Data Structures and Algorithms

Chapter 1 Introduction

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School of Software and Microelectronics, Northwest Polytechnical University

Outline

Next Section

1.1 Preliminary understanding

Symbol

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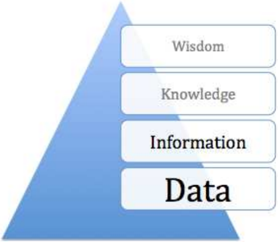
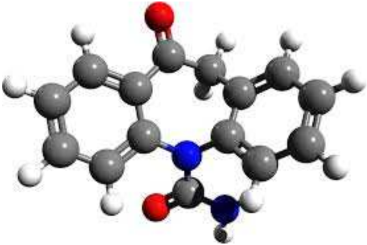


1.1 Preliminary understanding

Symbol

Relation



1.1 Preliminary understanding

- Program: Find out the max one from n numbers

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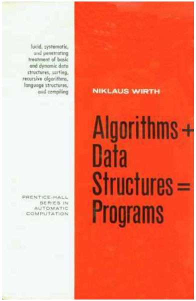
- Program: Find out the max one from n numbers
  - How to organize and store n numbers and other temp numbers?
  - What are operations of those numbers for processing the problem?
  - How to use those operations?
  - What are steps to deal with the problem by those operations?

1.1 Preliminary understanding

- Prof. Niklaus Wirth
- http://www.inf.ethz.ch/personal/wirth/
  - Received Turing Award in 1984
  - Father of Pascal
  - Algorithms+Data Structures = Programs
    Prentice-Hall, 1976



Where are Algorithms and Data Structures in follow program

```c
/* Orignal program segment of Tiny HTTPd */
void accept_request(int client){
 char buf[1024];
 int numchars;
 char method[255];
 char url[255];
 size_t i, j;
 struct stat st;
 int cgi = 0;

 numchars = get_line(client, buf, sizeof(buf));
 i = 0; j = 0;
 while (!ISspace(buf[j]) && (i < sizeof(method) - 1))
 {
  method[i] = buf[j]; i++; j++;
 }

 i = 0;
 while (ISspace(buf[j]) && (j < sizeof(buf)))
  j++;
 ... ...
```

Next Section

Next Subsection

1.2.1 The Contents of the course

- We have 12 weeks to learn fundamental data structures and algorithms for organizing and processing information
- Deeply understand the basic structures used in all software

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- We have 12 weeks to learn fundamental data structures and algorithms for organizing and processing information
- Deeply understand the basic structures used in all software
  - Understand the data structures and their trade-offs
  - Rigorously analyze the algorithms that use them (math!)
- You must learn this course, if you would like to find the answer of following questions:
  - How does Google quickly find web pages that contain a search term?
  - What's the fastest way to broadcast a message to a network of computers?
  - How can a subsequence of DNA be quickly found within the genome?
  - How does your operating system track which memory (disk or RAM) is free?
  - In the game Half-Life, how can the computer determine which parts of the scene are visible?
  - ......

Next Subsection

1.2.2 Data Structure Philosophy

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  - space for each data item it stores,
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- A data structure requires:
  - space for each data item it stores,
  - time to perform each basic operation,
  - programming effort.
- Each problem has constraints on available space and time.
- Only after a careful analysis of problem characteristics can we know the best data structure for the task.

1.2.2 Data Structure Philosophy

How to select a Data structures?

- Analyze the problem to determine the resource constraints a solution must meet.
- Determine the basic operations that must be supported.
- Quantify the resource constraints for each operation.
- Select the data structure that best meets these requirements.

Next Subsection

1.2.3 Purpose of Data Structure and Algorithms

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- Be able to make good design choices as a developer, project manager, etc.
- Be able to justify and communicate your design decisions

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- Be able to make good design choices as a developer, project manager, etc.
- Be able to justify and communicate your design decisions
- Must be included in post-graduate entrance examination (computer related)

Next Section

Next Subsection

What is Data Structure?

Preliminary Concepts

Data

- The difference between Data (Raw) and Information (Processed)
- (In computer) Data is carrier of Information, is symbols inputted, stored, processed and outputted by computers

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024020	Data Structure	64
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Data Object

A SET containing the same type of data elements

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1.3.1 Data Structure

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- Set + Relations (Constraint), Ordered pair
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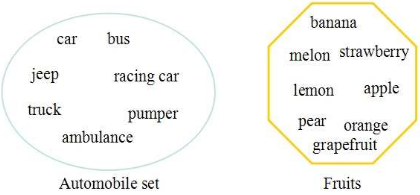

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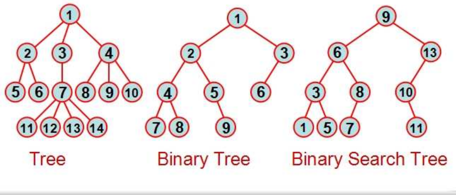

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- Set + Relations (Constraint), Ordered pair
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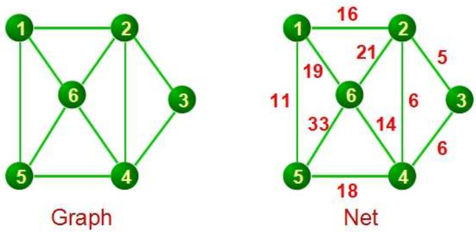
  - Sets: Uniform type, No specific relations between elements
  - Linear structure: One to one
  - Hierarchical Structure: One to many
  - Graph Structure: Many to many



Logical Form and Physical Form

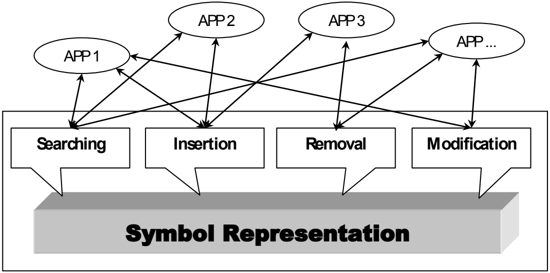
Data structure have

- Logical Form
  - Definition of the data item within an Abstract Data Type (ADT)
  - Problem orient: for example, Integers in mathematical sense: +, -
- Physical Form
  - Implementation of the data item within a data structure.
  - Computer orient: for example, 16/32 bit integers, overflow, Storage Structure in computer
    $(123)_{10} = (1111011)_2$

Next Subsection

1.3.2 Abstract Data Type (ADT)

- Abstract Data Type (ADT): An abstract data type is defined as "class of objects whose logical behavior is defined by a set of values and a set of operations"
  - Encapsulation: Each ADT operation is defined by its inputs and outputs (Interface), Hide implementation details.
  - Abstract: Extract problem essential.
  - Data objects, Relations, Functions (Special relations)



ADT of Natural Number

```
ADT NaturalNumber is
{
Objects: An ordered subset of integers, beginning at 0, ending
    at the maximum (MaxInt).

Relation: C={<i, i+1>| i=0, 1, ..., MaxInt}

Function:  For any x, y belong NaturalNumber;
    False, True belong Boolean, +,-,<,==,= are all available
        properties and methods
Zero( ) :NaturalNumber      return 0
IsZero(x) :Boolean  if (x==0) return True else return False
Add (x, y) :NaturalNumber
      if (x+y<=MaxInt) return x+y  else return MaxInt
Subtract (x, y) :NaturalNumber
      if (x < y) return 0 else return x - y
Equal (x, y) :Boolean
      if (x==y) return True else return False
Successor (x) :NaturalNumber
      if (x==MaxInt) return x else  return x+1
} ADT NaturalNumber
```

ADT of Queue

```
ADT Queue is
{
Objects:

Relation:

Function:


} ADT NaturalNumber
```

Data Type vs ADT

- A data type consists of the values it represents and the operations defined upon it.
- A data type is the physical implementation of an ADT.
  - Each operation associated with the ADT is implemented by one or more subroutines in the implementation
- Data type usually refers to an organization for data in main memory.

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What is Algorithm?

Algorithm

- Is n(n>2) prime number?

What is Algorithm?

Algorithm

- Is n(n>2) prime number?
- An algorithm is a finite set of instructions that, if followed, accomplishes a particular task.
- In addition, all algorithms must satisfy the following characteristic:
  - Input: zero, one, or more
  - Output: at least one output
  - Definiteness: each instruction is clear and unambiguous
  - Effectiveness: every instruction must be basic enough to be carried out, in principle, by a person using only pencil and paper
  - Finiteness: terminates after a finite number of steps
- In computational theory
  - Main distinguish between an algorithm and a program is the characteristic Finiteness.

Algorithm Description

- Using a natural language
- Using flow diagram
- Using a programming language
- Combine with the above

Is n(n>2) prime number?

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1.4.1 Algorithm Criterion

- There are often many algorithms to solve a problem. How do we choose between them?

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- There are often many algorithms to solve a problem. How do we choose between them?
- Algorithm Criterion
  - Validity （正确性）
  - Usability（可用性）
  - Readability（可读性）
  - Robustness（健壮性）
  - Efficiency（效率）

1.4.1 Algorithm Criterion

- There are often many approaches (algorithms) to solve a problem. How do we choose between them?
- At the heart of computer, program design are two (sometimes conflicting) goals.
  - (1) To design an algorithm that is easy to understand, code, and debug.
  - (2) To design an algorithm that makes efficient use of the computer's resources.

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- Goal (1) is the concern of Software Engineering
- Goal (2) is the concern of data structures and algorithm analysis.
- When goal (2) is important, how do we measure an algorithm's cost?

Next Subsection

Algorithm Efficiency: How to Measure the Efficiency?

- (1) Empirical comparison (run programs)

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  - Factors affecting running time;
    - Strategy of algorithm
    - Scale of problem
    - Program language
    - Compiler
    - Computer speed

Algorithm Efficiency: How to Measure the Efficiency?

- (1) Empirical comparison (run programs)
- (2) Asymptotic Algorithm Analysis (before run)
    - Critical resources;
    - Factors affecting running time;
        - Strategy of algorithm
        - Scale of problem
        - Program language
        - Compiler
        - Computer speed
    - For most algorithms, running time depends on "size" of the input.
    - Running time is expressed as T(n) for some function T on input size n.

1.4.2 Algorithm Efficiency

- Algorithm = control structure + meta operation

```
int largest(int array[],int n)
{
    int currlarge=0; //Largest value seen
    for (int i=1; i<n; i++) //For each val
    {
        if(array[currlarge]<array[i])
            currlarge=i;//Remember pos
    }
    return currlarge;//Return largest
}
```

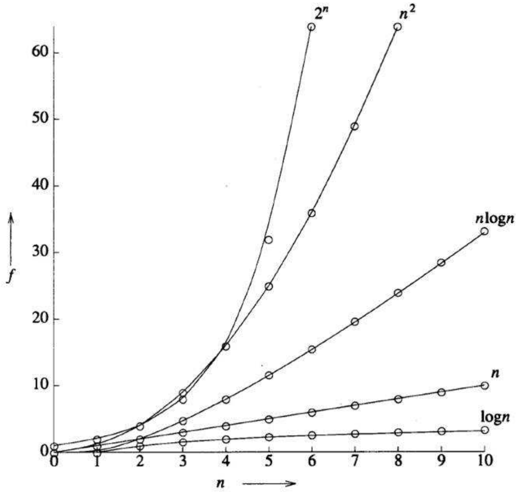
$T(n) = C_1 n + C_2$ steps

compute n squared

```
//compute n squared
int n2(int n)
{
    sum=0;
    for(i=1;i<=n;i++)
        for(j=1;j<n;j++)
            sum++;
    return sum;
}
```

$$T(n) = C_1 n^2 + C_2$$

1.4.2 Algorithm Efficiency



Grow Rate of Functions

1.4.2 Algorithm Efficiency

Growth Rates Compared

	n=1	n=2	n=4	n=8	n=16	n=32
1	1	1	1	1	1	1
logn	0	1	2	3	4	5
n	1	2	4	8	16	32
nlogn	0	2	8	24	64	160
n^2	1	4	16	64	256	1024
n^3	1	8	64	512	4096	32768
2^n	2	4	16	256	65536	4294967296

$$f(n) = n^2 + 100n + \log_2 n + 1000$$

Asymptotic Analysis: Big-O

- Running time of the algorithm takes to execute depends on the value of N
  asymptotic complexity
  Time Complexity $T(n) = O(f(n))$
  Space Complexity $S(n) = O(f(n))$

Asymptotic Analysis: Big-O

- Running time of the algorithm takes to execute depends on the value of N asymptotic complexity
  Time Complexity $T(n) = O(f(n))$
  Space Complexity $S(n) = O(f(n))$

- Definition:
  f(n) is O(g(n)) if there exist positive numbers c and N such that $f(n) \leq cg(n)$ for all $n > N$

- Usage:
  The algorithm is in $O(n^2)$ in **[best, average, worst]** case.

Best, Worst, Average Cases

Not all inputs of a given size take the same time to run.

- Sequential search for K in an array of n integers:
- Begin at first element in array and look at each element in turn until K is found
  - Best case: 1 time of comparison
  - Worst case: n times of comparison
  - Average case: $(n+1)/2$

```c
int lookup(int k, int array[], int n)
{
    int i;
    for (i = 0; i < n; i++)
    {
        if (k == array[i])
        {   return k; }
    }
    return -1;
}
```

1.4.2 Algorithm Efficiency

Which is fairest? Which is most important? it may be difficult to determine!

A Common Misunderstanding

- "The best case for my algorithm is $n = 1$ because that is the fastest." **WRONG!**
- Big-O refers to a growth rate as n grows to ∞.
- Best case is defined as which input of size n is cheapest among all inputs of size n.

Next Subsection

1.4.3 Big-O Examples

Example 1:

```
a = b;
```

This assignment takes constant time, so it is $T(n) = c$. We say this is in $O(1)$.

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a = b;
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This assignment takes constant time, so it is T(n) = c. We say this is in O(1).

Example 2: $T(n) = c_1 n^2 + c_2 n$ in average case.

$c_1 n^2 + c_2 n \leq c_1 n^2 + c_2 n^2 \leq (c_1 + c_2) n^2$ for all $n > 1$.

$T(n) \leq cn^2$ for $c = c_1 + c_2$ and $n_0 = 1$.

Therefore, T(n) is in $O(n^2)$ by the definition.

Simplifying Rules

- If $f(n)$ is in $O(g(n))$ and $g(n)$ is in $O(h(n))$, then $f(n)$ is in $O(h(n))$.
- If $f(n)$ is in $O(kg(n))$ for any constant $k > 0$, then $f(n)$ is in $O(g(n))$.
- If $f1(n)$ is in $O(g1(n))$ and $f2(n)$ is in $O(g2(n))$, then $(f1 + f2)(n)$ is in $O(max(g1(n), g2(n)))$.
- If $f1(n)$ is in $O(g1(n))$ and $f2(n)$ is in $O(g2(n))$ then $f1(n)f2(n)$ is in $O(g1(n)g2(n))$.

1.4.3 Big-O Examples

Example 3:

```
sum = 0;
for (i=1; i<=n; i++)
  sum += n;
```

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```
sum = 0;
for (i=1; i<=n; i++)
  sum += n;
```

$O(n)$.

1.4.3 Big-O Examples

Example 4:

```
sum = 0;
for (j=1; j<=n; j++)
  for (i=1; i<=j; i++)
    sum++;
for (k=0; k<n; k++)
  A[k] = k;
```

1.4.3 Big-O Examples

Example 4:

```
sum = 0;
for (j=1; j<=n; j++)
  for (i=1; i<=j; i++)
    sum++;
for (k=0; k<n; k++)
  A[k] = k;
```

$O(n^2)$.

1.4.3 Big-O Examples

Example 5:

```
sum1 = 0;
for (i=1; i<=n; i++)
  for (j=1; j<=n; j++)
    sum1++;

sum2 = 0;
for (i=1; i<=n; i++)
  for (j=1; j<=i; j++)
    sum2++;
```

1.4.3 Big-O Examples

Example 5:

```
sum1 = 0;
for (i=1; i<=n; i++)
  for (j=1; j<=n; j++)
    sum1++;

sum2 = 0;
for (i=1; i<=n; i++)
  for (j=1; j<=i; j++)
    sum2++;
```

$O(n^2)$.

1.4.3 Big-O Examples

Example 5:

```
sum1 = 0;
for (k=1; k<=n; k*=2)
  for (j=1; j<=n; j++)
    sum1++;

sum2 = 0;
for (k=1; k<=n; k*=2)
  for (j=1; j<=k; j++)
    sum2++;
```

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```

First loop is Σn for $k = 1$ to $\log n, O(n \log n)$.
Second loop is $\Sigma 2^k$ for $k = 0$ to $\log(n-1), O(n)$.

1.4.3 Big-O Examples

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First loop is Σn for $k = 1$ to $\log n, O(n \log n)$.

Second loop is $\Sigma 2^k$ for $k = 0$ to $\log(n-1), O(n)$.

$O(n \log_2 n)$.

Space Bounds

Space bounds can also be analyzed with asymptotic complexity analysis.

Time: Algorithm

Space: Data Structure

Next Subsection

1.4.4 Space and Time Tradeoff Principle

- One can often reduce time if one is willing to sacrifice space, or vice versa
  - Table lookup
    Factorials
    Cryptography

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- One can often reduce time if one is willing to sacrifice space, or vice versa
  - Table lookup
    Factorials
    Cryptography
- Disk-based Space/Time Tradeoff Principle:
  The smaller you make the disk storage requirements, the faster your program will run.

Next Section

1.5 Brief Summary

1. Preliminary understanding
2. Introduction of the course
   - The Contents of the course
   - Data Structure Philosophy
   - Purpose of Data Structure and Algorithms
3. Related Concepts
   - Data Structure
   - Abstract Data Type (ADT)
   - Algorithm
4. Algorithm Efficiency and Analysis
   - Algorithm Criterion
   - Algorithm Efficiency
   - Big-O Examples
   - Space and Time Tradeoff Principle
5. Brief Summary