Overview
Write a program to play the card game "War."

Goals.
- Practice with linked lists and pointers.
- Appreciate the central role played by data structures.
- Learn how to design a "large" program.
- Learn how to read a "large" program.

WAR Demo

Rules of the game.
- Each player is dealt half of the cards.
- Each player plays top card.
  - whichever is higher captures both cards
  - in event of tie, WAR
- Repeat until one player has all the cards.

Before You Write Any Code

Determine a high-level view of the code you plan to write.

Break it up into manageable pieces.
- Create the deck of cards.
- Shuffle the cards.
- Deal the cards.
- Play the game.

Determine how you will represent the data.
- The cards.
- The deck.
- The hands.
Representing The Cards

Represent 52 cards using an integer between 0 and 51.

<table>
<thead>
<tr>
<th>Clubs</th>
<th>Diamonds</th>
<th>Hearts</th>
<th>Spades</th>
</tr>
</thead>
<tbody>
<tr>
<td>Card</td>
<td>Card</td>
<td>Card</td>
<td>Card</td>
</tr>
<tr>
<td>Card</td>
<td>#</td>
<td>#</td>
<td>#</td>
</tr>
<tr>
<td>2♣</td>
<td>0</td>
<td>2♥</td>
<td>2♠</td>
</tr>
<tr>
<td>3♣</td>
<td>1</td>
<td>3♥</td>
<td>3♠</td>
</tr>
<tr>
<td>4♣</td>
<td>2</td>
<td>4♥</td>
<td>4♠</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>K♣</td>
<td>11</td>
<td>K♥</td>
<td>K♠</td>
</tr>
<tr>
<td>A♣</td>
<td>12</td>
<td>A♥</td>
<td>A♠</td>
</tr>
</tbody>
</table>

46 ≡ 3 \cdot 13 + 9

typedef int Card;
int CARDrank(Card c);
int CARDsuit(Card c);
void CARDshow(Card c);
Card CARDith(unsigned int i);

CARD.h

int CARDrank(Card c) { return c % 13; }
int CARDsuit(Card c) { return c / 13; }
Card CARDith(unsigned int i) { return i; }

card.c

void CARDshow(Card c) {
    switch (CARDrank(c)) {
        case 0: printf("Deuce of "); break;
        case 1: printf("Three of "); break;
        ....
        case 12: printf("Ace of "); break;
    }
    switch (CARDsuit(c)) {
        case 0: printf("Clubs\n"); break;
        case 1: printf("Diamonds\n"); break;
        case 2: printf("Hearts\n"); break;
        case 3: printf("Spades\n"); break;
    }
}

Testing the Code As We Write It

% gcc war.c card.c
% a.out

Deuce of Clubs
Three of Clubs
Four of Clubs
Five of Clubs
Six of Clubs
Seven of Clubs
... 
King of Spades
Ace of Spades
Representing the Deck and Hands

Use a linked list to represent the deck and hands.

Why use linked lists?
- Draw cards from the top, captured cards go to bottom.
  - need direct access to top and bottom cards
  - no need for direct access to middle cards
- Gain practice with linked lists.

typedef struct node* link;
struct node {
  Card card;
  link next;
};
link Atop, Abot;
link Btop, Bbot;

represent a pile of cards

showPile()
void showPile(link pile) {
  link x;
  for (x = pile; x != NULL; x = x->next)
    CARDshow(x->card);
}

countPile()
int countPile(link pile) {
  link x;
  int cnt = 0;
  for (x = pile; x != NULL; x = x->next)
    cnt++;
  return cnt;
}

Showing a Hand

Use printf() method for debugging.
- May need to build supplemental functions to print out contents of data structures.
- Print out contents of player’s hand.

standard linked list traversal
Creating the Deck

**Goal:** create a 52 card deck.
- Need to dynamically allocate memory.
- Good programming practice to write helper function to allocate memory and initialize it.

```c
#include <stdlib.h>

link NEWnode(Card card, link next) {
    link x;
    x = malloc(sizeof *x);
    if (x == NULL) {
        printf("Out of memory.
");
        exit(EXIT_FAILURE);
    }
    x->next = next;
    x->card = card;
    return x;
}
```

### NEWnode()
- **Needed for malloc()**
- **Allocate memory**
- **Malloc() failed**
- **Initialize node**

```c
link makePile(int N) {
    link x = NULL;
    int i;
    for (i = N - 1; i >= 0; i--)
        x = NEWnode(CARDith(i), x);
    return x;
}
```

### makePile()
- **x is link to top of pile**
- **Add next card to top of pile**

**Testing the Code**

```c
#include <stdio.h>
#include <stdlib.h>
#include "CARD.h"
#define DECKSIZE 52

typedef struct node* link ...;

link NEWnode(Card card, link next) {...}
lspin makePile(int N) {...}
lspin showPile(link pile) {...}

int main(void) {
    link deck;
    deck = makePile(DECKSIZE);
    showPile(deck);
    return 0;
}
```

**Unix**

```
% gcc war.c card.c
% a.out
```

```
Deuce of Clubs
Three of Clubs
Four of Clubs
Five of Clubs
Six of Clubs
Seven of Clubs

King of Spades
Ace of Spades
```

**Dealing**

**Deal cards one at a time.**
- **Input:** deck of cards (linked list).
- **Creates:** two new linked lists for players A and B.
  - global variable Atop, Btop point to first node
  - global variable Abot, Bbot point to last node
- **Does not create (malloc) new nodes.**

```
K 2 3 4 5
J Q 5
```

```
NULL
```
Dealing Code

```c
void deal(link d) {
    Atop = d; Abot = d; d = d->next;
    Btop = d; Bbot = d; d = d->next;
    while (d != NULL) {
        Abot->next = d; Abot = d; d = d->next;
        Bbot->next = d; Bbot = d; d = d->next;
    }
    Abot->next = NULL; Bbot->next = NULL;
}
```

handle first card of each pile
assumes deck has even # cards
mark end of piles

Testing the Code

```c
war.c

... as before
link Atop, Abot, Btop, Bbot;
void deal(link d) {
...
}

int main(void) {
    link deck;
    deck = makePile(DECKSIZE);
    deal(deck);
    printf("PLAYER A\n");
    showPile(Atop);
    printf("\nPLAYER B\n");
    showpile(Btop);
    return 0;
}
```

Unix

```
gcc war.c card.c
a.out

PLAYER A
Deuce of Clubs
Four of Clubs
Six of Clubs
... King of Spades

PLAYER B
Three of Clubs
Five of Clubs
Seven of Clubs
... Ace of Spades
```

Shuffling the Deck

Shuffle the deck.
- Disassemble linked list elements and put into an array.
- Shuffle array elements (using algorithm from Lecture P2).
- Reassemble linked list from shuffled array.

```
2♠ 3♠ 4♠ 5♠ 6♠ 7♠ 8♠ 9♠ NULL
```

```
<table>
<thead>
<tr>
<th>Array index</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2♠</td>
</tr>
<tr>
<td>1</td>
<td>3♠</td>
</tr>
<tr>
<td>2</td>
<td>4♠</td>
</tr>
<tr>
<td>3</td>
<td>5♠</td>
</tr>
<tr>
<td>4</td>
<td>6♠</td>
</tr>
<tr>
<td>5</td>
<td>7♠</td>
</tr>
<tr>
<td>6</td>
<td>8♠</td>
</tr>
<tr>
<td>7</td>
<td>9♠</td>
</tr>
</tbody>
</table>
```

```
2♠ 3♠ 4♠ 5♠ 6♠ 7♠ 8♠ 9♠ NULL
```

```
<table>
<thead>
<tr>
<th>Array index</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>4♠</td>
</tr>
<tr>
<td>1</td>
<td>6♠</td>
</tr>
<tr>
<td>2</td>
<td>9♠</td>
</tr>
<tr>
<td>3</td>
<td>2♠</td>
</tr>
<tr>
<td>4</td>
<td>8♠</td>
</tr>
<tr>
<td>5</td>
<td>7♠</td>
</tr>
<tr>
<td>6</td>
<td>5♠</td>
</tr>
<tr>
<td>7</td>
<td>3♠</td>
</tr>
</tbody>
</table>
```

```
4♠ 6♠ 9♠ 2♠ 8♠ 7♠ 5♠ 3♠ NULL
```

Shuffling the Deck

```
link shufflePile(link pile) {
    int i, n;
    link x;
    link a[DECKSIZE];

    for (x = pile, n = 0; x != NULL; x = x->next, n++)
        a[n] = x;

    shuffle(a, n);

    for (i = 0; i < n - 1; i++)
        a[i]->next = a[i+1];
    a[n-1]->next = NULL;
    return a[0];
}
```

shuffle pile of cards
shuffle array elements
reassemble linked list
Testing the Code

```
war.c

... as before

int randomInteger(int n) { }
void shufflePile(link pile) { ...}

int main(void) {
    link deck;
    deck = makePile(DECKSIZE);
    deck = shufflePile(deck);
    deal(deck);
    printf("PLAYER A\n");
    showpile(Atop);
    printf("\nPLAYER B
");
    showpile(Btop);
    return 0;
}
```

Unix

```
% gcc war.c card.c
% a.out
```

PLAYER A
Eight of Diamonds
Ten of Hearts
Four of Clubs
... 
Nine of Spades

PLAYER B
Jack of Hearts
Jack of Clubs
Four of Diamonds
... 
Ten of Clubs

Playing

"Peace" (game of war with no wars).
- Starting point for implementation.
- Assume player B wins if a tie instead of war.

What should happen?

```
peace.c

void play (void) {
    int Aval, Bval;
    link Ttop, Tbot;
    while ((Atop != NULL) && (Btop != NULL)) {
        Aval = CARDrank(Atop->card);
        Bval = CARDrank(Btop->card);
        Ttop = Atop; Tbot = Btop;
        Atop = Atop->next; Btop = Btop->next;
        Ttop->next = Tbot; Tbot->next = NULL;
        if (Aval > Bval) {
            if (Atop == NULL) Atop = Ttop;
            else Abot->next = Ttop; Abot = Tbot;
        } else {
            if (Btop == NULL) Btop = Ttop;
            else Bbot->next = Ttop;
            Bbot = Tbot;
        }
    }
}
```

Game Never Ends (well, Hardly Ever)

"Peace" (game of war with no wars).
- Starting point for implementation.
- Assume player B wins if a tie.

What should happen?

What actually happens?
One Bit of Uncertainty

What actually happens?
- Game "never" ends for many (almost all) deals.

Proper use of randomization is vital in simulation applications.
- Randomly exchange two cards in battle when picked up.

```
if (randomInteger(2) == 1) {
    Ttop = Atop;
    Tbot = Btop;
} else {
    Ttop = Btop;
    Tbot = Atop;
}
```

Ten Typical Games

```
B wins in  466 steps.
A wins in  404 steps.
B wins in  330 steps.
B wins in 1088 steps.
B wins in  430 steps.
A wins in  208 steps.
B wins in  214 steps.
B wins in  630 steps.
B wins in  170 steps.
```
Problems With Simulation

- Doesn’t precisely mirror game.
  - Deal allocates piles in reversed order.
  - People pick up cards differently.
  - “Sort-of” shuffle prize pile after war?
  - Separate hand and pile.
    - could have war as pile runs out
  - Our shuffling produces perfectly random deck.
    - modulo “randomness” of rand()

Tradeoffs.
- Convenience for implementation.
- Fidelity to real game.
- Such tradeoffs are typical in simulation.
- Try to identify which details matter.

Advantages of Simulation

- Speed.
  - Our War experiments infeasible for human players.

- Manipulate bits, not cards.
  - Computer simulation frees the experimenter from dealing with physical reality.
  - Very useful when “reality” is expensive or dangerous.

- Manipulate bits, not cars.
  - Ford (e.g.) does many crash tests via simulation.

- Many, many other uses of simulation methods.
  - Chip designs, chemical reactions, national economies, . . .

Summary

How to build a "large" program?
- Use top-down design.
- Break into small, manageable pieces. Makes code:
  - easier to understand
  - easier to debug
  - easier to change later on
- Debug each piece as you write it.
- Good algorithmic design starts with judicious choice of data structures.

How to work with linked lists?
- Draw pictures to read and write pointer code.

Lecture P10: Extra Notes
War Using Queue ADT

Use first class queue ADT. Why queue?
- Always draw cards from top, return captured cards to bottom.

```c
void deal(Queue Deck) {
    A = QUEUEinit();
    B = QUEUEinit();
    while (!QUEUEisempty(Deck)) {
        QUEUEput(A, QUEUEget(Deck));
        QUEUEput(B, QUEUEget(Deck));
    }
}
```

Advantages:
- Simplifies code.
- Avoids details of linked lists.

Disadvantage:
- Adds detail of interface.