Poll Everywhere

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About how long did Exercise 2 take you?

A. [0, 2) hours
B. [2, 4) hours
C. [4, 6) hours
D. [6, 8) hours
E. 8+ Hours
F. I didn't submit / I prefer not to say

Modules, C Preprocessor

CSE 333 Winter 2022

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Mitchell Levy	Timmy Yang	

Relevant Course Information

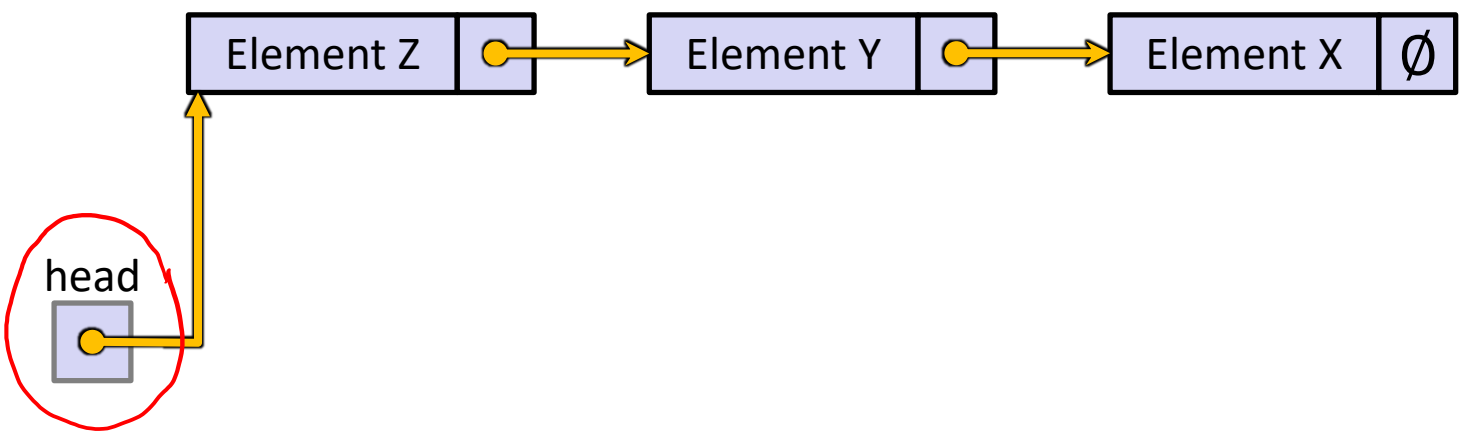
- Exercise 3 out today, due Monday morning
  - Depends on content from Lectures 4 & 5
  - Monday is a holiday, but keeping schedule so you have time to work on Homework 1
- Homework 1 due a week from Thursday
  - You should be well under way now
  - Be sure to read headers *carefully* while implementing
  - Use git add/commit/push regularly to save work – easier to share with partner and course staff
- Section this week will involve group debugging!
  - Be prepared for drawing memory diagrams and using your terminal

Lecture Outline

- **Generic Data Structures in C**
- Modules & Interfaces
- C Preprocessor Intro

Simple Linked List in C

- Each node in a linear, singly-linked list contains:
  - Some element as its payload
  - A pointer to the next node in the linked list
    - This pointer is `NULL` (or some other indicator) in the last node in the list



Linked List Node

- Let's represent a linked list node with a struct
  - For now, assume each element is an `int`

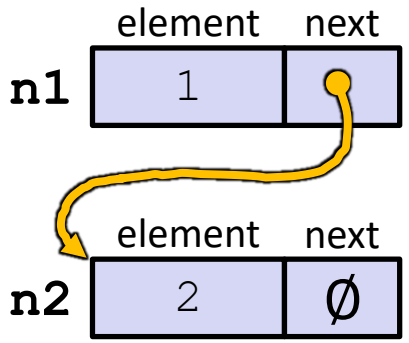
```
typedef struct node_st {
  int element;
  struct node_st* next;
} Node;

int main(int argc, char** argv) {
  Node n1, n2;

  n1.element = 1;
  n1.next = &n2;
  n2.element = 2;
  n2.next = NULL;
  return EXIT_SUCCESS;
}
```

tagname is necessary because pointer to it is part of struct definition

n1, n2 ← on Stack



manual_list.c

Push Onto List

Arrow points to *next* instruction.

```
typedef struct node_st {
  int element;
  struct node_st* next;
} Node;

                        NULL        1
Node* Push(Node* head, int e) {
  Node* n = (Node*) malloc(sizeof(Node));
  assert(n != NULL);  // crashes if false
  n->element = e;
  n->next = head;
  return n;
}

int main(int argc, char** argv) {
  Node* list = NULL;
  list = Push(list, 1);
  list = Push(list, 2);
  return EXIT_SUCCESS;
}
```

(main) list Ø

push_list.c

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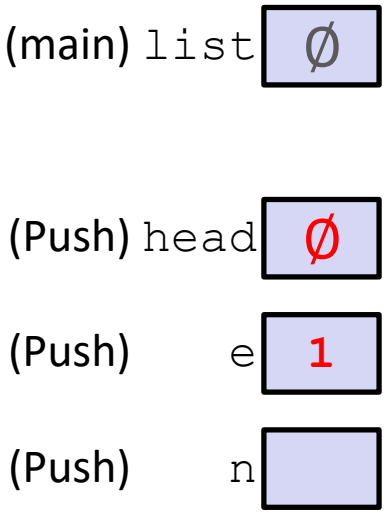

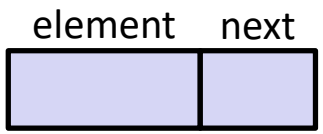

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  n->next = head;
  return n;
}

int main(int argc, char** argv) {
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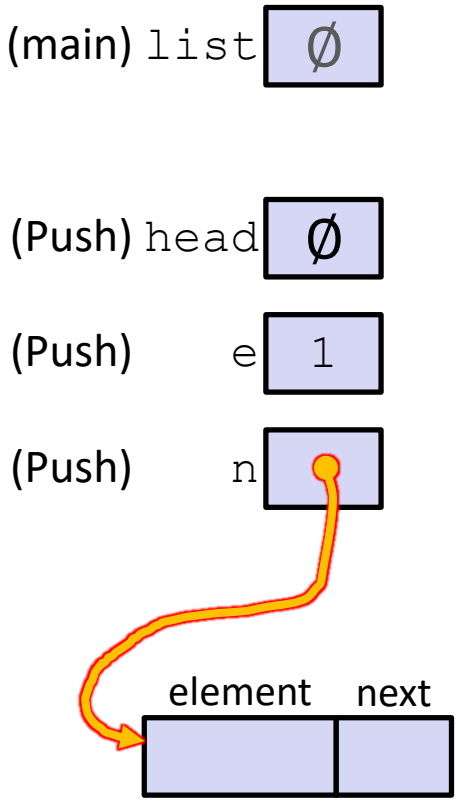
  list = Push(list, 1);
  list = Push(list, 2);
  return EXIT_SUCCESS;
}
```

only use assert in testing code!



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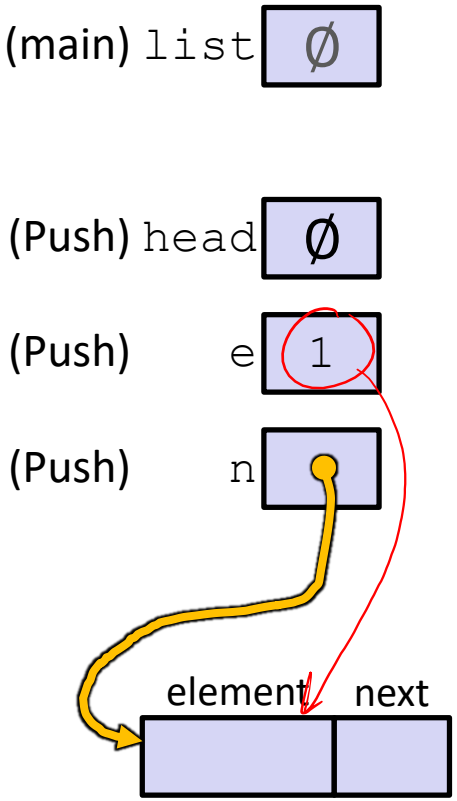

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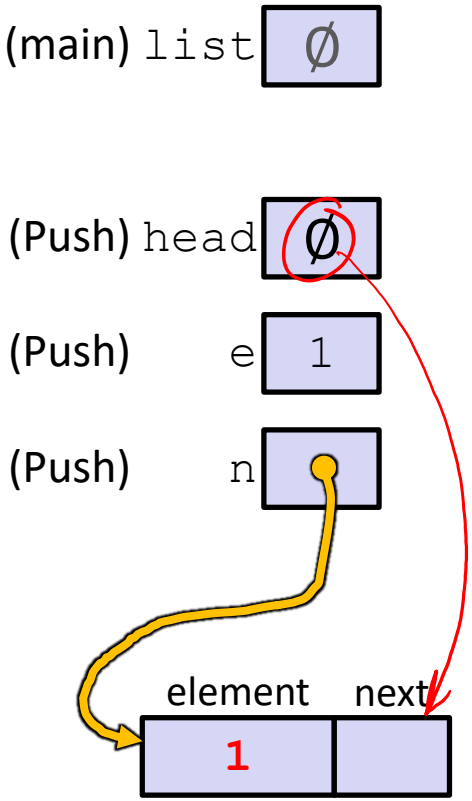

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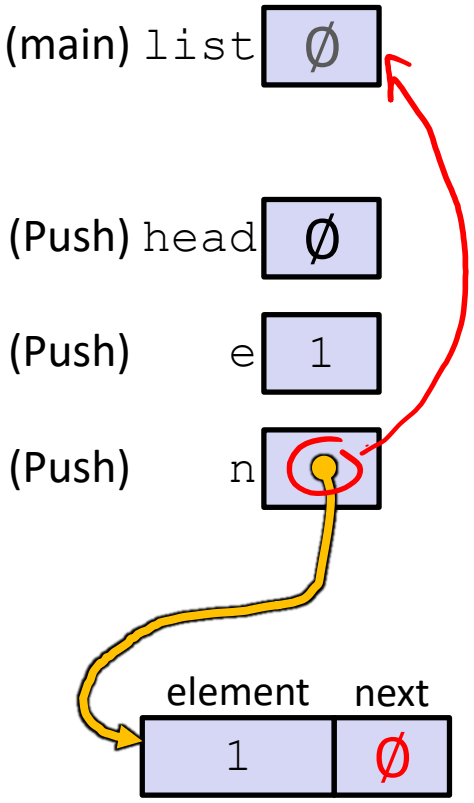

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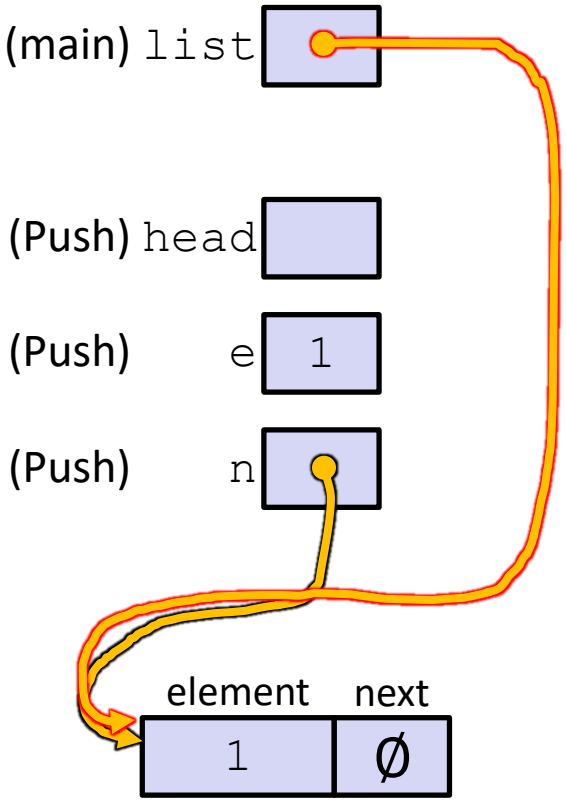

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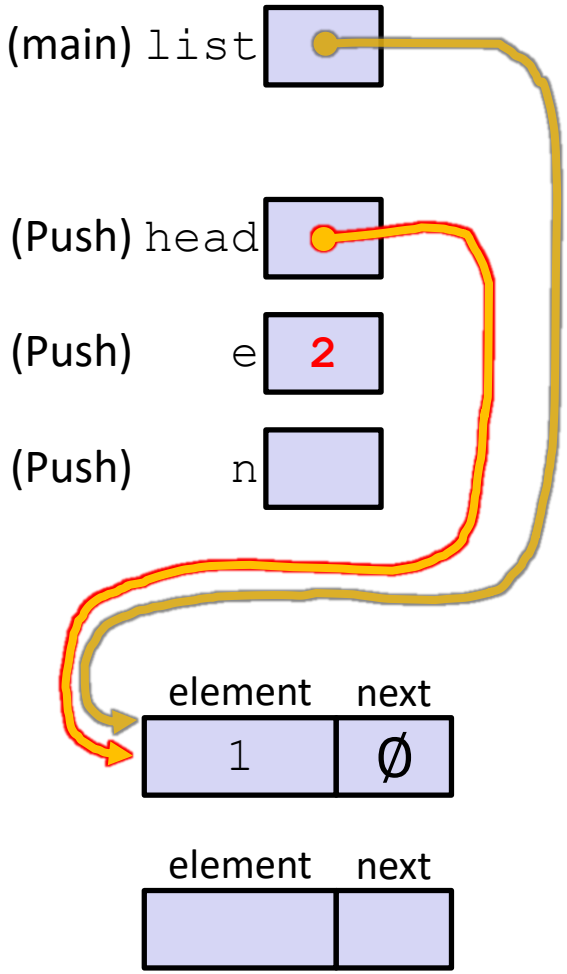

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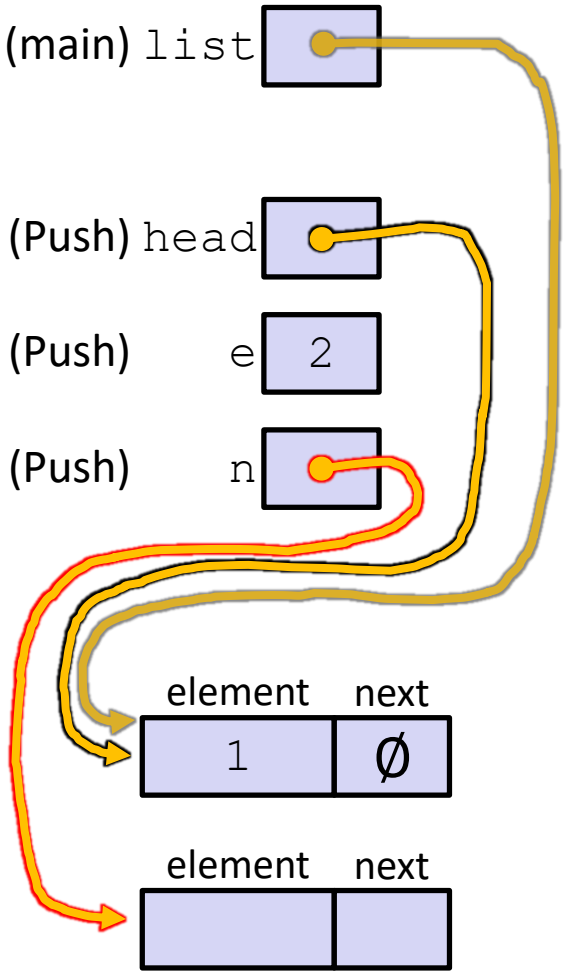

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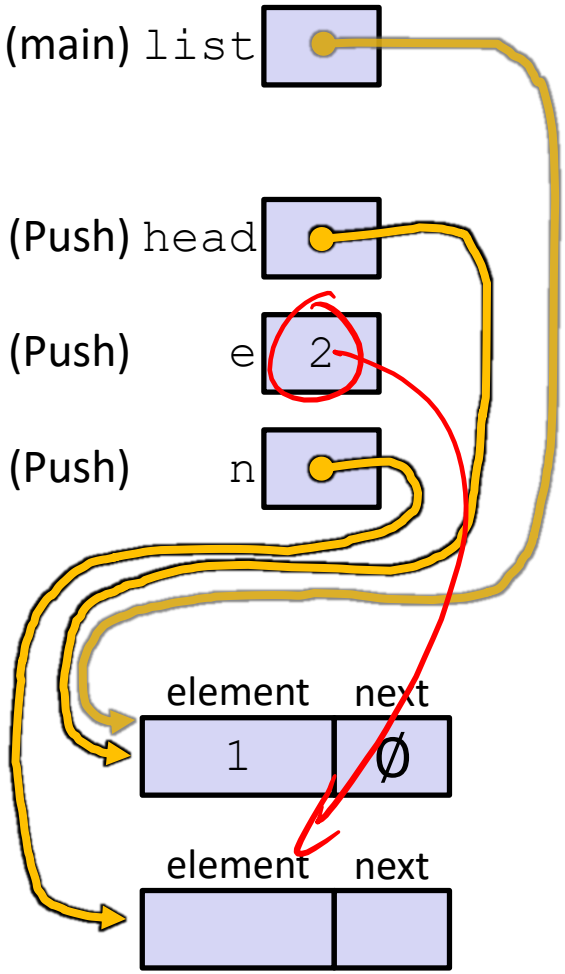

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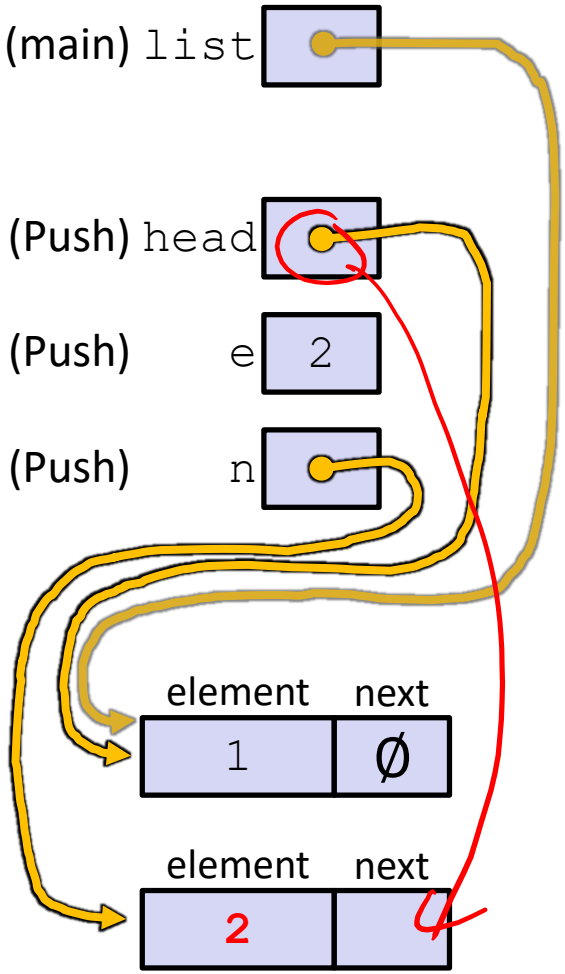

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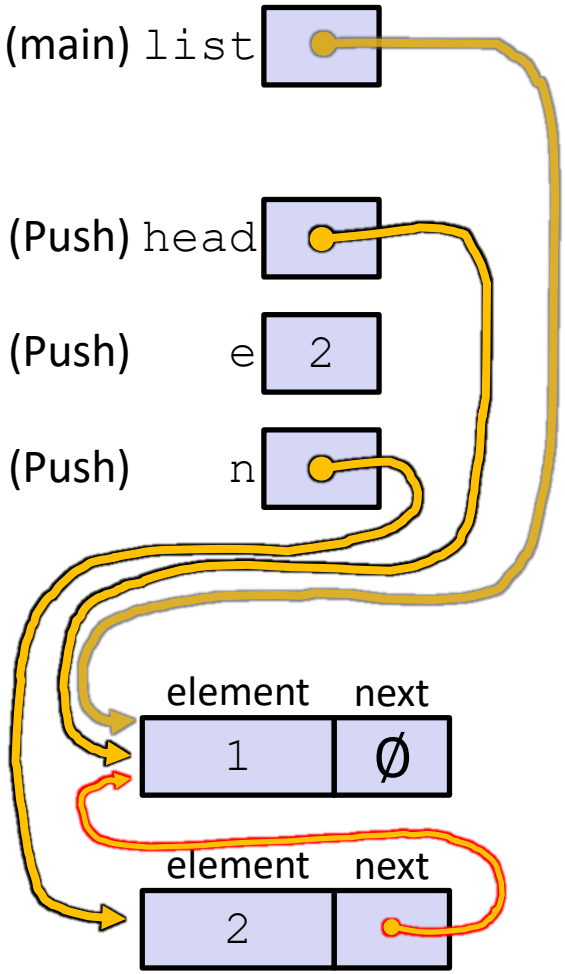

push_list.c

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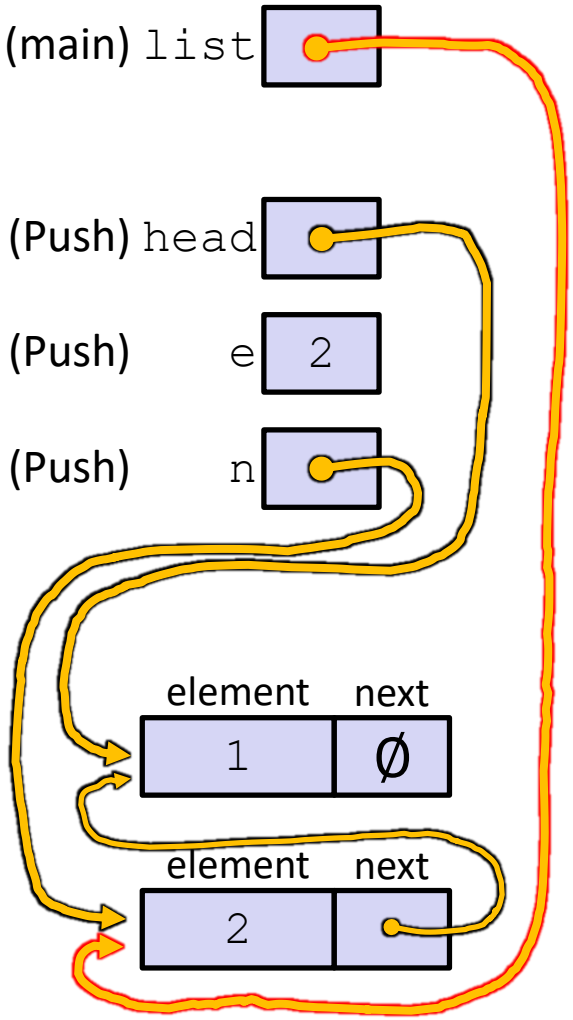
push_list.c



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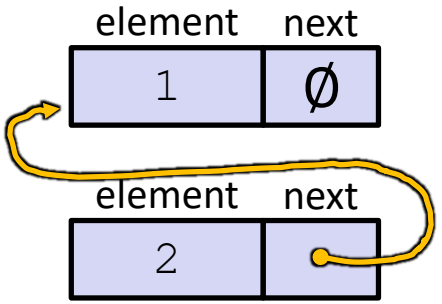


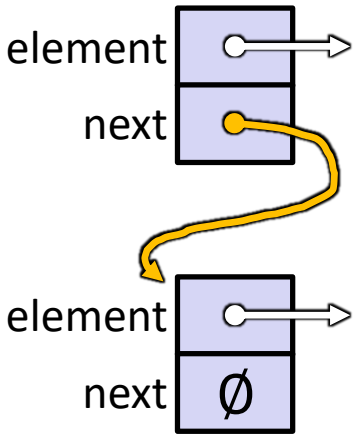
push_list.c

A Generic Linked List

- Let's generalize the linked list element type
  - Let customer decide type (instead of always `int`)
  - Idea: let them use a generic pointer (*i.e.*, a `void*`)

```
typedef struct node_st {
  void* element;
  struct node_st* next;
} Node;

Node* Push(Node* head, void* e) {
  Node* n = (Node*) malloc(sizeof(Node));
  assert(n != NULL);  // crashes if false
  n->element = e;
  n->next = head;
  return n;
}
```



Using a Generic Linked List

- Type casting needed to deal with `void*` (raw address)
  - Before pushing, need to convert to `void*`
  - Convert back to data type when accessing

```
typedef struct node_st {
  void* element;
  struct node_st* next;
} Node;

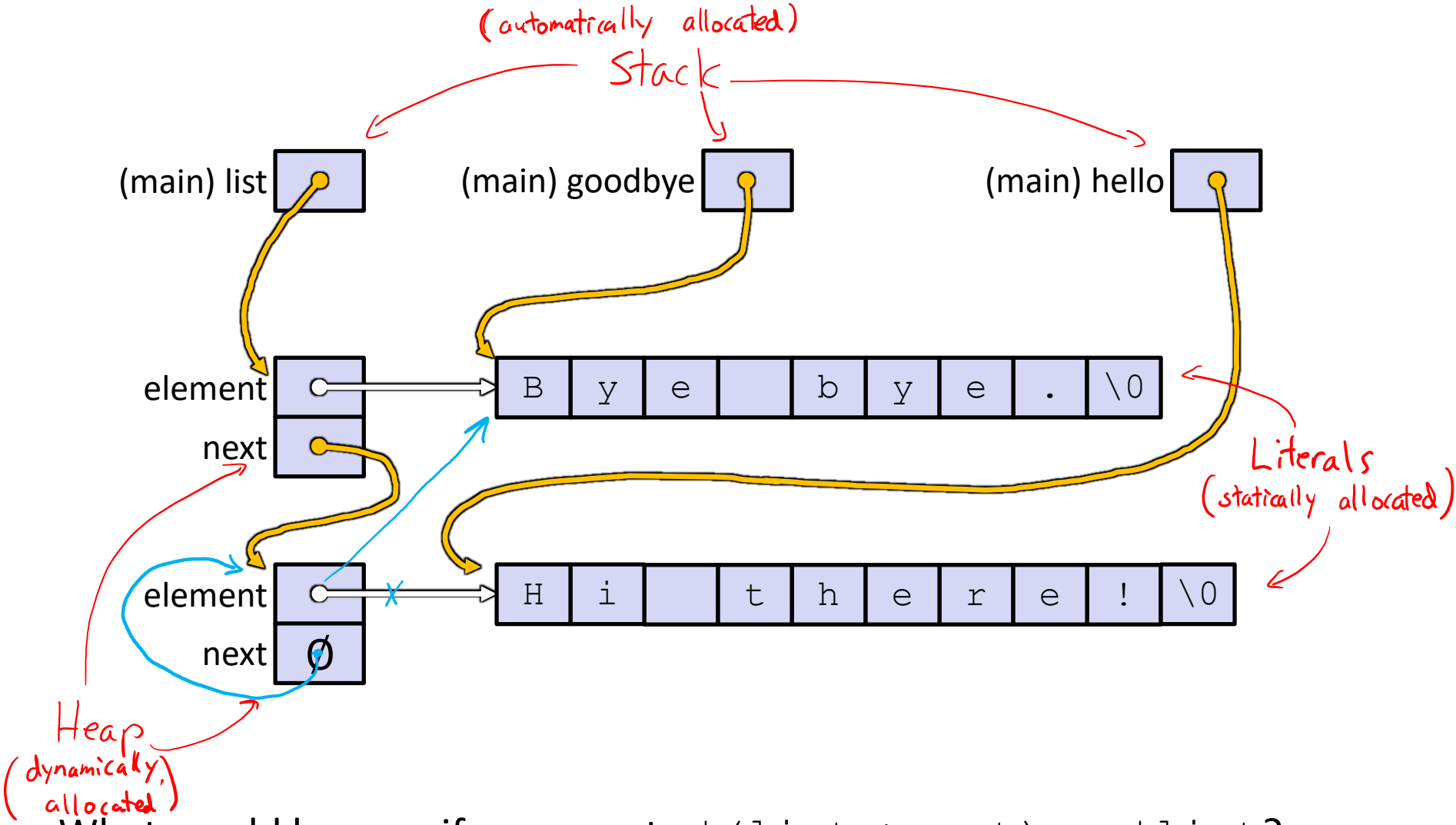
Node* Push(Node* head, void* e);   // assume last slide's code

int main(int argc, char** argv) {
  char* hello = "Hi there!";
  char* goodbye = "Bye bye.";
  Node* list = NULL;

  list = Push(list, (void*) hello);
  list = Push(list, (void*) goodbye);
  printf("payload: '%s'\n", (char*) ((list->next)->element) );
  return EXIT_SUCCESS;
}
```

manual_list_void.c

Resulting Memory Diagram



What would happen if we execute `*(list->next) = *list`?

structs are copied by value

Something's Fishy… 

- A (benign) memory leak!

```
int main(int argc, char** argv) {
  char* hello = "Hi there!";
  char* goodbye = "Bye bye.";
  Node* list = NULL;

  list = Push(list, (void*) hello);
  list = Push(list, (void*) goodbye);
  return EXIT_SUCCESS;
}
```

- Try running with Valgrind:

```
bash$ gcc -Wall -g -o manual_list_void manual_list_void.c
bash$ valgrind --leak-check=full ./manual_list_void
```

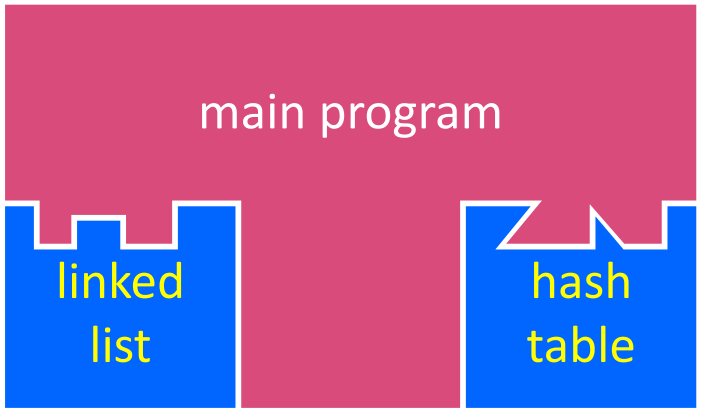
Lecture Outline

- Generic Data Structures in C
- **Modules & Interfaces**
- C Preprocessor Intro

Multi-File C Programs

- Let's create a linked list *module*
  - A module is a self-contained piece of an overall program
    - Has externally visible functions that customers can invoke
    - Has externally visible `typedef`s, and perhaps global variables, that customers can use
    - May have internal functions, `typedef`s, or global variables that customers should *not* look at
  - Can be developed independently and re-used in different projects

- The module's *interface* is its set of public functions, `typedef`s, and global variables



C Header Files

- Header: a file whose only purpose is to be `#include`'d
  - Generally has a filename `.h` extension
  - Holds the variables, types, and function prototype declarations that make up the interface to a module (not definitions)
  - There are <system-defined> and "programmer-defined" headers
    `#include <stdio.h>` `#include "my_header.h"`
- Main Idea:
  - Every `name.c` is intended to be a module that has a `name.h`
  - `name.h` declares the interface to that module
  - Other modules can use `name` by `#include`-ing `name.h`
    - They should assume as little as possible about the implementation in `name.c`

C Module Conventions (1 of 2)

- File contents:
  - `.h` files only contain *declarations*, never *definitions*
  - `.c` files never contain prototype declarations for functions that are intended to be exported through the module interface
  - Public-facing functions are `ModuleName_functionname()` and take a pointer to "`this`" as their first argument

GenericLinkedList_Push()

- Including:
  - ***NEVER*** `#include` a `.c` file – only `#include .h` files
  - `#include` all of headers you reference, even if another header (transitively) includes some of them
- Compiling:
  - Any `.c` file with an associated `.h` file should be able to be compiled (together via `#include`) into a `.o` file

C Module Conventions (2 of 2)

- Commenting:
  - If a function is declared in a header file (`.h`) and defined in a C file (`.c`), *the header needs full documentation because it is the public specification*
    - Don't copy-paste the comment into the C file (don't want two copies that can get out of sync)
  - If prototype and implementation are in the same C file:
    - School of thought #1: Full comment on the prototype at the top of the file, no comment (or "declared above") on code
    - School of thought #2: Prototype is for the compiler and doesn't need comment; comment the code to keep them together

e.g., 333 project code

Lecture Outline

- Generic Data Structures in C
- Modules & Interfaces
- **C Preprocessor Intro**

`#include` and the C Preprocessor

- The C preprocessor (`cpp`) is a *sequential* and *stateful* search-and-replace text-processor that transforms your source code before the compiler runs
  - The input is a C file (text) and the output is still a C file (text)
  - It processes the directives it finds in your code (`#`*directive*)
    - *e.g.* `#include "ll.h"` is replaced by the post-processed content of `ll.h`
    - *e.g.* `#define PI 3.1415` defines a symbol and replaces later occurrences
    - Several others that we'll see soon…
  - Run automatically on your behalf by `gcc` during compilation

" " – look in local directory
< > – look in library directory

macro text substitution

Preprocessor Tricks: Constants

- A way to deal with "magic constants"

```
int globalbuffer[1000];

void circalc(float rad,
             float* circumf,
             float* area) {
  *circumf = rad * 2.0 * 3.1415;
  *area = rad * 3.1415 * 3.1415;
}
```

Bad code
(littered with magic constants)

```
#define BUFSIZE 1000
#define PI 3.14159265359

int globalbuffer[BUFSIZE];

void circalc(float rad,
             float* circumf,
             float* area) {
  *circumf = rad * 2.0 * PI;
  *area = rad * PI * PI;
}
```

Better code

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Exploration: Which of the following text will remain in the preprocessor output?

```
#define BAR 2 + FOO

typedef long long int verylong;
```

cpp_example.h

```
#define FOO 1

#include "cpp_example.h"

int main(int argc, char** argv) {
  int x = FOO;    // a comment
  int y = BAR;
  verylong z = FOO + BAR;
  return 0;
}
```

cpp_example.c

Keep in mind:
1. Pre-processor goes line by line
2. builds up "state" as it processes directives

A. #define

B. BAR

C. FOO

D. verylong

E. // a comment

C Preprocessor Example

Arrow points to *next* line to process

- We can manually run the preprocessor:
  - `cpp` is the preprocessor (can also use `gcc -E`)
  - "`-P`" option suppresses some extra debugging annotations

```
#define BAR 2 + FOO

typedef long long int verylong;
```

cpp_example.h

```
#define FOO 1

#include "cpp_example.h"

int main(int argc, char** argv) {
  int x = FOO;    // a comment
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}
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cpp_example.c

```
bash$ cpp -P cpp_example.c out.c
bash$ cat out.c
```

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Pre-processor state

FOO	1

```
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```

cpp_example.h

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  verylong z = FOO + BAR;
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Pre-processor state

FOO	1

```
#define BAR 2 + FOO

typedef long long int verylong;
```

cpp_example.h

```
#define FOO 1

#include "cpp_example.h"

int main(int argc, char** argv) {
  int x = FOO;    // a comment
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  verylong z = FOO + BAR;
  return 0;
}
```

cpp_example.c

```
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```

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  verylong z = 1 + 2 + 1;
  return 0;
}
```

Program Using a Linked List

```c
#include <stdlib.h>
#include <assert.h>
#include "ll.h"

Node* Push(Node* head,
           void* element) {
  ... // implementation here
}
```

ll.c

```c
typedef struct node_st {
  void* element;
  struct node_st* next;
} Node;

Node* Push(Node* head,
           void* element);
```

ll.h

```c
#include "ll.h"

int main(int argc, char** argv) {
  Node* list = NULL;
  char* hi = "hello";
  char* bye = "goodbye";

  list = Push(list, (void*)hi);
  list = Push(list, (void*)bye);

  ...

  return 0;
}
```

example_ll_customer.c

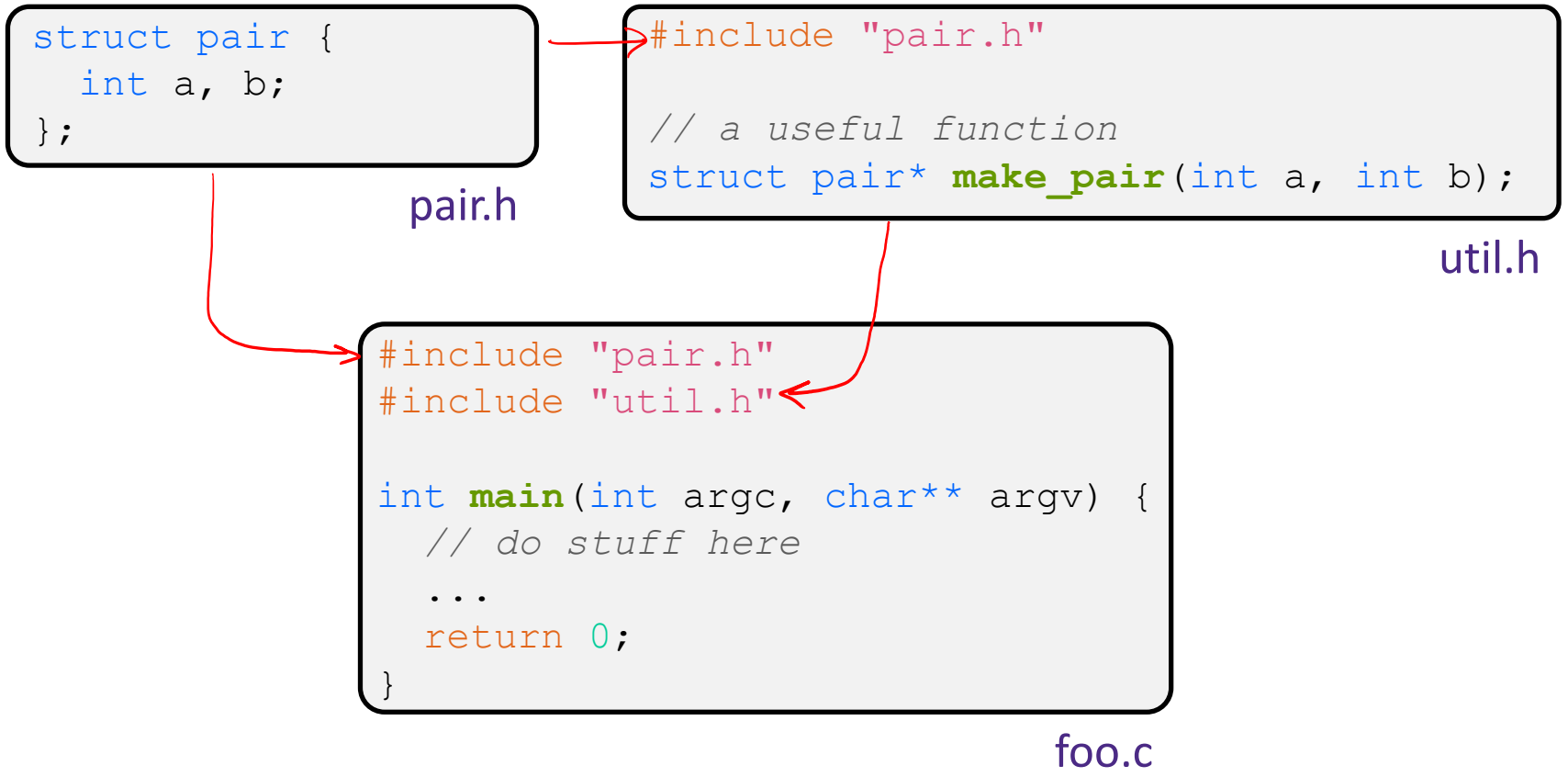
Compiling the Program

- Four parts:
  - 1/2) Compile `example_ll_customer.c` into an object file
  - 2/1) Compile `ll.c` into an object file
  - 3) Link both object files into an executable
  - 4) Test, Debug, Rinse, Repeat

```
(1) bash$ gcc -Wall -g -c -o example_ll_customer.o example_ll_customer.c
(2) bash$ gcc -Wall -g -c -o ll.o ll.c
(3) bash$ gcc -g -o example_ll_customer ll.o example_ll_customer.o
(4) bash$ ./example_ll_customer
Payload: 'yo!'
Payload: 'goodbye'
Payload: 'hello'
(4) bash$ valgrind -leak-check=full ./example_ll_customer
... etc ...
```

But There's a Problem with `#include`

- What happens when we compile `foo.c`?



A Problem with #include

- What happens when we compile `foo.c`?

```
bash$ gcc -Wall -g -o foo foo.c
In file included from util.h:1:0,
                 from foo.c:2:
pair.h:1:8: error: redefinition of 'struct pair'
 struct pair { int a, b; };
        ^
In file included from foo.c:1:0:
pair.h:1:8: note: originally defined here
 struct pair { int a, b; };
        ^
```

- `foo.c` includes `pair.h` twice!
  - Second time is indirectly via `util.h`
  - Struct definition shows up twice
    - Can see using `cpp`

Preprocessor Tricks: Header Guards

- A standard C Preprocessor trick to deal with this
  - Uses macro definition (`#define`) in combination with conditional compilation (`#ifndef` and `#endif`)

preprocessor state
① PAIR_H_ ✓
② UTIL_H_ ✓

① not defined ③ defined

```
#ifndef PAIR_H_
#define PAIR_H_

struct pair {
  int a, b;
};

#endif   // PAIR_H_
```

① now define

pair.h

empty include!

② not defined

```
#ifndef UTIL_H_
#define UTIL_H_

#include "pair.h"

// a useful function
struct pair* make_pair(int a, int b);

#endif   // UTIL_H_
```

② now define

even if #included twice, header guard PAIR_H_ saves us!

util.h

includes struct pair

foo.c

```
#include "pair.h"
#include "util.h"

int main(int argc, char** argv) {
```

Extra Exercise #1

- Extend the linked list program we covered in class:
  - Add a function that returns the number of elements in a list
  - Implement a program that builds a list of lists
    - *i.e.* it builds a linked list where each element is a (different) linked list
  - Bonus: design and implement a "Pop" function
    - Removes an element from the head of the list
    - Make sure your linked list code, and customers' code that uses it, contains no memory leaks

Extra Exercise #2

- Implement and test a binary search tree
  - https://en.wikipedia.org/wiki/Binary_search_tree
    - Don't worry about making it balanced
  - Implement key insert() and lookup() functions
    - Bonus: implement a key delete() function
  - Implement it as a C module
    - `bst.c`, `bst.h`
  - Implement `test_bst.c`
    - Contains main() and tests out your BST

Extra Exercise #3

- Implement a Complex number module
  - `complex.c`, `complex.h`
  - Includes a typedef to define a complex number
    - a + bi, where a and b are `doubles`
  - Includes functions to:
    - add, subtract, multiply, and divide complex numbers
  - Implement a test driver in `test_complex.c`
    - Contains `main()`