Program Patterns
Recursion, Update/Copy/Move Patterns

Recursion
(Recursive Function)

Self-Referential Structure with a Pointer Type Member (a type of recursion)

```
struct   NODE {
        int                     key;
        struct NODE     *next;
};
```

Recursion Example: Factorial

- 0! = 1 (recursion termination condition)
- n! = n * (n-1)! for n >= 1

- 3! = 3 * 2!
- 2! = 2 * 1!
- 1! = 1 * 0!
- 0! = 1

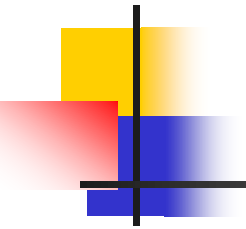
- 3! = 3 * (2 * (1 * (1))) = 6

Factorial in C

pseudo code for factorial

```
if n=0
    factorial = 1
else
    factorial = n * factorial(n-1)
```

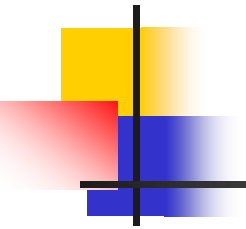
```
int factorial (int n) {
   if (n==0)
      return (1);
   else
      return (n * factorial(n-1));
}
```



Recursion

- Solution in terms of itself
- Must terminate

- Recursive functions have equivalent iterative functions.



Essence of Recursion

- Remember
  - n = n -1
    - make the problem smaller
  - n = 0 or 1
    - terminate recursion
- Experiment
  - n = 2, 3, 4, or 5
- Draw a Recursion Diagram

How Recursion Works: First Way to Understand It

```
void main(){

result = factorial(3);
}

int factorial (int n) {
    if (n==0)
        return (1);
    else
        return (n * factorial(n-1));
}
```

Evaluating Recursion (Using an Array)

```
void main(){

result = factorial(3);
}

int factorial (int n) {
    if (n==0)
        return (1);
    else
        return (n * factorial(n-1));
}
```

(Step by Step Illustration) Start

result =	factorial(3)

(1/8)

return (3 *	factorial(2)
result =	factorial(3)

(2/8)

return (2 *	factorial(1)
return (3 *	factorial(2)
result =	factorial(3)

(3/8)

return (1 *	factorial(0)
return (2 *	factorial(1)
return (3 *	factorial(2)
result =	factorial(3)

(4/8)

return (1)	
return (1 *	factorial(0)
return (2 *	factorial(1)
return (3 *	factorial(2)
result =	factorial(3)

(5/8)

return (1 *	1
return (2 *	factorial(1)
return (3 *	factorial(2)
result =	factorial(3)

(6/8)

return (2 *	1
return (3 *	factorial(2)
result =	factorial(3)

(7/8)

return (3 *	2
result =	factorial(3)

(8/8)

result =	6

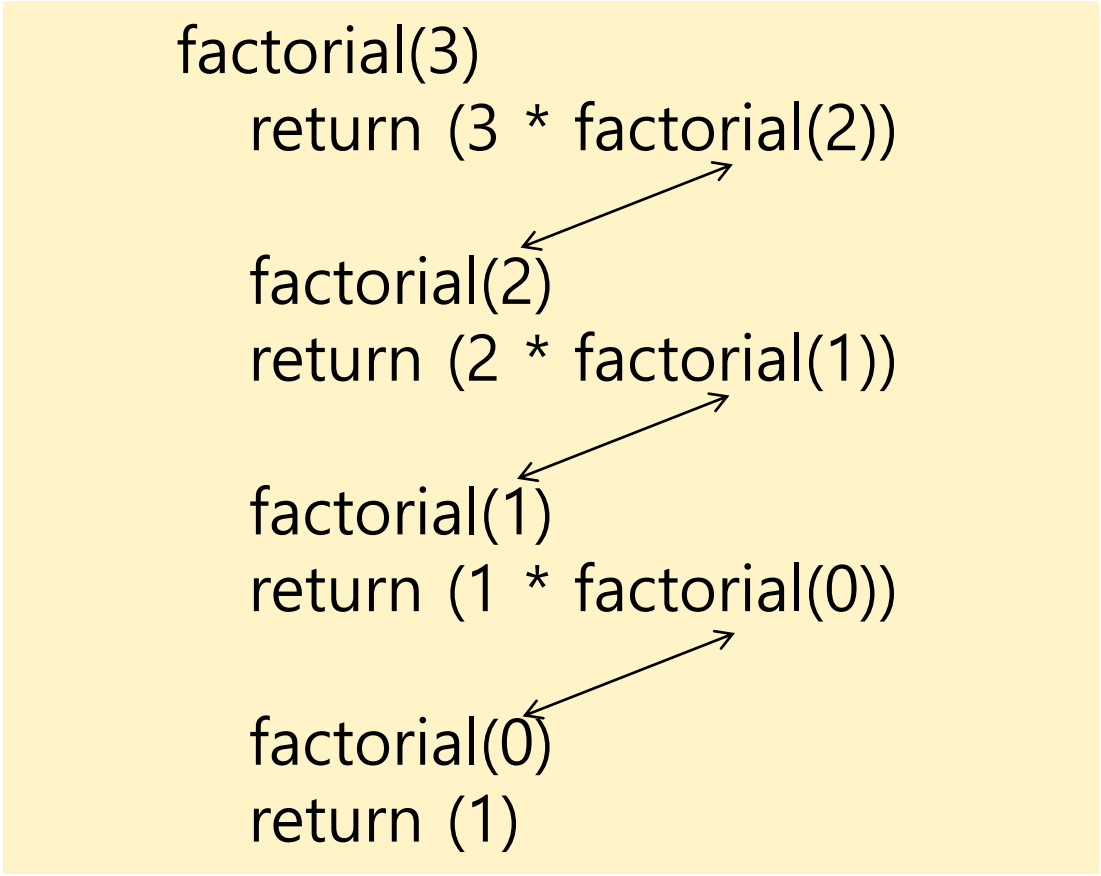
How Recursion Works: Second Way to Understand It

```
void main(){

result = factorial(3);
}

int factorial (int n) {
    if (n==0)
        return (1);
    else
        return (n * factorial(n-1));
}
```

1. factorial(3)
   3 * factorial(2)
2. factorial(2)
   2 * factorial(1)
3. factorial(1)
   1 * factorial(0)
4. factorial(0)
   return 1

5. 1 * 1
6. 2 * (1 * 1)
7. 3 * (2 * (1 * 1))

Recursion Diagram (1)



Recursion Diagram (2)

```
factorial(3)
3 * factorial(2)
    2 * factorial(1)
        1 * factorial(0)
            return 1

        1 * 1
    2 * (1 * 1)
3 * (2 * (1 * 1))
```

Simple Thinking
(*Imagine Each Call Is to a Different Function)

```
void main(){

result = factorial(3);
}

int factorial (int n) {
    if (n==0)
        return (1);
    else
        return (n * factorial(n-1));
}
```

1. factorial1(3)
   3 * factorial(2)
2. factorial2(2)
   2 * factorial(1)
3. factorial3(1)
   1 * factorial(0)
4. factorial4(0)
   return 1

5. 1 * 1
6. 2 * (1 * 1)
7. 3 * (2 * (1 * 1))

Exercise: Write a recursive C function that returns the n^{th} number in a Fibonacci sequence, and draw a recursion diagram.

- Fibonacci sequence

  0, 1, 1, 2, 3, 5, 8, 13, 21, 34, 55, 89, 144,…

- How to formulate this?
  - What is the pattern?
  - How to terminate the recursion?

Solution (formulation and code)

- Fib(n) = n for n < 2
- Fib(n) = Fib(n-1) + Fib(n-2) for n >=2

```
int  fib (int n) {

   if (n < 0)
      return -1;
   if (n < 2)
      return  n;
   return (fib(n-1) + fib(n-2);
}
```

Recursion Diagram (for n=4)

- Fib(n) = n for n < 2
- Fib(n) = Fib(n-1) + Fib(n-2) for n >=2

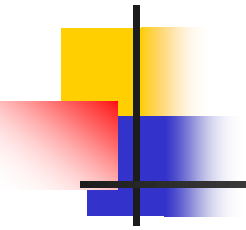
```
fib(4) =      fib(3)
                 fib(2)
                    fib(1)
                      1
                      1 + fib(0)
                      1 +  0
                   1  +  fib(1)
                   1  +   1
                2   +  fib(2)
                2   +      fib(1)
                2   +          1 + fib(0)
                2   +          1 +   0     =  3
```

Exercise: Draw a Recursion Diagram for wrt_backward (using "okay₩n" as input)

```
#include <stdio.h>
void wrt_backward(void);

void main () {
    printf ("input a line");
    wrt_back();
    printf ("₩n");
}

void wrt_backward() {
    int c;
    if ((c = getchar()) != '₩n')
        wrt_backward();
    putchar(c);
}
```

Recursive Function vs. Iterative Function

- For a recursive function, there is an equivalent iterative function.
- Recursive function may be more compact.
  - Often used for operations on data structures



Exercise: Write an Iterative Factorial Function

```
int iter_factorial (int n)
```

Solution

```
int iter_factorial (int n) {
    int result = 1;
    int k;
    for (k = 1; k <= n; k++) {
        result = result * k;
    }
    return result;
}
```

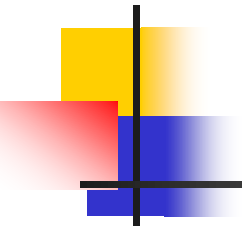
Exercise: Write a Recursive Function

- for adding the first n elements of an array a[ ]

```
int sum_of (int a[], int n)
```

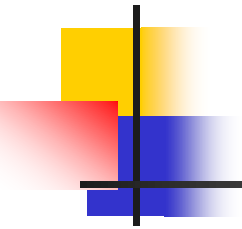
Solution

```
int sum_of (int a[], int n) {
    if (n < 1 || n > MAX) {
        printf ("array boundary error");
        exit(1); }
    else
        if (n == 1)
            return a[0];
        else
            return (a[n-1] + sum_of (a,n-1));
```



Exercise: Draw a Recursion Diagram

- For adding the first 4 elements of array (20, 30, 10, 50, 15, 45, 80, 25)

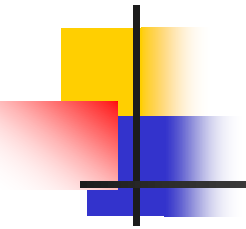


Exercise: Write a Recursive pow Function

- double pow (float, int)

Solution

```
double power(float val, int pow) {

    if (pow == 0)       /* pow(x, 0) returns 1 */
        return(1.0);
    else
        return (power (val, pow - 1) * val); }
```



Exercise

- Draw a recursion diagram (for power (100, 3)

Homework: (5 points) Draw a recursion diagram, and the result of calling the following recursive function with n=5.

```
int puzzle(int n) {
    if (n == 1)
        return 1;
    if (n % 2 == 0)
      return (puzzle(n/2) + n);
    else
      return (puzzle(3*n+1));
}
```

Homework (10 points)

- The C program on the next page is a recursive function.
- Draw a recursion diagram for n=5, and list contains 5, 10, 15, 25, 45.
- State what the program is designed to do.
  - To find this, experiment with a few lists of different sizes (n), and different contents.
  - Note: The list must be pre-sorted; for example,

    (1,3,4,6,8,10,11),

    (23,24,25, 27,29,30,35,40,45,46,50)

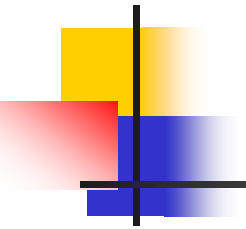
Example Program

```
int bs(int list[], int lo, int hi, int key)
{
    int mid;

    if (lo > hi)
        return -1;
    mid = (lo + hi) / 2;
    if (list[mid] == key)
        return 0;
    else if (list[mid] > key)
        bs(list, lo, mid - 1, key);
    else if (list[mid] < key)
        bs(list, mid + 1, hi, key);
}
```

Program Patterns

Data Processing Program Patterns

- Data Search
- Data Update
- Data Copying & Moving
- Data Transformation
- Data Reorganization
- Data Derivation



Roadmap

- Data update
- Data copying/moving

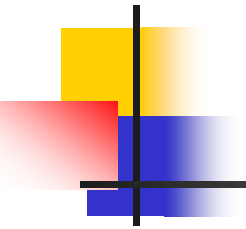
Some WORD Operations (Update After Search)

- Case Changes
  - all lower case, all uppercase, first letter uppercase
- Font Changes
  - bold, italic
  - Size
  - type
- Color Changes
- Move
- Copy
- Delete
- Update
- Insert

Types of Data Update

- insert
- append
- update/replace
- delete

- Often there are constraints on update.
  - semantic constraints
  - physical constraints



Constraints

- A constraint is a condition the data must satisfy for insert, update, and delete.
- (A Program) Must check constraints on insert, update and delete of data

Types of Constraint

- Semantic constraints on data
  - data type
    - char, int, float, ADT,…
  - data value range
    - (17..65), (>16000 && <250000),…
  - uniqueness of key
  - null-value allowed
  - conditional value
    - < avg (age), > min (salary),…
  - …
- Physical constraints on data
  - sort order (ascending or descending order)
  - physical size

Value Range Constraint

constraint: (>=17 && <=65)

Age

17
20
20
25
25
65

insert 75 (invalid)
insert 45 (valid)

Uniqueness Constraint

constraint: (e.g.) name must be unique.

name

Bae
Chung
Hong
Kong
Kim
Lee

insert Kim (invalid)
insert Choi (valid)

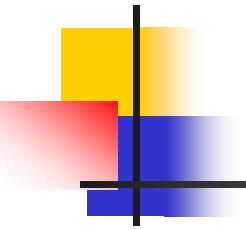
Conditional Value Constraint

constraint: (e.g.)
(age must be > or < 5 of the average age)

age

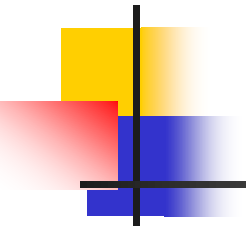
20
20
30
30

insert 75 (invalid)
insert 29 (valid)



Roadmap

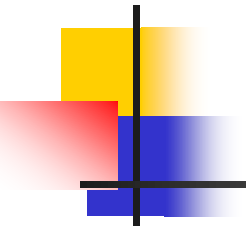
- Data update
- Data copying/moving



Data Copying & Moving

- data copying
  - strcpy
  - strcat
- data moving
- data compaction

Data Copying



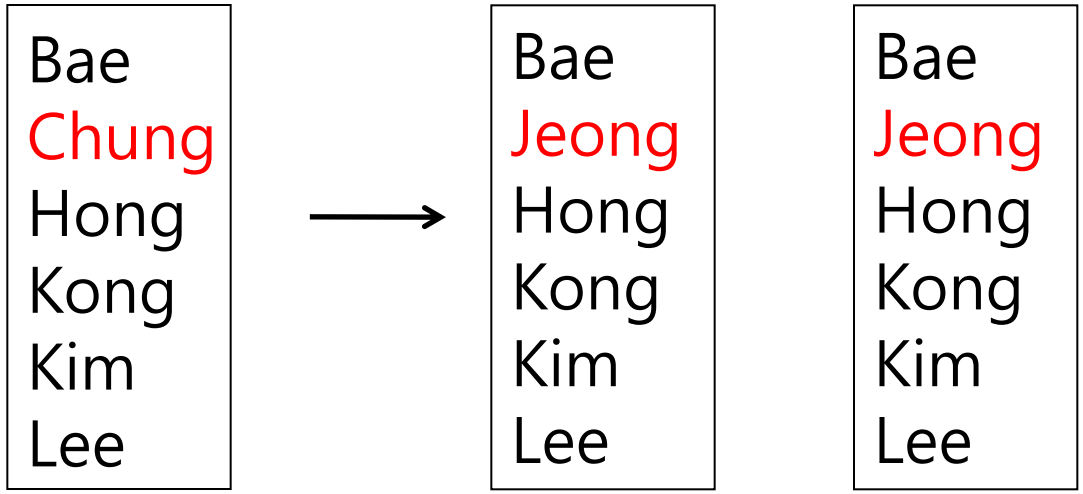
Data Copying

- From one data structure to another
  - between the same type of data structure
    - from a 1-dimensional array to a 1-dimensional array
    - from a singly linked list to a singly linked list
    - …
  - between different types of data structure
    - from an array to a linked list
    - from a singly linked list to a doubly linked list
    - …
- Data synchronization problem
  - Update to one copy may need to be made to all other copies.
- Data copy integrity problem
  - need to verify correctness when copying

Data Synchronization

Chung
changed to
Jeong

Jeong



copy 1 copy 2 copy 3

Integrity Problem on Data Copying/Transmission

original	copy	copy
Bae	Bae	Bae
Chung	Chung	Hing
Hong	Hong	King
Kong	Kong	Kom
Kim	Kin	Lee
Lee	Lee	

Verification Data

- Checksum
  - Use computation on all data being copied or moved
  - exclusive OR, add, some other function are used
- Special data
  - total count or average or timestamp or some other data can be separately stored or computed (to verify other data).

Checksum

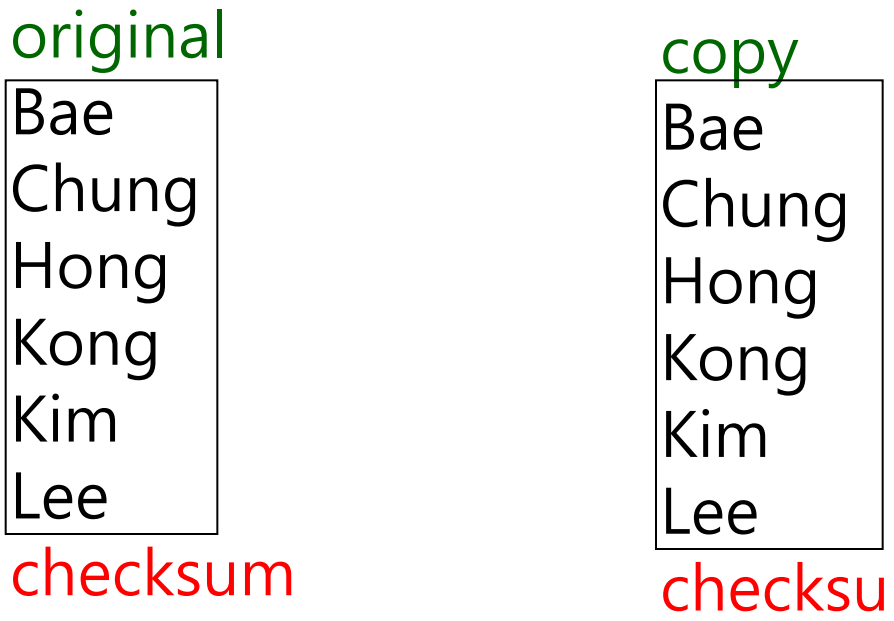
checksum = Bae ^ Chung ^ Hong ^ Kong ^….

(* ^ is bit-wise exclusive OR (later))

Checksum is computed for the original.

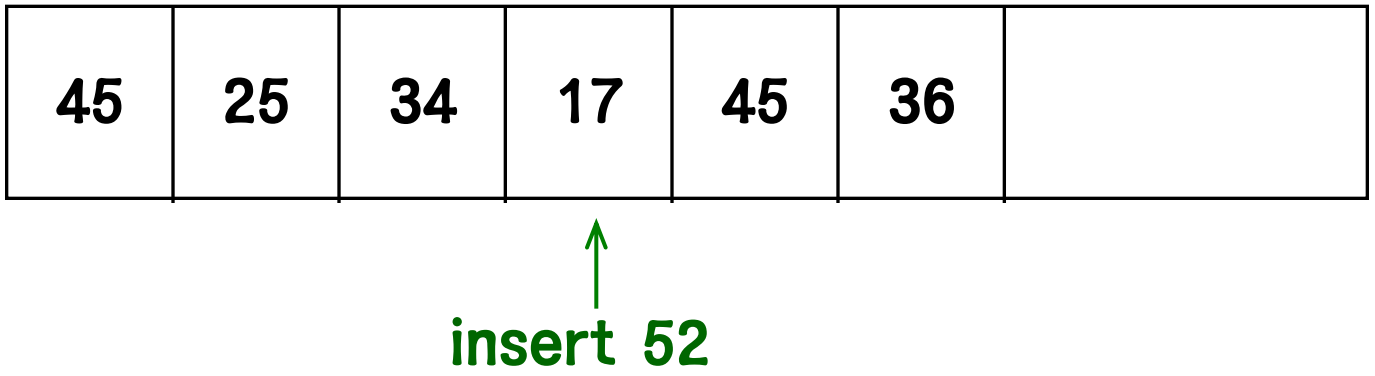
Checksum is computed for the copy and compared with the checksum for the original.

If the two checksums are the same, copying was OK.



Data Moving

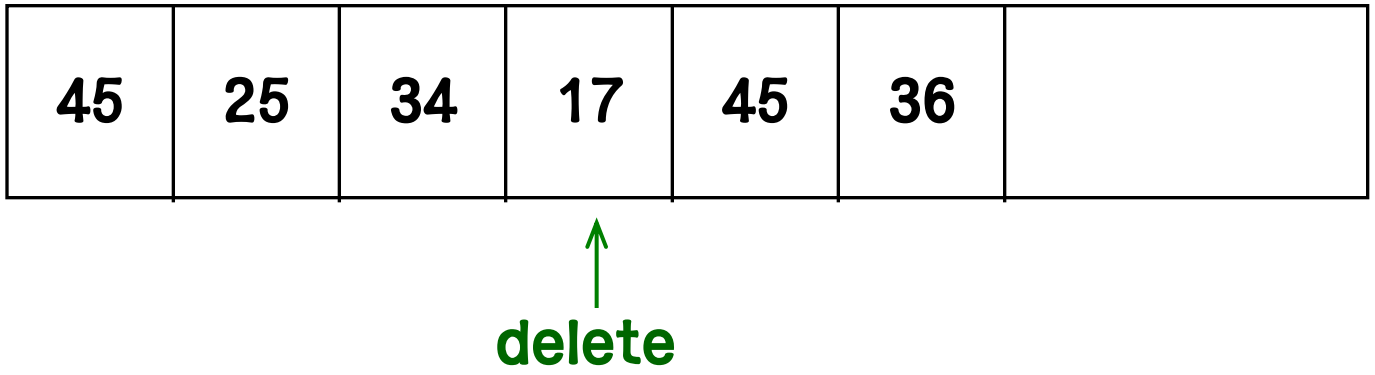
Data Moving in an Array Due To Insert



logic:

define array-2.
copy data before the insert point in array-1
to array-2.
append the new data to array-2.
append data after the insert point in array-1
to array-2

Data Moving in an Array Due To Delete



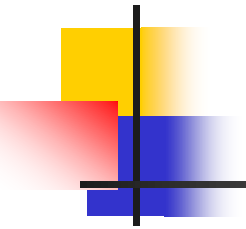
logic-1

leave NULL for the deleted array element.

logic-2:

move all data after the delete point in the array one position to the left

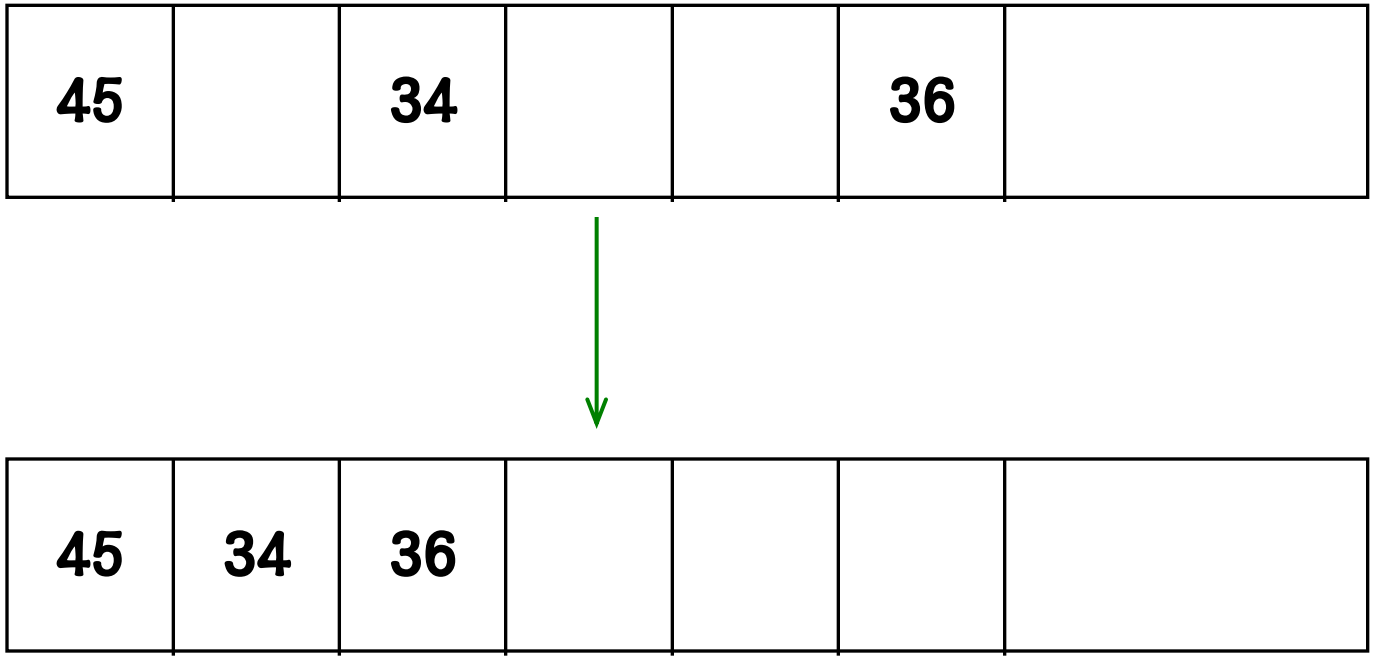
Data Compaction



Data Compaction

- For main memory
  - Garbage collection
  - Fill unused memory locations by moving data from other memory locations.
- For hard disk drive
  - Fill unused memory locations by moving data from other memory locations.
  - Form blocks of unused memory locations for allocation later.

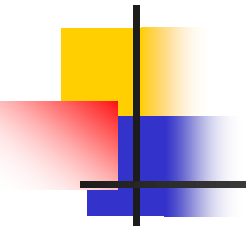
Illustration



Lab (10 points): Inserting a new element into a struct array with constraints

```
struct {
    char RRN[13];            // constraint: unique
    char name[20];
    float salary;
    float bonus;             //  constraint: bonus < salary
} employee[1000];
```

- Write the following C program:
  - Read RRN, name, salary and bonus and insert it to a struct array employee
  - Check constraints before insertion and print suitable error message if it is invalid
    - Two kinds of error messages – see above inline comments



End of Class