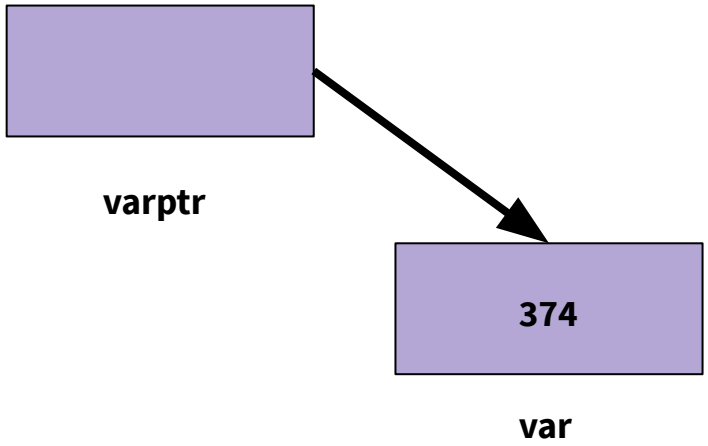
CSE 374 Lecture 12

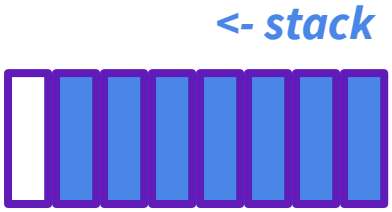
The Heap

Pointer review

- Pointers point to an address in memory
- Declare a variable to have a pointer type, points to a specific type/size of memory:
  - T * x; or T* x; or T *x; or T*x;
  - (where T is a type and x is a variable)
- An expression to dereference a pointer:
  - *x (or more generally *e)
  - where e is an expression
- Arrays have implicit pointer type
  - T =x[n] implies x is of type T*



The stack



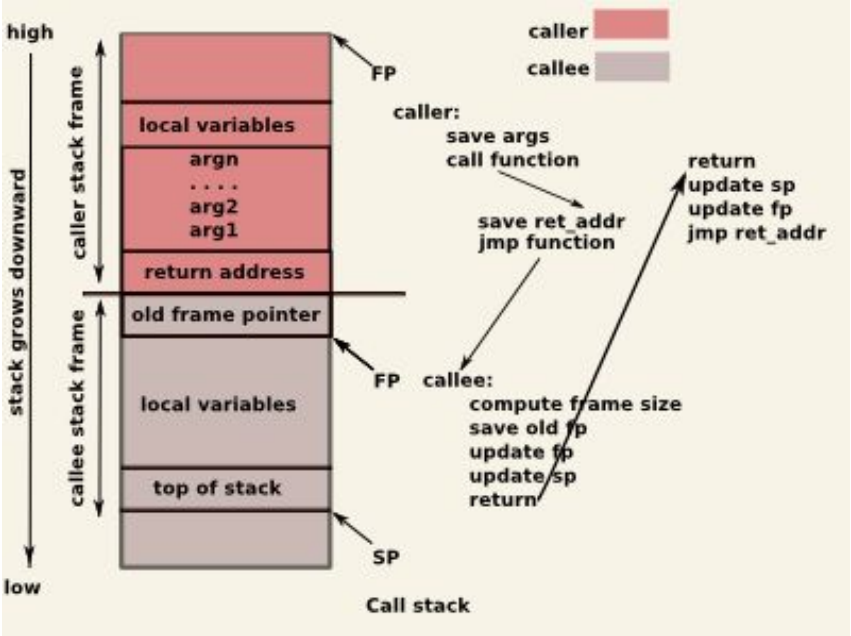
Stack stores active functions & local variables

Frames deleted when function returns

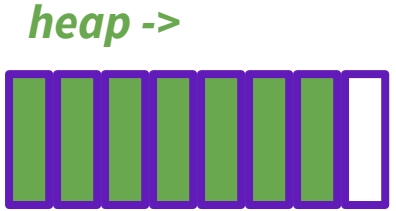
Local variables do not persist

Local variables must have defined size

Can not make run-time adjustments



The heap



- Gives us flexible space
- Allocated at run time, with current space requirements
- Persistent until specifically free-ed
- User allocates memory with `malloc`

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

Allocate memory block

Allocates a block of size bytes of memory, returning a pointer to the beginning of the block.
Returns NULL in failure -> *should always check for NULL before using a pointer*

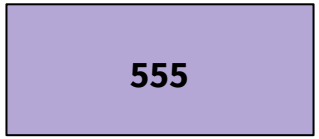
Malloc

- malloc is used in a specific way: `(T*)malloc(e * sizeof(T))`
  - User doesn't need to know `sizeof(T)` - use `sizeof` instead of '16'.
- Returns a pointer to memory large enough to hold an array of length `e` with elements of type `T`
- malloc returns an untyped pointer `(void*)`; the cast `(T*)` tells C to treat it as a pointer to a block of type `T`
- If allocation fails (extremely rare, but can happen), returns `NULL`. Programs must always check.

Initialization

Malloc does not initialize

Must go set initial values manually



var = 555
Or
***varptr=555**

var

Calloc:

void* calloc (size_t num, size_t size);

Allocate and zero-initialize array

Allocates a block of memory for an array of num elements, each of them size bytes long, and initializes all its bits to zero.

*Malloc is faster

Half-way done with memory management!

- We can now allocate memory of any size and have it “live” forever
  - For example, we can allocate an array and use it indefinitely
  - Unfortunately, computers do not have infinite memory so “living forever” could be a problem

Garbage Collection

- Java solution: Conceptually objects live forever, but the system has a garbage collector that finds unreachable objects and reclaims their space
- C solution: You explicitly free an object’s space by passing a pointer to it to the library function free
  - Managing heap memory correctly is hard in complex software and is the disadvantage of C-style heap allocation

Freeing memory

Dynamically allocating memory

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

Deallocate memory block

A block of memory previously allocated by a call to malloc, calloc or realloc is deallocated, making it available again for further allocations.
If ptr does not point to a block of memory allocated with the above functions, it causes *undefined behavior*.

If ptr is a *null pointer*, the function does nothing. Notice that this function does not change the value of ptr itself, hence it still points to the same (now invalid) location.

Example

```
int * p = (int*)malloc(sizeof(int));
p = NULL; /* LEAK! - lost address */
int * q = (int*)malloc(sizeof(int));
free(q);
free(q); /* Best case: crash */
int * r = (int*)malloc(sizeof(int));
free(r);
int * s = (int*)malloc(sizeof(int));
*s = 19;
*r = 17; /* Best case: crash */
```

If `foo` returns a pointer, can the caller free the memory? (Who owns that pointer?)

If `bar` gets two pointers, can it free one, or both?

Rules

- ➔ For every run-time call to malloc there should be one runtime call to free
- ➔ If you “lose all pointers” to an object, you can’t ever call free (a leak)!
  - ◆ Think hard before re-assigning a pointer; where is it pointing
- ➔ If you “use an object after it’s freed” (or free it twice), you used a dangling pointer!
- ➔ Note: It’s possible but rare to use up too much memory without creating “leaks via no more pointers to an object”

Valgrind

`$valgrind` ***`program arguments`***

Tool used to analyze memory usage (and other things)

Catches pointer errors during execution

Prints summary of heap usage, including details of memory leaks

So why didn't we free our array in reverse.c?

The process (a running program) has a single address space for code, globals, the stack, & the heap

When the process exits, the entire address space is freed.

OK to rely on this in many cases

However, good practice to provide mechanism to free any memory allocated in a package, allowing potential clients to release code if desired

```
/* Header stuff */
/* Return a new string with the contents of s backwards */
char * reverse(char * s) {
  char * result = NULL;           /* the reversed string */
  int L, R;  char ch;
  int strsize = strlen(s)+1; // CHANGED
  result = (char *)malloc(strsize); // CHANGED
  strncpy(result, s, strsize); // CHANGED

  L = 0;  R = strlen(result) - 1; // CHANGED
  while (L < R) {
    ch = result[L];
    result[L] = result[R];
    result[R] = ch;
    L++; R--;
  }
  return result;
}

/* Main:  also doesn't free the memory pointed to by result */
```

Puzzle: What prints?

```
#include <stdio.h>

void mystery(char *a, int
*b, int c) {
  int *d = b - 1;
  c = *b + c;
  *b = c - *d;
  *d = *b - *d;
  a[2] = a[b - d];
}
```

```
int main(int argc, char **argv) {
  char ant[4] = "bed";
  int x[2];
  *x = 6;
  x[1] = 7;
  int y = 4;
  int *z = &y;
  *z = *x;
  printf("%d %d %d %s\n", *x, \
          x[1], y, ant);
  mystery(ant, x + 1, y);
  printf("%d %d %d %s\n", *x, \
          x[1], y, ant);
}
```