Debugging Techniques for C Programs

Debugging Basics

- Will focus on the gcc/gdb combination.
- Will also talk about the ddd gui for gdb (lots of value added to gdb).
- First, debugging in the abstract:
  - Program *state* is a snapshot of all variables, PC, etc.
  - A statement in your program transforms one program state into another.
  - You should be able (at some level) to express what you expect the state of your program to be after every statement.
  - Often state *predicates* on program state; i.e., “if control is here, I expect the following to be true.”
- Map into a toy example.

Small Example: ave.c

```
#include <stdio.h>

int sum=0, val, num=0;
double ave;

main()
{

while (scanf("%d\n",&val) != EOF) {
   sum += val;
   num++;
 }

if (num > 0) {
   ave = sum/num;

   printf("Average is %f\n", ave);
 }
}
```

`sum` should be 0 and `num` should be 0.

`sum` should be the total of the `num` input values processed.

`sum` should be the total of the `num` input values and there is no more input.

`ave` should be the floating point mean of the num input data values.

Small Example: ave.c

```
% a.out
1
Average is 1.000000
% a.out
1
2
3
Average is 2.000000
% a.out
1
2
3
4
Average is 2.000000
```

Experienced programmer can probably “eyeball debug” the program from this output

Using `gdb`

- Make sure to compile source with the `-g` switch asserted.
- In our case, `gcc -g ave.c`
- *Breakpoint*: line in source code at which debugger will pause execution. At breakpoint, can examine values of relevant components of program state. `break` command sets a breakpoint; `clear` removes the breakpoint.
- Diagnostic `printf()` crude, but effective way of getting a snapshot of program state at a given point.
- Once paused at a breakpoint, use gdb `print`, or `display` to show variable or expression values. `display` will automatically print values when execution halts at breakpoint.
- From a breakpoint, may `step` or `next` to single step the program. `step` stops after next source line is executed. `next` similar, but executes functions without stopping.

Using `gdb`

- May find out where execution is, in terms of function call chain, with the `where` command; also shows function argument values.
- Apply some of this in context of bogus averaging program.
- To make things easier, put the problematic data set in a file named data.

```
% a.out < data
Average is 2.000000
```

Using gdb (ave.c)

```
% gdb a.out
GNU gdb 6.1
Copyright 2004 Free Software Foundation, Inc.
GDB is free software, covered by the GNU General Public
License, and you are welcome to change it and/or distribute
copies of it under certain conditions.
Type "show copying" to see the conditions.
There is absolutely no warranty for GDB.  Type "show warranty"
for details.
This GDB was configured as "i586-suse-linux"...Using host
libthread_db library "/lib/tls/libthread_db.so.1".

(gdb)
```

Using gdb (ave.c)

```
(gdb) l
1       #include <stdio.h>
2
3       int sum=0, val, num=0;
4       double ave;
5
6       main()
7       {
8         while (scanf("%d\n",&val) != EOF) {
9           sum += val;
10          num++;
(gdb) l
11        }
12        if (num > 0) {
13          ave = sum/num;
14          printf("Average is %f\n", ave);
15        }
16      }
17
(gdb)
```

Interesting point: top of main loop.

Another interesting point: just before `ave` is computed.

Using gdb (ave.c)

```
(gdb) break 8
Breakpoint 1 at 0x80483dc: file ave.c, line 8.
(gdb) break 13
Breakpoint 2 at 0x8048414: file ave.c, line 13.
(gdb) display num
(gdb) display val
(gdb) display sum
(gdb) r < data
Starting program: /home/jmayo/courses.d ...
Breakpoint 1, main () at ave.c:8
8       while (scanf("%d\n", &val) != EOF) {
3: sum = 0
2: val = 0
1: num = 0
(gdb) c
Continuing.

Breakpoint 1, main () at ave.c:8
8       while (scanf("%d\n", &val) != EOF) {
3: sum = 1
2: val = 1
1: num = 1
```

Using gdb (ave.c)

```
(gdb) c
Continuing.

Breakpoint 1, main () at ave.c:8
8       while (scanf("%d\n",&val) != EOF) {
3: sum = 3
2: val = 2
1: num = 2
(gdb) c
Continuing.

Breakpoint 1, main () at ave.c:8
8       while (scanf("%d\n",&val) != EOF) {
3: sum = 6
2: val = 3
1: num = 3
```

Using gdb (ave.c)

```
(gdb) c
Continuing.

Breakpoint 1, main () at ave.c:8
8       while (scanf("%d\n",&val) != EOF) {
3: sum = 10
2: val = 4
1: num = 4
(gdb) c
Continuing.

Breakpoint 2, main () at ave.c:13
13      ave = sum/num;
3: sum = 10
2: val = 4
1: num = 4
```

Using gdb (ave.c)

```
(gdb) n
14          printf("Average is %f\n", ave);
3: sum = 10
2: val = 4
1: num = 4
(gdb) p ave
$1 = 2
(gdb) p (double)sum/(double)num
$2 = 2.5
(gdb) c
Continuing.
Average is 2.000000

Program exited with code 024.
(gdb) q
%
```

Everything fine until ave is computed. Integer division the problem.

Evaluate expression inside gdb to validate our reasoning.

A GUI for `gdb`: `ddd`

- The `ddd` program is just a GUI front-end for `gdb`.
- Value added three main ways:
  - Can mouse left on source line, then mouse left on `Break at()` to set a breakpoint. Or mouse right on a source line and set a breakpoint in the menu that pops up.
  - Can mouse left on variable, then mouse left on `Print()` or `Display()` to examine data values. Or get value displayed at bottom of `ddd` window by ``mouse hovering'' over a variable name.
  - Displayed values graphically displayed. Click on a pointer value, graphically display thing pointed to. Visualize complex linked data structures.
- Play with inorder tree traversal program.

Using ddd (inorder.c)

Introduce a pointer-related bug into the program by modifying the inorder() function:

```
.....

void inorder(r)
struct node *r;
{
   inorder(r->left);
   printf("%c",r->data);
   inorder(r->right);
}
```

Formerly:

```
if (r != NILNODE) {
   inorder(r->left);
   printf("%c",r->data);
   inorder(r->right);
}
```

Quickie Post Mortem Debugging (inorder.c)

```
% a.out
Segmentation fault (core dumped)
```

```
% gdb a.out core
GNU gdb 6.1
..........
Core was generated by `./a.out core'.
Program terminated with signal 11, Segmentation fault.
..........
Reading symbols from /lib/tls/libc.so.6...done.
Loaded symbols for /lib/tls/libc.so.6
Reading symbols from /lib/ld-linux.so.2...done.
Loaded symbols for /lib/ld-linux.so.2
#0  0x080484d5 in inorder (r=0x0) at buggy_inorder.c:38
38          inorder(r->left);
(gdb)
```

Function in which segfaulted.

Arguments to function.

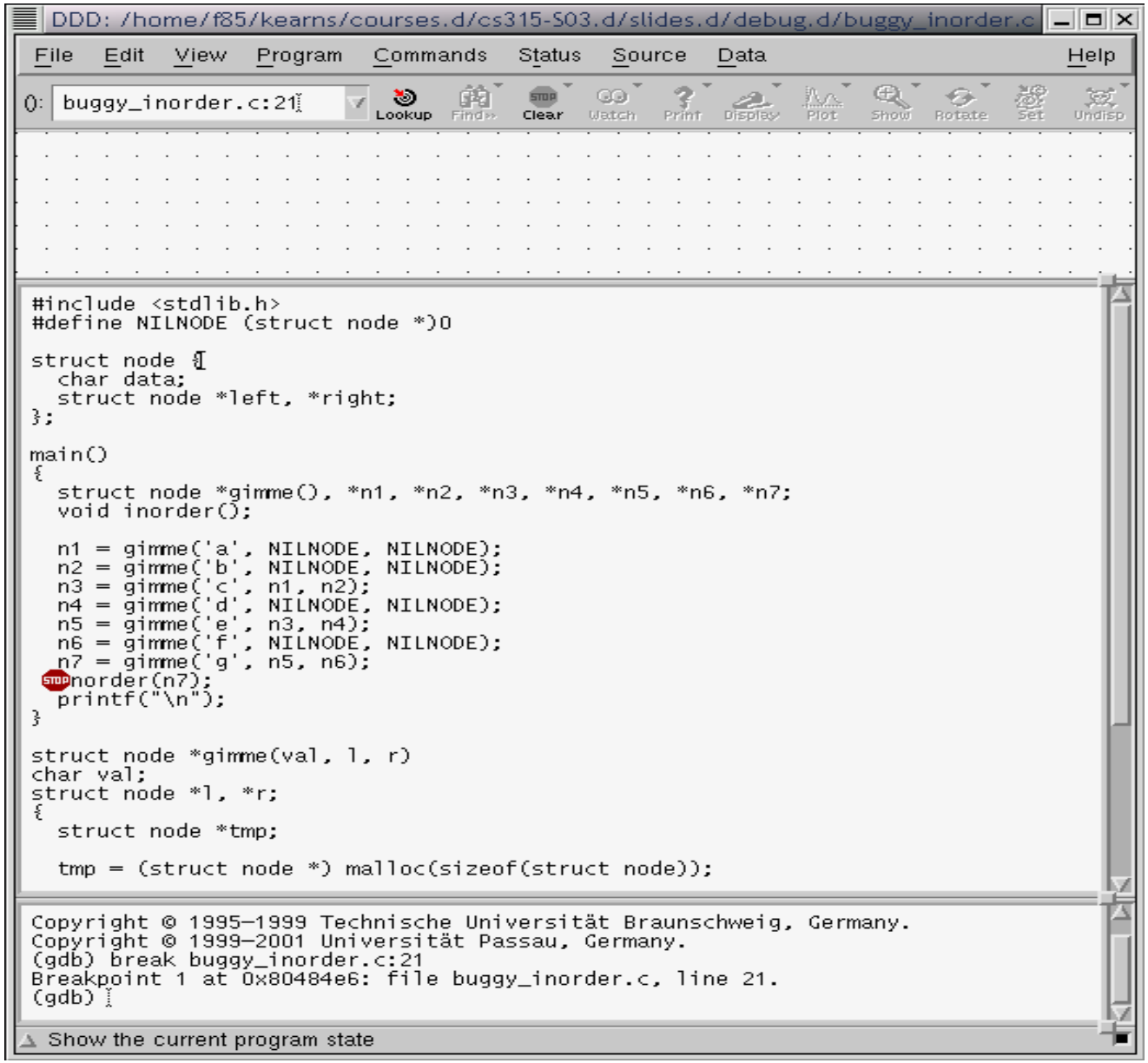
Line of source where segfaulted.

Quickie Post Mortem Debugging (inorder.c)

```
(gdb) where
#0  0x080484d5 in inorder (r=0x0) at buggy_inorder.c:38
#1  0x080484dd in inorder (r=0x804a008) at buggy_inorder.c:38
#2  0x080484dd in inorder (r=0x804a028) at buggy_inorder.c:38
#3  0x080484dd in inorder (r=0x804a048) at buggy_inorder.c:38
#4  0x080484dd in inorder (r=0x804a068) at buggy_inorder.c:38
#5  0x08048479 in main () at buggy_inorder.c:21
```

The above listing walks back the call chain as it was at the moment of the segfault.

Clear that we dereferenced a null pointer in a call to `inorder()` at a leaf node of the binary tree.


DDD: /home/f85/kearns/courses.d/cs315-S03.d/slides.d/debug.d/buggy_inorder.c
File Edit View Program Commands Status Source Data Help
buggy_inorder.c:21
Lookup Find Clear Watch Print Display Plot Show Rotate Set Undisp
#include <stdlib.h>
#define NILNODE (struct node *)0
struct node {
char data;
struct node *left, *right;
};
main()
{
struct node *gimme(), *n1, *n2, *n3, *n4, *n5, *n6, *n7;
void inorder();
n1 = gimme('a', NILNODE, NILNODE);
n2 = gimme('b', NILNODE, NILNODE);
n3 = gimme('c', n1, n2);
n4 = gimme('d', NILNODE, NILNODE);
n5 = gimme('e', n3, n4);
n6 = gimme('f', NILNODE, NILNODE);
n7 = gimme('g', n5, n6);
STOP norder(n7);
printf("\n");
}
struct node *gimme(val, l, r)
char val;
struct node *l, *r;
{
struct node *tmp;
tmp = (struct node *) malloc(sizeof(struct node));
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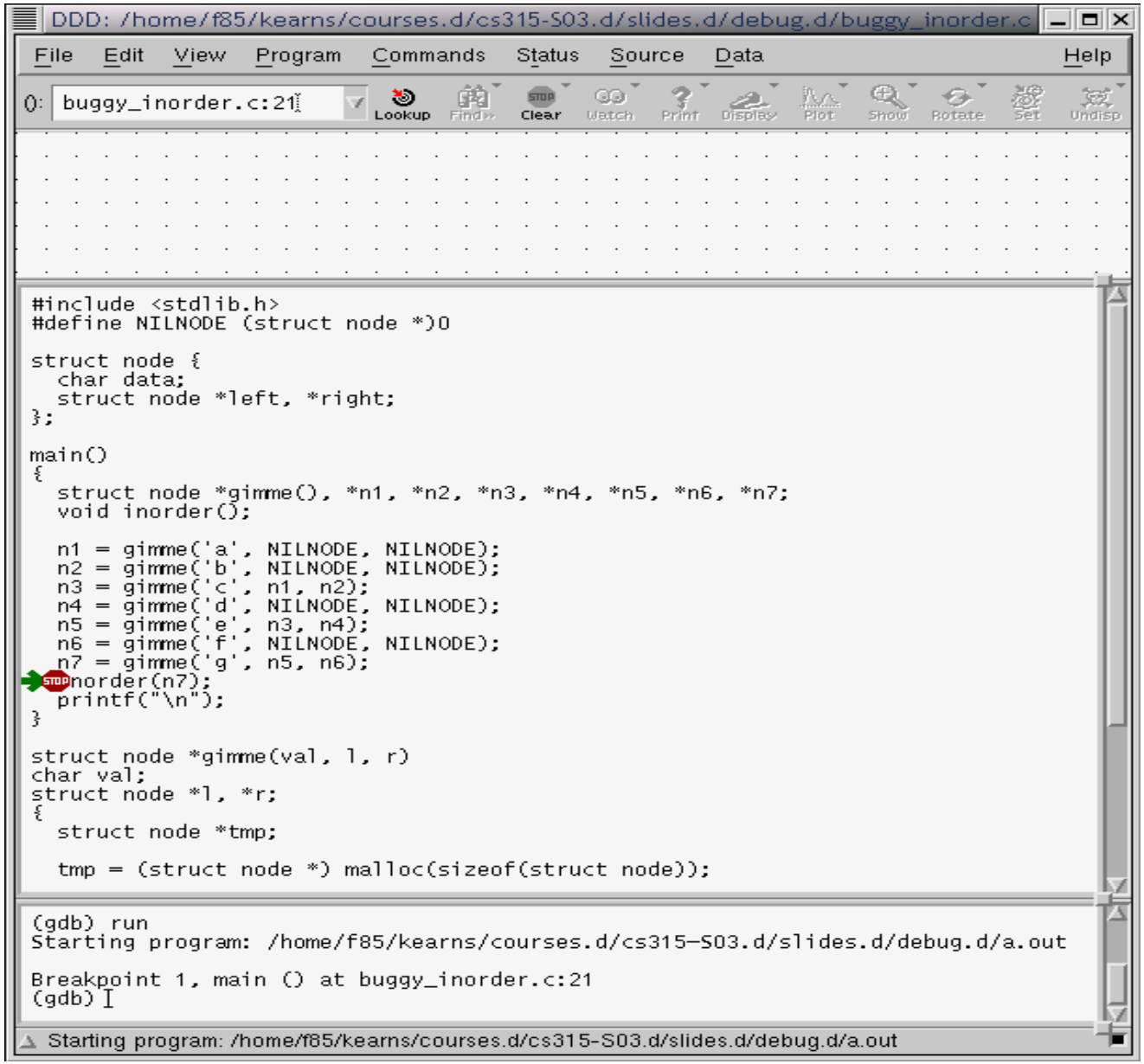
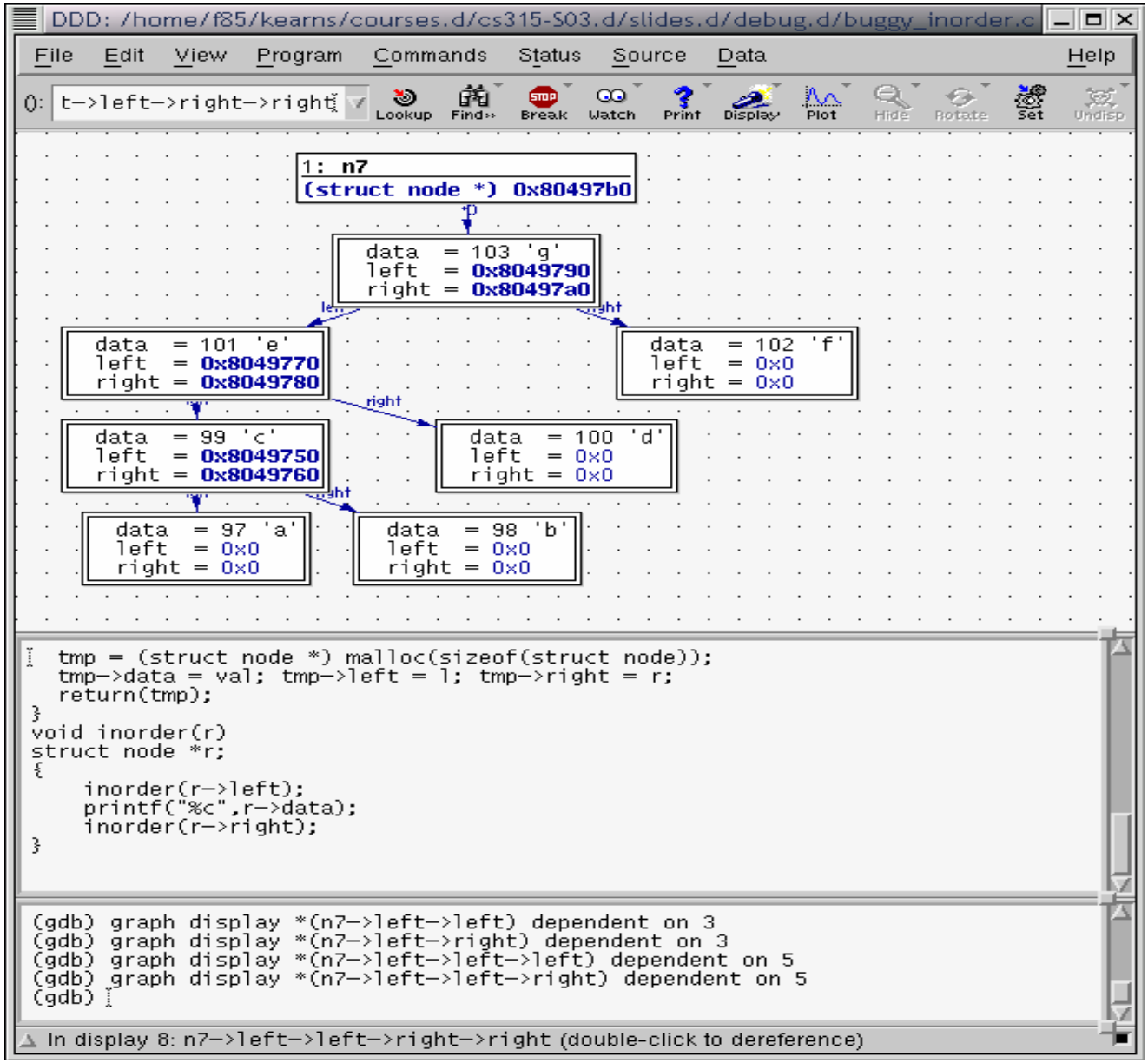
Copyright © 1999-2001 Universität Passau, Germany.
(gdb) break buggy_inorder.c:21
Breakpoint 1 at 0x80484e6: file buggy_inorder.c, line 21.
(gdb)
Show the current program state


DDD: /home/f85/kearns/courses.d/cs315-S03.d/slides.d/debug.d/buggy_inorder.c
File Edit View Program Commands Status Source Data Help
buggy_inorder.c:21
Lookup Find Clear Watch Print Display Plot Show Rotate Set Undisp
#include <stdlib.h>
#define NILNODE (struct node *)0
struct node {
char data;
struct node *left, *right;
};
main()
{
struct node *gimme(), *n1, *n2, *n3, *n4, *n5, *n6, *n7;
void inorder();
n1 = gimme('a', NILNODE, NILNODE);
n2 = gimme('b', NILNODE, NILNODE);
n3 = gimme('c', n1, n2);
n4 = gimme('d', NILNODE, NILNODE);
n5 = gimme('e', n3, n4);
n6 = gimme('f', NILNODE, NILNODE);
n7 = gimme('g', n5, n6);
STOP norder(n7);
printf("\n");
}
struct node *gimme(val, l, r)
char val;
struct node *l, *r;
{
struct node *tmp;
tmp = (struct node *) malloc(sizeof(struct node));
(gdb) run
Starting program: /home/f85/kearns/courses.d/cs315-S03.d/slides.d/debug.d/a.out
Breakpoint 1, main () at buggy_inorder.c:21
(gdb)
Starting program: /home/f85/kearns/courses.d/cs315-S03.d/slides.d/debug.d/a.out


DDD: /home/f85/kearns/courses.d/cs315-S03.d/slides.d/debug.d/buggy_inorder.c
File Edit View Program Commands Status Source Data Help
t->left->right->right
Lookup Find» Break Watch Print Display Plot Hide Rotate Set Undisp
1: n7
(struct node *) 0x80497b0
data = 103 'g'
left = 0x8049790
right = 0x80497a0
data = 101 'e'
left = 0x8049770
right = 0x8049780
data = 102 'f'
left = 0x0
right = 0x0
data = 99 'c'
left = 0x8049750
right = 0x8049760
data = 100 'd'
left = 0x0
right = 0x0
data = 97 'a'
left = 0x0
right = 0x0
data = 98 'b'
left = 0x0
right = 0x0
tmp = (struct node *) malloc(sizeof(struct node));
tmp->data = val; tmp->left = l; tmp->right = r;
return(tmp);
}
void inorder(r)
struct node *r;
{
inorder(r->left);
printf("%c",r->data);
inorder(r->right);
}
(gdb) graph display *(n7->left->left) dependent on 3
(gdb) graph display *(n7->left->right) dependent on 3
(gdb) graph display *(n7->left->left->left) dependent on 5
(gdb) graph display *(n7->left->left->right) dependent on 5
(gdb)
In display 8: n7->left->left->right->right (double-click to dereference)

Debugging Tips

- Examine the most recent change
- Debug it now, not later
- Read before typing
- Make the bug reproducible
- Display output to localize your search
- Write a log file
- Use tools
- Keep records