Stacks and Queues

- Stacks and queues ubiquitous data-structure in computing.
- Part of many important algorithms .
- Good example of abstract data types.
- Good example to practice programming with arrays
- Good example to practice programming with linked lists

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Stack - Abstract Data Type

- a *stack* is a collection of items such that the *last* item to enter is the *first* one to exit
- “last in, first out” (LIFO)
- based on the idea of a stack of books, or plates
- essential Stack operations:
  - `push() // add new item to stack`
  - `pop() // remove top item from stack`
- additional Stack operations:
  - `top() // fetch top item (but don't remove it)`
  - `size() // number of items`
  - `is_empty()`

Stack Applications

- page-visited history in a Web browser
- undo sequence in a text editor
- checking for balanced brackets
- HTML tag matching
- postfix (RPN) calculator
- chain of function calls in a program

Stack - Abstract Data Type - C Interface

```c
typedef struct stack *stack_t;
stack_t stack_create(void);
void stack_free(stack_t stack);
void stack_push(stack_t stack, int item);
int stack_pop(stack_t stack);
int stack_is_empty(stack_t stack);
int stack_top(stack_t stack);
int stack_size(stack_t stack);
```

Stack - Abstract Data Type - using C Interface

```c
stack_t s;
s = stack_create();
stack_push(s, 10);
stack_push(s, 11);
stack_push(s, 12);
printf("%d\n", stack_size(s)); // prints 3
printf("%d\n", stack_top(s)); // prints 12
printf("%d\n", stack_pop(s)); // prints 12
printf("%d\n", stack_pop(s)); // prints 11
printf("%d\n", stack_pop(s)); // prints 10
```

- Implementation of stack is **opaque** (hidden from user).
- User programs can not depend on how stack is implementated.
- Stack implementation can change without risk of breaking user programs.
- This type of **information hiding** is crucial to managing complexity in large software systems.

Queue Abstract Data Type

- a *queue* is a collection of items such that the *first* item to enter
  is the *first* one to exit, i.e. "first in, first out" (FIFO)
- based on the idea of queueing at a bank, shop, etc.
- Essential Queue operations:
  - `enqueue() // add new item to queue`
  - `dequeue() // remove front item from queue`
- Additional Queue operations:
  - `front() // fetch front item (but don't remove it)`
  - `size() // number of items`
  - `is_empty()`

Queue Applications

- waiting lists, bureaucracy
- access to shared resources (printers, etc.)
- phone call centres
- multiple processes in a computer

Queue - Abstract Data Type - C Interface

```c
queue_t queue_create(void);
void queue_free(queue_t queue);
void queue_enqueue(queue_t queue, int item);
int queue_dequeue(queue_t queue);
int queue_is_empty(queue_t queue);
int queue_front(queue_t queue);
int queue_size(queue_t queue);
```

Queue - Abstract Data Type - C Interface

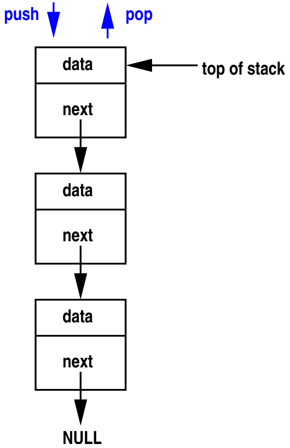
```
queue_t q;
q = queue_create();
queue_enqueue(q, 10);
queue_enqueue(q, 11);
queue_enqueue(q, 12);
printf("%d\n", queue_size(q)); // prints 3
printf("%d\n", queue_front(q)); // prints 10
printf("%d\n", queue_dequeue(q)); // prints 10
printf("%d\n", queue_dequeue(q)); // prints 11
printf("%d\n", queue_dequeue(q)); // prints 12
```

- Again mplementation of stack is **opaque**..

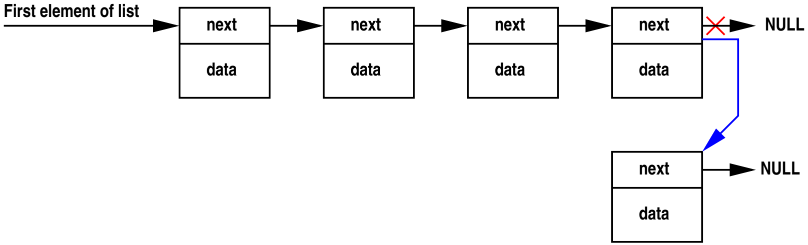
- Queue implementation can change without risk of breaking user programs.

Implementing A Stack with a Linked List

- a stack can be implemented using a linked list, by adding and removing at the head [`push()` and `pop()`]
- for a queue, we need to either add or remove at the tail
  - can either of these be done *efficiently*?



Adding to the Tail of a List



- adding an item at the tail is achieved by making the last node of the list point to the new node
- we first need to scan along the list to find the last item

Adding to the Tail of a List

```
struct node *add_to_tail( *new_node, struct node *head) {
   if (head == NULL) {          // list is empty
       head = new_node;
   } else {                     // list not empty
       struct node *node = head;
       while (node->next != NULL) {
           node = node->next; // scan to end
       }
       node->next = new_node;
   }
   return head;
}
```

Efficiency Issues

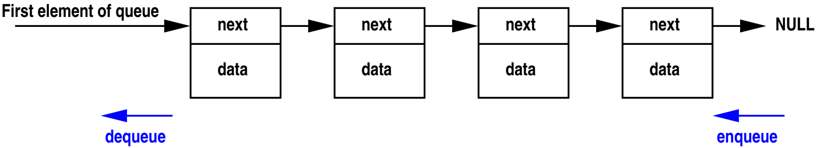
Unfortunately, this implementation is very slow. Every time a new item is inserted, we need to traverse the entire list (which could be very large).
We can do the job much more efficiently if we retain a direct link to the last item or “tail” of the list:

```
if (tail == NULL) { // list is empty
    head = node;
} else {            // list not empty
    tail->next = node;
}
tail = node;
```

Note: there is no way to efficiently *remove* items from the tail. (Why?)

Queues

- a *queue* is a collection of items such that the *first* item to enter
  is the *first* one to exit, i.e. "first in, first out" (FIFO)
- based on the idea of queueing at a bank, shop, etc.



Queue Structure

We can use this structure to implement a queue efficiently:

```
typedef struct queue Queue;

struct queue {
    struct node *head;
    struct node *tail;
    int size;
};
```

Making a new Queue

```
queue_t *makeQueue() {
   queue_t *q = (queue_t *)malloc(sizeof (queue_t));
   if (q == NULL) {
      fprintf(stderr, "Out of memory\n");
      exit(1);
   }
   q->head = NULL;
   q->tail = NULL;
   q->size = 0;
   return q;
}
```

Adding a new Item to a Queue

```
void enqueue(struct node *new_node, queue_t *q) {
   if (q->tail == NULL) { // queue is empty
       q->head = new_node;
   } else {                // queue not empty
       q->tail->next = new_node;
   }
   q->tail = new_node;
   q->size++;
}
```

Removing an Item from a Queue

```
struct node *dequeue(queue_t *q) {
   struct node *node = q->head;
   if (q->head != NULL) {
       if( q->head == q->tail ) { // only one item
           q->tail = NULL;
       }
       q->head = q->head->next;
       q->size--;
   }
   return node;
}
```

Example: queue.c

```c
int main(void) {
   queue_t *q = makeQueue();
   struct node *node;
   int  ch;

   while ((ch = getchar()) != EOF) {
      if (ch == '-') {
          node = dequeue( q );
          if( node != NULL ) {
              printf("Dequeueing %c\n", node->data );
              free( node );
          }
      }
```

Example: queue.c

```
  ...
      else if (ch == '\n') {
          print_list(q->head);
      }
      else {
          enqueue(makeNode(ch), q);
      }
  }
  free_list(q->head);

  return 0;
}
```

Reverse Polish Notation

Some early calculators and programming languages used a convention known as *Reverse Polish Notation* (RPN) where the operator comes after the two operands rather than between them:

```
1 2 +
result = 3
3 2 *
result = 6
4 3 + 6 *
result = 42
1 2 3 4 + * +
result = 15
```

Postfix Calculator

A calculator using RPN is called a *Postfix Calculator*; it can be implemented using a stack:

- when a number is entered: push it onto the stack
- when an operator is entered: pop the top two items from the stack, apply the operator to them, and push the result back onto the stack.

postfix.c

```c
int main(void) {
  struct node *list = NULL;
  int num;
  int a,b, num;
  while ((ch = getc(stdin)) != EOF) {
     if (ch == '\n') {
         printf("Result: %d\n", list->data);
     }
     else if (isdigit(ch)) {
         ungetc(ch, stdin);  // put first digit back
         scanf("%d", &num);  // now scan entire number
         list = push(makeNode(num), list);
     }
```

postfix.c

```
    else if (ch == '+' || ch == '-' || ch == '*') {
        if (list != NULL) {
            a = list->data;      // fetch top item
            list = pop(list);
            if (list != NULL) {
                b = list->data;  // fetch 2nd item
                list = pop(list);
                switch (ch) {
                  case '+':  num = b + a;  break;
                  case '-':  num = b - a;  break;
                  case '*':  num = b * a;  break;
                }
                list = push(make_node(num), list);
            }
        }
    }
}
```