Abstract Data Types (ADTs), After More on the Heap

COS 217

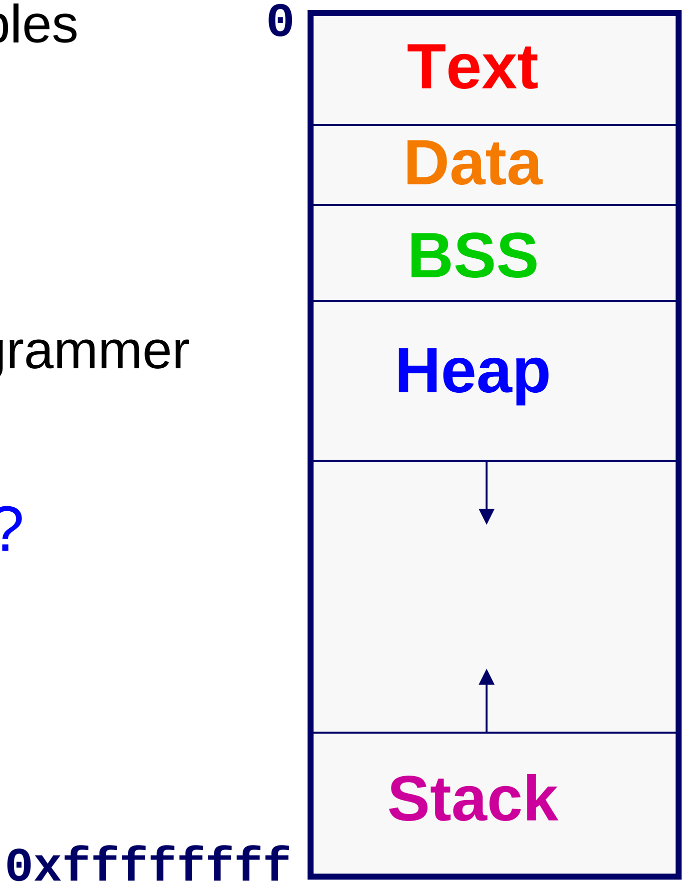
Preparing for the Midterm Exam

- Exam logistics
  - Date/time: Thursday October 27 at 10:00-10:50am (in lecture)
  - Open books, open notes, open mind, but not open laptop/PDA
  - Covering material from lecture, precept, and reading, but not tools
- Preparing for the midterm
  - Lecture and precept materials available online
  - Course textbooks, plus optional books on reserve
  - Office hours and the course listserv
  - Old midterm exams on the course Web site
- Review in Thu Oct 13 lecture
  - Chris DeCoro will work out some practice questions
  - He'll announce which questions in advance
  - I encourage you to try the problems before the lecture

http://www.cs.princeton.edu/courses/archive/fall05/cos217/exams.html

A Little More About the Heap…

- Memory layout of a C program
  - Text: code, constant data
  - Data: initialized global & static variables
  - BSS: uninitialized global & static variables
  - Heap: dynamic memory
  - Stack: local variables
- Purpose of the heap
  - Memory allocated explicitly by the programmer
  - Using the functions **`malloc`** and **`free`**
- But, why would you ever do this???
  - Glutton for punishment???



Example: Read a Line (or URL)

- Write a function that reads a word from stdin
  - Read from stdin until encountering a space, tab, ‘\n’, or EOF
  - Output a pointer to the sequence of characters, ending with ‘\0’
- Example code (very, very buggy)

```
#include <stdio.h>

int main(void) {
    char* buf;

    scanf(“%s”, buf);
    printf(“Hello %s\n”, buf);
    return 0;
}
```

Problem: Need Storage for String

- Improving the code
  - Allocate storage space for the string
  - Example: define an array
- Example (still somewhat buggy)

```
#include <stdio.h>

int main(void) {
   char buf[64];

   scanf("%s", buf);
   printf("Hello %s\n", buf);
   return 0;
}
```

Problem: Input Longer Than Array

- Improving the code
  - Don’t allow input that exceeds the array size
- Example (better, but not perfect)

```
#include <stdio.h>

int main(void) {
   char buf[64];

   if (scanf(“63s”, buf) == 1)
       printf(“Hello %s\n”, buf);
   else
       fprintf(stderr, Input error\n”);
   return 0;
}
```

Problem: How *Much* Storage?

- Improving the code
  - Finding out how much space you need from the user
  - Allocate exactly that much space, to avoid wasting
- Beginning of the example (is this really better?)

```
int main(void) {
    int n;
    char* buf;

    printf("Max size of word: ");
    scanf("%d", &n);

    buf = malloc((n+1) * sizeof(char));
    scanf("%s", buf);
    printf("Hello %s\n", buf);
    return 0;
}
```

Really Solving the Problem

- Remaining problems
  - User can’t input long words
  - Storage wasted on short words
- But, how do we proceed?
  - Too little storage, and we’ll run pass the end or have to truncate
  - Yet, we don’t *know* how big the word might be
- The gist of a solution
  - Pick a storage size (“line_size”) and read up to that length
  - If we stay within the limit, we’re done
  - If the user input exceeds the space, we can
    - Allocate space for another line, and keep on reading
    - At the end, allocate one big buffer and copy all the lines into it

Warning: Avoid Dangling Pointers

- Dangling pointers point to data that's not there anymore

```
int f(void)
{
    char* p;
    p = (char *) malloc(8 * sizeof(char));
    …
    return 0;
}

int main() {
    f();
    …
}
```

Abstract Data Types (ADTs)

Abstract Data Type (ADT)

- An ADT module provides:
  - Data type
  - Functions that operate on the type
- Client does not manipulate the data representation directly
  - The client should just call functions
- "Abstract" because the observable results (obtained by client) are independent of the data representation
- Programming language support for ADT
  - Ensure that client cannot possibly access representation directly
  - C++, Java, other object-oriented languages have ***private*** fields
  - C has opaque pointers

An ADT Example: Stacks

- LIFO: Last-In, First-Out
- Like the stack of trays at the cafeteria
  - "Push" a tray onto the stack
  - "Pop" a tray off the stack
- Useful in many contexts

Stack Interface (stack.h)

What's this for?

```
#ifndef STACK_INCLUDED
#define STACK_INCLUDED

typedef struct Item_t *Item_T;
typedef struct Stack_t *Stack_T;

extern Stack_T Stack_new(void);
extern int Stack_empty(Stack_T stk);
extern void Stack_push(Stack_T stk, Item_T item);
extern Item_T Stack_pop(Stack_T stk);

#endif
```

Notes on `stack.h`

- Type **`Stack_T`** is an opaque pointer
  - Clients can pass **`Stack_T`** around but can't look inside
- Type **`Item_T`** is also an opaque pointer
  - … but defined in some other ADT
- **`Stack_`** is a disambiguating prefix
  - A convention that helps avoid name collisions

Stack Implementation: Array

stack.c

```
#include <assert.h>
#include <stdlib.h>
#include “stack.h”

#define CAPACITY 1000

struct Stack_t {
    int count;
    Item_T data[CAPACITY];
};

Stack_T Stack_new(void) {
  Stack_T stk = malloc(sizeof *stk);
  assert(stk != NULL);
  stk->count = 0;
  return stk;
}
```

Careful Checking With Assert

stack.c

```
#include <assert.h>
#include <stdlib.h>
#include “stack.h”

#define CAPACITY 1000

struct Stack_t {
    int count;
    Item_T data[CAPACITY];
 };

Stack_T Stack_new(void) {
  Stack_T stk = malloc(sizeof *stk);
  assert(stk != NULL);
  stk->count = 0;
  return stk;
}
```

Make sure stk!=NULL, or halt the program!

Stack Implementation: Array (Cont.)

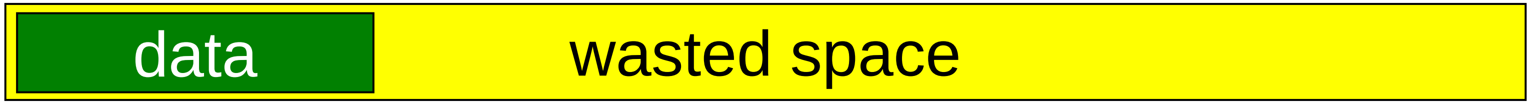
```
int Stack_empty(Stack_T stk) {
     assert(stk);
    return (stk->count == 0);
}

void Stack_push(Stack_T stk, Item_T item) {
   assert(stk);
   assert(stk->count < CAPACITY);
   stack->data[stack->count++] = item;
}

Item_T Stack_pop(Stack_T stk) {
    assert(stk && stk->count > 0);
    return stk->data[--(stk->count)];
}
```

Problems With Array Implementation

`CAPACITY` too large: waste memory

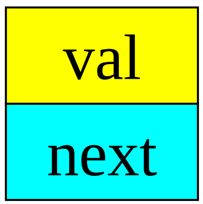


`CAPACITY` too small:

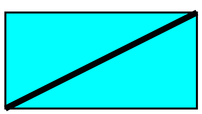
assertion failure (if you were careful)

buffer overrun (if you were careless)

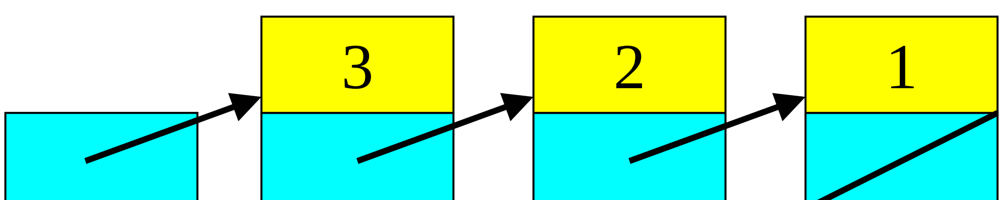
Linked List Would be Better…



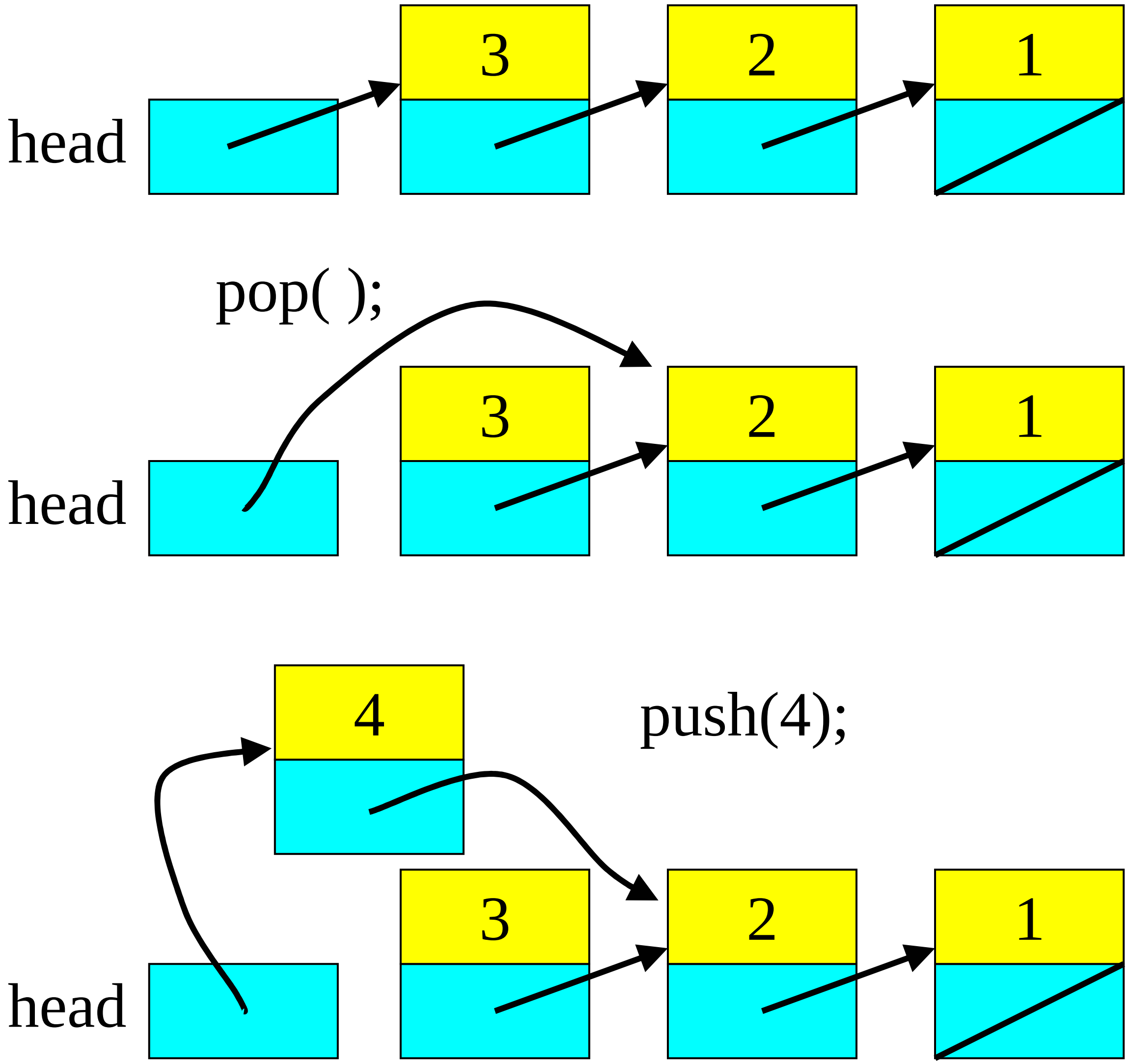

```
struct stack {
        int val;
        struct stack *next;
} *head;
```

head  empty stack

push(1); push(2); push(3);

head 

Popping and Pushing



Stack Implementation: Linked List

stack.c

```
#include <assert.h>
#include <stdlib.h>
#include “stack.h”

struct Stack_t {struct list *head;};
struct list {Item_T val; struct list *next;};

Stack_T Stack_new(void) {
  Stack_T stk = malloc(sizeof *stk);
  assert(stk != NULL);
  stk->head = NULL;
  return stk;
}
```

Stack Implementation: Linked List

```
int Stack_empty(Stack_T stk) {
    assert(stk);
   return (stk->head == NULL);
}

void Stack_push(Stack_T stk, Item_T item) {
    Stack_T t = malloc(sizeof(*t));
   assert(t); assert(stk);
    t->val = item; t->next = stk->head;
   stk->head = t;
}
```

Draw pictures of
these data structures!

stack.c, continued

```
Item_T Stack_pop(Stack_T stk) {
   Item_T x; struct list *p;
   assert(stk && stk->head);
   x = stk->head->val;
   p = stk->head;
   stk->head = stk->head->next;
   free(p);
   return x;
}
```

Draw pictures of these data structures!

Client Program: Uses Interface

client.c

```
#include <stdio.h>
#include <stdlib.h>
#include "item.h"
#include "stack.h"

int main(int argc, char *argv[]) {
   int i;
   Stack_T s = Stack_new();
   for (i = 1; i < argc; i++)
      Stack_push(s, Item_new(argv[i]));
   while (!Stack_empty(s))
      Item_print(Stack_pop(s));
   return EXIT_SUCCESS;
}
```

Problem: Multiple Kinds of Stacks?

- Good, but still not flexible enough
  - What about a program with multiple kinds of stacks
  - E.g., a stack of books, and a stack of pancakes
  - But, can you can only define Item_T once
- Solution in C, though it is a bit clumsy
  - Don't define Item_T (i.e., let it be a "void *")
  - Good flexibility, but you lose the C type checking

```
typedef struct Item_t *Item_T;
typedef struct Stack_t *Stack_T;

extern Stack_T Stack_new(void);
extern int Stack_empty(Stack_T stk);
extern void Stack_push(Stack_T stk, void *item);
extern void *Stack_pop(Stack_T stk);
```

Conclusions

- Heap
  - Memory allocated and deallocated by the programmer
  - Useful for making efficient use of memory
  - Useful when storage requirements aren't known in advance
- Abstract Data Types (ADTs)
  - Separation of interface and implementation
  - Don't even allow the client to manipulate the data directly
  - Example of a stack
    - Implementation #1: array
    - Implementation #2: linked list
  - Backup slides on void pointers follow…

Backup Slides
on Void Opaque Pointers

`stack.h` (with void*)

```
#ifndef STACK_INCLUDED
#define STACK_INCLUDED
```

~~`typedef struct Item_t *Item_T;`~~

```
typedef struct Stack_t *Stack_T;

extern Stack_T Stack_new(void);
extern int Stack_empty(Stack_T stk);
extern void Stack_push(Stack_T stk, void *item);
extern void *Stack_pop(Stack_T stk);

/* It's a checked runtime error to pass a NULL Stack_T to any
   routine, or call Stack_pop with an empty stack
*/

#endif
```

Stack Implementation (with void*)

stack.c

```
#include <assert.h>
#include <stdlib.h>
#include "stack.h"

struct Stack_t {struct list *head;};
struct list {void *val; struct list *next;};

Stack_T Stack_new(void) {
   Stack_T stk = malloc(sizeof *stk);
   assert(stk);
   stk->head = NULL;
   return stk;
}
```

stack.c (with void*) continued

```
int Stack_empty(Stack_T stk) {
    assert(stk);
   return stk->head == NULL;
}

void Stack_push(Stack_T stk, void *item) {
    Stack_T t = malloc(sizeof(*t));
   assert(t); assert(stk);
    t->val = item; t->next = stk->head;
   stk->head = t;
}
```

`stack.c` (with `void*`) **continued**

```
void *Stack_pop(Stack_T stk) {
   void *x; struct list *p;
   assert(stk && stk->head);
   x = stk->head->val;
   p = stk->head;
   stk->head = stk->head->next;
   free(p);
   return x;
}
```

Client Program (With Void)

client.c (with void*)

```
#include <stdio.h>
#include <stdlib.h>
#include "item.h"
#include "stack.h"

int main(int argc, char *argv[]) {
   int i;
   Stack_T s = Stack_new();
   for (i = 1; i < argc; i++)
      Stack_push(s, Item_new(argv[i]));
   while (!Stack_empty(s))
      printf("%s\n",Stack_pop(s));
   return EXIT_SUCCESS;
}
```

(The line `#include "item.h"` and the call `Item_new(` are struck through on the slide.)

Structural Equality Testing

Suppose we want to test two stacks for equality:

```
int Stack_equal(Stack_T s1, Stack_T s2);
```

How can this be implemented?

```
int Stack_equal(Stack_T s1, Stack_T s2) {
  return (s1 == s2);
}
```

We want to test whether two stacks are equivalent stacks, not whether they are the *same* stack.

Almost, But Not Quite...

How about this:

```
int Stack_equal(Stack_T s1, Stack_T s2) {
  struct list *p, *q;
  for (p=s1->head, q=s2->head;  p && q;
            p=p->next, q=q->next)
      if (p->val != q->val)
         return 0;
  return p==NULL && q==NULL;
}
```

This is better, but what we want to test whether **`s1->val`** is *equivalent* to **`s2->val`**, not whether it is the *same*.

Item ADT Provides Equal Test

How about this:

```
int Stack_equal(Stack_T s1, Stack_T s2) {
  struct list *p, *q;
  for (p=s1->head, q=s2->head;  p && q;
            p=p->next, q=q->next)
      if ( ! Item_equal(p->val, q->val))
         return 0;
  return p==NULL && q==NULL;
}
```

This is good for the “Item_T” version of stacks (provided the Item interface has an Item_equal function), but what about the void* version of stacks?

Function Pointers

How about this:

```
int Stack_equal(Stack_T s1, Stack_T s2,
                int (*equal)(void *, void *)) {
  struct list *p, *q;
  for (p=s1->head, q=s2->head;  p && q;
               p=p->next, q=q->next)
      if ( ! equal((void*)p->val, (void*) q->val))
         return 0;
  return p==NULL && q==NULL;
}
```

The client must pass an equality-tester function to Stack_equal.

Passing a Function Pointer

```
int Stack_equal(Stack_T s1, Stack_T s2,
                int (*equal)(void *, void *)) {
  struct list *p, *q;
  for (p=s1->head, q=s2->head;  p && q;
              p=p->next, q=q->next)
      if ( ! equal((void*)p->val, (void*) q->val))
         return 0;
  return p==NULL && q==NULL;
}
```

Client:

```
int char_equal (char *a, char *b) {
   return (!strcmp(a,b));
}
int string_stacks_equal(Stack_T st1, Stack_T st2) {
   return Stack_equal(st1, st2,
             & (int (*  )(void *, void*)) char_equal);
}
```

cast