ECE 220

Lecture x0010 - 10/21

Dynamic Memory Allocation

Slides based on material originally by: Yuting Chen & Thomas Moon

Announcements

- Final exam schedule is now available
    - DRES-TAC reservation deadline is **November 1.**
- Midterm 2 will be held on 10/30
    - Practice material is posted
    - Check HKN website: https://hkn.illinois.edu/services for review session

Recap

- Last few weeks
  - Streams, buffers, queue (FIFO)
  - File I/O, formatted IO
  - Structs
    - Arrays of structs
  - Pointers to structs
  - Structs within structs
  - Passing structs in functions
  - Writing structs to files
- Examples

Other user defined types: `enums`

- Enum is short for *enumeration.* Idea is to assign meaningful names to integers for code readability.

- *Syntax:* `enum [tag] {enumerator list};`

```
enum weekday {SUN, MON, TUE, WED, THR, FRI, SAT};

int is_workday(enum weekday day){
  if (day>SUN && day<SAT)
    return 1;
  else
    return 0;
}
```

Find out: Can you override default values assigned to enums?

Other user defined types: `enums`

```
enum weekday {SUN, MON, TUE, WED, THR, FRI, SAT};

int is_workday(enum weekday day){
  if (day>SUN && day<SAT)
    return 1;
  else
    return 0;
}
```

```
int main(void){

   enum weekday today=THR;
   enum weekday day_after_next = today+2;

   printf("Today is day #%d of the week.\n", today);
   printf("Today is %s\n", is_workday(today) ? "a workday" : "not a workday");

   printf("\n");
   printf("Day after tomorrow is day #%d of the week.\n", day_after_next);
   printf("That day is %s\n",
           is_workday(day_after_next) ? "a workday" : "not a workday");
}
```

Lesson objectives

- Understand difference betwen dynamically allocated and automatically allocated memory.
  - Understand heap
- Learn and be able to use malloc family of functions and know the differences between them.
- Understand lack of *garbage-collection* in C and what that implies for the programmer.

Dynamic memory allocation

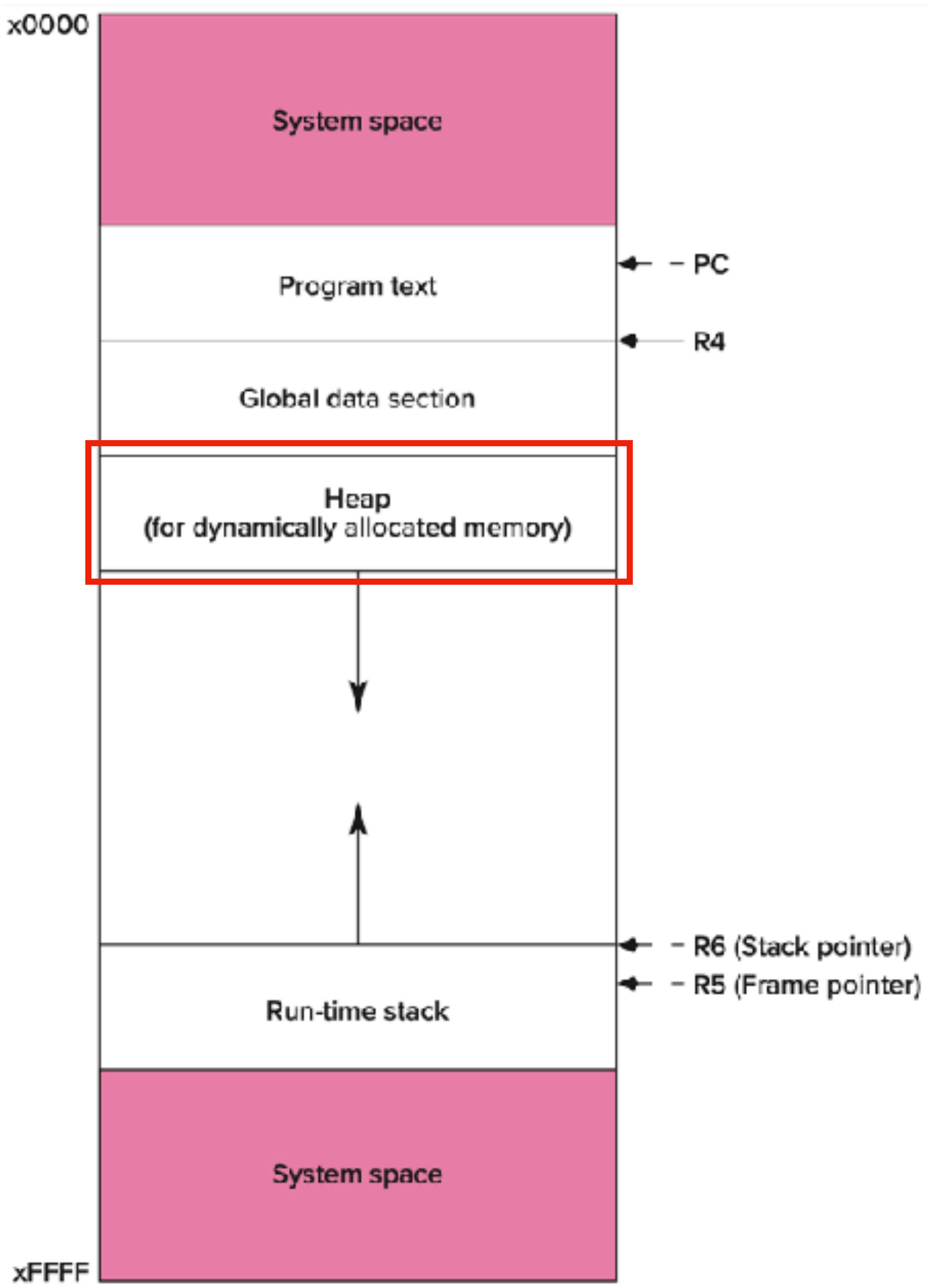
- We specify `numplanes` to use `fread` and allocate `Flight array` of size 50.
  - If usually only ~5 flights, then memory is wasted.
  - If we read in a large file >50 then not enough memory is allocated.
  - May only know `numplanes` at runtime!

- Ideally, we want to allocate as much memory as needed rather than a pre-set amount.

- In most cases, this memory comes from an area of the architecture called the *heap*.

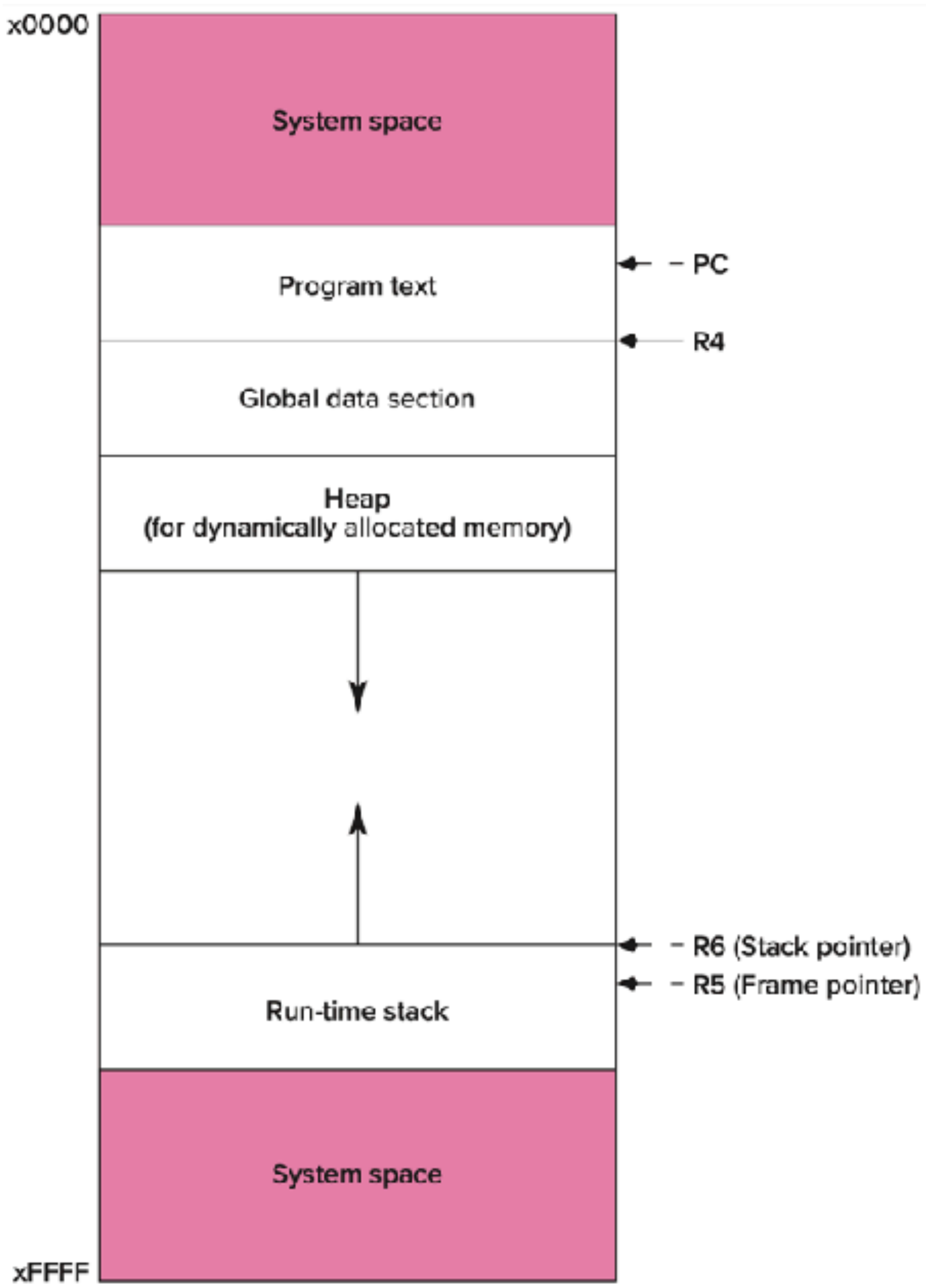
Dynamic memory allocation

- During the execution, a program makes a request to the *memory allocator* for a contiguous piece of memory of a particular size
- The allocator reserves the memory and returns a pointer to it. We interact with the memory allocation manager by using *malloc* family & *free* functions.



Automatic vs. dynamic memory

	Automatic	Dynamic
Mechanism	Automatic	Use `malloc` family
Lifetime	Compiler makes decisions; variables “die” when functions & blocks end	Programmer makes decision, must use `free()` to deallocate
Location	Stack or global data area	Heap
Size	Fixed	Adjustable



The malloc function

```
void *malloc(size_t size)
```

- Parameters
  - `size`: Number of bytes to allocate
  - `size_t`: A *type* defined in the user library ~ unsigned integer
- Return value: NULL (failure) or pointer to beginning of allocated block (success).

https://en.cppreference.com/w/c/memory/malloc

Using malloc

- Memory allocated by `malloc` is not initialized (there could be garbage values or leftover values).

- 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.

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

malloc returns *void* pointer

Standard pointer declaration

```
int *ptr = (int *) malloc(sizeof(int));
```

Juxtaposition with *(int *) casts* the *void* pointer as an *int* pointer

The free function

```
void free(void *ptr)
```

- Parameters
  - *`*ptr`*: Pointer to beginning of block to be *deallocated*. Should have been generated by the `malloc` family.

- Memory allocated via `malloc` ***must*** be deallocated via `free` or reallocated via `realloc` to prevent memory leaks!

- Use `valgrind` to check for memory leaks

https://valgrind.org/

The calloc function

```
void *calloc(size_t n_items, size_t item_size)
```

- Parameters
  - *`size`*: Number of items to be allocated
  - *`item_size`*: Size of each item
- Return value: NULL (failure) or pointer to beginning of allocated block (success).
- Identical to `malloc`, except `calloc` initializes memory to zero.

The realloc function

```
void *realloc(void *ptr, size_t size)
```

- Parameters
  - *ptr*: Pointer to memory block to be reallocated
  - *size*: New size of block

- Return value: NULL (failure) or pointer to beginning of allocated block (success).

The realloc function

```
void *realloc(void *ptr, size_t size)
```

- The content of the memory block is preserved, even if the block is moved to a new location (if the new size is larger than the old size, the added memory will not be initialized).
  - If `ptr` is NULL, it is same as malloc
  - If `size` is 0 and `ptr` is not NULL, *implementation dependent!*
  - `ptr` must have been returned by the `malloc` family

Example of malloc & free

- Casting:

```
          int *ptr = (int *) malloc(sizeof(int));
Flight *ptr = (Flight *) malloc(numFlight*sizeof(Flight));
```

- Why: recall C is *statically* typed; so compiler needs to know what type to assign to allocated memory locations.
  - Sorta-kinda a fib (C can tell by looking at LHS, but C++ won't)
  - Types can be built-in or user-defined.

Example of malloc & free

```c
int main(){
  int *ptr1 = (int *) malloc(sizeof(int));
  if(ptr1==NULL){
    printf("Error - malloc failure\n");
    return -1;
  }
  *ptr1 = 10;
  int *ptr2 = (int *) malloc(sizeof(int));
  *ptr2 = 5;
}
```

What is wrong with this code?

Didn’t free memory allocated!

Example of malloc & free

```
int main(){
  int *ptr1 = (int *) malloc(sizeof(int));
  if(ptr1==NULL){
    printf("Error - malloc failure\n");
    return -1;
  }
  *ptr1 = 10;
  int *ptr2 = (int *) malloc(sizeof(int));
  *ptr2 = 5;

  ptr1 = ptr2;
  free(ptr1);
  free(ptr2);
}
```

Swap

This one frees the memory, but has a bug. What should we do?

Example of realloc

```
int *ptr;
int *ptr_new;

/* What does this code do? */
ptr = (int *) calloc(2, sizeof(int));
*ptr = 10;

/* What is the contents of memory now? */
ptr_new = (int *) realloc(ptr, 4*sizeof(int));
*(ptr_new+2) = 30;
*(ptr_new+3) = 40;

/* How much memory are we deallocating here? */
free(ptr_new);
```

Do we need `free(ptr)`?

Allocating 2D arrays

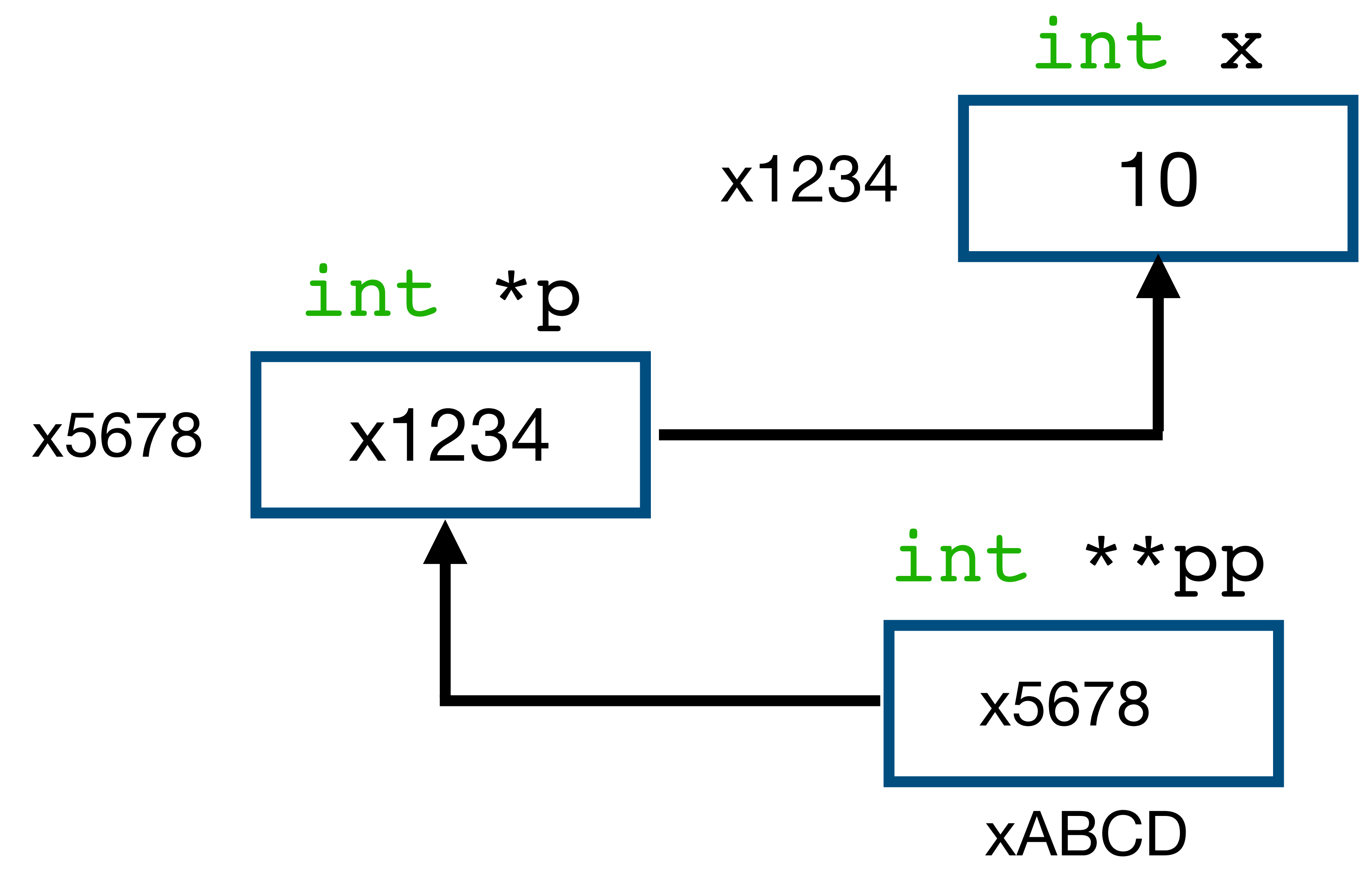
- Here is **one** method of allocating 2D arrays:

```
FILE *infile = fopen("mat.csv", "r");
int nr, nc;

fscanf(infile, "%d, %d", &nr, &nc);
int *mat = (int *) malloc(sizeof(int)*nr*nc);

for (int i=0; i < nr; i++)
  for (int j=0; j< nc; j++)
    fscanf(infile, "%d, ", &mat[i*nc+j]);

fclose(infile);
```

Allocating 2D arrays - another way

- Recall pointers to pointers?

```
int x = 10;
int *p = &x;
int **pp = &p;
```



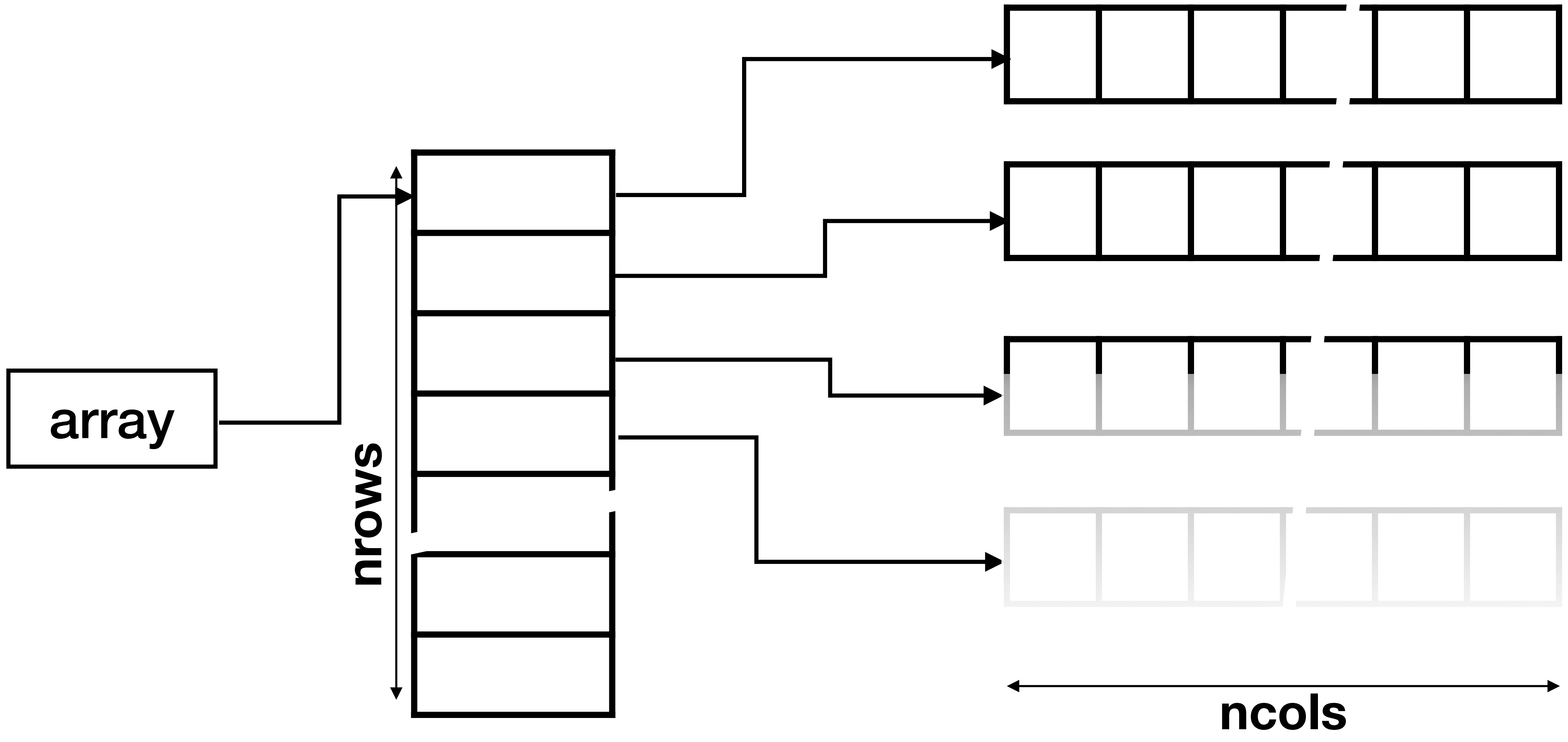
Allocating 2D arrays - another way

- Recall pointers to pointers?
- We can use that:

```
int **array;

array = (int**) malloc(nrows*sizeof(int*));
for(i=0;i<nrows;i++)
  array[i] = (int*) malloc(ncols*sizeof(int));
array[0][0] = 3;
…
```

Allocating 2D arrays - another way

```
int **array;

array = (int**) malloc(nrows*sizeof(int*));
for(i=0;i<nrows;i++)
  array[i] = (int*) malloc(ncols*sizeof(int));
array[0][0] = 3;
```



Pointer to pointer - caveat

- How do you **deallocate** a 2D array?
  - Method 1: Free the single pointer: `int * mat`
  - Method 2: Need to free ***each*** pointer separately!!
    - **Not** enough to free the top level pointer `(int **array)`
      - Unless made free, lower level pointers `(int *)` will leak memory!

Example with *valgrind*

```c
#include <stdio.h>
#include <stdlib.h>

int main(void){
  char *p;

  /* Allocation #1 of 19 bytes */
  p = (char *) malloc(19);

  /* Allocation #2 of 12 bytes */
  p = (char *) malloc(12);
  free(p);

  /* Allocation #3 of 16 bytes */
  p = (char *) malloc(16);

  return 0;
}
```

- Get on to EWS. Compile the standard way. Then run:

```
> valgrind ./a.out
```

- Can you figure out where the leaks are?

Exercise

- Use this second method of memory allocation for 2D arrays (pointer of pointers) to read in a given file (`matrix.csv`) and print out its transpose.
- The first row of the file lists the number of rows and columns of the matrix.

Introduced in C99, discarded/relegated in C11 — modern compilers not required to support it!

Aside: Variable Length Arrays

- You could still define an array size using user input.
  - Array still allocated on the stack
    - Mechanism is far more complicated
  - Still cannot modify size after definition
  - We pay that performance overhead for convenience

```
void fun(int n)
{
 int arr[n];
 /* More code follows
 ...
 ...
 */
}
int main()
{
  fun(6);
}
```

Exercise - do it yourself

- Recall how to use `malloc` for our struct

```
Flight *ptr = (Flight *) malloc(numFlight*sizeof(Flight));
```

- Write a function to read the provided binary file and return a struct containing the n-th flight record. *Discard* the first *n-1*.

```
Flight * nth_flight(char *filename, int num_total, int N)
```

- Make sure to free memory!

Next time - important

- So far our use of `malloc` has been to load records or data from a file
  - Thus we no longer have to know the sizes at compile time
  - Nevertheless `realloc/malloc/free` is cumbersome to keep using
  - Need a data structure that takes care of this automatically - enter ***linked-lists*.**

Time permitting - *key idea*

- Basic idea of a linked list:

```
typedef struct node{
  char *name;
  struct node * next;
}node;
```

- Definition is *recursive*; a node is either
  - *NULL* or
  - Contains a reference to another node