Implementation of DBMS - Exercise Sheet 4
Instructor: Ali, WS 2024 / 2025

Exercise 1: Field Alignment and Record Size Calculation

1. Suppose a record contains the following fields in order:

- **Employee Name**: A character string of length 25 bytes
- **Employee ID**: An integer of 4 bytes
- **Date of Joining**: An SQL date requiring 10 bytes
- **Salary**: A floating-point number of 8 bytes

Questions:
a) Calculate the total record size if fields can start at **any byte**.
b) Calculate the record size if fields must start at a byte that is a **multiple of 4**.
c) Calculate the record size if fields must start at a byte that is a **multiple of 8**.

Exercise 2: Record Header and Alignment Constraints

2. Assume the fields are as in **Exercise 1**, but the records also include a **header** consisting of:

- **Two 4-byte integers**
- **A 2-byte character field**

Questions:
Calculate the total record size, considering the three alignment constraints:
a) Fields can start at **any byte**.
b) Fields must start at a byte that is a **multiple of 4**.
c) Fields must start at a byte that is a **multiple of 8**.

Exercise 3: Block Storage and Record Packing

3. Assume records are as in **Exercise 2**, and we wish to pack as many records as possible into a **block of 8192 bytes**, using a **block header** consisting of **five 8-byte integers**.

Questions:
a) How many records can fit in the block if fields can start at **any byte**?
b) How many records can fit in the block if fields must start at a **multiple of 4**?
c) How many records can fit in the block if fields must start at a **multiple of 8**?
Assume unspanned storage for records.

Exercise 4: Variable-Length Record Organization

4. A **product inventory record** consists of the following:

- Fixed-length fields: **Product ID (10 bytes)**, **Category ID (10 bytes)**, and **Stock Quantity (4 bytes)**.
- Variable-length fields: **Product Name**, **Description**, and **Manufacturer Details**.

Additional Information:

- Each pointer within the record requires **4 bytes**.
- The record also includes a **4-byte field for the record length**.

Questions:
a) Calculate the total size of the record, excluding the variable-length fields.
b) Propose ways to **optimize internal storage** to reduce the record size.

Exercise 5: Variable-Length Field Size Estimation

5. Suppose records are as described in **Exercise 4**. The variable-length fields have the following size ranges:

- **Product Name**: 20–60 bytes
- **Description**: 50–300 bytes
- **Manufacturer Details**: 0–500 bytes

Questions:
a) Calculate the **average size** of each variable-length field.
b) Determine the **average size** of the total record, including both fixed and variable-length fields.

Learning Objectives:

1. Understand **field alignment** and its impact on memory usage.
2. Calculate **storage efficiency** in different scenarios (fixed vs. variable-length records).
3. Explore **record organization** techniques to optimize storage and reduce overhead.
4. Analyze the trade-offs between **alignment constraints** and **data packing** in database systems.

4a) **A fixed-length record design**:
A student record contains the following fixed-length fields: student ID (10 bytes), enrollment year (4 bytes), and major code (6 bytes). The record also includes pointers to two variable-length fields: name and email. Each pointer is 4 bytes long, and the record includes a 4-byte field for the record length.

- How many bytes are required for the record, excluding the variable-length fields?
- Could the record size be reduced by reorganizing its structure? If yes, explain how.

4b) **Optimization for variable-length fields**:
A company record contains the following fixed-length fields: company ID (12 bytes) and industry code (6 bytes). It also includes pointers to three variable-length fields: company name, headquarters address, and CEO name. Each pointer requires 4 bytes, and the record contains a 4-byte field for the record length.

- Calculate the size of the record without including the variable-length fields.
- Propose a design adjustment to reduce the record size further.

4c) **Variable-length fields and alignment**:
Consider a hospital record that contains the following fields: patient ID (10 bytes), doctor ID (10 bytes), and a field for record length (4 bytes). The record also has two pointers (each 4 bytes) to variable-length fields: diagnosis and prescriptions. If field alignment adds 2 bytes of padding wherever required,

- How many bytes are required for the record, including padding but excluding the variable-length fields?
- How can the record design be optimized to reduce padding while keeping the overall structure efficient?

These questions focus on storage calculations, optimization, and efficient record design in database systems.

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1) Record Size and Field Alignment with Padding

Suppose a record has the following fields in this order:

- A fixed-length character string of **15 bytes**
- A floating-point number (4 bytes)
- A 2-byte integer
- An SQL date (10 bytes)

Question:
How many bytes does the record occupy under the following alignment conditions?

a) Fields can start at **any byte**.
b) Fields must start at a byte that is a **multiple of 4**.
c) Fields must start at a byte that is a **multiple of 8**.

2) Record with Header and Alignment Constraints

Assume the fields are as in **Exercise 1**, but now the records also include a **header** consisting of:

- Two 4-byte integers
- A single character field (1 byte)

Question:
Calculate the total length of the record, considering field alignment under the three alignment constraints:

a) Any byte
b) Multiple of 4
c) Multiple of 8

3) Packing Records into a Block

Suppose records are as in **Exercise 2**, and we want to pack as many records as possible into a **block of 8192 bytes**. The block includes a **header consisting of five 4-byte integers**.

Question:
How many records can fit into the block for each of the three field alignment scenarios? Assume **unspanned storage** of records.

4) Variable-Length Fields and Record Headers

A **student record** consists of the following **fixed-length fields**:

- Student ID (10 bytes)
- Enrollment number (10 bytes)
- Date of birth (10 bytes)

It also includes **variable-length fields**: Name, Address, Notes

Each **pointer** within the record requires **4 bytes**, and the record has a **4-byte integer** for its length.

Question:
How many bytes, excluding the variable-length fields, are required for the record? Assume no alignment requirements. Additionally, optimize the record layout to further reduce its size.

5) Average Record Size with Variable-Length Fields

Suppose the records are as described in **Exercise 4**, and the **variable-length fields** have the following properties:

- Name: Uniformly distributed length between **15 and 45 bytes**
- Address: Uniformly distributed length between **30 and 90 bytes**
- Notes: Uniformly distributed length between **0 and 2000 bytes**

Question:
What is the **average length** of a student record, including variable-length fields?

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6) Estimating Records in a Block with Variable-Length Fields

For the **records described in Exercise 5**, assume:

- The **block size** is **4096 bytes**
- The block header contains **eight 4-byte integers**

Question:
How many records, on **average**, can fit into a single block? Assume that variable-length fields are stored **inside the block** and that records are stored **unspanned**.

record layout, field alignment, block packing, and space calculation in DBMS implementation. I'll teach the concepts first, then prepare **advanced exam-style questions**.

🧠 Key Concepts from Sheet 03

1️⃣ Field Alignment & Record Length

- **Why alignment matters:**
  Many CPUs require certain data types to start at specific memory addresses (multiples of 2, 4, or 8). This improves access speed.
- **Without alignment:**
  Fields start immediately after the previous field.
- **With alignment:**
  We may insert **padding bytes** so the field starts at the required multiple.

Example:

- Field = `int` (4 bytes)
- If current offset = 3, we insert 1 padding byte so offset becomes multiple of 4.

2️⃣ Record Header

- A record header stores metadata about the record:
  - Record length
  - Timestamps
  - Pointers to variable-length fields
  - Flags (deleted/active)
- Header size depends on the number and type of metadata fields.

3️⃣ Block Structure & Unspanned Records

- **Block:** Smallest unit of data transfer between disk and memory (e.g., 4096 bytes).
- **Block header:** Stores metadata for the block:
  - Free space info
  - Page ID
  - Transaction/LSN info
- **Unspanned storage:**
  A record must fit entirely inside one block (cannot cross block boundaries).

4️⃣ Variable-Length Fields

- Examples: Name, Address, History.
- Stored as:
  - **Pointer (offset + length)** to actual data (stored elsewhere)
  - Or **inline** if short enough
- **Pointer size** adds to fixed-length space.

5️⃣ Expected Value for Variable-Length Fields

If field length is uniformly distributed between `min` and `max`:

Average length=min+max2\text{Average length} = \frac{\text{min} + \text{max}}{2}

📊 Example Walkthrough (Exercise 1a)

Fields:

- Char(19) → 19 bytes
- Int(2) → 2 bytes
- Date (SQL) → 10 bytes
- Time (SQL) → 8 bytes

No alignment:
Total = 19+2+10+8=3919 + 2 + 10 + 8 = 39 bytes.

Alignment multiple of 4:

- Char(19) starts at byte 0 → offset after = 19 → pad 1 → next offset 20
- Int(2) starts at 20 → after = 22 → pad 2 → next offset 24
- Date(10) starts at 24 → after = 34 → pad 2 → next offset 36
- Time(8) starts at 36 → after = 44 → **final size = 44**

Alignment multiple of 8 would require even more padding.

🎯 Advanced Exam-Level Questions

Q1 — Complex Alignment

You have a record with:

- Header: 2-byte short, 1-byte char, 8-byte timestamp
- Fields: Char(15), Double(8), Int(4), Char(3)
- Compute record length with:
    1. No alignment
    2. Alignment multiple of 4
    3. Alignment multiple of 8

Q2 — Block Packing with Mixed Records

A block is 8192 bytes with a 64-byte header.
You store:

- 60% records of 120 bytes
- 40% records of 200 bytes
  Alignment = multiple of 8.
  How many total records fit per block? How much free space remains?

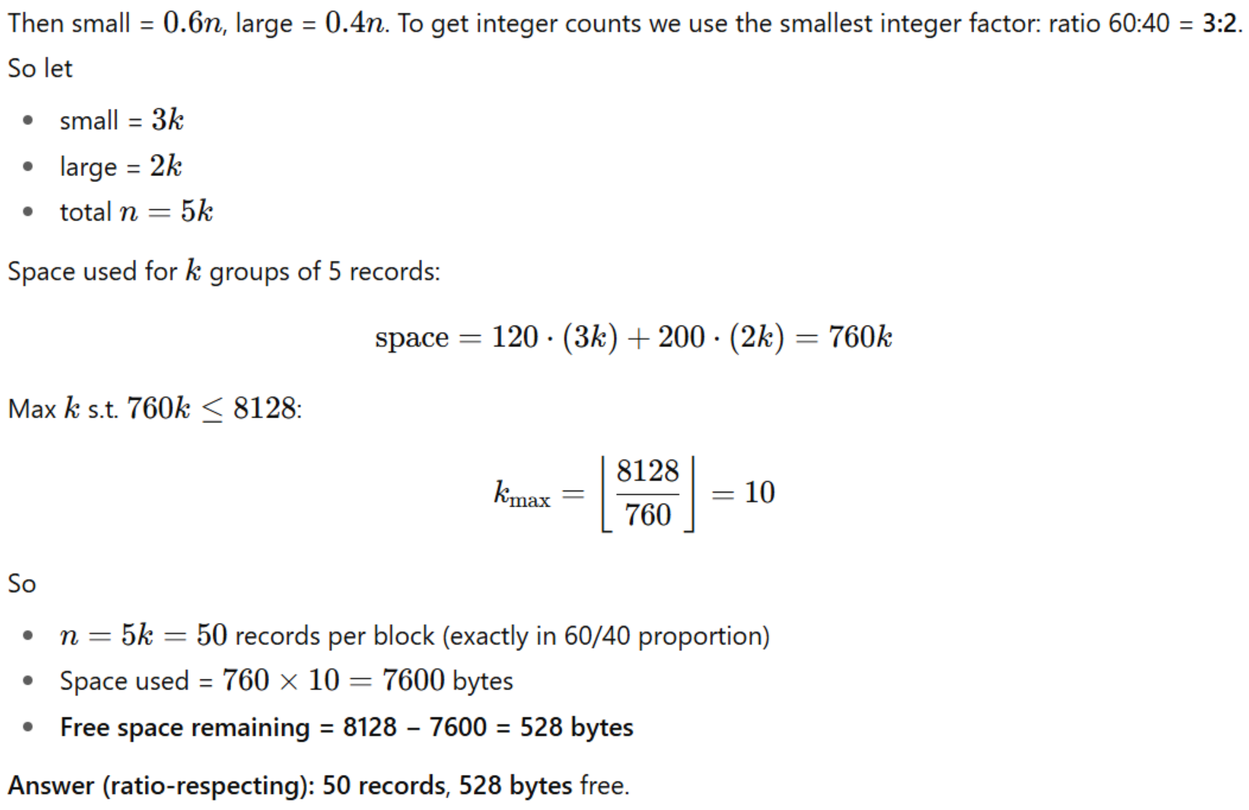
Nice — let's solve Q2 carefully and show a couple of useful variants so you fully understand the packing trade-offs.

Given

- Block size = **8192 bytes**
- Block header = **64 bytes** → usable payload per block = **8192 − 64 = 8128 bytes**
- Two record types:
  - **Small** = 120 bytes (60% of records)
  - **Large** = 200 bytes (40% of records)
- Alignment = **multiple of 8 bytes**
  → 120 and 200 are already multiples of 8, so **no padding** is required.

A — If you must keep the 60% / 40% ratio exactly (i.e. pack records in the same proportion)

Let the total number of records in the block be n.



Then small = $0.6n$, large = $0.4n$. To get integer counts we use the smallest integer factor: ratio 60:40 = **3:2**.

So let

- small = $3k$
- large = $2k$
- total $n = 5k$

Space used for k groups of 5 records:

$$\text{space} = 120 \cdot (3k) + 200 \cdot (2k) = 760k$$

Max k s.t. $760k \le 8128$:

$$k_{\text{max}} = \left\lfloor \frac{8128}{760} \right\rfloor = 10$$

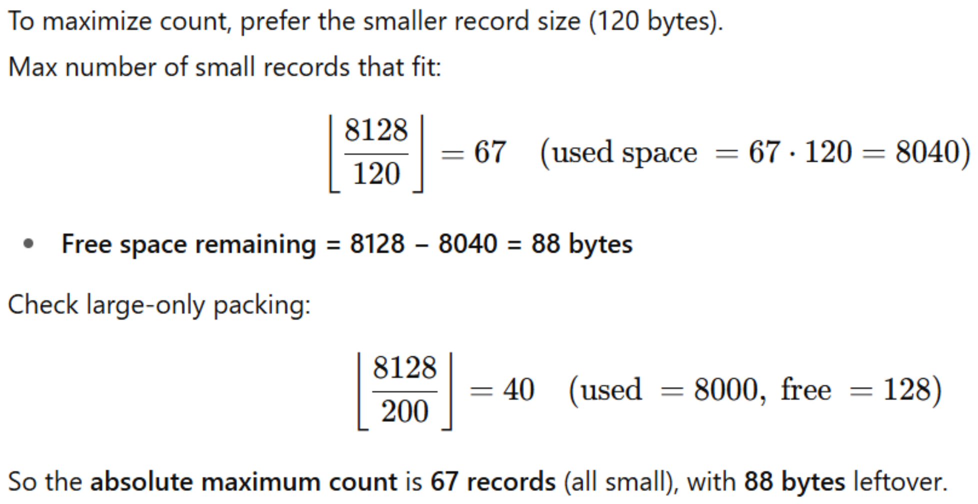
So

- $n = 5k = 50$ records per block (exactly in 60/40 proportion)
- Space used = $760 \times 10 = 7600$ bytes
- **Free space remaining = 8128 − 7600 = 528 bytes**

Answer (ratio-respecting): 50 records, 528 bytes free.

B — If you only care about maximizing the total number of records (no ratio constraint)

To maximize count, prefer the smaller record size (120 bytes).
Max number of small records that fit:



To maximize count, prefer the smaller record size (120 bytes).

Max number of small records that fit:

$$\left\lfloor \frac{8128}{120} \right\rfloor = 67 \quad (\text{used space } = 67 \cdot 120 = 8040)$$

- **Free space remaining = 8128 − 8040 = 88 bytes**

Check large-only packing:

$$\left\lfloor \frac{8128}{200} \right\rfloor = 40 \quad (\text{used } = 8000, \text{ free } = 128)$$

So the **absolute maximum count** is **67 records** (all small), with **88 bytes** leftover.

C — If you want to maximize used space (minimize slack) while keeping 60/40 roughly

We already have the exact ratio solution (50 recs, 528 free). If you allow small deviations from 60/40 you might pack 51 or 52 records with different mixes, but usually the exact-ratio solution is simpler and predictable.

Quick summary

- Respect 60%/40% exactly → **50 records**, **528 bytes** free.
- Maximize count (ignore ratio) → **67 records** (all small), **88 bytes** free.
- Large-only → **40 records**, **128 bytes** free.

Q3 — Variable-Length Average with Alignment

A record has:

- Fixed fields: ID(4 bytes), Status(1 byte), Flags(2 bytes)
- Variable-length fields: Bio(50–150 bytes), Notes(0–300 bytes)
  Header stores record length (4 bytes) and 2 pointers (4 bytes each).
  Assume alignment to multiple of 4.
  Find the **average record size**.

Q4 — Storage Utilization Optimization

A 4096-byte block stores unspanned records with 20-byte headers and variable-length fields stored inline.
Average record size = 130 bytes, but distribution is skewed (10% are 400 bytes).
Devise an **improved block organization** to maximize utilization, and calculate the new utilization %.

Q5 — Trade-Off Question

Explain how **alignment** improves CPU access but can reduce **storage utilization**, and give **three DBMS design strategies** to minimize wasted space while keeping performance.
