

# Ph.D. Comprehensive Examination

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Student Name:

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Student Number:

Problem number	Points (10 max)
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
Total:	



## 1. Data organization; Algorithms and complexity

Each item  $x$  in a set  $S$  has a unique key  $key[x]$ . We need to implement the following operations.

- (a) Search ( $S, key$ )
- (b) Insert ( $S, x$ )
- (c) Successor ( $S, x$ )
- (d) Predecessor ( $S, x$ )

Give the 4 running times as an  $O()$  for the following implementations:

- (a) Ordered (sorted) array,
- (b) Ordered doubly linked list,
- (c) Min-Heap, and
- (d) Hash table

(a) ordered array

- Search  $O(\log(n))$
- Insert  $O(\log(n))$
- Successor  $O(\log(n))$
- Predecessor  $O(\log(n))$

(d) Hash table

- Search  $O(1)$
- Insert  $O(1)$
- Successor  $O(1)$
- Predecessor  $O(1)$

(b) ordered doubly linked list

- Search  $O(n)$
- Insert  $O(n)$
- Successor  $O(n)$
- Predecessor  $O(n)$

(c) Min-Heap

- Search  $O(\log(n))$
- Insert  $O(\log(n))$
- Successor  $O(\log(n))$
- Predecessor  $O(\log(n))$



## 2. Program control and structure; Programming language and notations

Suppose that procedure *swap* is declared as follows:

```
procedure swap( x, y: integer);  
  procedure f(): integer;  
    var z: integer;  
    begin // f  
      z = x; x = y; return z;  
    end // f  
  begin // swap  
    y = f();  
  end // swap
```

Describe the effect of the procedure call *swap*(*i*, *A*[*i*]) under each of the following parameter passing methods:

- (a) Call-by-value
- (b) Call-by-reference
- (c) Call-by-value-result

(a) Procedure *swap* in effect assign the value of *i* to *A*[*i*]. Since *f*() change the value of *z* to the value of *x*, statement *y* = *f*() change the value of *A*[*i*] to the result of *f*(), *i*.

(b) Call-by-reference pass the memory address of the parameters. *Swap* in effect switch the address between *i* and *A*[*i*]

(c) call-by-value-result in effect switch the value between variables *i* and *A*[*i*]



### 3. Software engineering

From the software engineering point of view, any software development process can be divided into several sub-disciplines:

- (a) Requirement Analysis
- (b) Functional Specification
- (c) Architectural Design
- (d) Implementation
- (e) Testing and Evaluation
- (f) Maintenance

Choose three sub-disciplines or tasks within these sub-disciplines that involve a mathematical approach, and illustrate them with examples.

(a) Requirement Analysis may involve mathematical approach. If we require a system that produces an accuracy above certain level, or works properly with certain confidence level. We should analyse the goal mathematically.

(d) Implementation involve mathematical approach, complex algorithms often come with maths theoretical background. We need to implement the methods in accordance with the theories.

(e) Testing and evaluation should involve mathematical approach. In order to evaluate the performance, we need to quantify the results and analyse them.





## 4. Systems

- (a) dynamic linked libraries can support shared library code, allowing one copy of a library routine to be used by several different processes.  
absolute    relative    static    **dynamic**    none of these is correct
- (b) When it is not known at compile time where a process will reside in memory, relocatable code must be generated.  
logical    physical    absolute    **relocatable**
- (c) A UNIX process calls *fork()* to create a child process as shown: *pid = fork()*;  
i. What value will be assigned to *pid* in the parent process by the call to *fork()*?  
the parent's process id    the child's process id    **zero**    none of these  
ii. What value will be assigned to *pid* in the child process by the call to *fork()*?  
the parent's process id    the child's process id    zero    **none of these**
- (d) The Banker's algorithm is used for deadlock prevention.  
denial    **prevention**    avoidance    recovery
- (e) Belady's anomaly can affect the performance of the FLFO page replacement algorithm.  
FIFO    LRU    optimal    SJF
- (f) direct access files are made of fixed length records that allow programs to read and write records in no particular order.  
sequential    **direct**    logical    none of these is correct
- (g) When an I/O request is being handled for a user's process, which term refers to the policy of returning control to the user process before the I/O is completed?  
synchronous I/O    **asynchronous I/O**    delayed I/O    none of these
- (h) Which multithreading model requires that a new kernel thread be created for each new user thread?  
many-to-one    **one-to-one**    many-to-many    none of these is correct
- (i) A process that does not affect, and is not affected by, another process is referred to as:  
static    **independent**    cooperating    dynamic    unbounded



**5. Software, Programming Techniques**

Given that

$B(x)$  means "x is a bear"

$F(x)$  means "x is a fish", and

$E(x, y)$  means "x eats y",

what is the best English translation of

$\forall x[F(x) \rightarrow \forall y(E(y, x) \rightarrow B(y))]$ ?

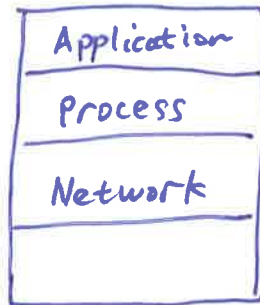
- (a) All fish eat bears.
- (b) Every fish is eaten by some bear.
- (c) Bears only eat fish.
- (d) Every bear eats fish.
- (e) Only bears eat fish.



**6. Networking and Communications**

- (a) Draw a diagram showing layers of the Internet Protocol Stack and briefly discuss role of each layer.
- (b) Describe functions of each layer when a file is transferred from a source to destination using (file transfer protocol (FTP)).

(a)



Application layer handles the programs for transferring data packets.

Process layer manages every processes.

Network layer controls the network infrastructure.



**7. Algorithms and complexity**

Describe an algorithm that takes two input lists of integers  $A = a_1, \dots, a_n$  and  $B = b_1, \dots, b_m$  and delivers the list of all the elements that belong to  $A$  but not to  $B$ .  $A$  and  $B$  do not contain redundant elements, however, the elements of  $A$  and  $B$  might have a large range.

The algorithm should run in  $O(n \log m + m \log m)$  time.

Sort list  $B$  by using MergeSort, this should run in  $O(m \log m)$  time. Create a empty list Result.

Then check each input item whether it's in list  $A$  and list  $B$ . If the integer is in list  $A$  but not in  $B$ , append it to Result.

Output the result list.

Search a item in sorted list  $B$  runs in  $O(\log m)$ . Assume input size  $n$ , checking every input runs in  $O(n \log m)$  time. Then the algorithm has the run time of  $O(n \log m + m \log m)$ .





## 8. Automata and language theory

Consider the following grammar:

$$G \rightarrow S \$ \$$$

$$S \rightarrow A M$$

$$M \rightarrow S | \epsilon$$

$$A \rightarrow a E | b A A$$

$$E \rightarrow a B | b A | \epsilon$$

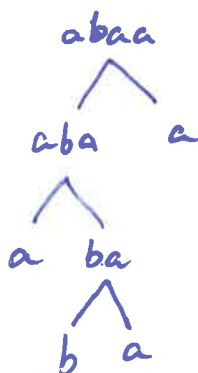
$$B \rightarrow b E | a B B$$

$S$   
 $AM$   
 $AS | AE$   
 $A^* \epsilon$   
 $AE | bAA$   
 $aaB$   
 $a$   
 $aaBE$   
 $aaBB$   
 $baE = E$   
 $| ba a B a a B$

- (a) Describe the language that the grammar generates in English.  
 (b) Show a parse tree for the string  $a b a a$ .  
 (c) Is the grammar LL(1)? If so, show the parse table; if not, identify a prediction conflict.

(a) The language generates strings that contain  $\{a, b\}$

(b)



(c) LL(1)



### 9. Discrete Structures

Recall that the Hamiltonian Cycle Problem is the problem of deciding, on input graph  $G$ , whether  $G$  has a cycle that visits all the nodes exactly once. Show that this problem is polynomial time decidable if the input is restricted to the graphs with the property that each node has at most two neighbors (i.e., at most two adjacent nodes).

The input graphs with nodes that have at most two neighbors.

We can write a program to traverse the input graph. It starts with a random node, select an node that connects to the it which hasn't been visited and doesn't form a cycle. Otherwise it backtrack to the neighbor which hasn't been selected.

If it traverses all nodes and comes back to the starting node, there is a Hamiltonian cycle. This algorithm runs in polynomial time. Therefore the problem is polynomial time decidable.



### 10. Other Topics

Give a detailed explanation of any one approach to machine learning. Give a substantial example that illustrates the technical operation of the approach, and demonstrates interesting knowledge learned.

Random Forest is a machine learning approach that belongs to ensemble learning family.

The purpose of ensemble learning is to combine the predictive power of many weak learners through some voting mechanism. In the case of RF, it usually consists of large number of decision trees. Each tree is trained on a subset of the feature space, i.e. randomly selected features from the training data. The input data is also randomly sampled by using bootstrap. Therefore each tree in the forest learns some properties of the training dataset.

When predicting new data samples, each decision tree makes a prediction on the labels. The class label which gets the majority vote is the final result for classification.

RF is very effective in terms of classification accuracy. It is also very efficient and fast. The randomness in data sampling and feature space partition boost the performance of RF. The method of ensemble is also very powerful since the majority vote significantly improve accuracy compared to individual trees.

