Lecture P5: Abstract Data Types
Review

Data type:
- Set of values and collection of operations on those values.

Example: int
- Set of values: between -32,767 and 32,767 (minimum limits).
- Operations: +, -, *, /, %, printf("%d"), sqrt
- How is an int represented?
Overview

Separate implementation from specification.
- INTERFACE: specify the allowed operations.
- IMPLEMENTATION: provide code for operations.
- CLIENT: code that uses operations.

Abstract data type (ADT):
- Data type whose representation is HIDDEN.
- Don’t want client to directly manipulate data type.
- Operations ONLY permitted through interface.

Principle of least privilege.
"Non ADT’s"

Is `Complex` data type an ABSTRACT data type?

```c
#include "COMPLEX.h"

int main(void) {
    Complex a = COMPLEXinit(1.0, 2.0);
    a.re = 5.0;
    COMPLEXshow(a);
    return 0;
}
```

Violates "principle of least privilege."
ADT’s for Stacks and Queues

Fundamental data type.
  - Set of operations (insert, delete) on generic data.

Stack ("last in first out" or LIFO).
  - push: add info to the data structure
  - pop: remove the info MOST recently added
  - initialize, test if empty

Queue ("first in first out" or FIFO).
  - put: add info to the data structure
  - get: remove the info LEAST recently added
  - initialize, test if empty

Could use EITHER array or "linked list"
to implement EITHER stack or queue.
Stack Interface

Stack operations.

- **STACKinit()**: initialize empty stack
- **STACKisempty()**: return 1 if stack is empty; 0 otherwise
- **STACKpush(int)**: insert new item
- **STACKpop()**: delete and return item most recently added

```
void STACKinit(void);
int  STACKisempty(void);
void STACKpush(int);
int  STACKpop(void);
```

STACK.h
Stack Implementation with Arrays

Push and pop at the end of array.

Demo:

Drawback:

```c
#include "STACK.h"
#define MAX_SIZE 1000
static int s[MAX_SIZE];
static int N;

void STACKinit(void) {
    N = 0;
}

int STACKisempty(void) {
    return N == 0;
}

void STACKpush(int item) {
    s[N++] = item;
}

int STACKpop(void) {
    return s[--N];
}
```

big enough?
Stack Client: Balanced Parentheses

```
#include <stdio.h>
#include "STACK.h"

int main(void) {
    int c, balanced = 1;
    STACKinit();

    . . . /* MAIN CODE HERE */

    if (balanced)
        printf("Balanced.\n");
    else
        printf("NOT Balanced.\n");

    return 0;
}
```

Good: ( ( ( ) ( ) ) )
Bad: ( ( ) ) ) ( ( ) )
Stack Client: Balanced Parentheses

```c
while (balanced && (c = getchar()) != EOF) {
    if (c == '(')
        STACKpush(c);
    else if (c == ')') {
        if (STACKisempty())
            balanced = 0;
        else
            STACKpop();
    }
}
if (!STACKisempty())
    balanced = 0;
```

Good:  ( ( ( ) ( ) ) )
Bad:   ( ( ) ) ) ( ( )

par.c (cont)

- Read character from stdin
- Push left parentheses
- Check for matching left parenthesis
- Stop loop if unbalanced
- Balanced if empty stack when no more input
Stack Client: Balanced Parentheses

Check if your C program has unbalanced parentheses.

Exercise: extend to handle square and curly braces.

- Good: { ( [ ( [ ] ) ( ) ] ) }
- Bad: ( ( [ ] ] )

Unix

% gcc par.c stackarray.c
% a.out < myprog.c
balanced

% a.out < someprogram.c
unbalanced

How could valid C program have unbalanced parentheses?
Practical example of use of stack abstraction.

Put operator after operands in expression.

- Use stack to evaluate.
  - operand: push it onto stack.
  - operator: pop operands, push result.
- Systematic way to save intermediate results.

Example 1.

1 2 3 4 5 * + 6 * * 7 8 9 + + * +
Practical example of use of stack abstraction.

Put operator after operands in expression.
  - Use stack to evaluate.
    - operand: push it onto stack.
    - operator: pop operands, push result.
  - Systematic way to save intermediate results.

Example 2a: convert 27531 from octal to decimal.
  - 2 8 8 8 8 * * * * 7 8 8 8 * * * 5 8 8 * * 3 8 * 1 + + + +

Example 2b: convert 27531 from octal to decimal.
  - 2 8 * 7 + 8 * 5 + 8 * 3 + 8 * 1 +
  - Stack never has more than two numbers on it!
  - Horner’s method (see lecture A3).
Stack Client: Postfix Evaluation

```c
#include <stdio.h>
#include <ctype.h>
#include "STACK.h"

int main(void) {
    int c;
    STACKinit();
    while ((c = getchar()) != EOF) {
        if ('+' == c)
            STACKpush(STACKpop() + STACKpop());
        else if ('*' == c)
            STACKpush(STACKpop() * STACKpop());
        else if (isdigit(c))
            STACKpush(c - '0');
    }
    printf("top of stack = %d\n", STACKpop());
    return 0;
}
```

- pop 2 elements and push sum
- convert char to integer and push
Stack Client: Postfix Evaluation

Program has some flaws.

% gcc postfix.c stackarray.c
% a.out
2 4 +
top of stack = 6

% a.out
1 2 3 4 5 * + 6 * * 7 8 9 ++ *
top of stack = 6624

% a.out
5 9 8 + 4 6 * * 7 + *
top of stack = 2075

% a.out
2 8 * 7 + 8 * 5 + 8 * 3 + 8 * 1 +
top of stack = 12121
Stack Client: Infix to Postfix

Infix to postfix algorithm:

- Left paren: ignore.
- Right paren: pop and print.
- Operator: push.
- Digit: print.

Unix

% gcc infix2postfix.c ...
% a.out
(2 + ((3 + 4) * (5 * 6)))
2 3 4 + 5 6 * * +

```c
#include <stdio.h>
#include <ctype.h>
#include "STACK.h"

int main(void) {
    int c;
    STACKinit();
    while ((c = getchar()) != EOF) {
        if (c == ')
            printf("%c ", STACKpop());
        else if (c == '+' || c == '*')
            STACKpush(c);
        else if (isdigit(c))
            printf("%c ", c);
    }
    printf("\n");
    return 0;
}
```
ADT Review

Client can access data type ONLY through interface.
- Example: STACK.

Representation is HIDDEN in the implementation.
- Provides security.

Convenient way to organize large problems.
- Decompose into smaller problems.
- Substitute alternate solutions (time / space tradeoffs).
- Separation compilation.
- Build libraries.
- Different clients can share the same ADT.

Powerful mechanism for building layers of abstraction.
- Client works at a higher level of abstraction.
First Class ADT

So far, only 1 stack per program.

First Class ADT:

- ADT that is just like a built-in C type.
- Can declare multiple instances of them.
- Pass specific instances of them to interface as inputs.
- Details omitted in COS 126. (See Sedgewick 4.8 or COS 226.)
```c
#include <stdio.h>
#include <ctype.h>
#include "STACK.h"

int main(void) {
    Stack s1 = STACKinit();
    Stack s2 = STACKinit();
    int c, op;
    while ((c = getchar()) != EOF) {
        if (c == ')') {
            op = STACKpop(s1);
            if (op == '+')
                STACKpush(s2, STACKpop(s2) + STACKpop(s2));
            else if (op == '*')
                STACKpush(s2, STACKpop(s2) * STACKpop(s2));
        } else if (c == '+' || c == '*')
            STACKpush(s1, c);
        else if (isdigit(c))
            STACKpush(s2, c - '0');
    }
    printf("Result = %d\n", STACKpop(s2));
    return 0;
}
```
PostScript: Abstract Stack Machine

Language of most printers nowadays.
  - Postfix language.
  - Abstract stack machine.

Ex: convert 27531 from octal to decimal.
  - 2 8 mul 7 add 8 mul 5 add 8 mul 3 add 8 mul 1 add

Stack uses:
  - Operands for operators.
  - Arguments for functions.
  - Return value(s) for functions.
PostScript: Abstract Stack Machine

Some commands:

- Coordinate system: rotate, translate, scale, ...
- Turtle commands: moveto, lineto, rmoveto, rlineto, ...
- Graphics commands: stroke, fill, ...
- Arithmetic: add, sub, mul, div, ...
- Stack commands: copy, exch, dup, currentpoint, ...
- Control constructs: if, ifelse, while, for, ...
- Define functions: /XX { ... } def

Everyone’s first PostScript program (draw a box).

%! 50 50 translate
0 0 moveto 0 512 rlineto 512 0 rlineto
0 -512 rlineto -512 0 rlineto
stroke
showpage
Overview

Data type.
  ● Set of values and collection of operations on those values.

ABSTRACT data type (ADT).
  ● Data type whose representation is completely HIDDEN from client.

Stacks and queues.
  ● Fundamental ADT’s.
    – calculators
    – printers and PostScript language
    – compiler uses to implement functions (see next lecture)
Lecture P5: Supplemental Notes
"Non ADT’s"

Is complex data type an ABSTRACT data type?
- NO: Representation in interface.

Are C built-in types like int ADT’s?
- ALMOST: we generally ignore representation.
- NO: set of values depends on representation.
  - might use \((x \ & \ 0)\) to test if even
  - works only if they’re stored as "two’s complement integers"
- CONSEQUENCE: strive to write programs that function properly independent of representation.
  - \((x \ % \ 2 == 0)\) is more portable way to test if even
  - also, use `<limits.h>` for machine-specific ranges of int, long
Queue Interface

Queue operations.

- QUEUEinit(): initialize empty queue.
- QUEUEisempty(): return 1 if queue is empty; 0 otherwise
- QUEUEput(int): insert new item at end of list.
- QUEUEget(): return and remove item at beginning of list.

QUEUE.h

```c
void QUEUEinit(void);
int  QUEUEisempty(void);
void QUEUEput(int);
int  QUEUEget(void);
```
Queue Implementation

```c
#include "QUEUE.h"
#define MAX_SIZE 1000

static int q[MAX_SIZE];
static front, back;

void QUEUEinit(void) {
    front = N;
    back = 0;
}

int QUEUEisempty(void) {
    return front % N == back;
}

void QUEUEput(int item) {
    q[back++] = item;
    back = back % N;
}

int QUEUEget(void) {
    front = front % N;
    return q[front++];
}
```

<table>
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</thead>
<tbody>
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<td>M</td>
<td>D</td>
<td>T</td>
<td>E</td>
<td>X</td>
<td>A</td>
</tr>
</tbody>
</table>

MAX_SIZE = 6
Queue Client: Josephus Problem

Flavius Josephus. (first century)

- Band of 41 Jewish rebels trapped in cave by Romans.
- Preferring suicide to capture, rebels formed a circled and killed every 3rd remaining person until no one was left.
- Where should you stand to be among last two survivors?

![Josephus Problem Diagram]
Queue Client: Josephus Problem

\[ N = 8, \ M = 3 \]

```
#include <stdio.h>
#include "QUEUE.h"
#define N 41
#define M 3

int main(void) {
  int i;
  QUEUEinit();
  for (i = 1; i <= N; i++)
    QUEUEput(i);
  while (!QUEUEisempty()) {
    for (i = 0; i < M - 1; i++)
      QUEUEput(QUEUEget());
    printf("%d\n", QUEUEget());
  }
  return 0;
}
```