Lecture P5: Abstract Data Types



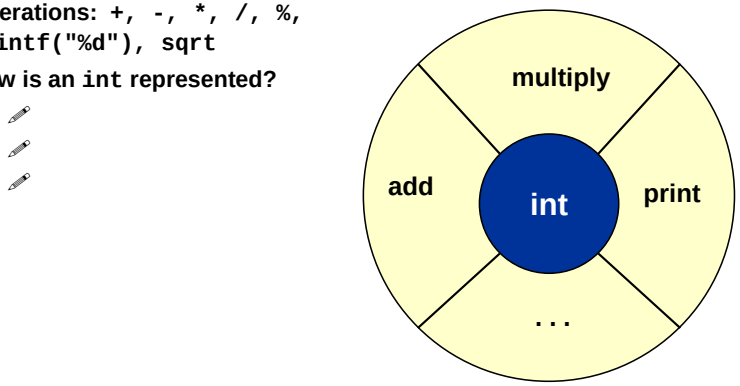

Review

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 `Rational` data type an ABSTRACT data type?

RAT.h

```
typedef struct {
  int num;
  int den;
} Rational;

Rational RATadd(Rationa
Rational RATmul(Rational a, Rational b);
Rational RATshow(Rational a);
Rational RATinit(int x, int y);
```

legal C, but very bad software design

client.c

```
#include "RAT.h"

int main(void) {
   Rational a;
   a.num = 5;
   a.den = 8;
   RATshow(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

STACK.h

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


Stack Implementation with Arrays

Push and pop at the end of array.

Demo: 

stackarray.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];
}
```

```
s[N] = item;
N++;
```

```
N--;
return s[N];
```


Stack Client: Balanced Parentheses

par.c

```
#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

par.c (cont)

stop loop if unbalanced

Read character from stdin

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

push left parentheses

check for matching left parenthesis

balanced if empty stack when no more input

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

Stack Client: Balanced Parentheses

Check if your C program has unbalanced parentheses.

Unix

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

% a.out < someprogram.c
unbalanced
```

How could valid C program have unbalanced parentheses?

Exercise: extend to handle square and curly braces.

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

Stack Client: Postfix Evaluation

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 + + * +

Stack Client: Postfix Evaluation

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 P2).

Stack Client: Postfix Evaluation

postfix.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.

Unix

```
% 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

Unix

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

infix2postfix.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;
}
```

Infix to postfix algorithm:

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

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.

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
```


Summary

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

First Class ADT

So far, only 1 stack per program.

```
STACKinit();
. . .
STACKpush(a);
. . .
b = STACKpop();
```

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.)

```
Stack s1, s2;

s1 = STACKinit();
s2 = STACKinit();
. . .
STACKpush(s1, a);
STACKpush(s2, b);
. . .
c = STACKpop(s2);
```


First Class ADT Client: Infix

infix.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;
}
```

s1
s2

Unix

```
% gcc infix.c ...
% a.out
 (2 + ((3 + 4) * (5 * 6)))
 212
```


"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

```
void QUEUEinit(void);
int  QUEUEisempty(void);
void QUEUEput(int item);
int  QUEUEget(void);
```

Queue Implementation

queuearray.c

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

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

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

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

queuearray.c

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

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

front

Variable	q[0]	q[1]	q[2]	q[3]	q[4]	q[5]
Value	M	D	T	E	X	A

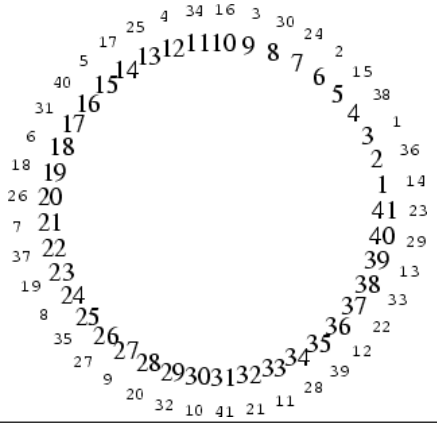
back

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?



Queue Client: Josephus Problem

N = 8, M = 3

1	2	3	4	5	6	7	8
2	3	4	5	6	7	8	1
3	4	5	6	7	8	1	2
4	5	6	7	8	1	2	
5	6	7	8	1	2	4	
6	7	8	1	2	4	5	
7	8	1	2	4	5		

. . .

josephus.c

```
#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;
}
```