Dynamic Memory

CS 211

Initial code setup

The code in this course is available in your Unix shell account. You can get your own copy like this:

```
% cd cs211
% tar -xvkf ~cs211/lec/06_dynamic.tgz
⋮
% cd 06_dynamic
```

Road map

Where to store strings

- Uniform-capacity strings
- Storing C-style strings

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  - Uniform-capacity strings
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- Dynamic memory allocation
  - The mechanics
  - Examples

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- Appendix: The Nulls

How can we work with strings?

```
bool is_comment(string);

// Concatenates sequence of strings, stripping comments.
string strip_concat(vector<string> lines)
{
    string result = "";

    for (string line : lines) {
        if (! is_comment(line)) {
            result += line + "\n";
        }
    }

    return result;
}
```

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This is actually C++.

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    }

    return result;
}
```

This is actually (very inefficient) C++.

Up next

Where to store strings

- Uniform-capacity strings
- Storing C-style strings

Dynamic memory allocation

- The mechanics
- Examples

Appendix: The Nulls

Where should strings live?

Solution
in each function’s automatic storage
in one function’s automatic storage
someplace else...

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Where should strings live?

Solution	Problem
in each function’s automatic storage	inflexible & inefficient
in one function’s automatic storage	functions return
someplace else…	difficult

Up next

A uniform-capacity string

Can be passed, returned, assigned:

src/string80.c

```
struct string80
{
    char data[81];
};

typedef struct string80 string80_t;
```

The easy-but-inflexible solution: all strings have the same capacity

Up next

So C uses pointers to 0-terminated `char` arrays

src/ptr_string.c

```c
// Copies characters from 0-terminated
// string src to dst.
void our_strcpy(char* dst, char const* src)
{
    while ( (*dst++ = *src++) )
    { }
}
```

So C uses pointers to 0-terminated `char` arrays

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```
// Copies characters from 0-terminated
// string src to dst.
//
// PRECONDITION (unchecked): dst points to an array whose
// size is at least strlen(src) + 1.
void our_strcpy(char* dst, char const* src)
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This works provided `src` is actually terminated and `dst` has sufficient capacity

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This works provided `src` is actually terminated and `dst` has sufficient capacity

But how can we ensure that `dst` has sufficient capacity?

Solution 1: Reuse existing memory

src/ptr_string.c

```
#include <ctype.h>

// Converts s to uppercase in place
void string_toupper_inplace(char* s)
{
    for (; *s; ++s) *s = toupper(*s);
}
```

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#include <ctype.h>

// Converts s to uppercase in place
void string_toupper_inplace(char* s)
{
    for (; *s; ++s) *s = toupper(*s);
}

int main(void)
{
    char hello[] = "Hello, malloc";
    string_toupper_inplace(hello);
    puts(hello);   // HELLO, MALLOC
}
```

Solution 2: Kick the can (to the caller)

src/ptr_string.c

```
// Uppercases src into dst.
void strcpy_toupper(char* dst, char const* src)
{
    while (*src) *dst++ = toupper(*src++);
}
```

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// Uppercases src into dst.
void strcpy_toupper(char* dst, char const* src)
{
    while (*src) *dst++ = toupper(*src++);
}

int main(void)
{
    char const hello[] = "Hello, malloc";
    char upper_hello[sizeof hello];

    strcpy_toupper(upper_hello, hello);

    puts(upper_hello);   // HELLO, MALLOC
}
```

Solution 3: Find some new memory?

src/stack_string.c

```c
// Returns an uppercase copy of src.
char* bad_string_clone_toupper(char const* src)
{
    char result[strlen(src) + 1];
    strcpy_toupper(result, src);
    return result;
}
```

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`bad_string_clone_toupper()` is wrong, and cannot work

You can't return a pointer to a stack (local) variable

Here's an example with `int`s:

```
int* faulty_inc(int z)
{
    int result = z + 1;
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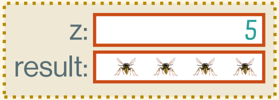

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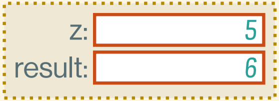

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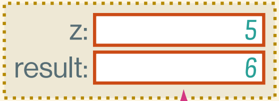

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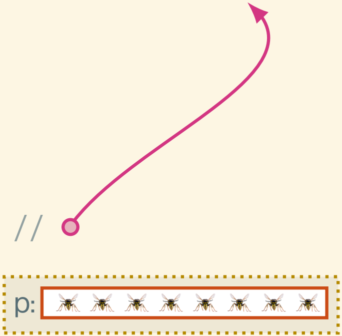

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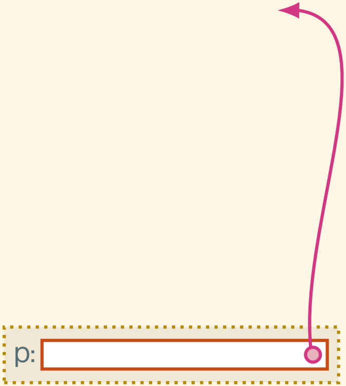

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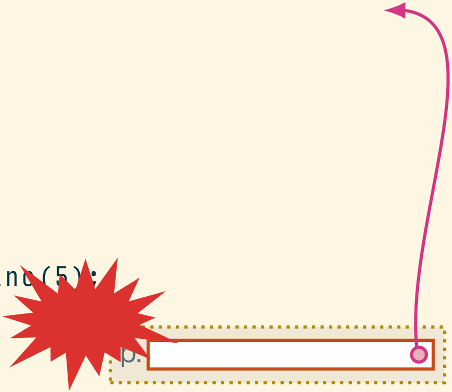

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(Type `void*` literally means “pointer to nothing,” but better to think of it as a pointer to *uninitialized memory of unknown size*.)

Dynamic memory allocation: The basics

- Function `void* malloc(size_t size)` requests `size` bytes of memory from the system.
- `malloc()` either returns a pointer to a new object of the requested size, or indicates failure by returning special “pointer-to-nowhere” `NULL`.
- Function `void free(void* ptr)` releases memory back to the system.

(Type `void*` literally means “pointer to nothing,” but better to think of it as a pointer to *uninitialized memory of unknown size*.)

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4. A object that was not obtained from `malloc()` must not be freed (or else nasal demons, a/k/a UB)
5. Except: `free(NULL)` is just fine

Up next

Heap allocation example

src/heap_string.c

```
#include "ptr_string.h"
#include <stdlib.h>

// Makes an uppercase copy of `s`.
char* string_clone_toupper(char const* s)
{
    char* result = malloc(our_strlen(s) + 1);
    if (!result) return NULL;

    strcpy_toupper(result, s);
    return result;
}
```

Example of using str_toupper_clone

```
char* string_clone_toupper(char const*);

int main(void)
{
    char const *hello = "Hello, malloc";

    char* upper_hello = string_clone_toupper(hello);
    if (! upper_hello) {
        perror(NULL);
        return 1;
    }

    puts(upper_hello);  // HELLO, MALLOC
    free(upper_hello);
}
```

Concatenating two strings, result in the heap

src/string_fun.c

```
char* string_concat(char const* s, char const* t)
{
    size_t s_len = strlen(s),
           t_len = strlen(t);

    char* result = malloc(s_len + t_len + 1);
    if (! result) return NULL;

    strcpy(result, s);
    strcpy(result + s_len, t);

    return result;
}
```

Concatenating two strings, result in the heap, v. 2

Using `snprintf(3)`:

```
char* string_concat(char const* s, char const* t)
{
    char c;
    size_t size = snprintf(&c, 1, "%s%s", s, t);

    char* result = malloc(size);
    if (! result) return NULL;

    snprintf(result, size, "%s%s", s, t);
    return result;
}
```

Our initial example

src/string_fun.c

```
char* strip_concat(char const* const lines[], size_t n)
{
    size_t total_len = 0;


    for (size_t i = 0; i < n; ++i)
        if (!is_comment(lines[i]))
            total_len += strlen(lines[i]) + 1;

    char* result const = malloc(total_len + 1);
    if (result == NULL) return NULL;

    char* fill = result;

    for (size_t i = 0; i < n; ++i) {
        if (is_comment(lines[i])) continue;
        strcpy(fill, lines[i]);
        fill += strlen(fill);
        *fill++ = '\n';
    }

    *fill = 0;

    return result;
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    size_t total_len = 0;


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    char* result const = malloc(total_len + 1);
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    for (size_t i = 0; i < n; ++i) {
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        *fill++ = '\n';
    }

    *fill = 0;

    return result;
}
```

src/string_fun.c

test/test_string_fun.c

Our initial example

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char* strip_concat(char const* const lines[], size_t n)
{
    size_t total_len = 0;


    for (size_t i = 0; i < n; ++i)
        if (!is_comment(lines[i]))
            total_len += strlen(lines[i]) + 1;

    char* result const = malloc(total_len + 1);
    if (result == NULL) return NULL;

    char* fill = result;

    for (size_t i = 0; i < n; ++i) {
        if (is_comment(lines[i])) continue;
        strcpy(fill, lines[i]);
        fill += strlen(fill);
        *fill++ = '\n';
    }

    *fill = 0;

    return result;
}
```

src/string_fun.c

test/test_string_fun.c

src/strip_concat_main.c

– Next time: Undefined Behavior –

```
struct page* intentionally_blank = NULL;
```

Up next

`NULL` versus null versus NUL

Thing	Type of Thing	Purpose of Thing

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So `NULL` is null, but nul is something completely different.