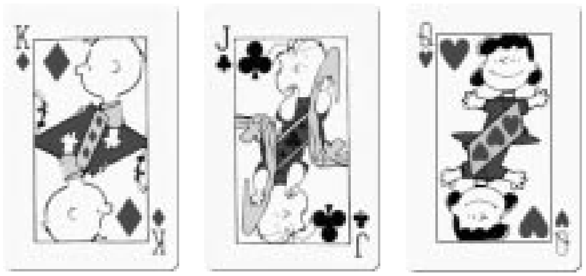
Lecture P9: WAR Card Game

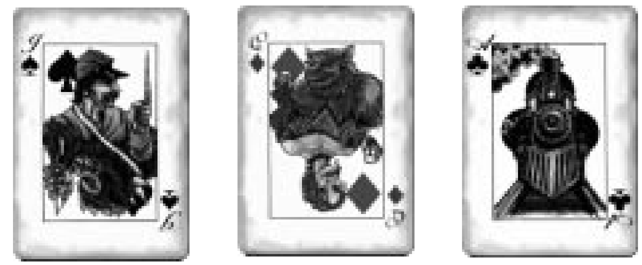


Overview

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

Goals.

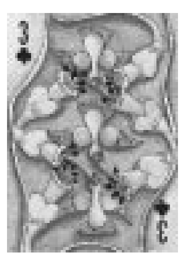
- Practice with linked lists and pointers.
- Appreciate the central role played by data structures.
- Learn how to design a "large" program.
- Learn how to read a "large" program.



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.



WAR demo.

Before You Write Any Code

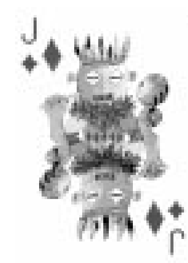
Determine a high-level view of the code you plan to write.

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.

Clubs		Diamonds		Hearts		Spades	
Card	#	Card	#	Card	#	Card	#
2 ♣	0	2 ♦	13	2 ♥	26	2 ♠	39
3 ♣	1	3 ♦	14	3 ♥	27	3 ♠	40
4 ♣	2	4 ♦	15	4 ♥	28	4 ♠	41
. . .	. .	. . .	. .	. . .	. .	. . .	. .
K ♣	11	K ♦	24	K ♥	37	K ♠	50
A ♣	12	A ♦	25	A ♥	38	A ♠	51

Representing The Cards

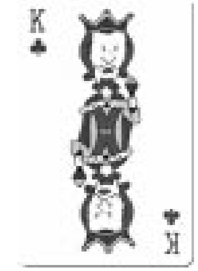
Represent 52 cards using an integer between 0 and 51.

- War if `(rank(c1) == rank(c2))`

Card type

```
typedef int Card;

int rank(Card c) {
  return c % 13;
}

int suit(Card c) {
  return (c % 52) / 13;
}
```

c % 52 to allow for multiple deck war



Representing The Cards

Card type

```
void showcard(Card c) {
   switch (rank(c)) {
      case  0: printf("Deuce of ");  break;
      case  1: printf("Three of ");  break;

      . . .

      case 12: printf("Ace of " );   break;
   }

   switch (suit(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

war.c (test code)

```
#include <stdio.h>
#define DECKSIZE 52

typedef int Card;

int rank(Card c) {...}
int suit(Card c) {...}
void showCard(Card c) {...}

int main(void) {
  Card c;
  for (c = 0; c < DECKSIZE; c++)
    showCard(c);
  return 0;
}
```

Unix

```
% gcc war.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

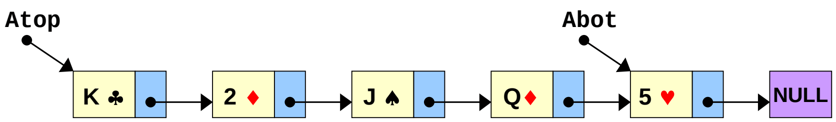
Use a linked list to represent the deck and hands.

standard linked list structure

maintain pointer to first and last card in A's pile

represent a pile of cards

```
typedef struct node* link;
struct node {
   Card card;
   link next;
};

link Atop, Abot;
link Btop, Bbot;
```

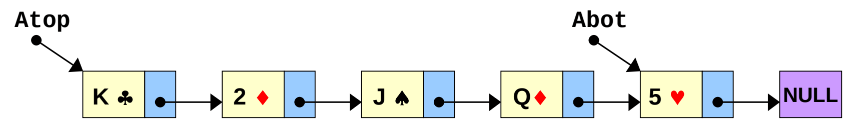


Representing the Deck and Hands

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.



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

showPile( )

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


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.
- Count number of cards in player's hand.

standard linked list traversal

countPile( )

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

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.

NEWnode( )

```
#include <stdlib.h>

link NEWnode(Card card, link next) {
   link x;
   x = malloc(sizeof *x);
   if (x == NULL) {
      printf("Error.\n");
      exit(EXIT_FAILURE);
   }
   x->next = next;
   x->card = card;
}
```

- needed for `malloc()` → `#include <stdlib.h>`
- allocate memory → `x = malloc(sizeof *x);`
- `malloc()` failed → `if (x == NULL) {`
- initialize node → `x->next = next;`

Creating the Deck

Goal: create a 52 card deck.

- Need to dynamically allocate memory.

makePile

```
link makePile(int N) {
  Card c;
  link x, y, pile;
  x = pile = NEWnode(0, NULL);

  for (c = 1; c < N; c++) {
    y = NEWnode(c, NULL);
    x->next = y;
    x = y;
  }

  return pile;
}
```

- start deck with 0^{th} card → `x = pile = NEWnode(0, NULL);`
- add next card to bottom of pile → `y = NEWnode(c, NULL);`
- return link to first node of pile → `return pile;`

Testing the Code

war.c

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

typedef int Card;
[ rank(), suit(), showCard() ]

typedef struct node* link ...
link NEWnode(Card card, link next) {...}
link makePile(int N) {...}
link showPile(link pile) {...}

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

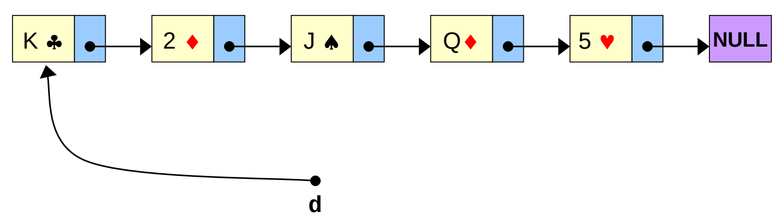
Unix

```
% gcc war.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.



Dealing Code

deal

```
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

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
% 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 P3).
- Reassemble linked list from shuffled array.

2♣ → 3♣ → 4♣ → 5♣ → 6♣ → 7♣ → 8♣ → 9♣ → NULL

Array index	0	1	2	3	4	5	6	7
Value	2♣	3♣	4♣	5♣	6♣	7♣	8♣	9♣

Array index	0	1	2	3	4	5	6	7
Value	4♣	6♣	9♣	2♣	8♣	7♣	5♣	3♣

4♣ → 6♣ → 9♣ → 2♣ → 8♣ → 7♣ → 5♣ → 3♣ → NULL

Shuffling the Deck

shuffle pile of cards

```
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 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\n");
  showpile(Btop);
  return 0;
}
```

Unix

```
% gcc war.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
```

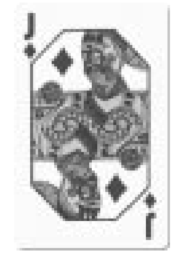

Playing

"Peace" (war with no wars).

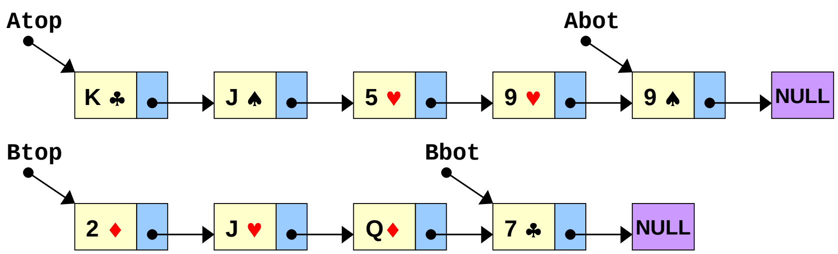
- Starting point for implementation.
- Assume player B wins if a tie.

What should happen?

- Intuitively, B has an advantage, so should usually win.



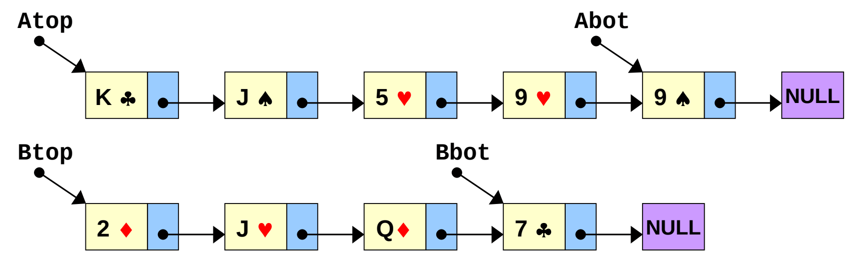
Playing



A wins if `(Aval > Bval)`

```
Aval = rank(Atop->card);
Bval = rank(Btop->card);
```

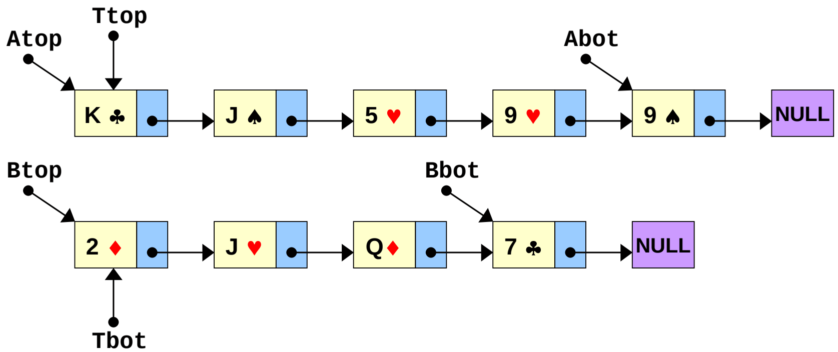

Playing



`Ttop, Tbot` delimit pile to be awarded to winner (prize).

```
Ttop = Atop;
Tbot = Btop;
```

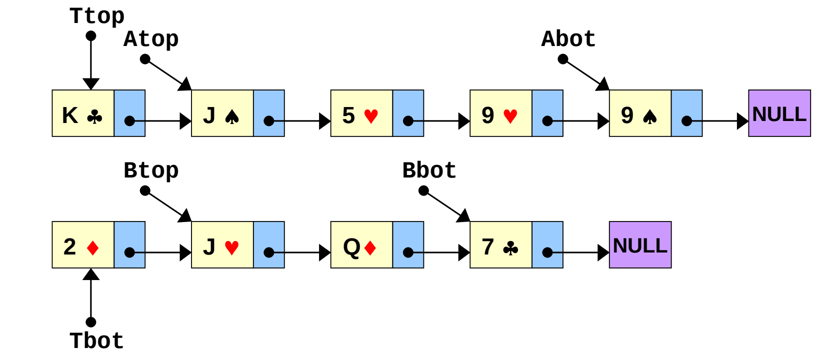
Playing



Reset top of each player's piles.

```
Atop = Atop->next;
Btop = Btop->next;
```

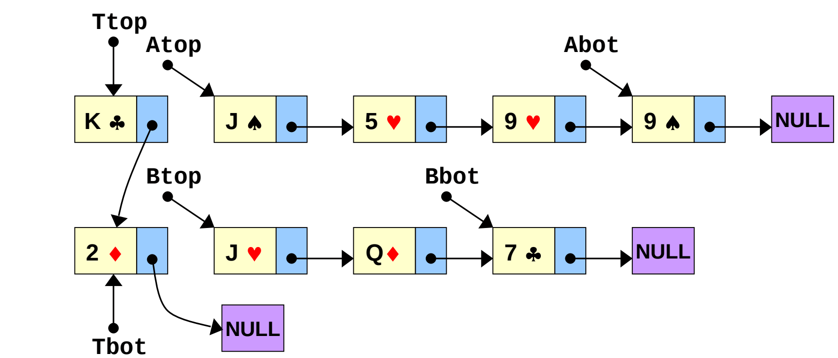

Playing



Link prize pile together.

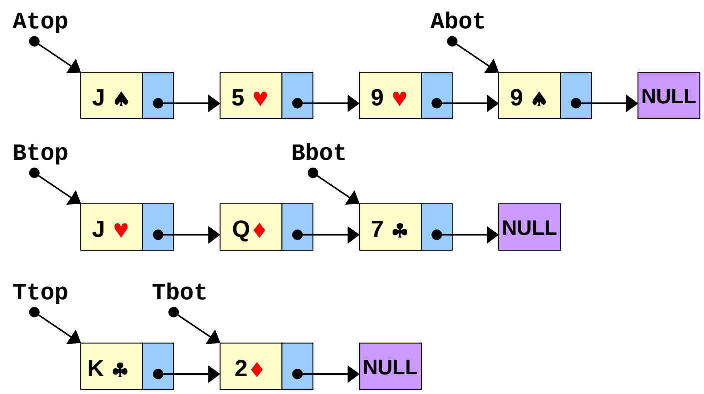
```
Ttop->next = Tbot;
Tbot->next = NULL;
```


Playing



Cleaning up the picture . . . .

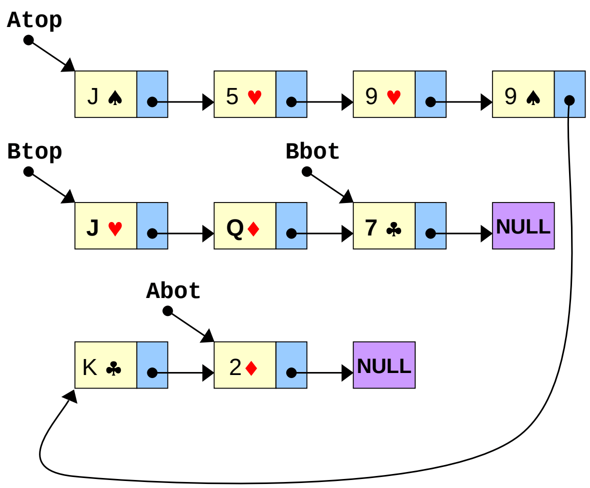
Playing



Award prize to A.

```
Abot->next = Ttop;
Abot = Tbot;
```

Playing



Peace Code

war.c

```
void play (void) {
  int Aval, Bval;
  link Ttop, Tbot;
  while ((Atop != NULL) && (Btop != NULL)) {
    Aval = rank(Atop->card);
    Bval = rank(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;
    }
  }
}
```

Until a player loses

A wins

B wins

Game Never Ends

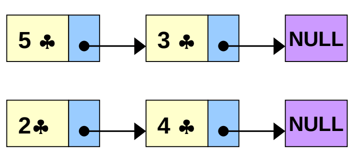
"Peace" (war with no wars).

- Starting point for implementation.
- Assume player B wins if a tie.

What should happen?

- Intuitively, B has an advantage, so should usually win.

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;
```

exchange cards randomly

Ten Typical Games
B wins in 446 steps.
A wins in 404 steps.
B wins in 330 steps.
B wins in 1088 steps.
B wins in 566 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.

Add Code for War

Add code to handle ties.

- Insert in `play(void)` before `if (Aval > Bval)`

while not if to handle multiple wars

A's war card

add `WARSIZE` cards to temporary pile

B's war card

```
while (Aval == Bval) {
  for (i = 0; i < WARSIZE; i++) {
    if (Atop == NULL)
      return;
    Tbot->next = Atop; Tbot = Atop;
    Atop = Atop->next;
  }
  Aval = rank(Tbot->card);

  for (i = 0; i < WARSIZE; i++) {
    if (Btop == NULL)
      return;
    Tbot->next = Btop; Tbot = Btop;
    Btop = Btop->next;
  }
  Bval = rank(Tbot->card);
}
Tbot->next = NULL;
```


Answer

Q. "So how long does it take?"

A. "About 10 times through deck (254 battles)."

Q. "How do you know?"

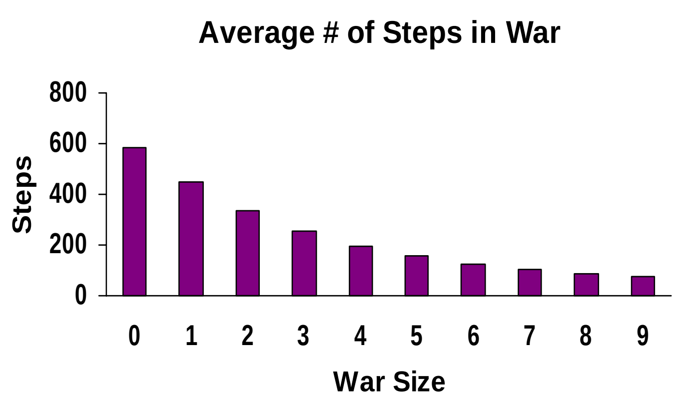
A. "I played a million games. . . ."

Ten Typical Games
B wins in 60 steps.
A wins in 101 steps.
B wins in 268 steps.
A wins in 218 steps.
B wins in 253 steps.
A wins in 202 steps.
B wins in 229 steps.
A wins in 78 steps.
B wins in 84 steps.
A wins in 654 steps.

Answer

Q. "That sounds like fun."

A. "Let's try having bigger battles. . . ."



Problems With Simulation

Doesn't precisely mirror game.

- 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 (up to "randomness" of `rand()` library function).

Tradeoff

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

War Using Queue ADT

Use first class queue ADT. Why queue?

- Always draw cards from top, return captured cards to bottom.

peace.c

```
void play(Queue A, Queue B) {
  Card Acard, Bcard;
  Queue T = QUEUEinit();

  while  (!QUEUEisempty(A) && !QUEUEisempty(B)) {
    Acard = QUEUEget(A); Bcard = QUEUEget(B);
    QUEUEput(T, Acard); QUEUEput(T, Bcard);
    if (rank(Acard) > rank(Bcard))
       while (!QUEUEisempty(T))
          QUEUEput(A, QUEUEget(T));
    else
       while (!QUEUEempty(T))
          QUEUEput(B, QUEUEget(T));
  }
}
```


War Using Queue ADT

Use first class queue ADT. Why queue?

Advantages:

- Simplifies code.
- Avoids details of linked lists.

Disadvantage:

- Adds detail of interface.

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.