Arrays

Arrays are contiguous sequences of data items

- All data items are of the same type
- Declaration of an array of integers: “int a[20];”
- Access of an array item: “a[15]”

Array index always start at 0

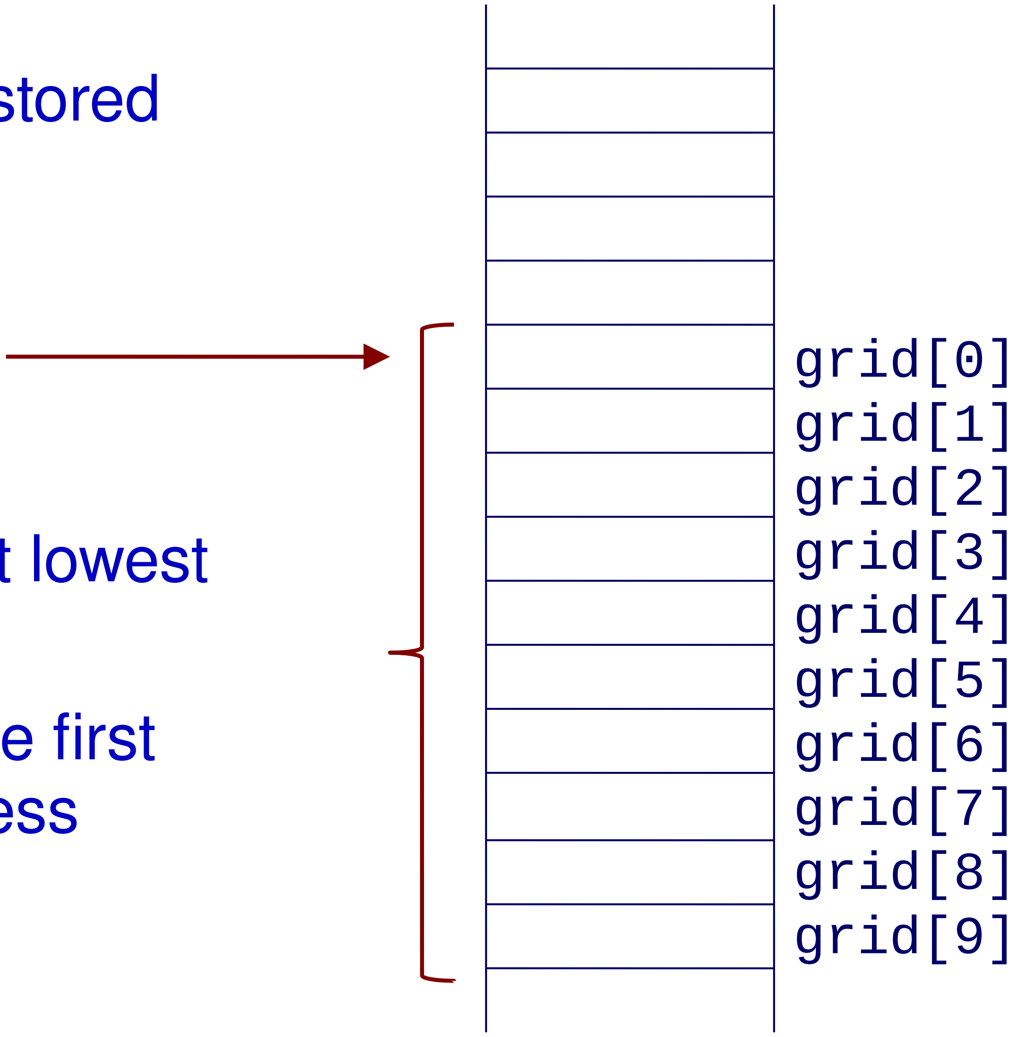
The C compiler and runtime system do not check array boundaries

- The compiler will happily let you do the following:
  - int a[10]; a[11] = 5;

Array Storage

Elements of an array are stored sequentially in memory

char grid[10];



First element (grid[0]) is at lowest address of sequence

Knowing the location of the first element is enough to access any element

Arrays & Pointers

An array name is essentially a pointer to the first element in the array

```
1. char word[10];
2. char *cptr;
3. cptr = word;  /* points to word[0] */
```

Difference:

- Line 1 allocates space for 10 char items
- Line 2 allocates space for 1 pointer
- Can change value of cptr whereas cannot change value of word
  - Can only change value of word[i]

Arrays & Pointers (Continued)

Given

```
char word[10];
char *cptr;
cptr = word;
```

Each row in following table gives equivalent forms

`cptr`	`word`	`&word[0]`
`cptr + n`	`word + n`	`&word[n]`
`*cptr`	`*word`	`word[0]`
`*(cptr + n)`	`*(word + n)`	`word[n]`

Pointer Arithmetic

Be careful when you are computing addresses

Address calculations with pointers are dependent on the size of the data the pointers are pointing to

Examples:

- `int *i; …; i++;  /* i = i  + 4 */`
- `char *c; …; c++;    /* c = c + 1 */`
- `double *d; …; d++;  /* d = d + 8 */`

Another example:

```
double x[10];
double *y = x;
*(y + 3) = 13;   /* x[3] = 13 */
```

Passing Arrays as Arguments

Arrays are passed as pointers (like passing the array itself by reference).

Array items are passed by value (No need to declare size of array for function parameters)

```
#include <stdio.h>

int *bogus;

void foo(int seqItems[], int item)
{
    seqItems[1] = 5;
    item = 5;
    bogus = &item;
}

int main(int argc, char **argv)
{
    int bunchOfInts[10];

    bunchOfInts[0] = 0;
    bunchOfInts[1] = 0;

    foo(bunchOfInts, bunchOfInts[0]);

    printf("%d, %d\n", bunchOfInts[0], bunchOfInts[1]);
    printf("%d\n", *bogus);
}
```

Common Pitfalls with Arrays in C

Overrun array limits

- There is no checking at run-time or compile-time to see whether reference is within array bounds.

```
int array[10];
int i;
for (i = 0; i <= 10; i++) array[i] = 0;
```

Declaration with variable size

- Size of array must be known at compile time.

```
void SomeFunction(int num_elements) {
        int temp[num_elements];
        …
}
```

Strings: Arrays of Characters

Allocate space for a string just like any other array:

```
char outputString[16];
```

Each string should end with a ‘\0’ character

Special syntax for initializing a string:

```
char outputString[16] = "Result";
```

…which is the same as:

```
outputString[0] = 'R';
outputString[1] = 'e';
...
outputString[6] = ‘\0’;
```

The ‘\0’ allows functions like strlen() to work on arbitrary strings

Useful functions for Strings

Useful string related functions in standard C libraries

`#include <string.h>`	
`char *strcpy(char *d, char *s)`	Copy string s to d
`int strcmp(s1, s2)`	Compare string s1 to s2
`size_t strlen(s)`	Returns length of cs

Use "man" to learn more about these functions

- man strcpy

Special Character Literals

Certain characters cannot be easily represented by a single keystroke, because they

- correspond to whitespace (newline, tab, backspace, ...)
- are used as delimiters for other literals (quote, double quote, ...)

These are represented by the following sequences:

`\n`	newline
`\t`	tab
`\b`	backspace
`\\`	backslash
`\'`	single quote
`\"`	double quote
`\0`*nnn*	ASCII code *nnn* (in octal)
`\x`*nnn*	ASCII code *nnn* (in hex)

Structures

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

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 items together

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 are laid out in memory

- But it does not allocate any memory
- Memory is only allocated when a variable is declared

Declaring and Using a Struct

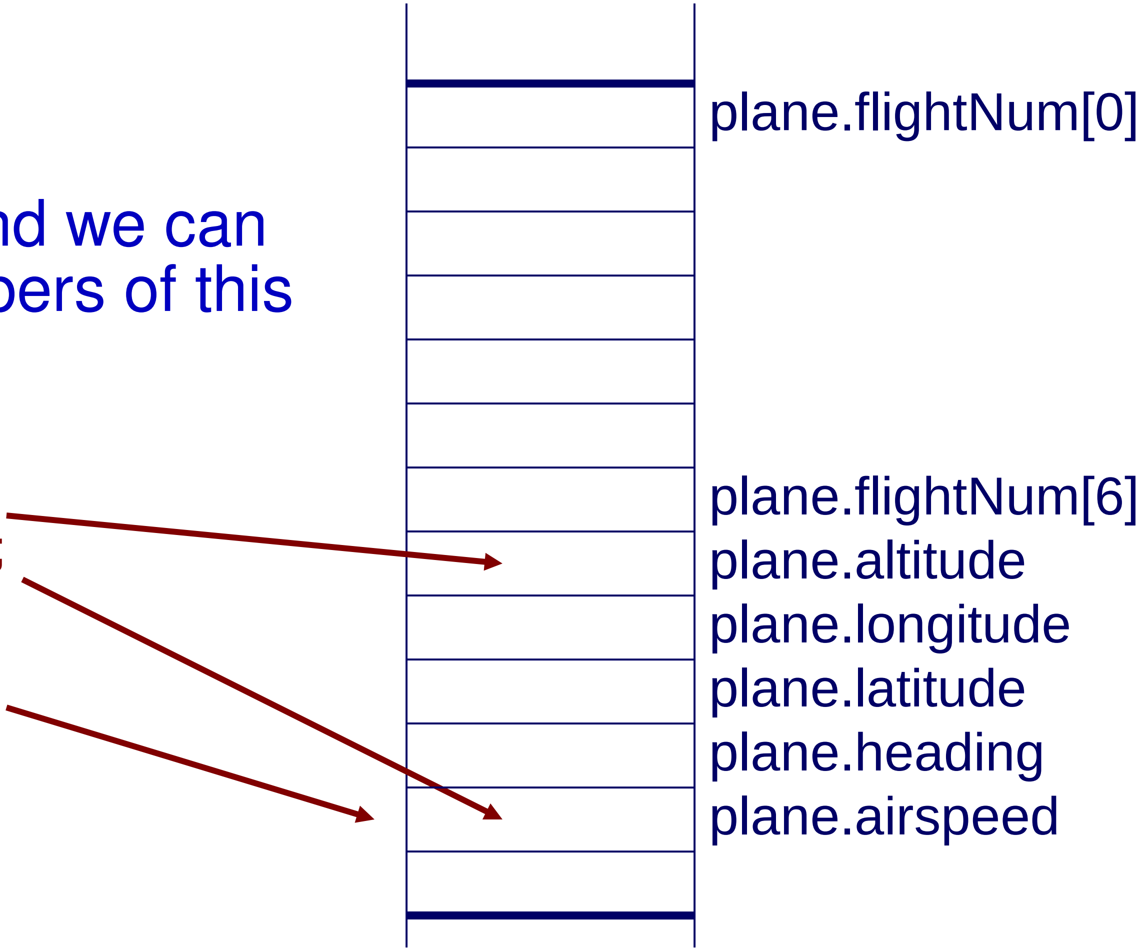
To allocate memory for a struct, we declare a variable using our new data type.

```
struct flightType plane;
```

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

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

foo(&(plane.airSpeed));
/* pass the address of
   plane.airSpeed */
```



Array of Structs

Can declare an array of struct items:

- struct flightType planes[100];

Each array element is a struct item of type “struct flightType”

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:

```
struct flightType *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 item is passed by value

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

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

Dynamic Allocation

What if we want to write a program to handle a variable amount of data?

- E.g., sort an arbitrary set of numbers
- Can’t allocate an array because don’t know how many numbers we will get
  - Could allocate a very large array
  - Inflexible and inefficient

Answer: dynamic memory allocation

- Similar to “new” in Java

Memory Management 101

When a function call is performed in a program, the run-time system must allocate resources to execute it

- Memory for any local variables, arguments, and result

The same function can be called many times (Example: recursion)

- Each instance will require some resources

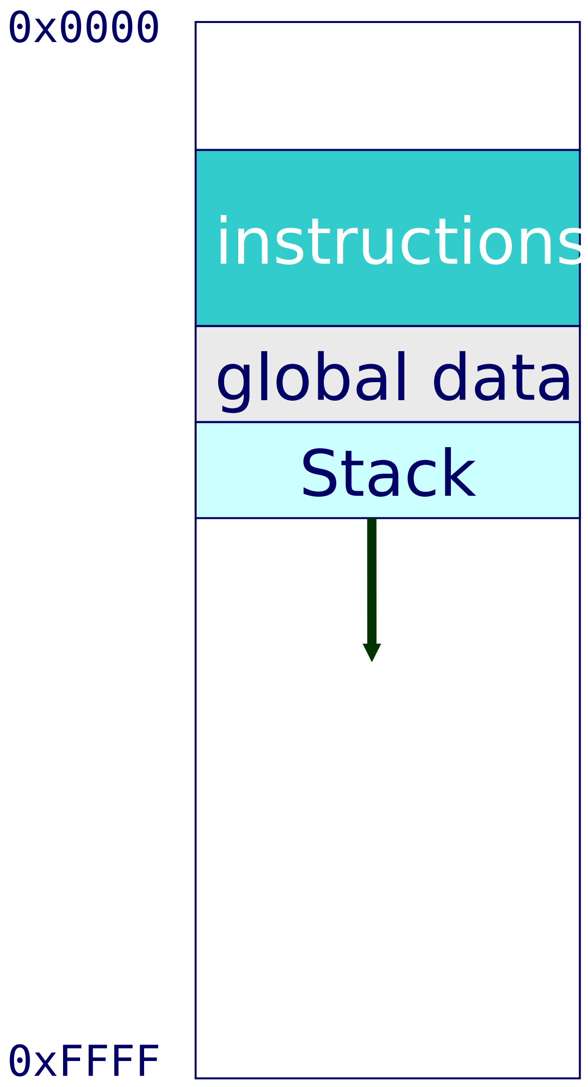
The state associated with a function is called an activation record

Allocating Space for Variables

Activation records are allocated on a call stack

- Function calls leads to a new activation record pushed on top of the stack
- Activation record is popped off the stack when the function returns

Let’s see an example



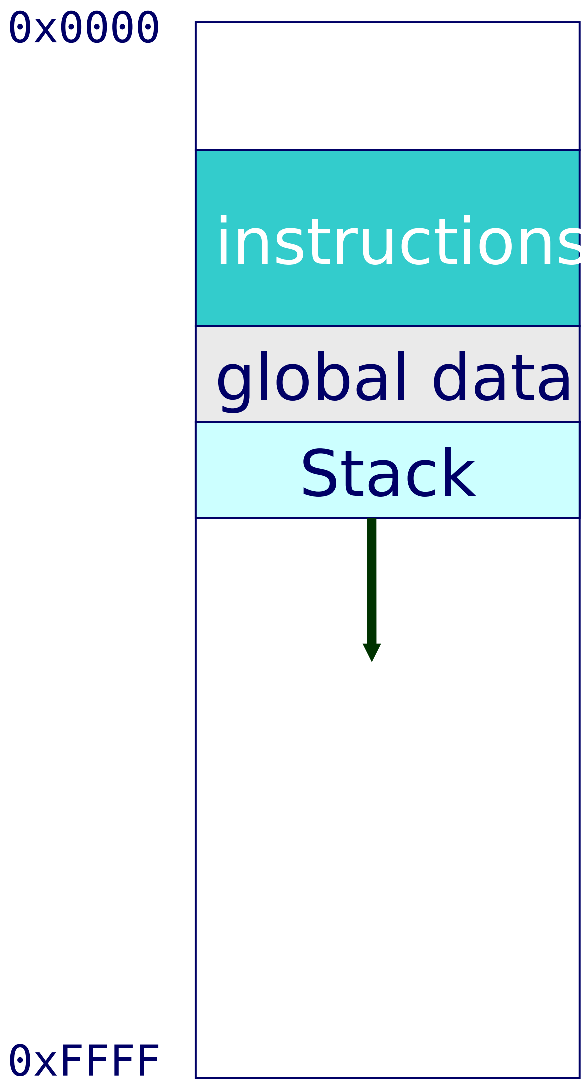
Allocating Space for Variables

Compute the sum of number from 1 to N

```
int summation(int n){
  if(n == 0) return 0
  else return n + summation(n-1);
}
…
summation(5);
```

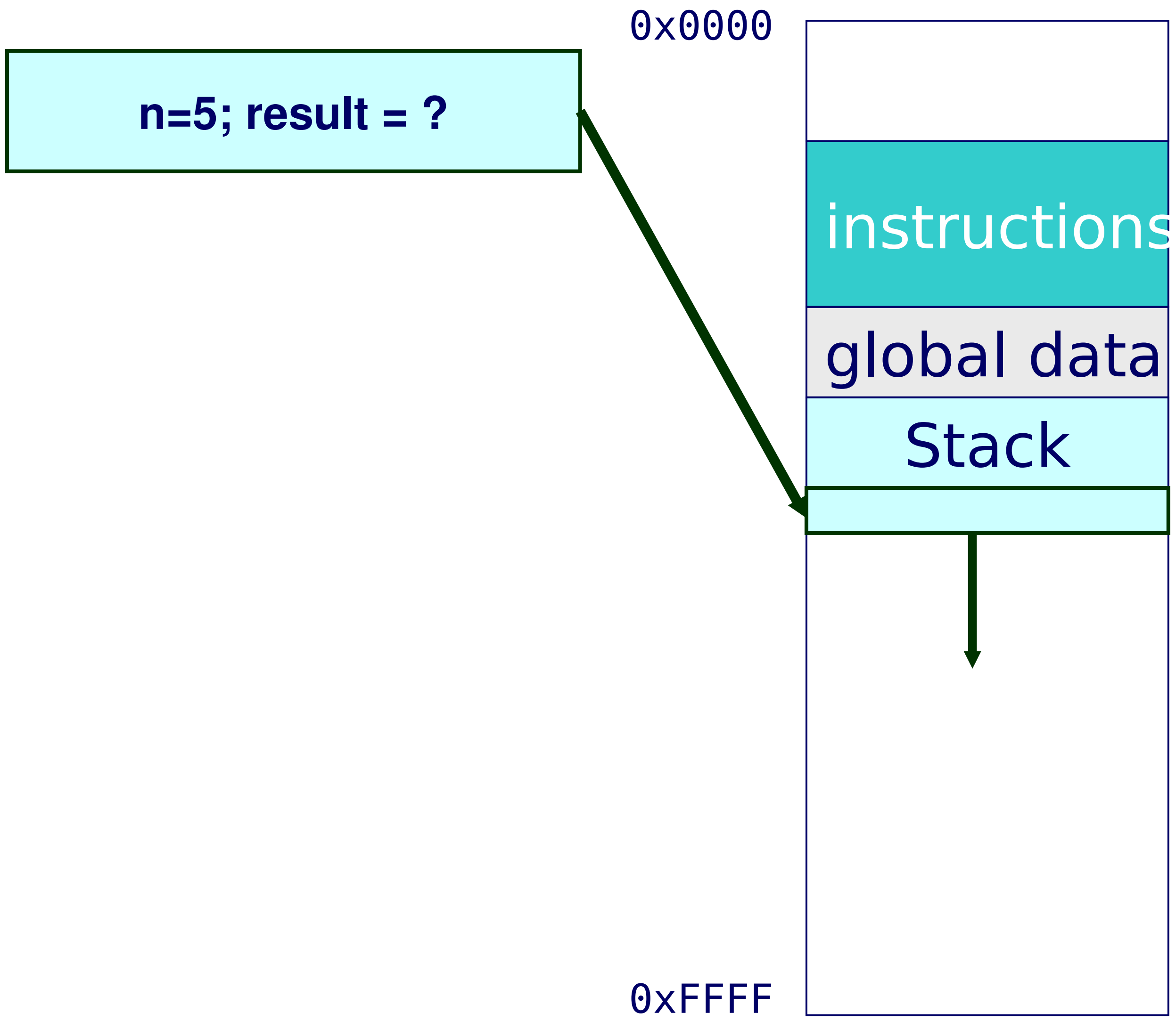
Recall that the activation record for a function contains state for all arguments, local variables, and result

int n; int result;

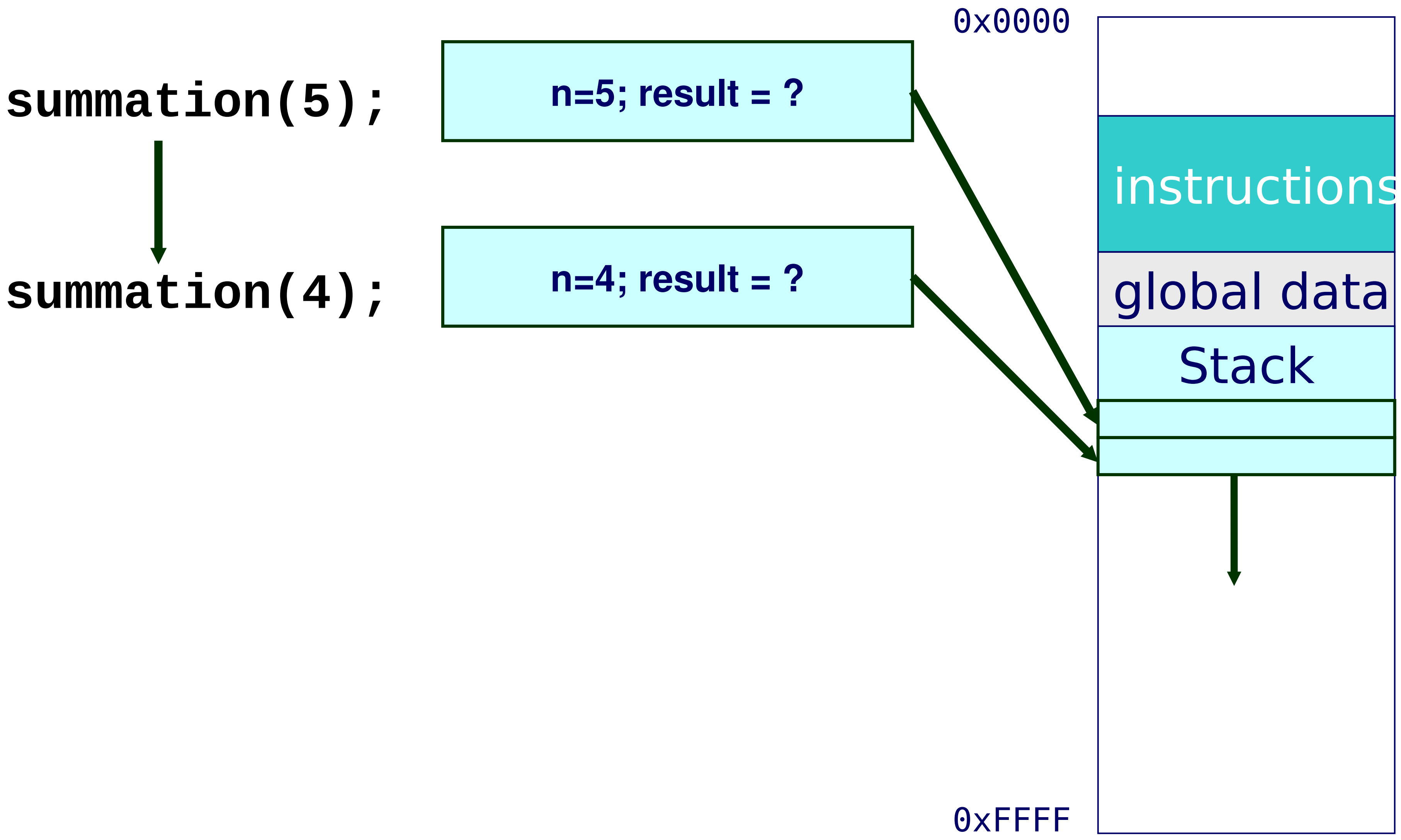


Allocating Space for Variables

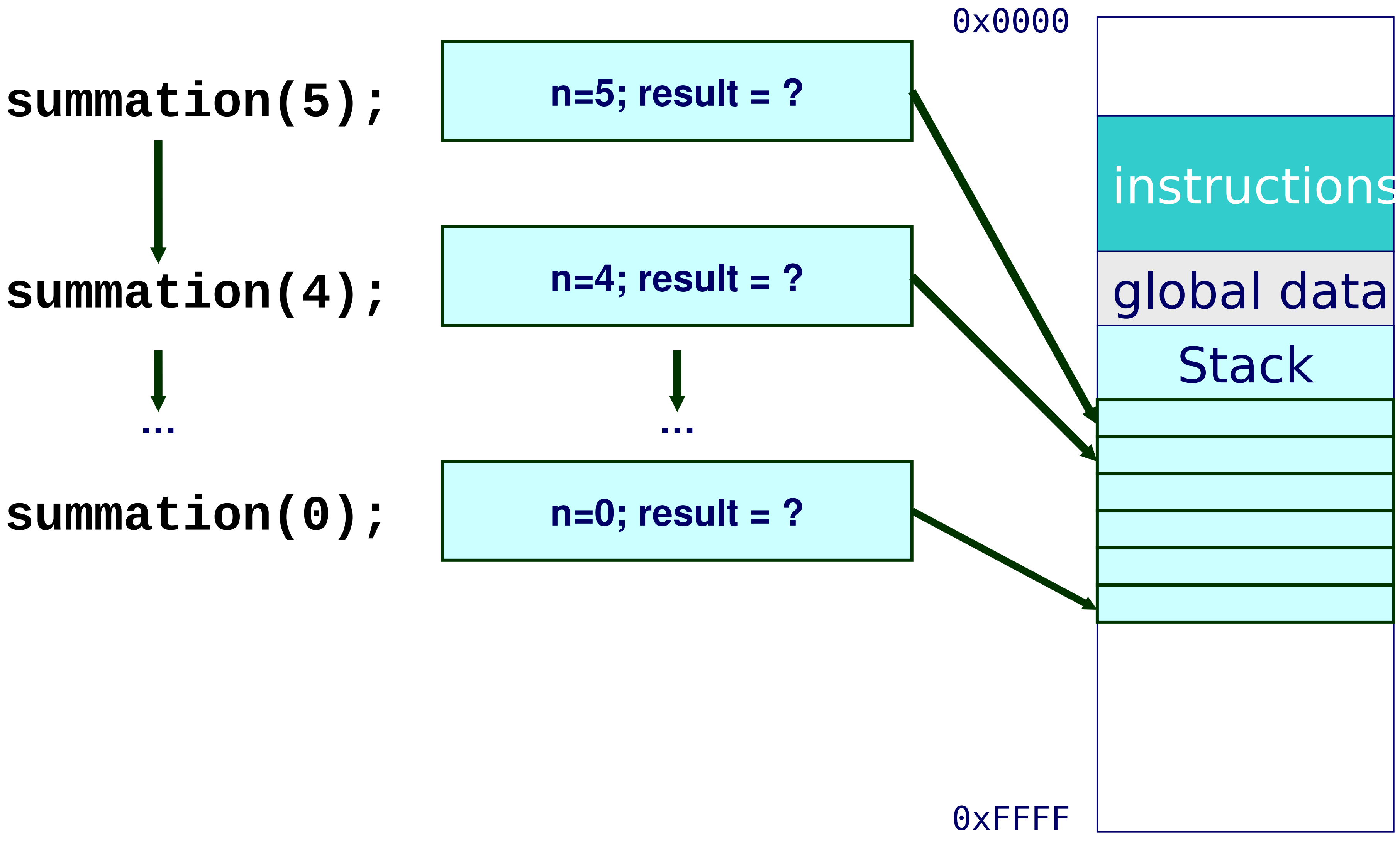
```
summation(5);
```



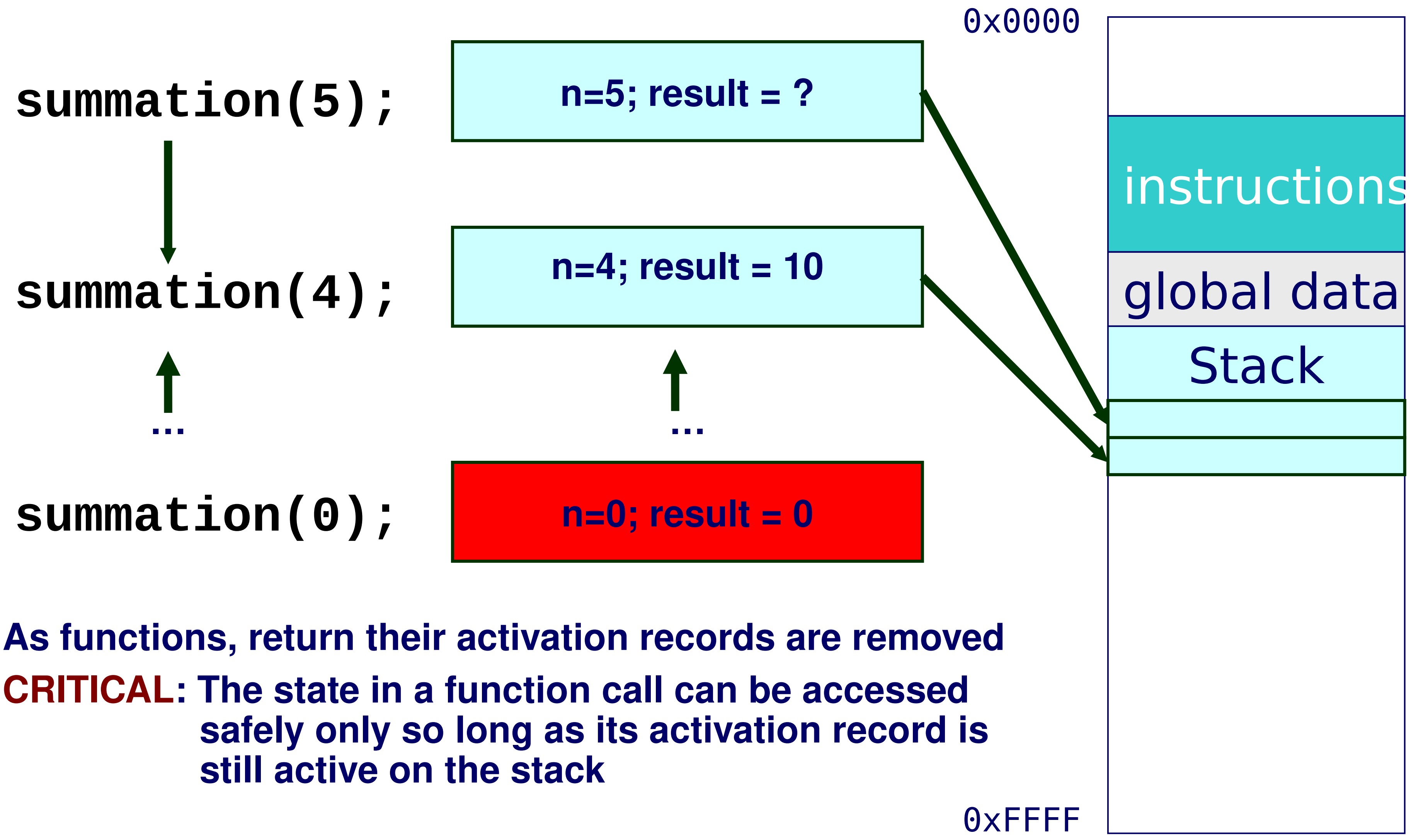
Allocating Space for Variables



Allocating Space for Variables



Allocating Space for Variables



As functions, return their activation records are removed

CRITICAL: The state in a function call can be accessed safely only so long as its activation record is still active on the stack

Dynamic Allocation

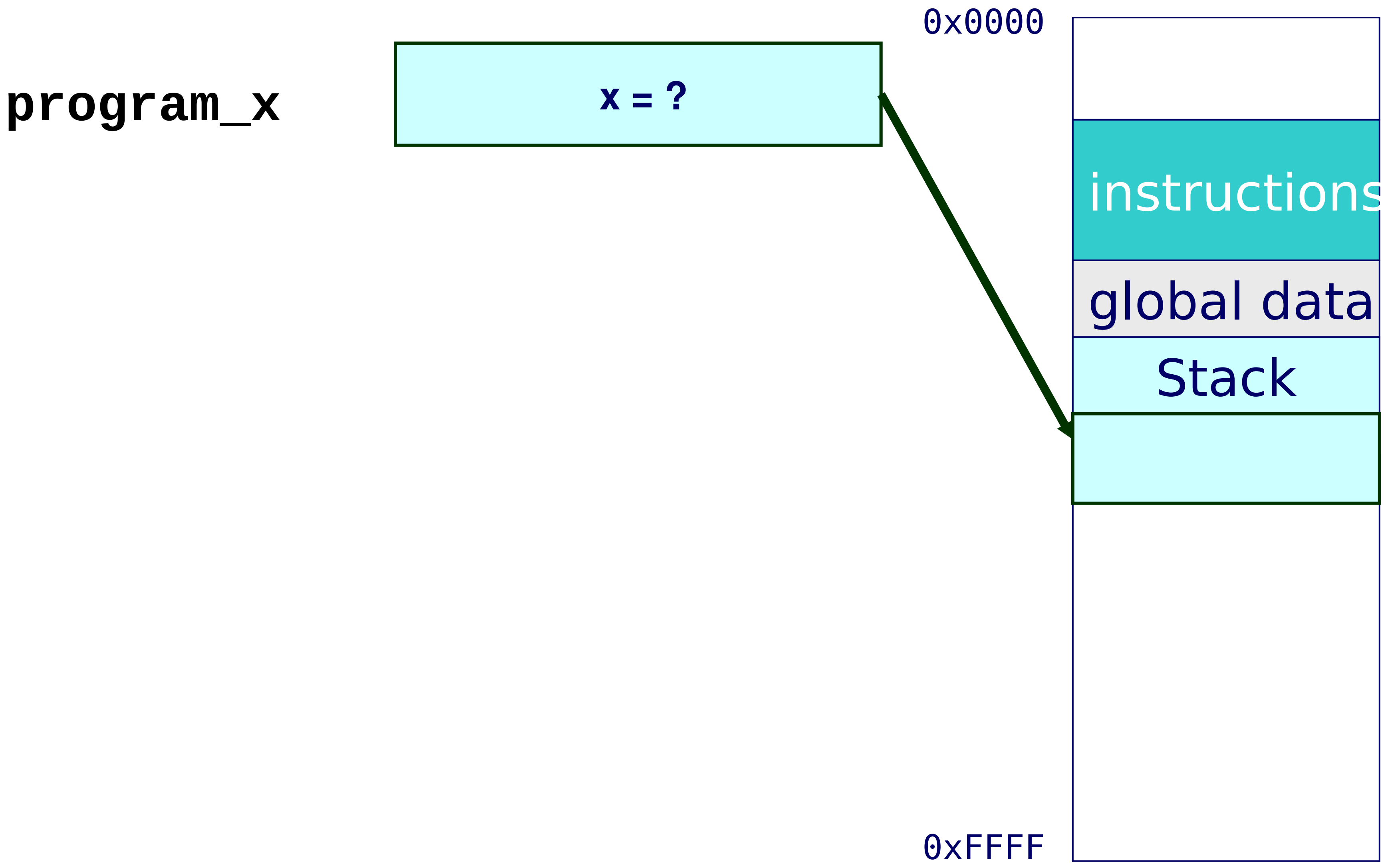
What if we want

- Memory area whose lifetime does not match any particular function?
- Memory area whose size is not known at compile time?

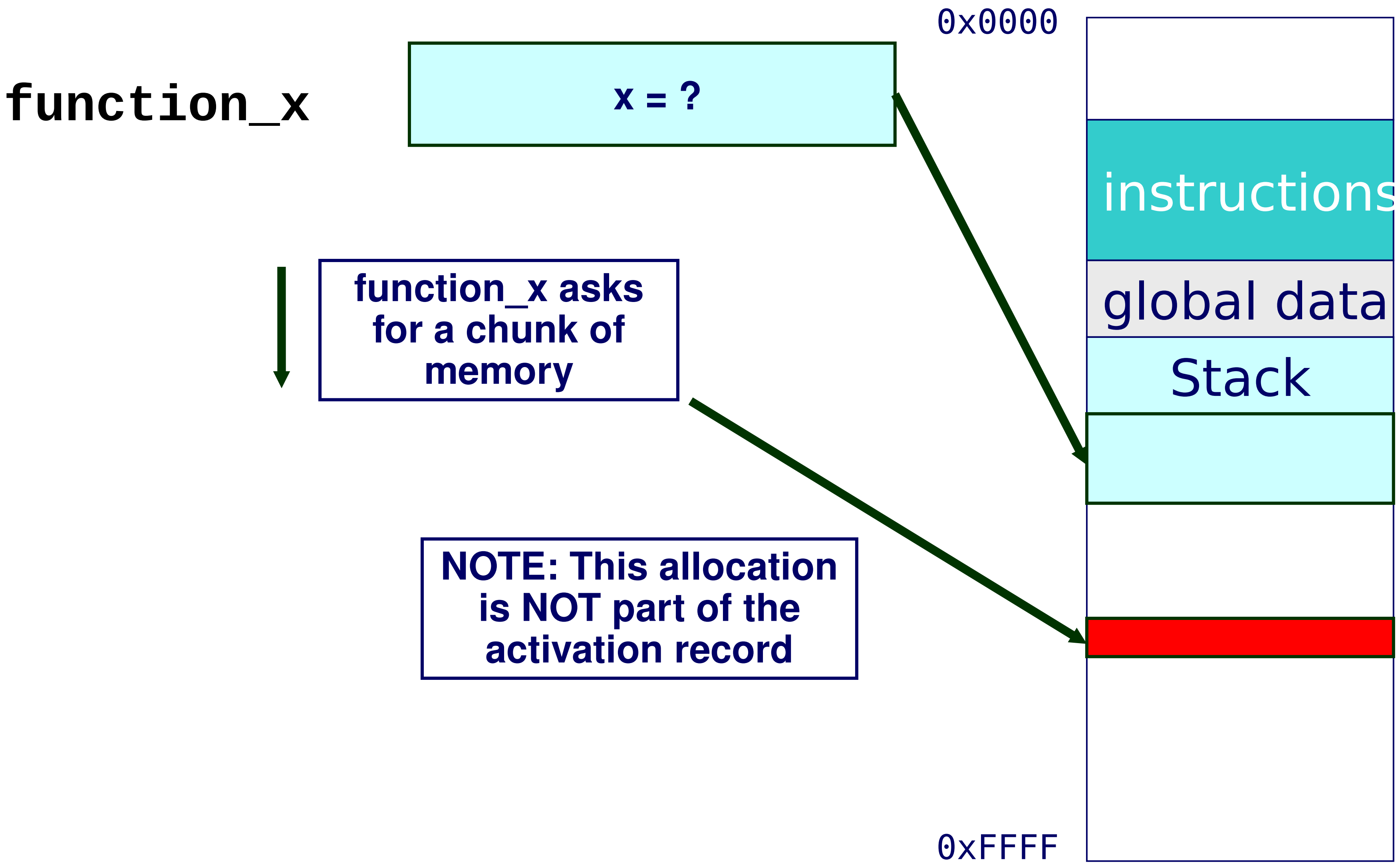
Two ways to “get memory”

- Declare a variable
  - Placed in global area or stack
  - Either “lives” forever or “live-and-die” with containing function
  - Size must be known at compile time
- Ask the run-time system for a “chunk” of memory dynamically

Allocating Space for Variables



Allocating Space for Variables

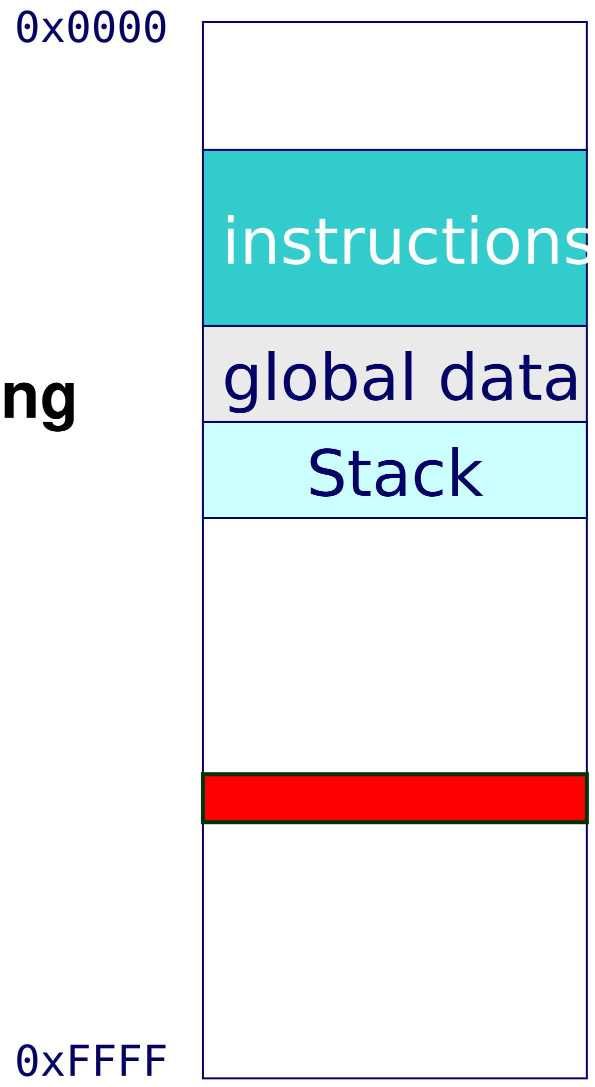

0x0000
function_x
x = ?
instructions
global data
Stack
function_x asks for a chunk of memory
NOTE: This allocation is NOT part of the activation record
0xFFFF

Allocating Space for Variables

After function returns, memory is still allocated

Request for dynamic chunks of memory performed using a call to the underlying runtime system (a system call).

- Commands: malloc and free

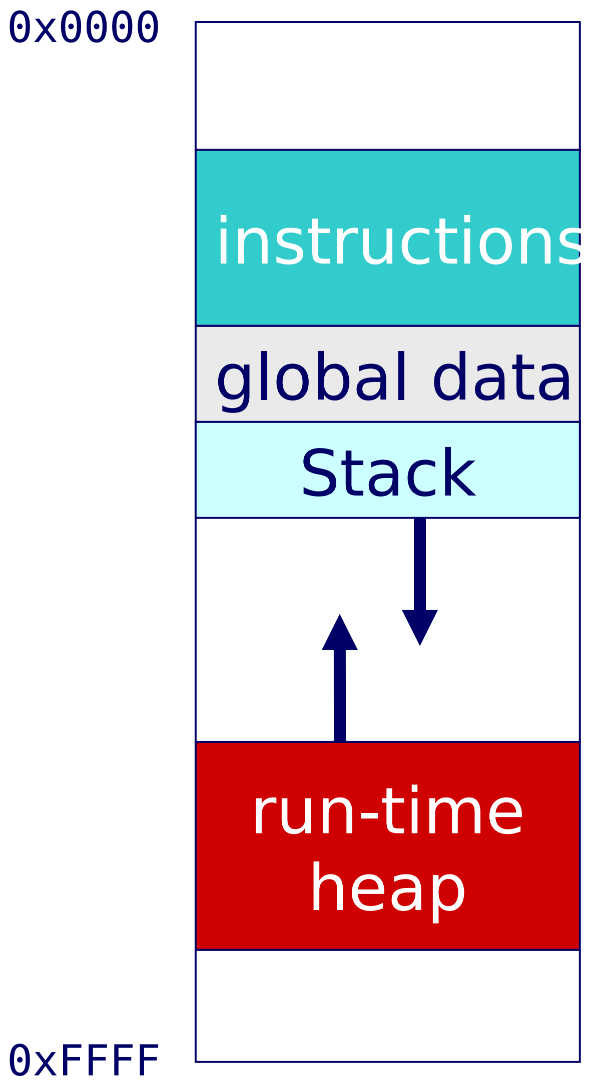


Dynamic Memory

Another area region of memory exists, it is called the heap

Dynamic request for memory are allocated from this region

Managed by the run-time system (actually, just a fancy name for a library that's linked with all C code)



malloc

The Standard C Library provides a function for dynamic memory allocation

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

malloc() (and free()) manages a region of memory called the heap

- We'll explain what a heap is later on and how it works

malloc() allocates a contiguous region of memory of size numBytes if there is enough free memory and returns a pointer to the beginning of this region

- Returns NULL if insufficient free memory

Why is the return type void*?

Using malloc

How do we know how many bytes to allocate?

Function

```
sizeof(type)
sizeof(variable)
```

Allocate right number of bytes, then cast to the right type

```
int *numbers = (int *)malloc(sizeof(int) * n);
```

free

Once a dynamically allocated piece of memory is no longer needed, need to release it

- Have finite amount of memory
- If don’t release, will eventually run out of heap space

Function:

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

Example

```
int airbornePlanes;
struct flightType *planes;

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

planes =
 (struct flightType*)malloc(sizeof(struct flightType) *

                airbornePlanes);
if (planes == NULL) {
  printf(“Error in allocating the data array.\n”);
  ...
}
planes[0].altitude = ...

…

free(planes);
```

If allocation fails, malloc returns NULL.

Note: Can use array notation or pointer notation.

File I/O

A file is a contiguous set of bytes

- Has a name
- Can create, remove, read, write, and append

Unix/Linux supports persistent files stored on disk

- Access using system calls: open(), read(), write(), close(), creat(), lseek()
- Provide random access
- Section 2 of online manual (man)

C supports extended interface to UNIX files

- fopen(), fscanf(), fprintf(), fgetc(), fputc(), fclose()
- View files as streams of bytes
- Section 3 of online manual (man)

fopen

The fopen (pronounced "eff-open") function associates a physical file with a stream.

```
FILE *fopen(char* name, char* mode);
```

First argument: `name`

- The name of the physical file, or how to locate it on the storage device. This may be dependent on the underlying operating system.

Second argument: `mode`

- How the file will be used:
  `"r"` -- read from the file
  `"w"` -- write, starting at the beginning of the file
  `"a"` -- write, starting at the end of the file (append)

fprintf and fscanf

Once a file is opened, it can be read or written using fscanf() and fprintf()

These are just like scanf() and printf() except with an additional argument specifying a file pointer

- fprintf(outfile, "The answer is %d\n", x);
- fscanf(infile, "%s %d/%d/%d %lf",
  &name, &bMonth, &bDay, &bYear, &gpa);

When started, each executing program has three standard streams open for input, output, and errors

- stdin, stdout, stderr