Lecture P8: 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	number	Card	number	Card	number	Card	number
2 ♣	0	2 ♦	13	2 ♥	26	2 ♠	39
3 ♣	1	3 ♦	14	3 ♥	27	3 ♠	40
2 ♣	2	2 ♦	15	2 ♥	28	2 ♠	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))`

```
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

Card type

Representing The Cards

```
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;
  }
}
```

Card type

Testing the 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;
}
```

test code

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
```

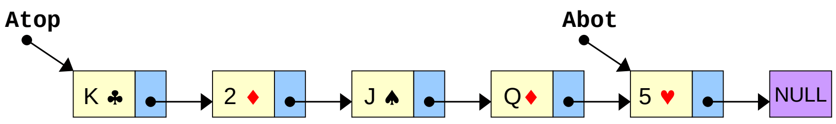
Representing the Deck and Hands

Use a linked list to represent the deck and hands. Why?

- 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 cardlist* link;
struct cardlist { Card card; link next; };
link Atop, Btop;  /* points to first card */
link Abot, Bbot;  /* points to last  card */
```

Card pile



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

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

showpile

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

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

countpile

Creating the Deck

Goal: create a 52 card deck.

- Need to dynamically allocate memory.

start deck with 0^{th} card

add remaining cards to bottom

mark end of deck

```
link makePile(int N) {
  Card c;
  link x, pile;

  pile = malloc(sizeof *deck);
  x = deck;
  x->card = 0;

  for (c = 1; c < N; c++) {
    x->next = malloc(sizeof *x);
    x = x->next;
    x->card = c;
  }
  x->next = NULL;

  return pile;
}
```

makePile

Testing the Code

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

typedef int Card;

int rank (Card c) {...}
int suit (Card c) {...}
void showCard (Card c) {...}
link makePile (int N) {...}
link showPile (link pile) {...}

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

war.c

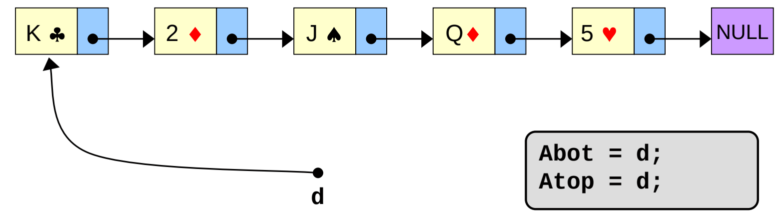
Unix

```
% 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.



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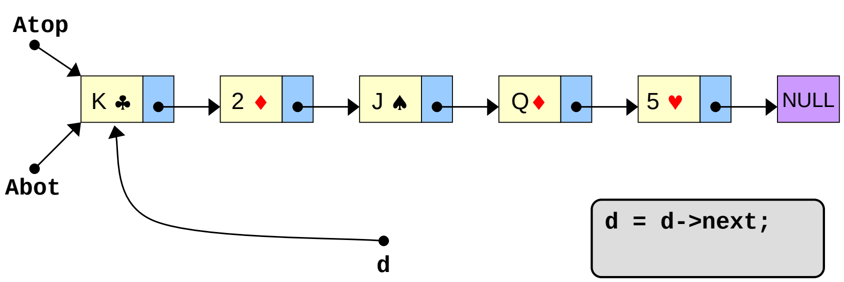

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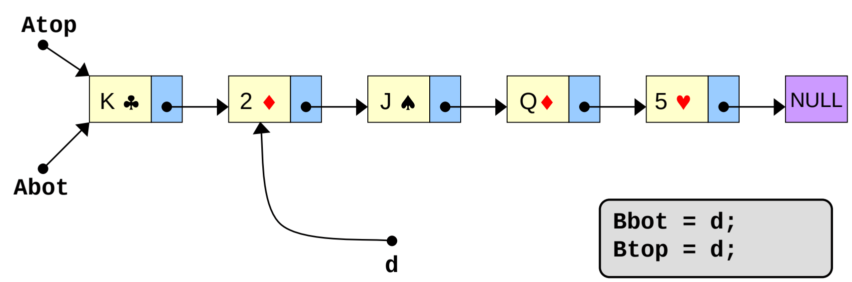

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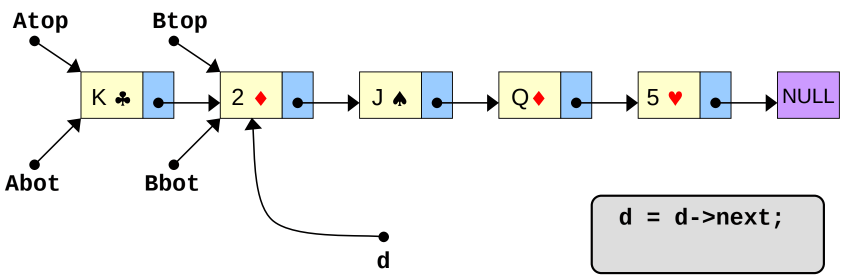

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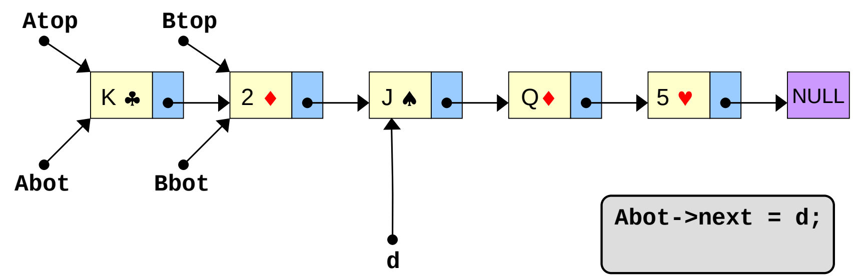

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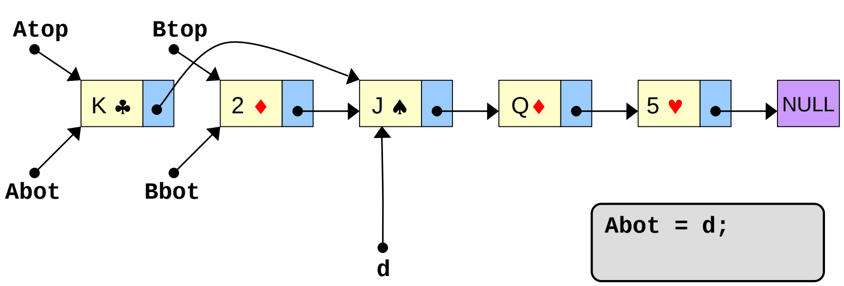

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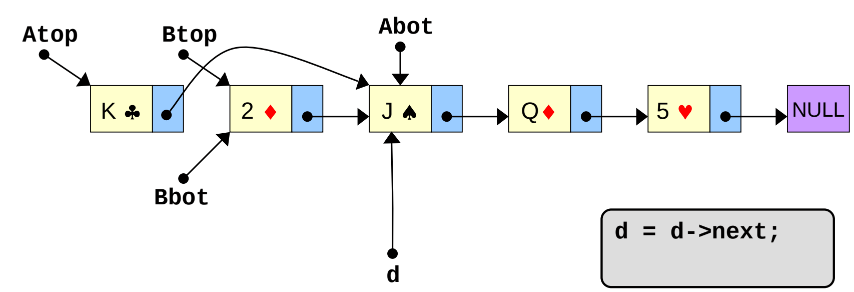

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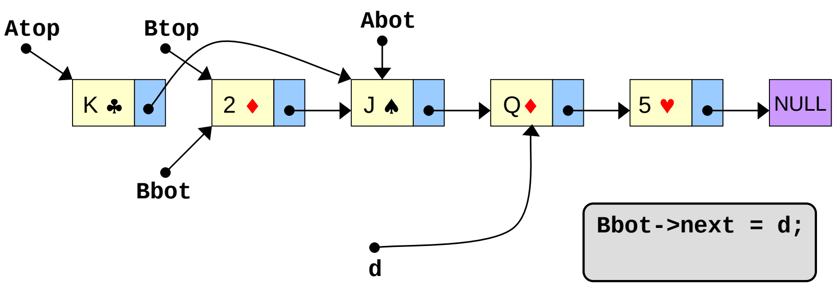

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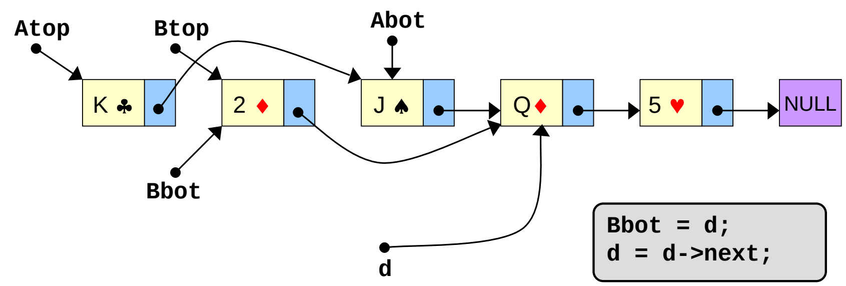

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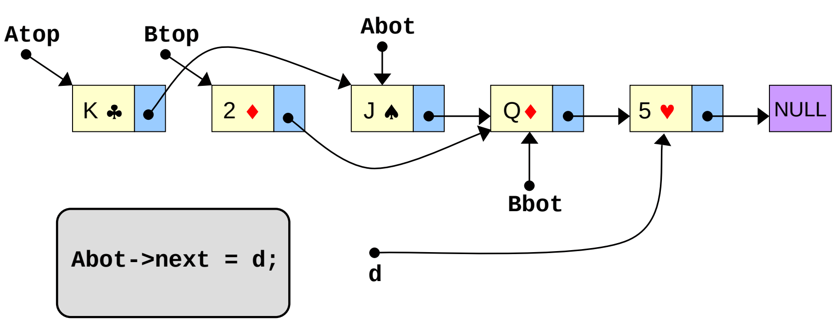

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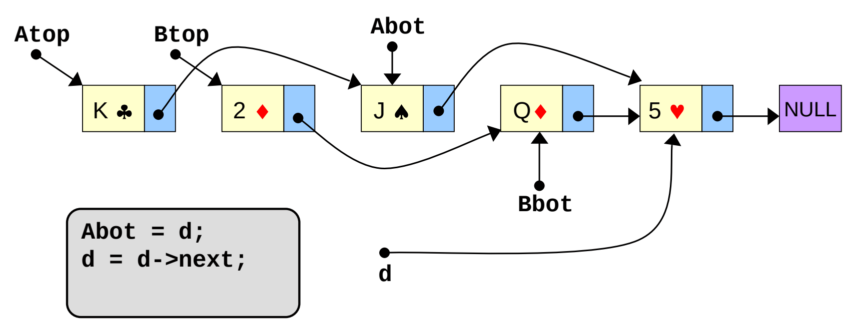

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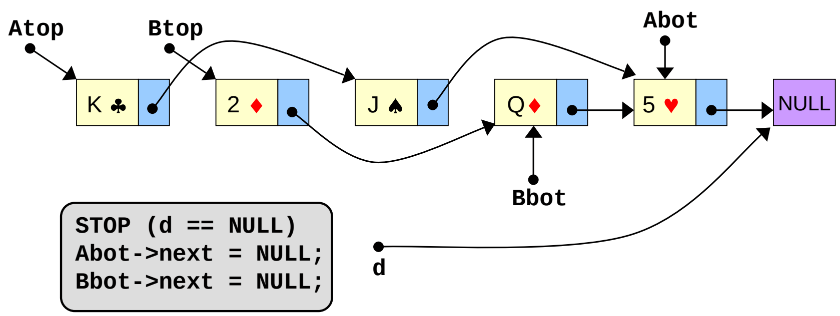

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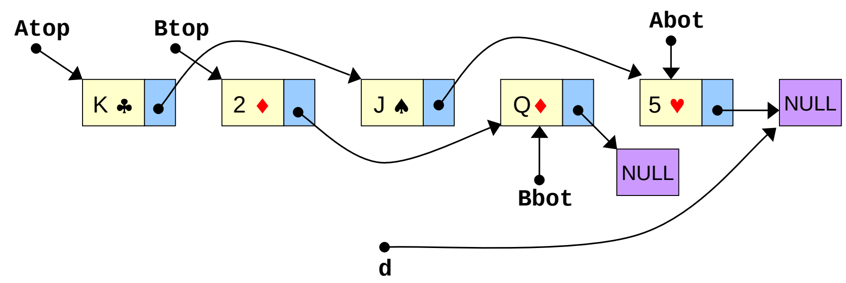

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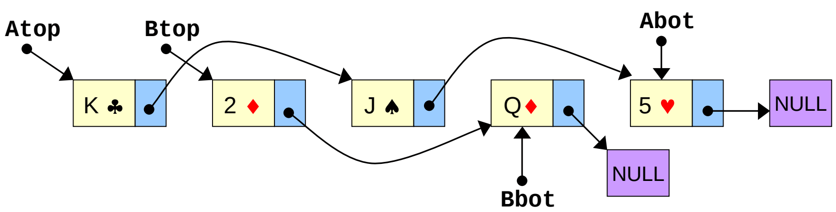
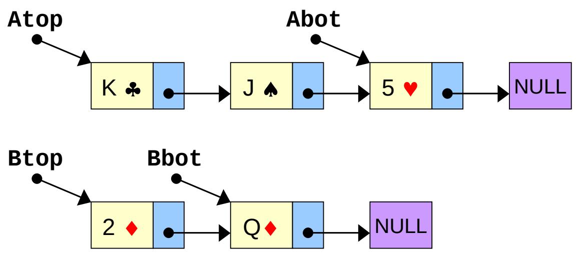


Cleaning up the picture:



Dealing Code

handles first card of each pile specially

handle odd deck size

mark end of piles

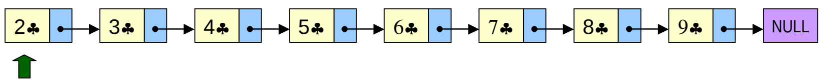
```
void deal(link d) {
  Atop = d; Abot = d; d = d->next;
  Btop = d; Bbot = d; d = d->next;
  while (d != NULL) {
    Abot->next = d; Abot = d; d = d->next;
    if (d == NULL) break;
    Bbot->next = d; Bbot = d; d = d->next;
  }
  Abot->next = NULL; Bbot->next = NULL;
}
```

deal

Shuffling the Deck

Shuffling Algorithm 2 (from Lecture P3):

- Traverse linked list containing pile to be shuffled. In ith iteration:
  - choose random integer r between 0 and i
  - put card previous in r^{th} position into i^{th} position
  - put card i in r^{th} position of array



Array index	0	1	2	3	4	5	6	7
Link	?	?	?	?	?	?	?	?

Iteration 0: random number = 0.

Shuffling the Deck

Shuffling Algorithm 2:

- Traverse linked list containing pile to be shuffled. In ith iteration:
  - choose random integer r between 0 and i
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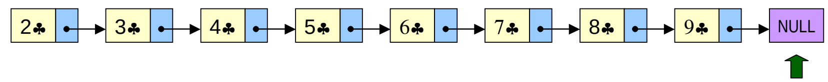
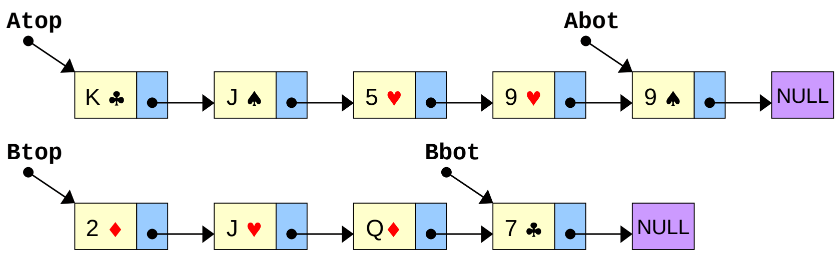


Array index	0	1	2	3	4	5	6	7
Link	4 ♣	6 ♣	9 ♣	7 ♣	8 ♣	3 ♣	5 ♣	2 ♣

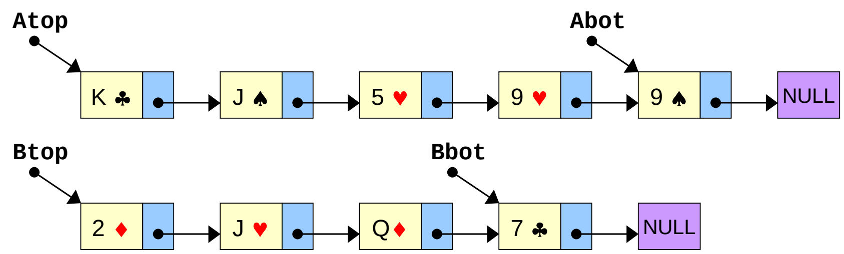
Playing



A wins if `(Aval > Bval)`

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

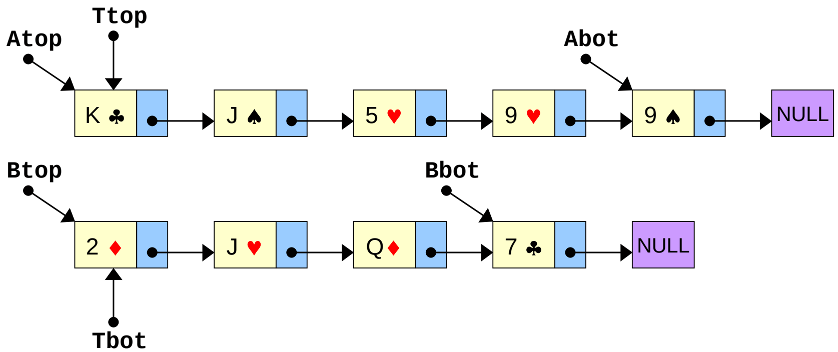

Playing



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

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

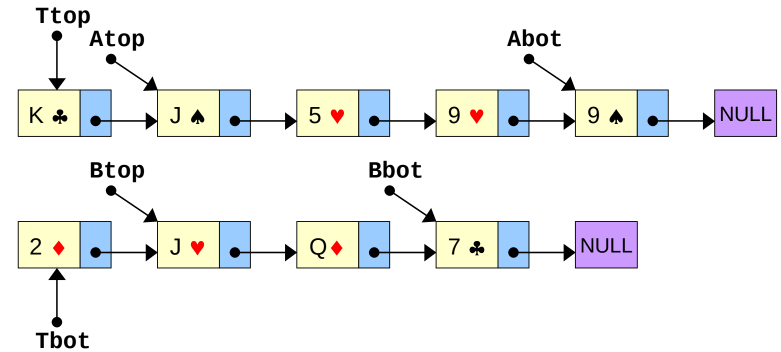
Playing



Reset top of each player's piles.

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

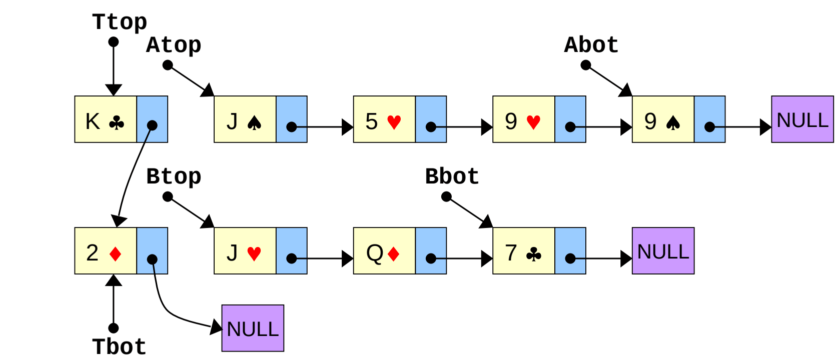

Playing



Link prize pile together.

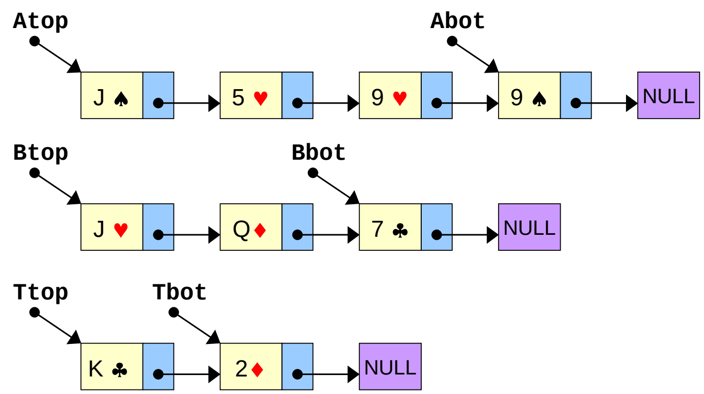
```
Ttop->next = Tbot;
Tbot->next = NULL;
```


Playing



Cleaning up the picture . . . .

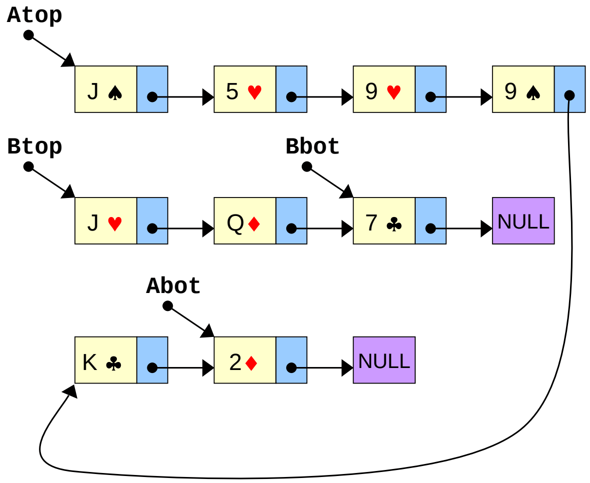
Playing



Award prize to A.

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

Playing



Peace Code

Until a player loses → while loop

A wins → if (Aval > Bval)

B wins → else

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;
    }
  }
}
```


Game Never Ends

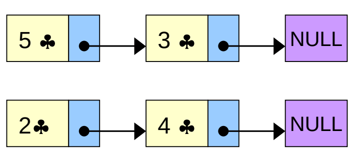
"Peace" (war with no wars).

- 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

add 4 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;
```

play war

Answer

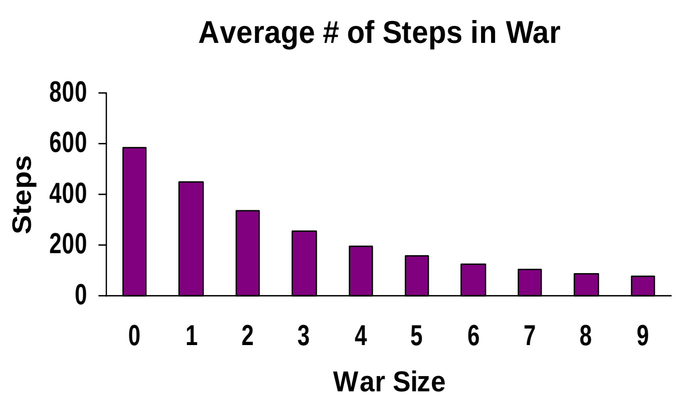
Q. "So how long does it take?"
A. "About 10 times through deck (254 battles)."

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  (!QUEUEempty(A) && !QUEUEempty(B)) {
    Acard = QUEUEget(A); Bcard = QUEUEget(B);
    QUEUEput(T, Acard); QUEUEput(T, Bcard);
    if (rank(Acard) > rank(Bcard))
       while (!QUEUEempty(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
  - makes code debug
  - makes code 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.

