Pointers and Dynamic Data Structures

Chapter 13

Problem Solving & Program Design in C

Eighth Edition

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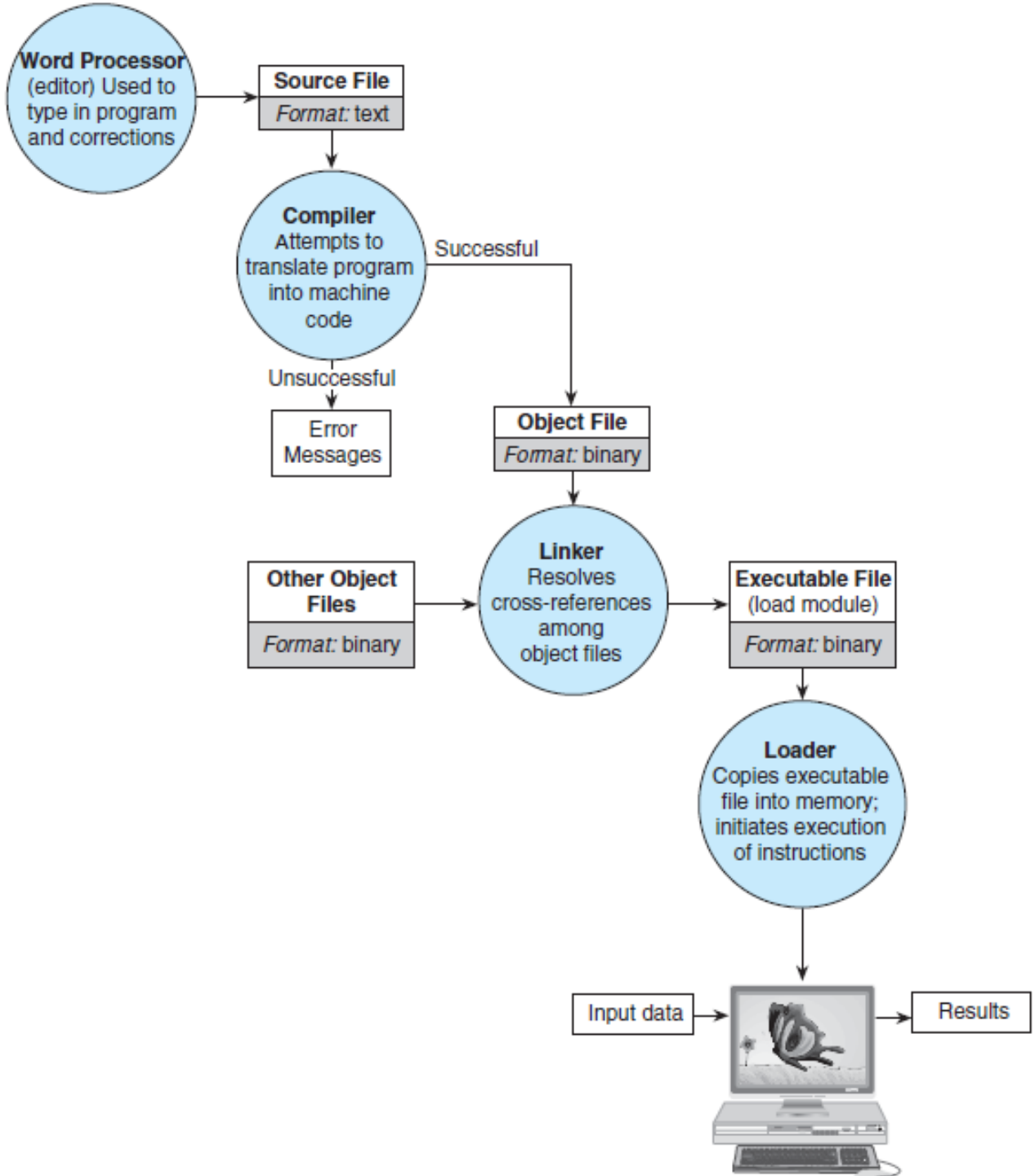
Chapter Objectives

- To understand dynamic allocation on the heap
- To learn how to use pointers to access structs
- To learn how to use pointers to build linked data structures
- To understand how to use and implement a linked list

Previous uses of pointers…

- Reference to data
- Output parameters
- Arrays and strings
- File pointers


Word Processor
(editor) Used to type in program and corrections
Source File
Format: text
Compiler
Attempts to translate program into machine code
Successful
Unsuccessful
Error Messages
Object File
Format: binary
Other Object Files
Format: binary
Linker
Resolves cross-references among object files
Executable File
(load module)
Format: binary
Loader
Copies executable file into memory; initiates execution of instructions
Input data
Results

What happens when we run our executable file?


```
func1(int x) {
    x += 1;
    return(x);
}

int main(void) {
    int n = 10;
    n = func1(n);
    return(0);
}
```

Stack memory

What happens when we run our executable file?


```
func1(int x) {
    x += 1;
    return(x);
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int main(void) {
    int n = 10;
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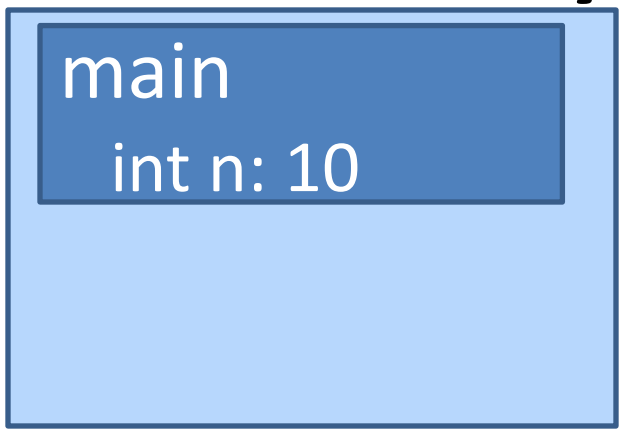
Stack memory



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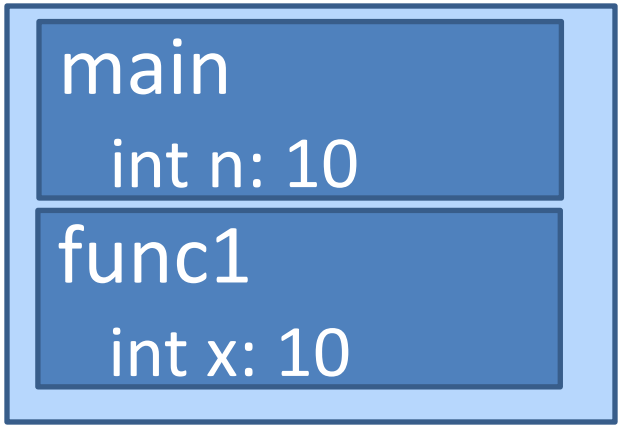
```

Stack memory



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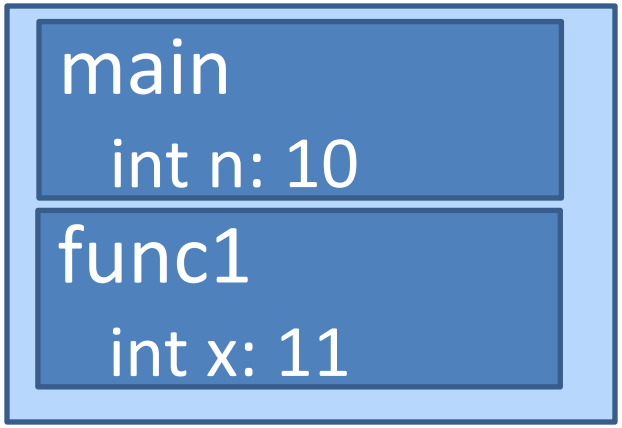
```

Stack memory



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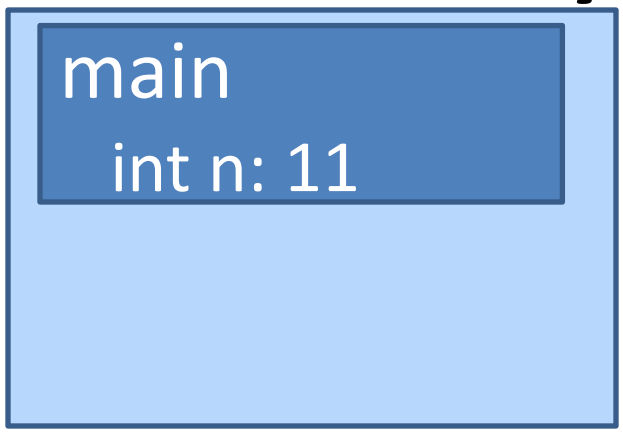
Stack memory



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    return(0);
}
```

Stack memory

What happens when we run our executable file?

Stack memory

What happens when we run our executable file?


```
int main(void) {
    int* nump;
    nump = malloc(sizeof(int));
    *nump = 10;
    free(nump);
}
```

Stack memory

Heap memory

What happens when we run our executable file?


```
int main(void) {
    int* nump;
    nump = malloc(sizeof(int));
    *nump = 10;
    free(nump);
}
```

Stack memory

main
int* nump: ??

Heap memory

What happens when we run our executable file?


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int main(void) {
    int* nump;
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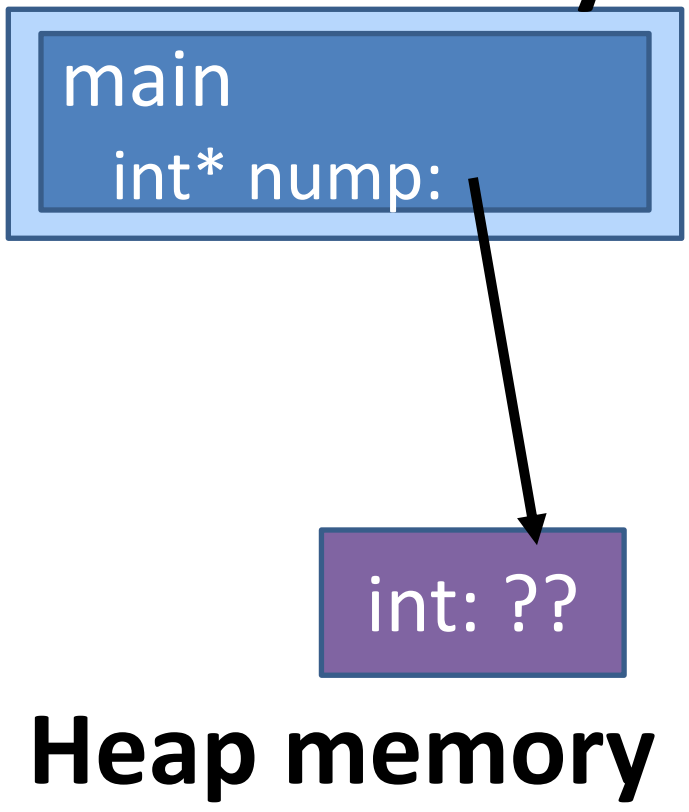
    free(nump);
}
```



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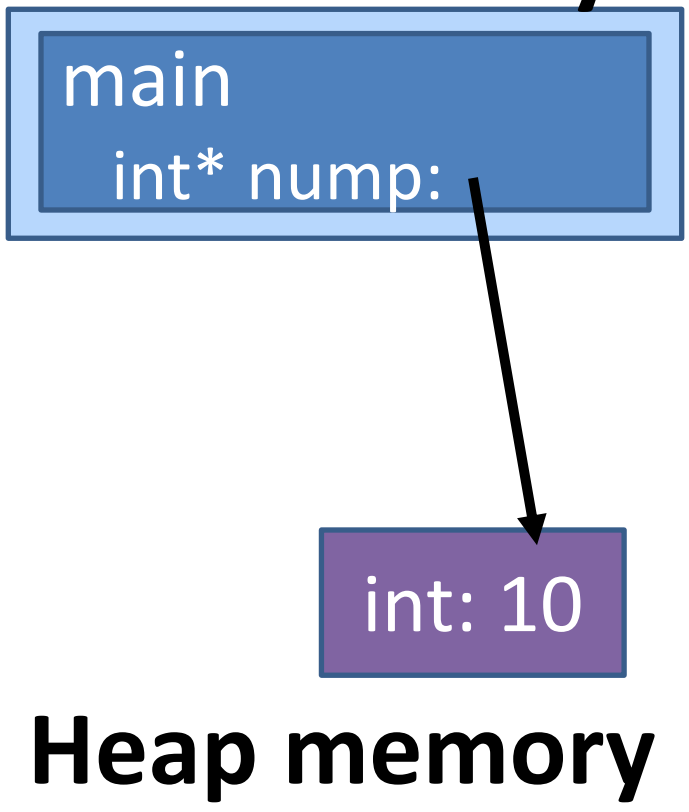

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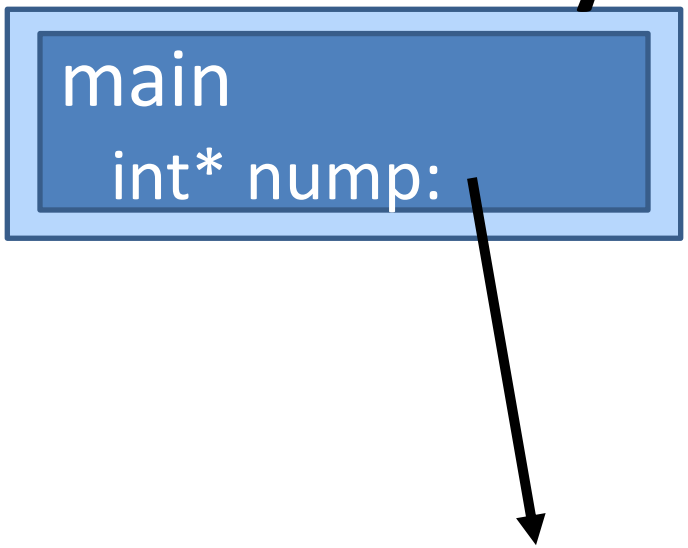
}
```

Stack memory



Heap memory

What happens when we run our executable file?


```
int main(void) {
    int* nump;
    nump = malloc(sizeof(int));
    *nump = 10;
    free(nump);
}
```

Stack memory

Heap memory

Dynamic Memory Allocation

- heap
  - region of memory in which function malloc dynamically allocates blocks of storage
- stack
  - region of memory in which function data areas are allocated and reclaimed

Important functions

- malloc(<amnt of memory to reserve>)
- calloc(<num>, <amnt of memory to reserve>)
- free(pointer)

These are all from stdlib.h.

What happens when we run our executable file?


```
int main(void) {
    int* nump;
    nump = malloc(sizeof(int));
    *nump = 10;
    char* string1;
    string1 = calloc(10, sizeof(char));
    strcpy(string1, “hello”);
    free(nump);
}
```

Stack memory

Heap memory

What happens when we run our executable file?


```
int main(void) {
    int* nump;
    nump = malloc(sizeof(int));
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    free(nump);
}
```

Stack memory

Heap memory

What happens when we run our executable file?


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}
```

Stack memory

Heap memory

What happens when we run our executable file?


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    *nump = 10;
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    string1 = calloc(10, sizeof(char));
    strcpy(string1, “hello”);
    free(nump);
}
```

Stack memory

main
int* nump: ??

Heap memory

What happens when we run our executable file?


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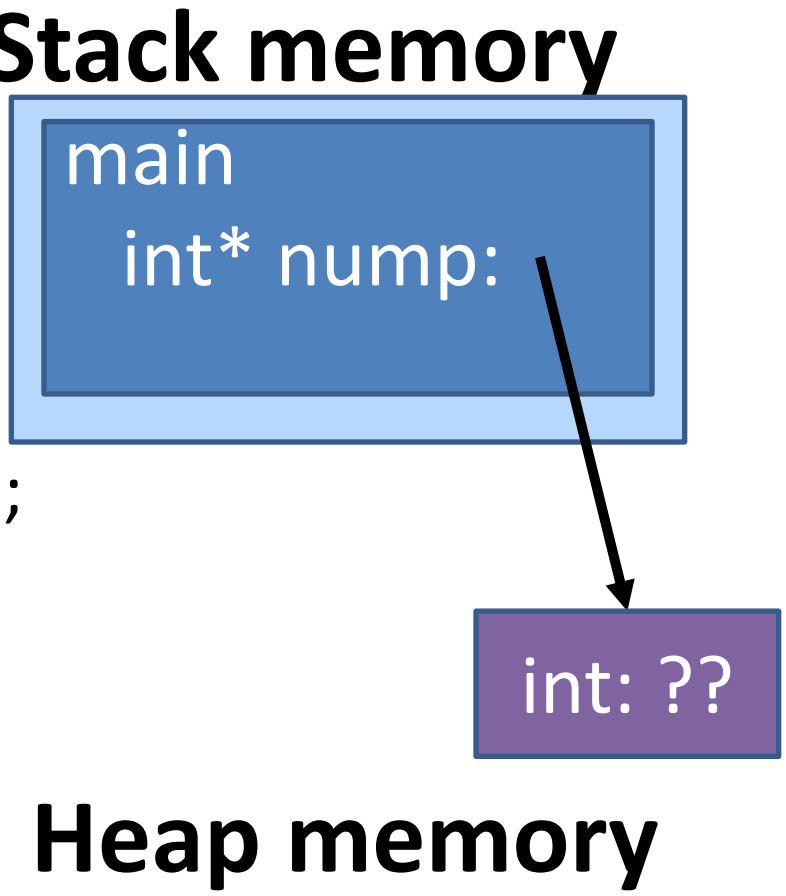
    strcpy(string1, “hello”);
    free(nump);
}
```



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    free(nump);
}
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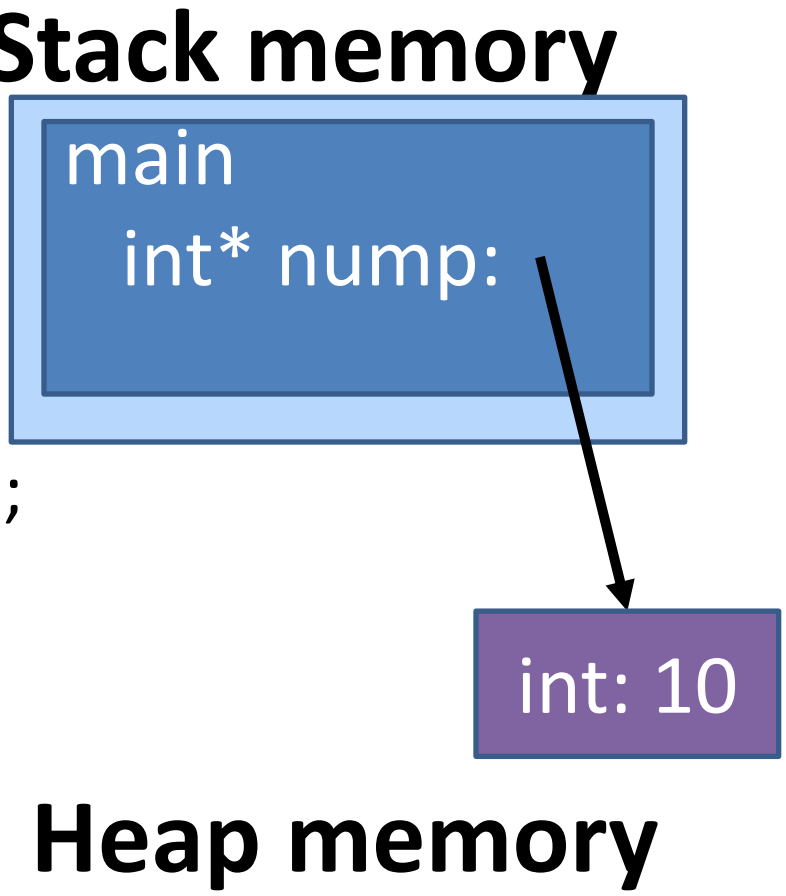

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```
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    int* nump;
    nump = malloc(sizeof(int));
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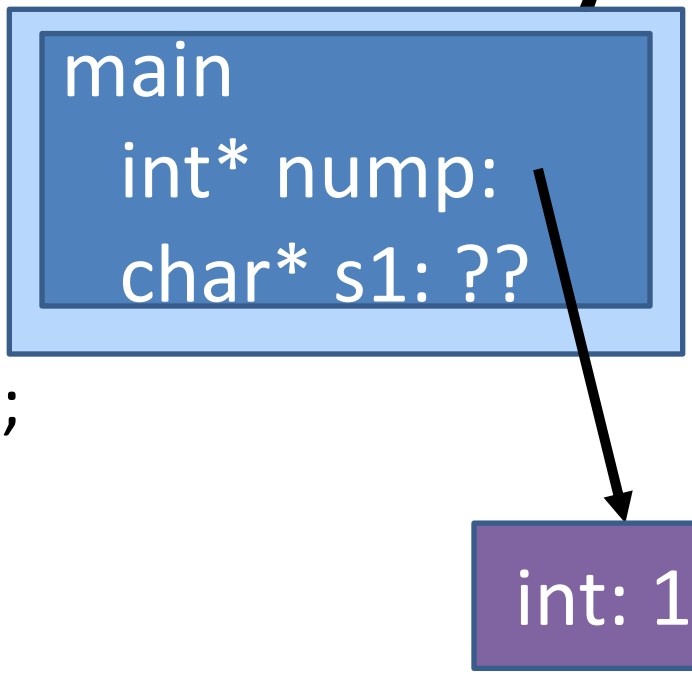
    string1 = calloc(10, sizeof(char));
    strcpy(string1, “hello”);
    free(nump);
}
```

Stack memory



Heap memory

What happens when we run our executable file?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    nump = malloc(sizeof(int));
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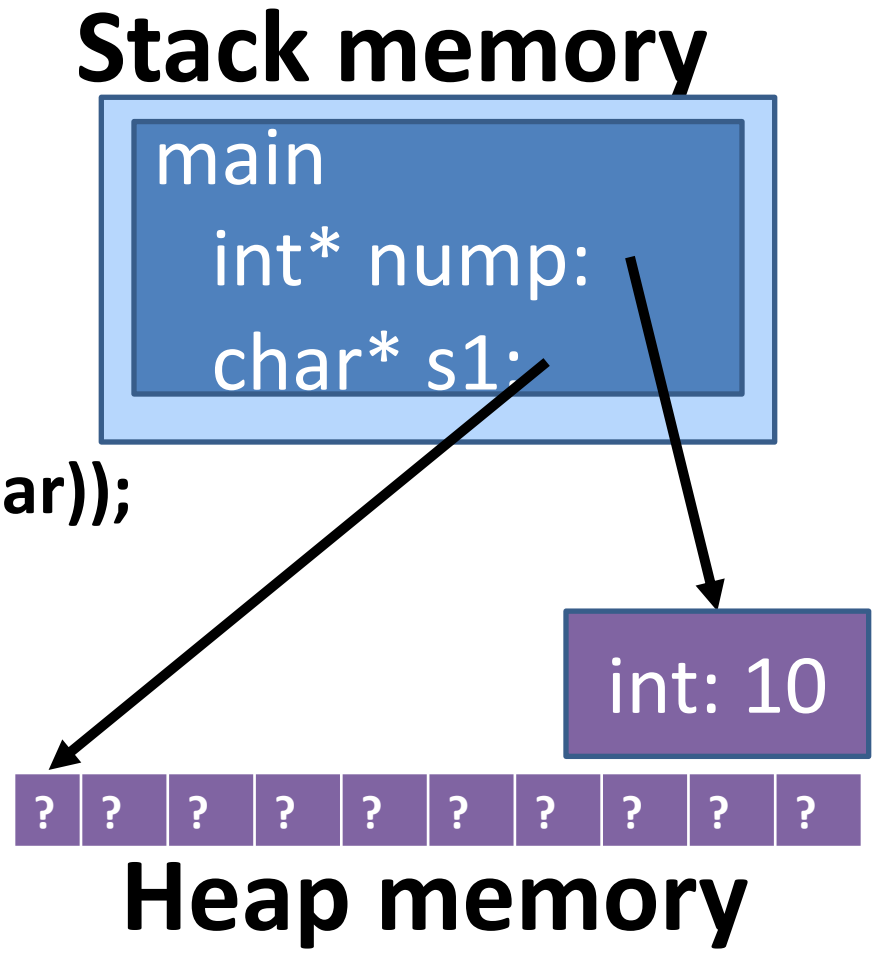
    free(nump);
}
```



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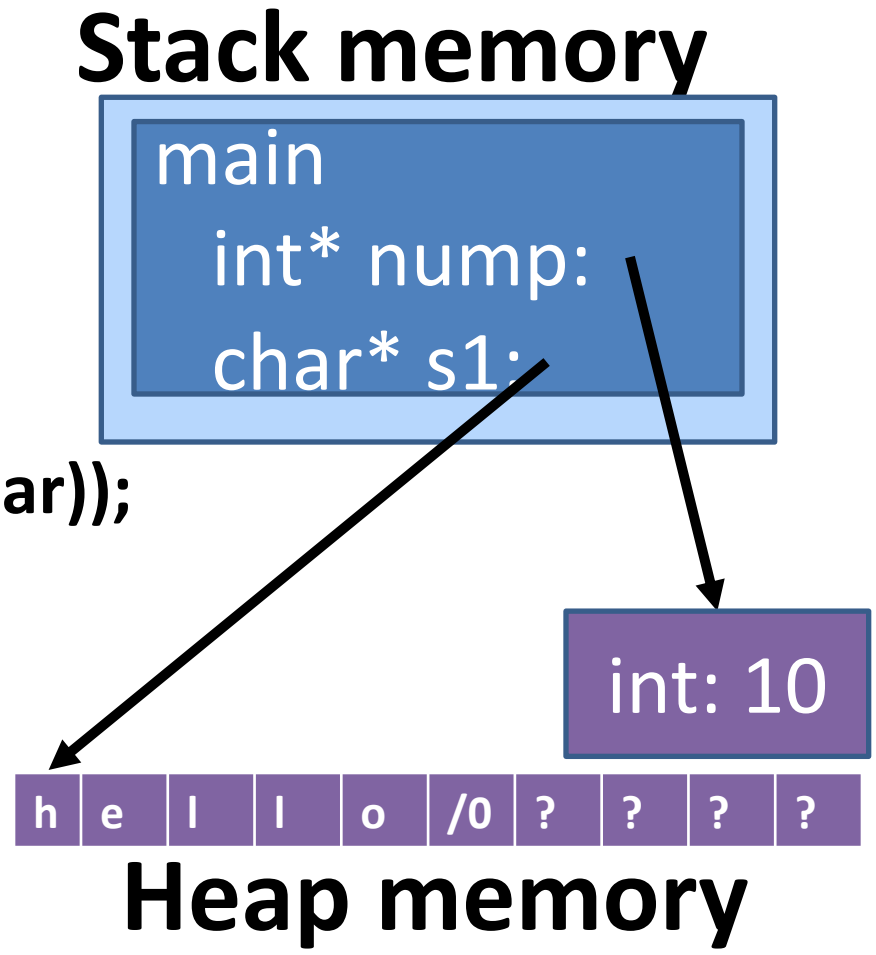
    int* nump;
    nump = malloc(sizeof(int));
    *nump = 10;
    char* string1;
    string1 = calloc(10, sizeof(char));
    strcpy(string1, "hello");
    free(nump);
}
```



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    nump = malloc(sizeof(int));
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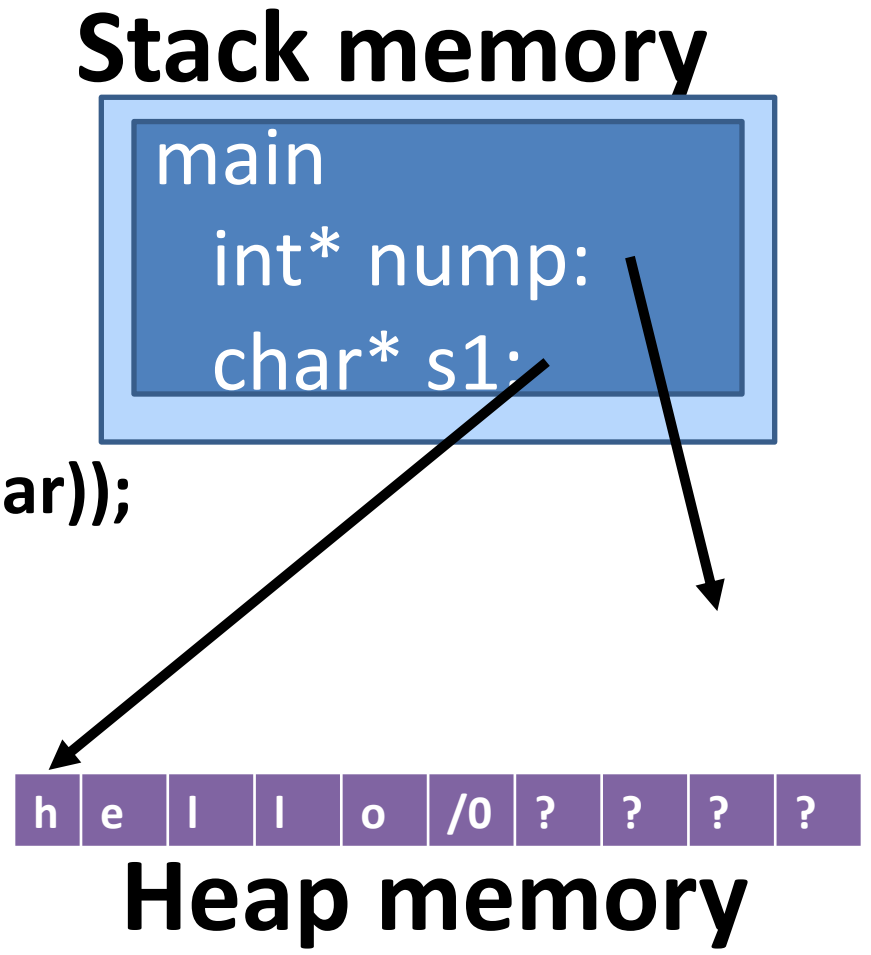
    strcpy(string1, "hello");
    free(nump);
}
```



What happens when we run our executable file?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    int* nump;
    nump = malloc(sizeof(int));
    *nump = 10;
    char* string1;
    string1 = calloc(10, sizeof(char));
    strcpy(string1, “hello”);
    free(nump);
}
```

Stack memory

h	e	l	l	o	/0	?	?	?	?

Heap memory

What happens when we run our executable file?


```
int main(void) {
    int* nump;
    nump = malloc(sizeof(int));
    *nump = 10;
    char* string1;
    string1 = calloc(10, sizeof(char));
    strcpy(string1, “hello”);
    free(nump);
}
```

Stack memory

h	e	l	l	o	/0	?	?	?	?

Heap memory

Memory leaks

- When not all heap memory is freed before the end of a program
- Next time, we'll see a program (valgrind) that can check for memory leaks

(in reality, for a short-running program, not freeing our memory would be okay…but we want to be in the habit of freeing memory!)

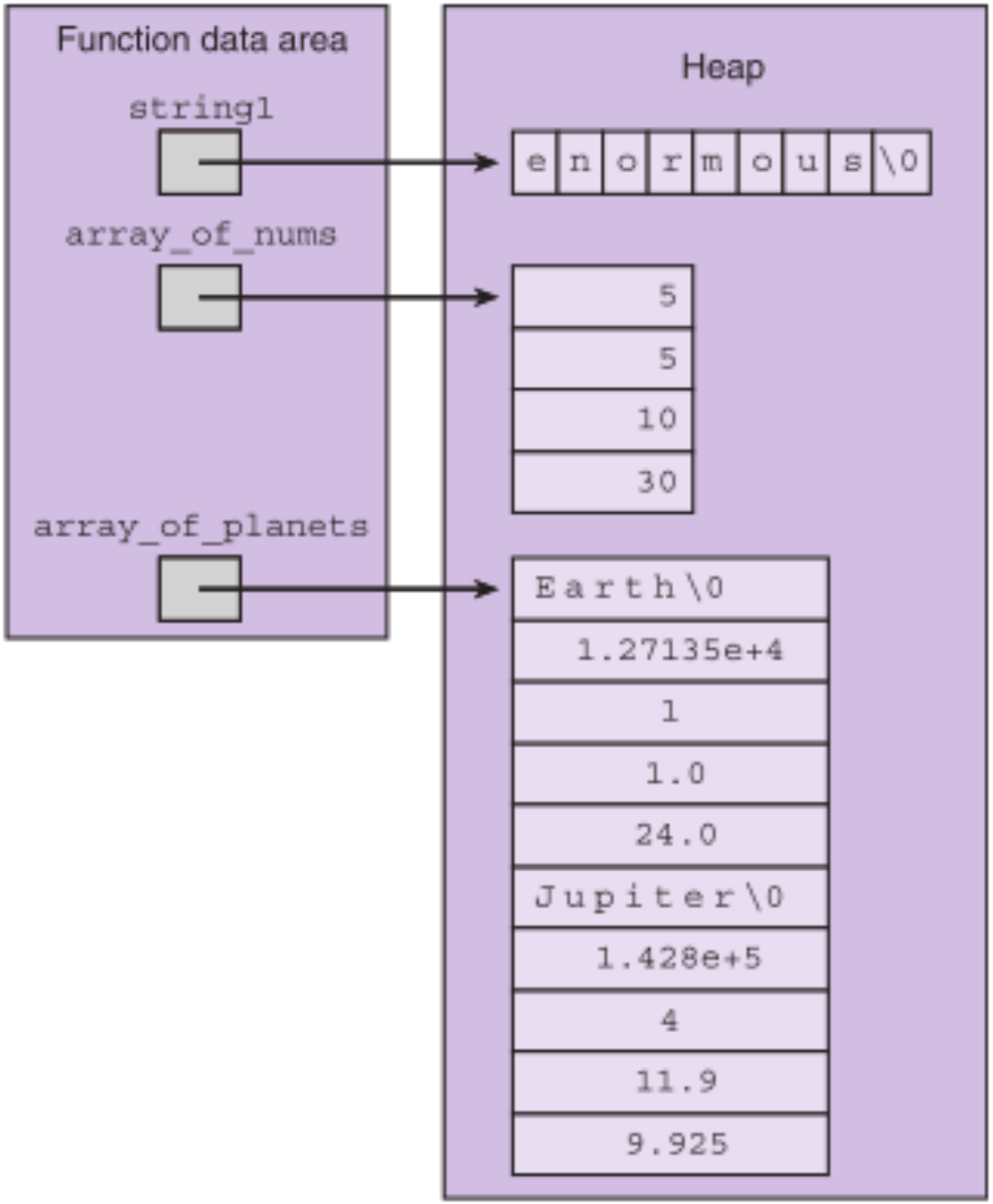
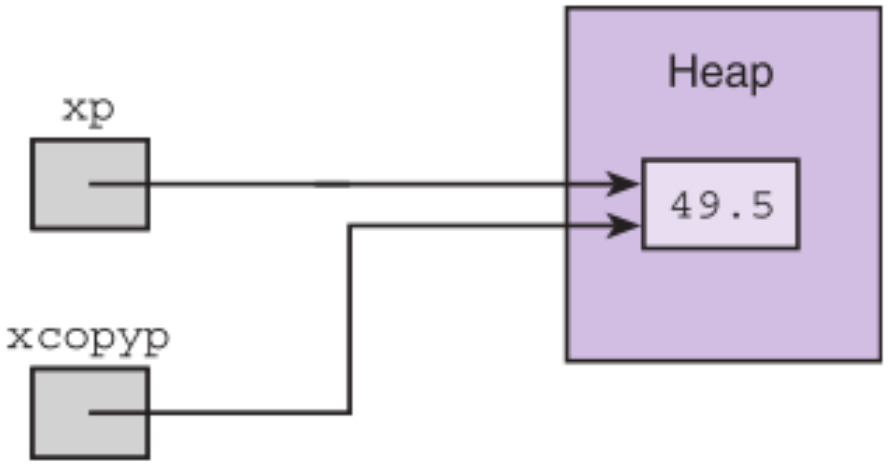

Function data area
string1
array_of_nums
array_of_planets
Heap
e n o r m o u s \0
5
5
10
30
Earth\0
1.27135e+4
1
1.0
24.0
Jupiter\0
1.428e+5
4
11.9
9.925

FIGURE 13.9

Multiple Pointers to a Cell in the Heap



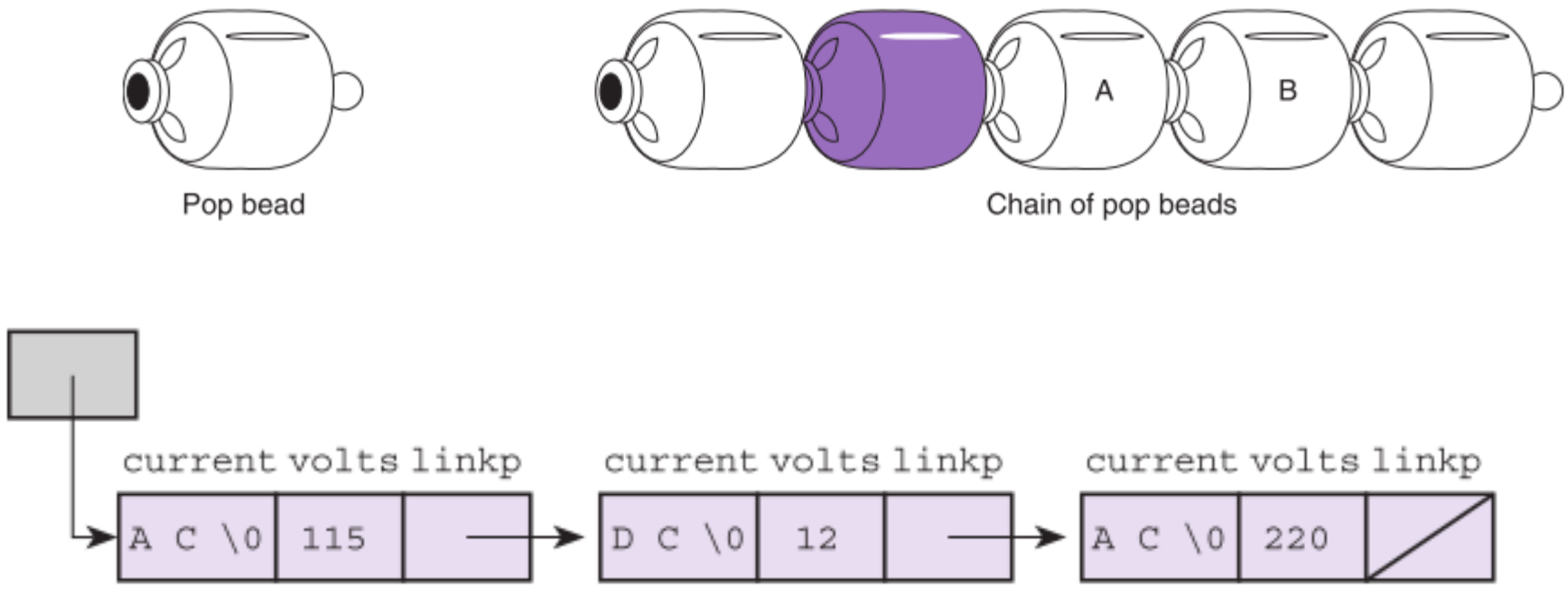

```
double *xp, *xcopyp;

xp = (double *)malloc(sizeof (double));
*xp = 49.5;
xcopyp = xp;
free(xp);
. . .
```

Linked Lists

- linked list
  - a sequence of nodes in which each node but the last contains the address of the next node
- empty list
  - a list of no nodes
  - represented in C by the pointer NULL, whose value is zero
- list head
  - the first element in a linked list

FIGURE 13.10 Children's Pop Beads in a Chain



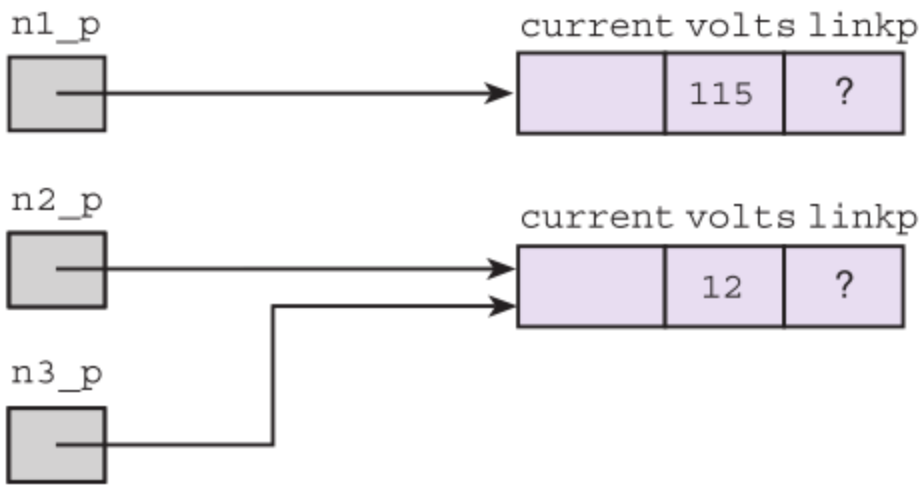


FIGURE 13.11

Multiple Pointers to the Same Structure

```
node_t *n1_p, *n2_p, *n3_p;
n1_p = (node_t *)malloc(sizeof (node_t));
strcpy(n1_p->current, "AC");
n1_p->volts = 115;
n2_p = (node_t *)malloc(sizeof (node_t));
strcpy(n2_p->current, "DC");
n2_p->volts = 12;

n3_p = n2_p;
```

FIGURE 13.12

Linking Two Nodes

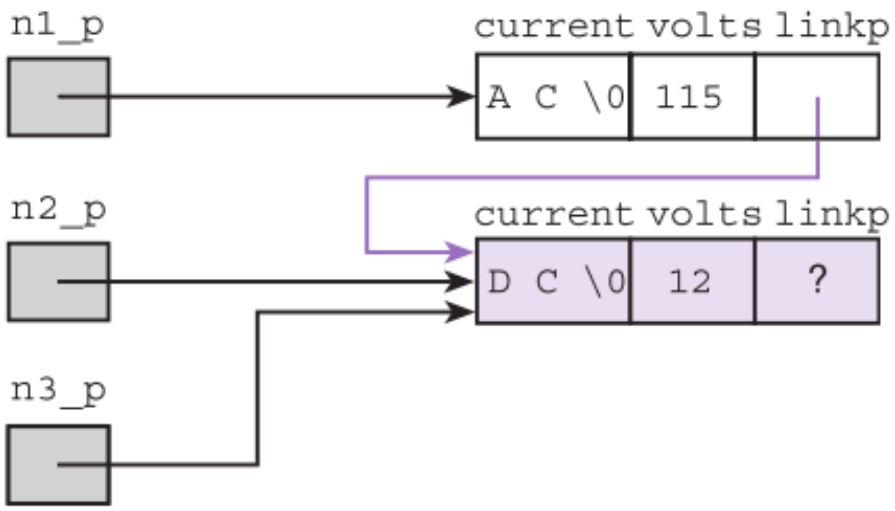
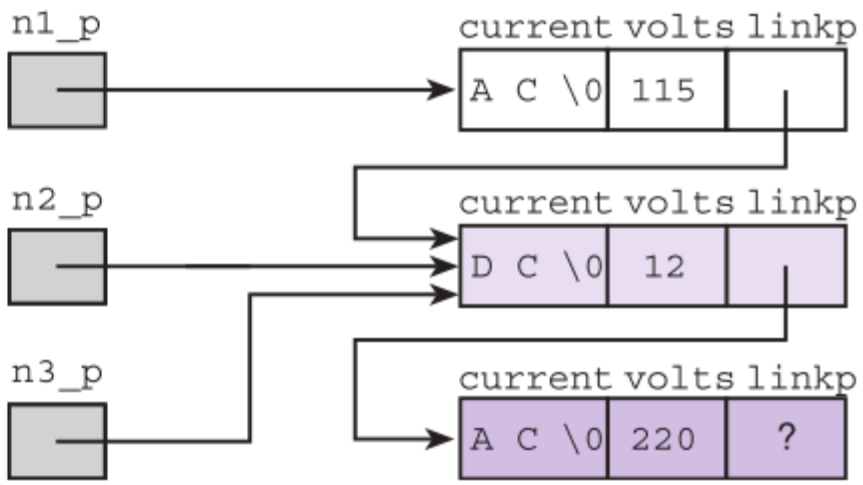


TABLE 13.2 Analyzing the Reference n1_p->linkp->volts

Section of Reference	Meaning
`n1_p->linkp`	Follow the pointer in `n1_p` to a structure and select the `linkp` component.
`linkp->volts`	Follow the pointer in the `linkp` component to another structure and select the `volts` component.

FIGURE 13.13

Three-Node Linked List with Undefined Final Pointer



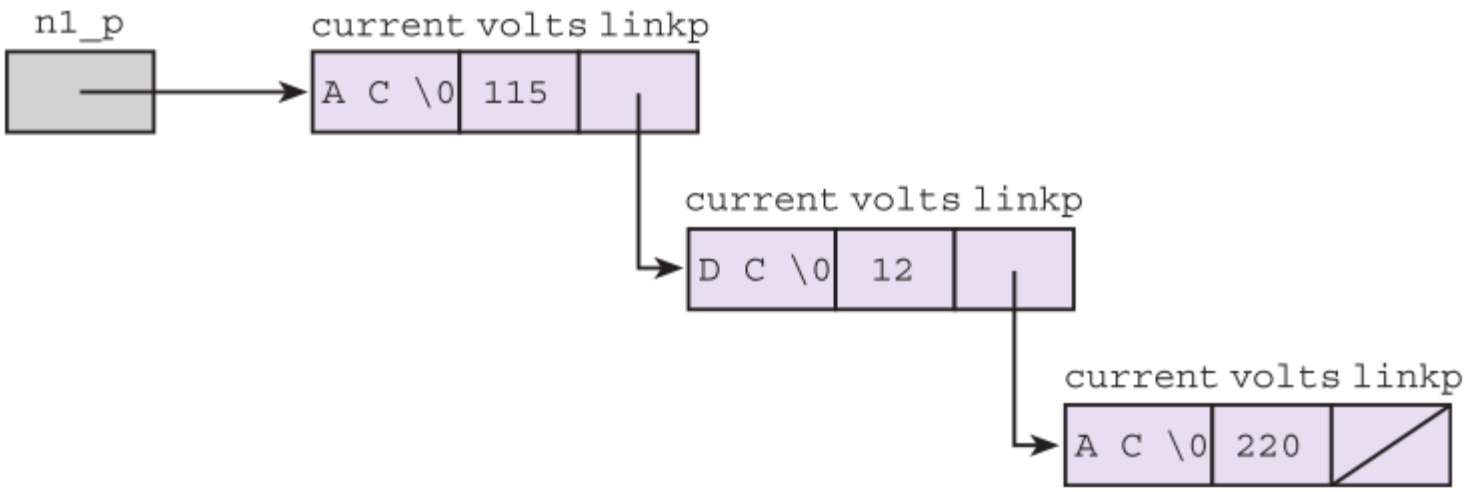


FIGURE 13.14

Three-Element Linked List Accessed Through n1_p

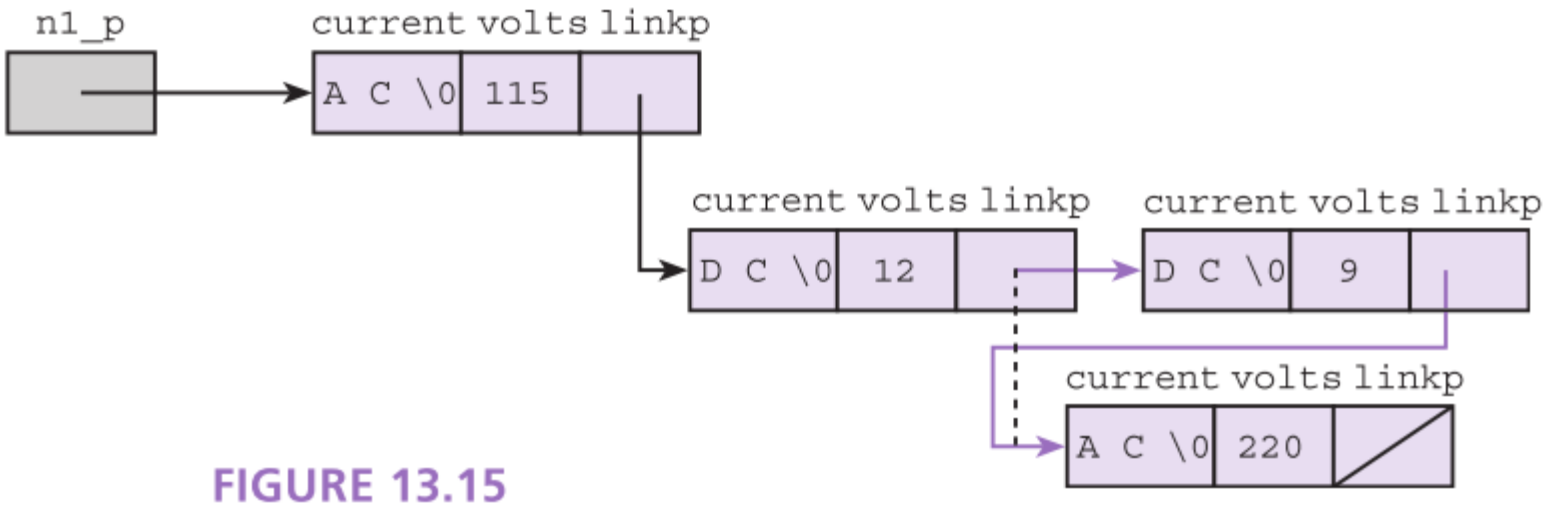
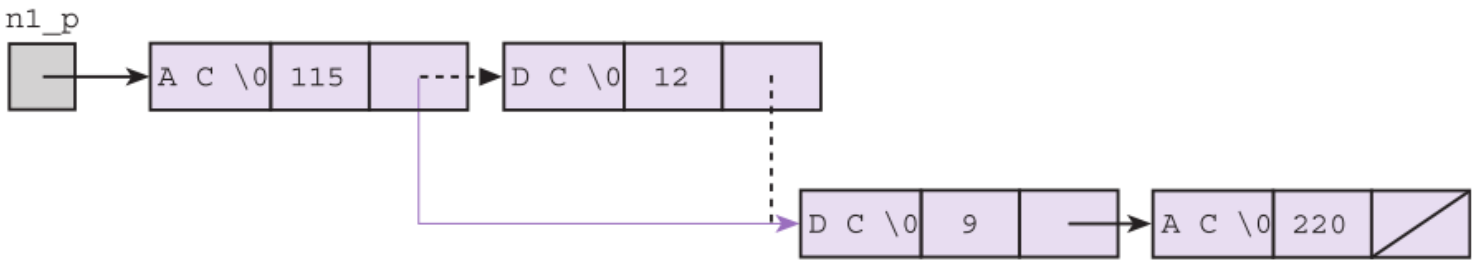


FIGURE 13.15

Linked List After an Insertion

FIGURE 13.16 Linked List After a Deletion



Advantages of Linked Lists

- It can be modified easily.
- The means of modifying a linked list works regardless of how many elements are in the list.
- It is easy to delete an element.

Linked List Operators

- traversing a list
  - processing each node in a linked list in sequence, starting at the list head
- tail recursion
  - any recursive call that is executed as a function's last step

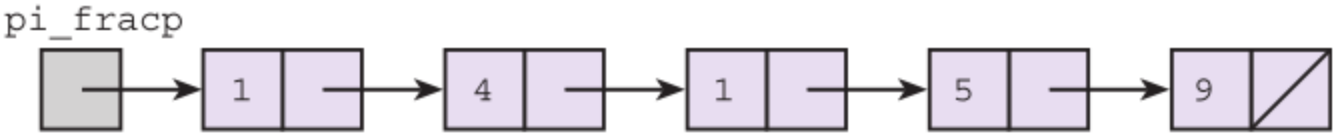


FIGURE 13.17 Function print_list

```
1.  /*
2.   * Displays the list pointed to by headp
3.   */
4.  void
5.  print_list(list_node_t *headp)
6.  {
7.       if (headp == NULL) {    /* simple case - an empty list                */
8.            printf("\n");
9.       } else {                /* recursive step - handles first element     */
10.           printf("%d", headp->digit);  /*        leaves rest to             */
11.           print_list(headp->restp);    /*        recursion                  */
12.      }
13. }
```

FIGURE 13.18 Comparison of Recursive and Iterative List Printing

```
/* Displays the list pointed to by headp */
void
print_list(list_node_t *headp)
{
 if (headp == NULL) {/* simple case */
     printf("\n");
 } else {          /* recursive step */
     printf("%d", headp->digit);
     print_list(headp->restp);
 }
}
```

```
{ list_node_t *cur_nodep;

  for  (cur_nodep = headp; /* start at
                              beginning */
        cur_nodep != NULL; /* not at
                              end yet   */
        cur_nodep = cur_nodep->restp)
      printf("%d", cur_nodep->digit);
  printf("\n");
}
```

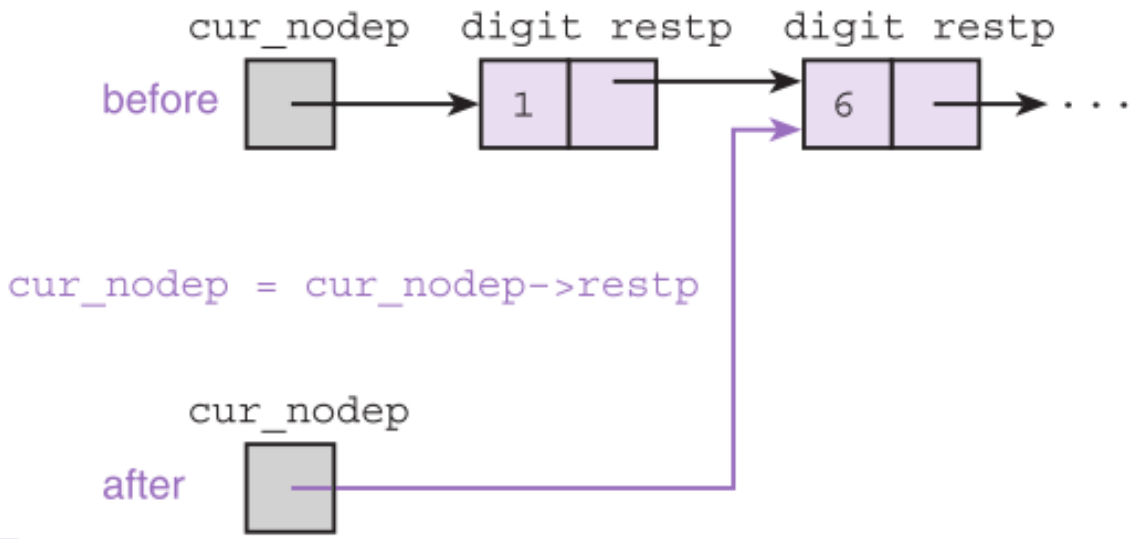


FIGURE 13.19

Update of List-Traversing Loop Control Variable

FIGURE 13.20 Recursive Function get_list

```
1.  #include <stdlib.h>  /*  gives access to malloc */
2.  #define SENT -1
3.  /*
4.   *  Forms a linked list of an input list of integers
5.   *  terminated by SENT
6.   */
7.  list_node_t *
8.  get_list(void)
9.  {
10.      int data;
11.      list_node_t *ansp;
12.
13.      scanf("%d", &data);
14.      if (data == SENT) {
15.            ansp = NULL;
16.      } else {
17.            ansp = (list_node_t *)malloc(sizeof (list_node_t));
18.            ansp->digit = data;
19.            ansp->restp = get_list();
20.      }
21.
22.      return (ansp);
23. }
```

FIGURE 13.21 Iterative Function get_list

```
1.  /*
2.   *  Forms a linked list of an input list of integers terminated by SENT
3.   */
4.  list_node_t *
5.  get_list(void)
6.  {
7.        int data;
8.        list_node_t *ansp,
9.                    *to_fillp, /* pointer to last node in list whose
10.                               restp component is unfilled         */
11.                   *newp;     /* pointer to newly allocated node     */
12.
13.       /* Builds first node, if there is one */
14.       scanf("%d", &data);
15.       if (data == SENT) {
16.             ansp = NULL;
17.       } else {
18.             ansp = (list_node_t *)malloc(sizeof (list_node_t));
19.             ansp->digit = data;
20.             to_fillp = ansp;
21.
22.             /* Continues building list by creating a node on each
23.                iteration and storing its pointer in the restp component of the
24.                node accessed through to_fillp */
25.             for  (scanf("%d", &data);
26.                   data != SENT;
27.                   scanf("%d", &data)) {
28.                newp = (list_node_t *)malloc(sizeof (list_node_t));
29.                newp->digit = data;
30.                to_fillp->restp = newp;
31.                to_fillp = newp;
32.             }
33.
34.             /* Stores NULL in final node's restp component */
35.             to_fillp->restp = NULL;
36.       }
37.       return (ansp);
38. }
```

FIGURE 13.22 Function search

```
1.  /*
2.   *  Searches a list for a specified target value. Returns a pointer to
3.   *  the first node containing target if found. Otherwise returns NULL.
4.   */
5.  list_node_t *
6.  search(list_node_t *headp,  /* input - pointer to head of list */
7.         int         target)  /* input - value to search for     */
8.  {
9.       list_node_t *cur_nodep; /* pointer to node currently being checked */
10.
11.      for  (cur_nodep = headp;
12.            cur_nodep != NULL  &&  cur_nodep->digit != target;
13.            cur_nodep = cur_nodep->restp) {}
14.
15.      return (cur_nodep);
16. }
```

Wrap Up

- Function malloc from the stdlib library can be used to allocate single elements, or nodes, or a dynamic data structure.
- Function calloc from stdlib dynamically allocates an array.
- Function free from stdlib returns memory cells to the storage heap.
- Linked lists can implement stacks, queues, and ordered lists

Appendix A: More about pointers

Pointer arithmetic