C Dynamic Data Structures

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.

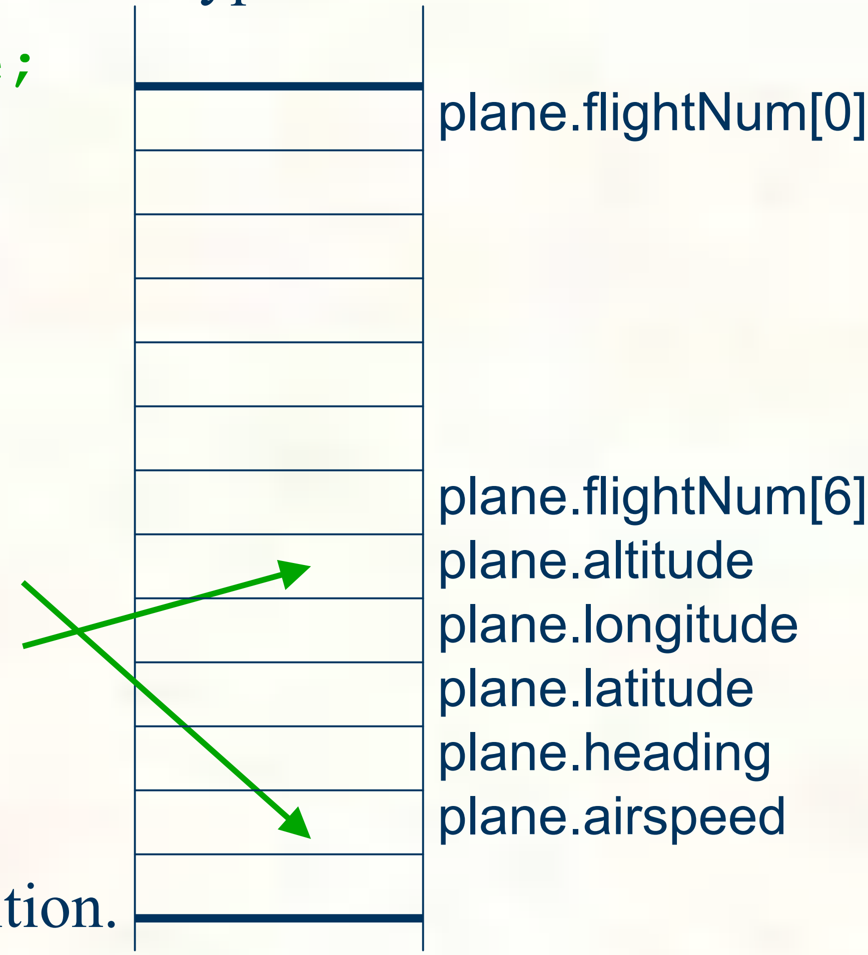
Declaring and Using a Struct

- 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.

Generating Code for Structs

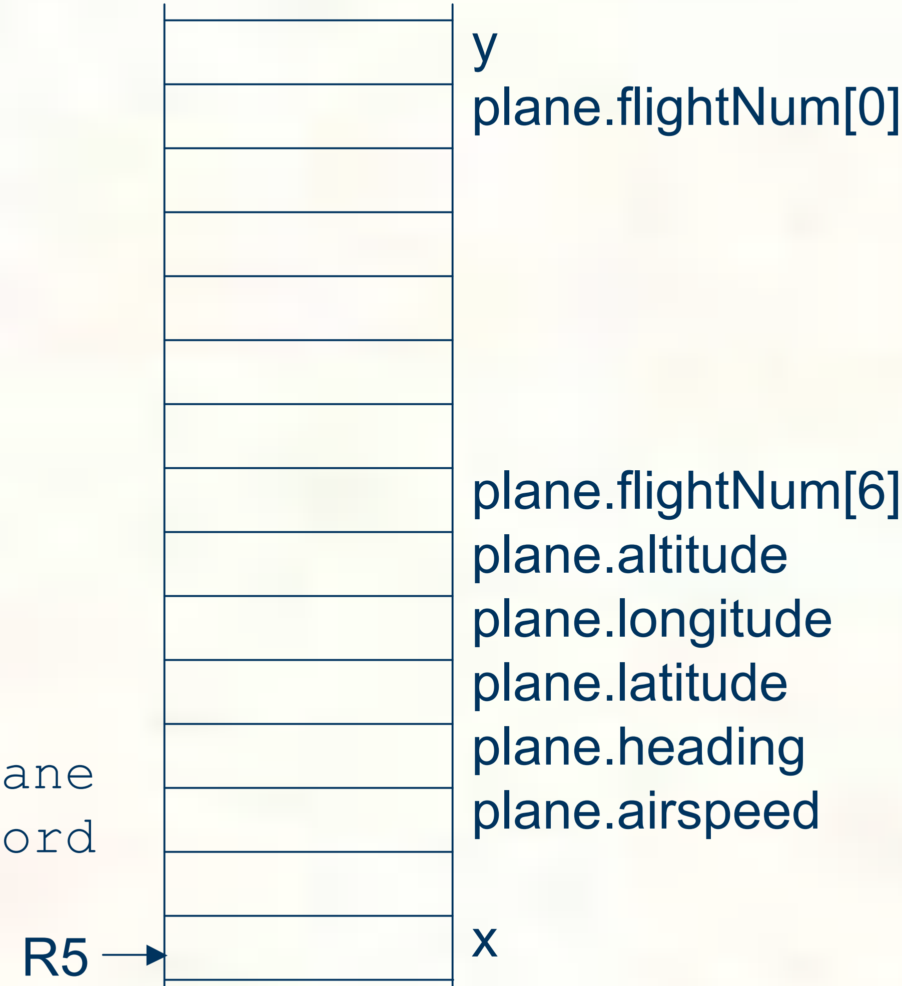
- Suppose our program starts out like this:

```
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
```



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

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

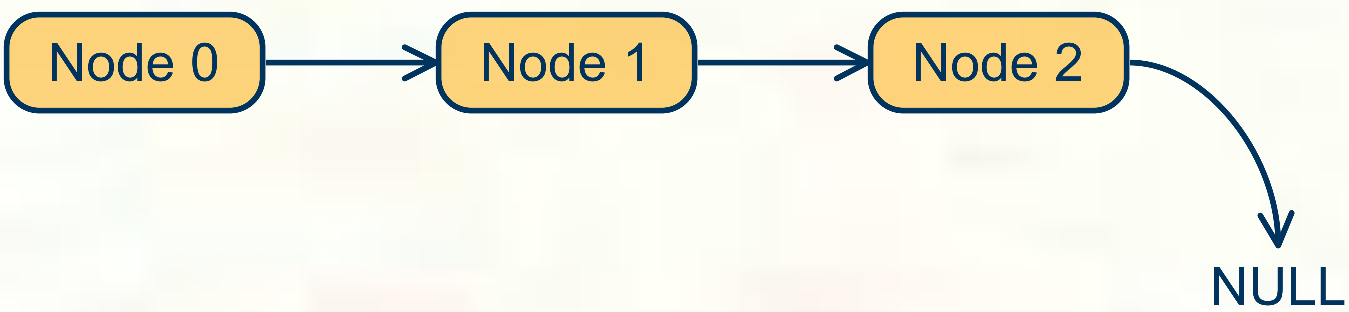
- This is done using the free function,
  passing it the same address that was returned by malloc.

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

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

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 */
}
```

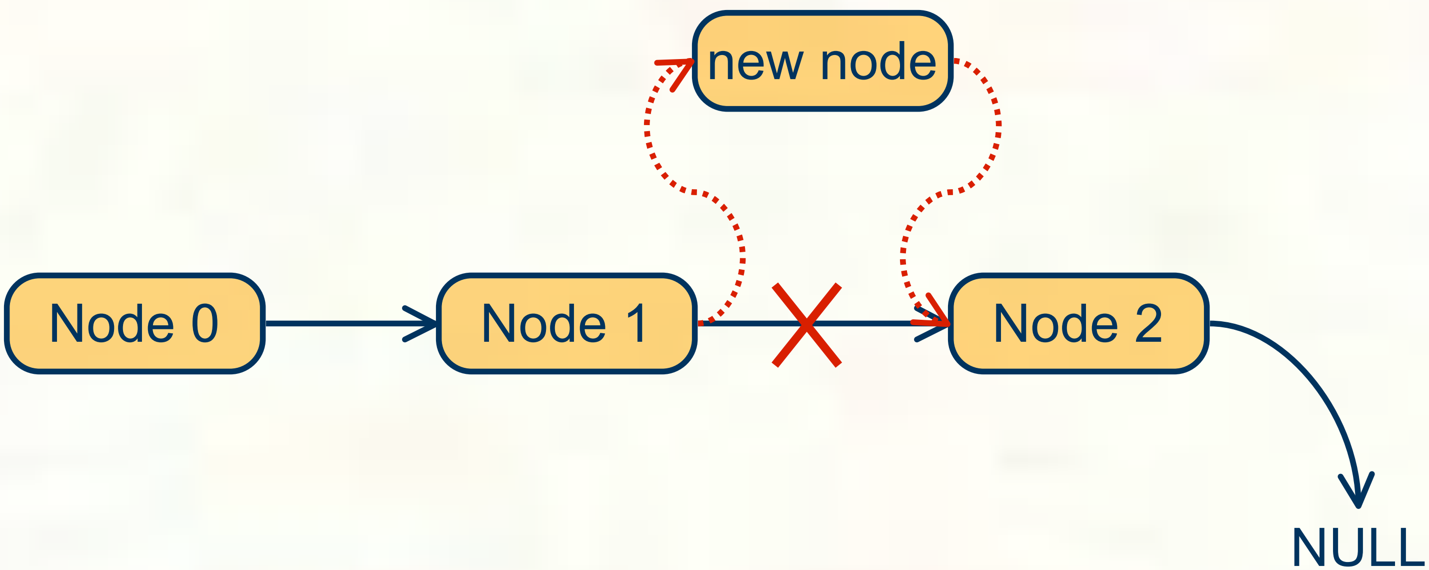
Scanning the List

- 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:



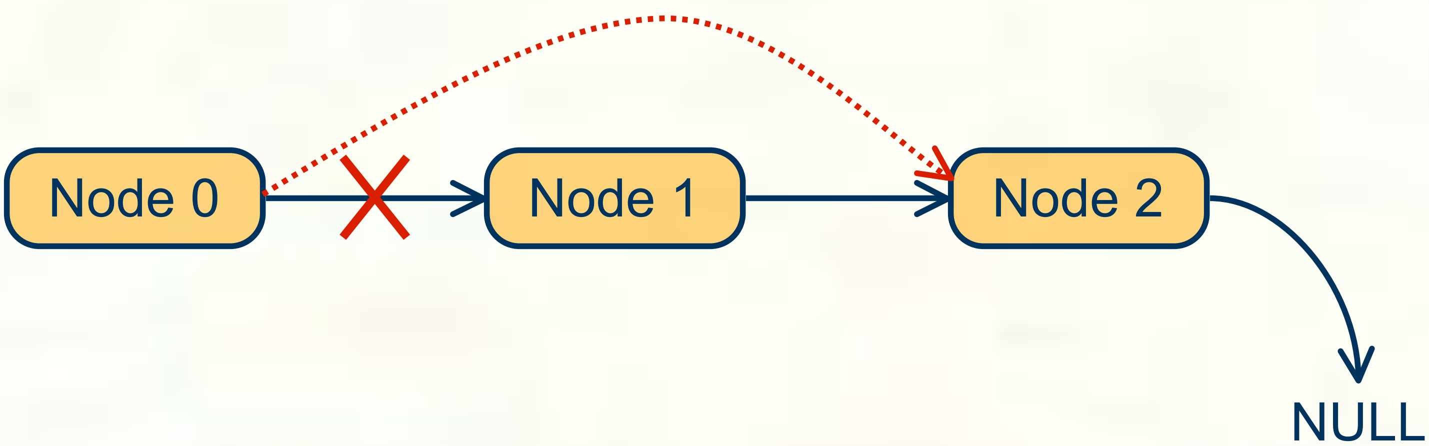
Excerpts from Code to Add a Node

```
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
  - ...