# CS 126 Lecture P5: Abstract Data Type

# Outline

- **<u>Introduction</u>**
- Stacks (and queues)
- Stack and queue applications

# Data Type and ADT

Data type

- set of values
- collection of operations on those values

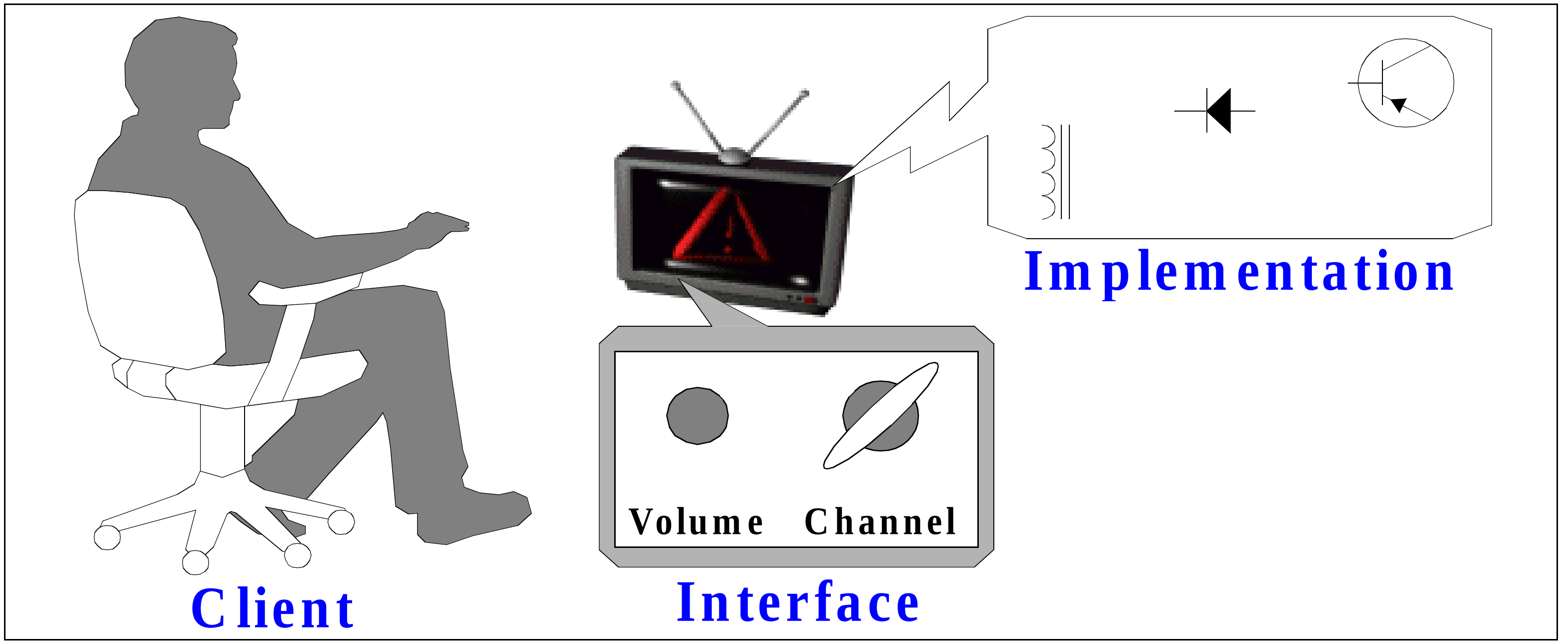
ex: short int

- set of values between -32768 and 32767
- arithmetic operations + - * /

Abstract data type (ADT)

- data type whose representation is hidden

# Interface, Implementation, and Client




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

# Advantages of ADT

Representation is hidden in the implementation
Client program does not need to know
    *how* the implementation works

- Advantages
    * different clients can use the same ADT
    * can change ADT without changing clients

- Convenient way to organize large programs
    - decompose into smaller problems
    - substitute alternate solutions
    - separate compilation
    - build librarys

Powerful mechanism
    for building layers of abstraction

Client can work at higher level of abstraction

# “Non-ADTs”

**interface:** `typedef struct {int p; int q;} Rational;`
**client:** `Rational a; a.p = 3;` **Non-ADT**

**ADT**

**interface:**
```
typedef struct {int p; int q;} Rational;
void setRationalP(Rational *r; int x);
```
---
**implementation:**
```
void setRationalP(Rational *r; int x)
    {r->p = x;}
```
---
**client:** `Rational a; setRational(&r, 3);`

- Rational data type (Assignment 3) is NOT an ADT
  - representation is in interface

Are C built-in types ADTs ?

- ALMOST: we generally ignore representation
- NO: set of values depends on representation
- YES: good programs use <limits.h> to function properly independent of representation

# Outline

- ~~Introduction~~
- **Stacks (and queues)**
- Stack and queue applications

# Stack and Queue Definitions

- Prototypical data types
  - set of operations on generic data

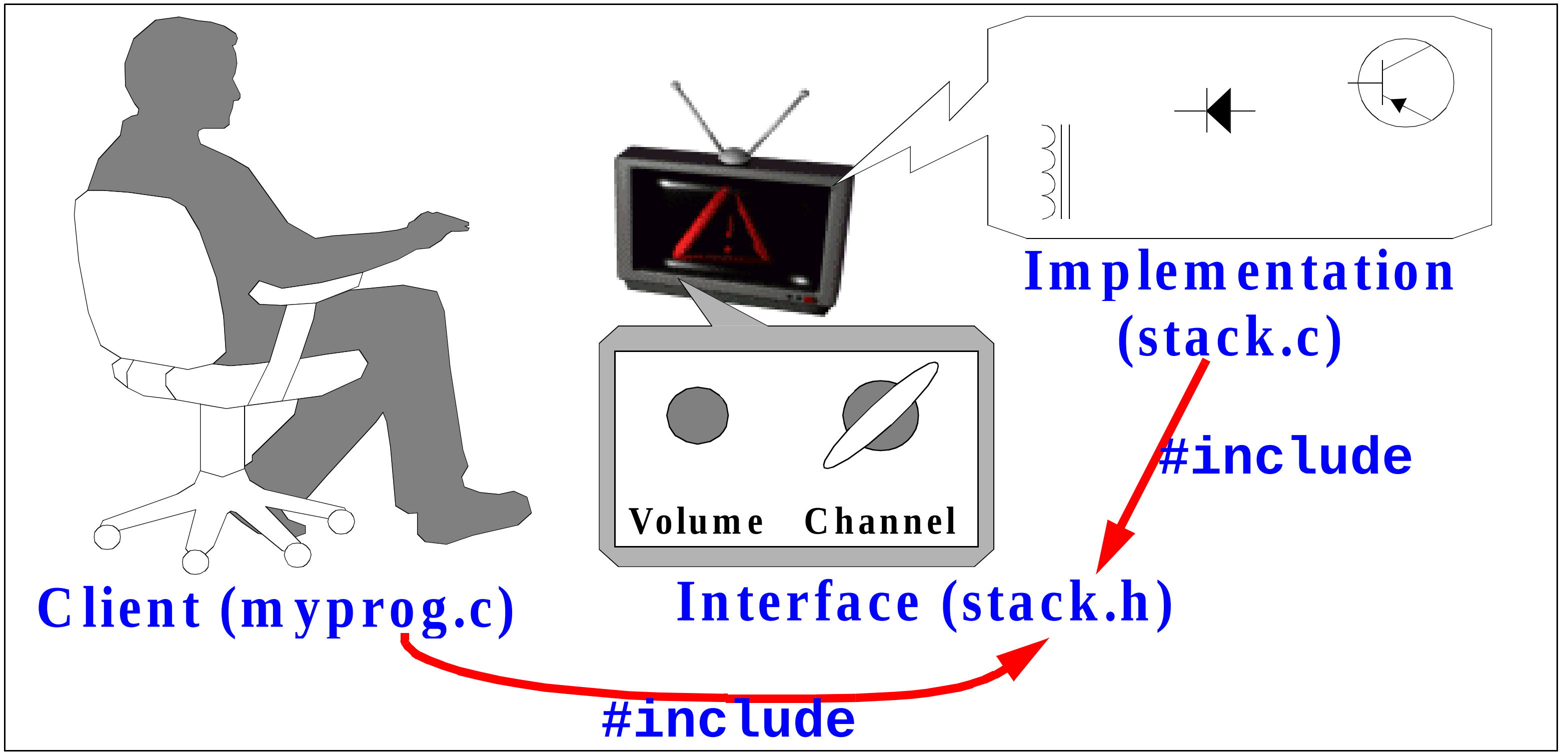
STACK (``last in, first out`` or LIFO)
- push: add info to the data structure
- pop: remove the info most recently added
- (initialize, test if empty)

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

Client can work at higher level of abstraction
(stay tuned)

# Interface, Implementation, and Client




- "Client" needs to know how to use the "interface"
- "Implementation" needs to know what "interface" to implement

**Interface (STACK.h)**

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

**Client (myprog.c)**

```
#include "STACK.h"
main()
  { int a, b;
      ...
      STACKinit();
      ...
      STACKpush(a);
      ...
      b = STACKpop();
      ...
  }
```

**Client uses data type, without regard to how it is represented or implemented**

- Push and pop at the end of the array

```
#include <stdlib.h>
#include "STACK.h"
int s[1000];
int N;

void STACKinit()
   { N = 0; }
int STACKempty()
   { return N == 0; }
void STACKpush(int item)
   { s[N++] = item; }
int STACKpop()
   { return s[--N]; }
```

**Post-increment:**

```
s[N] = item;
N+=1;
```

**Pre-decrement:**

```
N-=1;
return s[N];
```

- Client and implementation both include STACK.h
  (could be compiled separately)
  can be compiled with one command

```
cc myprog.c stackArray.c
a.out
```

Problem: have to reserve space for max size
(see Program 4.4 in text for solution)

# Array stack example

Index of 1st empty slot

Time

| | N | t | s[0] | s[1] | s[2] | s[3] |
|---|---|---|---|---|---|---|
| | 0 | | | | | |
| push(3) | 1 | | 3 | | | |
| push(1) | 2 | | 3 | 1 | | |
| t = pop() | 1 | 1 | 3 | | | |
| push(4) | 2 | | 3 | 4 | | |
| push(t) | 3 | | 3 | 4 | 1 | |
| push(5) | 4 | | 3 | 4 | 1 | 5 |
| t = pop() | 3 | 5 | 3 | 4 | 1 | |
| t = pop() | 2 | 1 | 3 | 4 | | |
| t = pop() | 1 | 4 | 3 | | | |

# Linked-list implementation of stack

- Push and pop nodes at the front of the list

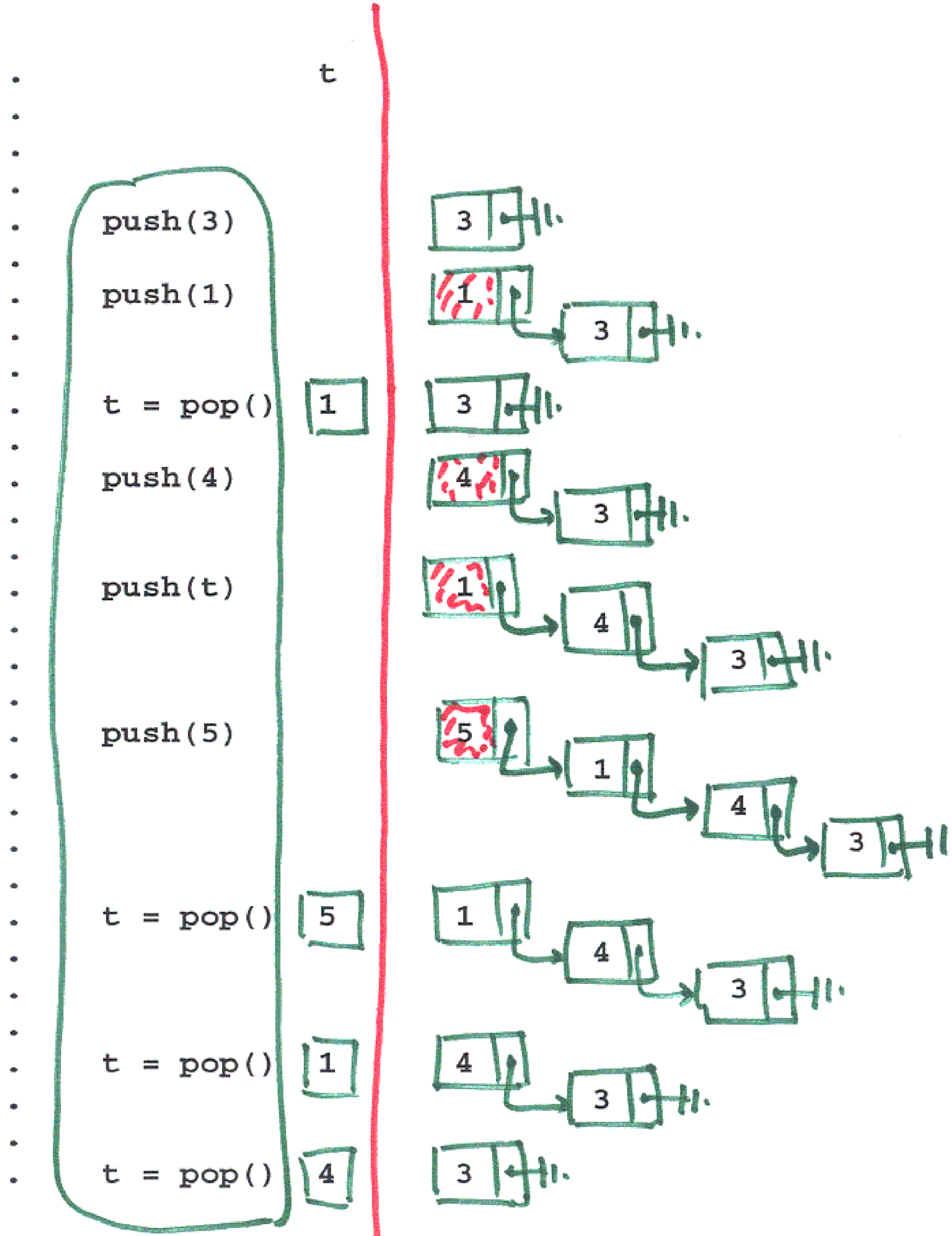
```
#include <stdlib.h>
#include <STACK.h>
typedef struct STACKnode* link;
struct STACKnode { int item; link next; };
static link head;
link NEW(int item, link next)
   { link x = malloc(sizeof *x);
     x->item = item; x->next = next;
     return x;
   }
void STACKinit()
   { head = NULL; }
int STACKempty()
   { return head == NULL; }
STACKpush(int item)
   { head = NEW(item, head); }
int STACKpop()
   { int item = head->item;
     link t = head->next;
     free(head); head = t;
     return item;
   }
```

**Opposite of `malloc`: gives memory back to computer**

- Switch implementations without changing interface or client

```
cc myprog.c stackList.c
a.out
```

# Demo Linked List Stack


t
push(3)
push(1)
t = pop()
1
push(4)
push(t)
push(5)
t = pop()
5
t = pop()
1
t = pop()
4

# Outline

- ~~Introduction~~
- ~~Stacks (and queues)~~
- **Stack and queue applications**

Reverse polish (postfix) notation

## Practical example of use of stack abstraction

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

infix: a + b
postfix: a b +
infix: 9*16^4 + 7*16^3+5*16^2 + 3*16^1

Ex: convert 97531 from hex to decimal

```
9 16 16 16 16 * * * * 7 16 16 16 * * *
     5 16 16 * * 3 16 * 1 + + + +
9
9 16
9 16 16
9 16 16 16
9 16 16 16 16
9 16 16 256
9 16 4096
9 65536
589824
589824 7
...
589824 28672 1280 48 1
589824 28672 1280 49
589824 28672 1329
589824 30001
619825
```

22+
4

Ex: alternate implementation

```
9 16 * 7 + 16 * 5 + 16 * 3 + 16 * 1 +
```

- Stack never has more than two numbers on it!
  HORNER's METHOD (see lecture A1)

## Classic pushdown stack client [Sedgewick, Program 4.2]

```
#include <stdio.h>
#include <string.h>
#include "Item.h"
#include "STACK.h"
main(int argc, char *argv[])
  { char *a = argv[1]; int i, N = strlen(a);
    STACKinit(N);
    for (i = 0; i < N; i++)
      {
        if (a[i] == '+')
          STACKpush(STACKpop()+STACKpop());
        if (a[i] == '*')
          STACKpush(STACKpop()*STACKpop());
        if ((a[i] >= '0') && (a[i] <= '9'))
          STACKpush(0);
        while ((a[i] >= '0') && (a[i] <= '9'))
          STACKpush(10*STACKpop()+(a[i++]-'0'));
      }
    printf("%d  ", STACKpop());
  }
```

- argc: number of inputs to main
- *argv[]: array of input strings
- strlen(a): number of characters in string
- for (i = 0; i < N; i++): for each character in the string
- STACKpush(STACKpop()+STACKpop()): pop two items, add them up, and push result back
- digit handling: deal with digits: pop the previous digits, multiply the number by 10, add the new digit, and push the partial answer back.

```
% a.out "2 2 +"
4
% a.out "12 24 +"
36
% a.out "5 9 8 + 4 6 * * 7 + * "
2075
```

# Demo Postfix Calculator

postfix language, abstract stack machine

Ex: convert 9753 from hex to decimal

```
9 16 mul 7 add 16 mul 5 add
      16 mul 3 add 16 mul 1 add
```

(Horner's method)

Stack:

- operands for operators
- arguments for functions
- return values for functions

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 program: draw a box

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

# "First Class" ADTs

```
{
    ...
    stackInit();
    ...
    stackPush(5);
}
```

```
{
    Stack s1, s2;
    s1 = stackInit();  s2 = stackInit();
    ...
    stackPush(s1, 5);  stackPush(s2, 8);
}
```

- So far, only one stack (or queue) per program
- "First Class" ADTs
  - An ADT that is just like a built-in C type
  - Can declare multiple instances of them
  - Pass specific instances of them to the interface functions as inputs

# "WAR" using abstract data types

- Need "first class" queue ADT
  - declare variables of type queue
  - use them as arguments to functions
  - hide representation from clients
- Interface, implementation?
  ["object-oriented programming"; stay tuned]

"peace" client code, FYI
("QUEUE -> "Q" in identifiers, for brevity)

```
int play(Q deck)
  { int Aval, Bval, i, cnt = 0; Q T = Qinit();
    deal(deck);
    while  ((!(Qempty(A)) && (!Qempty(B))))
      { cnt++;
        Aval = Qget(A); Bval = Qget(B);
        if (randI(2))
              { Qput(T, Aval); Qput(T, Bval); }
        else { Qput(T, Bval); Qput(T, Aval); }
        if (Aval % 13 > Bval % 13)
          while (!Qempty(T)) Qput(A, Qget(T));
        else
          while (!Qempty(T)) Qput(A, Qget(T));
      }
    return cnt;
  }
```

B

**Take one element from the T queue at a time, add it to the A queue, and repeat until the T queue is empty.**

**(Not most efficient.)**

Advantage: avoid details of linked lists
Disadvantage: add details of interface

# Conclusion

- ADT is one of the most important concepts for managing software engineering complexity
- Learn to identify the possible use of ADTs in a program
- Learn the proper decomposition and encapsulation using interface and implementation files