Queues, Stack Modules, and Abstract Data Types

CS2023 Winter 2004

Outcomes: Queues, Stack Modules, and Abstract Data Types

- *C for Java Programmers*, Chapter 11 (11.5) and *C Programming - a Modern Approach*, Chapter 19
- After the conclusion of this section you should be able to
  - Write queue and stack modules using a linked list
  - Use `static` to modify the linkage of functions and global variables
  - Use opaque data types to create modules that implement abstract data types

Queue

Queue can be implemented as a linked list:

```
typedef unsigned int data;
typedef struct node{
  data d;
  struct node *next;
} NodeT;

NodeT *front;
NodeT *rear;

int initialize() {
  front = NULL;
  rear = NULL;
}
```

```
Void enqueue(data d) {
  NodeT *newNode;

  newNode = malloc(sizeof(NodeT));
  if (newNode == NULL) {
    fprintf(stderr, "queue is full\n");
    exit(EXIT_FAILURE);
  }
  newNode->d = d;
  newNode->next = NULL;
  if(!empty()) {
    rear->next = newNode;
    rear = newNode;
  } else
    front = rear = newNode;
}
```

```
data dequeue(data d) {
  data d;
  NodeT *oldNode;

  d = front->d;
  oldNode = front;
  front = front->next;
  free(oldNode);
  return d;
}

data get_front() {
  return front->d;
}

int is_empty() {
  return front == NULL;
}
```

Stack Module

- A well-designed module often keeps information secret from its clients
  - information hiding
- Clients of a stack module have no need to know whether it is stored in an array, in a linked list, or in some other way
- In C, the major tool for enforcing information hiding is the **`static`** storage class

Storage Duration, Scope & Linkage

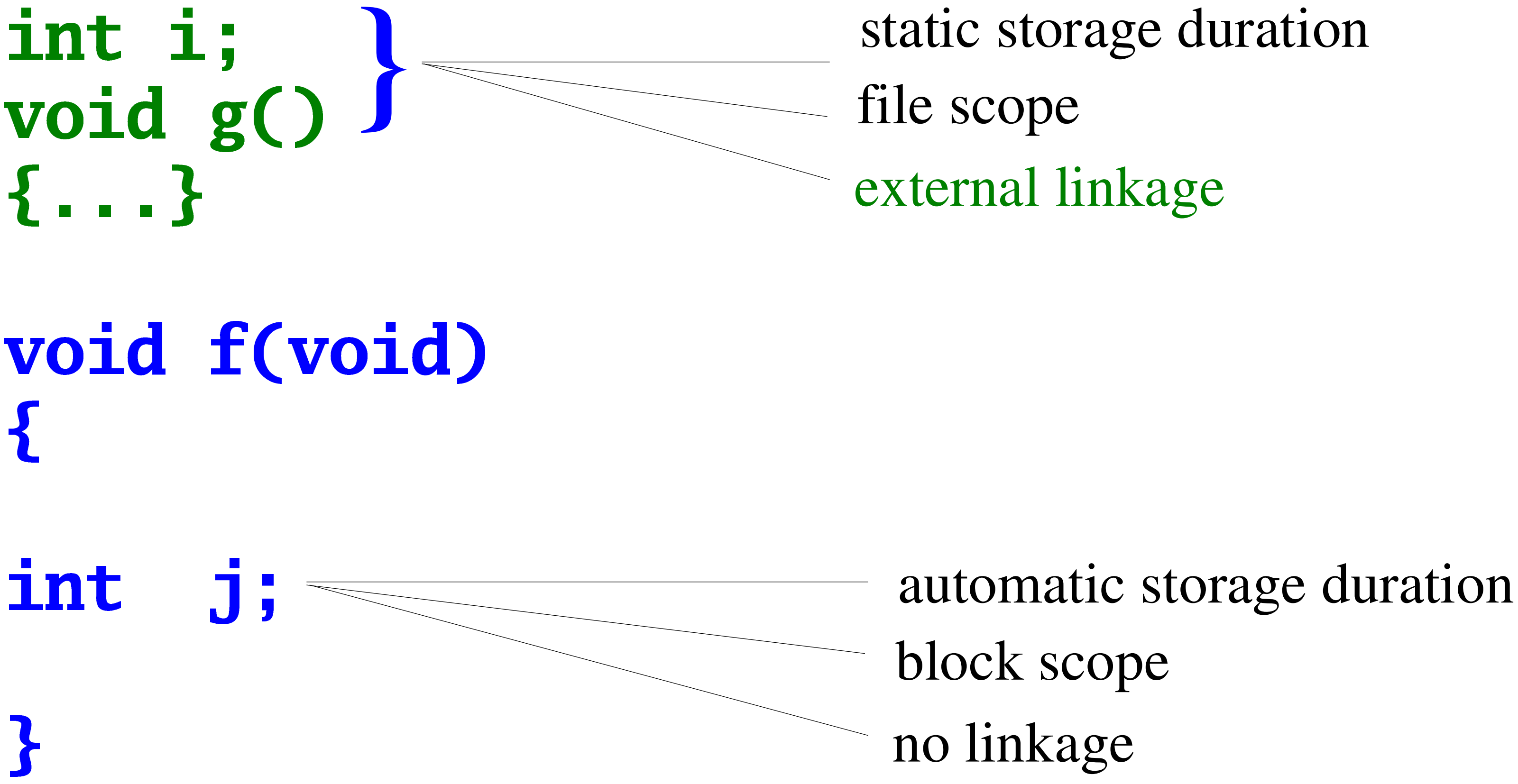
- Every variable in a C program has three properties:

  1. Storage duration
     - automatic
     - static
  2. Scope
     - block scope
     - file scope
  3. **Linkage**

Linkage

- Linkage of a variable determines extent to which it can be shared by different files in a program.
  - Variables with **external linkage** may be shared by several files in a program
  - Variables with **internal linkage** are restricted to a single file, but may be shared by the functions in that file
  - Variables with **no linkage** belong to a single function and can't be shared at all

Storage Duration, Scope & Linkage



```
int i;      }
void g()    }
{...}

void f(void)
{

int   j;

}
```

static storage duration

file scope

external linkage

automatic storage duration

block scope

no linkage

Static keyword

```
static int i;
static void g()
{...}
```

static storage duration

file scope

internal linkage

```
void f(void)
{

static int  j;

}
```

static storage duration

block scope

no linkage

Extern keyword

```
extern int i;

void f(void)
{

extern int  j;

}
```

static storage duration

file scope

external linkage

static storage duration

block scope

external linkage

What Gets Printed?

```
int z;
void g(void);
void f(int x)
{
  x = 2;
  z += x;
}

int main()
{
  z = 5;
  f(z);
  g();
  printf("z=%d\n", z);
  return 0;
}
```

```
extern int z;
void g(void)
{
  z *= 2;
}
```

What Gets Printed Now?

```
static int z;
void g(void);
void f(int x)
{
  x = 2;
  z += x;
}

int main()
{
  z = 5;
  f(z);
  g();
  printf("z=%d\n", z);
  return 0;
}
```

```
extern int z;
void g(void)
{
  z *= 2;
}
```

Stack Module

stack.h

```c
#ifndef STACK_H
#define STACK_H

void make_empty(void);
int is_empty(void);
void push(int i);
int pop(void);

#endif
```

Stack as array

```
#include "stack.h"
#define STACK_SIZE 100

static int contents[STACK_SIZE];
static int top = 0;

void make_empty(void){
  top = 0;
}
int is_empty(void){
  return top == 0;
}
```

```
static int is_full(void){
  return top == STACK_SIZE;
}

void push(int i){
  if (is_full()) {
    fprintf(stderr, "push: stack is full\n");
    exit(EXIT_FAILURE);
  }
  contents[top++] = i;
}

int pop(void) {
  if(is_empty()) {
    fprintf(stderr, "pop: stack is empty\n");
    exit(EXIT_FAILURE);
  }
  return contents[--top];
}
```

Stack as Linked List

```
#include "stack.h"

typedef struct node {
  int data;
  struct node *next;
} NodeT;

static NodeT *top = NULL;
```

```
void make_empty(void)
{
  NodeT *next;
  while(top != NULL){
    next = top->next;
    free(top);
    top = next;
  }
}

int is_empty(void) {
  return top == NULL;
}
```

```
void push(int i) {
  NodeT *newNode;

  newNode = malloc(sizeof(NodeT));
  if (newNode == NULL) {
    fprintf(stderr, "push: stack is full\n");
    exit(EXIT_FAILURE);
  }
  newNode->data = i;
  newNode->next = top;
  top = newNode;
}
```

```
int pop(void) {
  NodeT *oldTop;
  int i;
  if(is_empty()) {
    fprintf(stderr, "pop: stack is empty\n");
    exit(EXIT_FAILURE);
  }
  oldTop = top;
  i = top->data;
  top = top->next;
  free(oldTop);
  return i;
  }
```

Stack Data Type

- Can only have one instance of preceding stack modules
- Need to create a stack *type*:

```
#include "stack.h"
int main()
{
  StackT s1, s2;
  new_stack(&s1);
  new_stack(&s2);
  push(&s1, 1);
  if (!is_empty(&s1))
    printf("%d\n", pop(&s1)); /* prints "1" */
  ...
}
```

Stack Data Type

stack.h

```
typedef struct node {
  int data;
  struct node *next;
} NodeT;
typedef struct {
  NodeT *top;
} StackT

void new_stack(StackT *s);
void make_empty(StackT *s);
int is_empty(const StackT *s);
void push(StackT *s, int i);
int pop(StackT *s);
```

Stack Type as Linked List

```
#include "stack.h"

void new_stack(StackT *s){
  s->top = NULL;
}

void make_empty(StackT *s){
  NodeT *next;
  while(s->top != NULL){
    next = s->top->next;
    free(s->top);
    s->top = next;
  }
}
```

```
void push(StackT *s, int i) {
  NodeT *newNode;

  newNode = malloc(sizeof(NodeT));
  if (newNode == NULL) {
    fprintf(stderr, "push: stack is full\n");
    exit(EXIT_FAILURE);
  }
  newNode->data = i;
  newNode->next = s->top;
  s->top = newNode;
}
```

```
int is_empty(const StackT *s) {
  return s->top == NULL;
}
int pop(StackT *s) {
  NodeT *oldTop;
  int i;

  if(is_empty()) {
    fprintf(stderr, "pop: stack is empty\n");
    exit(EXIT_FAILURE);
  }
  oldTop = s->top;
  i = s->top->data;
  s->top = s->top->next;
  free(oldTop);
  return i;
  }
```

Stack Type

- The previous module allowed for multiple instances, but at the expense of information hiding!
- Nothing prevents a client from using a `StackT` variable as a structure:

```
StackT s1;

s1.top = NULL;
...
```

Opaque Data Type

- Incomplete structure definition:
  - can define the type of a structure that hasn't been defined yet:

    ```
    typedef struct hidden *Visible;
    ```

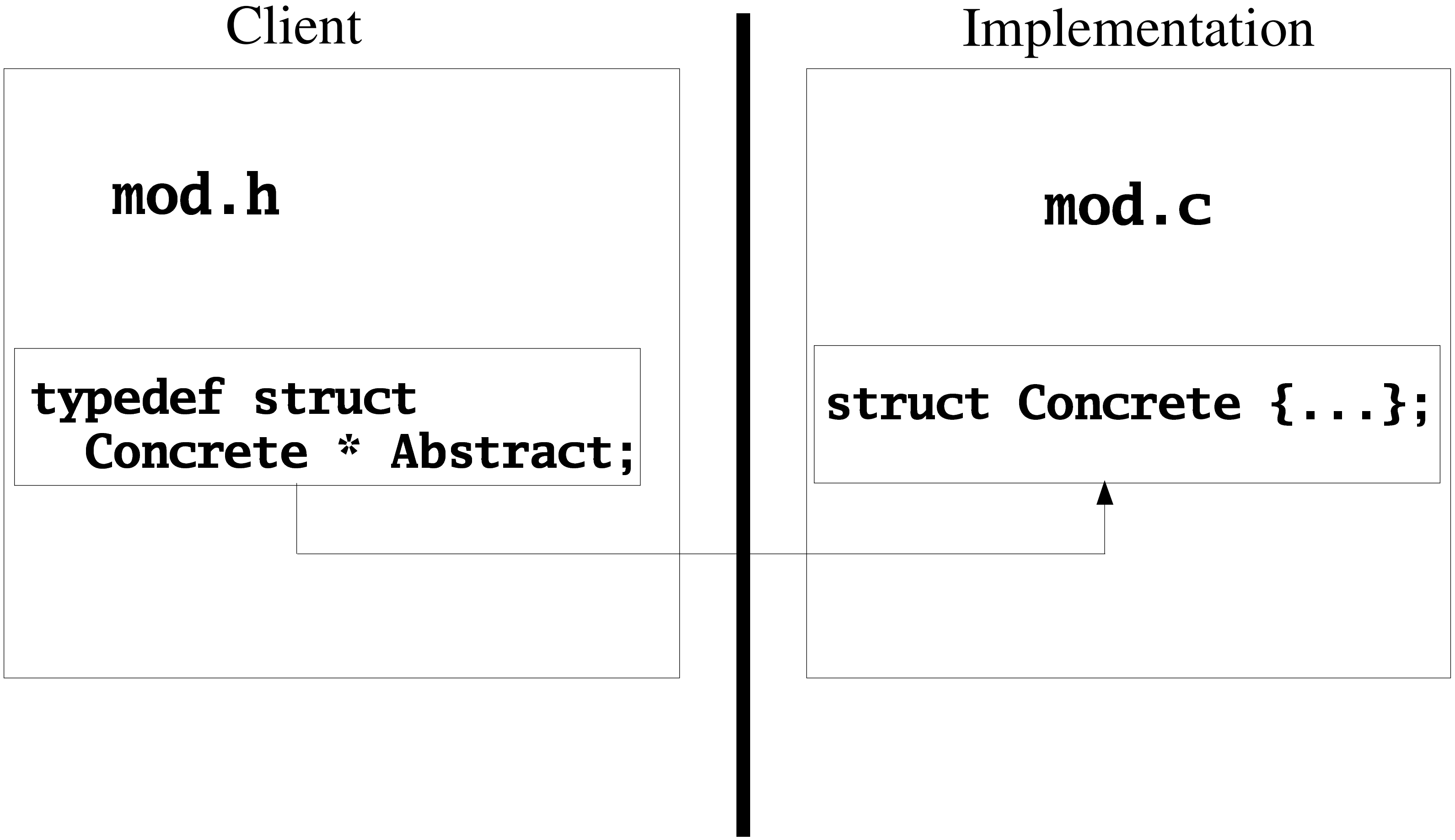
  - allows one to use the type **`Visible`** as a synonym for **`struct hidden *`**.

Opaque Data Type

- A data type is opaque because the client cannot access its full representation
  - all the client knows is that it is represented by another data type
  - client doesn't know that that data type is
- Consider module **Mod** that exports a data type called **Abstract** to the client
  - **mod.h** defines a type **Abstract** as a pointer to a structure type called **Concrete**

```
typedef struct Concrete *Abstract;
```

  - there is no definition of **Concrete** in this file



Client

mod.h

```
typedef struct
  Concrete * Abstract;
```

Implementation

mod.c

```
struct Concrete {...};
```

Opaque Data Type

- The type **`Concrete`** is defined in an implementation file
- The client can use the type provided there are no attempts to dereference values of this type

```
void f(Abstract p);
```

– is legal, but

```
Abstract p;
p->x;
```

– is illegal, because the type **`Abstract`** represents a pointer to the **`Concrete`** type, and the compiler has no information about this type

Stack ADT Module

1) the type `DataType` of the data stored in the stack is *known to the implementation*

2) any number of stacks can be created; all stacks must have elements of the *same* type, `DataType`

3) the representation of the stack and stack elements are not visible to the client.

The first version will operate on a stack of integers.

Stack ADT Header

```
#ifndef STACK_H
#define STACK_H

typedef int DataType;
typedef struct StackCDT *StackADT;

StackADT Stack_new(void);
int      Stack_empty(StackADT s);
void     Stack_push(StackADT s, DataType i);
DataType Stack_pop(StackADT s);
void     Stack_free(StackADT *s);

#endif
```

Application of Stack ADT

```
#include "stack.h"

StackADT s1, s2;

s1 = Stack_new();
s2 = Stack_new();
Stack_push(s1, 1);
if (!Stack_empty(s1))
    printf("%d\n", Stack_pop(s1));
  ...
```

Stack ADT Implementation

```
#include "stack.h"

typedef struct node {
  DataType d;
  struct node *next;
} NodeT;

typedef struct StackCDT {
  int count;
  NodeT *top;
} StackCDT;
```

Stack ADT Implementation

```
StackADT Stack_new(void) {
  StackADT s;

  if((s = malloc(sizeof(StackCDT))) == NULL)
    exit(EXIT_FAILURE);
  s->count = 0;
  s->top = NULL;
  return s;
}

int Stack_empty(StackADT s) {
  return s->count == 0;
}
```

Stack ADT Implementation

```
void Stack_push(StackADT s, DataType d) {
  NodeT *newNode;

  if ((newNode = malloc(sizeof(NodeT))) ==
      NULL) {
    fprintf(stderr, "push: stack is full\n");
    exit(EXIT_FAILURE);
  }
  newNode->d = d;
  newNode->next = s->top;
  s->top = newNode;
  s->count++;
}
```

Stack ADT Implementation

```
DataType Stack_pop(StackADT s) {
  DataType d;
  NodeT *oldNode;

  oldNode = s->top;
  s->top = oldNode->next;
  s->count--;
  d = oldNode->d;
  free(oldNode);

  return d;
}
```

Stack ADT Implementation

```
void Stack_free(StackADT *s) {
  NodeT *p, *q;

  for (p = (*s)->top; p; p = q) {
    q = p->next;
    free(p);
  }

  free(*s);
  *s = NULL
}
```

Shallow and Deep Copy

- To push a new element **`d`** onto the stack:

  ```
  newNode->d = d;
  ```

- If **`newNode->d`** and **`d`** are pointers, this results in a *shallow* copy.
  - If client deallocates variable pointed to by **`d`** then **`newNode->d`** becomes a dangling reference

Shallow and Deep Copy

For a deep copy, use a callback function `copyData_Stack()`.

For example, for strings and doubles:

```
DataType copyData_Stack(const DataType v) {
    return strdup(v);
}
DataType copyData_Stack(const DataType v) {
    return v;
}
```

```
char *strdup(const char *s) {
/* return a copy of s */
   char *kopy;    /* copy of s */

   if((kopy = calloc(strlen(s) + 1,
              sizeof(char))) == NULL)
      return NULL;
   strcpy(kopy, s);

   return kopy;
}
```

Shallow and Deep Copy

We need another *callback* function, `freeData_Stack()`

For example, for string and doubles:

```
void freeData_Stack(DataType v) {
    free(v);
}
```

```
void freeData_Stack(DataType v) {
}
```

Stack ADT Header with Deep Copy

```
typedef char* DataType;
typedef struct StackCDT *StackADT;

DataType copyData_Stack(const Datatype v);
void freeData_Stack(DataType v);
StackADT Stack_new(void);
int      Stack_empty(StackADT s);
void     Stack_push(StackADT s, DataType i);
DataType Stack_pop(StackADT s);
void     Stack_free(StackADT s);
```

Stack ADT Header with Deep Copy

- Implementation of callback functions must be provided by the client

```
DataType copyData_Stack(const Datatype v);
void freeData_Stack(DataType v);
```

- They are declared in the header file so that the implementation code can call them

Stack ADT Implementation with Deep Copy

```
void Stack_push(StackADT s, DataType d) {
  NodeT *newNode;

  if ((newNode = malloc(sizeof(NodeT))) ==
      NULL) {
    fprintf(stderr, "push: stack is full\n");
    exit(EXIT_FAILURE);
  }
  newNode->d = copyData_Stack(d);
  newNode->next = s->top;
  s->top = newNode;
  s->count++;
}
```

Stack ADT Implementation with Deep Copy

```
DataType Stack_pop(StackADT s) {
  DataType d;
  NodeT *oldNode;

  oldNode = s->top;
  s->top = oldNode->next;
  s->count--;
  d = copyData_Stack(oldNode->d);
  freeData_Stack(oldNode->d);
  free(oldNode);

  return d;
}
```

Stack ADT Implementation with Deep Copy

```
void Stack_free(StackADT *s) {
  NodeT *p, q;

  for (p = (*s)->top; p; p = q) {
    q = p->next;
    freeData_Stack(p->d);
    free(p);
  }

  free(*s);
  *s = NULL
}
```