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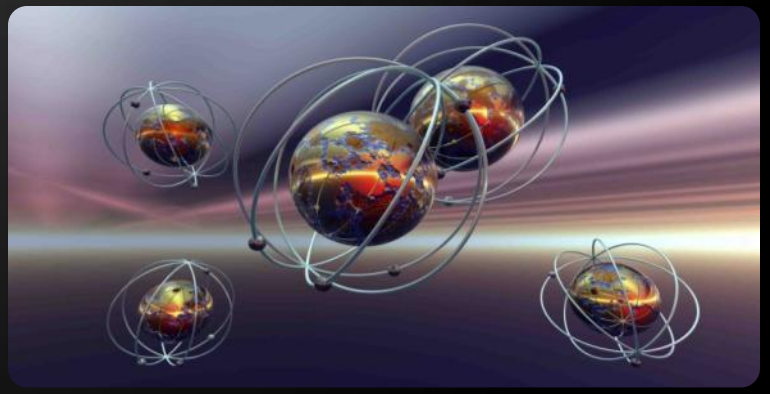
Methodology of Problem Solving

Efficiently Solving Computer Programming Problems



Data Structures and Algorithms

Telerik Software Academy

http://academy.telerik.com

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Problems Solving

From Chaotic to Methodological Approach

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Understanding the Requirements

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Read and Analyze the Problems

- Consider you are at traditional computer programming exam or contest
  - You have 5 problems to solve in 8 hours
- First read carefully all problems and try to estimate how complex each of them is
  - Read the requirements, don't invent them!
- Start solving the most easy problem first!
- Leave the most complex problem last!
- Approach the next problem when the previous is completely solved and well tested

Analyzing the Problems

- Example: we are given 3 problems:
  1. Shuffle-cards
     - Shuffle a deck of cards in random order
  2. Students
     - Read a set of students and their marks and print top 10 students with the best results (by averaging their marks)
  3. Sorting numbers
     - Sort a set of numbers in increasing order

Analyzing the Problems (2)

- Read carefully the problems and think a bit about their possible solutions
- Order the problems from the easiest to the most complex:
  1. Sorting numbers
     - Trivial – we can use the built-in sorting in .NET
  2. Shuffle-cards
     - Need to randomize the elements of array
  3. Students
     - Needs summing, sorting and text file processing

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Using a Paper and a Pen

Visualizing and Sketching your Ideas

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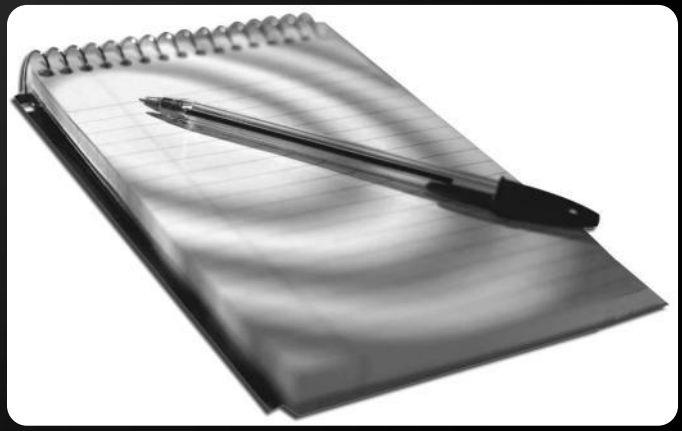
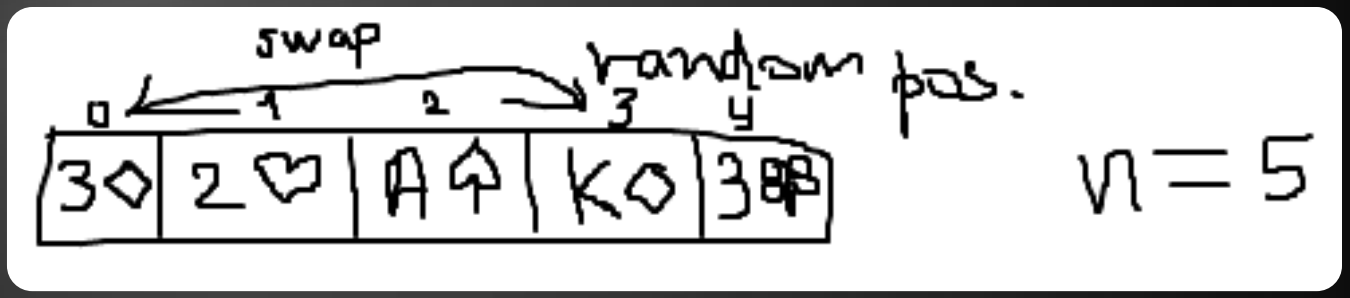
Use a Sheet of Paper and a Pen

- Never start solving a problem without a sheet of paper and a pen
  - You need to sketch your ideas
  - Paper and pen is the best visualization tool
    - Allows your brain to think efficiently
  - Paper works faster than keyboard / screen
  - Other visualization tool could also work well



Paper and Pen

- Consider the "cards shuffle" problem
  - We can sketch it to start thinking



  - Some ideas immediately come, e.g.
    - Split the deck into two parts and swap them a multiple times
    - Swap 2 random cards a random number of times
    - Swap each card with a random card

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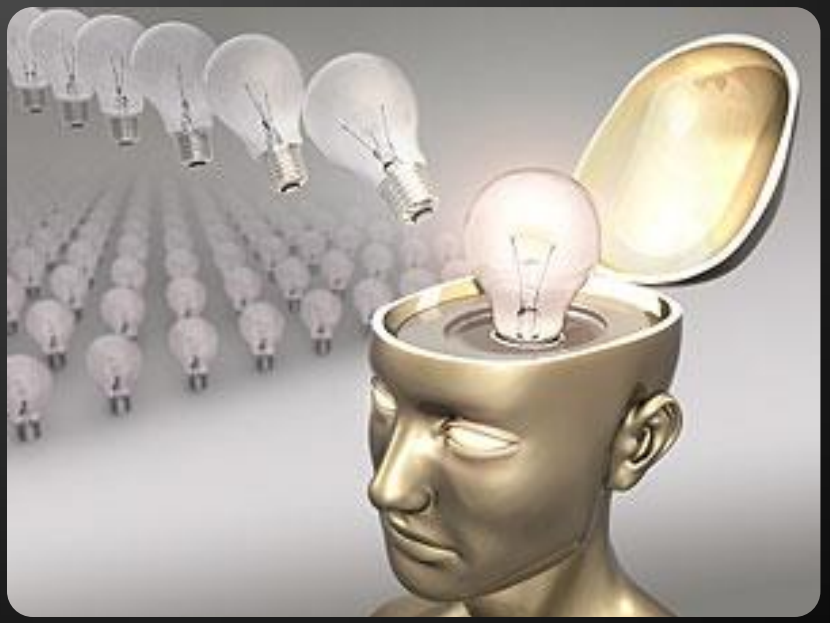
Invent Ideas

Think-up, Invent Ideas and Check Them



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Think up, Invent and Try Ideas

- First take an example of the problem
  - Sketch it on the sheet of paper
- Next try to invent some idea that works for your example
- Check if your idea will work for other examples
  - Try to find a case that breaks your idea
  - Try challenging examples and unusual cases
- If you find your idea incorrect, try to fix it or just invent a new idea

Invent and Try Ideas – Example

- Consider the "cards shuffle" problem
- Idea #1: random number of times split the deck into left and right part and swap them
  - How to represent the cards?
  - How to chose a random split point?
  - How to perform the exchange?
- Idea #2: swap each card with a random card
  - How many times to repeat this?
  - Is this fast enough?

Invent and Try Ideas – Example (2)

- Idea #3: swap 2 random cards a random number of times
  - How to choose two random cards?
  - How many times repeat this?
- Idea #4: choose a random card and insert it in front of the deck
  - How to choose random card?
  - How many times repeat this?

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Divide and Conquer

Decompose Problems into Manageable Pieces

Decompose the Problem into Subproblems

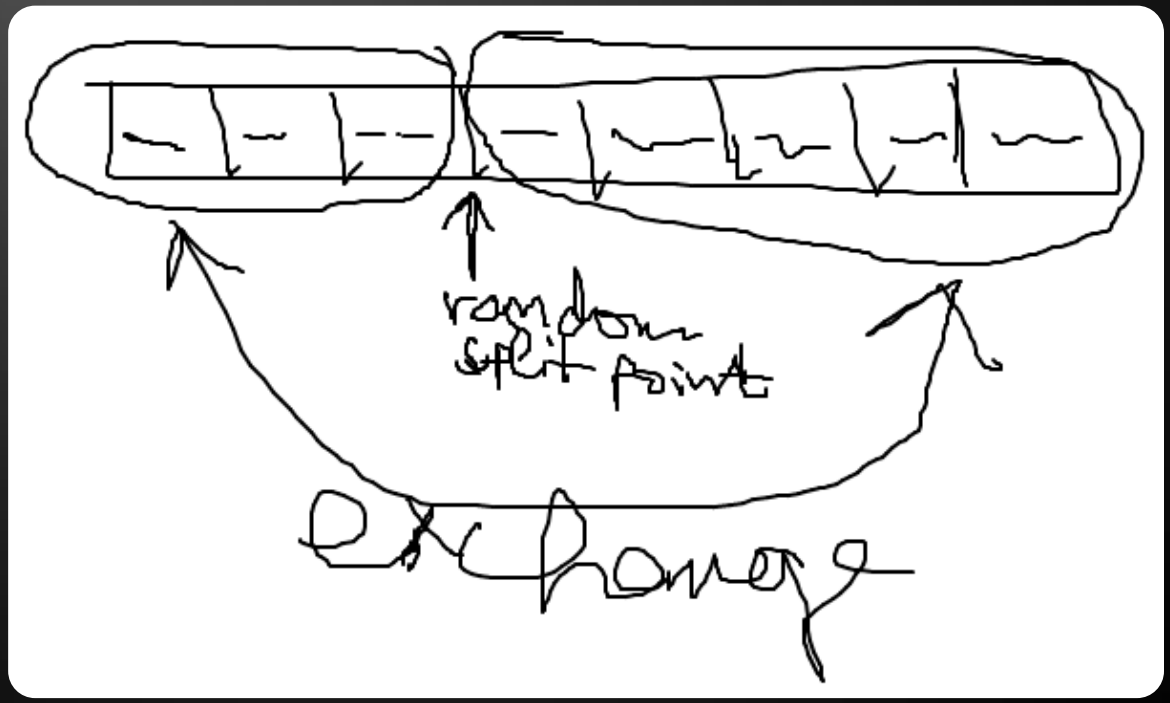
- Work decomposition is natural in engineering
  - It happens every day in the industry
  - Projects are decomposed into subprojects
- Complex problems could be decomposed into several smaller subproblems
  - Technique known as "Divide and Conquer"
  - Small problems could easily be solved
  - Smaller subproblems could be further decomposed as well

Divide and Conquer – Example

- Let's try idea #1:
  - Multiple times split the deck into left and right part and swap them
- Divide and conquer
  - Subproblem #1 (single exchange) – split the deck into two random parts and exchange them
  - Subproblem #2 – choosing a random split point
  - Subproblem #3 – combining single exchanges
    - How many times to perform "single exchange"?

Subproblem #1 (Single Exchange)

- Split the deck into 2 parts at random split point and exchange these 2 parts
  - We visualize this by paper and pen:



Subproblem #2 (Random Split Point)

- Choosing a random split point
  - Needs to understand the concept of pseudo-random numbers and how to use it
  - In Internet lots of examples are available, some of them incorrect
- The class `System.Random` can do the job
- Important detail is that the `Random` class should be instantiated only once
  - Not at each random number generation

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Subproblem #3 (Combining Single Exchanges)

- Combining a sequence of single exchanges to solve the initial problem
  - How many times to perform single exchanges to reliably randomize the deck?
  - N times (where N is the number of the cards) seems enough
- We have an algorithm:
  - N times split at random position and exchange the left and right parts of the deck

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Check-up Your Ideas

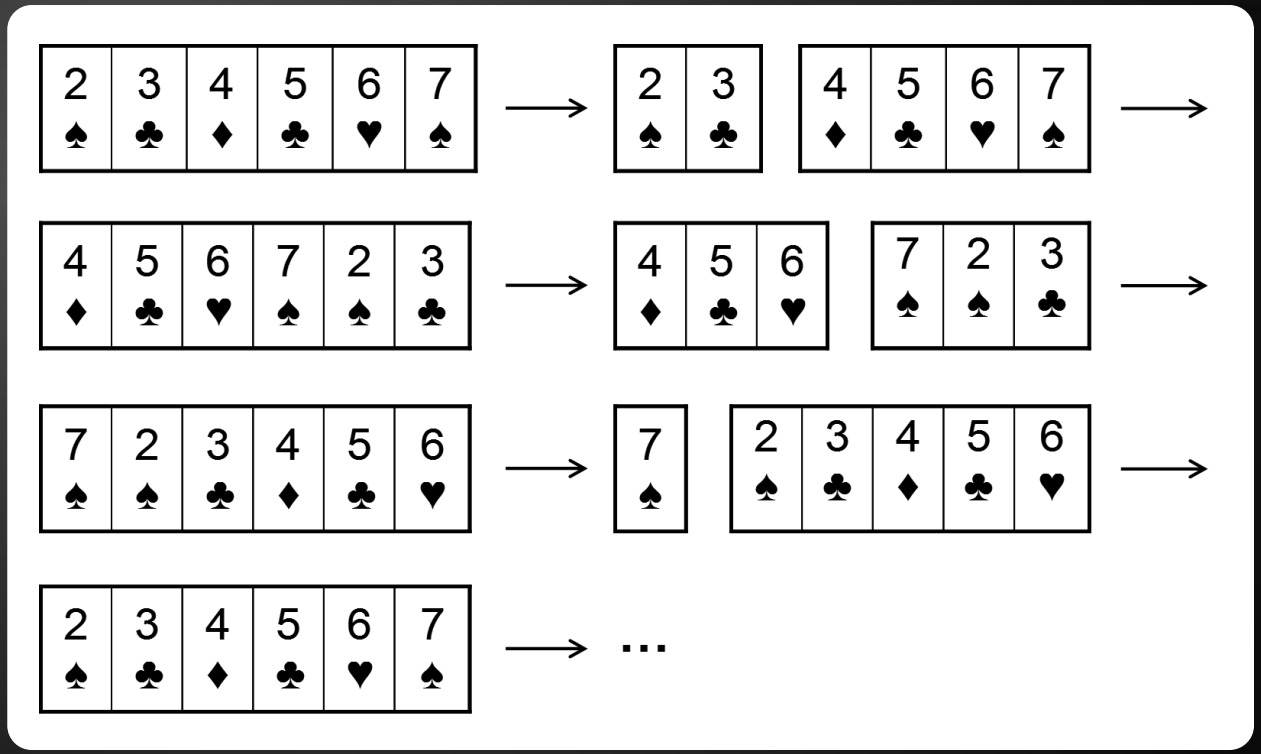
Don't go Ahead before Checking Your Ideas

Check-up Your Ideas

- Check-up your ideas with examples
  - It is better to find a problem before the idea is implemented
  - When the code is written, changing radically your ideas costs a lot of time and effort
- Carefully select examples for check-up
  - Examples should be simple enough to be checked by hand in a minute
  - Examples should be complex enough to cover the most general case, not just an isolated case

Check-up Your Ideas – Example

- Let's check the idea:



- After 3 random splits and swaps we obtain the start position → seems like a bug!

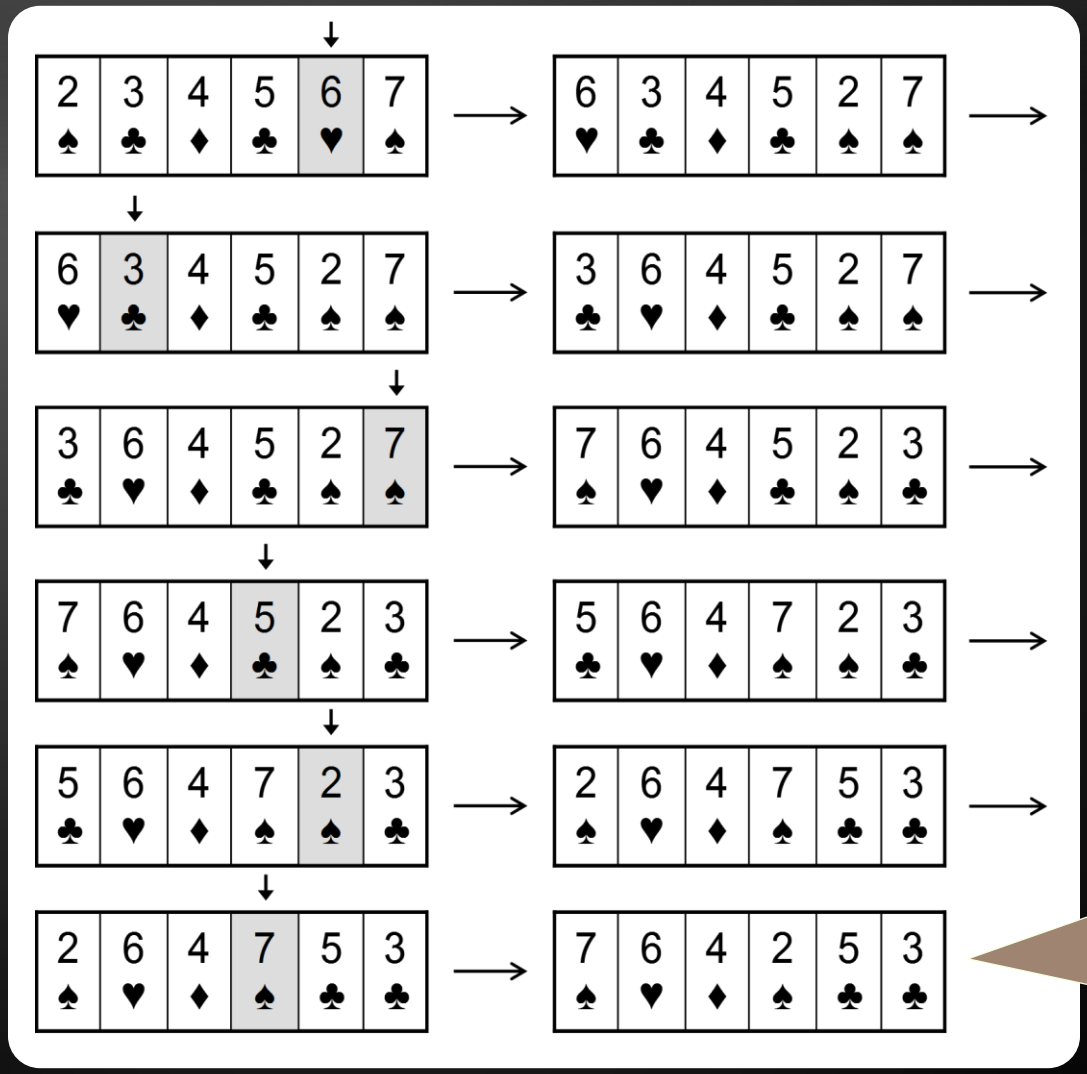
Invent New Idea If Needed

- What to do when you find your idea is not working in all cases?
  - Try to fix your idea
    - Sometime a small change could fix the problem
  - Invent new idea and carefully check it
- Iterate
  - It is usual that your first idea is not the best
  - Invent ideas, check them, try various cases, find problems, fix them, invent better idea, etc.

Invent New Ideas – Example

- Invent few new ideas:
  - New idea #1 – multiple times select 2 random cards and exchange them
  - New idea #2 – multiple times select a random card and exchange it with the first card
  - New idea #3 – multiple times select a random card and move it to an external list
- Let's check the new idea #2
  - Is it correct?

Check-up the New Idea – Example



The result seems correct

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Think about Data Structures

Select Data Structures that Will Work Well

Choosing Appropriate Data Structures

- Choose appropriate data structures before the start of coding
  - Think how to represent input data
  - Think how to represent intermediate program state
  - Think how to represent the requested output
- You could find that your idea cannot be implemented efficiently
  - Or implementation will be very complex or inefficient

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Choose Appropriate Data Structures – Example

- How to represent a single card?
  - The best idea is to create a structure `Card`
    - `Face` – could be `string`, `int` or enumeration
    - `Suit` – enumeration
- How to represent a deck of cards?
  - Array – `Card[]`
  - Indexed list – `List<Card>`
  - `Set` / `Dictionary` / `Queue` / `Stack` – not a fit

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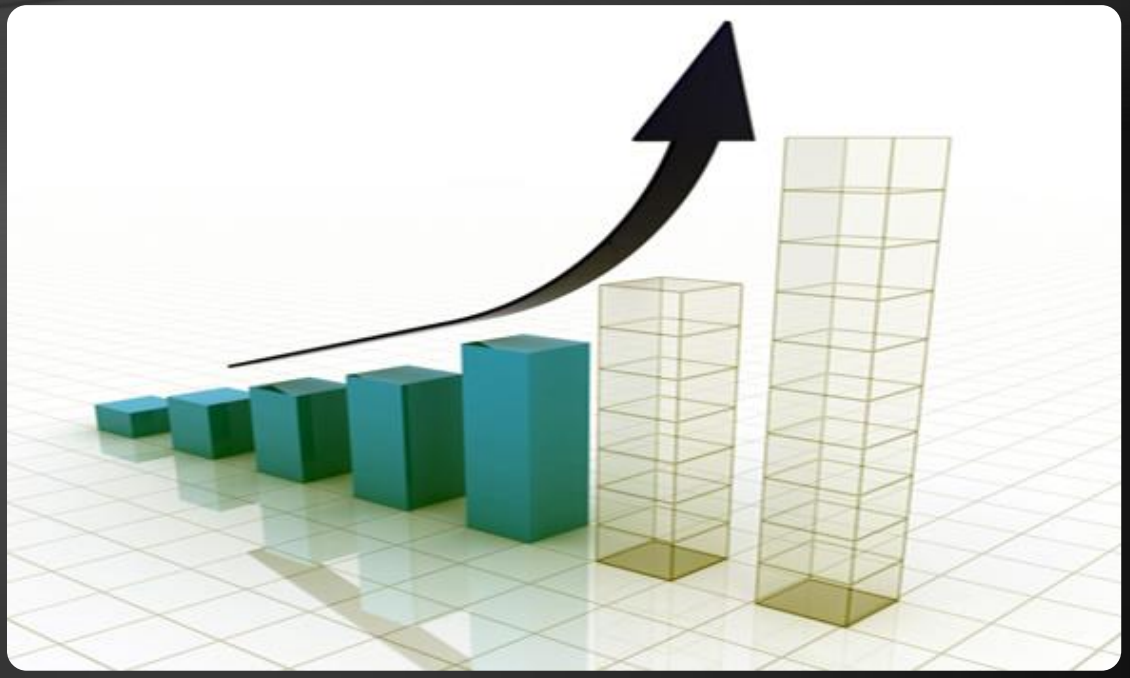

Efficiency and Performance

Is Your Algorithm Fast Enough?

Think About the Efficiency

- Think about efficiency before writing the first line of code
  - Estimate the running time (asymptotic complexity)
  - Check the requirements
    - Will your algorithm be fast enough to conform with them
- You don't want to implement your algorithm and find that it is slow when testing
  - You will lose your time

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Efficiency is not Always Required

- Best solution is sometimes just not needed
  - Read carefully your problem statement
  - Sometimes ugly solution could work for your requirements and it will cost you less time
  - Example: if you need to sort n numbers, any algorithm will work when $n \in [0..500]$
- Implement complex algorithms only when the problem really needs them

Efficiency – Example

- How much cards we have?
  - In a typical deck we have 52 cards
    - No matter how fast the algorithm is – it will work fast enough
  - If we have N cards, we perform N swaps → the expected running time is O(N)
  - O(N) will work fast for millions of cards
- Conclusion: the efficiency is not an issue in this problem

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Implementation

Coding and Testing Step-by-Step

Start Coding: Check List

- Never start coding before you find correct idea that will meet the requirements
  - What you will write before you invent a correct idea to solve the problem?
- Checklist to follow before start of coding:
  - Ensure you understand well the requirements
  - Ensure you have invented a good idea
  - Ensure your idea is correct
  - Ensure you know what data structures to use
  - Ensure the performance will be sufficient

Coding Check List – Example

- Checklist before start of coding:
  - Ensure you understand well the requirements
    - Yes, shuffle given deck of cards
  - Ensure you have invented a correct idea
    - Yes, the idea seems correct and is tested
  - Ensure you know what data structures to use
    - Class `Card`, enumeration `Suit` and `List<Card>`
  - Ensure the performance will be sufficient
    - Linear running time → good performance

Implement your Algorithm Step-by-Step

- "Step-by-step" approach is always better than "build all, then test"
  - Implement a piece of your program and test it
  - Then implement another piece of the program and test it
  - Finally put together all pieces and test it
- Small increments (steps) reveal errors early
  - "Big bang" integration takes more time

Step #1 – Class Card

```
class Card
{
  public string Face { get; set; }
  public Suit Suit { get; set; }

  public override string ToString()
  {
    string card =
      "(" + this.Face + " " + this.Suit +")";
    return card;
  }
}

enum Suit
{
  Club, Diamond, Heart, Spade
}
```

Step #1 – Test

- Testing the class Card to get feedback as early as possible:

```
static void Main()
{
  Card card = new Card() { Face="A", Suit=Suit.Club };
  Console.WriteLine(card);
}
```

- The result is as expected:

```
(A Club)
```

Step #2 – Create and Print a Deck of Cards

```
static void Main()
{
  List<Card> cards = new List<Card>();
  cards.Add(new Card() { Face = "7", Suit = Suit.Heart });
  cards.Add(new Card() { Face = "A", Suit = Suit.Spade });
  cards.Add(new Card() { Face = "10", Suit = Suit.Diamond });
  cards.Add(new Card() { Face = "2", Suit = Suit.Club });
  cards.Add(new Card() { Face = "6", Suit = Suit.Diamond });
  cards.Add(new Card() { Face = "J", Suit = Suit.Club });
  PrintCards(cards);
}

static void PrintCards(List<Card> cards)
{
  foreach (Card card in cards)
  {
    Console.Write(card);
  }
  Console.WriteLine();
}
```

Step #2 – Test

- Testing the deck of cards seems to be working correctly:

```
(7 Heart)(A Spade)(10 Diamond)(2 Club)(6 Diamond)(J Club)
```

Step #3 – Single Exchange

```
static void PerformSingleExchange(List<Card> cards)
{
  Random rand = new Random();
  int randomIndex = rand.Next(1, cards.Count - 1);
  Card firstCard = cards[1];
  Card randomCard = cards[randomIndex];
  cards[1] = randomCard;
  cards[randomIndex] = firstCard;
}
```

Step #3 – Test

- To test the single exchange we use the following code:

```
static void Main()
{
  List<Card> cards = new List<Card>();
  cards.Add(new Card() { Face = "2", Suit = Suit.Club });
  cards.Add(new Card() { Face = "3", Suit = Suit.Heart });
  cards.Add(new Card() { Face = "4", Suit = Suit.Spade });
  PerformSingleExchange(cards);
  PrintCards(cards);
}
```

- The result is unexpected:

```
(2 Club)(3 Heart)(4 Spade)
```

Step #3 – Fix Bug and Test

- The first element of list is at index 0, not 1:

```
static void PerformSingleExchange(List<Card> cards)
{
  Random rand = new Random();
  int randomIndex = rand.Next(1, cards.Count - 1);
  Card firstCard = cards[0];
  Card randomCard = cards[randomIndex];
  cards[0] = randomCard;
  cards[randomIndex] = firstCard;
}
```

- The result is again incorrect (3 times the same):

```
(3 Heart)(2 Club)(4 Spade)
(3 Heart)(2 Club)(4 Spade)
(3 Heart)(2 Club)(4 Spade)
```

Step #3 – Fix Again and Test

- Random.Next() has exclusive end range:

```
static void PerformSingleExchange(List<Card> cards)
{
  Random rand = new Random();
  int randomIndex = rand.Next(1, cards.Count);
  Card firstCard = cards[0];
  Card randomCard = cards[randomIndex];
  cards[0] = randomCard;
  cards[randomIndex] = firstCard;
}
```

- The result now seems correct:

```
(3 Heart)(2 Club)(4 Spade)
(4 Spade)(3 Heart)(2 Club)
(4 Spade)(3 Heart)(2 Club)
```

Step #4 – Shuffle the Deck

- Shuffle the entire deck of cards:

```
static void ShuffleCards(List<Card> cards)
{
  for (int i = 1; i <= cards.Count; i++)
  {
    PerformSingleExchange(cards);
  }
}
```

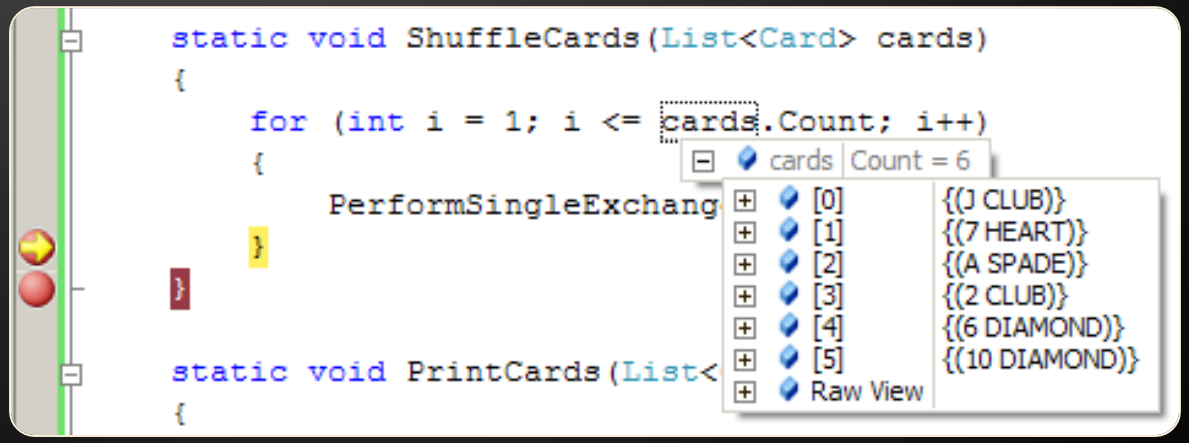
- The result is surprisingly incorrect:

```
Initial deck: (7 Heart)(A Spade)(10 Diamond)(2 Club)(6
Diamond)(J Club)
After shuffle: (7 Heart)(A Spade)(10 Diamond)(2 Club)(6
Diamond)(J Club)
```

Step #4 – Strange Bug

- When we step through the code with the debugger, the result seems correct:

```
Initial deck:  (7 Heart)(A Spade)(10 Diamond)(2 Club)(6
Diamond)(J Club)
After shuffle: (10 Diamond)(7 Heart)(A Spade)(J Club)(2
Club)(6 Diamond)
```



- Without the debugger the result is wrong!

Step #4 – Fix Again and Test

- Random should be instantiated only once:

```
private static Random rand = new Random();
static void PerformSingleExchange(List<Card> cards)
{
  int randomIndex = rand.Next(1, cards.Count);
  Card firstCard = cards[0];
  Card randomCard = cards[randomIndex];
  cards[0] = randomCard;
  cards[randomIndex] = firstCard;
}
```

- The result finally is correct with and without the debugger

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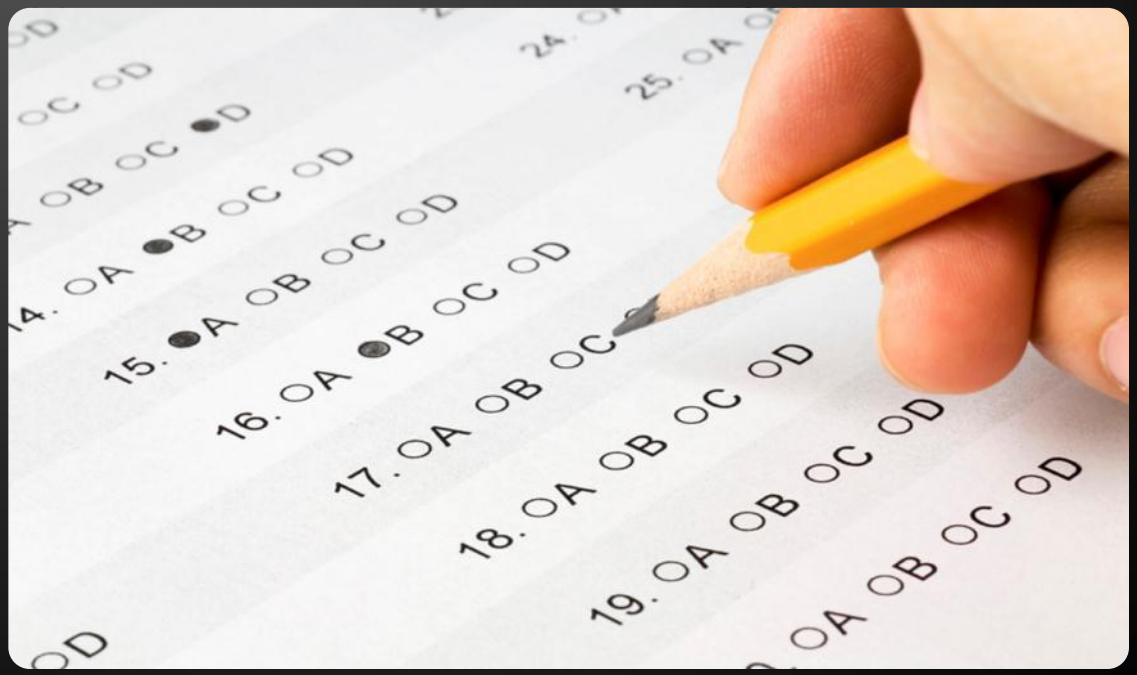
Testing

Thoroughly Test Your Solution



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Thoroughly Test your Solution

- Wise software engineers say that:
  - Inventing a good idea and implementing it is half of the solution
  - Testing is the second half of the solution
- Always test thoroughly your solution
  - Invest in testing
  - One 90-100% solved problem is better than 2 or 3 partially solved
  - Testing existing problem takes less time than solving another problem from scratch

How to Test?

- Testing could not certify absence of defects
  - It just reduces the defects rate
  - Well tested solutions are more likely to be correct
- Start testing with a good representative of the general case
  - Not a small isolated case
  - Large and complex test, but
    - Small enough to be easily checkable

How to Test? (2)

- Test the border cases
  - E.g. if n ∈ [0..500] → try n=0 , n=1, n=2, n=499, n=500
- If a bug is found, repeat all tests after fixing it to avoid regressions
- Run a load test
  - How to be sure that your algorithm is fast enough to meet the requirements?
  - Use copy-pasting to generate large test data

Read the Problem Statement

- Read carefully the problem statement
  - Does your solution print exactly what is expected?
  - Does your output follow the requested format?
  - Did you remove your debug printouts?
- Be sure to solve the requested problem, not the problem you think is requested!
  - Example: "Write a program to print the number of permutations on n elements" means to print a single number, not a set of permutations!

Testing – Example

- Test with full deck of 52 cards
  - Serious error found → change the algorithm
- Change the algorithm
  - Exchange the first card with a random card → exchange cards 0, 1, …, N-1 with a random card
  - Test whether the new algorithm works
- Test with 1 card
- Test with 2 cards
- Test with 0 cards
- Load test with 52 000 cards

Test with 52 Cards – Example

```
static void TestShuffle52Cards()
{
   List<Card> cards = new List<Card>();
   string[] allFaces = new string[] { "2", "3", "4", "5",
     "6", "7", "8", "9", "10", "J", "Q", "K", "A" };
   Suit[] allSuits = new Suit[] { Suit.Club, Suit.Diamond,
   Suit.Heart, Suit.Spade };
   foreach (string face in allFaces)
   {
      foreach (Suit suit in allSuits)
      {
         Card card = new Card() { Face = face, Suit = suit };
         cards.Add(card);
      }
   }
   ShuffleCards(cards);
   PrintCards(cards);
}
```

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Test with 52 Cards – Example (2)

- The result is surprising:

```
(4 Diamond)(2 Diamond)(6 Heart)(2 Spade)(A Spade)(7 Spade)(3
Diamond)(3 Spade)(4 Spade)(4 Heart)(6 Club)(K Heart)(5 Club)(5
Diamond)(5 Heart)(A Heart)(9 Club)(10 Club)(A Club)(6 Spade)(7
Club)(7 Diamond)(3 Club)(9 Heart)(8 Club)(3 Heart)(9 Spade)(4
Club)(8 Heart)(9 Diamond)(5 Spade)(8 Diamond)(J Heart)(10
Diamond)(10 Heart)(10 Spade)(Q Heart)(2 Club)(J Club)(J
Spade)(Q Club)(7 Heart)(2 Heart)(Q Spade)(K Club)(J Diamond)(6
Diamond)(K Spade)(8 Spade)(A Diamond)(Q Diamond)(K Diamond)
```

- Half of the cards keep their initial positions
  - We have serious problem – the randomization algorithm is not reliable

Fixing the Algorithm

- New idea that slightly changes the algorithm:
  - Exchange the first card with a random card → exchange cards 0, 1, …, N-1 with a random card

```
static void PerformSingleExchange(List<Card> cards, int index)
{
  int randomIndex = rand.Next(1, cards.Count);
  Card firstCard = cards[index];
  cards[index] = cards[randomIndex];
  cards[randomIndex] = firstCard;
}

static void ShuffleCards(List<Card> cards)
{
  for (int i = 0; i < cards.Count; i++)
  {
    PerformSingleExchange(cards, i);
  }
}
```

Test with 52 Cards (Again)

- The result now seems correct:

```
(9 Heart)(5 Club)(3 Club)(7 Spade)(6 Club)(5 Spade)(6 Heart)
(4 Club)(10 Club)(3 Spade)(K Diamond)(10 Heart)(8 Club)(A
Club)(J Diamond)(K Spade)(9 Spade)(7 Club)(10 Diamond)(9
Diamond)(8 Heart)(6 Diamond)(8 Spade)(5 Diamond)(4 Heart)
(10 Spade)(J Club)(Q Spade)(9 Club)(J Heart)(K Club)(2 Heart)
(7 Heart)(A Heart)(3 Diamond)(K Heart)(A Spade)(8 Diamond)(4
Spade)(3 Heart)(5 Heart)(Q Heart)(4 Diamond)(2 Spade)(A
Diamond)(2 Diamond)(J Spade)(7 Diamond)(Q Diamond)(2 Club)
(6 Spade)(Q Club)
```

- Cards are completely randomized

Test with 1 Card

- Create a method to test with 1 card:

```
static void TestShuffleOneCard()
{
  List<Card> cards = new List<Card>();
  cards.Add(new Card() { Face = "A", Suit = Suit.Club });
  CardsShuffle.ShuffleCards(cards);
  CardsShuffle.PrintCards(cards);
}
```

- We found a bug:

```
Unhandled Exception: System.ArgumentOutOfRangeException:
Index was out of range. Must be non-negative and less than
the size of the collection. Parameter name: index
…
```

Test with 1 Card – Bug Fixing

- We take 1 card are special case:

```
static void ShuffleCards(List<Card> cards)
{
  if (cards.Count > 1)
  {
    for (int i = 0; i < cards.Count; i++)
    {
      PerformSingleExchange(cards, i);
    }
  }
}
```

- Test shows that the problem is fixed

Test with 2 Cards

- Create a method to test with 2 cards:

```
static void TestShuffleTwoCards()
{
  List<Card> cards = new List<Card>();
  cards.Add(new Card() { Face = "A", Suit = Suit.Club });
  cards.Add(new Card() { Face = "3", Suit = Suit.Diamond });
  CardsShuffle.ShuffleCards(cards);
  CardsShuffle.PrintCards(cards);
}
```

- Bug: sequential executions get the same result:

```
(3 Diamond)(A Club)
```

- The problem: the first and the second cards always exchange each other exactly once

Test with 2 Cards – Bug Fixing

- We allow each card to be exchanged with any other random card, including itself

```
static void PerformSingleExchange(List<Card> cards, int
index)
{
  int randomIndex = rand.Next(0, cards.Count);
  Card firstCard = cards[index];
  Card randomCard = cards[randomIndex];
  cards[index] = randomCard;
  cards[randomIndex] = firstCard;
}
```

- Test shows that the problem is fixed

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Test with 0 Cards; Regression Tests

- Testing with 0 cards (empty list) generates an empty list → correct result
- Seems like the cards shuffle algorithm works correctly after the last few fixes
- Needs a regression test
  - Test again that new changes did not break all previously working cases
- Test with full deck of 52 cards; with 1 card; with 2 cards with 0 cards → everything works

Load Test – 52 000 Cards

- Finally we need a load test with 52 000 cards:

```
static void TestShuffle52000Cards()
{
  List<Card> cards = new List<Card>();
  string[] allFaces = new string[] {"2", "3", "4", "5",
    "6", "7", "8", "9", "10", "J", "Q", "K", "A"};
  Suit[] allSuits = new Suit[] {
    Suit.Club, Suit.Diamond, Suit.Heart, Suit.Spade};
  for (int i = 0; i < 1000; i++)
    foreach (string face in allFaces)
      foreach (Suit suit in allSuits)
        cards.Add(new Card()
          { Face = face, Suit = suit });
  ShuffleCards(cards);
  PrintCards(cards);
}
```

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How to Search in Google?

Some Advices for Successful Google Searching during Problem Solving

Search in Google Laws

- Keep it simple
  - Most queries do not require advanced operators or unusual syntax → simple is good
- Think what the page you are looking for is likely to contain → use the words that are most likely to appear on the page
  - A search engine is not a human, it is a program that matches the words you specify
  - For example, instead of saying "my head hurts", say "headache", because that's the term a medical page will use

Search in Google Laws (2)

- Describe what you need with as less terms
  - Since all words are used, each additional word limits the results
  - If you limit too much, you will miss a lot of useful information
- Choose descriptive words
  - The more unique the word is the more likely you are to get relevant results
  - Even if the word is correct, most people may use other word for the same concept

Search in Google Rules

- Search is always case insensitive
- Generally, punctuation is ignored, including @#$%^&*()=+[]\ and other special characters
- Functional words like 'the', 'a', 'and', and 'for' are usually ignored
- Synonyms might replace some words in your original query
- A particular word might not appear on a page in your results if there is sufficient other evidence that the page is relevant

Search in Google Tips

- Explicit phrase
  - Example: `"path in a graph"`
- Exclude words
  - Example: `path graph -tree`
- Site specific search
  - Search a specific website for content that matches a certain phrase
  - Example: `graph site:msdn.microsoft.com`

Search in Google Tips (2)

- Similar words and synonyms
  - If you want to include a word in your search, but want to include results that contain similar words or synonyms
  - Example: `"dijkstra" ~example`
- Specific Document Types
  - Example: `"dijkstra" filetype:cs`
- This OR That
  - Example: `"shortest path" graph OR tree`

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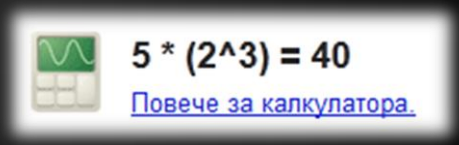
Search in Google Tips (3)

- Numeric ranges
  - Example: `"prime numbers" 50..100`
- Units converter
  - Example: `10 radians in degrees`
- Calculator
  - Example: `5 * 2^3`



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Search in Google Tips (4)

- Fill in the blanks (*)
  - It tells Google to try to treat the star as a placeholder for any unknown term(s) and then find the best matches
  - Example: `"* path in graph"`
    - Results: *shortest*, *longest*, *Hamiltonian*, *etc.*
- If you want to search C# code you can just add `"using System;"` to the search query
- www.google.com/advanced_search

Summary

- Problems solving needs methodology:
  - Understanding and analyzing problems
  - Using a sheet of paper and a pen for sketching
  - Thinking up, inventing and trying ideas
  - Decomposing problems into subproblems
  - Selecting appropriate data structures
  - Thinking about the efficiency and performance
  - Implementing step-by-step
  - Testing the nominal case, border cases and efficiency

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Methodology of Problem Solving

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