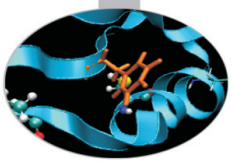
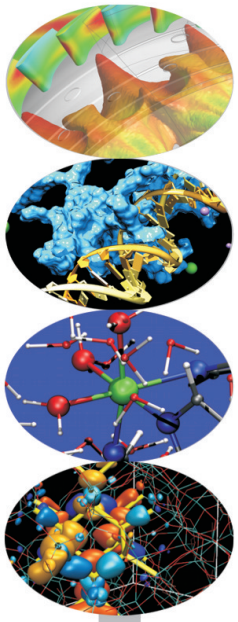
SuperComputing Applications and Innovation



HPC Scientific programming: tools and techniques

P. Lanucara V. Ruggiero
F. Salvadore

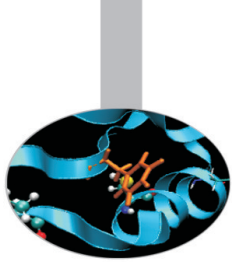
CINECA Roma - SCAI Department



Roma, 9-11 April 2013

Outline

HPC development tools

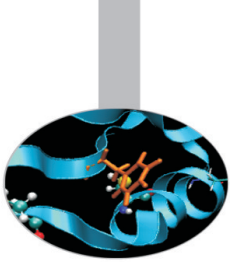


- What do I need to develop my HPC application? At least:
  - A compiler, e.g. GNU, Intel, PGI, PathScale, Sun
  - Code editor
- Several tools may help you (even for non HPC applications)
  - Debugger, e.g. gdb, TotalView, DDD
  - Profiler, e.g. gprof, Scalasca, Tau, Vampir
  - Project management, e.g. make, projects
  - Revision control, e.g. svn, git, cvs, mercurial
  - Generating documentation, e.g. doxygen
  - Source code repository, e.g. sourceforge, github, google.code
  - Data repository, currently under significant increase
  - and more . . .

Code editor

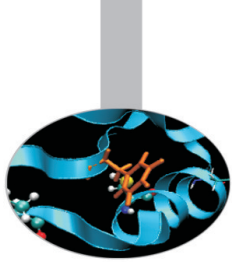
- You can select the code editor among a very wide range
  - from the light and fast text editors, e.g. the wonderful VIM, emacs
  - to the more sophisticated Integrated development environment (IDE), e.g. Ecplise
  - or you have intermediate options, e.g. Geany
- The choice obviously depends on the complexity and on the software tasks
- ...but also on your personal taste

Project management



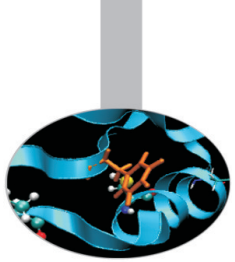
- Non trivial programs are hosted in several source files and link libraries
- Different types of files require different compilation
  - different optimization flags
  - different languages may be mixed, too
  - compilation and linking require different flags
  - and the code could work on different platforms
- During development (and debugging) several recompilations are needed, and we do not want to recompile all the source files but only the modified ones
- How to deal with it?
  - use the IDE (with plug-ins) and their project files to manage the content (e.g. Eclipse)
  - use language-specific compiler features
  - use external utilities, e.g. Make!

GNU Make



- “Make is a tool which controls the generation of executables and other non-source files of a program from the program’s source files”
- Make gets its knowledge from a file called the makefile, which lists each of the non-source files and how to compute it from other files
- When you write a program, you should write a makefile for it, so that it is possible to use Make to build and install the program
- GNU Make has some powerful features for use in makefiles, beyond what other Make versions have

Preparing and Running Make

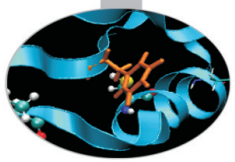


- To prepare to use make, you have to write a file that describes:
  - the relationships among files in your program
  - commands for updating each file
- Typically, the executable file is updated from object files, which are in turn made by compiling source files
- Once a suitable makefile exists, each time you change some source files, the shell command

```
make -f <makefile_name>
```

  suffices to perform all necessary recompilations
- If **`-f`** option is missing, the default names **`makefile`** or **`Makefile`** are used

Rules



- A simple makefile consists of “rules”:

```
target ... : prerequisites ...
        recipe
        ...
        ...
```

  - a **`target`** is usually the name of a file that is generated by a program; examples of targets are executable or object files. A target can also be the name of an action to carry out, such as clean
  - a **`prerequisite`** is a file that is used as input to create the target. A target often depends on several files.
  - a **`recipe`** is an action that make carries out. A recipe may have more than one command, either on the same line or each on its own line. Recipe commands must be preceded by a tab character.
- By default, make starts with the first target (default goal)

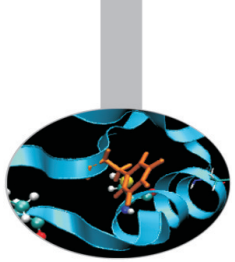
My first rule

- A simple rule:

```
foo.o : foo.c defs.h
        gcc -c -g foo.c
```

- This rule says two things
  - how to decide whether foo.o is out of date: it is out of date if it does not exist, or if either foo.c or defs.h is more recent than it
  - how to update the file foo.o: by running gcc as stated. The recipe does not explicitly mention defs.h, but we presume that foo.c includes it, and that that is why defs.h was added to the prerequisites.
- Remember the tab character before starting the recipe lines!

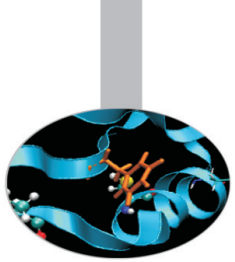
A simple example in C



- The main program is in laplace2d.c file
  - includes two header files: timing.h and size.h
  - calls functions in two source files: update_A.c and copy_A.c
- update_A.c and copy_A.c includes two header files: laplace2d.h and size.h
- A possible (naive) Makefile

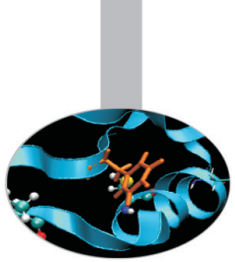
```
laplace2d_exe: laplace2d.o update_A.o copy_A.o
        gcc -o laplace2d_exe laplace2d.o update_A.o copy_A.o

laplace2d.o: laplace2d.c timing.h size.h
        gcc -c laplace2d.c

update_A.o: update_A.c laplace2d.h size.h
        gcc -c update_A.c

copy_A.o: copy_A.c laplace2d.h size.h
        gcc -c copy_A.c

.PHONY: clean
clean:
        rm -f laplace2d_exe *.o
```

How it works



- The default goal is (re-)linking laplace2d_exe
- Before make can fully process this rule, it must process the rules for the files that edit depends on, which in this case are the object files
- The object files, according to their own rules, are recompiled if the source files, or any of the header files named as prerequisites, is more recent than the object file, or if the object file does not exist
- Note: in this makefile .c and .h are not the targets of any rules, but this could happen it they are automatically generated
- After recompiling whichever object files need it, make decides whether to relink edit according to the same “updating” rules.
- Try to follow the path: what happens if, e.g., laplace2d.h is modified?

A simple example in Fortran

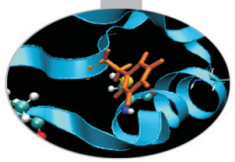


- The main program is in laplace2d.f90 file
  - uses two modules named prec and timing
  - calls subroutines in two source files: update_A.f90 and copy_A.f90
- update_A.f90 and copy_A.f90 use only prec module
- sources of prec and timing modules are in the prec.f90 and timing.f90 files
- Beware of the Fortran modules:
  - program units using modules require the mod files to exist
  - a target may be a list of files: e.g., both timing.o and timing.mod depend on timing.f90 and are produced compiling timing.f90
- Remember: the order of rules is not significant, except for determining the default goal

A simple example in Fortran / 2

```
laplace2d_exe: laplace2d.o update_A.o copy_A.o prec.o timing.o
        gfortran -o laplace2d_exe prec.o timing.o laplace2d.o update_A.o copy_A.o

prec.o prec.mod: prec.f90
        gfortran -c prec.f90

timing.o timing.mod: timing.f90
        gfortran -c timing.f90

laplace2d.o: laplace2d.f90 prec.mod timing.mod
        gfortran -c laplace2d.f90

update_A.o: update_A.f90 prec.mod
        gfortran -c update_A.f90

copy_A.o: copy_A.f90 prec.mod
        gfortran -c copy_A.f90

.PHONY: clean
clean:
        rm -f laplace2d_exe *.o *.mod
```

Phony Targets and clean



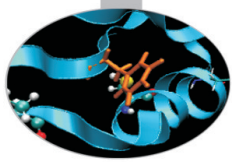
- A phony target is one that is not really the name of a file; rather it is just a name for a recipe to be executed when you make an explicit request.
  - avoid target name clash
  - improve performance
- **`clean`**: an ubiquitous target

```
.PHONY: clean
clean:
        rm *.o temp
```

- Another common solution: since **`FORCE`** has no prerequisite, recipe and no corresponding file, make imagines this target to have been updated whenever its rule is run

```
clean: FORCE
        rm *.o temp
FORCE:
```

Variables



- The previous makefiles have several duplications
  - error-prone and not expressive
- Use variables!
  - define
    `objects = laplace2d.o update_A.o copy_A.o`
  - and use as **`$(objects)`**

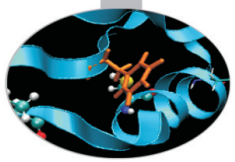
```
objects := laplace2d.o update_A.o copy_A.o

laplace2d_exe: $(objects)
        gcc -o laplace2d_exe $(objects)

laplace2d.o: laplace2d.c timing.h size.h
        gcc -c laplace2d.c

update_A.o: update_A.c laplace2d.h size.h
        gcc -c update_A.c

copy_A.o: copy_A.c laplace2d.h size.h
        gcc -c copy_A.c

.PHONY: clean
clean:
        rm -f laplace2d_exe *.o
```

More Variables

- Use more variables to enhance readability and generality
- Modifying the first four lines it is easy to modify compilers and flags

```
CC       := gcc
CFLAGS   := -O2
CPPFLAGS :=
LDFLAGS  :=

objects  := laplace2d.o update_A.o copy_A.o

laplace2d_exe: $(objects)
        $(CC) $(CFLAGS) $(CPPFLAGS) -o laplace2d_exe $(objects) $(LDFLAGS)

laplace2d.o: laplace2d.c timing.h size.h
        $(CC) $(CFLAGS) $(CPPFLAGS) -c laplace2d.c

update_A.o: update_A.c laplace2d.h size.h
        $(CC) $(CFLAGS) $(CPPFLAGS) -c update_A.c

copy_A.o: copy_A.c laplace2d.h size.h
        $(CC) $(CFLAGS) $(CPPFLAGS) -c copy_A.c

.PHONY: clean
clean:
        rm -f laplace2d_exe *.o
```

Implicit rules



- There are still duplications: each compilation needs the same command except for the file name
  - immagine what happens with hundred of files!
- What happens if Make does not find a rule to produce one or more prerequisite (e.g., and object file)?
- Make searches for an implicit rule, defining default recipes depending on the processed type
  - C programs: n.o is made automatically from n.c with a recipe of the form

```
$(CC) $(CPPFLAGS) $(CFLAGS) -c
```

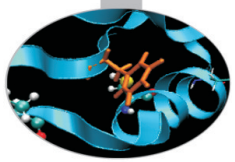
  - C++ programs: n.o is made automatically from n.cc, n.cpp or n.C with a recipe of the form

```
$(CXX) $(CPPFLAGS) $(CXXFLAGS) -c
```

  - Fortran programs: n.o is made automatically from n.f, n.F (`$(CPPFLAGS)` only for .F)

```
$(FC) $(FFLAGS) $(CPPFLAGS) -c
```

Pattern rules



- Implicit rules allow for saving many recipe lines
  - but what happens is not clear reading the Makefile
  - and you are forced to use a predefined structure and variables
  - to clarify the types to be processed, you may define **`.SUFFIXES`** variable at the beginning of Makefile

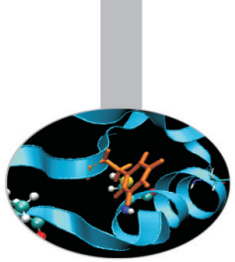
```
.SUFFIXES:
.SUFFIXES: .o .f
```

- You may use re-define an implicit rule by writing a pattern rule
  - a pattern rule looks like an ordinary rule, except that its target contains one character `%`
  - usually written as first target, does not become the default target

```
%.o : %.c
        $(CC) -c $(OPT_FLAGS) $(DEB_FLAGS) $(CPP_FLAGS) $< -o $@
```

- Automatic variables are usually exploited
  - `$@` is the target
  - `$<` is the first prerequisite (usually the source code)
  - `$^` is the list of prerequisites (useful in linking stage)

Running make targets



- It is possible to select a specific target to be updated, instead of the default goal (remember **`clean`**)

```
make copy_A.o
```

  - of course, it will update the chain of its prerequisite
  - useful during development when the full target has not been programmed, yet
- And it is possible to set target-specific variables as (repeated) target prerequisites
- Consider you want to write a Makefile considering both GNU and Intel compilers
- Use a default goal which is a help to inform that compiler must be specified as target

C example

```
CPPFLAGS :=
LDFLAGS  :=

objects  := laplace2d.o update_A.o copy_A.o

.SUFFIXES :=
.SUFFIXES := .c .o

%.o: %.c
        $(CC) $(CFLAGS) $(CPPFLAGS) -c $<

help:
        @echo "Please select gnu or intel compilers as targets"

gnu: CC       := gcc
gnu: CFLAGS   := -O3
gnu: $(objects)
        $(CC) $(CFLAGS) $(CPPFLAGS) -o laplace2d_gnu $(objects) $(LDFLAGS)

intel: CC     := icc
intel: CFLAGS := -fast
intel: $(objects)
        $(CC) $(CFLAGS) $(CPPFLAGS) -o laplace2d_intel $(objects) $(LDFLAGS)

laplace2d.o: laplace2d.c timing.h size.h
update_A.o : update_A.c laplace2d.h size.h
copy_A.o   : copy_A.c laplace2d.h size.h

.PHONY: clean
clean:
        rm -f laplace2d_gnu laplace2d_intel $(objects)
```

Fortran example

```
LDFLAGS :=
objects := prec.o timing.o laplace2d.o update_A.o copy_A.o
.SUFFIXES:
.SUFFIXES: .f90 .o .mod

%.o: %.f90
        $(FC) $(FFLAGS) -c $<
%.o %.mod: %.f90
        $(FC) $(FFLAGS) -c $<

help:
        @echo "Please select gnu or intel compilers as targets"
gnu: FC        := gfortran
gnu: FCFLAGS   := -O3
gnu: $(objects)
        $(FC) $(FCFLAGS) -o laplace2d_gnu $^ $(LDFLAGS)
intel: FC      := ifort
intel: FCFLAGS := -fast
intel: $(objects)
        $(FC) $(CFLAGS) -o laplace2d_intel $^ $(LDFLAGS)

prec.o prec.mod:     prec.f90
timing.o timing.mod: timing.f90
laplace2d.o:         laplace2d.f90 prec.mod timing.mod
update_A.o:          update_A.f90 prec.mod
copy_A.o:            copy_A.f90 prec.mod

.PHONY: clean
clean:
        rm -f laplace2d_gnu laplace2d_intel $(objects) *.mod
```

Defining variables

- Another way to support different compilers or platforms is to include a platform specific file (e.g., make.inc) containing the needed definition of variables

```
include make.inc
```

- Common applications feature many make.inc.<platform_name> which you have to select and copy to make.inc before compiling

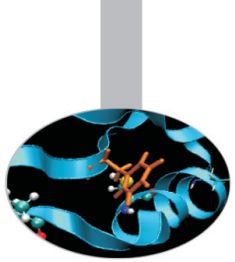
- When invoking `make`, it is also possible to set a variable

```
make OPTFLAGS=-O3
```

  - this value will override the value inside the Makefile
  - unless `override` directive is used
  - but override is useful when you want to add options to the user defined options, e.g.

```
override CFLAGS += -g
```

Variable Flavours



- The variables considered until now are called *simply expanded* variables, are assigned using `:=` and work like variables in most programming languages.
- The other flavour of variables is called *recursively expanded*, and is assigned by the simple `=`
  - recursive expansion allows to make the next assignments working as expected

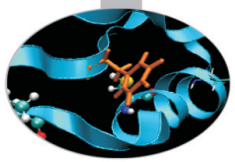
```
CFLAGS        = $(include_dirs) -O
include_dirs = -Ifoo -Ibar
```

  - but may lead to unpredictable substitutions or even impossibile circular dependencies

```
CFLAGS        = $(CFLAGS) -g
```

- You may use `+=` to add more text to the value of a variable
  - acts just like normal `=` if the variable in still undefined
  - otherwise, exactly what `+=` does depends on what flavor of variable you defined originally
- Use recursive variables only if needed

Wildcards



- A single file name can specify many files using wildcard characters: `*`, `?` and `[...]`
- Wildcard expansion depends on the context
  - performed by make automatically in targets and in prerequisites
  - in recipes, the shell is responsible for
  - what happens typing **`make print`** in the example below? (The automatic variable **`$?`** stands for files that have changed)

```
print: *.c
       lpr -p $?
       touch print
```

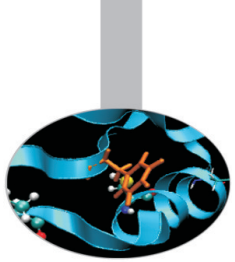
  - if you define

```
objects = *.o
foo : $(objects)
       gcc -o foo $(objects)
```

    it is expanded only when is used and it is not expanded if no .o file exists: in that case, foo depends on a oddly-named `.o` file
  - use instead the **`wildcard`** function:

```
objects := $(wildcard *.o)
```

Conditional parts of Makefile

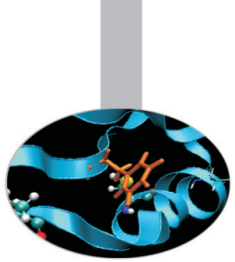


- Environment variables are automatically transformed into make variables
- Variables could be not enough to generalize rules
  - e.g., you may need non-trivial variable dependencies
- Immagine your application has to be compiled using GNU on your local machine mac_loc, and Intel on the cluster mac_clus
- You can catch the hostname from shell and use a conditional statement (**$SHELL** is not exported)

```
SHELL := /bin/sh
HOST  := $(shell hostname)
ifeq ($(HOST),mac_loc)
   CC     := gcc
   CFLAGS := -O3
endif
ifeq ($(HOST),mac_clus)
   CC     := icc
   CFLAGS := -fast
endif
```

- Be careful on Windows systems!

Directories for Prerequisites

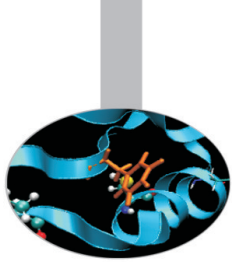


- For large systems, it is often desirable to put sources and headers in separate directories from the binaries
- Using Make, you do not need to change the individual prerequisites, just the search paths
- A **`vpath`** pattern is a string containing a `%` character.
  - **`%.h`** matches files that end in **`.h`**

```
vpath %.c foo
vpath %   blish
vpath %.c bar
```

  will look for a file ending in `.c` in foo, then blish, then bar
- using `vpath` without specifying directory clears all search paths associated with patterns

Directories for Prerequisites / 2



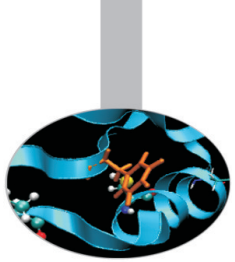
- When using directory searching, recipe generalizing is mandatory

```
vpath %.c src
vpath %.h ../headers
foo.o : foo.c defs.h hack.h
        gcc -c $< -o $@
```

- Again, automatic variables solve the problem
- And implicit or pattern rules may be used, too
- Directory search also works for linking libraries using prerequisites of the form `-lname`
- `make` will search for the file libname.so and, if not found, for libname.a first searching in vpath and then in system directory

```
foo : foo.c -lcurses
      gcc $^ -o $@
```

Advanced topics



- Functions, also user-defined
  - e.g., define objects as the list of file which will be produced from all .c files in the directory

```
objects := $(patsubst %.c,%.o,$(wildcard *.c))
```

  - e.g., sorts the words of list in lexical order, removing duplicate words

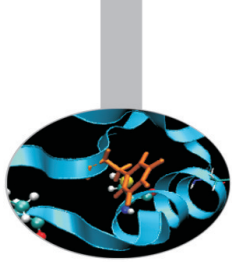
```
headers := $(sort math.h stdio.h timer.h math.h)
```

- Recursive make, i.e. make calling chains of makes
  - MAKELEVEL variable keeps the level of invocation

Standard Targets (good practice)

- all → Compile the entire program. This should be the default target
- install → Compile the program and copy the executables, libraries, and so on to the file names where they should reside for actual use.
- uninstall → Delete all the installed files
- clean → Delete all files in the current directory that are normally created by building the program.
- distclean → Delete all files in the current directory (or created by this makefile) that are created by configuring or building the program.
- check → Perform self-tests (if any).
- install-html/install-dvi/install-pdf/install-ps → Install documentation
- html/dvi/pdf/ps → Create documentation

Much more...



- Compiling a large application may require several hours
- Running make in parallel can be very helpful, e.g. to use 8 processes

```
make -j8
```

  - but not completely safe (e.g., recursive make compilation)
- There is much more you could know about **`make`**
  - this should be enough for your in-house application
  - but probably not enough for understanding large projects you could encounter

http://www.gnu.org/software/make/manual/make.html

Hands-on

- Write a Makefile managing a simple mixed C/Fortran project
- Sources are in **`c_src`** and **`f90_src`** directories
- How to compile and build is described in the README file:

```
target all_c ==> Main and functions in C:
gcc avg_main.c avg_fun.c

target all_f90 ==> Main and functions in Fortran:
gfortran avg_fun.f90 avg_main.f90

target main_f90_fun_c ==> Fortran Main and C functions:
gcc -c avg_fun.c
gfortran avg_fun.o mod_wrapC.f90 avg_main.f90

target main_c_fun_f90 ==> C Main and Fortran functions:
gcc -c avg_main.c
gfortran avg_main.o avg_fun.f90 mod_wrapF.f90
```

- Use **`vpath`**, implicit rules, a default help target, and be careful about Fortran modules

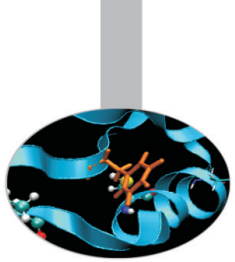
Hands-on: solution

```
SHELL      := /bin/sh
FC         := gfortran
CC         := gcc
CFLAGS     := -O3
FCFLAGS    := -O3

.SUFFIXES :=
.SUFFIXES := .c .f90 .o

vpath %.c   c_src
vpath %.f90 f90_src

%.o: %.c
        $(CC) $(CFLAGS) $(CPPFLAGS) -c $<
%.o: %.f90
        $(FC) $(FFLAGS) -c $<

help:
        @echo "Please specify a valid target:"
        @echo "all_c/all_f90/main_f90_fun_c/main_c_fun_90"

..............
```

Hands-on: solution / 2

```
...............

all_c: avg_main_c.o avg_fun_c.o
        $(CC) $(CFLAGS) -o $@ $^ $(LDFLAGS)

all_f90: avg_main_f90.o avg_fun_f90.o
        $(FC) $(FCFLAGS) -o $@ $^ $(LDFLAGS)

main_f90_fun_c: avg_fun_c.o mod_wrapC.o avg_main_f90.o
        $(FC) $(FCFLAGS) -o $@ $^ $(LDFLAGS)

main_c_fun_f90: avg_main_c.o mod_wrapF.o avg_fun_f90.o
        $(FC) $(FCFLAGS) -o $@ $^ $(LDFLAGS)

avg_main_f90.o: avg_main_f90.f90 statistics.mod
statistics.mod: avg_fun_f90.o mod_wrapC.o mod_wrapF.o

.PHONY: clean
clean:
        rm -f all_c all_f90 main_f90_fun_c main_c_fun_f90
rm -f *.o *.mod
```

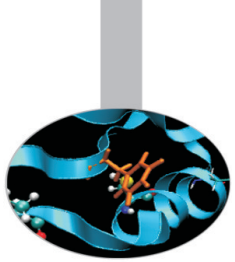
Outline



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.

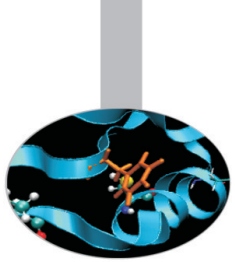
Testing-Debugging



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

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

Testing-Debugging

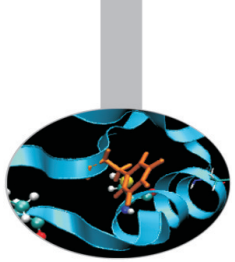


- TESTING: finds errors.
- DEBUGGING: localizes and repairs them.

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

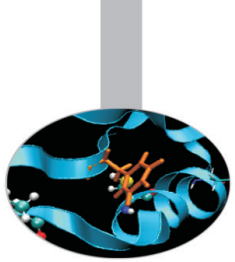
Program testing can be used to show the presence of bugs, but never to show their absence!
Edsger Dijkstra

What is a bug?



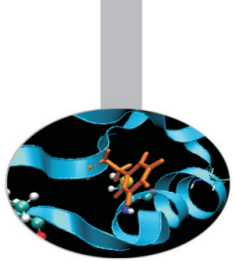
- Defect: An incorrect program code

What is a bug?



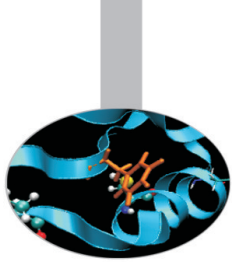
- Defect: An incorrect program code $\Longrightarrow$ a bug in the code.

What is a bug?



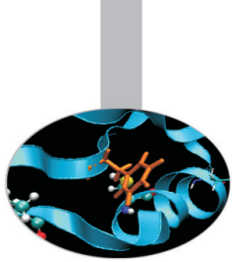
- Defect: An incorrect program code $\Longrightarrow$ a bug in the code.
- Infection: An incorrect program state

What is a bug?



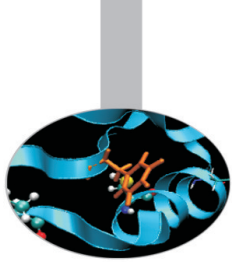
- Defect: An incorrect program code $\Longrightarrow$ a bug in the code.
- Infection: An incorrect program state $\Longrightarrow$ a bug in the state.

What is a bug?



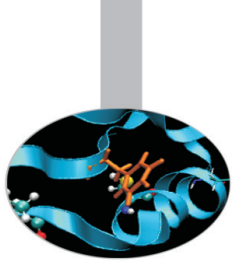
- Defect: An incorrect program code $\Longrightarrow$ a bug in the code.
- Infection: An incorrect program state $\Longrightarrow$ a bug in the state.
- Failure: An osservable incorrect program behaviour

What is a bug?



- Defect: An incorrect program code $\Longrightarrow$ a bug in the code.
- Infection: An incorrect program state $\Longrightarrow$ a bug in the state.
- Failure: An osservable incorrect program behaviour $\Longrightarrow$ a bug in the behaviour.

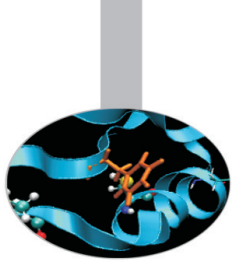
Infection chain



Defect

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

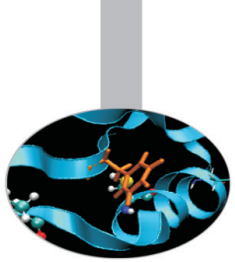
Infection chain



$$\boxed{\text{Defect} \Longrightarrow \text{Infection}}$$

- 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.

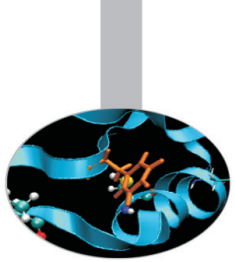
Infection chain



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

- 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.

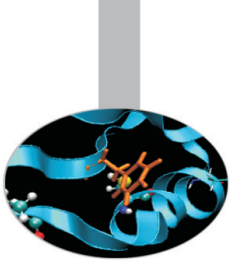
Tracking down defect



Failure

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

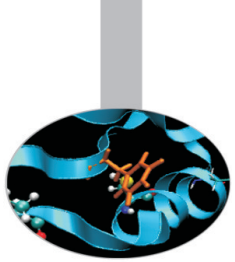
Tracking down defect



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

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

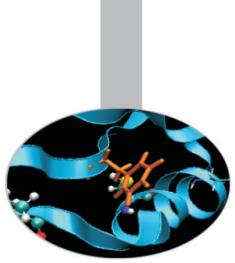
Tracking down defect



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

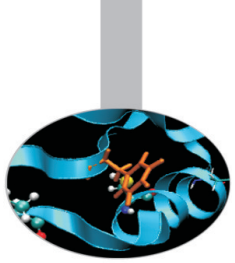
- A Failure is visible to the end user of a program. For example, the program prints an incorrect output.
- Infection is the underlying state of the program at runtime that leads to a Failure. For example, the program might display the incorrect output because the wrong value is stored in avariable.
- A Defect is the actual incorrect fragment of code that the programmer wrote; this is what must be changed to fix the problem.

First of all..



THE BEST WAY TO DEBUG A PROGRAM IS
TO MAKE NO MISTAKES

First of all..



THE BEST WAY TO DEBUG A PROGRAM IS
TO MAKE NO MISTAKES

- Preventing bugs.
- Detecting/locating bugs.

First of all..

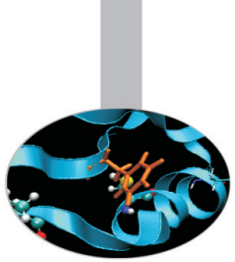
THE BEST WAY TO DEBUG A PROGRAM IS
TO MAKE NO MISTAKES

- Preventing bugs.
- Detecting/locating bugs.

Ca. 80 percent of software development costs spent on identifying and correcting defects.

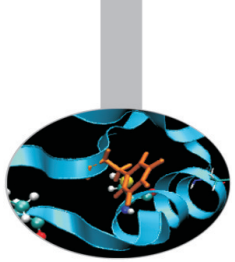
It is much more expensive (in terms of time and effort) to detect/locate exisisting bugs, than prevent them in the first place.

IfSQ Institute for Software Quality



www.ifsq.org

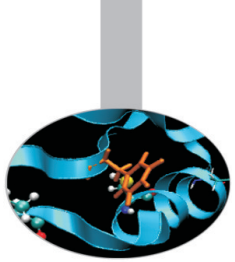
IfSQ Institute for Software Quality



www.ifsq.org

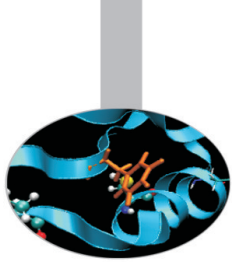
- We have an agreed common goal: to raise the standard of software (and software development) around the world by promoting Code Inspection as a prerequisite to Software Testing in the production and delivery cycle.
- Our strong hope is that eventually the idea of inspecting code before testing will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

The Fundamental question



How can I prevent Bugs?

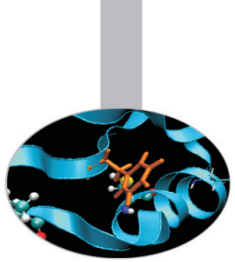
The Fundamental question



How can I prevent Bugs?

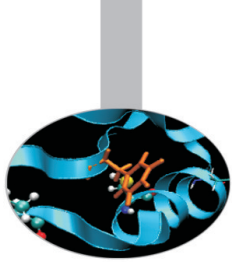
- Design.
- Good writing.
- Self-checking code.
- Test scaffolding.

Preventing bugs via design



Programming is a design activity.
It's a creative act, not mechanical code generation.

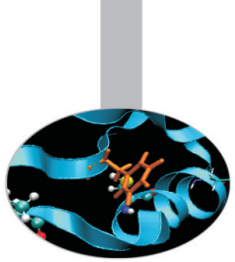
Preventing bugs via design



Programming is a design activity.
It's a creative act, not mechanical code generation.

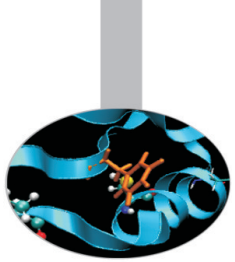
- Good modularization.
- Strong encapsulation/information hiding.
- Clear,simple pre- and post-processing.
- Requirements of operations should testable.

What is a module?



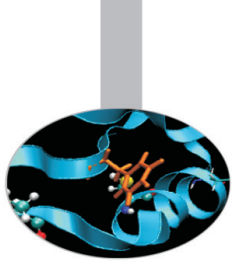
- A module is a discrete, well-defined, small component of a system.
- The smaller the component, the easier it is to understand.
- Every component has interfaces with other components, and all interfaces are sources of confusion.

What is a module?



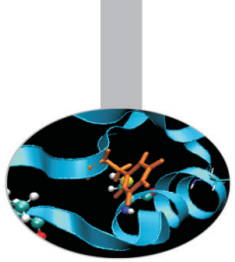
- A module is a discrete, well-defined, small component of a system.
- The smaller the component, the easier it is to understand.
- Every component has interfaces with other components, and all interfaces are sources of confusion.
  39% of all errors are caused by internal
  interface errors / errors in communication between routines.

What is a module?



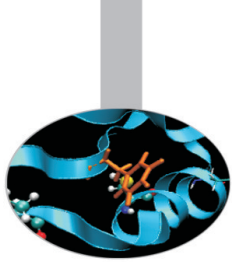
- A module is a discrete, well-defined, small component of a system.
- The smaller the component, the easier it is to understand.
- Every component has interfaces with other components, and all interfaces are sources of confusion.
  39% of all errors are caused by internal
  interface errors / errors in communication between routines.
- Large components reduce external interfaces but have complicated internal logic that may be difficult or impossible to understand.
- The art of software engineering is setting component size and boundaries at points that balance internal complexity against interface complexity to achieve an overall complexity minimization.

What is a module?



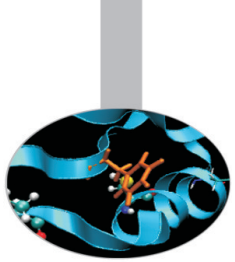
- A module is a discrete, well-defined, small component of a system.
- The smaller the component, the easier it is to understand.
- Every component has interfaces with other components, and all interfaces are sources of confusion.
  39% of all errors are caused by internal
  interface errors / errors in communication between routines.
- Large components reduce external interfaces but have complicated internal logic that may be difficult or impossible to understand.
- The art of software engineering is setting component size and boundaries at points that balance internal complexity against interface complexity to achieve an overall complexity minimization.
  A study showed that when routines averaged 100 to 150 lines each, code was more stable and required less changes.

Good modularization...



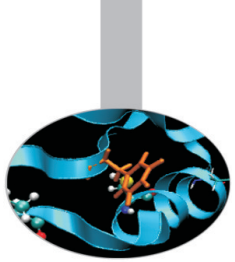
- reduces complexity
- avoids duplicate code
- facilitates reusable code
- limits effects of the changes
- facilitates test
- results in easier implementation

Strong encapsulation/information hiding



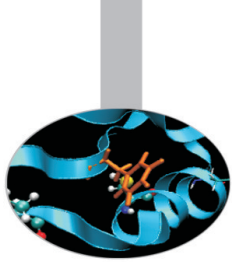
- The principle of information hiding suggests that modules be characterized by design decisions that each hides from all others.
- The information contained within a module is inaccesible to other modules that have no need for such information.
- Hiding implies that effective modularity can be achieved 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.

Cohesion & Coupling



- Cohesion: a measure of how closely the instructions in a module are related to each other.
- Coupling: a measure of how closely a modules' execution depends upon other modules.

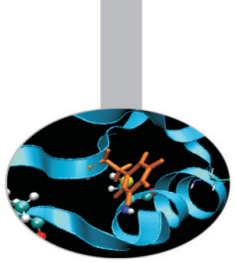
Cohesion & Coupling



- Cohesion: a measure of how closely the instructions in a module are related to each other.
- Coupling: a measure of how closely a modules' execution depends upon other modules.

- Avoid global variables.
- 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.

Cohesion & Coupling

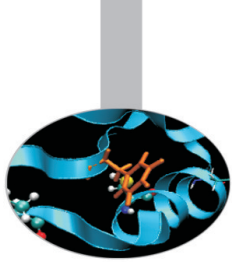


- Cohesion: a measure of how closely the instructions in a module are related to each other.
- Coupling: a measure of how closely a modules' execution depends upon other modules.

- Avoid global variables.
- 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.

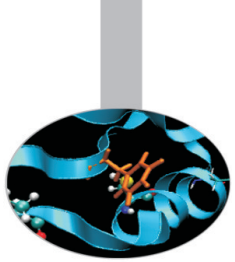
Spaghetti code is characterized by very strong coupling.

Preventing bugs via good writing



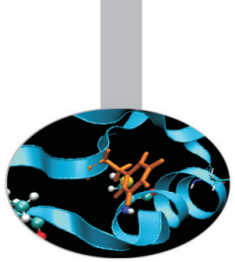
- Clarity is more important than efficiency: clarity of writing and style.
  - Use simple expressions, not complex
  - Use meaningful names
  - Clarity of purpose for:
    - Functions.
    - Loops.
    - Nested constructs.

Preventing bugs via good writing



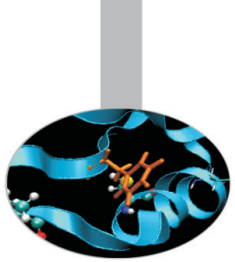
- Clarity is more important than efficiency: clarity of writing and style.
  - Use simple expressions, not complex
  - Use meaningful names
  - Clarity of purpose for:
    - Functions.
    - Loops.
    - Nested constructs.
      Studies have shown that few people can understand nesting of conditional statements to more than 3 levels.

Preventing bugs via good writing



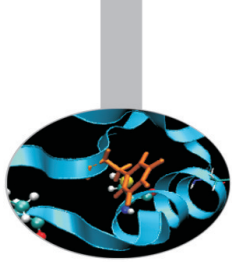
- Clarity is more important than efficiency: clarity of writing and style.
  - Use simple expressions, not complex
  - Use meaningful names
  - Clarity of purpose for:
    - Functions.
    - Loops.
    - Nested constructs.
      Studies have shown that few people can understand nesting of conditional statements to more than 3 levels.
- Comments,comments,comments.
- Small size of functions,routines.

Preventing bugs via good writing



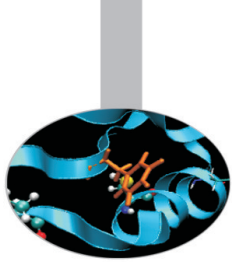
- Clarity is more important than efficiency: clarity of writing and style.
  - Use simple expressions, not complex
  - Use meaningful names
  - Clarity of purpose for:
    - Functions.
    - Loops.
    - Nested constructs.
      Studies have shown that few people can understand nesting of conditional statements to more than 3 levels.
- 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.

Preventing bugs via good writing 2



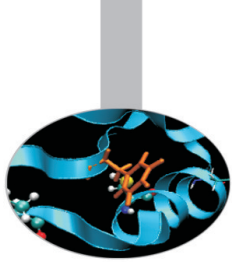
- Use the smallest acceptable scope for:
  - Variable names.
  - Static/local functions.
- Use named intermediate values.
- Avoid "Magic numbers".
- Generalize your code.
- Document your program.
- Write standard language.

Preventing bugs via Self-checking code



- Checking assumptions.
- "assert" macro.
- Custom "assert" macros.
- Assertions about intermediate values.
- Preconditions,postcondition.

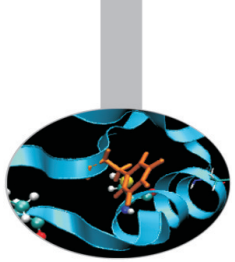
Preventing bugs via Self-checking code



- Checking assumptions.
- "assert" macro.
- Custom "assert" macros.
- Assertions about intermediate values.
- Preconditions,postcondition.

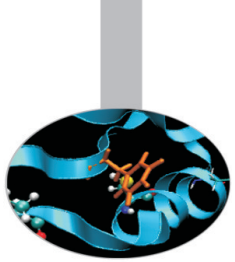
Defensive programming.

Checking assumptions



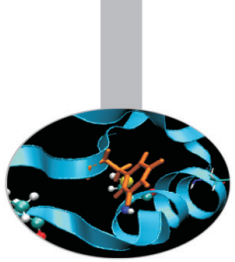
- That an input parameter's value falls within its expected range (or an output parameters' value does)
- That the value of an input-only variable is not changed by a routine.
- That a pointer is non-NULL.
- That an array or other container passed into a routine can contain at least X data number of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

Assertions



- 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.

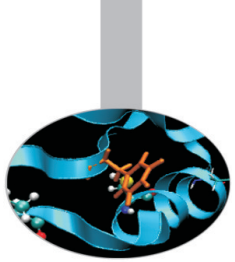
Error handling technique



- 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.

Outline

Testing: a simple program



Input

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

Testing: a simple program

Input

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

Output

Tell whether the triangle is:
Scalene
Isosceles
Equilater.

Testing: a simple program

Input

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

Output

Tell whether the triangle is:
Scalene
Isosceles
Equilater.

Create a set of test cases for this program.

Testing: a simple program

Input

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

Output

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)

Testing: a simple program

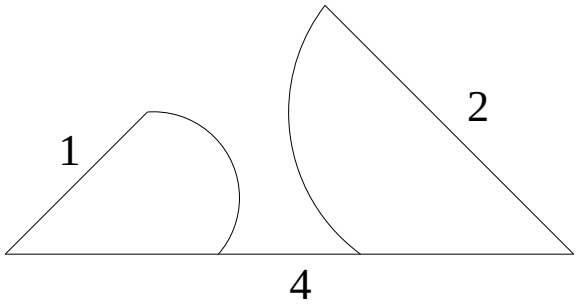
Q:1 Do you have a test case with three integers greater than zero such that the sum of two of the numbers is less than the third ?

Testing: a simple program

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 invalide triangle.

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

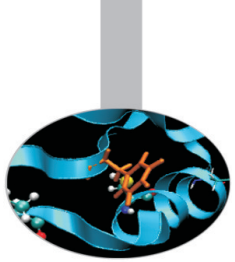


Define valide triangles $a < b + c$

Testing: a simple program

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

Testing: a simple program



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

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

Fulfill above definition, but are still invalid.

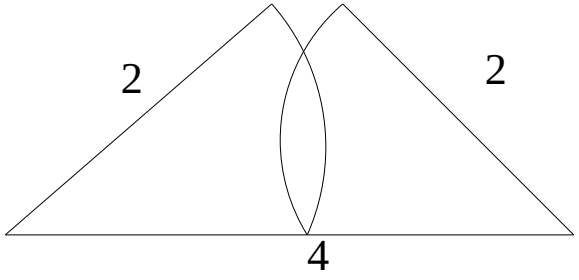
Patch definition of valid triangles:
$a < b + c$ $b < a + c$ and $c < a + b$

Testing: a simple program

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?

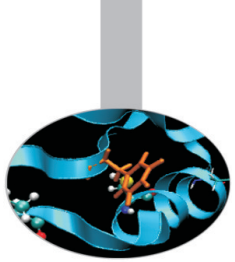
Testing: a simple program

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 and b $<$ a+c and c $<$ a+b

Testing: a simple program

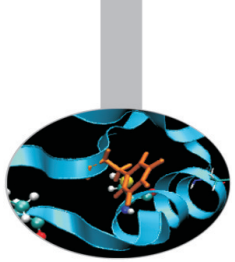


Do you have a test case:

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)

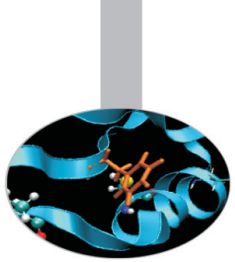
Q:14 For each test case did you specify the expected output from the program in addition to the input values?

About the example



- 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.

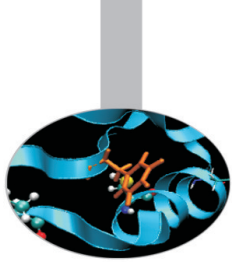
Classification of errors



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.

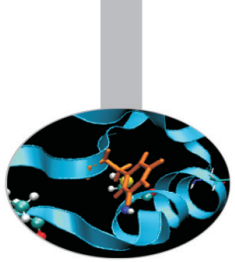
Classification of errors



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.
  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.

Classification of errors



Runtime

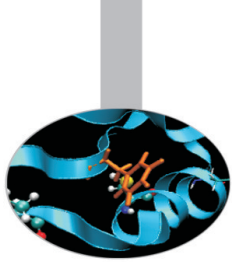
- Definition: "Asking the computer to do the impossible!"
- Examples: division by zero, taking the square root of a negative number, referring to the 101th on a list of only 100 items, deferencing a null pointer, etc.
- Occur: an error that is not detected until the program is executed, and then causes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

Classification of errors

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.
  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.

Classification of errors



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.

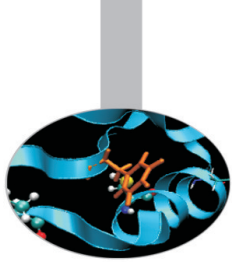
Classification of errors

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.
  It is a type of error that only the programmer can recognize.Finding and correcting logic errors in a program is known as debugging.

Outline

Definitions



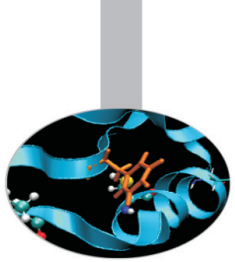
Static analysis refers to a method of examinig software that allows developers to discover dangerous programming pratices or potential errors in source code, without actually run the code.

Definitions

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.

Compiler and errors

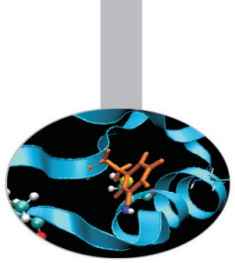


Source Program $\Longrightarrow$ Compiler $\Longrightarrow$ Target program

$\Downarrow$

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

Compiler and errors



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

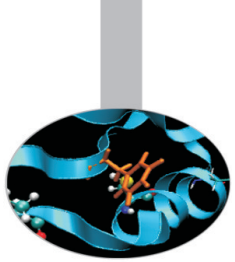
$\Downarrow$

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

Compiler checks:

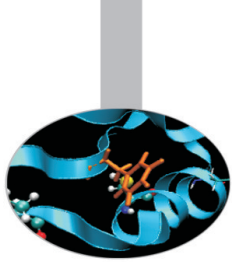
- Syntax.
- Semantic.

Lexical (Syntactic) errors



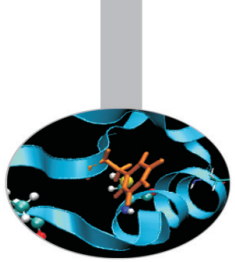
- Characters in the source that aren't in the alphabet of the language.
- Words in the source that aren't in the vocabulary of the language.

Syntactic errors



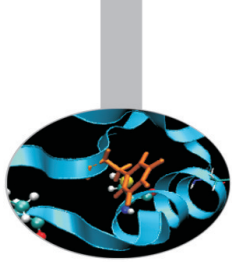
- Comment delimiters that have been put in wrong place or omitted.
- Literal delimiters that have been put in wrong place or omitted.
- Keywords that have been misspelled.
- Required punctuation that is missing.
- Construct delimiters such as parentheses or braces that have been missplaced.
- Blank or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

Semantic errors



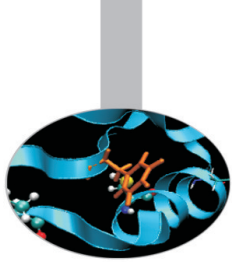
- Names that aren't declared.
- Operands of the wrong type for the operator they're used with.
- Values that have the wrong type for the name to which they're assigned.
- Procedures that are invoked with the wrong number of arguments.
- Procedures that are invoked with the wrong type of arguments.
-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

Semantic errors



- 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.

Compilers



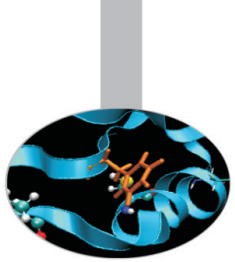
- Not all compilers find the same defects.
- The more information a compilers has, the more defects it can find.
- Some compilers operate in "forgiving" mode but have "strict" or "pedantic" mode, if you request it.

Outline

Static analysis:example 1 part one

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

Static analysis:example 1 part one



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

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

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

```
Two plus two is 0.000000
```

Static analysis:example 1 part two

```
<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'
```

Static analysis:example 1 part two

```
<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'
```

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

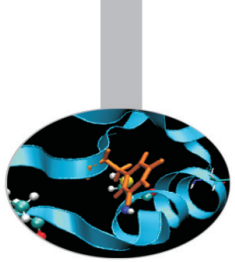
Static analysis:example 1 part two

```
<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'
```

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

gcc options



-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

Oher compilers

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

Oher compilers

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

```
[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);
                                    ^
```

check.c:source

```
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  }
```

check.c:compilation

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

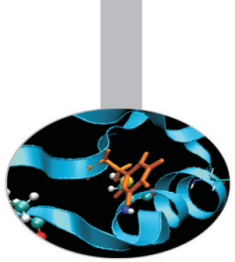
check.c:compilation

```
<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
```

gcc options



-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)
```

check1.c:source

```
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   }
```

check1.c:source

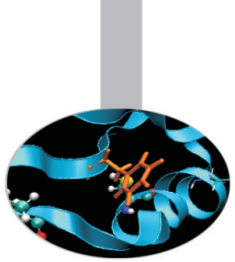
```
1  #include <stdio.h>
2   int main (void)
3   {
4          double x = 10.0;
5          double y = 11.0;
6          double z = 0.0;
7          if (x == y) {
8                      z = x * y;
9          }
10           return 0;
11  }
```

```
<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
```

gcc: other compiler options



-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

testinit.c:source

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

testinit.c:source

```
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
```

testinit.c:source

```
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
```

testinit.c:source

```
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
```

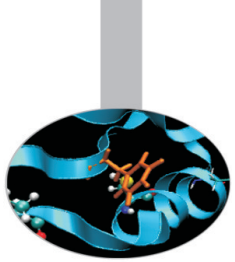
```
ruggiero@shiva:~> gcc -O1 -Wall -Wextra -Wuninitialized testinit.c
```

```
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;
```

Compilation: default options



```
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
```

Compilation: default options

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

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

```
11
```

Compilation: default options

```
> 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
```

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.
```

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
```

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.
```

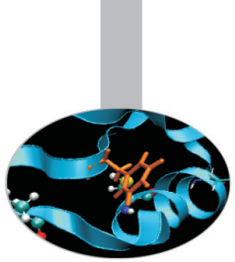
```
<ruggiero@ife2 ~>ifort par.f -assume noprotect_constants -o par.x
```

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

```
11
```

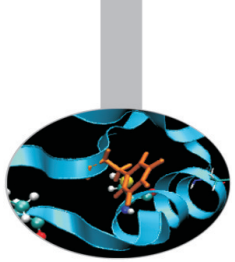
Outline

splint



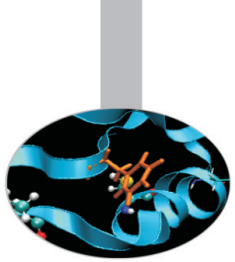
- Open Source Static Analysis Tool developed at University of Virginia by Professor Dave Evans
- Based on Lint
- www.splint.org
- splint [-option -option ...] filename [filename ...]

splint can detect with just source code...



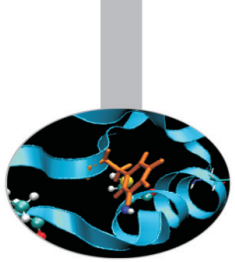
- Unused declarations.
- Type inconsistencies.
- Variables used before being assigned.
- Function return values that are ignored.
- Execution paths with no return.
- Switch cases that fall through.
- Apparent infinite loops.

splint can detect with annotation information



- 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.

splint can detect with annotation information



- 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.

Static analysis:example 1 part one

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

check.c:source

```
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  }
```

splint:examples

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

```
Finished checking --- no warnings
```

splint:examples

```
<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
```

check1.c:source

```
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
```

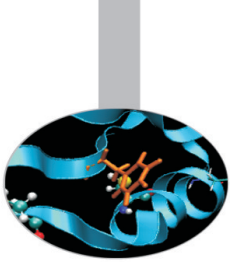
```
check1.c: In function main:
check1.c:8: warning: comparing  floating point
with == or != is unsafe
```

splint:examples

```
<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
```

check1.c: rewritten



```
int main (void)
  {
          double x = 10.0;
          double y = 11.0;
          double z = 0.0;
          double norma=0.1e-16;
          double epsilon;
         epsilon=x-y;
         if (epsilon < norma) {
                    z = x * y;
         }

           return 0;
 }
```

average.c: source

```
1  #include <stdio.h>
2  int main (void) {
3    int size = 5;
4    int a;
5    float total;
6    float art[size];
7
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 }
```

average.c: compilation e run

```
<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
```

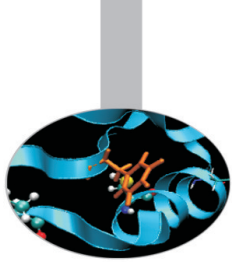
```
nan
```

average.c: splint

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

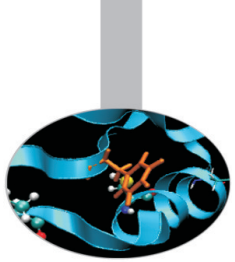
```
Splint 3.1.2 --- 28 Mar 2008

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
```

average.c: new version



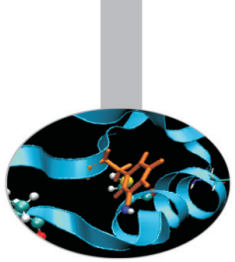
```
1  #include <stdio.h>
2  int main (void) {
3    int size = 5;
4    int a;
5    float total;
6    float art[size];
7     total=0;
8   for(a = 0 ; a < size; ++ a) {
9     art[a] = (float) a;
10    total  += art[a]; }
11   printf(" %f\n" , total / (float) size);
12   return 0;
13 }
```

assign.c: source and compilation



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

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

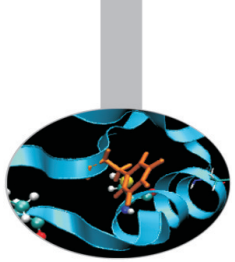
```
<ruggiero@shiva:~>splint-3.1.2/bin/splint assign.c
```

```
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
```

memory.c: source and compilation

```
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



```
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 }
```

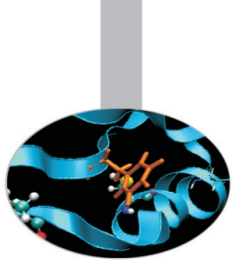
```
<ruggiero@shiva:~> gcc -Wall -Wextra memory.c
```

memory.c: splint

```
<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
```

memory.c: new version



```
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  }
```

out_b.c: source

```
1   #include<stdio.h>
2   #define N 5
3   int main (void)
4   {
5           int t[N];
6           int i;
7
8           i=6;
9           t[i] = i+1;
10
11          return 0;
12  }
```

out_b.c: splint

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

out_b.c: splint

```
<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
```

error.f: source

```
          REAL FUNCTION COMPAV(SCORE,COUNT)
              INTEGER SUM,COUNT,J,SCORE(5)
              DO 30 I = 1,COUNT
                  SUM = SUM + SCORE(I)
 30           CONTINUE
              COMPAV = SUM/COUNT
              write(*,*) compav
          END
          PROGRAM AVENUM
            PARAMETER(MAXNOS=10)
            INTEGER I, COUNT
            REAL NUMS(MAXNOS), AVG
            COUNT = 0
            DO 80 I = 1,MAXNOS
                  READ (5,*,END=100) NUMS(I)
                  COUNT = COUNT + 1
80            CONTINUE
100           AVG = COMPAV(NUMS, COUNT)
          END
```

error.f: compilation

```
<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)
```

error.f: compilation

```
<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)
-------------------^
```

error.f: compilation

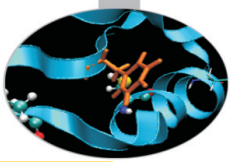
```
<ruggiero@ife2 /ftnchek>g95 -Wall -Wextra error.f
```

```
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
```

error.f: compilation

```
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)
```

www.dsm.fordham.edu/~ftnchek/



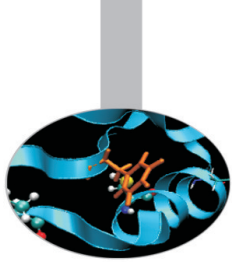
<ruggiero@ife2/ftnchek>./bin/ftnchek error.f

```
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
```

www.dsm.fordham.edu/∼ftnchek/

```
 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
```

Static analyzer for Fortran



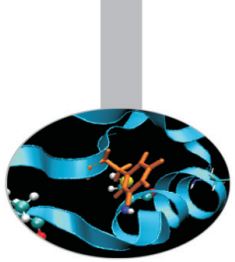
- Forcheck can handle up Fortran 95 and some Fortran 2003. item Cleanscape FortranLint can handle up to Fortran 95.
- plusFORT is a multi-purpose suite of tools for analyzing and improving Fortran programs.
- ...

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

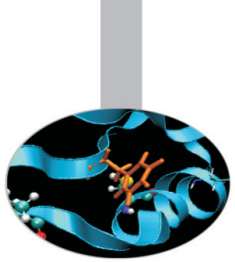


- Do not ignore compiler warnings, even if they appear to be harmless.
- Use multiple compilers to check the code.
- Familiarize yourself with a static checker.
- Reduce static checker errors to (almost) zero.
- Rerun all test cases after a code cleanup.
- Doing regular sweeps of the source code will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

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

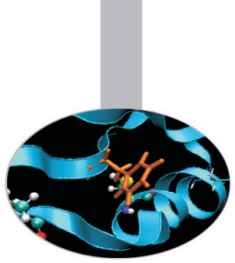
Outline

Runtime signals



- 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.

Runtime signals

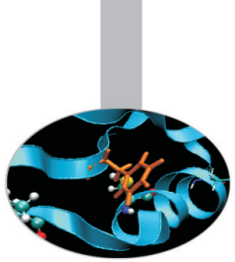


You can find out why the job was killed using:

```
[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)
......
```

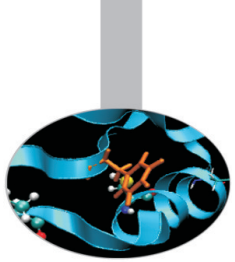
Action description

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.

FPE example



```
main()
{
  int a = 1.;
  int b = 0.;
  int c = a/b;
}
```

FPE example

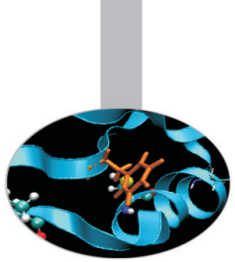
```
main()
{
  int a = 1.;
  int b = 0.;
  int c = a/b;
}
```

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

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

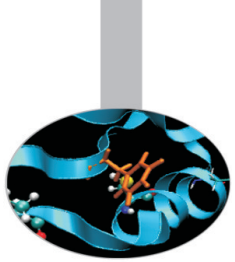
```
Floating exception
```

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  }
```

SEGV example



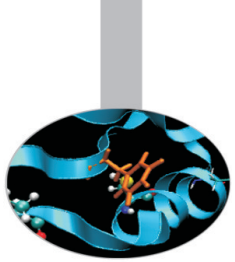
```
1  main()
2  {
3  int array[5]; int i;
4       for(i = 0; i < 255; i++) {
5            array[i] = 10;}
6      return 0;
7  }
```

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

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

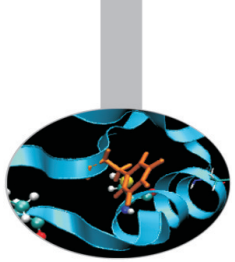
Segmentation fault

ABORT example



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

ABORT example



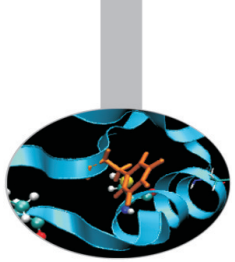
```
1  #include <assert.h>
2  main()
3  {
4    int i=0;
5    assert(i!=0);
6  }
```

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

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

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

Common runtime errors

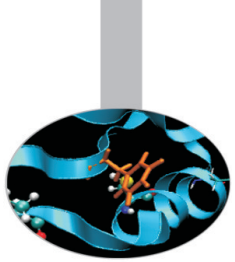


- Allocation Deallocation errors (AD).
- Array conformance errors (AC).
- Array Index out of Bound (AIOB).
- Language specific errors (LS).
- Floating Point errors (FP).
- Input Output errors (IO).
- Memory leaks (ML).
- Pointer errors (PE).
- String errors (SE).
- Subprogram call errors (SCE).
- Uninitialized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

Useful link

- Iowa State University's High Performance Computing Group
- Run Time Error Detection Test Suites for Fortran, C, and C++
- http://rted.public.iastate.edu

Grading Methodology: score

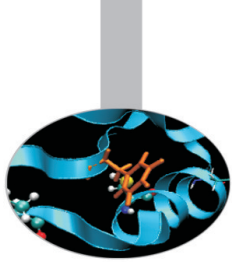


- 0.0: is given when the error was not detected.
- 1.0: is given for error messages with the correct error name.
- 2.0: is given for error messages with the correct error name and line number where the error occurred but not the file name where the error occurred.
- 3.0: is given for error messages with 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

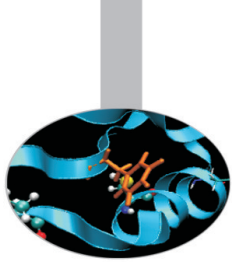
```
!*********************************************************************
!  copyright (c) 2005 Iowa State University, Glenn Luecke, James Coyle,
!  James Hoekstra, Marina Kraeva, Olga Taborskaia, Andre Wehe, Ying Xu,
!  and Ziyu Zhang, All rights reserved.
!  Licensed under the Educational Community 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



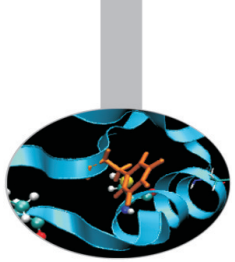
```
!
!     Last modified:     1/17/2005
!
!     Programmer:        Ying Xu, Iowa State Univ.
!*********************************************************************

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
```

Grading Methodology: an example



```
      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
```

Grading Methodology: an example



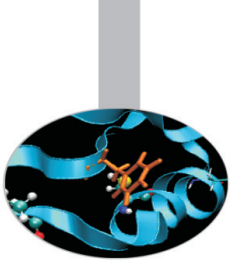
Real message (grade 1.0)

```
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
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-12.0.2	0.421053	1.62963	3.44727	2.82353	0.571428	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
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

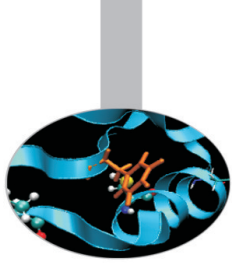
Fortran Results

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
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-12.0.2	0	3.55469	0	0.166667	0.292994
open64.4.2.3	0	3.00391	0	0	0.0127389
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
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	AloB	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
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-12.0.2	0.44	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
sun-12.1	0.44	0.00925926	0	0	0.2
sun-12.1+bcheck	0.16	0	0	0	0

C Results

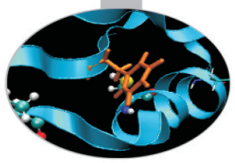


Compiler	ML	PE	SE	SCE	UV
gcc-4.3.2	0.0166667	0.0166667	0.05	0	0
gcc-4.4.3	0.0166667	0.0166667	0.05	0	0
gcc-4.6.3	0.0166667	0.0166667	0.05	0	0
gcc-4.7.0	0.0166667	0.0166667	0.05	0	0
intel-10.1.021	0.0666667	0.0166667	0.05	0	0
intel-11.0.074	0.0666667	0.0166667	0.05	0	0
intel-12.0.2	0.0666667	0.0166667	0.05	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
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
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-12.0.2	0.311927	0.00903614	0	0.0714286	0.047619	0.0254777	0.05	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
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

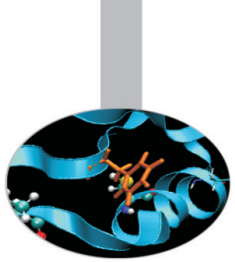
gcc	-O0 -g -fbounds-check -ftrapv
intel	-O0 -C -g -traceback
open64	-g -C -O0
pgi	-g -C -Mchkptr -O0
sun	-g -C -O0 -xs -ftrap=%all -fnonstd -xcheck=%all

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

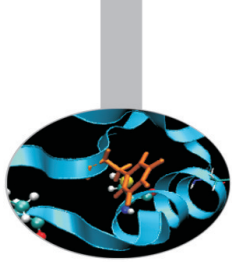
Outline

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.

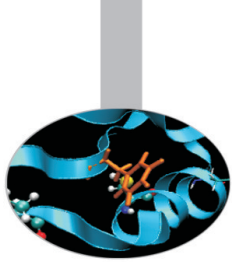
Valgrind



- 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).

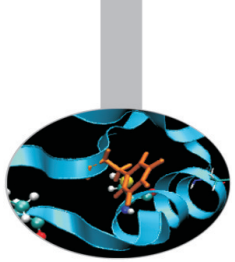
www.valgrind.org

Valgrind:tools



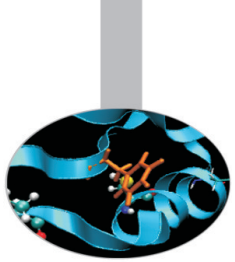
- Memcheck: a memory checker.
- Callgrind: a runtime profiler.
- Cachegrind: a cache profiler.
- Helgrind: find race conditions.
- Massif: a memory profiler.

Why should use I use Valgrind?



- Valgrind will tell you about tough to find bugs.
- Valgrind is very through.
- 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.

Why should use I use Valgrind?



- Valgrind will tell you about tough to find bugs.
- Valgrind is very through.
- 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...

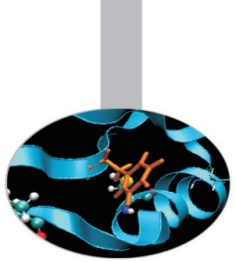
Valgrind is kind-of like a virtual x86 interpeter. So your program will run 10 to 30 times slower than normal.

Valgrind won't check static arrays.

Use of uninitialized memory:test1.c

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

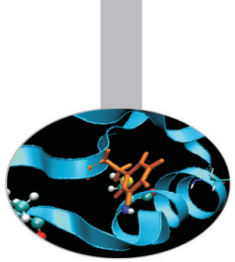
Use of uninitialized memory:test1.c



- 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)
6           t=p+1;
7           b[p]=100;
8       return 0;
9  }
```

Use of uninitialized memory:test1.c



- 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  }
```

Valgrind output

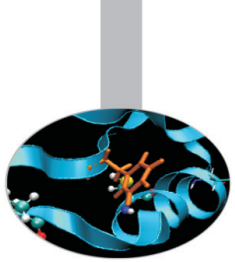
```
ruggiero@shiva:> valgrind --tool=memcheck --leak-check=full ./t1
```

Valgrind output

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

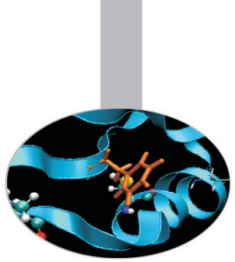
```
==7879== Memcheck, a memory error detector.
             ....
==7879== Conditional jump or move depends on uninitialised value(s)
==7879==    at 0x8048399: main (test1.c:5)
==7879==
==7879== Use of uninitialised value of size 4
==7879==    at 0x80483A7: main (test1.c:7)
==7879==
==7879== Invalid 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
```

Illegal read/write test2.c



```
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  }
```

Illegal read/write test2.c



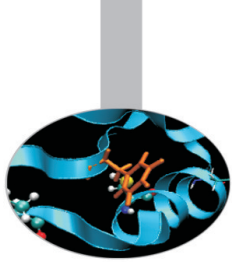
```
1   #include <stdlib.h>
2   int main()
3   {
4       int *p,i,a;
5       p=malloc(10*sizeof(int));
6           p[11]=1; ERROR
7           a=p[11]; ERROR
8           free(p);
9       return 0;
10  }
```

Illegal read/write: Valgrind output

```
ruggiero@shiva:> valgrind --tool=memcheck --leak-check=full ./t2
```

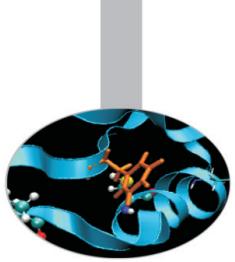
```
        .....
==8081== Invalid write of size 4
==8081==    at 0x804840A: main (test2.c:6)
==8081==  Address 0x417B054 is 4 bytes after a block of size 40 alloc'd
==8081==    at 0x40235B5: malloc (in /usr/lib/valgrind/x86-linux/vgpreload_memcheck.so)
==8081==    by 0x8048400: main (test2.c:5)
==8081==
==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.
```

Invalid free:test3.c



```
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  }
```

Invalid free:test3.c



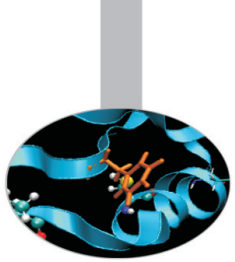
```
1   #include <stdlib.h>
2   int main()
3   {
4       int *p,i;
5       p=malloc(10*sizeof(int));
6           for(i=0;i<10;i++)
7               p[i]=i;
8           free(p);
9           free(p);     ERROR
10      return 0;
11  }
```

Invalid free: Valgrind output

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

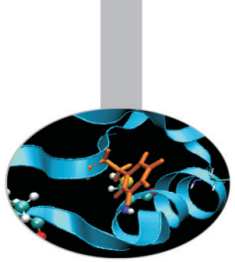
```
        .....
==8208== Invalid free() / delete / delete[]
==8208==    at 0x40231CF: free (in /usr/lib/valgrind/x86-linux/vgpreload_memcheck.so)
==8208==    by 0x804843C: main (test3.c:9)
==8208==  Address 0x417B028 is 0 bytes inside a block of size 40 free'd
==8208==    at 0x40231CF: free (in /usr/lib/valgrind/x86-linux/vgpreload_memcheck.so)
==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.
```

Mismatched use of functions:test4.cpp



- 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.**

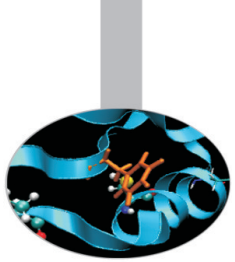
Mismatched use of functions:test4.cpp



- 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 }
```

Mismatched use of functions:test4.cpp



- 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);     ERROR
9       return 0;
10 }
```

Mismatched use of functions: Valgrind output

```
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_memche
==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.
```

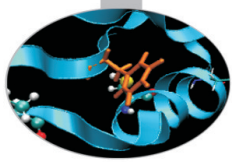
Invalid system call parameter:test5.c

```
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 }
```

Invalid system call parameter:test5.c

```
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 }
```

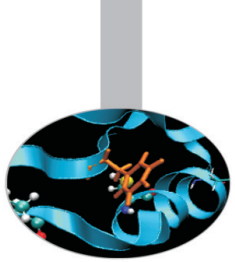
Invalid system call parameter: Valgrind output



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

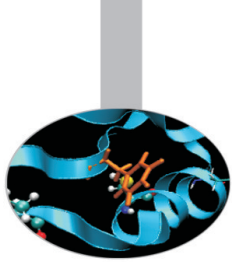
```
...
==18007== Syscall param read(buf) points to unaddressable byte(s)
==18007==    at 0x4EEC240: __read_nocancel (in /lib64/libc-2.5.so)
==18007==    by 0x40056F: main (test5.c:7)
==18007==  Address 0x517d04a is 0 bytes after a block of size 10 alloc'd
==18007==    at 0x4C21168: malloc (vg_replace_malloc.c:236)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

Memory leak detection:test6.c



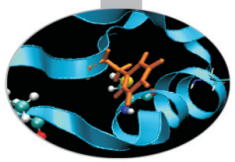
```
1   #include <stdlib.h>
2           int main()
3           {
4               int *p,i;
5               p=malloc(5*sizeof(int));
6               for(i=0; i<5;i++)
7                   p[i]=i;
8
9                   return 0;
10          }
```

Memory leak detection:test6.c



```
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          }
```

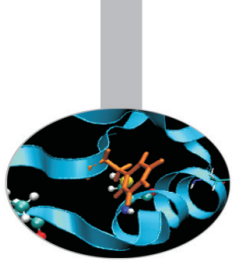
Memory leak detection: Valgrind output



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

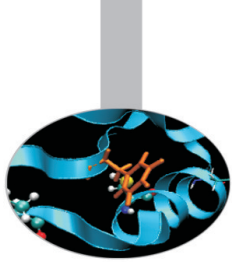
```
    .....
==8237== ERROR SUMMARY: 0 errors from 0 contexts (suppressed: 3 from 1)
    ==8237== malloc/free: in use at exit: 20 bytes in 1 blocks.
    ==8237== malloc/free: 1 allocs, 0 frees, 20 bytes allocated.
    ==8237== For counts of detected errors, rerun with: -v
    ==8237== searching for 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.
```

What won't Valgrind find?



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

What won't Valgrind find?



```
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.

sum.c: source

```
1  #include <stdio.h>
2  #include <stdlib.h>
3  int main (int argc, char* argv[])  {
4      const int size=10;
5      int n, sum=0;
6      int* A = (int*)malloc( sizeof(int)*size);
7
8      for(n=size; n>0; n--)
9          A[n] = n;
10     for(n=0; n<size; n++)
11         sum+=A[n];
12     printf("sum=%d\n", sum);
13     return 0;
14 }
```

sum.c: compilation and run

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

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

```
sum=45
```

Valgrind:example

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

```
==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==
```

outbc.c

```
#include <stdio.h>
#include<stdlib.h>
        int main (void)
        {
            int i;
            int *a = (int*) malloc( 9*sizeof(int));

            for ( i=0; i<=9; ++i){
               a[i] = i;
                printf ("%d\n ", a[i]);
            }

            free(a);
            return 0;
        }
```

outbc.c: compilation and run

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

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

```
0
1
2
3
4
5
6
7
8
9
```

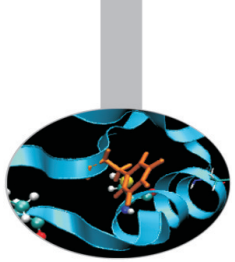
outbc.c: compilation and run

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

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

```
0
1
2
3
4
5
6
7
8
9
```

Electric Fence



- 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.

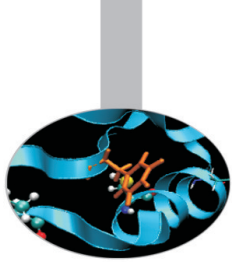
Electric Fence

```
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
```

Esercitazione:Run time errors

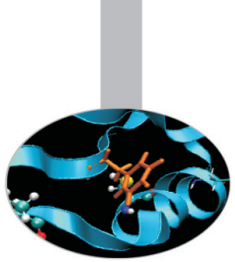


- Eseguire i seguenti comandi

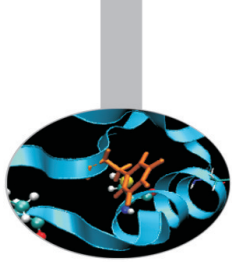
```
cp /afs/icaspur.it/project/open/space/RTED.tar /scratch
cd /scratch
tar xvf RTED.tar
```

- Nella directory RTED leggere il file Readme
- Modificare il compilatore e le relative opzioni per cercare di ottenere il valore piu' alto possibile
- Posso migliorare i risultati usando valgrind?

Outline

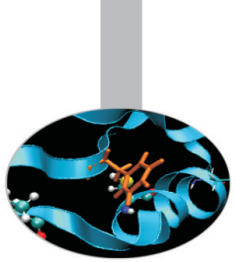


My program fails!



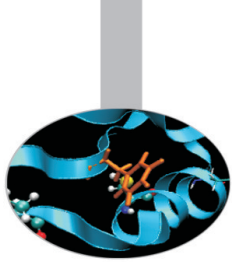
- Erroneous program results.
- Execution deadlock.
- Run-time crashes.

The ideal debugging process



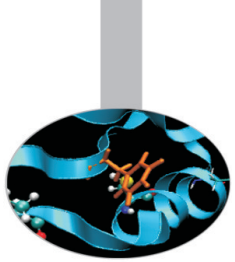
- Find origins.
  - Identify test case(s) that reliably show existence of fault (when possible). Duplicate the bug.
- Isolate the origins of infection.
  - Correlate incorrect behaviour with program logic/code error.
- Correct.
  - Fixing the error, not just a symptom of it.
- Verify.
  - Where there 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.

Bugs that can't be duplicated



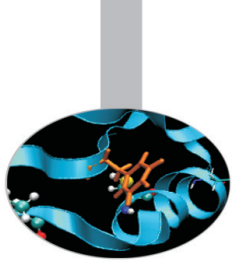
- Dangling pointers.
- Initializations errors.
- Poorly syinchronized threads.
- Broken hardware.

Isolate the origins of infection



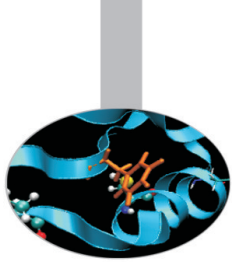
- Divide and conqueror.
- Change one thing at time.
- Determine what you changed since the last time it worked.
- Write down what you did, in what order, and what happened as a result.
- Correlate the events.

Why is debugging so difficult?



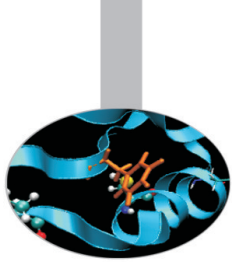
- The symptom and the cause may be geographically remote.
- The symptom may disappear (temporarily) when another error is corrected.
- The symptom may actually be caused by nonerrors (e.g., round-off inaccuracies).
- It may be difficult to accurately reproduce input conditions (e.g, a real time application 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.

Eight elements



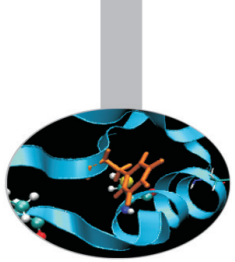
- Reproducibility.
- Reduction.
- Deduction.
- Experimentation.
- Experience.
- Tenacity.
- Good tools.
- A bit of luck.

Why use a Debugger?



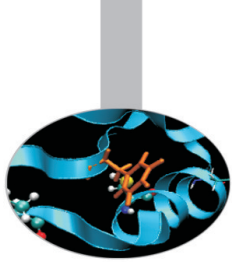
- No need for precognition of what the error might be.
- Flexible.
  - Allows for ”live” error checking (no need to re−write and re−compile when you realize a certain type of error may be occuring).
- Dynamic.
  - Execution Control Stop execution on specified conditions: breakpoints
  - Interpretation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

Why people don't use debuggers?



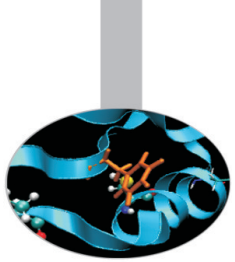
- With simple errors, may not want to bother with starting up the debugger environment.
  - Obvious error.
  - Simple to check using prints/asserts.
- Hard-to-use debugger environment.
- Error occurs in optimized code.
- Changes execution of program
  (error doesn't occur while running debugger).

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.

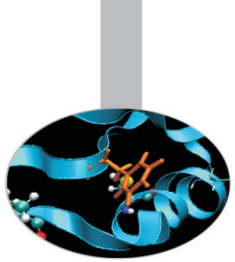
Remember



Finding bug is a process of confirming the many things you believe are true, until you find one which is not true.

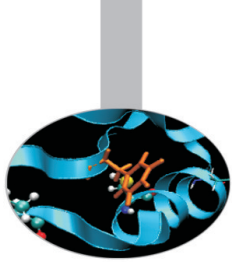
- You believe that at a certain point in your source file, a certain variable has a certain value.
- You believe that in given if-then-else statment, the ”else” part is the one that is excuted.
- You believe that when you call a certain function, the function receives its parameters correctly.
- You believe ...

Strategy

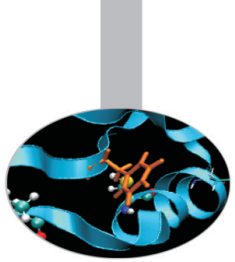


- Observe the failure.
- Invent a hypothesis.
- Use the hypothesis to make predictions.
- Test hypothesis by experiments.

Outline

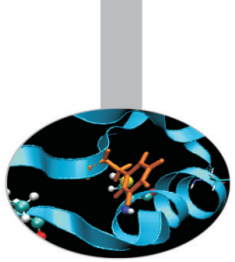


What is gdb?



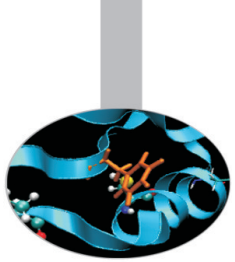
- The GNU Project debugger, is an open-source debugger.
- Protected by GNU General Public License (GPL).
- Runs on many Unix-like systems.
- Was first written by Richard Stallmann in 1986 as part of his GNU System.
- Is an Workstation Application Code extremely powerful all-purpose debugger.
- Its text-based 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

prime-numbers finding program



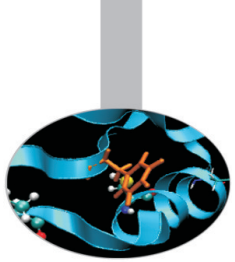
- Print a list of all primes which are less than or equal to the user-supplied upper bound *UpperBound*.
- See if J divides $K \leq$ *UpperBound*, for all values J which are
  - themselves prime (no need to try J if it is nonprime)
  - less than or equal to sqrt(K) (if K has a divisor larger than this 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.

Main.c



```
1  #include <stdio.h>
2  #define MaxPrimes 50
3  int Prime[MaxPrimes],UpperBound;
4  int main()
5  {
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 }
```

CheckPrime.c



```
1   #define MaxPrimes 50
2   extern int Prime[MaxPrimes];
3   void CheckPrime(int K)
4   {
5       int J; J = 2;
6       while (1)  {
7           if (Prime[J] == 1)
8               if (K % J == 0)  {
9                   Prime[K] = 0;
10                  return;
11              }
12              J++;
13      }
14      Prime[K] = 1;
15  }
```

Compilation and run

```
<ruggiero@matrix2 ~>gcc Main.c CheckPrime.c -O3 -o trova_primi
```

Compilation and run

```
<ruggiero@matrix2 ~>gcc Main.c CheckPrime.c -O3 -o trova_primi
```

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

Compilation and run

```
<ruggiero@matrix2 ~>gcc Main.c CheckPrime.c -O3 -o trova_primi
```

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

```
enter upper bound
```

Compilation and run

```
<ruggiero@matrix2 ~>gcc Main.c CheckPrime.c -O3 -o trova_primi
```

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

```
enter upper bound
```

20

Compilation and run

```
<ruggiero@matrix2 ~>gcc Main.c CheckPrime.c -O3 -o trova_primi
```

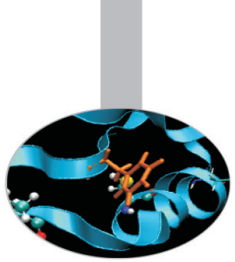
```
<ruggiero@matrix2 ~> ./trova_primi
```

```
enter upper bound
20
Segmentation fault
```

Compilation options for gdb

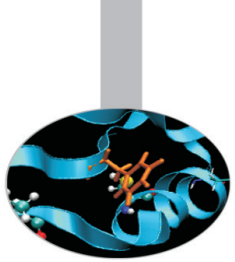
- You will need to compile your program with the appropriate flag to enable generation of symbolic debug information, the -g option is used for this.
- Don't compile your program with optimization flags while you are debugging it.
  Compiler optimizations can "rewrite" your program and produce machine 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.

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.

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.

Starting gdb

```
<ruggiero@matrix2 ~>gcc Main.c CheckPrime.c -g -O0 -o trova_primi
```

Starting gdb

```
<ruggiero@matrix2 ~>gcc Main.c CheckPrime.c -g -O0 -o trova_primi
```

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

Starting gdb

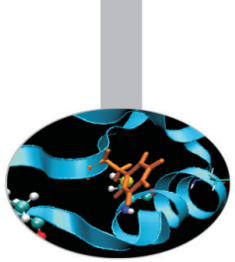
```
<ruggiero@matrix2 ~>gcc Main.c CheckPrime.c -g -O0 -o trova_primi
```

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

```
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



- run (r): start debugged program.
- help (h): print list of commands.
- she: execute the rest of the line as a shell command.
- where, backtrace (bt): print a backtrace of entire stack.
- kill (k): kill the child process in which program is running under gdb.
- list (l) linenum: print lines centered around line number lineum in the current source file.
- quit(q): exit gdb.

prime-number finding program

```
(gdb) r
```

prime-number finding program

```
(gdb) r
```

```
Starting program: trova_primi
enter upper bound
```

prime-number finding program

```
(gdb) r
```

```
Starting program: trova_primi
enter upper bound
```

20

prime-number finding program

```
(gdb) r
```

```
Starting program: trova_primi
enter upper bound
```

20

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

```
(gdb) where
```

prime-number finding program

```
(gdb) r
```

```
Starting program: trova_primi
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
```

prime-number finding program

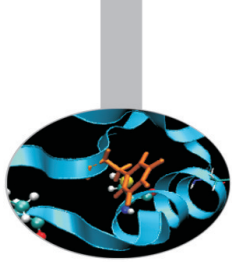
```
(gdb) list Main.c:8
```

prime-number finding program

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

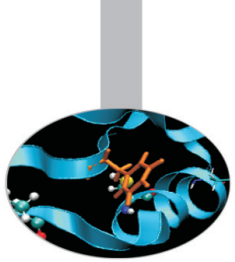
```
3    int Prime[MaxPrimes],UpperBound;
5      main()
6      {   int N;
7          printf("enter upper bound\n");
8          scanf("%d",UpperBound);
9          Prime[2] = 1;
10         for (N = 3; N <= UpperBound; N += 2)
11            CheckPrime(N);
12            if (Prime[N]) printf("%d is a prime\n",N);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

Main.c :new version



```
1   #include <stdio.h>
2   #define MaxPrimes 50
3   int Prime[MaxPrimes],UpperBound;
4   int main()
5   {
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  }
```

Main.c :new version



```
1  #include <stdio.h>
2  #define MaxPrimes 50
3  int Prime[MaxPrimes],UpperBound;
4  int main()
5  {
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 }
```

Main.c :new version

```
#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

prime-number finding program

```
(gdb) kill
```

Kill the program being debugged? (y or n)

prime-number finding program

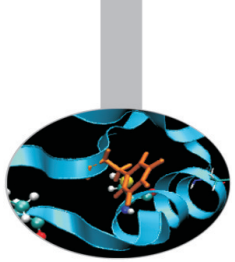
```
(gdb) kill
```

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

```
(gdb) run
```

```
Starting program: trova_primi
enter upper bound
```

prime-number finding program



```
(gdb) kill
```

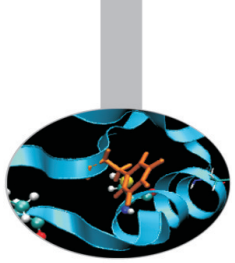
Kill the program being debugged? (y or n) y

```
(gdb) run
```

```
Starting program: trova_primi
enter upper bound
```

20

prime-number finding program



```
(gdb) kill
```

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

```
(gdb) run
```

```
Starting program: trova_primi
enter upper bound

20

Program received signal SIGSEGV, Segmentation fault.
0x0000000004005bb in CheckPrime (K=0x3) at CheckPrime.c:7
7                 if (Prime[J] == 1)
```

prime-number finding program

```
(gdb) p J
```

prime-number finding program

```
(gdb) p J
```

```
$1 = 1008
```

prime-number finding program

```
(gdb) p J
```

```
$1 = 1008
```

```
gdb l CheckPrime.c:7
```

prime-number finding program

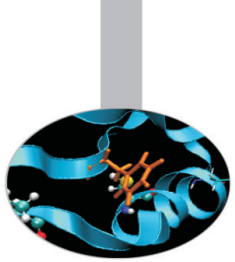
```
(gdb) p J
```

```
$1 = 1008
```

```
gdb l CheckPrime.c:7
```

```
2        extern int Prime[MaxPrimes];
3          CheckPrime(int K)
4          {
5              int J; J = 2;
6              while (1)  {
7                 if (Prime[J] == 1)
8                    if (K % J == 0)  {
9                       Prime[K] = 0;
10                      return;
11                   }
```

CheckPrime.c:new version



```
1   #define MaxPrimes 50
2   extern int Prime[MaxPrimes];
3   void CheckPrime(int K)
4      {
5        int J; J = 2;
6         while (1){
7            if (Prime[J] == 1)
8               if (K % J == 0)  {
9                  Prime[K] = 0;
10                 return;
11              }
12        J++;
13        }
14        Prime[K] = 1;
15     }
```

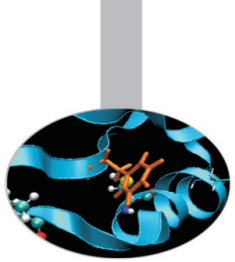
CheckPrime.c:new version

```
#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;
   }
```

prime-number finding program

In other shell COMPILATION

prime-number finding program

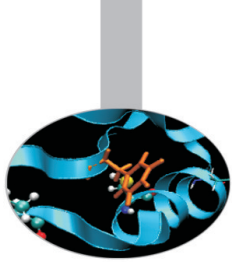


In other shell COMPILATION

```
(gdb)
```

Kill the program being debugged? (y or n)

prime-number finding program



In other shell COMPILATION

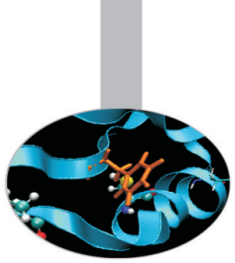
```
(gdb)
```

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

```
(gdb) run
```

```
Starting program: trova_primi
enter upper bound
```

prime-number finding program



In other shell COMPILATION

```
(gdb)
```

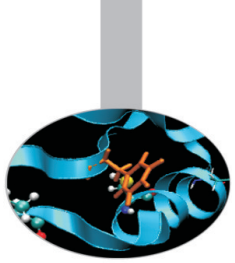
Kill the program being debugged? (y or n) y

```
(gdb) run
```

```
Starting program: trova_primi
enter upper bound
```

20

prime-number finding program



In other shell COMPILATION

```
(gdb)
```

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

```
(gdb) run
```

```
Starting program: trova_primi
enter upper bound
```

20

```
Program exited normally.
```

gdb commands

```
(gdb) help break
```

gdb commands

(gdb) help break

```
Set breakpoint at specified line or function.
break [LOCATION] [thread THREADNUM] [if CONDITION]
LOCATION may be a line number, function name, or "*" and an address.
If a line number is specified, break at start of code for that line.
If a function is specified, break at start of code for that function.
If an address is specified, break at that exact address.
.........
Multiple breakpoints at one place are permitted,
and useful if conditional.
.........
```

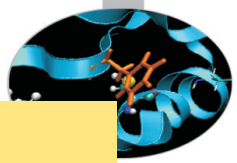
gdb commands

(gdb) help break

```
Set breakpoint at specified line or function.
break [LOCATION] [thread THREADNUM] [if CONDITION]
LOCATION may be a line number, function name, or "*" and an address.
If a line number is specified, break at start of code for that line.
If a function is specified, break at start of code for that function.
If an address is specified, break at that exact address.
.........
Multiple breakpoints at one place are permitted,
and useful if conditional.
.........
```

(gdb) help display

gdb commands



(gdb) help break

```
Set breakpoint at specified line or function.
break [LOCATION] [thread THREADNUM] [if CONDITION]
LOCATION may be a line number, function name, or "*" and an address.
If a line number is specified, break at start of code for that line.
If a function is specified, break at start of code for that function.
If an address is specified, break at that exact address.
.........
Multiple breakpoints at one place are permitted,
and useful if conditional.
.........
```

(gdb) help display

```
Print value of expression EXP each time the program stops.
.........
Use "undisplay" to cancel display requests previously made.
```

gdb commands

```
(gdb) help next
```

gdb commands

(gdb) help next

```
Step program, proceeding through subroutine calls.
Like the "step" command as long as subroutine calls do not happen;
when they do, the call is treated as one instruction.
Argument N means do this N times
(or till program stops for another reason).
```

gdb commands

```
(gdb) help next
```

```
Step program, proceeding through subroutine calls.
Like the "step" command as long as subroutine calls do not happen;
when they do, the call is treated as one instruction.
Argument N means do this N times
(or till program stops for another reason).
```

```
(gdb) help step
```

gdb commands

```
(gdb) help next
```

```
Step program, proceeding through subroutine calls.
Like the "step" command as long as subroutine calls do not happen;
when they do, the call is treated as one instruction.
Argument N means do this N times
(or till program stops for another reason).
```

```
(gdb) help step
```

```
Step program until it reaches a different source line.
Argument N means do this N times
(or till program stops for another reason).
```

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

gdb commands

```
(gdb) help next
```

```
Step program, proceeding through subroutine calls.
Like the "step" command as long as subroutine calls do not happen;
when they do, the call is treated as one instruction.
Argument N means do this N times
(or till program stops for another reason).
```

```
(gdb) help step
```

```
Step program until it reaches a different source line.
Argument N means do this N times
(or till program stops for another reason).
```

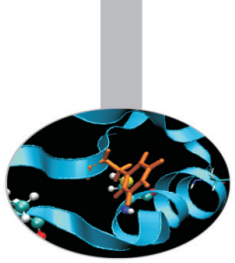
```
(gdb) break Main.c:1
```

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

prime-number finding program

```
(gdb) r
```

prime-number finding program

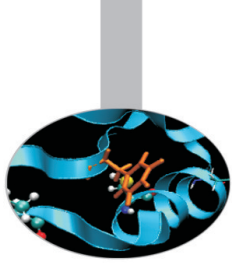


```
(gdb) r
```

```
Starting program: trova_primi
Failed to read a valid object file image from memory.

Breakpoint 1, main () at Main.c:6
6           {  int N;
```

```
(gdb) next
```

prime-number finding program



```
(gdb) r
```

```
Starting program: trova_primi
Failed to read a valid object file image from memory.

Breakpoint 1, main () at Main.c:6
6           {  int N;
```

```
(gdb) next
```

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

prime-number finding program

```
(gdb) next
```

prime-number finding program

```
(gdb) next
```

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

```
(gdb) next
```

prime-number finding program

```
(gdb) next
```

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

```
(gdb) next
```

```
20
```

prime-number finding program

```
(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);
```

prime-number finding program

```
(gdb) display N
```

prime-number finding program

```
(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
```

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
```

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

```
(gdb) next
```

```
13        }
```

prime-number finding program

```
(gdb)  n
```

prime-number finding program

```
(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
```

prime-number finding program

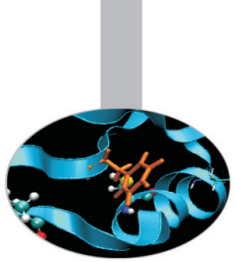
```
(gdb) l  Main.c:10
```

prime-number finding program

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

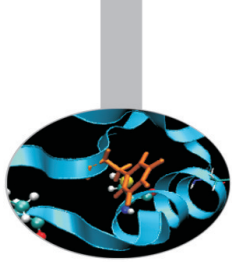
```
5          main()
6          {  int N;
7             printf("enter upper bound\n");
8             scanf("%d",&UpperBound);
9             Prime[2] = 1;
10            for (N = 3; N <= UpperBound; N += 2)
11               CheckPrime(N);
12               if (Prime[N]) printf("%d is a prime\n",N);
13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

Main.c :new version



```
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)
11           CheckPrime(N);
12           if (Prime[N]) printf("%d is a prime\n",N);
13
14        return 0;
15    }
```

Main.c :new version

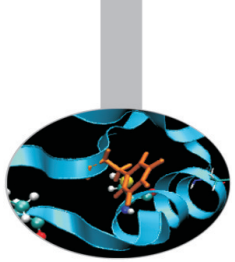


```
1  #include <stdio.h>
2  #define MaxPrimes 50
3   int Prime[MaxPrimes],
4   UpperBound;
5     main()
6     {  int N;
7        printf("enter upper bound\n");
8        scanf("%d",&UpperBound);
9        Prime[2] = 1;
10       for (N = 3; N <= UpperBound; N += 2){
11          CheckPrime(N);
12          if (Prime[N]) printf("%d is a prime\n",N);
13       }
14       return 0;
15    }
```

prime-number finding program

In other shell COMPILATION

prime-number finding program

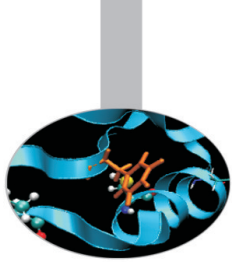


In other shell COMPILATION

```
(gdb) kill
```

Kill the program being debugged? (y or n)

prime-number finding program



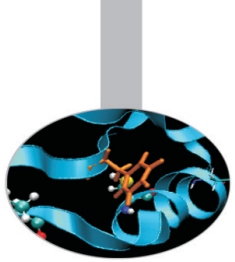
In other shell COMPILATION

```
(gdb) kill
```

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

```
(gdb) d
```

prime-number finding program



In other shell COMPILATION

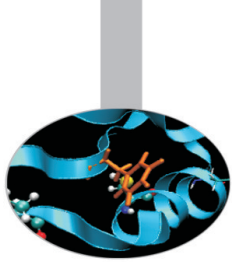
```
(gdb) kill
```

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

```
(gdb) d
```

Delete all breakpoints? (y or n)

prime-number finding program



In other shell COMPILATION

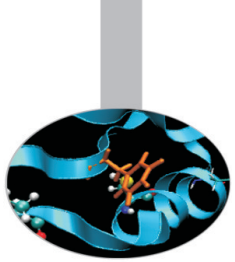
```
(gdb) kill
```

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

```
(gdb) d
```

Delete all breakpoints? (y or n) y

prime-number finding program



In other shell COMPILATION

```
(gdb) kill
```

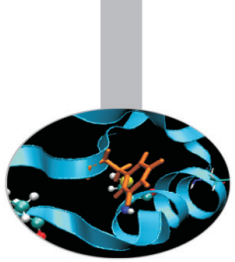
Kill the program being debugged? (y or n) y

```
(gdb) d
```

Delete all breakpoints? (y or n) y

```
(gdb)r
```

prime-number finding program



In other shell COMPILATION

```
(gdb) kill
```

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

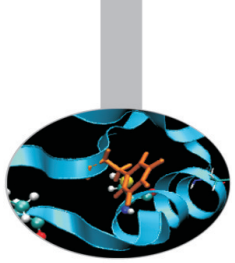
```
(gdb) d
```

Delete all breakpoints? (y or n) y

```
(gdb)r
```

```
Starting program: trova_primi
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: trova_primi
enter upper bound
```

20

prime-number finding program

```
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.
```

prime-number finding program

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

prime-number finding program

```
(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){
```

prime-number finding program

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

prime-number finding program

```
(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: trova_primi
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: trova_primi
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: trova_primi
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;
```

prime-number finding program

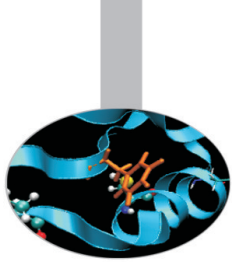
```
(gdb) set UpperBound=40
(gdb) continue
```

prime-number finding program

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

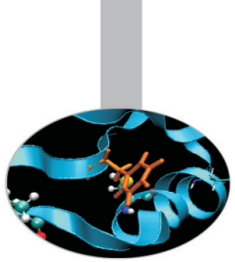
```
Continuing.
3 is a prime
5 is a prime
7 is a prime
11 is a prime
13 is a prime
17 is a prime
19 is a prime
23 is a prime
29 is a prime
31 is a prime
37 is a prime

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.

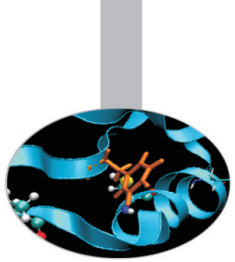
Debugging post mortem



- 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
```

Graphical Debuggers



- 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.

Why don't optmize?

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

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.
```

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
```

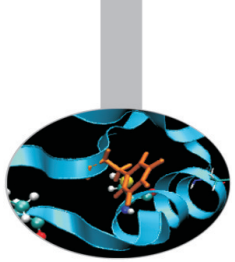
```
Breakpoint 1 at 0x8048395: file opt.c, line 4.
```

```
<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.
```

Outline

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.

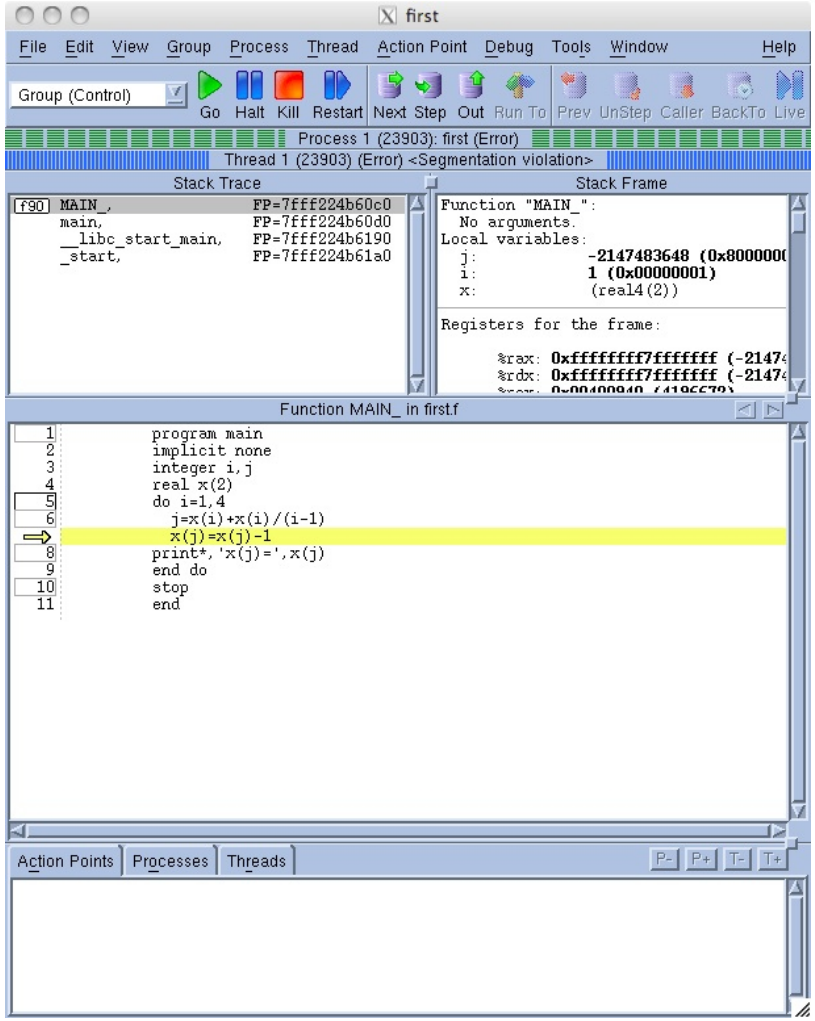
```
ifort [option] -O0 -g file_source.f -o filename
```

Starting Totalview

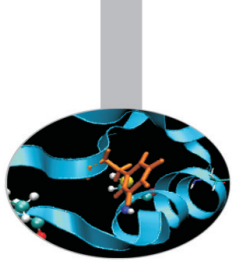
Command	Action
totalview	Starts the debugger.You can then load a program or corefile, or else attach to a running process.
totalview *filename*	Starts the debugger and loads the program specified by *filename*.
totalview *filename corefile*	Starts the debugger and loads the program specified by *filename* 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.

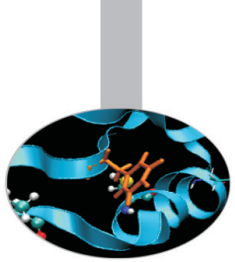


Totalview:Action points



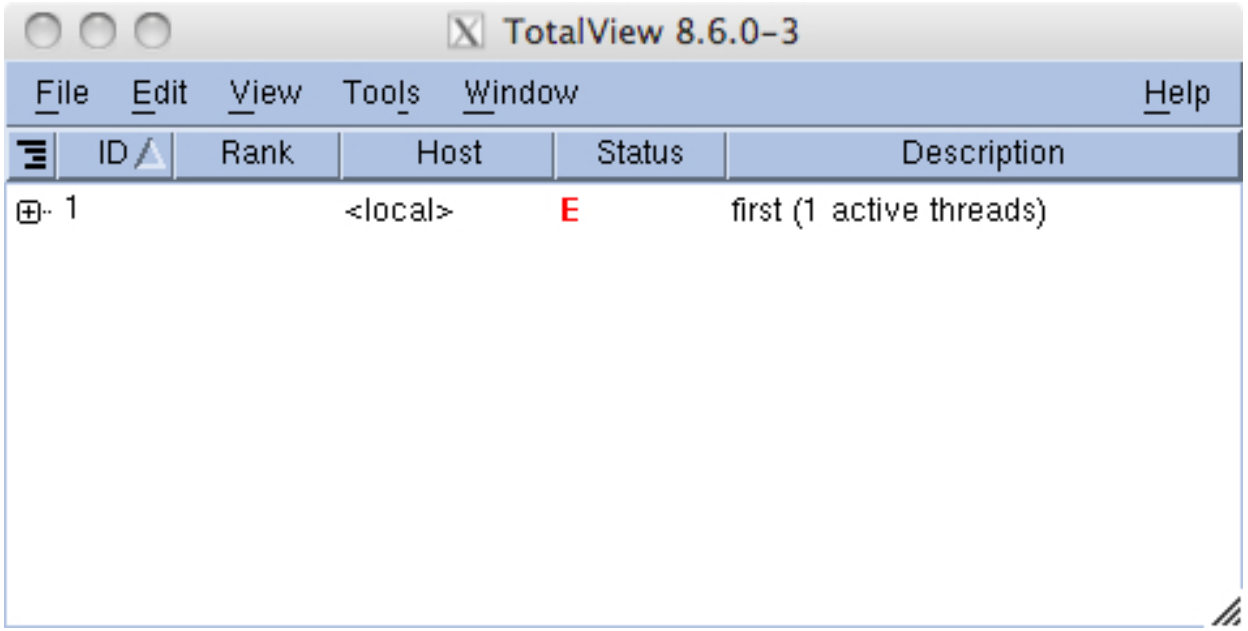
- Breakpoint stops the excution of the process and threads that reach it.
  - Unconditional
  - Conditional: stop only if the condition is satisfied.
  - Evaluation: stop and excute a code fragment when reached.
- Process barrier point synchronizes a set of processes or threads.
- Watchpoint monitors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

Totalview:Setting Action points



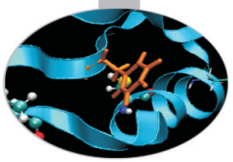
- Breakpoint
  - Right click on a source line → Set breakpoint
  - Click on the line number
- Watchpoint
  - Right click on a variable → Create watchpoint
- Barrier point
  - Right click on a source line → Set barrier
- Edit action point property
  - Rigth click on a action point in the Action Points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

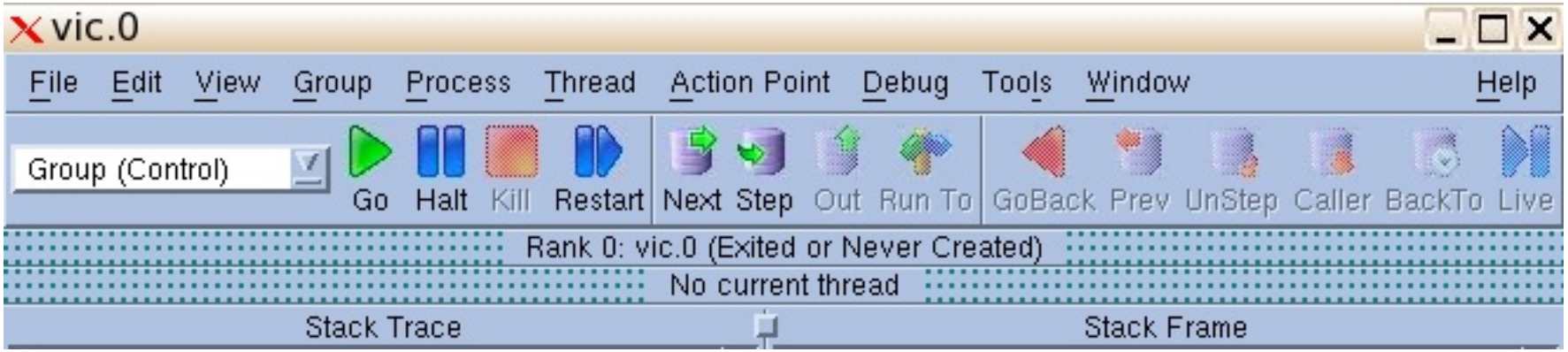
Totalview:Status



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

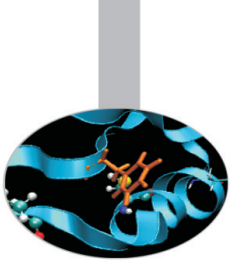
Totalview:Execution control commands





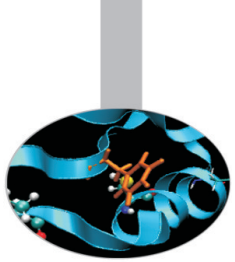
Command	Description
Go	Start/resume excution
Halt	Stop excution
Kill	Terminate the job
Restart	Restarts a running program, or one that has stopped without exiting
Next	Run to next source line or instruction. If the next line/instruction calls a function the entire function will be excuted and control 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.

I've checked everything!



what else could it be?

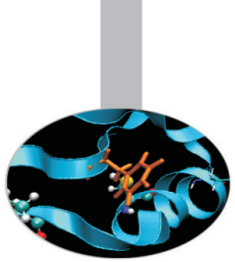
- Full file system.
- Disk quota exceeded.
- File protection.
- Maximum number of processes exceeded.
- Are all object file are up do date? Use Makefiles to build your projects
- What did I change since last version of my code?
  Use a version control system: CVS,RCS,...
- Does any environment variable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

Outline

Last resorts

- Ask for help.
- Explain your code to somebody.
- Go for a walk, to the movies,leave it to tomorrow.

Errare humanum est ...

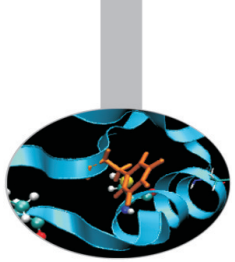


- Where was error made?
- Who made error?
- What was done incorrectly?
- How could the error have been prevented?
- Why wasn't the error detected earlier?
- How could the error have been detected earlier?

Bibliography

- **Why program fail. A guide to systematic debugging.** A. Zeller *Morgan Kaufmann Publishers* 2005.
- **Expert C Programming deep C secrets** P. Van der Linden *Prentice Hall PTR* 1994.
- **How debuggers works Algorithms, data,structure, and Architecture** J. B. Rosemberg *John Wiley & Sons* 1996.
- **Software Exorcism: A Handbook for Debugging and Optimizing Legacy Code** R. B. Blunden *Apress* 2003.
- **Debugging: The 9 Indispensable Rules for Finding Even the Most Elusive Software and Hardware Problems** D.J. Agans *American Management Association* 2002.
- **The Art of Debugging** N. Matloff, P. J. Salzman *No starch press* 2008.

Bibliography



- **Debugging With GDB: The Gnu Source-Level Debugger** R.M. Stallmann, R.H. Pesch, S. Shebs *Free Software Foundation* 2002.
- **The Practice of Programming** B.W. Kernighan, R. Pike *Addison-Wesley* 1999.
- **Code Complete** S. McConnell *Microsoft Press* 2004.
- **Software Testing Technique** B. Beizer *The Coriolis Group* 1990.
- **The Elements of Programming Style** B. W. Kernighan P.J. Plauger *Computing Mcgraw-Hill* 1978.
- **The Art of Software testing** K.J. Myers *Kindle Edition* 1979.
- **The Developer's Guide to Debugging** H. GrÃ¶tker, U. Holtmann, H. Keding, M.Wloka *Kindle Edition* 2008.

Esercitazione:debugging

```
cp /afs/icaspur.it/project/open/space/test_debug.tar /scratch
cd /scratch
tar xvf test_debug.tar
```

Nella directory TEST_DEBUG:

- TEST1: semplice bug per familiarizzare con i comandi
- TEST2: altro semplice bug per familiarizzare con i comandi
- TEST3: calcolo di un elemento della successione di Fibonacci.
  - Input: un numero che rappresenta la posizione dell'elemento della successione di cui si vuole il valore
  - Output: stampa a schermo del valore dell'elemento richiesto
- TEST4: sorting
  - Input: un intero che rappresenta il numero di interi che si vogliono ordinare ed i relativi valori (in C i valori da ordinare)
  - Output: i valori in ordine crescente
- TEST5: Crivello di Eratostene (ricerca dei numeri primi)
  - Input: un numero intero che rappresenta il limite di ricerca
  - Output: L'elenco dei numeri primi inferiori e uguali a quello fornito come limite

Rights & Credits

Slides and examples were authored by:

- I vari riferimenti
- Giorgio Amati
- Federico Massaioli
- Paride Dagna
- Paolo Ramieri
- Alice Invernizzi
- Maurizio Cremonesi