Stack

Handin 1

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1 Stack

The objective is to create a stack that maintains a first-in, last-out data structure. Essentially, we need to implement a list. We will have stack_push and stack_pop functions.
The stack should have the ability to dynamically adjust its size. If the stack is full and we attempt a stack_push operation, we need to allocate a stack twice the current size.
Similarly, if the stack becomes half empty, we can shrink it by deallocating half of its memory.

2 The power of 10 rules

We have been exposed to the so-called "Power of 10 Rules," by Gerard J. Holzmann of the NASA/JPL Laboratory for Reliable Software, which is a set of guidelines for writing safety-critical C code. This is why we always test our return values to ensure that our pointer is not **NULL**. Additionally, we check whether our memory allocation was successful. This is not part of the assignment, but we wanted to make some robust code.

3 Compile

So because we want this to be a robust and rigorous program, we compile with this:

```
gcc -Wall -Wextra -Wpedantic -Wconversion -Wshadow -Werror \
  -Wstrict-prototypes -Wold-style-definition -Wmissing-prototypes \
  -Wmissing-declarations -Wfloat-equal -Wformat=2 \
  -fanalyzer main.c -o new_stack.out
```

- **-Wall**: Enables most common warnings.
- **-Wextra**: Enables additional warnings not included in `-Wall`.
- **-Wpedantic**: Ensures strict compliance with the C standard.
- **-Wconversion**: Warns about implicit type conversions that might be unsafe.
- **-Wshadow**: Warns when a variable declaration hides another variable (e.g., in an outer scope).
- **-Werror**: Treats all warnings as errors, forcing the code to be fixed before compilation succeeds.
- **-Wstrict-prototypes**: Requires function declarations to explicitly specify their argument types.
- **-Wold-style-definition**: Warns against using old C function definitions without prototypes.
- **-Wmissing-prototypes**: Warns if a function is defined without a prototype.
- **-Wmissing-declarations**: Warns if a function is defined without a corresponding declaration.
- **-Wfloat-equal**: Warns when floating-point values are directly compared (as this can be unreliable due to precision errors).
- **-Wformat=2**: Enables extra format string checking (useful for preventing `printf`/`scanf` mismatches).
- **-fanalyzer**: Enables the static code analyzer to detect potential issues like memory leaks and undefined behavior.
- **main.c**: The input source file to compile.
- **-o new_stack.out**: Specifies the output file name (`new_stack.out` instead of `a.out`).

4 Code snippets

4.1 Function: stack_push

Description: Pushes an element into the stack. If the stack is full, it doubles its capacity before adding the new element.

Returns:

- 0 on success.
- -1 if memory allocation fails.

Listing 1: Implementation of stack_push

```c
int stack_push(struct stack *s, int x) {
    assert(s != NULL);

    // If stack is full, double its capacity
    if (s->height == s->capacity) {
        int new_capacity = s->capacity * 2;
        int *new_data = (int *)malloc((size_t)new_capacity * sizeof(int));

        if (new_data == NULL) {
            return -1; // Error: Not enough memory
        }

        // Copy existing data manually
        for (int i = 0; i < s->height; i++) {
            new_data[i] = s->data[i];
        }

        // Free old memory
        free(s->data);

        // Update stack
        s->data = new_data;
        s->capacity = new_capacity;
    }

    // Add element
    s->data[s->height] = x;
    s->height++;

    return 0; // Success
}
```

4.2 Function: stack_pop

Description: Removes the top element from the stack and stores it in `dst`. If the stack becomes too empty, it shrinks its capacity.

Returns:

- 0 on success.
- -1 if the stack is empty.

Listing 2: Implementation of stack_pop

```c
int stack_pop(struct stack *s, int *dst) {
    assert(s != NULL); // Validate pointer is not NULL

    if (s->height == 0) {
        printf("Stack is empty! Cannot pop.\n");
        return -1; // Error: Stack is empty
    }

    *dst = s->data[s->height - 1]; // Store value
    s->height--; // Reduce height

    // Shrink stack if it becomes too empty (under 1/4 of capacity)
    int new_capacity = s->capacity;
    if (s->height > 0 && s->height <= s->capacity / 4) {
        new_capacity = s->capacity / 2;
        if (new_capacity < 2) { // Keep minimum capacity at 2
            new_capacity = 2;
        }
    }

    // Only shrink if the capacity actually changes
    if (new_capacity < s->capacity) {
        int *new_data = (int *)malloc((size_t)new_capacity * sizeof(int));

        if (new_data == NULL) {
            return -1; // Error: Not enough memory
        }

        // Manually copy existing data
        for (int i = 0; i < s->height; i++) {
            new_data[i] = s->data[i];
        }

        // Free old memory
        free(s->data);

        // Update stack
        s->data = new_data;
        s->capacity = new_capacity;
        printf("Stack shrunk to capacity: %d\n", s->capacity);
    }

    return 0; // Success
}
```

5 Memory

Unlike languages such as Java, **C does not have automatic garbage collection**. This means that programmers must **manually allocate and free memory** to avoid memory leaks and inefficiencies. As our professor says, "C assumes you know what you are doing," which is rarely the case. In C, when memory is allocated dynamically, it must be explicitly **freed** once it is no longer needed. Failure to do so can result in **memory leaks**, where memory is allocated but never returned to the system.

There are multiple ways we can manipulate memory allocation.

- **malloc(size_t size)**: Allocates a specified number of bytes in memory but does not initialize them.
- **calloc(size_t num, size_t size)**: Allocates memory for an array of elements and initializes all bytes to zero.
- **realloc(void *ptr, size_t new_size)**: Resizes previously allocated memory to a new size.
- **free(void *ptr)**: Releases previously allocated memory back to the system.

In the hand-in, we are not allowed to use `realloc`, which is a bit annoying since it would be a nicer solution, but it is what it is. In code snippets, you can see that we use `malloc` to allocate memory, and when we need to resize, we copy and paste everything over to a larger or smaller stack, depending on operations.