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Exam Architecture of Machine Learning Systems (SoSe 2024)

Important notes: The working time is **90min**, and lecture materials or any kind of mobile devices are not allowed. Please, make sure to put your name and matriculation number on the top right of the first page of the task description, and each additional piece of your own paper. You may give the answers in English or German, written directly into the task description.

Task 1 Parameter Servers (16 points)

(a) Describe the overall system architecture of *data-parallel parameter servers*, explain its components and interaction among these components. (**10 points**)

(b) Describe synchronous (BSP) and asynchronous (ASP) *update strategies* in data-parallel parameter servers and name their advantages and disadvantages. (**6 points**)

	Synchronous Updates	Asynchronous Updates
Description		
Advantages		
Disadvantages		

Task 2 Data Preparation (22 points)

(a) Given the raw input data below, apply *recoding and one-hot encoding* to all categorical columns, and *binning* with three equi-width bins to all numerical columns. (**10 points**)

A	B	C
Low	0	S
High	3.1	M
Med	7	L
Low	9	XL
Low	15	M
Low	7	M
Med	4	L
High	12	XL
High	13	L

(b) Explain *feature hashing* and what is its advantage over recoding? (**3 points**)

(c) Describe the text encodings bag-of-word and word-embeddings. (**6 points**)

- **Bag-of-Words:**

- **Word Embeddings:**

(d) What is *data augmentation* and name two concrete techniques. (**3 points**)

Task 3 Model Selection (18 points)

(a) Describe the task of *hyper-parameter tuning by example of Grid Search*. Assume three hyper-parameters with 10 discretized values each, how many models do we need to train? (**8 points**)

- **Hyper-parameter Tuning:**

- **Grid Search:**

- **Example #Models:**

(b) Explain *Bayesian Optimization* as a more directed search strategy, and how it balances exploitation and exploration? (**5 points**)

(c) Describe the problem of *Neural Architecture Search (NAS)*, and how to deal with multiple optimization objectives (e.g., accuracy and runtime). (**5 points**)

Task 4 Model Debugging (12 points)

(a) Describe sources of *bias* in machine learning and name examples how to ensure *fairness* when building ML models with examples. (**4 points**)
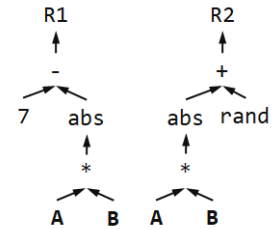
(b) Explain the concept of a *confusion matrix* and describe it in detail. (**4 points**)

(c) Explain the concept of *occlusion-based explanations* by example of classifying below hand-written digit as a seven. (**4 points**)
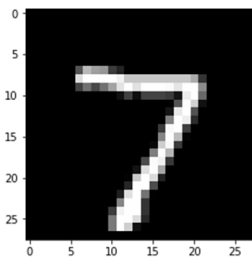
Task 5 Compilation Techniques (15 points)

(a) Describe the purpose of the rewrite *common subexpression elimination (CSE)* and sketch an algorithm to perform CSE on a directed acyclic graph (DAG) of operators. (**5 points**)

```
   R1              R2
    ↑               ↑
    -               +
  ⟋  ↖           ⟋   ↖
 7    abs      abs   rand
       ↑        ↑
       *        *
     ⟋  ↖     ⟋  ↖
    A    B   A    B
```

(b) Explain the concept of *operator fusion* (or loop fusion) and how it can improve runtime performance. (**3 points**)

(c) Assume an example chain of matrix multiplications (**A B C D E**), describe the problem of *matrix multiplication chain optimization*, and a dynamic programming algorithm for solving it efficiently. (**7 points**)

Task 6 Data Access Optimizations (8 points)

(a) Describe min-max quantization of an `FP64` (64bit floating point) representation into `UINT8` (8bit integer). Why does such an encoding increasing training and/or inference performance? (**8 points**)

Task 7 Model Deployment (9 points)

(a) Consider a deployed model M in a cloud serving environment and assume 1000s of concurrent client requests. Explain three strategies for improving model scoring throughput at the serving site. (**9 points**)