Debugging and Tuning

Linux for EDA

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Outline

- Compiling
  - gcc
  - icc/ecc
- Debugging
  - valgrind
  - purify
  - ddd
- Profiling
  - gcov, gprof
  - quantify
  - vtl
  - valgrind

Compiling

- Compiler options related to
  - static checks
  - debugging
  - optimization
- Profiling-driven optimization

Compiling with GCC

- `gcc -Wall -O3 -g`
  - reports most uses of potentially uninitialized variables
  - `-O3` (or `-O6`) necessary to trigger dataflow analysis
  - can be fooled by

    ```
    if (cond) x = VALUE;
    ...
    if (cond) y = x;
    ```

  - Uninitialized variables not considered for register allocation may escape
- Achieving `-Wall`-clean code is not too painful and highly desirable
- Compiling C code with g++ is more painful, but has its rewards

Compiling with GCC

- `gcc -mcpu=pentium4 -malign-double`
  - `-mcpu=pentium4` optimizes for the Pentium 4, but produces code that runs on any x86
  - `-march=pentium4` uses Pentium 4-specific instructions
  - `-malign-double` forces alignment of `double`'s to double-word boundary
    - Use either for all files or for none
- `gcc -mfpmath=sse`
  - Controls the use of SSE instructions for floating point
- For complete listing, check gcc's info page under
  - Invoking gcc → Submodel Options

Compiling with ICC

- ICC is the Intel compiler for IA-32 systems.
  - http://www.intel.com/software/products/
- `icc -O3 -g -ansi -w2 -Wall`
  - Aggressive optimization
  - Retain debugging info
  - Strict ANSI conformance
  - Display remarks, warnings, and errors
  - Enable all warnings
- Remarks tend to be a bit overwhelming
- Fine grain control over diagnostic: see man page

Compiling with ICC

- `icc -tpp7`
  - Optimize instruction scheduling for Pentium 4
  - Also `icc -mcpu=pentium4`
- `icc -ipo`
  - Multi-file interprocedural optimizations
- `icc -axW`
  - Generate both Pentium 4 and generic instructions
- `icc -xW`
  - Generate code specific for the Pentium 4
  - Also `icc -march=pentium4`
- `icc -align`
  - Analyze and reorder memory layout

GCC: Profiler-Driven Optimization

- `gcc -fprofile-arcs test.c`
  - Instrumented compilation
- `./test input`
  - Instrumented execution
  - Produces `.da` files
  - Can be repeated with different inputs
- `gcc -fbranch-probabilities test.c`
  - Feedback compilation

ICC: Profiler-Driven Optimization

- `icc -prof_gen test.c`
  - Instrumented compilation
- `./test input`
  - Instrumented execution
  - Produces `.dyn` and `.dpi` files
  - Can be repeated with different inputs
- `icc -prof_use test.c`
  - Feedback compilation

Debugging

- Dynamic analysis tools
  - valgrind, purify
- Classical debuggers
  - gdb, idb and their graphical front-ends, especially. . .
  - ddd

Valgrind

- Tool for debugging and profiling Linux-x86 executables
- Valgrind consists of:
  - core: synthetic CPU
  - skins: perform analyses
- Available skins
  - memcheck and addcheck: memory debugging
  - cachegrind: cache profiling
  - helgrind: races in multithreaded programs

Valgrind: Memory Debugging

- Use of uninitialized memory
- Reading/writing memory after it has been free'd
- Reading/writing off the end of malloc'd blocks
- Reading/writing inappropriate areas on the stack
- Memory leaks – where pointers to malloc'd blocks are lost forever
- Passing of uninitialized and/or unaddressable memory to system calls
- Mismatched use of malloc/new/new [] vs. free/delete/delete []
- Some misuses of the POSIX pthreads API

Valgrind: Memory Debugging

```
#include <stdlib.h>
main()
{
  char *x, *d = "foo";

  x = malloc(922);
  x = malloc(123);
  x = malloc(-9);

  free(d);
  free(x);
  free(x);
}
```

Valgrind: Memory Debugging

```
valgrind -leak-check=yes -show-reachable=yes mtest
```

- Warning: silly arg (-9) to malloc()
- Invalid free() / delete / delete[]
  - in main (mtest.c:10)
- 123 bytes in 1 blocks are definitely lost
  - in main (mtest.c:7)
- 922 bytes in 1 blocks are definitely lost
  - in main (mtest.c:6)

Why isn’t the double `free(x)` reported?

Valgrind: Memory Debugging

- Valgrind tracks each byte with nine status bits
  - one tracks addressibility of that byte
  - the other eight track the validity of the byte
- Valgrind can be used to debug dynamically-linked ELF x86 executables, without modification, or recompilation
  - `valgrind ls -ls`
- Valgrind can attach GDB to the running program at the point(s) where errors are detected
- Valgrind works on large applications
  - Mozilla
  - emacs-21.2
  - AbiWord
  - OpenOffice
  - Gcc
  - KDE3

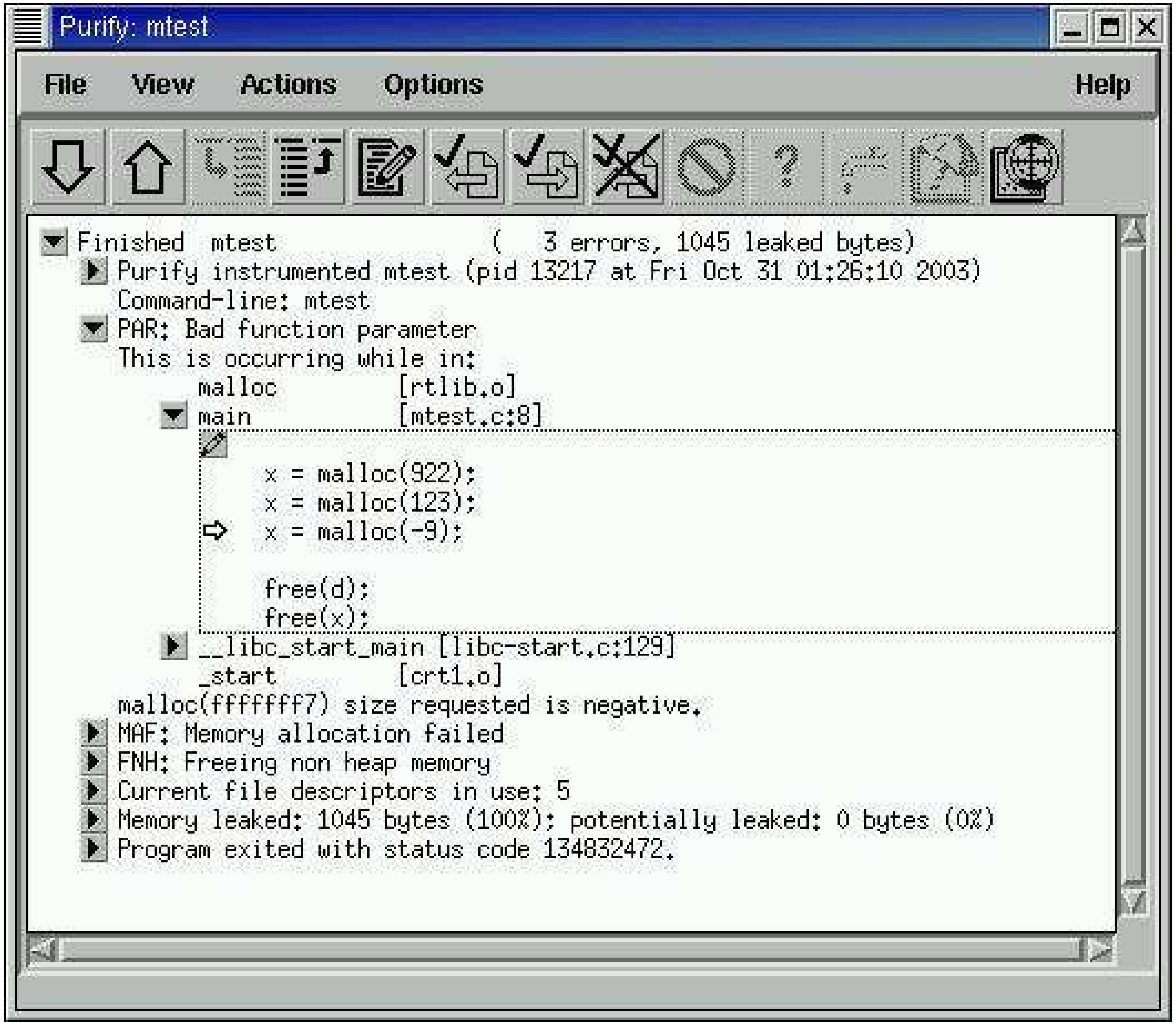
Valgrind

- `http://developer.kde.org/~sewardj/`
  - Last stable version 20031012
- Only on x86-Linux
- Works on many distributions, but not all
  - Yes: RH 7.2 7.3 8 9
  - No: RH 7.1
- `kcachegrind` GUI only available under KDE
- `memcheck` slows down execution by 25-50 times
- `addrcheck` is lighter weight, but does not track read-before-write's
- the `-gen-suppressions=yes` option tells Valgrind to print out a suppression for each error that appears

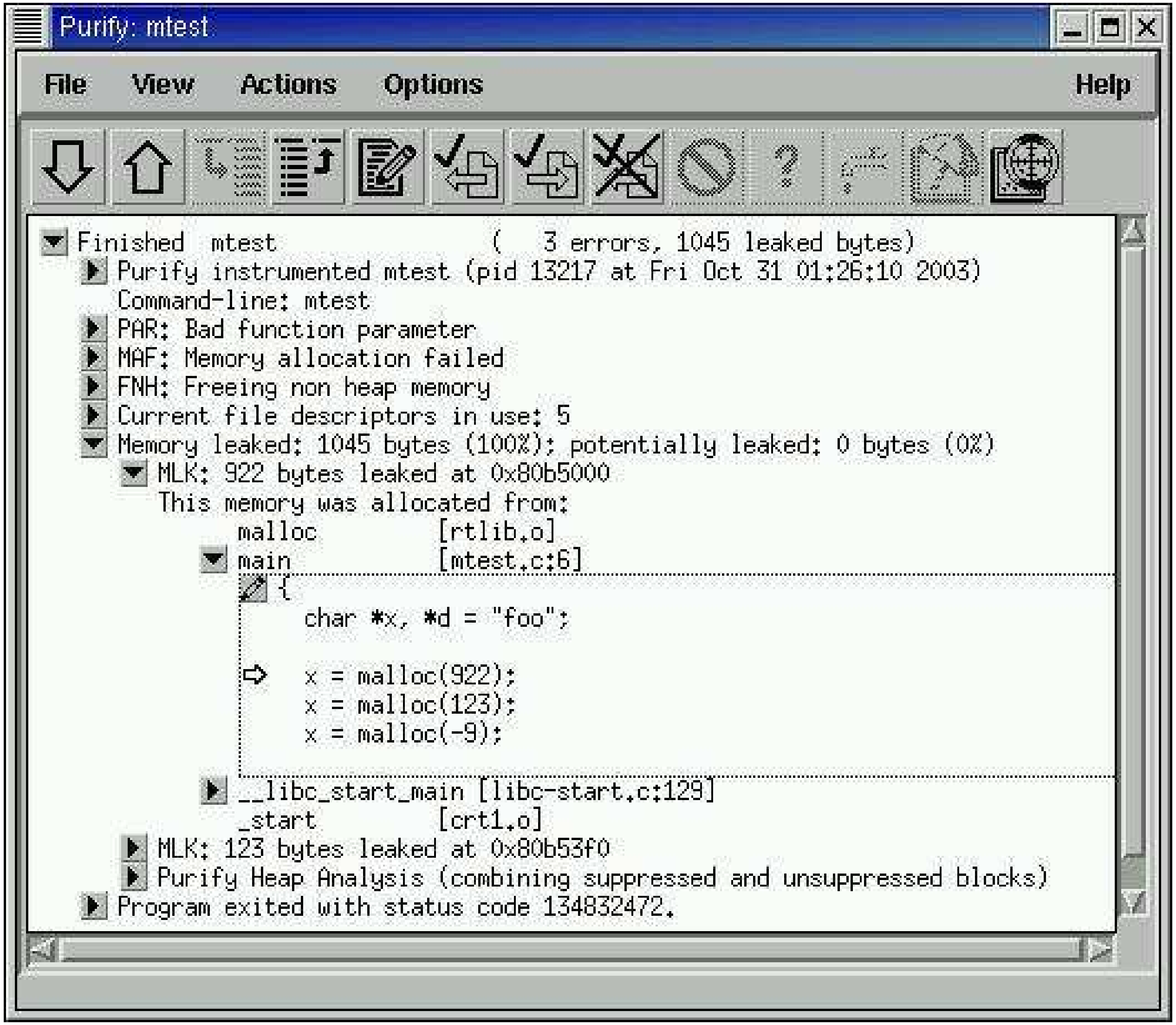
IBM Rational PurifyPlus

- http://www.rational.com/
- Runtime analysis
  - Memory corruption detection
  - Memory leakage detection
- Requires instrumentation
  - `purify gcc -g mtest.c`
- Languages: C, C++

Purify: Bad Function Parameter



Purify: Memory Leaks

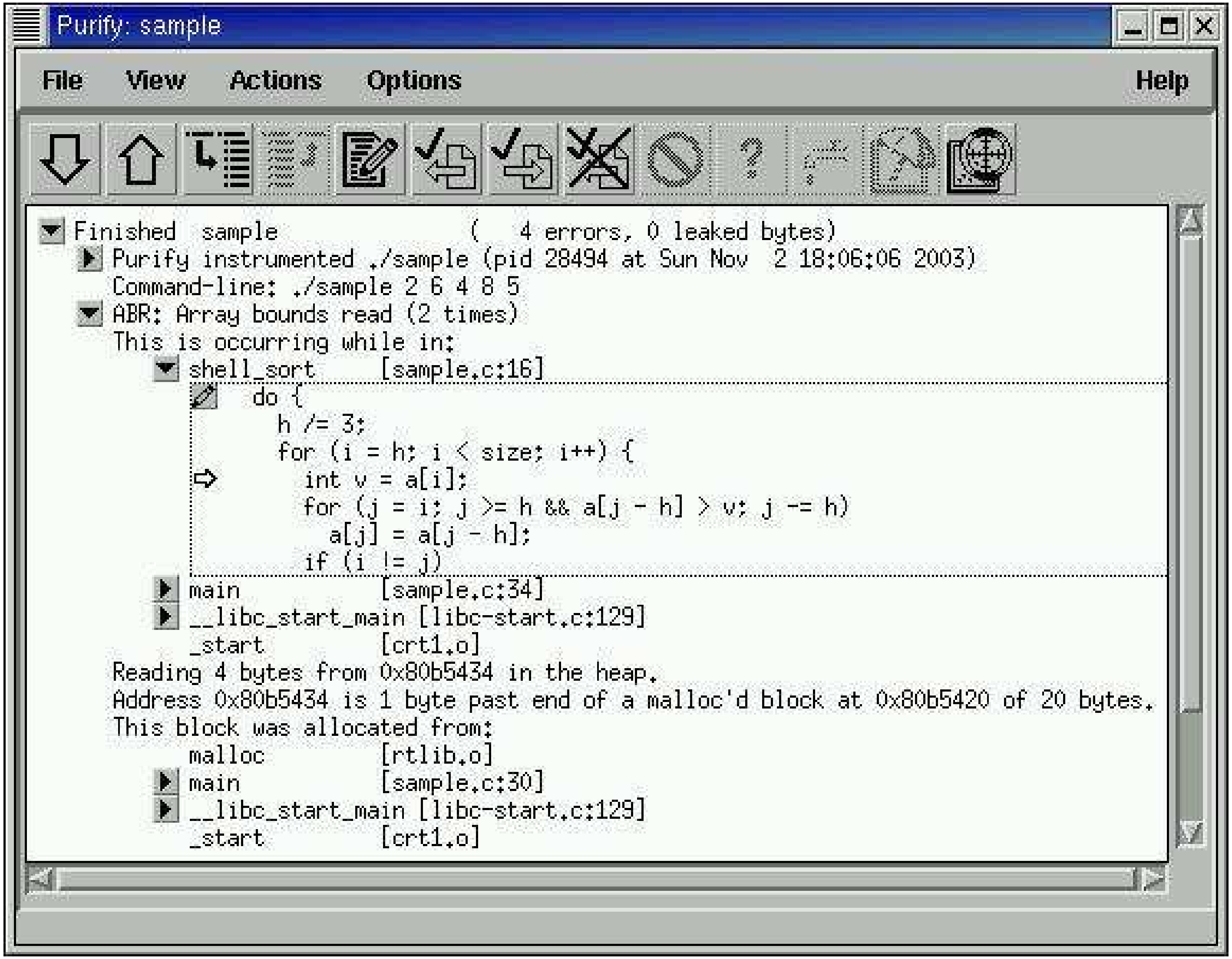


A Sample Program

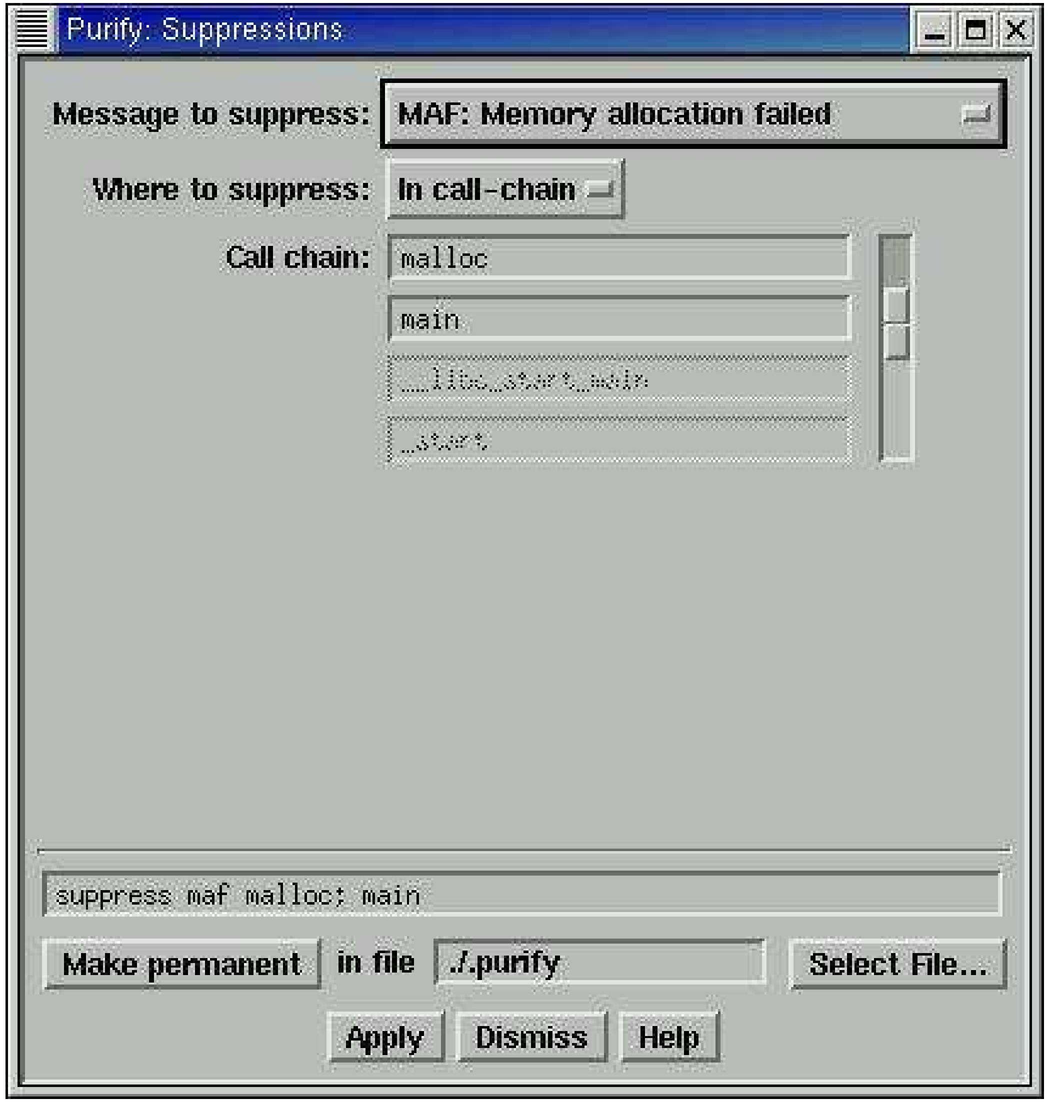
```
int main(int argc, char *argv[])
{
  int *a, i;

  a = (int *)malloc((argc - 1) * sizeof(int));
  for (i = 0; i < argc - 1; i++)
    a[i] = atoi(argv[i + 1]);
  shell_sort(a, argc);
  for (i = 0; i < argc - 1; i++)
    printf("%d ", a[i]);
  printf("\n");
  free(a);
  return 0;
}
```

Purify: Out-of-Bounds Read



Purify: Suppressions



Purify: Library Functions

- Library functions allow developer to customize data collected for a given application
- Memory usage profiling:

```
#ifdef PURIFY
    ...
    purify_all_inuse();
    ...
#endif
```

  Used in VIS together with a couple of scripts to profile memory usage on a per-package basis
- Link to `libpurify_stubs.a`

The Cost of Instrumentation

- One data point

no instrumentation	64 s
`valgrind -skin=addrcheck`	860 s
`valgrind -skin=memcheck`	1287 s
`purify`	1725 s

- The `addrcheck` skin checks the validity of addresses but not of data
- Only purify detects this uninitialized memory read

```
int main()
{
  int a;
  return a;
}
```

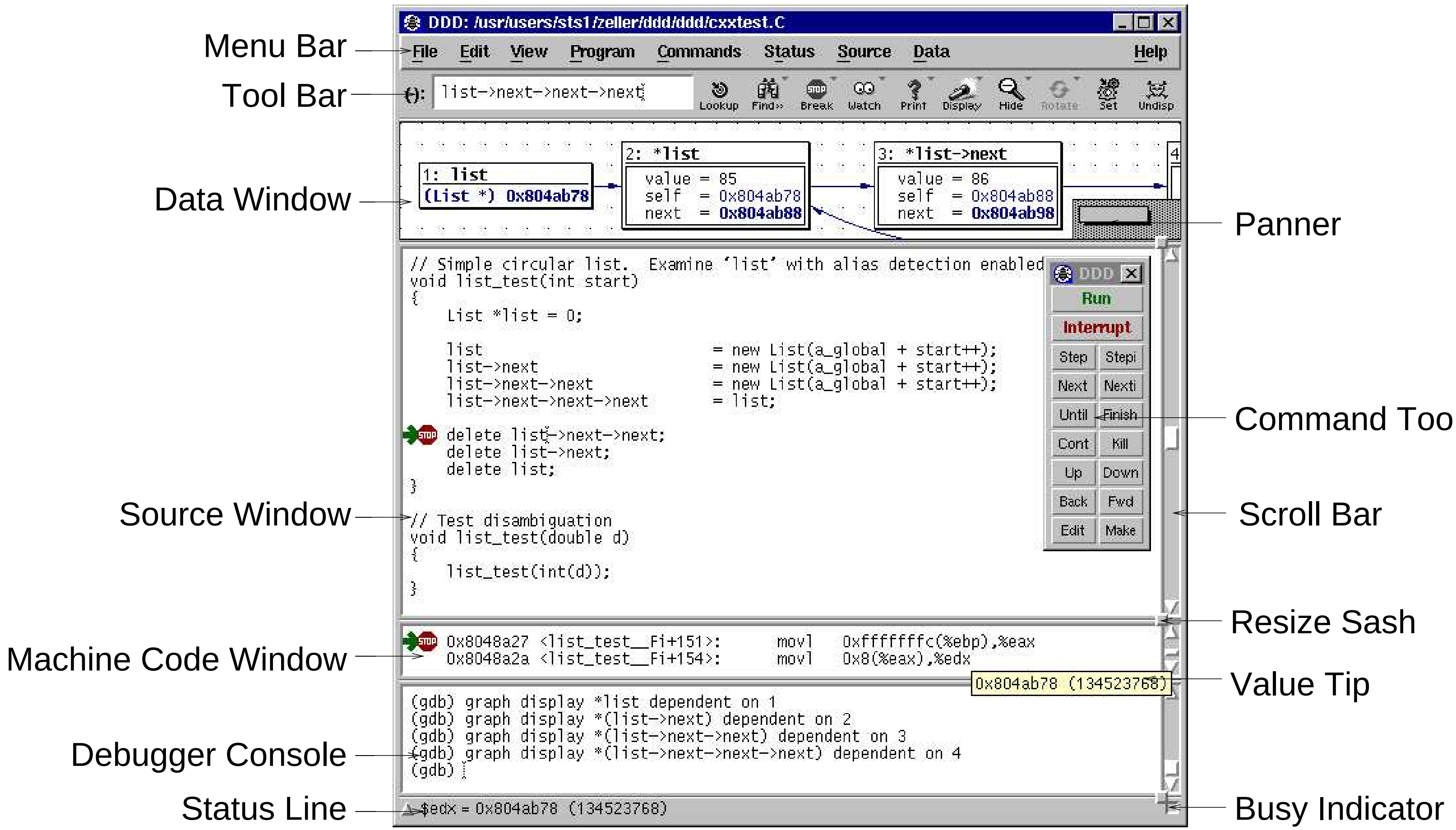
GDB and IDB

- Better used through a graphical front-end
  - Ddd
  - emacs's GUD
  - UPS (http://ups.sourceforge.net/main.html)
  - Insight (http://sources.redhat.com/insight/)
- GDB and IDB largely compatible
  - `idb -gdb` is similar to `gdb`
  - otherwise, it is similar to `dbx`
  - Both can be used with the "other" compiler
- There are other debuggers as well
  - TotalView
  - Idebug (Java)

The Data Display Debugger

- Front-end for
  - C/C++ (gdb, idb)
  - Other languages supported by gcc (e.g., Fortran)
  - Perl
  - Python
  - Java
- Available also for other operating systems
  - Works with other inferior debuggers too (e.g., dbx)
  - Requires X server
- http://www.gnu.org/software/ddd

The Data Display Debugger



The DDD Layout using Stacked Windows

DDD: Displaying Data

- `(gdb) graph display array[0] @ nelem`
  - Shows array slice in the data window
  - Optionally use `rotate` button for more compact display
- `(gdb) graph plot array[0] @ nelem`
  - runs `gnuplot` on array slice and displays result in new window
  - Plot is updated when data changes
  - Plot can be customized and saved
  - Animations are possible

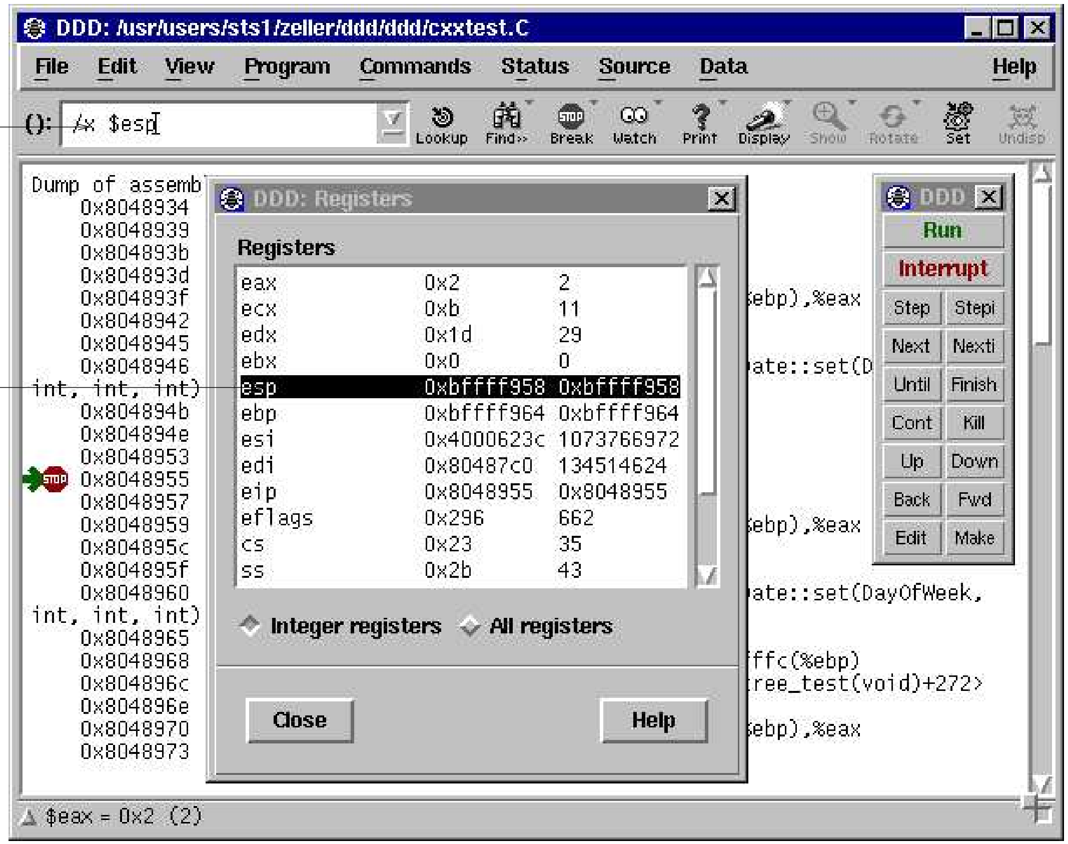
DDD: Plotting

Plotting 1−D and 2−D Arrays

DDD: Machine-Level Debugging

The register name is copied to ()

Select register



Displaying Register Values

Profiling

- Gcov
- Gprof
- VTune
- Valgrind

Optimization Tips

- Static branch prediction in the Pentium 4
  - Forward branches are not taken
  - Backward branches are taken
- Use `const`; avoid `register`
- Fit data structures to cache lines
- More at http://developer.intel.com/design/pentium4/manuals/
- Profiling tools help identify
  - hotspots
  - inefficient memory layout
  - insufficiently tested code
- Remember: Only optimize what is critical

Sampling vs. Counting

- Sampling: the program counter is periodically examined
- Basic block counting: the executable is instrumented so that the frequencies of execution of all basic blocks are recorded
  - Only reliable mechanism for
    - coverage measurement
    - fine tuning
  - Does not account for memory hierarchy

Gcov: Coverage Analysis

- `gcc -fprofile-arcs -ftest-coverage -o lfsr lfsr.c`
- `./lfsr`
- `gcov lfsr.c`

```
100.00% of 10 source lines executed in file lfsr.c
Creating lfsr.c.gcov.
```

Gcov: Coverage Analysis

```
               int main()
          1    {
          1      unsigned int r = 1;
          1      int i;
 1000000001      for (i = 0; i < 1000000000; i++) {
 1000000000        unsigned int b = r & 1;
 1000000000        r >>= 1;
 1000000000        if (b)
  500007631          r ^= 0x8805;
                 }
          1      printf("%u\n", r);
          1      exit(0);
               }
```

Gprof

```
gcc -o lfsr -g -pg -fprofile-arcs -O3 \
  -mcpu=pentium4 lfsr.c
./lfsr
gprof --line --flat-profile lfsr

Flat profile:
Each sample counts as 0.01 seconds.
  %   cumulative   self
 time   seconds   seconds    name
 61.59      8.11     8.11    main (lfsr.c:13)
 28.91     11.91     3.81    main (lfsr.c:17)
  3.19     12.33     0.42    main (lfsr.c:14)
  3.19     12.75     0.42    main (lfsr.c:15)
  2.89     13.13     0.38    main (lfsr.c:16)
  0.23     13.16     0.03    main (lfsr.c:14)
```

IBM Rational Quantify and Purecov

- Basic-block counting profiling
- Call graph analysis
- Source annotation

Intel VTune for Linux

- `vtl`: command line version of the performance analyzer for Linux
- Sampling: non-intrusive, system-wide profiling
  - relies on the CPU performance monitoring registers
- Call graph: low overhead analysis of program flow
  - requires instrumentation
- http://www.intel.com/software/products/vtune/vlin/
  - Current release is 1.1
  - Several Red Hat and SUSE releases supported

VTune: Sampling

- `vtl activity -c sampling run`
  - Runs the sampling collector for all processes
  - Automatically calibrates collection parameters
  - Collects data on clock ticks and retired instructions
- `vtl show`
  - Displays activities that have been run for a project
- `vtl view a1::r1 -processes`
  - Presents the results of activity `a1::r1` organized by process
- `vtl -help -c sampling`
  - Shows what events can be sampled

VTune: Call Graph

- `vtl activity -c callgraph -app ./mypgm \`
  `-moi ./mypgm run`
  - Runs the callgraph collector for `mypgm`
  - Performs instrumentation (including library functions)
  - Collects function call data
- `vtl show`
  - Displays activities that have been run for a project
- `vtl view a1::r1 -functions`
  - Shows timing information for each function
  - Use `-calls` for call-graph edge data
- `vtl view a1::r1 -critical-path`
  - Shows the critical path

Valgrind: Cache Profiling

- Valgrind contains built-in support for cache profiling
  - `valgrind -skin=cachegrind my-program`
  - detailed simulation of L1-D, L1-I, unified L2
- `vg_annotate` annotates source code
- Cache configuration auto-detected using the CPUID instruction
  - can be overridden

Valgrind: Cache Profiling

```
I   refs:      73,173,467
I1  misses:        70,260
L2i misses:         1,734
I1  miss rate:        0.9%
L2i miss rate:        0.0%

D   refs:      39,315,546  (28,535,016 rd + 10,780,530 wr)
D1  misses:       456,530  (   344,528 rd +    112,002 wr)
L2d misses:       249,456  (   162,814 rd +     86,642 wr)
D1  miss rate:        1.1% (       1.2%   +        1.0%  )
L2d miss rate:        0.6% (       0.5%   +        0.8%  )

L2 refs:          526,790  (   414,788 rd +    112,002 wr)
L2 misses:        251,190  (   164,548 rd +     86,642 wr)
L2 miss rate:         0.2% (       0.1%   +        0.8%  )
```

The End