CSE 333

Lecture 6 - data structures

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Administrivia

Exercises:

- ex5 is out: clean up the code from section yesterday, split into separate files, fix bugs
    - More towards the end of the hour
- no more exercises due until end of week after HW1

HW:

- HW1 due very soon; get going NOW if you haven't yet

Today's topics:

- implementing data structures in C
- multi-file C programs
- brief intro to the C preprocessor

Let's build a simple linked list

You've seen a linked list in CSE143

- each node in a linked list contains:
  - some element as its payload
  - a pointer to the next node in the linked list
- the last node in the list contains a NULL pointer (or some other indication that it is the last node)

Linked list node

Let's represent a linked list node with a struct

- and, for now, assume each element is an int

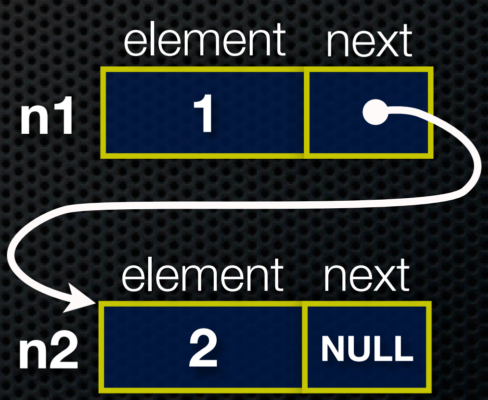
```
#include <stdio.h>

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

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

  n2.element = 2;
  n2.next = NULL;
  n1.element = 1;
  n2.next = &n2;
  return 0;
}
```

manual_list.c



PushOntoList

push_list.c

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

typedef struct Node {
  int element;
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Node *Push(Node *head, int e) {
  Node *n = (Node *) malloc(sizeof(Node));

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  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 0;
}
```

(main) list **NULL**

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}
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(main) list NULL

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  return 0;
}
```

(main) list NULL

(POL) head NULL

(POL) e 1

(POL) n ???

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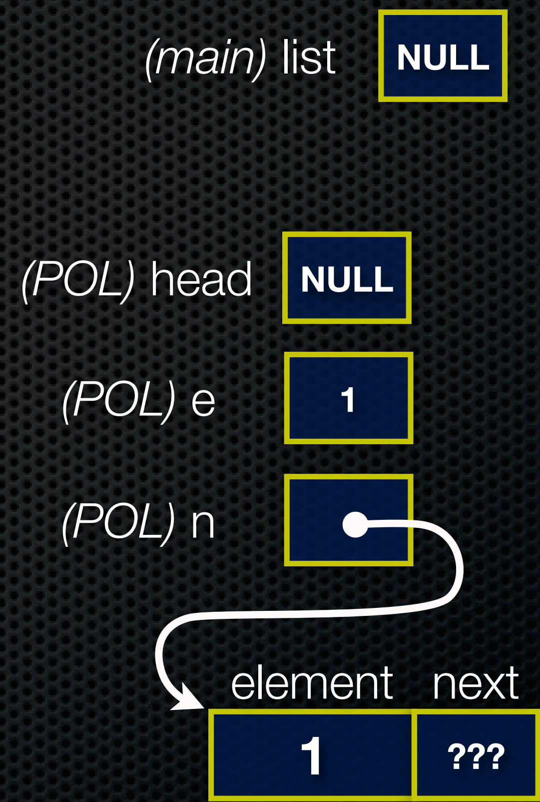

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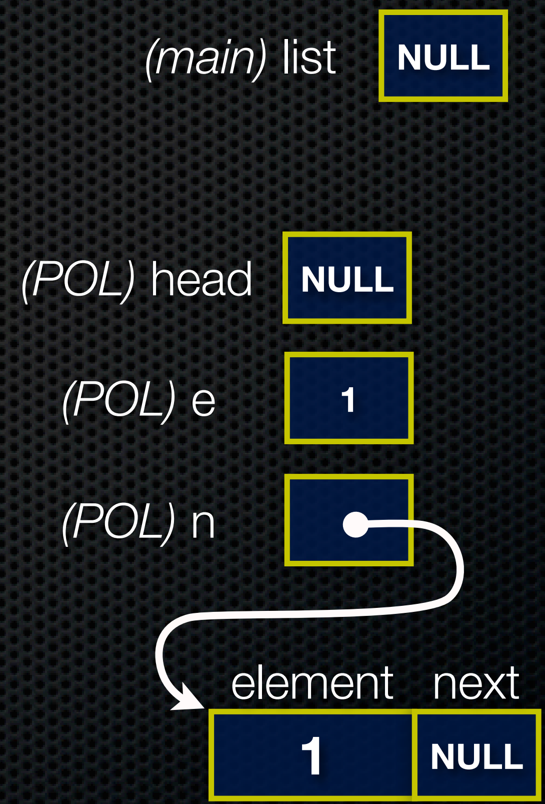

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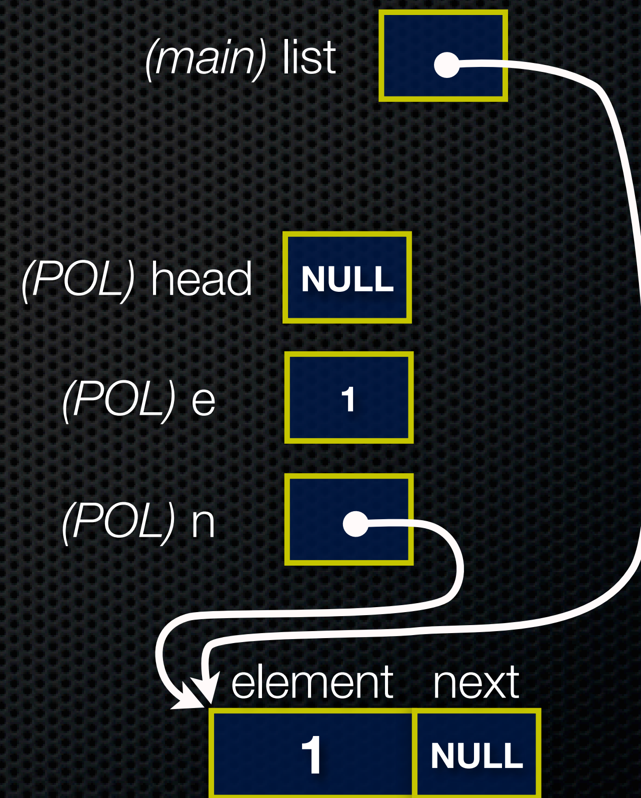

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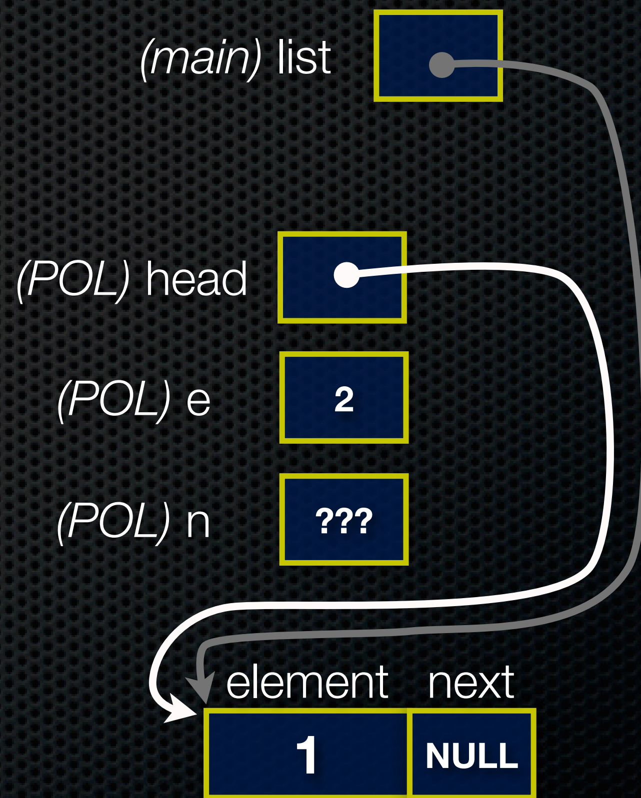

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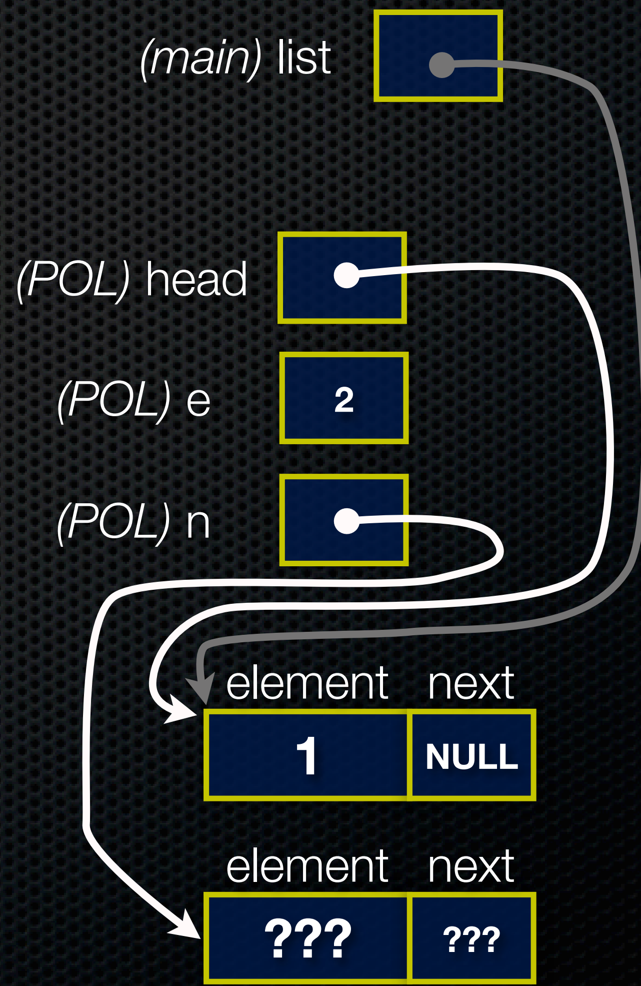

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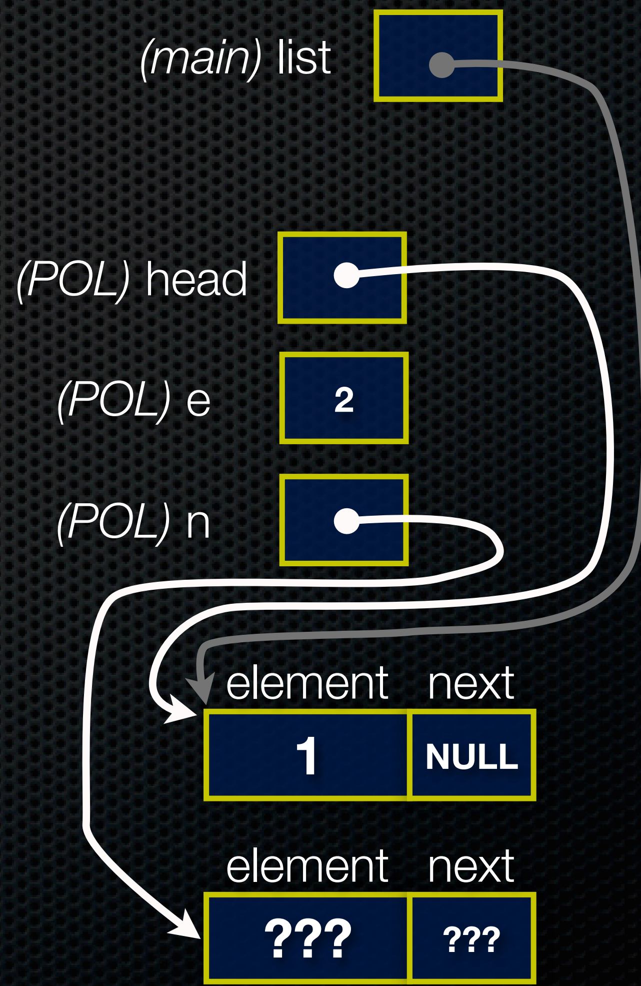

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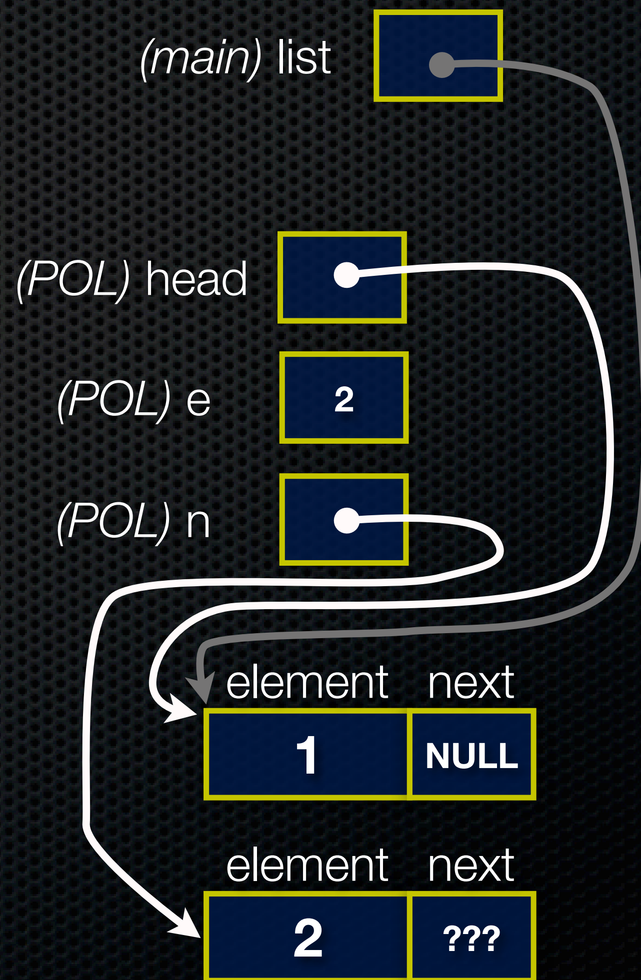

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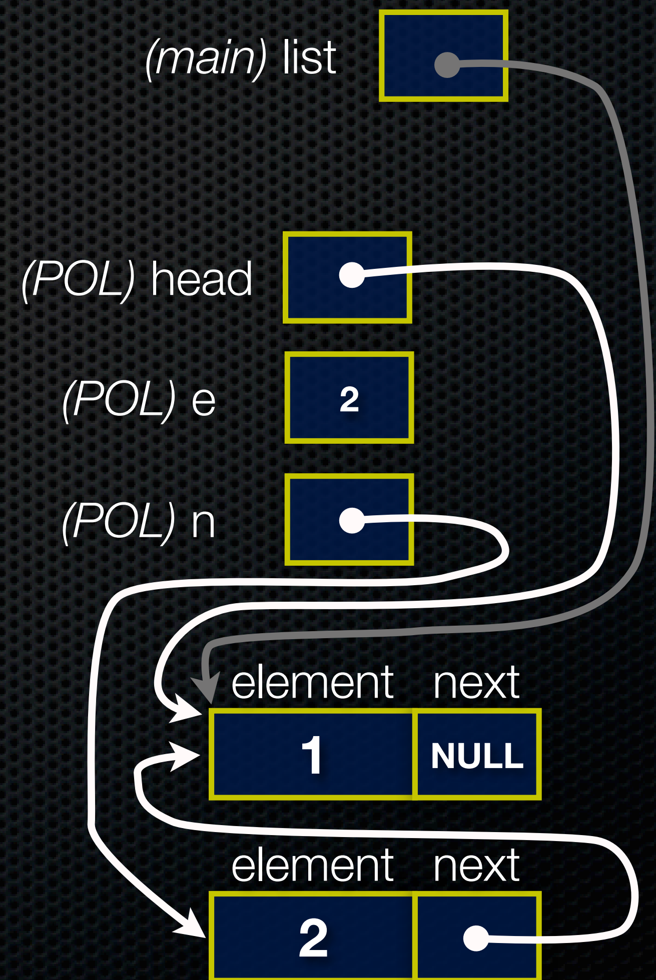

PushOntoList

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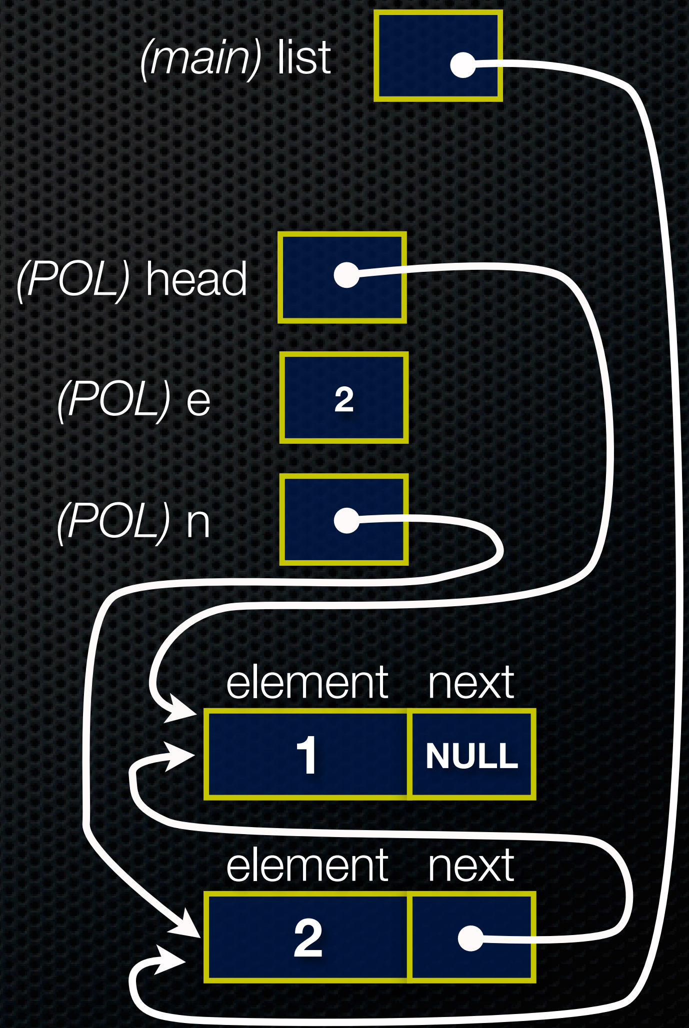

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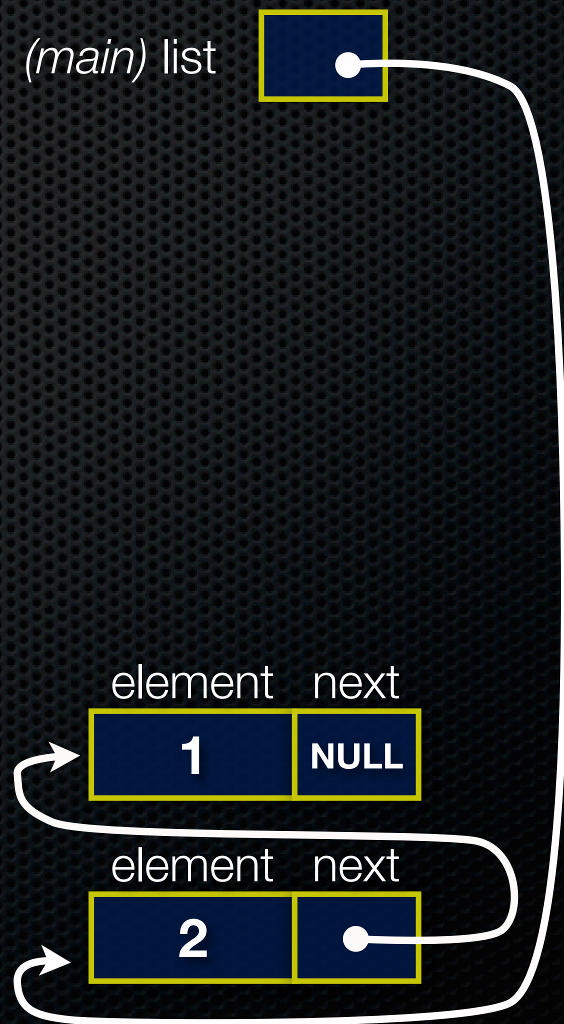

PushOntoList

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}

int main(int argc, char **argv) {
  Node *list = NULL;

  list = Push(list, 1);
  list = Push(list, 2);

  return 0;
}
```
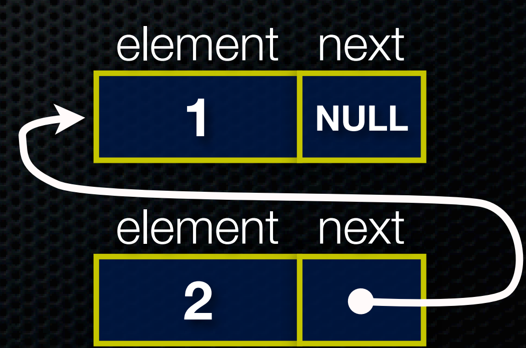

a (benign) leak!!

try running with valgrind:

```
bash$ gcc -o push_list -g -Wall
push_list.c

bash$ valgrind --leak-check=full
./push_list
```

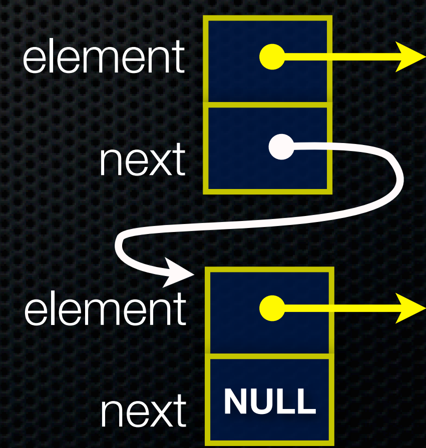


A generic linked list

Previously, our linked list elements were of type **int**

- what if we want to let our customer decide the element type?
- idea: let them push a generic pointer -- i.e., a **(void *)**

```
typedef struct Node {
  void *element;
  struct Node *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

To use it, customers will need to use type casting

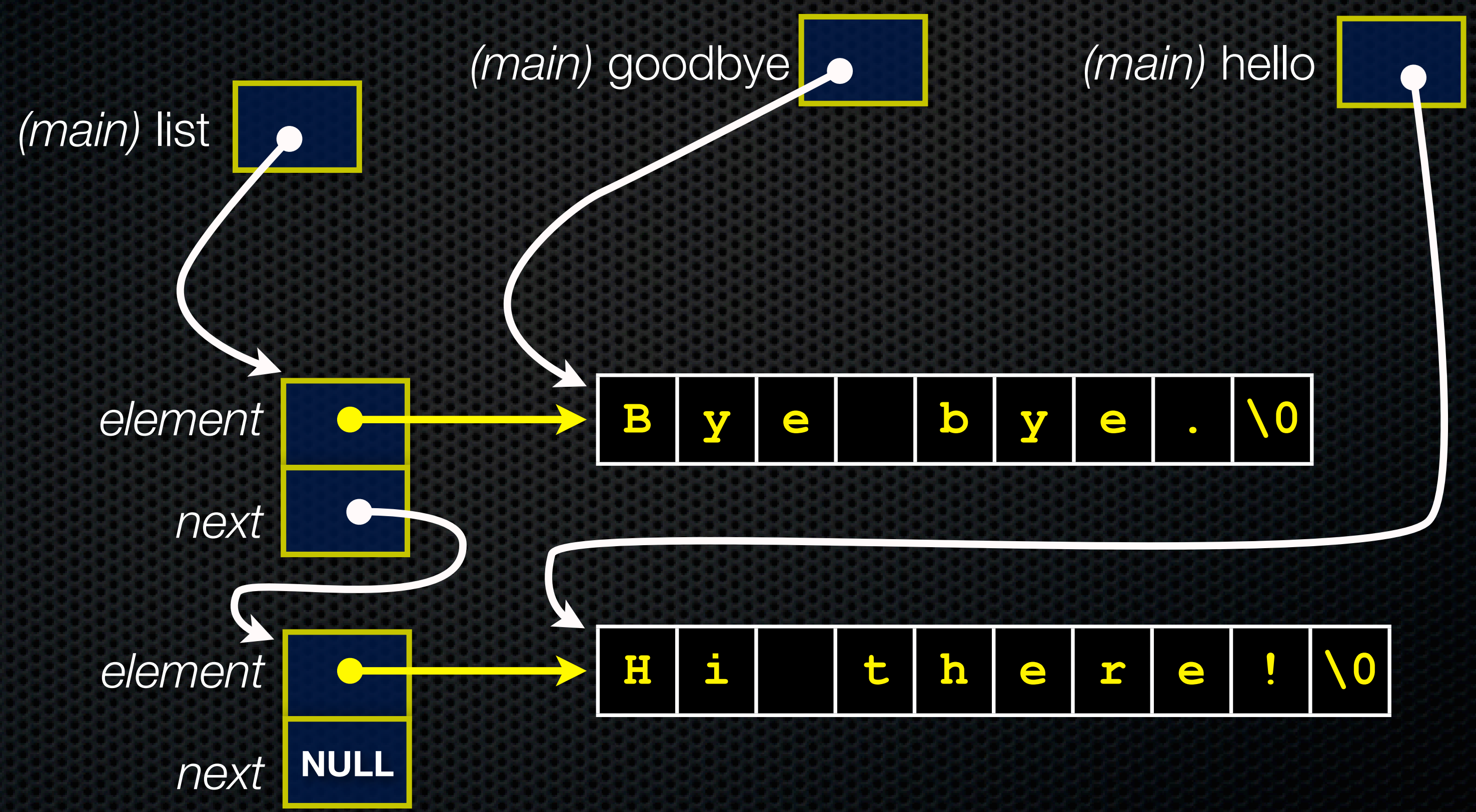
- convert their data type to a (void *) before pushing
- convert from a (void *) back to their data type when accessing

manual_list_void.c

```
typedef struct Node {
  void *element;
  struct Node *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 0;
}
```

Using a generic linked list

Results in:

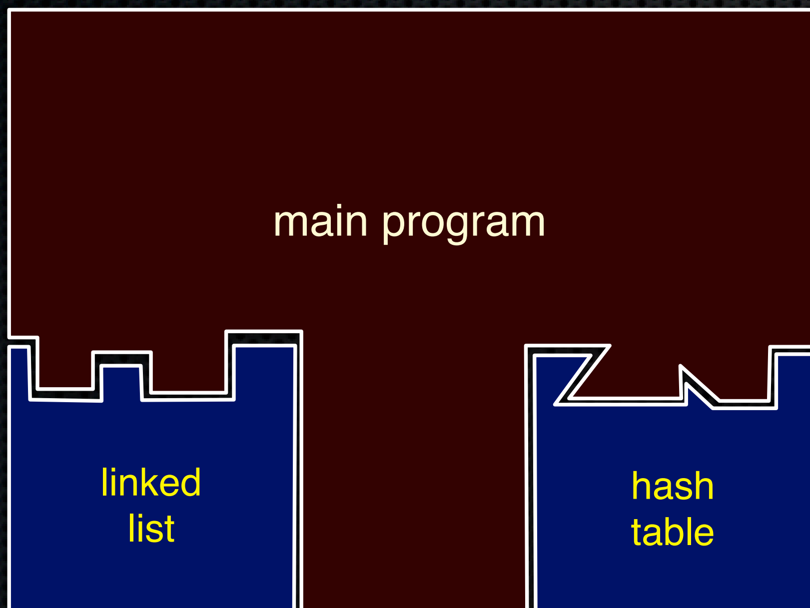


Multi-file C programs

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 typedefs, and perhaps global variables, that customers can use
    - may have internal functions, typedefs, global variables that customers should not look at
- the module's **interface** is its set of public functions, typedefs, and global variables

Modularity



The degree to which components of a system can be separated and recombined

- "loose coupling" and "separation of concerns"
- modules can be developed independently
- modules can be re-used in different projects

C header files

header: a C file whose only purpose is to be *#include*'d

- generally a filename with the .h extension
- holds the variables, types, and function prototype declarations that make up the interface to a module

the main idea

- every **name.c** intended to be a module has a **name.h**
- **name.h** declares the interface to that module
- other modules that want to use **name** will #include **name.h**
    - and they should assume as little as possible about the implementation in name.c

C module conventions

Most C projects adhere to the following rules:

- .h files never contain <u>definitions</u>, only <u>declarations</u>
- .c files never contain prototype declarations for functions that are intended to be exported through the module interface
    - those function prototype declarations belong in the .h file
- never #include a .c file -- only #include .h files
- any .c file with an associated .h file should be able to be compiled into a .o file

#include and the C preprocessor

The C preprocessor (cpp) transforms your source code before the compiler runs

- transforms your original C source code into transformed C source code
- processes the directives it finds in your code (*#something*)
  - `#include "ll.h"` -- replaces with post-processed content of **ll.h**
  - `#define PI 3.1415` -- defines a symbol, replaces later occurrences
  - and there are several others we'll see soon...
- run on your behalf by gcc during compilation

Example

```c
#define BAR 2 + FOO

typedef long long int verylong;
```

cpp_example.h

```c
#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

Let's manually run the pre-processor on cpp_example.c:

- cpp is the preprocessor
- *"-P" suppresses some extra debugging annotations*

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


typedef long long int verylong;

int main(int argc, char **argv) {
  int x = 1;
  int y = 2 + 1;
  verylong z = 1 + 2 + 1;
  return 0;
}
```

Program that uses 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 {
  void *element;
  struct Node *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, hi);
  list = Push(list, bye);

  return 0;
}
```

example_ll_customer.c

Compiling the program

Four steps:

- compile *example_ll_customer.c* into an object file
- compile *ll.c* into an object file
- link *ll.o*, *example_ll_customer.o* into an executable
- test, debug, rinse, repeat

```
bash$ gcc -Wall -g -o example_ll_customer.o -c example_ll_customer.c
bash$ gcc -Wall -g -o ll.o -c ll.c
bash$ gcc -o example_ll_customer -g ll.o example_ll_customer.o
bash$
bash$ ./example_ll_customer

Payload: 'yo!'
Payload: 'goodbye'
Payload: 'hello'

bash$ valgrind --leak-check=full ./example_customer
...etc.
```

Building systems

This doesn't really scale: gcc -Wall -g -o gadget *.c

- Could take hours (think gcc source, linux kernel, etc.)

If we change a single source file, what needs building?

- foo.c - at least recompile to get foo.o then relink
- foo.h - probably need to recompile foo.c then relink
  - But also need to recompile everything that #includes foo.h
    - Directly or indirectly...

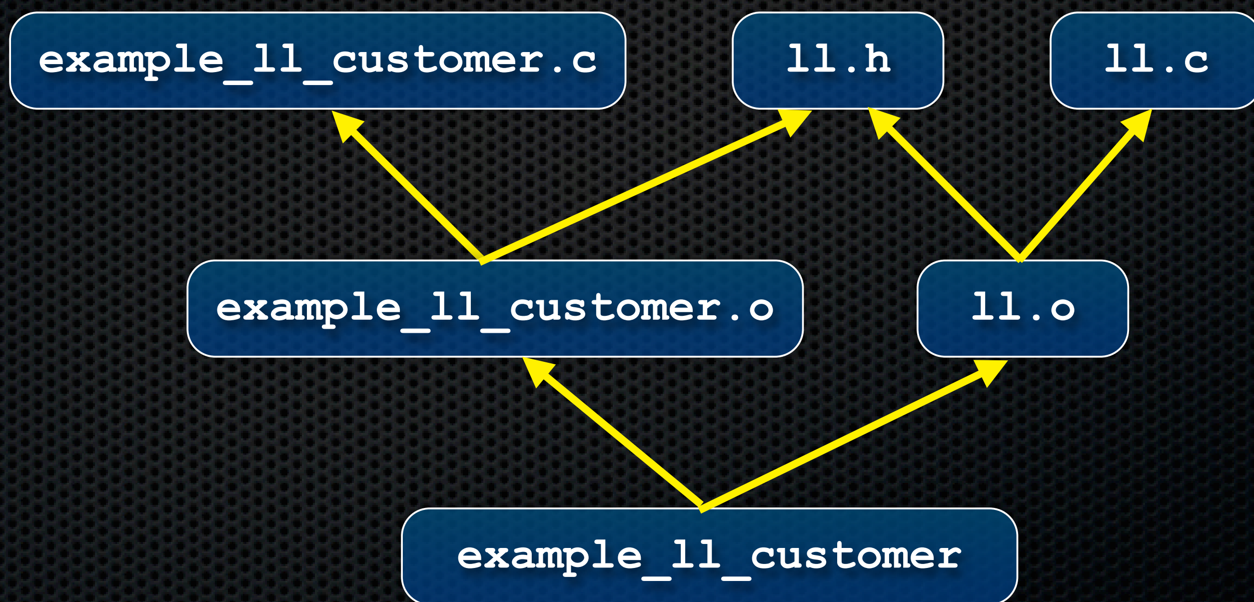
Easy to forget something and get a broken build

Solution: let the computer figure it out!

Build dependencies

All build tools work from same core idea: capture build dependencies and recompile only what's needed

ex: Dependency graph for example_ll_customer



make

Venerable unix tool to automate build tasks

Input is a Makefile with *rules* describing dependencies:

```
target:  sources
<tab char> command(s)
```

Meaning: if any *source* is newer (file system timestamp) than *target* then run *command(s)*

- Nothing actually requires *command(s)* to have anything to do with *sources* or *target*, although that is the typical usage. Makefiles can do interesting things.

Makefile for ll project

Makefile

```
# default target (i.e., first one) is the executable program
example_ll_customer: example_ll_customer.o ll.o
   gcc -Wall -g -o example_ll_customer example_ll_customer.o ll.o

# targets for individual source files
example_ll_customer.o: example_ll_customer.c ll.h
   gcc -Wall -g -c example_ll_customer.c

ll.o: ll.c ll.h
   gcc -Wall -g -c ll.c

# clean: remove files built by makefile and emacs backup files
clean:
   rm -f example_ll_customer *.o *~
```

Run “make” to build the default (first) target

Run “make *target*” to build named *target*

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
    - but each element in the list 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

Exercise 2

Implement and test a binary search tree

- http://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( ), tests out your BST

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( )

See you on Monday!