ife2 ~>ifort par.f -assume noprotect_constants -o par.x
```

```
<ruggiero@ife2 ~>./par.x
```

- Open Source Static Analysis Tool developed at University of Virginia by Professor Dave Evans

- Based on Lint

- www.splint.org

- splint [-option -option ...] filename [filename ...]

- Unused declarations.
- Type inconsistencies.
- Variables used before being assigned.
- Function return values that are ignored.
- Execution paths with no return.
- Switch cases that fall through.
- Apparent infinite loops.

- Dereferencing pointers with possible null values.
- Using storage that is undefined or partly undefined.
- Returning storage that is undefined or partly defined.
- Type mismatches.
- Using deallocated storage.

- Memory leaks.
- Inconsistent modification of caller visible states.
- Violations of information hiding.
- Undefined program behaviour due to evaluation order, incomplete logic, infinite loops, statements with no effect, and so on.
- Problematic uses of macros.

```c
#include <stdio.h>
int main (void)
{
  printf ("Two plus two is %f\n", 4);
   return 0;
}
```

```
1   #include <stdio.h>
2
3   int main (void)
4   {
5           return 0;
6   }
7   void checkVal(unsigned int n) {
8           if (n < 0) {
9                   /* Do something... */
10                  }
11              else if (n >= 0) {
12                      /* Do something else... */
13                  }
14  }
```
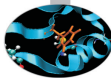
<ruggiero@shiva:~> splint-3.1.2/bin/splint bad.c

Finished checking --- no warnings

<ruggiero@shiva:~> splint-3.1.2/bin/splint bad.c

Finished checking --- no warnings

<ruggiero@shiva:~> splint-3.1.2/bin/splint check.c

splint 3.1.2 --- 28 Mar 2008
check.c: (in function checkVal)
check.c:8:15: Comparison of unsigned value involving zero: n < 0
 An unsigned value is used in a comparison with zero in a way that is
 a bug or confusing. (Use -unsignedcompare to inhibit warning)
check.c:11:22: Comparison of unsigned value involving zero: n >= 0
Finished checking --- 2 code warnings

```c
#include <stdio.h>
 int main (void)
 {
        double x = 10.0;
        double y = 11.0;
        double z = 0.0;
        if (x == y) {
                   z = x * y;
        }
          return 0;
 }
```

```
<ruggiero@shiva:~> gcc –Wall –Wextra  check1.c
```

```
<ruggiero@shiva:~> gcc –Wall –Wextra –Wfloat-equal check1.c
```

```
check1.c: In function main:
check1.c:8: warning: comparing  floating point
with == or != is unsafe
```

<ruggiero@shiva:~> splint-3.1.2/bin/splint check1.c

Splint 3.1.2 --- 28 Mar 2008

check1.c: (in function main)
check1.c:8:14: Dangerous equality comparison involving
double types: x == y Two real (float, double, or long double)
values are compared directly using == or != primitive. This
may produce unexpected results since floating point representations
are inexact. Instead, compare the difference to FLT_EPSILON
or DBL_EPSILON. (Use -realcompare to inhibit warning)

Finished checking --- 1 code warning
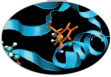
```
1    int main (void)
2      {
3            double x = 10.0;
4            double y = 11.0;
5            double z = 0.0;
6            double norma=0.1e-16;
7            double epsilon;
8          epsilon=x-y;
9          if (epsilon < norma) {
10                   z = x * y;
11         }
12
13            return 0;
14     }
```
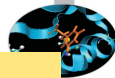
average.c: source

```c
#include <stdio.h>
int main (void) {
   int size = 5;
   int a;
   float total;
   float art[size];

 for(a = 0 ; a < size; ++ a) {
   art[a] = (float) a;
   total  += art[a]; }
  printf(" %f\n" , total / (float) size);
  return 0;
}
```

```
<ruggiero@shiva:~> gcc –Wall –Wextra average.c
```

```
<ruggiero@shiva:~> ./a.out
```

1.999994

average.c: compilation e run

```
<ruggiero@shiva:~> gcc –Wall –Wextra average.c
```

```
<ruggiero@shiva:~> ./a.out
```

1.999994

```
<ruggiero@shiva:~> gcc –Wall  –Wextra –O2 average.c
```

average.c: In function main:
average.c:5: warning: total may be used uninitialized
in this function

```
<ruggiero@shiva:~> ./a.out
```

nan

average.c: splint

Splint 3.1.2 --- 28 Mar 2008

average.c: (in function main)
average.c:10:4 Variable total used before definition
An rvalue is used that may not be initialized to a value
on some execution path. (Use -usedef to inhibit warning)
average.c:11:20: Variable total used before definition
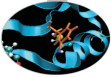
Finished checking --- 2 code warnings

```
1  #include <stdio.h>
2  int main (void) {
3    int size = 5;
4    int a;
5    float total;
6    float art[size];
7     total=0;
8   for(a = 0 ; a < size; ++ a) {
9     art[a] = (float) a;
10    total  += art[a]; }
11   printf(" %f\n" , total / (float) size);
12   return 0;
13 }
```

assign.c: source and compilation

```c
#include <stdio.h>
main()
{
        int a=0;
        while (a=1)
                printf("hello\n");
        return 0;
}
```

assign.c: source and compilation

```
1  #include <stdio.h>
2  main()
3  {
4        int a=0;
5        while (a=1)
6              printf("hello\n");
7        return 0;
8  }
```

```
<ruggiero@shiva:~> gcc -Wall -Wextra assign.c
```

```
assigna.c:3: warning: return type defaults to int
assign.c: In function main:
assign.c:5: warning: suggest parentheses around assignment used as
truth value
```
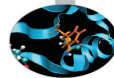
assign.c: splint

```
<ruggiero@shiva:~>splint-3.1.2/bin/splint assign.c
```

```
Splint 3.1.2 --- 28 Mar 2008
assign.c: (in function main)
assign.c:5:14: Test expression for while is assignment expression:a=1
The condition test is an assignment expression. Probably, you mean
to use == instead of =. If an assignment is intended, add an extra
parentheses nesting (e.g., if ((a = b)) ...) to suppress this message.
(Use -predassign to inhibit warning)
assign.c:5:14: Test expression for while not boolean, type int: a=1
Test expression type is not boolean or int. (Use -predboolint
to inhibit warning)
Finished checking --- 2 code warnings
```

```
1
2    #include <stdlib.h>
3    int main()
4    {
5            int *p = malloc(5*sizeof(int));
6
7
8
9            *p = 1;
10           free(p);
11           return 0;
12   }
```

memory.c: source and compilation

```c
#include <stdlib.h>
int main()
{
        int *p = malloc(5*sizeof(int));



        *p = 1;
        free(p);
        return 0;
}
```

```
<ruggiero@shiva:~> gcc -Wall -Wextra memory.c
```

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SuperComputing Applications and Innovation

<ruggiero@shiva:~> splint-3.1.2/bin/splint memory.c
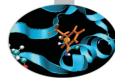
Splint 3.1.2 --- 28 Mar 2008

memory.c: (in function main)
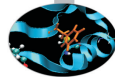memory.c:9:10: Dereference of possibly null pointer p: *p
A possibly null pointer is dereferenced. Value is either
the result of a function which may return null (in which
case, code should check it is not null), or a global,
parameter or structure field declared with the null
qualifier. (Use -nullderef to inhibit warning)
memory.c:5:18: Storage p may become null

Finished checking --- 1 code warning
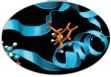
```
1   #include <stdlib.h>
2   #include <stdio.h>
3   int main()
4   {
5           int *p = malloc(5*sizeof(int));
6           if (p == NULL) {
7                   fprintf(stderr, "error in malloc");
8                   exit(EXIT_FAILURE);
9           } else  *p = 1;
10          free(p);
11          return 0;
12  }
```

```c
#include <stdio.h>
#define N 5
int main (void)
{
        int t[N];
        int i;

        i=6;
        t[i] = i+1;

        return 0;
}
```

```
<ruggiero@shiva:~> splint-3.1.2/bin/splint out_b.c
```

<ruggiero@shiva:~> splint-3.1.2/bin/splint out_b.c

<ruggiero@shiva:~> splint-3.1.2/bin/splint +bounds out_b.c

Splint 3.1.2 --- 28 Mar 2008

out_b.c: (in function main)
out_b.c:9:9: Likely out-of-bounds store: t[i]
    Unable to resolve constraint:
    requires 4 >= 6
     needed to satisfy precondition:
    requires maxSet(t @ out_b.c:9:9) >= i @ out_b.c:9:11
  A memory write may write to an address beyond the allocated buffer. (Use
  -likelyboundswrite to inhibit warning)

Finished checking --- 1 code warning
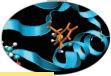
```
1            REAL FUNCTION COMPAV(SCORE,COUNT)
2                INTEGER SUM,COUNT,J,SCORE(5)
3                DO 30 I = 1,COUNT
4                    SUM = SUM + SCORE(I)
5    30          CONTINUE
6                COMPAV = SUM/COUNT
7                write(*,*) compav
8            END
9            PROGRAM AVENUM
10             PARAMETER(MAXNOS=10)
11             INTEGER I, COUNT
12             REAL NUMS(MAXNOS), AVG
13             COUNT = 0
14             DO 80 I = 1,MAXNOS
15                 READ (5,*,END=100) NUMS(I)
16                 COUNT = COUNT + 1
17   80          CONTINUE
18   100         AVG = COMPAV(NUMS, COUNT)
19           END
```

`<ruggiero@ife2 /ftnchek>gfortran –Wall –Wextra –O2 error.f`

In file error.f:2

        INTEGER SUM,COUNT,J,SCORE(5)
                         1
CWarning: Unused variable j declared at (1)
error.f: In function compav:
error.f:2: warning: sum may be used uninitialized in this function

error.f: compilation

```
<ruggiero@ife2/ftnchek>pgf90 -Minform=inform error.f
```

PGF90-I-0035-Predefined intrinsic sum loses intrinsic property (error.f: 5)
PGF90-I-0035-Predefined intrinsic count loses intrinsic property (error.f: 16)

`<ruggiero@ife2 /ftnchek>ifort -warn all error.f`

```
fortcom: Warning: error.f, line 4: This name has not been given an explicit type.   [I]
          DO 30 I = 1,COUNT
------------------^
fortcom: Info: error.f, line 2: This variable has not been used.    [J]
          INTEGER SUM,COUNT,J,SCORE(5)
------------------------------^
fortcom: Warning: error.f, line 13: This name has not been given an explicit type.   [MAXNOS]
        PARAMETER(MAXNOS=10)
--------------------^
fortcom: Warning: error.f, line 21: This name has not been given an explicit type.   [COMPAV]
100       AVG = COMPAV(NUMS, COUNT)
------------------^
```

```
<ruggiero@ife2 /ftnchek>g95 –Wall –Wextra error.f
```

```
In file error.f:6

 30           CONTINUE
                  1
Warning (142): Nonblock DO statement at (1) is obsolescent
In file error.f:1

     REAL FUNCTION COMPAV(SCORE,COUNT)
                          1
Warning (163): Actual argument 'score' at (1) does not have an INTENT
In file error.f:1

     REAL FUNCTION COMPAV(SCORE,COUNT)
                                1
Warning (163): Actual argument 'count' at (1) does not have an INTENT
In file error.f:2

        INTEGER SUM,COUNT,J,SCORE(5)
                          1
Warning (137): Variable 'j' at (1) is never used and never set
```

```
In file error.f:20

80          CONTINUE
                    1
Warning (142): Nonblock DO statement at (1) is obsolescent
In file error.f:21

100          AVG = COMPAV(NUMS, COUNT)
                  1
Warning (165): Implicit interface 'compav' called at (1)
In file error.f:15

          REAL NUMS(MAXNOS), AVG
                            1
Warning (112): Variable 'avg' at (1) is set but never used
In file error.f:21

100          AVG = COMPAV(NUMS, COUNT)
                            1
In file error.f:1

     REAL FUNCTION COMPAV(SCORE,COUNT)
                            2
Warning (155): Inconsistent types (REAL(4)/INTEGER(4))
in actual argument lists at (1) and (2)
```
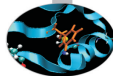
<ruggiero@ife2/ftnchek>./bin/ftnchek error.f

```
FTNCHEK Version 3.3 November 2004

File error.f:
      7                  COMPAV = SUM/COUNT
                                ^
Warning near line 7 col 21 file error.f:
 integer quotient expr SUM/COUNT  converted to real

Warning in module COMPAV in file error.f:
 Variables declared but never referenced:
    J declared at line 2 file error.f

Warning in module COMPAV in file error.f:
 Variables may be used before set:
    SUM used at line 5 file error.f
    SUM set at line 5 file error.f

Warning in module AVENUM in file error.f:
 Variables set but never used:
    AVG set at line 21 file error.f
```

```
 0 syntax errors detected in file error.f
 4 warnings issued in file error.f

Warning: Subprogram COMPAV argument data type mismatch at position 1:
    Dummy arg SCORE in module COMPAV line 1 file
 error.f is type intg
    Actual arg NUMS in module AVENUM line 21 file
 error.f is type real

Warning: Subprogram COMPAV argument arrayness mismatch at position 1:
    Dummy arg SCORE in module COMPAV line 1 file
 error.f has 1 dim size 5
    Actual arg NUMS in module AVENUM line 21 file
 error.f has 1 dim size 10
```
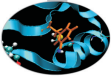
- Forcheck can handle up Fortran 95 and some Fortran 2003. item Cleanscape FortranLint can handle up to Fortran 95.
- plusFORT is a multi-purpose suite of tools for analyzing and improving Fortran programs.
- ...

Static analyzer: errors and warnings

- ▶ 40% false positive reports of correct code.
- ▶ 40% multiple occurence of same problem.
- ▶ 10% minor or cosmetic problems.
- ▶ 10% serious bugs, very hard to find by other methods.

From **"The Developer's Guide to Debugging"** T. Grotker, U. Holtmann, H. Keding, M. Wloka

Static analyzer: Lessons learned

- ▶ Do not ignore compiler warnings, even if they appear to be harmless.
- ▶ Use multiple compilers to check the code.
- ▶ Familiarize yourself with a static checker.
- ▶ Reduce static checker errors to (almost) zero.
- ▶ Rerun all test cases after a code cleanup.
- ▶ Doing regular sweeps of the source code will pay off in long term.

From **"The Developer's Guide to Debugging"** T. Grotker, U. Holtmann, H. Keding, M. Wloka

Bugs, Prevention and Testing

Static analysis

Run-time analysis
    Memory checker

Debugging

Conclusions

- When a job terminates abnormally, it usually tries to send a signal (exit code) indicating what went wrong.
- The exit code from a job is a standard OS termination status.
- Typically, exit code 0 (zero) means successful completion.
- Your job itself calling exit() with a non-zero value to terminate itself and indicate an error.
- The specific meaning of the signal numbers is platform-dependent.
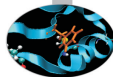
You can find out why the job was killed using:

```
[ruggiero@matrix1 ~]$ kill -l
```

```
 1) SIGHUP   2) SIGINT   3) SIGQUIT   4) SIGILL
 5) SIGTRAP  6) SIGABRT  7) SIGBUS    8) SIGFPE
 9) SIGKILL 10) SIGUSR1 11) SIGSEGV  12) SIGUSR2
13) SIGPIPE 14) SIGALRM 15) SIGTERM  16) SIGSTKFLT
17) SIGCHLD 18) SIGCONT 19) SIGSTOP  20) SIGTSTP
21) SIGTTIN 22) SIGTTOU 23) SIGURG   24) SIGXCPU
25) SIGXFSZ 26) SIGVTALRM 27) SIGPROF 28) SIGWINCH
29) SIGIO 30) SIGPWR 31) SIGSYS 34) SIGRTMIN
....
```

Runtime signals

To find out what all the "kill -l" words mean:

```
[ruggiero@matrix1 ~]$ man 7 signal
```

```
.....
Signal      Value      Action     Comment
--------------------------------------------------------------------------
SIGHUP       1         Term       Hangup detected on controlling terminal
                                  or death of controlling process
SIGINT       2         Term       Interrupt from keyboard
SIGQUIT      3         Core       Quit from keyboard
SIGILL       4         Core       Illegal Instruction
SIGABRT      6         Core       Abort signal from abort(3)
......
```
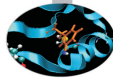
Term   Default action is to terminate the process.
Ign   Default action is to ignore the signal.
Core   Default action is to terminate the process and dump the core.
Stop   Default action is to stop the process.
Cont   Default action is to continue the process if is currently stopped.

Common runtime signals

Signal name	OS signal name	Description
Floating point exception	SIGFPE	The program attempted an arithmetic operation with values that do not make sense
Segmentation fault	SIGSEGV	The program accessed memory incorrectly
Aborted	SIGABRT	Generated by the runtime library of the program or a library it uses, after having detecting a failure condition.

```
1   main()
2   {
3       int a = 1.;
4       int b = 0.;
5       int c = a/b;
6   }
```
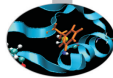
```
1  main()
2  {
3     int a = 1.;
4     int b = 0.;
5     int c = a/b;
6  }
```

```
[ruggiero@matrix1 ~]$ gcc fpe_example.c
```

```
[ruggiero@matrix1 ~]$ ./a.out
```

```
Floating exception
```

```
1  main()
2  {
3  int array[5]; int i;
4      for(i = 0; i < 255; i++) {
5          array[i] = 10;}
6      return 0;
7  }
```

SEGV example

```
1  main()
2  {
3  int array[5]; int i;
4      for(i = 0; i < 255; i++) {
5          array[i] = 10;}
6      return 0;
7  }
```

```
[ruggiero@matrix1 ~]$ gcc segv_example.c
```

```
[ruggiero@matrix1 ~]$ ./a.out
```

```
Segmentation fault
```

```
1  #include <assert.h>
2  main()
3  {
4     int i=0;
5     assert(i!=0);
6  }
```

```
1  #include <assert.h>
2  main()
3  {
4     int i=0;
5     assert(i!=0);
6  }
```

```
[ruggiero@matrix1 ~]$ gcc abort_example.c
```

```
[ruggiero@matrix1 ~]$ ./a.out
```

```
a.out: abort_example.c:5: main: Assertion 'i!=0' failed.
Abort
```

- Allocation Deallocation errors (AD).
- Array conformance errors (AC).
- Array Index out of Bound (AIOB).
- Language specific errors (LS).
- Floating Point errors (FP).
- Input Output errors (IO).
- Memory leaks (ML).
- Pointer errors (PE).
- String errors (SE).
- Subprogram call errors (SCE).
- Uninitialized Variables (UV).

- Iowa State University's High Performance Computing Group

- Run Time Error Detection Test Suites for Fortran, C, and C++

- http://rted.public.iastate.edu

- ▶ 0.0: is given when the error was not detected.
- ▶ 1.0: is given for error messages with the correct error name.
- ▶ 2.0: is given for error messages with the correct error name and line number where the error occurred but not the file name where the error occurred.
- ▶ 3.0: is given for error messages with the correct error name, line number and the name of the file where the error occurred.
- ▶ 4.0: s given for error messages which contain the information for a score of 3.0 but less information than needed for a score of 5.0 .
- ▶ 5.0: is given in all cases when the error message contains all the information needed for the quick fixing of the error.
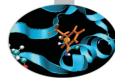
Grading Methodology : an example

```
!*****************************************************************************
!  copyright (c) 2005 Iowa State University, Glenn Luecke, James Coyle,
!  James Hoekstra, Marina Kraeva, Olga Taborskaia, Andre Wehe, Ying Xu,
!  and Ziyu Zhang, All rights reserved.
!  Licensed under the Educational Community License version 1.0.
!  See the full agreement at http://rted.public.iastate.edu/ .
!*****************************************************************************
!*****************************************************************************
!
!       Name of the test:  F_H_1_1_b.f90
!
!       Summary:           allocation/deallocation error
!
!       Test description:  deallocation twice
!                          for allocatable array in a subroutine
!                          contains in a main program
!
!       Support files:     Not needed
!
!       Env. requirements: Not needed
!
!       Keywords:          deallocation error
!                          subroutine contains in a main program
```
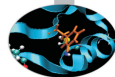
Grading Methodology: an example

```fortran
!
!       Last modified:      1/17/2005
!
!       Programmer:         Ying Xu, Iowa State Univ.
!*************************************************************************

program tests
   implicit none
   integer :: n=10, m=20
   double precision :: var

   call sub(n,m,var)
   print *,var
   contains
     subroutine sub(n,m,var)
       integer, intent(in) :: n,m
       double precision, intent(inout) :: var
       double precision, allocatable :: arr(:,:)    ! DECLARE
```

```fortran
      integer :: i,j
      allocate(arr(1:n,1:m))
      do i=1,n
          do j=1,m
              arr(i,j) = dble(i*j)
          enddo
      end do
      var = arr(n,m)
      deallocate(arr)
      deallocate(arr)    ! deallocate second time here. ERROR
      return
    end subroutine sub
end program tests
```

Real message (grade 1.0)

Fortran runtime error: Internal: Attempt to DEALLOCATE
unallocated memory.

Ideal message (grade 5.0)

ERROR: unallocated array
At line 52 column 17 of subprogram 'sub'
in file 'F_H_1_1_b.f90', the argument
'arr' in the DEALLOCATE statement is an
unallocated array. The variable is declared
in line 41 in subprogram 'sub' in file 'F_H_1_1_b.f90'.

Fortran Results

Compiler	AC	A D	AIOB	LS	FP	IO
gcc-4.3.2	1	0.981481	3.40025	2.88235	0	2.33333
gcc-4.3.2	1	1.38889	3.40025	2.88235	0	2.33333
gcc-4.4.3	1	1.38889	3.40025	2.88235	0	2.33333
gcc-4.6.3	1	1.27778	0.969504	0.94117	0	2.33333
gcc-4.7.0	1	1.38889	0.969504	0.94117	0.714286	2.33333
gcc-4.8.2	1	1.38889	0.969504	0.94117	0.142857	2.33333
gcc-4.9.2	1	1.42593	0.969504	0.94117	0.142857	2.33333
g95.4.0.3	0.421053	1.22222	3.60864	3.82353	0.571428	2.66667
intel-10.1.021	0.421053	1.42593	3.45362	2.82353	0.571428	2.11111
intel-11.0.074	0.421053	1.68519	3.446	2.82353	0.571428	2.11111
intel-11.1	1	1.90741	3.47649	2.88235	1.42857	2.33333
intel-12.0.2	0.421053	1.62963	3.44727	2.82353	0.571428	2.11111
intel-14.0.1	0.421053	1.62963	3.44854	2.82353	0.571428	2.11111
intel-15.0.2	0.421053	1.62963	3.44854	2.82353	2.85714	2.11111
open64.4.2.3	3	0.888889	2.63405	3	0	1
pgi-7.2-5	0.421053	0.388889	3.8526	3.82353	0	2.44444
pgi-8.0-1	0.421053	0.388889	3.8526	3.82353	0	2.44444
pgi-10.3	0.421053	0.388889	3.8526	3.82353	0	2.44444
pgi-11.8	0.421053	0.388889	3.8526	3.82353	0	2.44444
pgi-12.8	1	1	3.8831	3.82353	1	2.61111
pgi-13.10	1	1	3.8831	3.82353	1	2.72222
pgi-14.1.0	0.421053	0.5	3.8526	3.82353	0	2.61111
pgi-14.10.0	0.421053	0.5	3.8526	3.82353	0	2.61111
pgi-16.3	0.421053	0.5	3.8526	3.82353	0	2.61111
sun.12.1	3	2.77778	3.00381	3	2	2.16667
sun.12.1+bcheck	3	2.77778	3.03431	3	0.285714	2.16667

Fortran Results

Compiler	ML	PE	SE	SCE	UV
gcc-4.3.2	0	3.49609	3.25	0	0.0159236
gcc-4.3.2	0	3.49609	3.25	0	0.0286624
gcc-4.4.3	0	3.49609	3.25	0	0.0286624
gcc-4.6.3	0	1	3.25	0.166667	0.22293
gcc-4.7.0	0	1	3.25	0.166667	0.130573
gcc-4.8.2	0	1	3.25	0.166667	0.0955414
gcc-4.9.2	0	1	3.25	0.166667	0.0955414
g95.4.0.3	1	3	3.43333	0	0.0159236
intel-10.1.021	0	3.5625	0	0.166667	0.286624
intel-11.0.074	0	3.55469	0	0.166667	0.299363
intel-11.1	1	3.55469	1	1	1.07643
intel-12.0.2	0	3.55469	0	0.166667	0.292994
intel-14.0.1	0	3.55469	0	0.166667	0.292994
intel-15.0.2	0	3.55469	0	0.166667	0.286624
open64.4.2.3	0	3.3625	0	0.0833333	0.286624
pgi-7.2-5	0	4	0	0	0.022293
pgi-8.0-1	0	4	0	0	0.022293
pgi-10.3	0	4	0	0	0.0254777
pgi-11.8	0	4	0	0	0.0127389
pgi-12.8	1	4	1	1	1
pgi-13.10	1	4	1	1	1
pgi-14.1.0	0	4	0	0	0.143312
pgi-14.10.0	0	4	0	0	0.0127389
pgi-16.3	0	4	0	0	0.136943
sun.12.1	0	3.03125	3	0	0.022293
sun.12.1+bcheck	1.25	3.03125	3	1	0.640127

C Results

Compiler	AD	AIoB	LS	FP	IO
gcc-4.3.2	0.44	0.00925926	0.0416667	0.2	0.0666667
gcc-4.4.3	0.44	0.00925926	0.0416667	0.2	0.0666667
gcc-4.6.3	0.44	0.00925926	0.0416667	0.2	0.2
gcc-4.7.0	0.44	0.00925926	0.0416667	0.2	0.2
gcc-4.8.2	0.4	0.00925926	0.0416667	0	0.2
gcc-4.9.2	0.4	0.00925926	0.0416667	0	0.2
intel-10.1.021	0.52	0.00925926	0.0416667	0	0.2
intel-11.0.074	0.52	0.00925926	0.0416667	0	0.2
intel-11.1	0.68	1	1	1	1
intel-12.0.2	0.44	0.00925926	0.0416667	0	0.2
intel-14.0.1	0.4	0.00925926	0.0416667	0	0.2
intel-15.0.2	0.4	0.00925926	0.0416667	0	0.2
open64-4.2.3	0.52	0.00925926	0.0416667	0	0.2
pgi-7.2-5	0.44	0.00925926	0.0416667	0	0.2
pgi-8.0-1	0.44	0.00925926	0.0416667	0	0.2
pgi-10.3	0.44	0.00925926	0.0416667	0	0.2
pgi-11.8	0.44	0.00925926	0.0416667	0	0.2
pgi-12.8	0.68	2.40741	2.16667	0	1
pgi-13.10	0.68	2.40741	2.16667	0	1
pgi-14.1-0	0.48	1.93519	1.625	0	0.2
pgi-14.10-0	0.44	1.93519	1.625	0	0.3
pgi-16.3	0.44	0.00925926	0.0416667	0	0.2
sun-12.1	0.44	0.00925926	0	0	0.2
sun-12.1+bcheck	0.16	0	0	0	0
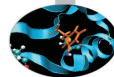
Compiler	ML	PE	SE	SCE	UV
gcc-4.3.2	0.0166667	0.0166667	0.05	0	0
gcc-4.4.3	0.0166667	0.0166667	0.05	0	0
gcc-4.6.3	0.0166667	0.0166667	0.05	0	0
gcc-4.7.0	0.0166667	0.0166667	0.05	0	0
gcc-4.8.2	0.0166667	0.0166667	0.075	0	0
gcc-4.9.2	0.0166667	0.0166667	0.075	0	0
intel-10.1.021	0.0666667	0.0166667	0.05	0	0
intel-11.0.074	0.0666667	0.0166667	0.05	0	0
intel-11.1	1	1	1	1	1
intel-12.0.2	0.0666667	0.0166667	0.05	0	0
intel-14.0.1	0.133333	0.0166667	0.05	0	0
intel-15.0.2	0.0166667	0.0166667	0.075	0	0
open64-4.2.3	0.0666667	0.0166667	0.05	0	0
pgi-7.2-5	0.0666667	0.0166667	0.05	0	0
pgi-8.0-1	0.0666667	0.0166667	0.05	0	0
pgi-10.3	0.0666667	0.0166667	0.05	0	0
pgi-11.8	0.0666667	0.0166667	0.05	0	0
pgi-12.8	1	1	1	1	1
pgi-13.10	1	1	1	1	1
pgi-14.1-0	0.133333	0.0166667	0.05	0	0
pgi-14.10-0	0.0666667	0.0166667	0.05	0	0
pgi-16.3	0.0666667	0.0166667	0.075	0	0
sun-12.1	0.0666667	0.0166667	0.05	0	0
sun-12.1+bcheck	1.13333	0.025	0	0	0

C++ Results
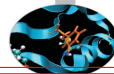
Compiler	AD	AIoB	FP	IO	ML	PE	SE	UV
gcc-4.3.2	0.44	0.00925926	0	0	0.0666667	0.0166667	0.05	0
gcc-4.4.3	0.44	0.00925926	0	0	0.0666667	0.0166667	0.05	0
gcc-4.6.3	0.44	0.00925926	0	0.2	0.0666667	0.0166667	0.05	0
gcc-4.7.0	0.44	0.00925926	0	0.2	0.0666667	0.0166667	0.05	0
gcc-4.8.2	0.4	0.00925926	0	0.2	0.0666667	0.0166667	0.075	0
gcc-4.9.2	0.4	0.00925926	0	0.2	0.0666667	0.0166667	0.075	0
intel-10.1.021	0.330275	0.00903614	0	0.0714286	0.047619	0.0254777	0.05	0
intel-11.0.074	0.330275	0.00903614	0	0.0714286	0.047619	0.0254777	0.05	0
intel-11.1	0.926606	1	1	1	1	1	1	1
intel-12.0.2	0.311927	0.00903614	0	0.0714286	0.047619	0.0254777	0.05	0
intel-14.1.0	0.4	0.00925926	0	0.2	0.133333	0.0166667	0.05	0
intel-15.0.2	0.4	0.00925926	0	0.2	0.0666667	0.0166667	0.075	0
open64-4.2.3	0.330275	0.00903614	0	0	0.047619	0.0254777	0.05	0
pgi-7.2.5	0.311927	0.00903614	0	0.0714286	0.047619	0.0254777	0.05	0
pgi-8.0.1	0.311927	0.00903614	0	0.0714286	0.047619	0.0254777	0.05	0
pgi-10.3	0.311927	0.00903614	0	0.0714286	0.047619	0.0254777	0.05	0
pgi-11.8	0.311927	0.00903614	0	0.0714286	0.047619	0.0254777	0.05	0
pgi-12.8	0.926606	2.23795	1	1	1	1	1	1
pgi-13.1	0.926606	2.23494	1	1	1	1	1	1
pgi-14.1-0	0.321101	1.69277	0	0.0714286	0.0714285	0.0254777	0.05	0
pgi-14.10-0	0.321101	1.69277	0	0.107143	0.047619	0.0254777	0.05	0
pgi-16.3	0.44	0.00925926	0	0.2	0.0666667	0.0166667	0.075	0
sun-12.1	0.311927	0.00903614	0	0	0.047619	0.0254777	0.05	0
sun-12.1+bcheck	0.247706	0.0150602	0	0	1.16667	0.0191083	0	0

Grading Methodology: Used options
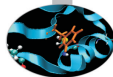
Fortran

gcc	-frange-check -O0 -fbounds-check -g -ffpe-trap=invalid,zero,overflow -fdiagnostics-show-location=every-line
g95	-O0 -fbounds-check -g -ftrace=full
intel	-O0 -C -g -traceback -ftrapuv -check
open64	-C -g -O0
pgi	-C -g -Mchkptr -O0
sun	-g -C -O0 -xs -ftrap=%all -fnonstd -xcheck=%all

C

gcc	-O0 -g -fbounds-check -ftrapv
intel	-O0 -C -g -traceback
open64	-g -C -O0
pgi	-g -C -Mchkptr -O0
sun	-g -C -O0 -xs -ftrap=%all -fnonstd -xcheck=%all

C++

gcc	-O0 -g -fbounds-check -ftrapv
intel	-O0 -C -g -traceback
open64	-g -C -O0
pgi	-g -C -Mchkptr -O0
sun	-g -C -O0 -xs -ftrap=%all -fnonstd -xcheck=%all

Bugs, Prevention and Testing

Static analysis

Run-time analysis
    Memory checker

Debugging

Conclusions

Fixing memory problems
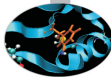
- ▶ **Memory leaks** are data structures that are allocated at runtime, but not deallocated once they are no longer needed in the program.
- ▶ **Incorrect use of the memory management** is associated with incorrect calls to the memory management: freeing a block of memory more than once, accessing memory after freeing...
- ▶ **Buffer overruns** are bugs where memory outside of the allocated boundaries is overwritten, or corrupted.
- ▶ **Uninitialized memory bugs**: reading uninitialized memory.

- Open Source Software, available on Linux for x86 and PowerPc processors.
- Interprets the object code, not needed to modify object files or executable, non require special compiler flags, recompiling, or relinking the program.
- Command is simply added at the shell command line.
- No program source is required (black-box analysis).

www.valgrind.org

- Memcheck: a memory checker.
- Callgrind: a runtime profiler.
- Cachegrind: a cache profiler.
- Helgrind: find race conditions.
- Massif: a memory profiler.

- Valgrind will tell you about tough to find bugs.
- Valgrind is very thorough.
- You may be tempted to think that Valgrind is too picky, since your program may seem to work even when valgrind complains. It is users' experience that fixing ALL Valgrind complaints will save you time in the long run.

  But...

- Valgrind will tell you about tough to find bugs.
- Valgrind is very thorough.
- You may be tempted to think that Valgrind is too picky, since your program may seem to work even when valgrind complains. It is users' experience that fixing ALL Valgrind complaints will save you time in the long run.

But...
Valgrind is kind-of like a virtual x86 interpeter.
So your program will run 10 to 30 times slower than normal.
Valgrind won't check static arrays.

- ▶ Local Variables that have not been initialized.
- ▶ The contents of malloc's blocks, before writing there.

- Local Variables that have not been initialized.
- The contents of malloc's blocks, before writing there.

```c
#include <stdlib.h>
int main()
{
    int p,t,b[10];
    if(p==5)
        t=p+1;
        b[p]=100;
    return 0;
}
```

▶ Local Variables that have not been initialized.

▶ The contents of malloc's blocks, before writing there.

```
1  #include <stdlib.h>
2  int main()
3  {
4        int p,t,b[10];
5        if(p==5)        ERROR
6            t=p+1;
7            b[p]=100;  ERROR
8        return 0;
9  }
```
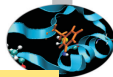
```
ruggiero@shiva:> valgrind --tool=memcheck --leak-check=full ./t1
```

```
ruggiero@shiva:> valgrind --tool=memcheck --leak-check=full ./t1
```

```
==7879== Memcheck, a memory error detector.
            ....
==7879== Conditional jump or move depends on uninitialised value(s)
==7879==    at 0x8048399: main (test1.c:5)
==7879==
==7879== Use of uninitialised value of size 4
==7879==    at 0x80483A7: main (test1.c:7)
==7879==
==7879== Invalid write of size 4
==7879==    at 0x80483A7: main (test1.c:7)
==7879==  Address 0xCEF8FE44 is not stack'd, malloc'd or (recently) free'd
==7879==
==7879== Process terminating with default action of signal 11 (SIGSEGV)
==7879==  Access not within mapped region at address 0xCEF8FE44
==7879==    at 0x80483A7: main (test1.c:7)
==7879==
==7879== ERROR SUMMARY: 3 errors from 3 contexts (suppressed: 3 from 1)
==7879== malloc/free: in use at exit: 0 bytes in 0 blocks.
==7879== malloc/free: 0 allocs, 0 frees, 0 bytes allocated.
==7879== For counts of detected errors, rerun with: -v
==7879== All heap blocks were freed -- no leaks are possible.
Segmentation fault
```

```
1   #include <stdlib.h>
2   int main()
3   {
4        int *p,i,a;
5        p=malloc(10*sizeof(int));
6            p[11]=1;
7            a=p[11];
8            free(p);
9        return 0;
10  }
```

```
1   #include <stdlib.h>
2   int main()
3   {
4         int *p,i,a;
5         p=malloc(10*sizeof(int));
6             p[11]=1;  ERROR
7             a=p[11];  ERROR
8             free(p);
9         return 0;
10  }
```

Illegal read/write: Valgrind output

```
ruggiero@shiva:> valgrind --tool=memcheck --leak-check=full ./t2
```
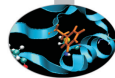
```
        .....
==8081== Invalid write of size 4
==8081==    at 0x804840A: main (test2.c:6)
==8081==  Address 0x417B054 is 4 bytes after a block of size 40 alloc'd
==8081==    at 0x40235B5: malloc (in /usr/lib/valgrind/x86-linux/vgpreload_memcheck.so)
==8081==    by 0x8048400: main (test2.c:5)
==8081==
==8081== Invalid read of size 4
==8081==    at 0x8048416: main (test2.c:7)
==8081==  Address 0x417B054 is 4 bytes after a block of size 40 alloc'd
==8081==    at 0x40235B5: malloc (in /usr/lib/valgrind/x86-linux/vgpreload_memcheck.so)
==8081==    by 0x8048400: main (test2.c:5)
==8081==
==8081== ERROR SUMMARY: 2 errors from 2 contexts (suppressed: 3 from 1)
==8081== malloc/free: in use at exit: 0 bytes in 0 blocks.
==8081== malloc/free: 1 allocs, 1 frees, 40 bytes allocated.
==8081== For counts of detected errors, rerun with: -v
==8081== All heap blocks were freed -- no leaks are possible.
```
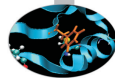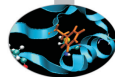
```
1  #include <stdlib.h>
2  int main()
3  {
4       int *p,i;
5       p=malloc(10*sizeof(int));
6           for(i=0;i<10;i++)
7               p[i]=i;
8           free(p);
9           free(p);
10      return 0;
11 }
```

```
1   #include <stdlib.h>
2   int main()
3   {
4       int *p,i;
5       p=malloc(10*sizeof(int));
6           for(i=0;i<10;i++)
7               p[i]=i;
8           free(p);
9           free(p);      ERROR
10      return 0;
11  }
```

```
ruggiero@shiva:> valgrind --tool=memcheck --leak-check=full ./t3
```

```
        .....
==8208== Invalid free() / delete / delete[]
==8208==    at 0x40231CF: free (in /usr/lib/valgrind/x86-linux/vgpreload_memcheck.so)
==8208==    by 0x804843C: main (test3.c:9)
==8208==  Address 0x417B028 is 0 bytes inside a block of size 40 free'd
==8208==    at 0x40231CF: free (in /usr/lib/valgrind/x86-linux/vgpreload_memcheck.so)
==8208==    by 0x8048431: main (test3.c:8)
==8208==
==8208== ERROR SUMMARY: 1 errors from 1 contexts (suppressed: 3 from 1)
==8208== malloc/free: in use at exit: 0 bytes in 0 blocks.
==8208== malloc/free: 1 allocs, 2 frees, 40 bytes allocated.
==8208== For counts of detected errors, rerun with: -v
==8208== All heap blocks were freed -- no leaks are possible.
```

- If allocated with **malloc**,**calloc**,**realloc**,**valloc** or **memalign**, you must deallocate with **free**.
- If allocated with **new[]**, you must dealloacate with **delete[]**.
- If allocated with **new**, you must deallocate with **delete**.

- ▶ If allocated with **malloc**,**calloc**,**realloc**,**valloc** or **memalign**, you must deallocate with **free**.
- ▶ If allocated with **new[]**, you must dealloacate with **delete[]**.
- ▶ If allocated with **new**, you must deallocate with **delete**.

```
1  #include <stdlib.h>
2  int main()
3  {
4       int *p,i;
5       p=(int*)malloc(10*sizeof(int));
6           for(i=0;i<10;i++)
7               p[i]=i;
8           delete(p);
9       return 0;
10 }
```

- ▶ If allocated with **malloc**,**calloc**,**realloc**,**valloc** or **memalign**, you must deallocate with **free**.
- ▶ If allocated with **new[]**, you must dealloacate with **delete[]**.
- ▶ If allocated with **new**, you must deallocate with **delete**.

```
#include <stdlib.h>
int main()
{
    int *p,i;
    p=(int*)malloc(10*sizeof(int));
        for(i=0;i<10;i++)
            p[i]=i;
        delete(p);    ERROR
    return 0;
}
```

```
ruggiero@shiva:> valgrind --tool=memcheck --leak-check=full ./t4
```

```
         .....
==8330== Mismatched free() / delete / delete []
==8330== at 0x4022EE6: operator delete(void*) (in /usr/lib/valgrind/x86-linux/vgpreload_memch
==8330==by 0x80484F1: main (test4.c:8)
==8330==Address 0x4292028 is 0 bytes inside a block of size 40 alloc'd
==8330==at 0x40235B5: malloc (in /usr/lib/valgrind/x86-linux/vgpreload_memcheck.so)
==8330==by 0x80484C0: main (test4.c:5)
==8330==
==8330==ERROR SUMMARY: 1 errors from 1 contexts (suppressed: 3 from 1)
==8330==malloc/free: in use at exit: 0 bytes in 0 blocks.
==8330==malloc/free: 1 allocs, 1 frees, 40 bytes allocated.
==8330==For counts of detected errors, rerun with: -v
==8330==All heap blocks were freed -- no leaks are possible.
```

```
1   #include <stdlib.h>
2   #include <unistd.h>
3   int main()
4   {
5        int *p;
6       p=malloc(10);
7        read(0,p,100);
8           free(p);
9       return 0;
10  }
```

```
1  #include <stdlib.h>
2  #include <unistd.h>
3  int main()
4  {
5       int *p;
6      p=malloc(10);
7       read(0,p,100); ERROR
8          free(p);
9      return 0;
10 }
```

```
ruggiero@shiva:> valgrind --tool=memcheck --leak-check=full ./t5
```

```
...
==18007== Syscall param read(buf) points to unaddressable byte(s)
==18007==    at 0x4EEC240: __read_nocancel (in /lib64/libc-2.5.so)
==18007==    by 0x40056F: main (test5.c:7)
==18007==  Address 0x517d04a is 0 bytes after a block of size 10 alloc'd
==18007==    at 0x4C21168: malloc (vg_replace_malloc.c:236)
==18007==    by 0x400555: main (test5.c:6)
...
```

```
1  #include <stdlib.h>
2         int main()
3         {
4              int *p,i;
5              p=malloc(5*sizeof(int));
6              for(i=0; i<5;i++)
7                  p[i]=i;
8
9                  return 0;
10         }
```

```
1   #include <stdlib.h>
2           int main()
3           {
4                 int *p,i;
5                 p=malloc(5*sizeof(int));
6                 for(i=0; i<5;i++)
7                     p[i]=i;
8                 free(p);
9                     return 0;
10          }
```

```
ruggiero@shiva:> valgrind --tool=memcheck --leak-check=full ./t6
```

```
    .....
==8237== ERROR SUMMARY: 0 errors from 0 contexts (suppressed: 3 from 1)
    ==8237== malloc/free: in use at exit: 20 bytes in 1 blocks.
    ==8237== malloc/free: 1 allocs, 0 frees, 20 bytes allocated.
    ==8237== For counts of detected errors, rerun with: -v
    ==8237== searching for pointers to 1 not-freed blocks.
    ==8237== checked 65,900 bytes.
    ==8237==
    ==8237== 20 bytes in 1 blocks are definitely lost in loss record 1 of 1
    ==8237==    at 0x40235B5: malloc (in /usr/lib/valgrind/x86-linux/vgpreload_memcheck.so)
==8237==    by 0x80483D0: main (test6.c:5)
    ==8237==
    ==8237== LEAK SUMMARY:
    ==8237==    definitely lost: 20 bytes in 1 blocks.
    ==8237==      possibly lost: 0 bytes in 0 blocks.
    ==8237==    still reachable: 0 bytes in 0 blocks.
    ==8237==         suppressed: 0 bytes in 0 blocks.
```

```
1          int main()
2          {
3              char x[10];
4              x[11]='a';
5          }
```
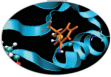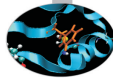
```
1          int main()
2          {
3              char x[10];
4              x[11]='a';
5          }
```

▶ Valgrind doesn't perform bound checking on static arrays (allocated on stack).

▶ Solution for testing purposes is simply to change static arrays into dinamically allocated memory taken from the heap, where you will get bounds-checking, though this could be a message of unfreed memory.

```c
#include <stdio.h>
#include <stdlib.h>
int main (int argc, char* argv[])  {
    const int size=10;
    int n, sum=0;
    int* A = (int*)malloc( sizeof(int)*size);

    for(n=size; n>0; n--)
        A[n] = n;
    for(n=0; n<size; n++)
        sum+=A[n];
    printf("sum=%d\n", sum);
    return 0;
}
```

sum.c: compilation and run

```
ruggiero@shiva:~> gcc -O0 -g -fbounds-check -ftrapv sum.c
```

```
ruggiero@shiva:~> ./a.out
```

sum=45

Valgrind:example
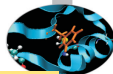
```
==21579== Memcheck, a memory error detector.
...
==21791==Invalid write of size 4
==21791==at 0x804842A: main (sum.c:9)
==21791==Address 0x417B050 is 0 bytes after a block of size 40 alloc'd
==21791==at 0x40235B5: malloc (in /usr/lib/valgrind/x86-linux/vgpreload_memcheck.so)
==21791==by 0x8048410: main (sum.c:6)
==21791==Use of uninitialised value of size 4
==21791== at 0x408685B: _itoa_word (in /lib/libc-2.5.so)
==21791==by 0x408A581: vfprintf (in /lib/libc-2.5.so)
==21791==by 0x4090572: printf (in /lib/libc-2.5.so)
==21791==by 0x804846B: main (sum.c:12)
==21791==
==21791==Conditional jump or move depends on uninitialised value(s)
==21791==at 0x4086863: _itoa_word (in /lib/libc-2.5.so)
==21791==by 0x408A581: vfprintf (in /lib/libc-2.5.so)
==21791==by 0x4090572: printf (in /lib/libc-2.5.so)
==21791==by 0x804846B: main (sum.c:12)
==21791==40 bytes in 1 blocks are definitely lost in loss record 1 of 1
==21791==at 0x40235B5: malloc (in /usr/lib/valgrind/x86-linux/vgpreload_memcheck.so)
==21791==by 0x8048410: main (sum.c:6)
==21791==
```
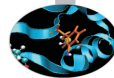
```
1   #include <stdio.h>
2   #include <stdlib.h>
3          int main (void)
4          {
5              int i;
6              int *a = (int*) malloc( 9*sizeof(int));
7
8              for ( i=0; i<=9; ++i){
9                  a[i] = i;
10                 printf ("%d\n ", a[i]);
11             }
12
13             free(a);
14             return 0;
15         }
```

```
ruggiero@shiva:~> icc –C –g outbc.c
```

```
ruggiero@shiva:~> ./a.out
```

0
1
2
3
4
5
6
7
8
9

```
ruggiero@shiva:~> pgcc -C -g outbc.c
```

```
ruggiero@shiva:~> ./a.out
```

0
1
2
3
4
5
6
7
8
9

- Electric Fence (efence) stops your program on the exact instruction that overruns (or underruns) a malloc() memory buffer.
- GDB will then display the source-code line that causes the bug.
- It works by using the virtual-memory hardware to create a red-zone at the border of each buffer - touch that, and your program stops.
- Catch all of those formerly impossible-to-catch overrun bugs that have been bothering you for years.

```
ruggiero@shiva:~> icc –g outbc.c libefence.a –o outbc –lpthread
```

```
ruggiero@shiva:~> ./outbc
```

```
0
1
2
3
4
5
6
7
8
Segmentation fault
```

- Erroneous program results.

- Execution deadlock.

- Run-time crashes.

The ideal debugging process

- ► Find origins.
  - ► Identify test case(s) that reliably show existence of fault (when possible). Duplicate the bug.

- ► Isolate the origins of infection.
  - ► Correlate incorrect behaviour with program logic/code error.

- ► Correct.
  - ► Fixing the error, not just a symptom of it.

- ► Verify.
  - ► Where there is one bug, there is likely to be another.
  - ► The probability of the fix being correct is not 100 percent.
  - ► The probability of the fix being correct drops as the size of the program increases.
  - ► Beware of the possibility that an error correction creates a new error.

- Dangling pointers.

- Initializations errors.

- Poorly syinchronized threads.

- Broken hardware.

- Divide and conqueror.
- Change one thing at time.
- Determine what you changed since the last time it worked.
- Write down what you did, in what order, and what happened as a result.
- Correlate the events.

Why is debugging so difficult?

- The symptom and the cause may be geographically remote.
- The symptom may disappear (temporarily) when another error is corrected.
- The symptom may actually be caused by nonerrors (e.g., round-off inaccuracies).
- It may be difficult to accurately reproduce input conditions (e.g, a real time application in which input ordering is indeterminate).
- The symptom may be due to causes that are distributed across a number of tasks running on different processors.

Why use a Debugger?

- No need for precognition of what the error might be.
- Flexible.
  - Allows for "live" error checking (no need to re−write and re−compile when you realize a certain type of error may be occuring).
- Dynamic.
  - Execution Control Stop execution on specified conditions: breakpoints
  - Interpretation Step-wise execution code
  - State Inspection Observe value of variables and stack
  - State Change Change the state of the stopped program.

- With simple errors, may not want to bother with starting up the debugger environment.
  - Obvious error.
  - Simple to check using prints/asserts.
- Hard-to-use debugger environment.
- Error occurs in optimized code.
- Changes execution of program
  (error doesn't occur while running debugger).

Why don't use print?

- Cluttered code.
- Cluttered output.
- Slowdown.
- Time consuming.
- And can be misleading.
  - Moves things around in memory, changes execution timing, etc.
  - Common for bugs to hide when print statements are added, and reappear when they're removed.

- The GNU Project debugger, is an open-source debugger.
- Protected by GNU General Public License (GPL).
- Runs on many Unix-like systems.
- Was first written by Richard Stallmann in 1986 as part of his GNU System.
- Is an Workstation Application Code extremely powerful all-purpose debugger.
- Its text-based user interface can be used to debug programs written in C, C++, Pascal, Fortran, and several other languages, including the assembly language for every micro-processor that GNU supports.
- www.gnu.org/software/gdb

- Basic:
  - Run the code and wait for it crash
  - Identify line where it crashes
  - With luck the problem is obvious
- Advanced:
  - Set breakpoints
  - Analyze data at breakpoints
  - Watch specific variables
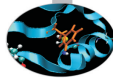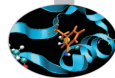
- Print a list of all primes which are less than or equal to the user-supplied upper bound *UpperBound*.
- See if *J* divides *K* ≤ *UpperBound*, for all values *J* which are
  - themselves prime (no need to try *J* if it is nonprime)
  - less than or equal to sqrt(K) (if *K* has a divisor larger than this square root, it must also have a smaller one, so no need to check for larger ones).
- *Prime[I]* will be 1 if *I* is prime, 0 otherwise.

```c
#include <stdio.h>
#define MaxPrimes 50
int Prime[MaxPrimes],UpperBound;
int main()
{
    int N;
    printf("enter upper bound\n");
    scanf("%d",UpperBound);
    Prime[2] = 1;
    for (N = 3; N <= UpperBound; N += 2)
        CheckPrime(N);
    if (Prime[N]) printf("%d is a prime\n",N);
    return 0;
}
```

```c
#define MaxPrimes 50
extern int Prime[MaxPrimes];
void CheckPrime(int K)
{
int J;
    for (J = 2; J*J <=K; J++)
        if (Prime[J] == 1)
            if (K % J == 0) {
             Prime[K] = 0;
             return ;
}
    Prime[K] = 1;
}
```

```
<ruggiero@matrix2 ~>gcc Main.c CheckPrime.c −O3 −o check_prime
```

```
<ruggiero@matrix2 ~>gcc Main.c CheckPrime.c –O3 –o check_prime
```

```
<ruggiero@matrix2 ~> ./check_prime
```

<ruggiero@matrix2 ~>gcc Main.c CheckPrime.c –O3 –o check_prime

<ruggiero@matrix2 ~> ./check_prime

enter upper bound

`<ruggiero@matrix2 ~>gcc Main.c CheckPrime.c –O3 –o check_prime`

`<ruggiero@matrix2 ~> ./check_prime`

enter upper bound

20

```
<ruggiero@matrix2 ~>gcc Main.c CheckPrime.c −O3 −o check_prime
```

```
<ruggiero@matrix2 ~> ./check_prime
```

enter upper bound

20

Segmentation fault

▶ You will need to compile your program with the appropriate flag to enable generation of symbolic debug information, the -g option is used for this.

▶ Don't compile your program with optimization flags while you are debugging it.
Compiler optimizations can "rewrite" your program and produce machine code that doesn't necessarily match your source code.
Compiler optimizations may lead to:

  ▶ Misleading debugger behaviour.
    ▶ Some variables you declared may not exist at all
    ▶ some statements may execute in different places because they were moved out of loops
  ▶ Obscure the bug.
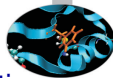
- ▶ When your program has crashed, disable or lower optimization to see if the bug disappears.
  (optimization levels are not comparable between compilers, not even -O0).

- ▶ If the bug persists $\implies$ you can be quite sure there's something wrong in your application.

- ▶ If the bug disappears,without a serious performance penalty $\implies$ send the bug to your computing center and continue your simulations.

- When your program has crashed, disable or lower optimization to see if the bug disappears.
  (optimization levels are not comparable between compilers, not even -O0).

- If the bug persists $\implies$ you can be quite sure there's something wrong in your application.

- If the bug disappears,without a serious performance penalty $\implies$ send the bug to your computing center and continue your simulations.

- But your program may still contain a bug that simply doesn't show up at lower optimization $\implies$ have some checks to verify the correctness of your code.

Lower optimization level
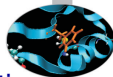
▶ When your program has crashed, disable or lower optimization to see if the bug disappears.
  (optimization levels are not comparable between compilers, not even -O0).

▶ If the bug persists $\Longrightarrow$ you can be quite sure there's something wrong in your application.

▶ If the bug disappears,without a serious performance penalty $\Longrightarrow$ send the bug to your computing center and continue your simulations.

▶ But your program may still contain a bug that simply doesn't show up at lower optimization $\Longrightarrow$ have some checks to verify the correctness of your code.

```
<ruggiero@matrix2 ~>gcc Main.c CheckPrime.c –g –O0 –o check_prime
```

▶ Option 1: Run gdb with the program passed in as parameter

Running under debugger

▶ Option 1: Run gdb with the program passed in as parameter

```
<ruggiero@matrix2 ~>gdb check_prime
```

```
GNU gdb (GDB) Red Hat Enterprise Linux (7.0.1-23.el5_5.1)
Copyright (C) 2009 Free Software Foundation, Inc.
License GPLv3+: GNU GPL version 3 or later <http://gnu.org/licenses/gpl.html>
This is free software: you are free to change and redistribute it.
There is NO WARRANTY, to the extent permitted by law.  Type "show copying"
and "show warranty" for details.
This GDB was configured as "x86_64-redhat-linux-gnu".
For bug reporting instructions, please see:
<http://www.gnu.org/software/gdb/bugs/>.
```
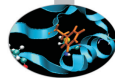
```
(gdb) r
```

▶ Option 2: Run gdb first and then load and execute the program from the debugger command line:

▶ Option 2: Run gdb first and then load and execute the program from the debugger command line:

```
<ruggiero@matrix2 ~>gdb
```

```
GNU gdb (GDB) Red Hat Enterprise Linux (7.0.1-23.el5_5.1)
Copyright (C) 2009 Free Software Foundation, Inc.
License GPLv3+: GNU GPL version 3 or later <http://gnu.org/licenses/gpl.html>
This is free software: you are free to change and redistribute it.
There is NO WARRANTY, to the extent permitted by law.  Type "show copying"
and "show warranty" for details.
This GDB was configured as "x86_64-redhat-linux-gnu".
For bug reporting instructions, please see:
<http://www.gnu.org/software/gdb/bugs/>.
```

```
(gdb) exec-file check_prime
```

▶ Option 2: Run gdb first and then load and execute the program from the debugger command line:

```
<ruggiero@matrix2 ~>gdb
```

```
GNU gdb (GDB) Red Hat Enterprise Linux (7.0.1-23.el5_5.1)
Copyright (C) 2009 Free Software Foundation, Inc.
License GPLv3+: GNU GPL version 3 or later <http://gnu.org/licenses/gpl.html>
This is free software: you are free to change and redistribute it.
There is NO WARRANTY, to the extent permitted by law.  Type "show copying"
and "show warranty" for details.
This GDB was configured as "x86_64-redhat-linux-gnu".
For bug reporting instructions, please see:
<http://www.gnu.org/software/gdb/bugs/>.
```

```
(gdb) exec-file check_prime
```

```
(gdb) r
```

► Option 3: Attach the debugger to a running program

► Option 3: Attach the debugger to a running program

```
<ruggiero@matrix2 ~> ps –u |grep  check_prime
```

Running under debugger

► Option 3: Attach the debugger to a running program

```
<ruggiero@matrix2 ~> ps -u |grep  check_prime
```

```
ruggiero 25934  0.0  0.0   4168   356 pts/80   T    13:55   0:00 ./check_prime
```

▶ Option 3: Attach the debugger to a running program

```
<ruggiero@matrix2 ~> ps –u |grep   check_prime
```

ruggiero 25934 0.0 0.0   4168   356 pts/80   T   13:55   0:00 ./check_prime

```
(gdb) attach 25934
```

- ▶ When you run the gdb command
  - ▶ The -d option is useful when source and executable reside in different directories
  - ▶ Use -q to skip the licensing message.
- ▶ In the gdb environment
  - ▶ Type help at any time to see a list of the debugger options and commands.
  - ▶ Type she execute the rest of the line as a shell command.
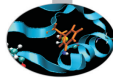
```
<ruggiero@matrix2 ~>gdb check_prime
```

\<ruggiero@matrix2 ~>gdb check_prime

```
GNU gdb (GDB) Red Hat Enterprise Linux (7.0.1-23.el5_5.1)
Copyright (C) 2009 Free Software Foundation, Inc.
License GPLv3+: GNU GPL version 3 or later <http://gnu.org/licenses/gpl.html>
This is free software: you are free to change and redistribute it.
There is NO WARRANTY, to the extent permitted by law.  Type "show copying"
and "show warranty" for details.
This GDB was configured as "x86_64-redhat-linux-gnu".
For bug reporting instructions, please see:
<http://www.gnu.org/software/gdb/bugs/>.
```

(gdb)

gdb: Basic commands

command	shorthand	argument	description
run/kill	r/k	NA	start/end program being debugged
continue	c	NA	continue running program from last breakpoint
step	s	NA	take a single step in the program from last position
next	n	NA	Step program, proceeding through subroutine calls
where/backtrace	NA/bt	NA	Print backtrace of all stack frames, or innermost COUNT frames
where/backtrace	NA/bt	negative value	print outermost -COUNT frames
print	p	variableNamee	show value of a variable
list	l	SrcFile:lineNumber	show the specified source code line
break	b	SrcFile:lineNumber functionName	set breakpoint at specified line set breakpoint at function name
watch	NA	variableName	stops when the variable changes value
display	NA	variableName	print value of variable name each time the program stops.
quit	q	NA	exit gdb

```
(gdb) r
```

```
(gdb) r
```

Starting program: check_prime
enter upper bound

```
(gdb) r
```

Starting program: check_prime
enter upper bound

20

prime-number finding program

```
(gdb) r
```

Starting program: check_prime
enter upper bound

20

Program received signal SIGSEGV, Segmentation fault.
0xd03733d4 in number () from /usr/lib/libc.a(shr.o)

```
(gdb) where
```

SuperComputing Applications and Innovation

```
(gdb) r
```

Starting program: check_prime
enter upper bound

20

Program received signal SIGSEGV, Segmentation fault.
0xd03733d4 in number () from /usr/lib/libc.a(shr.o)

```
(gdb) where
```

#0 0x0000003faa258e8d in _IO_vfscanf_internal () from /lib64/libc.so.6
#1 0x0000003faa25ee7c in scanf () from /lib64/libc.so.6
#2 0x000000000040054f in main () at Main.c:8

```
(gdb) list Main.c:8
```

prime-number finding program

```
#0 0x0000003faa258e8d in _IO_vfscanf_internal () from /lib64/libc.so.6
#1 0x0000003faa25ee7c in scanf () from /lib64/libc.so.6
#2 0x000000000040054f in main () at Main.c:8
```

```
3   int Prime[MaxPrimes],UpperBound;
5     main()
6     {   int N;
7         printf("enter upper bound\n");
8         scanf("%d",UpperBound);
9         Prime[2] = 1;
10        for (N = 3; N <= UpperBound; N += 2)
11            CheckPrime(N);
12            if (Prime[N]) printf("%d is a prime\n",N);
```

```c
#include <stdio.h>
#define MaxPrimes 50
int Prime[MaxPrimes],UpperBound;
int main()
{
        int N;
        printf("enter upper bound\n");
        scanf("%d",  UpperBound);
        Prime[2] = 1;
        for (N = 3; N <= UpperBound; N += 2)
           CheckPrime(N);
           if (Prime[N]) printf("%d is a prime\n",N);
        return 0;
}
```

```c
#include <stdio.h>
#define MaxPrimes 50
int Prime[MaxPrimes],UpperBound;
int main()
{
        int N;
        printf("enter upper bound\n");
        scanf("%d", &UpperBound);
        Prime[2] = 1;
        for (N = 3; N <= UpperBound; N += 2)
           CheckPrime(N);
           if (Prime[N]) printf("%d is a prime\n",N);
        return 0;
}
```

Main.c :new version

```c
#include <stdio.h>
#define MaxPrimes 50
int Prime[MaxPrimes],UpperBound;
int main()
{
    int N;
    printf("enter upper bound\n");
    scanf("%d", &UpperBound);
    Prime[2] = 1;
    for (N = 3; N <= UpperBound; N += 2)
        CheckPrime(N);
        if (Prime[N]) printf("%d is a prime\n",N);
    return 0;
}
```

In other shell COMPILATION

(gdb)

Kill the program being debugged? (y or n)

prime-number finding program

```
(gdb)
```

Kill the program being debugged? (y or n) y

```
(gdb) run
```

```
Starting program: check_prime
enter upper bound
```

prime-number finding program

Kill the program being debugged? (y or n)   y

(gdb) run

```
Starting program: check_prime
enter upper bound
```

20

prime-number finding program

```
(gdb)
```

Kill the program being debugged? (y or n)   y

```
(gdb) run
```

```
Starting program: check_prime
enter upper bound
```

20

```
Program exited normally.
```

- ▶ Stop the execution of the program
- ▶ Allow you to examine the execution state in detail
- ▶ Can be assigned to a line or function
- ▶ Can be set conditionally

command	argument	description
info	breakpoints/b/br	Prins to screen all breakpoints
breakpoint	srcFile:lineNumber a<b	Conditional insertion of breakpoint
enable/disable	breakpointNumber	Enable/disable a breakpoint
delete	breakpointNumber	Delete a breakpoint
clear	srcFile:lineNumber	Clear breakpoints at given line
	functionName	or function

gdb: Examining data

C	Fortran	Result
(gdb) p x	(gdb) p x	Print scalar data x value
(gdb) p V	(gdb) p V	Print all V vector components
(gdb) p V[i]	(gdb) p V(i)	Print element i of V vector
(gdb) p V[i]@n	(gdb) p V(i)@n	Print n consecutive elements starting with V_i
(gdb) p M	(gdb) p M	Print all matrix M elements
(gdb) p M[i]	Not Available	Print row i of matrix M
(gdb) p M[i]@n	Not Available	Print n consecutive rows starting with i row
(gdb) p M[i][j]	(gdb) p M(i,j)	Print matrix element Mij
(gdb) p M[i][j]@n	(gdb) p M(i,j)@n	Print n consecutive elements starting with Mij

```
(gdb) break Main.c:1
```

```
(gdb) break Main.c:1
```

Breakpoint 1 at 0x8048414: file Main.c, line 1.

```
(gdb) next
```

(gdb) next

```
main () at Main.c:7
7              printf("enter upper bound\n");
```
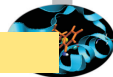
```
(gdb) next
```

```
(gdb) next
```

```
8                 scanf("%d",&UpperBound);
```

```
(gdb) next
```

(gdb) next

8   scanf("%d",&UpperBound);

(gdb) next

20

(gdb) next

8   scanf("%d",&UpperBound);

(gdb) next

20

9   Prime[2] = 1;

(gdb) next

prime-number finding program

```
(gdb) next

8              scanf("%d",&UpperBound);

(gdb) next

20

9              Prime[2] = 1;

(gdb) next

10             for (N = 3; N <= UpperBound; N += 2)

(gdb) next
```

prime-number finding program

```
(gdb) next
```

8   scanf("%d",&UpperBound);

```
(gdb) next
```

20

9   Prime[2] = 1;

```
(gdb) next
```

10   for (N = 3; N <= UpperBound; N += 2)

```
(gdb) next
```

11   CheckPrime(N);

```
(gdb) display N
```

```
(gdb) display N
```

```
1: N = 3
```

```
(gdb) step
```
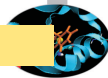
prime-number finding program

```
(gdb) display N
```

```
1: N = 3
```

```
(gdb) step
```

```
CheckPrime (K=3) at CheckPrime.c:6
6               for (J = 2; J*J <= K;  J++)
```

```
(gdb) next
```

```
(gdb) display N
```

```
1: N = 3
```

```
(gdb) step
```
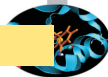
```
CheckPrime (K=3) at CheckPrime.c:6
6              for (J = 2; J*J <= K; J++)
```

```
(gdb) next
```

```
12             Prime[K] = 1;
```

```
(gdb) next
```

```
13         }
```

```
(gdb)   n
```

```
(gdb)  n
```

```
10              for (N = 3; N <= UpperBound; N += 2)
1: N = 3
}
```

```
(gdb) n
```

prime-number finding program

```
(gdb)  n
```

```
10              for (N = 3; N <= UpperBound; N += 2)
1: N = 3
}
```

```
(gdb) n
```

```
11                 CheckPrime(N);
1: N = 5
```

```
(gdb) n
```

prime-number finding program

```
(gdb)  n
```

```
10                for (N = 3; N <= UpperBound; N += 2)
1: N = 3
}
```

```
(gdb) n
```

```
11                   CheckPrime(N);
1: N = 5
```

```
(gdb) n
```

```
10                for (N = 3; N <= UpperBound; N += 2)
1: N = 5
```

```
(gdb) n
```

prime-number finding program

```
(gdb)  n

10              for (N = 3; N <= UpperBound; N += 2)
1: N = 3
}

(gdb) n

11                  CheckPrime(N);
1: N = 5

(gdb) n

10              for (N = 3; N <= UpperBound; N += 2)
1: N = 5

(gdb) n

11                  CheckPrime(N);
1: N = 7
```

```
(gdb) l  Main.c:10
```

prime-number finding program

```
5          main()
6          {  int N;
7              printf("enter upper bound\n");
8              scanf("%d",&UpperBound);
9              Prime[2] = 1;
10             for (N = 3; N <= UpperBound; N += 2)
11                 CheckPrime(N);
12                 if (Prime[N]) printf("%d is a prime\n",N);
13             return 0;
14         }
```

```c
#include <stdio.h>
#define MaxPrimes 50
 int Prime[MaxPrimes],
 UpperBound;
   main()
   { int N;
       printf("enter upper bound\n");
       scanf("%d",&UpperBound);
       Prime[2] = 1;
       for (N = 3; N <= UpperBound; N += 2)
          CheckPrime(N);
          if (Prime[N]) printf("%d is a prime\n",N);

       return 0;
   }
```

```c
#include <stdio.h>
#define MaxPrimes 50
 int Prime[MaxPrimes],
 UpperBound;
   main()
   {  int N;
      printf("enter upper bound\n");
      scanf("%d",&UpperBound);
      Prime[2] = 1;
      for (N = 3; N <= UpperBound; N += 2){
         CheckPrime(N);
         if (Prime[N]) printf("%d is a prime\n",N);
      }
      return 0;
   }
```

In other shell COMPILATION

In other shell COMPILATION

(gdb) kill

Kill the program being debugged? (y or n)

prime-number finding program

In other shell COMPILATION

```
(gdb) kill
```

Kill the program being debugged? (y or n)   y

```
(gdb) d
```

In other shell COMPILATION

```
(gdb) kill
```

Kill the program being debugged? (y or n)   y

```
(gdb) d
```

Delete all breakpoints? (y or n)

In other shell COMPILATION

(gdb) kill

Kill the program being debugged? (y or n)   y

(gdb) d

Delete all breakpoints? (y or n)   y

prime-number finding program

In other shell COMPILATION

```
(gdb) kill
```

Kill the program being debugged? (y or n)   y

```
(gdb) d
```

Delete all breakpoints? (y or n)   y

```
(gdb) r
```

In other shell COMPILATION

```
(gdb) kill
```

Kill the program being debugged? (y or n)   y

```
(gdb) d
```

Delete all breakpoints? (y or n)   y

```
(gdb) r
```

```
Starting program: check_prime
enter upper bound
```

prime-number finding program

In other shell COMPILATION

```
(gdb) kill
```

Kill the program being debugged? (y or n)   y

```
(gdb) d
```

Delete all breakpoints? (y or n)   y

```
(gdb) r
```

```
Starting program: check_prime
enter upper bound
```

20

```
3 is a prime
5 is a prime
7 is a prime
11 is a prime
13 is a prime
17 is a prime
19 is a prime

Program exited normally.
```

```
(gdb) list Main.c:6
```

```
(gdb) list Main.c:6
```

```
1        #include <stdio.h>
2        #define MaxPrimes 50
3         int Prime[MaxPrimes],
4        UpperBound;
5          main()
6          {   int N;
7             printf("enter upper bound\n");
8             scanf("%d",&UpperBound);
9             Prime[2] = 1;
10            for (N = 3; N <= UpperBound; N += 2){
```

```
(gdb) break Main.c:8
```

```
(gdb) break Main.c:8
```
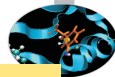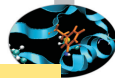
```
Breakpoint 1 at 0x10000388: file Main.c, line 8.
```

```
(gdb) run
```

prime-number finding program
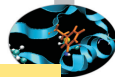
```
(gdb) break Main.c:8
```
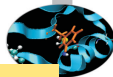
Breakpoint 1 at 0x10000388: file Main.c, line 8.

```
(gdb) run
```

Starting program: check_prime
enter upper bound
Breakpoint 1, main () at /afs/caspur.it/user/r/ruggiero/Main.c:8
8   scanf("%d",&UpperBound);

```
(gdb) next
```

prime-number finding program
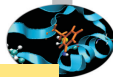
```
(gdb) break Main.c:8
```

Breakpoint 1 at 0x10000388: file Main.c, line 8.

```
(gdb) run
```

Starting program: check_prime
enter upper bound
Breakpoint 1, main () at /afs/caspur.it/user/r/ruggiero/Main.c:8
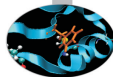8   scanf("%d",&UpperBound);

```
(gdb) next
```

20

prime-number finding program

```
(gdb) break Main.c:8
```

Breakpoint 1 at 0x10000388: file Main.c, line 8.

```
(gdb) run
```

Starting program: check_prime
enter upper bound
Breakpoint 1, main () at /afs/caspur.it/user/r/ruggiero/Main.c:8
8   scanf("%d",&UpperBound);

```
(gdb) next
```

20

9   Prime[2] = 1;

```
(gdb) set UpperBound=40
(gdb) continue
```
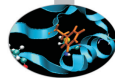
```
(gdb) set UpperBound=40
(gdb) continue
```

```
Continuing.
3 is a prime
5 is a prime
7 is a prime
11 is a prime
13 is a prime
17 is a prime
19 is a prime
23 is a prime
29 is a prime
31 is a prime
37 is a prime

Program exited normally.
```
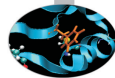
Debugging post mortem

- ▶ When a program exits abnormally the operating system can write out core file, which contains the memory state of the program at the time it crashed.

- ▶ Combined with information from the symbol table produced by -g the core file can be used fo find the line where program stopped, and the values of its variables at that point.

- ▶ Some systems are configured to not write core file by default, since the files can be large and rapidly fill up the available hard disk space on a system.

- ▶ In the GNU Bash shell the command ulimit -c control the maximum size of the core files. If the size limit is set to zero, no core files are produced.

Debugging post mortem

- When a program exits abnormally the operating system can write out core file, which contains the memory state of the program at the time it crashed.

- Combined with information from the symbol table produced by -g the core file can be used fo find the line where program stopped, and the values of its variables at that point.

- Some systems are configured to not write core file by default, since the files can be large and rapidly fill up the available hard disk space on a system.

- In the GNU Bash shell the command ulimit -c control the maximum size of the core files. If the size limit is set to zero, no core files are produced.
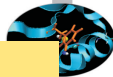
```
ulimit -c unlimited
gdb exe_file core
```
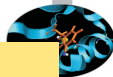
- gdb -tui or gdbtui
- ddd (data dysplay debugger) is a graphical front-end for command-line debuggers.
- ddt (Distributed Debugging Tool) is a comprehensive graphical debugger for scalar, multi-threaded and large-scale parallel applications that are written in C, C++ and Fortran.
- Etc.

```c
int main(void)
{
    float q;
    q=3.;
    return 0;
}
```

```
1   int main(void)
2   {
3       float q;
4       q=3.;
5       return 0;
6   }
```
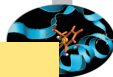
```
<ruggiero@shiva ~/CODICI>gcc  opt.c –g –O0 –o opt
<ruggiero@matrix2 ~>gdb opt
(gdb) b main
```

Breakpoint 1 at 0x8048395: file opt.c, line 4.

Why don't optmize?

```
1  int main(void)
2  {
3      float q;
4      q=3.;
5      return 0;
6  }
```

```
<ruggiero@shiva ~/CODICI>gcc  opt.c –g –O0 –o opt
<ruggiero@matrix2 ~>gdb opt
(gdb) b main
```

Breakpoint 1 at 0x8048395: file opt.c, line 4.

```
<ruggiero@shiva ~/CODICI>gcc  opt.c –g –O3 –o opt
<ruggiero@matrix2 ~>gdb opt
(gdb) b main
```

Breakpoint 1 at 0x8048395: file opt.c, line 6.

Totalview (www.totalviewtech.com)

- ▶ Used for debugging and analyzing both serial and parallel programs.
- ▶ Supported languages include the usual HPC application languages:
    - ▶ C,C++,Fortran
    - ▶ Mixed C/C++ and Fortran
    - ▶ Assembler
- ▶ Supported many commercial and Open Source Compilers.
- ▶ Designed to handle most types of HPC parallel coding (multi-process and/or multi-threaded applications).
- ▶ Supported on most HPC platforms.
- ▶ Provides both a GUI and command line interface.
- ▶ Can be used to debug programs, running processes, and core files.
- ▶ Provides graphical visualization of array data.
- ▶ Includes a comprehensive built-in help system.
- ▶ And more...

Compilation options for Totalview
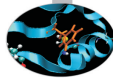
- You will need to compile your program with the appropriate flag to enable generation of symbolic debug information. For most compilers, the -g option is used for this.

- It is recommended to compile your program without optimization flags while you are debugging it.

- TotalView will allow you to debug executables which were not compiled with the -g option. However, only the assembler code can be viewed.

- Some compilers may require additional compilation flags. See the *TotalView User's Guide* for details.

```
ifort [option] -O0 -g file_source.f -o filename
```

Command	Action
totalview	Starts the debugger.You can then load a program or corefile, or else attach to a running process.
totalview *filename*	Starts the debugger and loads the program specified by *filename*.
totalview *filename corefile*	Starts the debugger and loads the program specified by *filename* and its core file specified by *corefile*.
totalview *filename* -a *args*	Starts the debugger and passes all subsequent arguments (specified by *args*) to the program specified by *filename*. The -a option must appear after all other TotalView options on the command line.

Totalview:panel
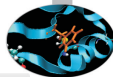
1. **Stack Trace**
   - Call sequence
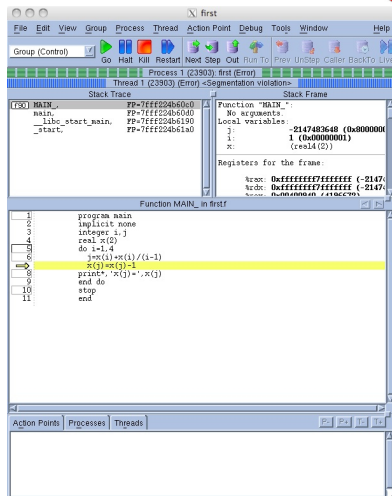2. **Stack Frame**
   - Local variables and their values
3. **Source Window**
   - Indicates presently executed statement
   - Last statement executed if program crashed
4. **Info tabs**
   - Informations about processes and action points.

- **Breakpoint** stops the excution of the process and threads that reach it.
  - Unconditional
  - Conditional: stop only if the condition is satisfied.
  - Evaluation: stop and excute a code fragment when reached.
- **Process barrier point** synchronizes a set of processes or threads.
- **Watchpoint** monitors a location in memory and stop execution when its value changes.
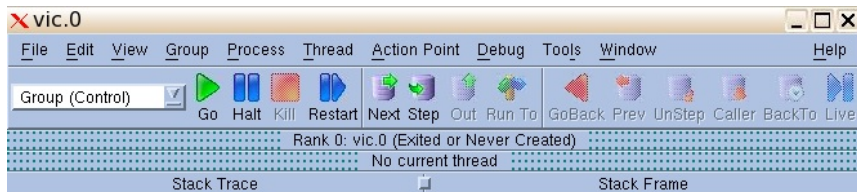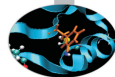
Totalview:Setting Action points

- **Breakpoint**
  - Right click on a source line → Set breakpoint
  - Click on the line number
- **Watchpoint**
  - Right click on a variable → Create watchpoint
- **Barrier point**
  - Right click on a source line → Set barrier
- **Edit action point property**
  - Rigth click on a action point in the Action Points tab → Properties.

Totalview:Status
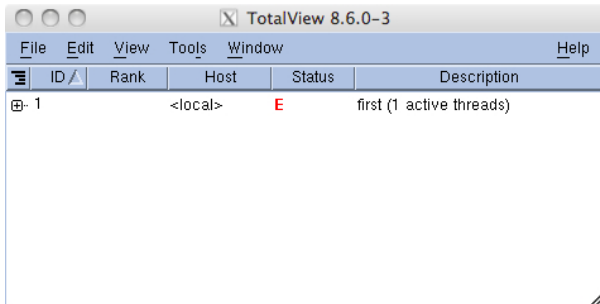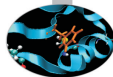
Status Code	Description
T	Thread is stopped
B	Stopped at a breakpoint
E	Stopped because of a error
W	At a watchpoint
H	In a Hold state
M	Mixed - some threads in a process are running and some not
R	Running

Command	Description
Go	Start/resume excution
Halt	Stop excution
Kill	Terminate the job
Restart	Restarts a running program, or one that has stopped without exiting
Next	Run to next source line or instruction. If the next line/instruction calls a function the entire function will be excuted and control will return to the next source line or instruction.
Step	Run to next source line or instruction. If the next line/instruction calls a function, excution will stop within function.
Out	Excute to the completion of a function. Returns to the instruction after one which called the function.
Run to	Allows you to arbitrarily click on any source line and then run to that point.

Totalview:Mouse buttons

Mouse Button	Purpose	Description	Examples
Left	Select	Clicking on object causes it to be selected and/ or to perform its action	Clicking a line number sets a breakpoint. Clicking on a process/thread name in the root window will cause its source code to appear in the Process Window's source frame.
Middle	Dive	Shows additional information about the object - usually by popping open a new window.	Clicking on an array object in the source frame will cause a new window to pop open, showing the array's values.
Rigth	Menu	Pressing and holding this button a window/frame will cause its associated menu to pop open.	Holding this but ton while the mouse pointer is in the Root Window will cause the Root Window menu to appear. A menu selection can then be made by dragging the mouse pointer while continuing to press the middle button down.

what else could it be?

- ► Full file system.
- ► Disk quota exceeded.
- ► File protection.
- ► Maximum number of processes exceeded.
- ► Are all object file are up do date? Use Makefiles to build your projects
- ► What did I change since last version of my code?
  Use a version control system: CVS,RCS,...
- ► Does any environment variable affect the behaviour of my program?

Bugs, Prevention and Testing

Static analysis

Run-time analysis

Debugging

Conclusions

- Ask for help.

- Explain your code to somebody.

- Go for a walk, to the movies,leave it to tomorrow.

- ▶ Where was error made?
- ▶ Who made error?
- ▶ What was done incorrectly?
- ▶ How could the error have been prevented?
- ▶ Why wasn't the error detected earlier?
- ▶ How could the error have been detected earlier?

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