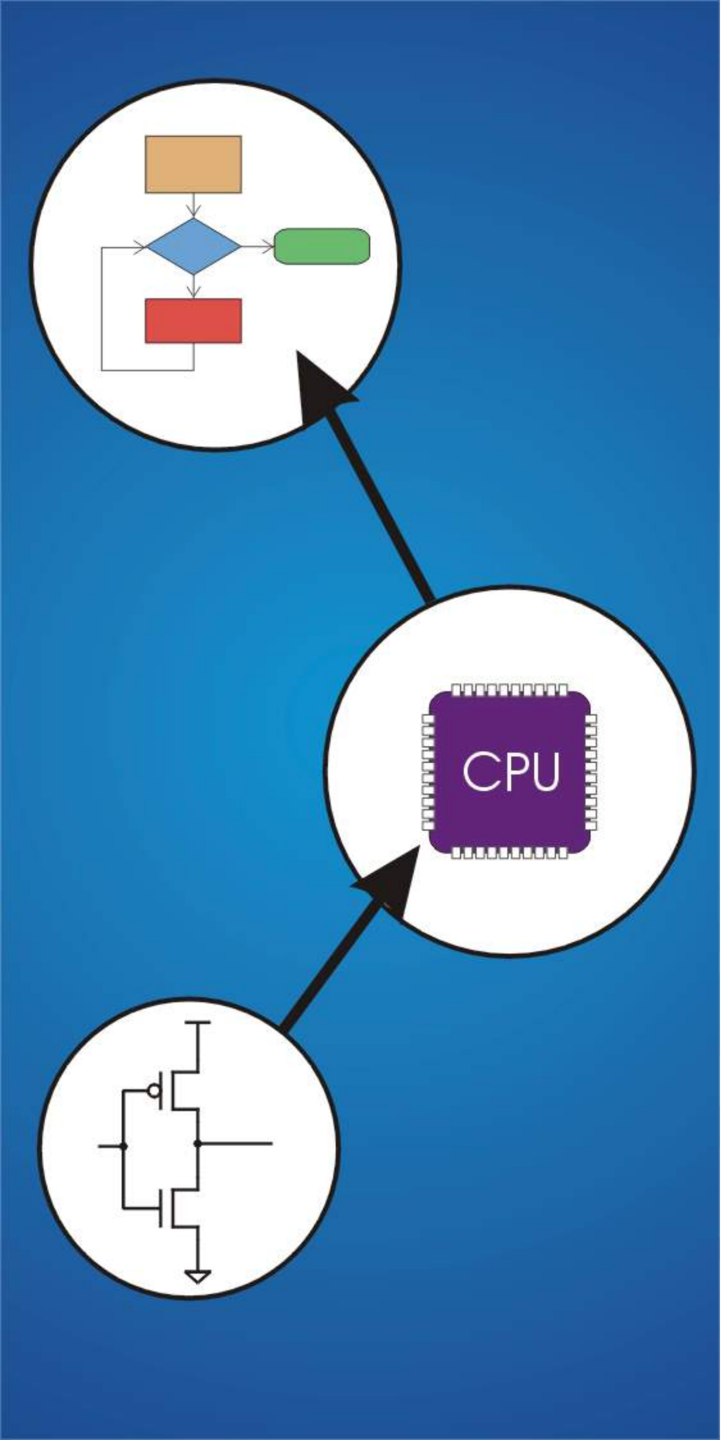


Chapter 19
Data Structures

-struct

-dynamic memory allocation

Data Structures

A data structure is a particular organization of data in memory.

- **We want to group related items together.**
- **We want to organize these data bundles in a way that is convenient to program and efficient to execute.**

An array is one kind of data structure.

In this chapter, we look at two more:

`struct` **– directly supported by C**

linked list – built from `struct` **and dynamic allocation**

Structures in C

A `struct` is a mechanism for grouping together related data items of different types.

- **Recall that an array groups items of a single type.**

Example:

We want to represent an airborne aircraft:

```
char flightNum[7];
int altitude;
int longitude;
int latitude;
int heading;
double airSpeed;
```

We can use a `struct` to group these data together for each plane.

Defining a Struct

We first need to define a new type for the compiler and tell it what our struct looks like.

```
struct flightType {
   char flightNum[7];  /* max 6 characters */
   int altitude;       /* in meters */
   int longitude;      /* in tenths of degrees */
   int latitude;       /* in tenths of degrees */
   int heading;        /* in tenths of degrees */
   double airSpeed;    /* in km/hr */
};
```

This tells the compiler how big our struct is and how the different data items ("members") are laid out in memory.

But it does not allocate any memory.

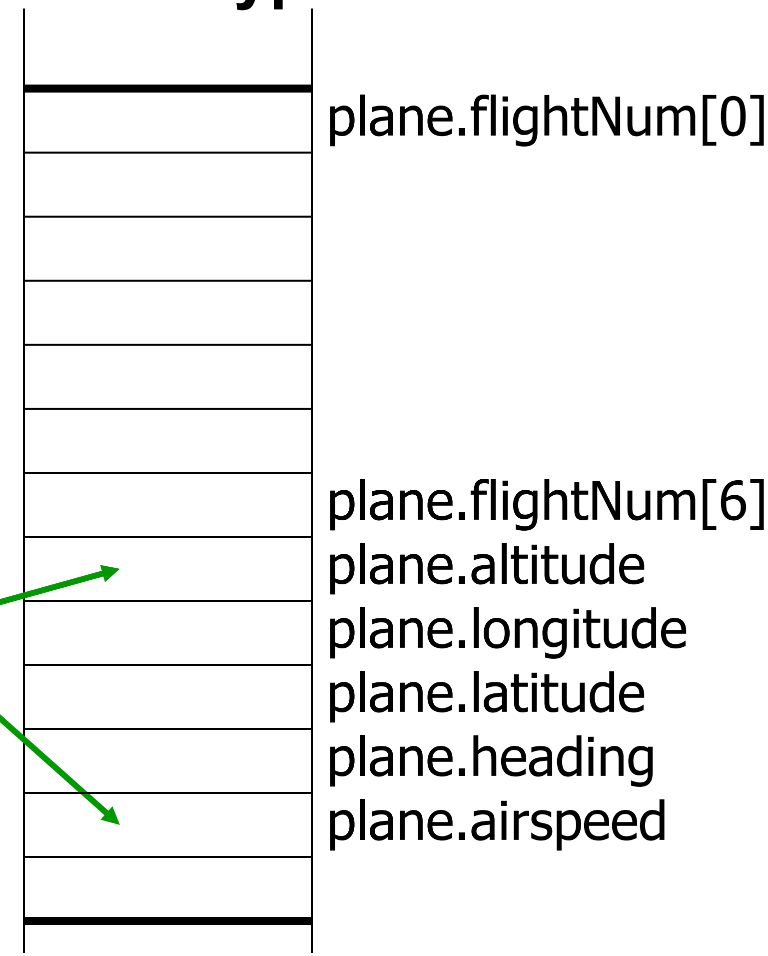
Declaring and Using a Struct

To allocate memory for a struct,
we declare a variable using our new data type.

```
struct flightType plane;
```

Memory is allocated, and we can access individual members of this variable:

```
plane.airSpeed = 800.0;
plane.altitude = 10000;
```



A struct's members are laid out in the order specified by the definition.

Defining and Declaring at Once

You can both define and declare a struct at the same time.

```
struct flightType {
  char flightNum[7];  /* max 6 characters */
  int altitude;       /* in meters */
  int longitude;      /* in tenths of degrees */
  int latitude;       /* in tenths of degrees */
  int heading;        /* in tenths of degrees */
  double airSpeed;    /* in km/hr */
} maverick;
```

And you can use the flightType name to declare other structs.

```
struct flightType iceMan;
```

typedef

C provides a way to define a data type by giving a new name to a predefined type.

Syntax:

```
typedef <type> <name>;
```

Examples:

```
typedef int Color;
typedef struct flightType WeatherData;
typedef struct ab_type {
  int a;
  double b;
} ABGroup;
```

Using typedef

This gives us a way to make code more readable by giving application-specific names to types.

```
Color pixels[500];
Flight plane1, plane2;
```

Typical practice:

Put typedef's into a header file, and use type names in main program. If the definition of Color/Flight changes, you might not need to change the code in your main program file.

Array of Structs

Can declare an array of structs:

```
Flight planes[100];
```

Each array element is a struct (7 words, in this case).

To access member of a particular element:

```
planes[34].altitude = 10000;
```

Because the `[]` and `.` operators are at the same precedence, and both associate left-to-right, this is the same as:

```
(planes[34]).altitude = 10000;
```

Pointer to Struct

We can declare and create a pointer to a struct:

```
Flight *planePtr;
planePtr = &planes[34];
```

To access a member of the struct addressed by dayPtr:

```
(*planePtr).altitude = 10000;
```

Because the . operator has higher precedence than *,
this is NOT the same as:

```
*planePtr.altitude = 10000;
```

C provides special syntax for accessing a struct member through a pointer:

```
planePtr->altitude = 10000;
```

Passing Structs as Arguments

Unlike an array, a struct is always passed by value into a function.

- **This means the struct members are copied to the function's activation record, and changes inside the function are not reflected in the calling routine's copy.**

Most of the time, you'll want to pass a pointer to a struct.

```
int Collide(Flight *planeA, Flight *planeB)
{
  if (planeA->altitude == planeB->altitude) {
     ...
  }
  else
    return 0;
}
```

Dynamic Allocation

Suppose we want our weather program to handle a variable number of planes – as many as the user wants to enter.

- **We can’t allocate an array, because we don’t know the maximum number of planes that might be required.**
- **Even if we do know the maximum number, it might be wasteful to allocate that much memory because most of the time only a few planes’ worth of data is needed.**

Solution:

Allocate storage for data dynamically, as needed.

malloc

The Standard C Library provides a function for allocating memory at run-time: malloc.

```
void *malloc(int numBytes);
```

It returns a generic pointer (`void*`) to a contiguous region of memory of the requested size (in bytes).

The bytes are allocated from a region in memory called the heap.

- **The run-time system keeps track of chunks of memory from the heap that have been allocated.**

Using malloc

To use malloc, we need to know how many bytes to allocate. The `sizeof` operator asks the compiler to calculate the size of a particular type.

```
planes = malloc(n * sizeof(Flight));
```

We also need to change the type of the return value to the proper kind of pointer – this is called "casting."

```
planes =
   (Flight*) malloc(n* sizeof(Flight));
```

Example

```
int airbornePlanes;
Flight *planes;

printf("How many planes are in the air?");
scanf("%d", &airbornePlanes);

planes =
  (Flight*) malloc(sizeof(Flight) * airbornePlanes);
if (planes == NULL) {
  printf("Error in allocating the data array.\n");
  ...
}
planes[0].altitude = ...
```

If allocation fails, malloc returns NULL.

Note: Can use array notation or pointer notation.

Free and Calloc

**Once the data is no longer needed,
it should be released back into the heap for later use.**

**This is done using the free function,
passing it the same address that was returned by malloc.**

```
void free(void*);
```

If allocated data is not freed, the program might run out of heap memory and be unable to continue.

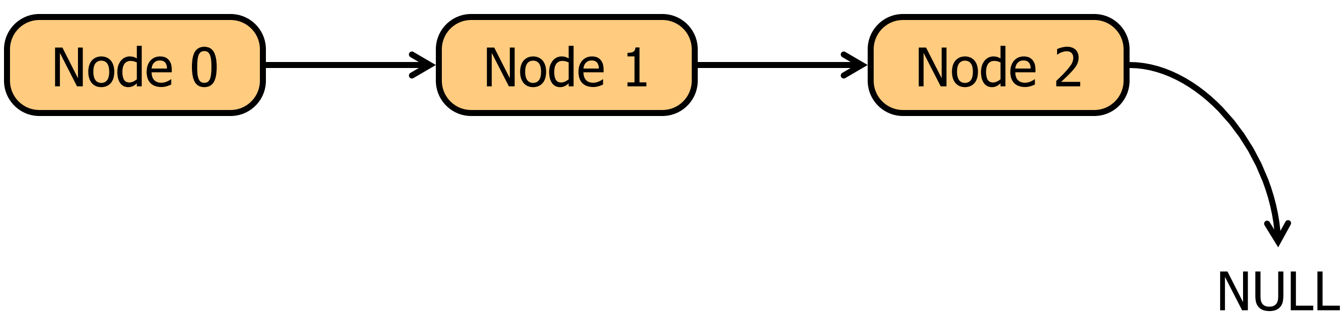
Sometimes we prefer to initialize allocated memory to zeros, calloc function does this:

```
void *calloc(size_t count, size_t size);
```

The Linked List Data Structure

A linked list is an ordered collection of nodes, each of which contains some data, connected using pointers.

- **Each node points to the next node in the list.**
- **The first node in the list is called the head.**
- **The last node in the list is called the tail.**



Linked List vs. Array

A linked list can only be accessed sequentially.

To find the 5th element, for instance,
you must start from the head and follow the links through four other nodes.

Advantages of linked list:

- **Dynamic size**
- **Easy to add additional nodes as needed**
- **Easy to add or remove nodes from the middle of the list (just add or redirect links)**

Advantage of array:

- **Can easily and quickly access arbitrary elements**

Example: Car Lot

Create an inventory database for a used car lot. Support the following actions:

- **Search the database for a particular vehicle.**
- **Add a new car to the database.**
- **Delete a car from the database.**

The database must remain sorted by vehicle ID.

Since we don't know how many cars might be on the lot at one time, we choose a linked list representation.

Car data structure

Each car has the following characteristics:
vehicle ID, make, model, year, mileage, cost.

Because it's a linked list, we also need a pointer to the next node in the list:

```
typedef struct carType Car;

struct carType {
  int vehicleID;
  char make[20];
  char model[20];
  int year;
  int mileage;
  double cost;
  Car *next; /* ptr to next car in list */
}
```

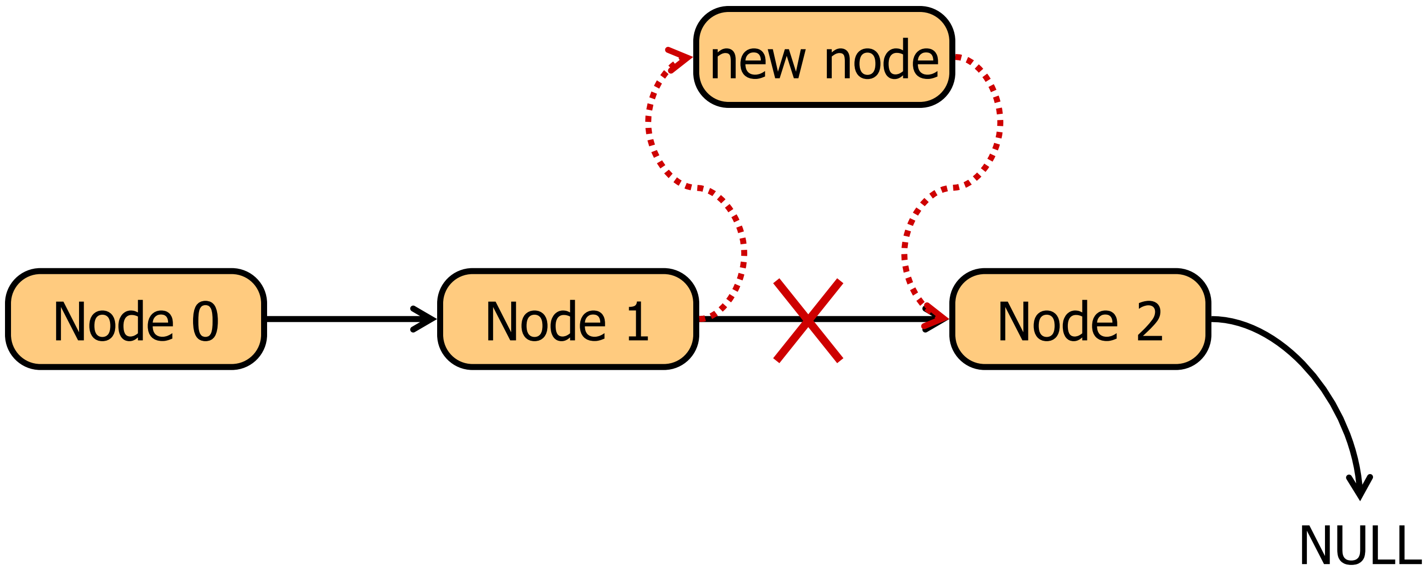
Scanning the List

Searching, adding, and deleting all require us to find a particular node in the list. We scan the list until we find a node whose ID is >= the one we're looking for.

```
Car *ScanList(Car *head, int searchID)
{
  Car *previous, *current;
  previous = head;
  current = head->next;
  /* Traverse until ID >= searchID */
  while ((current!=NULL)
          && (current->vehicleID < searchID)) {
    previous = current;
    current = current->next;
  }
  return previous;
}
```

Adding a Node

Create a new node with the proper info.
Find the node (if any) with a greater vehicleID.
"Splice" the new node into the list:



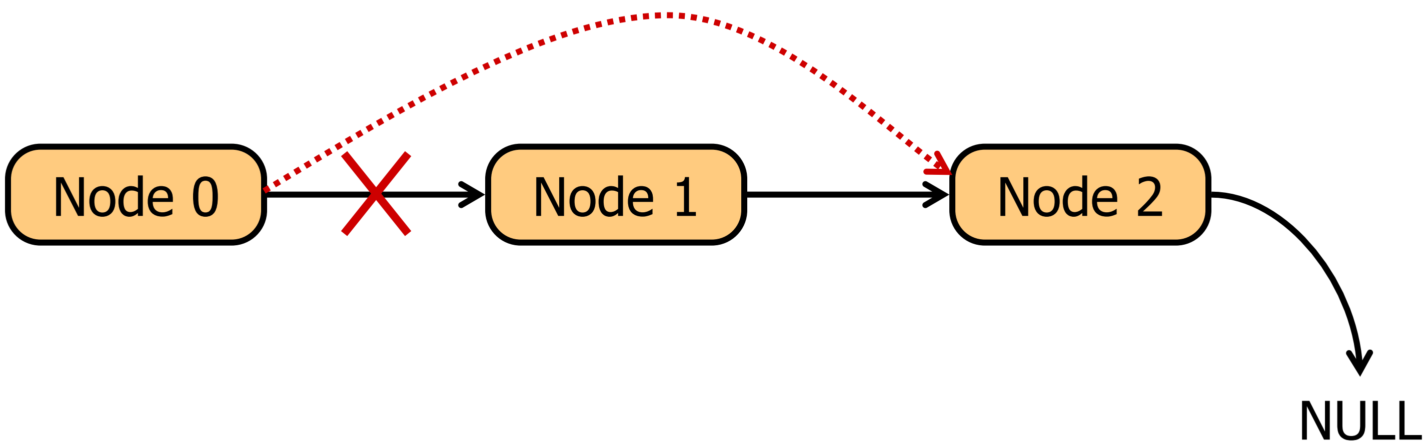
Excerpts from Code to Add a Node

```
newNode = (Car*) malloc(sizeof(Car));
/* initialize node with new car info */
...
prevNode = ScanList(head, newNode->vehicleID);
nextNode = prevNode->next;

if ((nextNode == NULL)
    || (nextNode->vehicleID != newNode->vehicleID))
  prevNode->next = newNode;
  newNode->next = nextNode;
}
else {
  printf("Car already exists in database.");
  free(newNode);
}
```

Deleting a Node

Find the node that points to the desired node.
Redirect that node's pointer to the next node (or NULL).
Free the deleted node's memory.



Excerpts from Code to Delete a Node

```
printf("Enter vehicle ID of car to delete:\n");
scanf("%d", vehicleID);

prevNode = ScanList(head, vehicleID);
delNode = prevNode->next;

if ((delNode != NULL)
     && (delNode->vehicleID == vehicleID))
  prevNode->next = delNode->next;
  free(delNode);
}
else {
  printf("Vehicle not found in database.\n");
}
```

Building on Linked Lists

The linked list is a fundamental data structure.

- **Dynamic**
- **Easy to add and delete nodes**

The concepts described here will be helpful when learning about more elaborate data structures:

- **Trees**
- **Hash Tables**
- **Directed Acyclic Graphs**
- **...**

Segmentation fault

Segmentation fault occurs when a memory access violation occurs.

Possible causes:

- Dereferencing null pointer
- Attempting to access a nonexistent memory address (outside process's address space)
- Attempting to access memory the program does not have rights to (such as kernel structures)
- Attempting to write read-only memory (such as code segment)

Buffer overflow:

- while writing data it overruns the buffer's boundary and overwrites adjacent memory locations.
- Can cause a segmentation fault
- Common cause of security vulnerabilities

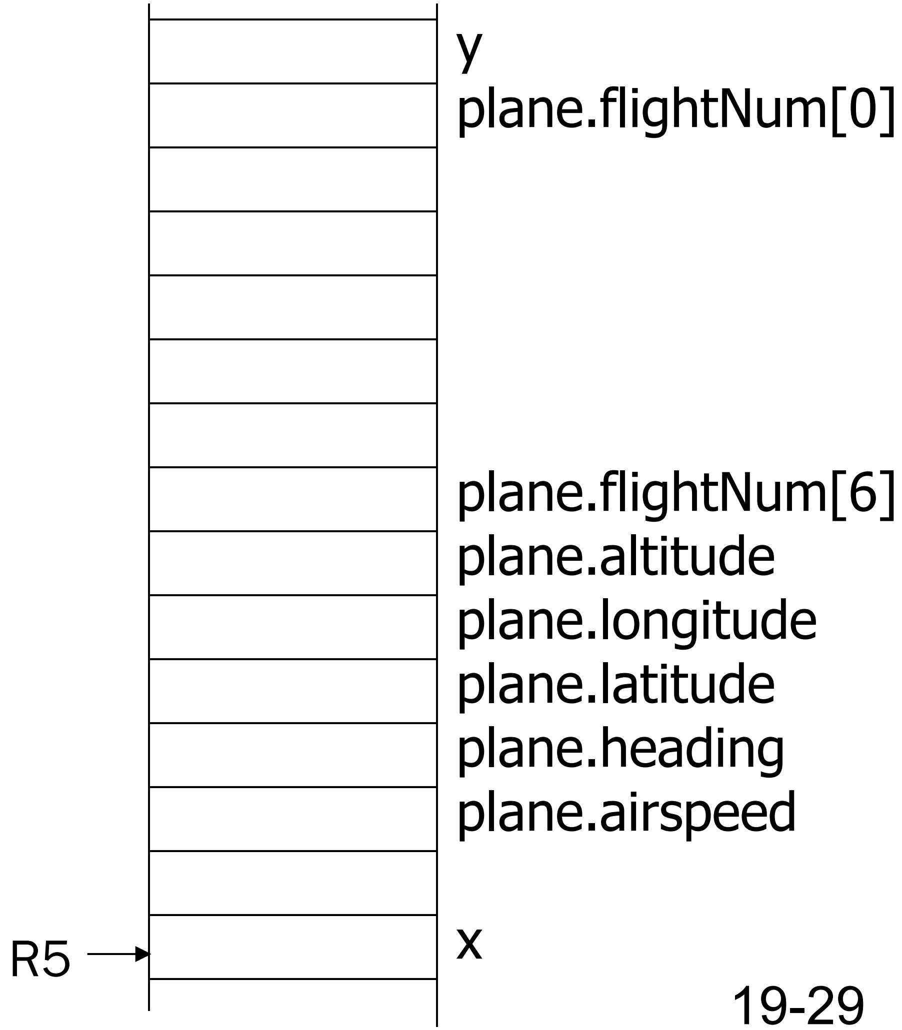
Slides after this skipped

Generating Code for Structs

Suppose our program starts out like this:

```
int x;
Flight plane;
int y;

plane.altitude = 0;
...
```



LC-3 code for this assignment:

```
AND   R1, R1, #0
ADD   R0, R5, #-13 ; R0=plane
STR   R1, R0, #7   ; 8th word
```