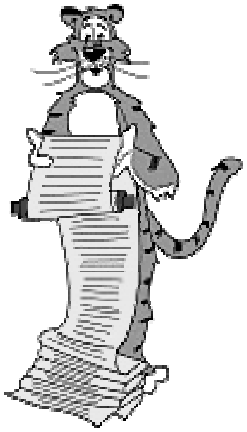
# Lecture P5: Abstract Data Types



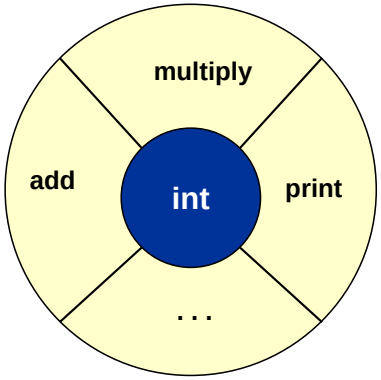

## Overview

**Data type:**

- Set of values and collection of operations on those values.

**Example: `int`**

- Set of values: between -32,768 and 32,767 (typically).
- Operations: `+, -, *, /, %, printf("%d"), sqrt`
- How is an `int` represented?
  - 16 bits
  - negative integers






## 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?**

**client.c**

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

int main(void) {
  Complex a = COMPLEXinit(1.0, 2.0);

  a.re = 5.0;
  COMPLEXshow(a);
  return 0;
}
```

legal C, but very bad software design

**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 and Client

**STACK.h**

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

STACK of integers

client uses data type, without regard to how it is represented or implemented.

**client.c**

```
#include "STACK.h"

int main(void) {
  int a, b;
  . . .
  STACKinit();
  STACKpush(a);
  . . .
  b = STACKpop();
  return 0;
}
```



# Stack Implementation with Arrays

**Push and pop at the end of array.**

**Demo:**

**Drawback:**

**stackarray.c**

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

void STACKinit(void) {
  N = 0;
}

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

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

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

big enough?



# Balanced Parentheses

**parentheses.c**

```
int balanced(char a[], int n) {
  int i;
  STACKinit();
  for (i = 0; i < n; i++) {
    if ( '(' == a[i] )
      STACKpush(a[i]);
    else {
      if (STACKisempty())
        return 0;
      STACKpop();
    }
  }
  return STACKisempty();
}
```

push all left parentheses

read in right parentheses

check for matching left parenthesis

balanced if empty stack when no more input

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

# Balanced Parentheses

**parentheses.c (cont)**

```
#include <stdio.h>
#include "STACK.h"
#define NMAX 1000

int main(void) {
  int c, n = 0;
  char a[NMAX];

  while ((c = getchar()) != EOF)
    if (c == '(' || c == ')' )
      a[n++] = c;

  if (balanced(a, n))
     printf("balanced\n");
  else
     printf("unbalanced\n");
  return 0;
}
```

Read from stdin, ignoring non-parentheses.

check if balanced



# Balanced Parentheses

Check if your C program has unbalanced parentheses.

**Unix**

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

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

How could valid C program have unbalanced parentheses?

Exercise: extend to handle square and curly braces.

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



# Reverse Polish (Postfix) Notation

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).



# Postfix Evaluation in C

**posfix.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

# Postfix in C

**Program has some flaws.**

- What happens with input `2 + 5`
- What happens with input `16 12 +`

**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
```



# ADT Review

**Client can access data type ONLY through implementation.**

- Example: STACK implementation.

**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 client 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 if interested.

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

```
Stack s1, s2;

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



# PostScript

**Language of most printers nowadays.**

- Postfix language.
- Abstract stack machine.

**Ex: convert 97531 from octal to decimal**

- 9 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

**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).**

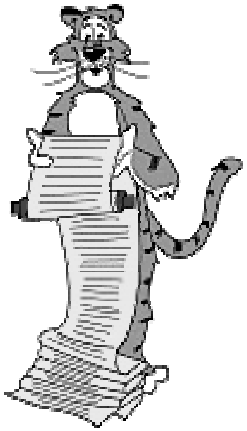
- Data type whose representation is completely HIDDEN from client.
  - client can't directly manipulate data type
  - operations only permitted through interface
- Powerful software engineering model.
  - different clients can use the same ADT
  - can change ADT without changing clients
  - client works at a higher level of abstraction

**Stacks and queues.**

- Fundamental abstract data type.
  - calculators
  - printers - PostScript language
  - functions (see next lecture)



# Lecture P5: Supplemental Notes



# Queue Interface and Implementation

**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 first item at beginning of list.

**QUEUE.h**

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

# Queue Interface and Implementation

**queuearray.c**

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

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

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

max size

**queuearray.c**

```
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++];
}
```