PA152: Efficient Use of DB

1. Introduction

Vlastislav Dohnal

Motivation

- End-users report slow responses

```
SELECT  s.RESTAURANT_NAME, t.TABLE_SEATING, to_char(t.DATE_TIME,'Dy, Mon FMDD') AS THEDATE,
to_char(t.DATE_TIME,'HH:MI PM') AS THETIME,to_char(t.DISCOUNT,'99') || '%' AS AMOUNTVALUE,t.TABLE_ID,
s.SUPPLIER_ID, t.DATE_TIME, to_number(to_char(t.DATE_TIME,'SSSSS')) AS SORTTIME
FROM TABLES_AVAILABLE t, SUPPLIER_INFO s,
      (SELECT s.SUPPLIER_ID, t.TABLE_SEATING, t.DATE_TIME, max(t.DISCOUNT) AMOUNT, t.OFFER_TYPE
       FROM TABLES_AVAILABLE t, SUPPLIER_INFO s
       WHERE t.SUPPLIER_ID = s.SUPPLIER_ID
            and (TO_CHAR(t.DATE_TIME, 'MM/DD/YYYY') != TO_CHAR(sysdate, 'MM/DD/YYYY')
             or TO_NUMBER(TO_CHAR(sysdate, 'SSSSS')) < s.NOTIFICATION_TIME - s.TZ_OFFSET)
            and t.NUM_OFFERS  > 0 and t.DATE_TIME > SYSDATE  and s.CITY = 'SF'
            and t.TABLE_SEATING = '2' and t.DATE_TIME between sysdate and (sysdate + 7)
            and to_number(to_char(t.DATE_TIME, 'SSSSS')) between 39600 and 82800
            and t.OFFER_TYPE = 'Discount'
       GROUP BY s.SUPPLIER_ID, t.TABLE_SEATING, t.DATE_TIME, t.OFFER_TYPE) u
WHERE t.SUPPLIER_ID=s.SUPPLIER_ID and u.SUPPLIER_ID=s.SUPPLIER_ID and t.SUPPLIER_ID=u.SUPPLIER_ID
      and t.TABLE_SEATING = u.TABLE_SEATING and t.DATE_TIME = u.DATE_TIME
      and t.DISCOUNT = u.AMOUNT and t.OFFER_TYPE = u.OFFER_TYPE
```

```
            and (TO_CHAR(t.DATE_TIME, 'MM/DD/YYYY') != TO_CHAR(sysdate, 'MM/DD/YYYY')
          or TO_NUMBER(TO_CHAR(sysdate, 'SSSSS'))  < s.NOTIFICATION_TIME - s.TZ_OFFSET)
    and t.NUM_OFFERS > 2 and t.DATE_TIME > SYSDATE and s.CITY = 'SF'
    and t.TABLE_SEATING = '2'  and t.DATE_TIME between sysdate and (sysdate + 7)
    and to_number(to_char(t.DATE_TIME, 'SSSSS')) between 39600 and 82800 and t.OFFER_TYPE = 'Discount'
ORDER BY AMOUNTVALUE DESC,  t.TABLE_SEATING ASC, upper(s.RESTAURANT_NAME) ASC,
          SORTTIME ASC, t.DATE_TIME ASC
```

Motivation (cont.)

```
Execution Plan
----------------------------------------------------------
  0     SELECT STATEMENT Optimizer=CHOOSE (Cost=165 Card=1 Bytes=106)
  1    0   SORT (ORDER BY) (Cost=165 Card=1 Bytes=106)
  2    1     NESTED LOOPS (Cost=164 Card=1 Bytes=106)
  3    2       NESTED LOOPS (Cost=155 Card=1 Bytes=83)
  4    3         TABLE ACCESS (FULL) OF 'TABLES_AVAILABLE' (Cost=72 Card=1 Bytes=28)
  5    3         VIEW
  6    5           SORT (GROUP BY) (Cost=83 Card=1 Bytes=34)
  7    6             NESTED LOOPS (Cost=81 Card=1 Bytes=34)
  8    7               TABLE ACCESS (FULL) OF 'TABLES_AVAILABLE' (Cost=72 Card=1 Bytes=24)
  9    7               TABLE ACCESS (FULL) OF 'SUPPLIER_INFO' (Cost=9  Card=20 Bytes=200)
 10    2       TABLE ACCESS (FULL) OF 'SUPPLIER_INFO' (Cost=9 Card=20 Bytes=460)
```

Access method

Evaluation costs

Course's Objectives

- Understand query processing
  - Identify weaknesses and optimize
- Implement advanced indexing
- Design storage for DB
  - Know important file structures
- Understand and implement high availability

Course Outline

- Data storage

  Storage hierarchy, RAID, failures, …
- Data formatting

  Records, blocks, …
- Indexing

  Trees, hashing, …
- Query processing

  Cost estimates, joining relations, …
- Query optimization

  Creating indexes, views, table partitioning, …

Course Outline

- Database tuning

  Tuning relation schema, db monitoring, …

- Transaction processing

  Concurrent processing, locking, logging, deadlocks, …

- Access control

  access rights, roles, rewrite rules, …

Recommended Reading

- Books
  - Database Systems Implementation
    - Hector Garcia-Molina, Jeffrey D. Ullman, Jennifer Widom
    - Prentice Hall, 2000
    - Signature in FI library: D89
  - Database Systems: The Complete Book
    - Hector Garcia-Molina, Jeffrey D. Ullman, Jennifer Widom
    - 2nd edition, Prentice Hall, 2009
    - Signature in FI library: D147

Credits

- Materials are based on presentations:
  - Courses CS245, CS345, CS345
    - Hector Garcia-Molina, Jeffrey D. Ullman, Jennifer Widom
    - Stanford University, California

Requirements to pass

- There are two possible completion types
  - Exam (‘zk’)
  - Credit (‘z’)
  - Double-check the requirements of your study program
- Home assignments and exam
  - see in course's study materials

Knowledge Prerequisites

- Relational model
- Query languages
  - SQL and relational algebra
- File organizations
  - Sequential file, …
- Most covered in bachelor-degree courses:
  - PB154 Fundamentals of Database Systems
  - PB168 Fundamentals of Information and Database Systems

Basic Terminology

- „Database“
  - “programmed” by most of the coders
  - needed by every business
  - included in most applications
  - queried by SQL

- Relational model
  - Structure – data in relations (tables)
  - Operations – querying, updates
    - SQL, relational algebra
- Database system (Database management system = DBMS)
  - a collection of tools for storing and processing data
- Database
  - data that are processed, interesting for a business
  - collection of relations, integrity constraints, indexes, …
  - database schema vs. database instance

Example

```
select * from student where
  program='N-SWE' and field='DEV'
```

- Query processing:
  1. Check the query and get attributes of *student*
  2. Read rows from *student* and evaluate the condition

No	UČO	Name	Type of completion	Covid	Program	Field
1.	4x4x7x	**Martin**	zk	● ONT	N-SWE	DEV
2.	4x5x9x	**Laura**	zk	● ONT	N-SWE	DEV
3.	5x6x0x	**Martin**	zk	● ONT	N-SWE	DEV
4.	4x5x5x	**Peter**	zk	● ONT	N-SWE	DEV
5.	4x5x2x	**Martin**	zk	● ONT	N-SWE	DEV
6.	4x4x4x	**Michal**	zk	● ONT	N-SWE	DEV

Example 2

`select A,B from R,S where` *`condition`*

- Query processing
  1. Read dictionary and get attributes of R and S
  2. Read R and for each line do:
     a. Read S and for each line do:
        i. Join the lines (records/tuples)
        ii. Evaluate condition
        iii. If valid, project and add to result

Implementation of example

- Relations stored in files on disk
  - Relation *student* in `/var/db/student`

```
4x4x7x # Martin # zk # ONT # N-SWE # DEV↵
4x5x9x # Laura # zk # ONT # N-SWE # DEV↵
5x6x0x # Martin # zk # ONT # N-SWE # DEV↵
4x5x5x # Peter # zk # ONT # N-SWE # DEV↵
4x5x2x # Martin # zk # ONT # N-SWE # DEV↵
4x4x4x # Michal # zk # ONT # N-SWE # DEV↵
  ⋮
```

  - Data schema is not present

Implementation of example

- List of existing relations in *dictionary*
  - `/var/db/dictionary`

```
student # UČO # INT # Name # STR # Type
of completion # STR # Covid # STR #
Program # STR # Field # STR↵
R # name # STR # id # INT # dept STR …↵
R2 # C # STR # A # INT …↵
    ⋮
```

Implementation Issues

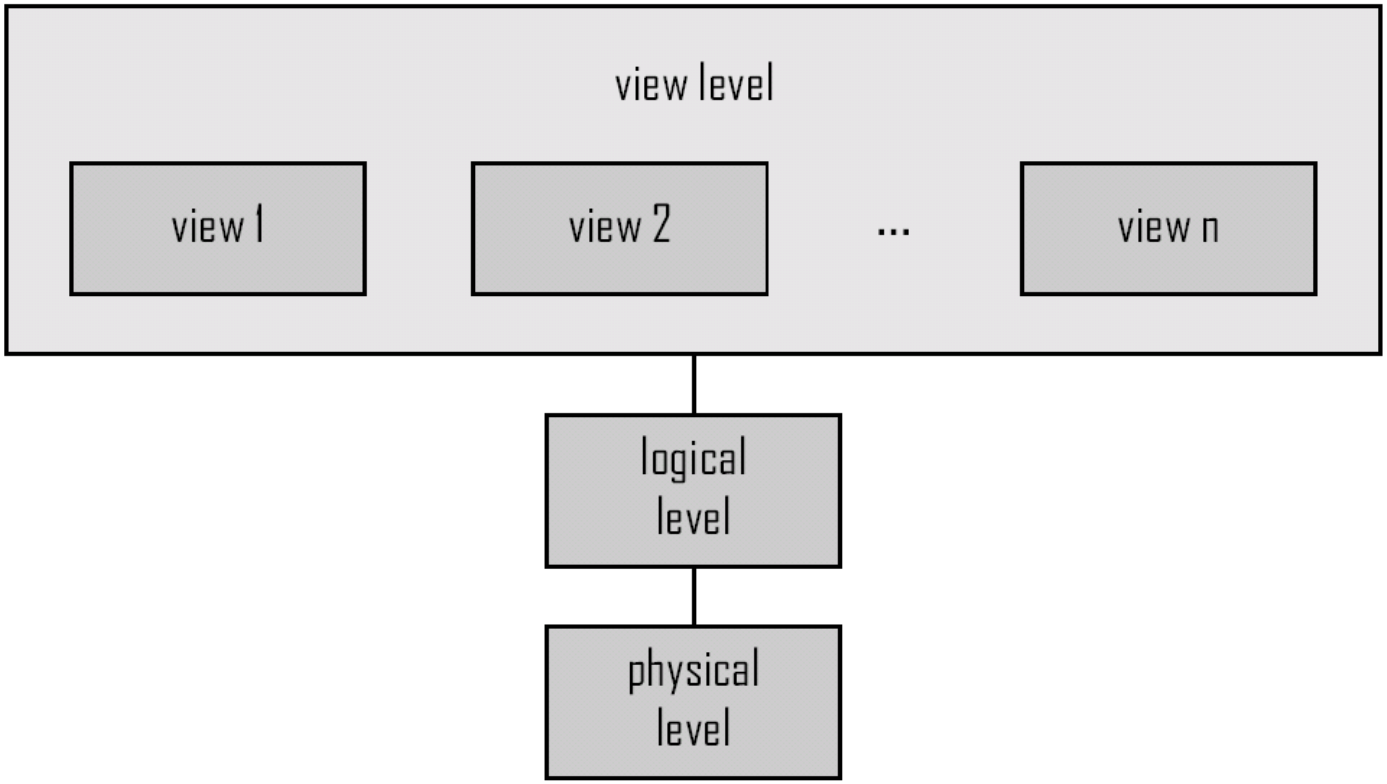
- Storage
  - Bizarre formatting – separators and new lines
    - Change in a value leads to change in whole file
  - Respecting underlying technology?
- Querying costly
  - Indexes?
- Data consistency
  - Primary keys, references, …

Implementation Issues

- No concurrent processing
- No reliability
  - Data loss frequent
  - Operation may not be finished
- No access control
  - Accessed checked on file-system level only
  - Rights too coarse
- No API, no GUI

Database System

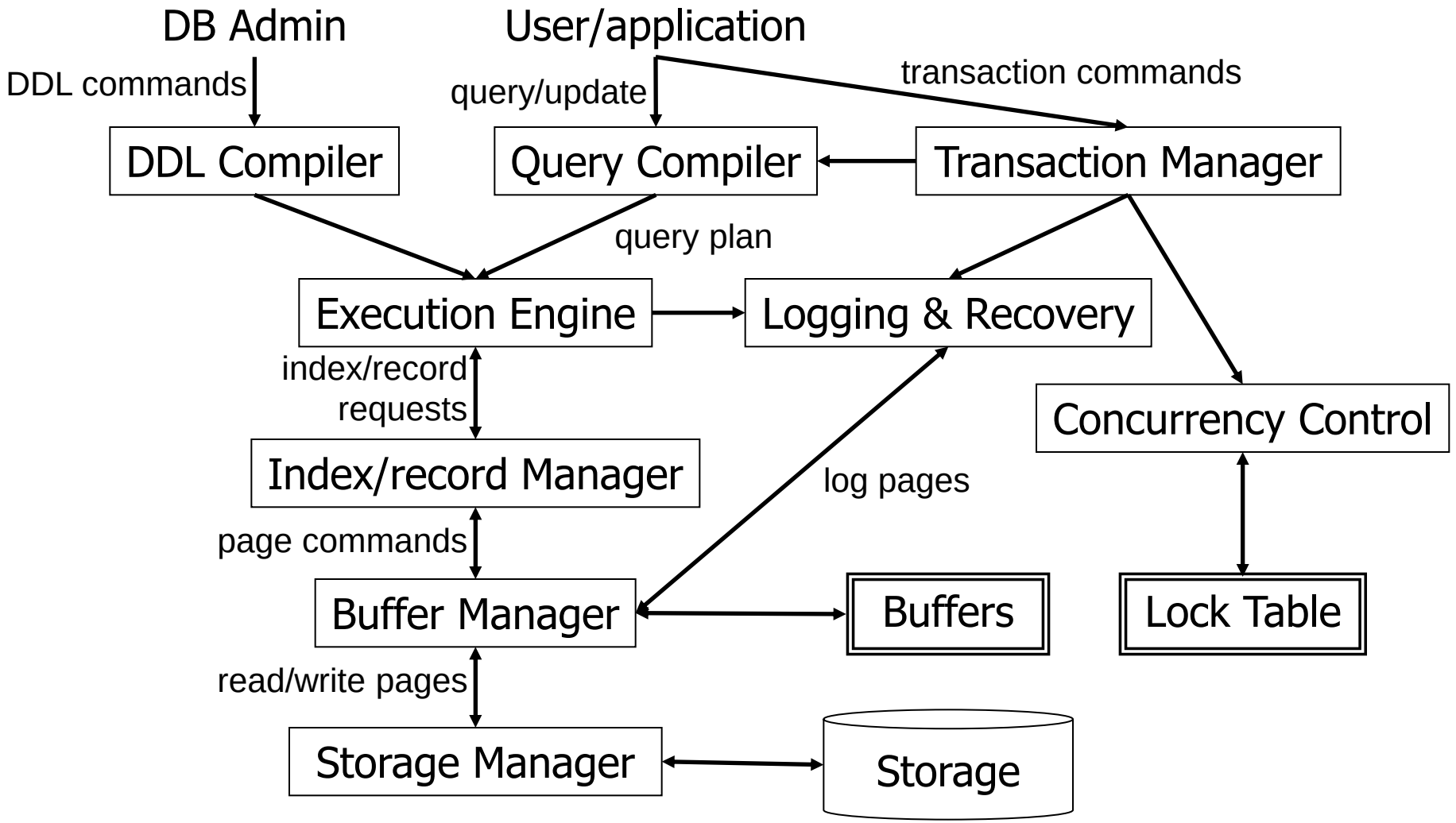
- DBMS (Database Management System)
  - Architecture:



DBMS Main Components

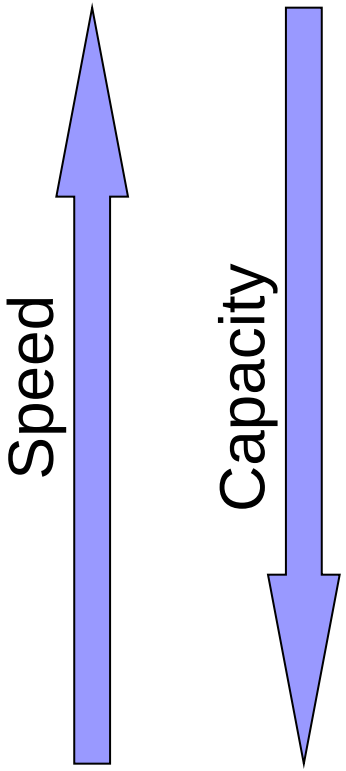
- Storage Manager
  - manages blocks on disks
  - manages buffers/caches
- Query Processor
  - query translation, optimization
  - query execution
- Transaction Manager
  - atomicity, consistency, isolation, durability of transaction processing

DBMS Components



Storage Hierarchy

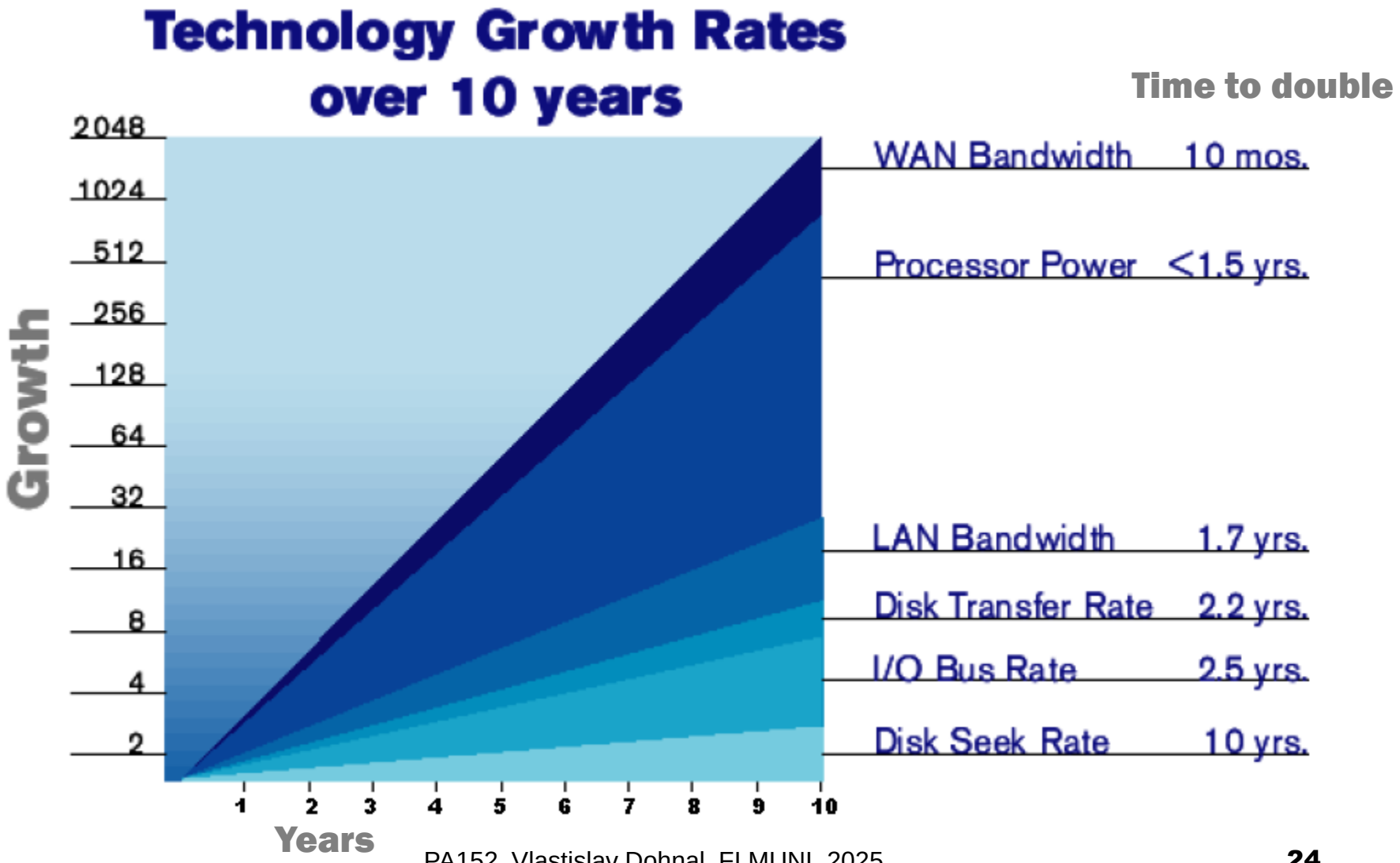
- Primary
  - cache
    - CPU
  - main (operation)
    - RAM
- Secondary
  - disk, flash
- Tertiary
  - tapes, optical discs
    - for backups



Empirical Laws

- Number of transistors
  - Density doubles each 2 years
  - CPU speed
  - Memory capacity
  - so-called Moore’s Law
- Disk capacity
  - Kryder's Law – 1000 times more in 15 years
  - Caveat: not applicable to disk speed!

Empirical Laws

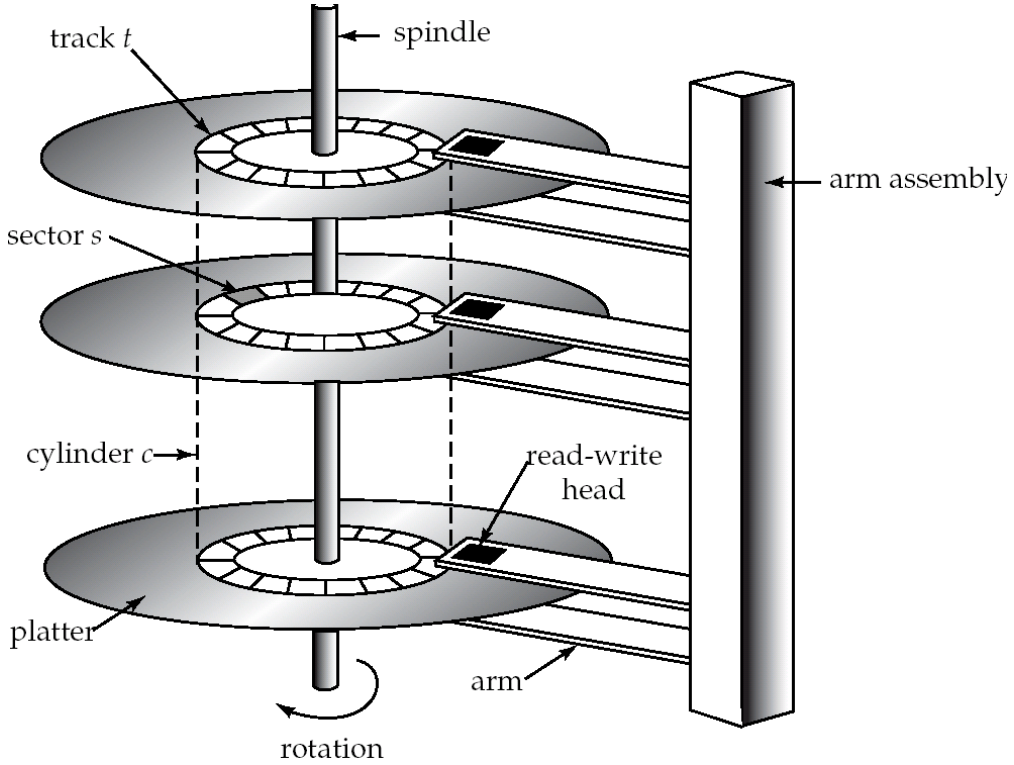


Storage Type

- Cache
  - Fastest, most expensive, volatile
- RAM
  - Fast – 10-100 ns (1 ns = 10^{-9} s)
  - Too small or expensive for whole database
  - Volatile
- Flash
  - Fast reads, non-volatile (25 µs = $25*10^{-6}$ s)
  - Slow writes
    - erase first, (whole region/bank) (2 ms = $2*10^{-3}$ s)
    - write then (250 µs = $250*10^{-6}$ s)
  - Limited write cycles

Storage Type

- Magnetic disk
  - Large capacity, non-volatile
  - Reads and writes of the same speed (10ms)

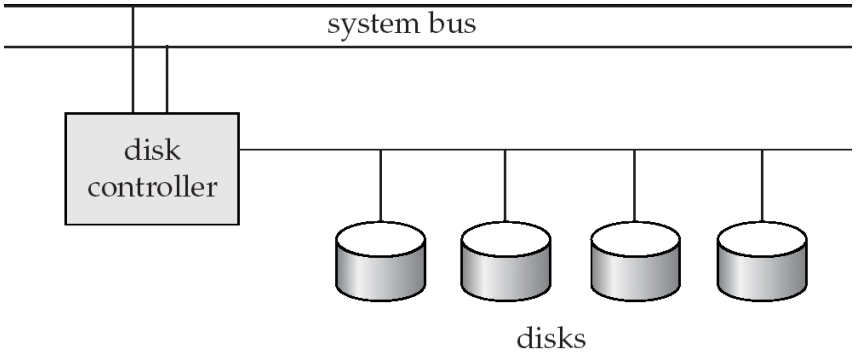


Magnetic disk

- Access time
  - Time from a request for reading/writing to the beginning of data transfer
- Blocking data
  - disk sector/block is atomic unit
- Access time components
  - Seek time – 4-10 ms
    - Move heads to the correct track
    - Average seek time = ½ worst case seek time
  - Rotational delay – 4-11ms (5400-15k rpm)
    - Time for revolving to the correct sector
    - Average latency = ½ worse case latency

Magnetic disk (cont.)

- Transfer rate
  - Speed of reading/writing from/to a disk
  - 50-200MB/s, lower for inner tracks
- Speed of controller
  - More drives connected to one controller
  - SATA 3.2 (16Gb/s) – 2 GB/s
  - SAS-3 (12Gb/s) – 1.17 GB/s



Magnetic disk (cont.)

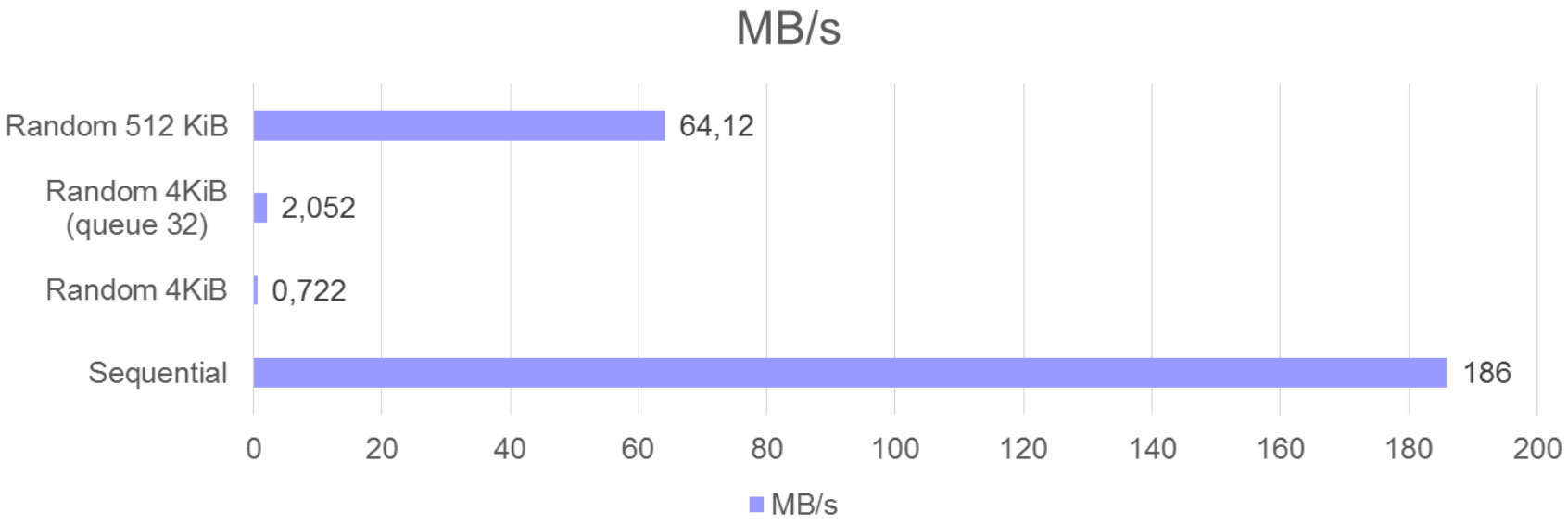
- Properties
  - Slow random read
    - access time can be up to 20ms
  - Fast sequential read
- Optimization in HW
  - Cache
    - Buffers for writing, battery backups or flash
  - Algorithms for arm moving minimization
    - Algorithm „elevator“
    - Work well when many concurrent requests

Magnetic disk (cont.)

- Example SATAII disk, 7200rpm, 100MB/s
  - Avg seek time = 8.9ms
  - Avg latency = (1/(7200/60))*0.5=0.00417s=4.17ms
  - Reading a sector (512B) = 13.07ms + 4.88µs
  - 10MB continuous = 13.07ms + 100ms = 113ms
    - consecutive sector reading includes also
      - track-to-track seek & platter / cylinder change
      - is neglected
  - 10MB randomly = 20480*13.07488ms = 268s

Magnetic disk (cont.)

Western Digital 10EZEX 1TB, SATA3, 7200 RPM, sustained transfer rate 150 MB/s



Disk ops

- Access in blocks (atomic unit)
  - Group of consecutive sectors (of 512KB)
  - Typically, 4KiB
- Block reading
- Block writing
  - Write and verify (rotate disk + reading!)
- Block update
  - Read
  - Change in memory
  - Write and verify

Algorithms in DBMS

- Work with blocks
  - block size in DB – 4KiB – 16KiB
  - block size in FS – 1-4KiB
  - block size in device – 512B, 4KiB
- Minimize random accesses
- Cost for reading and writing taken as same
  - Typical simplification

Solid State Drives

- Disk storage on „flash“ memory
- No moving parts
- More resistant to damage
- Quiet, low access time and delay
- 4x more expensive than HDD (per GB)

SSD – Flash memory

- NAND chips
  - SLC (single-level cells)
    - stores 1-bit information (2 voltage states)
    - fastest, highest cost
  - MLC (multi-level cells)
    - stores mostly 2-bit information
  - TLC (triple-level cells)
    - stores 3-bit information (8 voltage states)
    - slowest, least cost
  - QLC (quad-level cells)

SSD – Flash performance

	SLC	MLC	TLC	HDD	RAM
P/E cycles	100k	10k	5k	*	*
Bits per cell	1	2	3	*	*
Seek latency (µs)	*	*	*	9000	*
Read latency (µs)	25	50	100	2000-7000	0.04-0.1
Write latency (µs)	250	900	1500	2000-7000	0.04-0.1
Erase latency (µs)	1500	3000	5000	*	*
Notes	* metric is not applicable for that type of memory				

Source: https://www.extremetech.com/extreme/210492-extremetech-explains-how-do-ssds-work

SSD – Flash memory

- Terminology shift! (block ➔ page)
- Organization
  - Pages of 4KiB organized into blocks (64/128 pages)
  - Much faster reading than writing
    - Write: Only in “a new block"
      1. write a new copy of the changed data to a fresh block
      2. remap the file pointers
      3. then erase the old block later when it has time
  - Write restrictions – 1k-100k overwrite cycles
  - Reliability increased ECC sums
    - Hamming, Reed-Solomon

SSD – Flash memory

- A single NAND chip is relatively slow
  - SLC NAND
    - ~25 µs to read a 4 KiB page
    - ~250 µs to commit a 4 KiB page
    - ~2 ms to erase a 256 KiB block
- Data striping (RAID0) to improve performance

Lecture's Takeaways

- Terminology revision
- Categorization of storage
- Organization principles of HDD and SSD

Student's DB at FI

- FI provides a server with the following systems: https://www.fi.muni.cz/tech/unix/databases.html.en
  - Oracle, PostgreSQL, MariaDB
- Steps to use such a database system:
  1. Create an account in the selected DBMS
  2. Use a UI to access it.

Student's DB at FI – Steps to take

1. Create an account
   - Visit a page on fadmin.fi.muni.cz
     - Log in using your faculty credentials (ones you use to log in locally in a computer room)
     - Using a web browser with auto-translation is an advantage since the page is in Czech only.
   - Click on create an account in PostgreSQL secion
   - Set a proper password
     - It is independent from the FI's password!

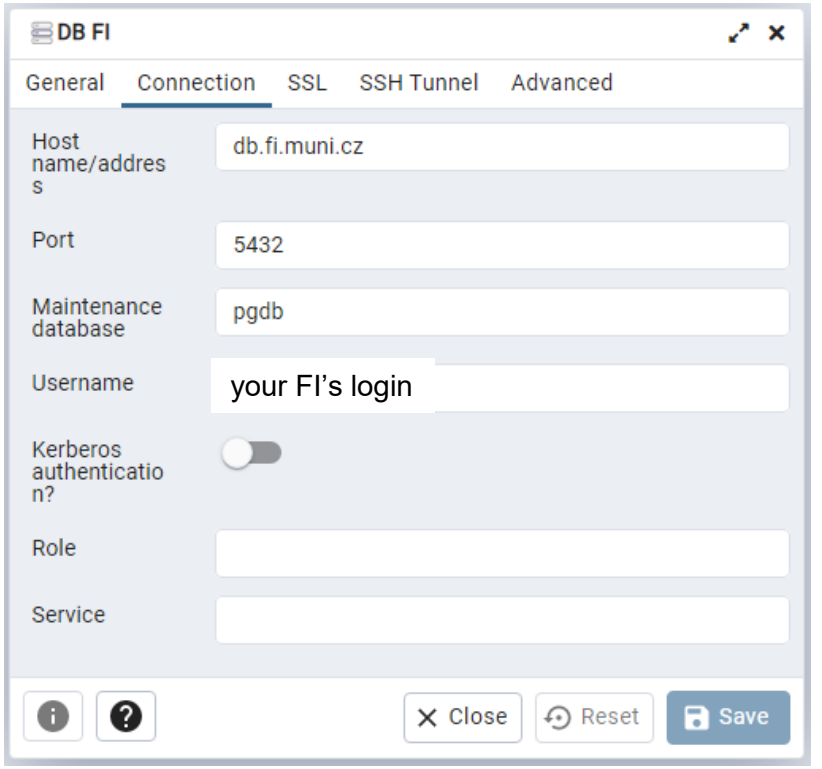
Student's DB at FI – Steps to take

2. Use a UI to access PostgreSQL
   - Caveat for A and B: You cannot connect to db.fi.muni.cz directly from Internet!
   A. Command line tool psql
      - ssh <login>@aisa.fi.muni.cz
      - psql -h db.fi.muni.cz pgdb <login>
   B. Web UI pgAdmin
      - Install it on your machine
      - Use FI's VPN or forward a local port to db.fi.muni.cz (see the next slide)

Student's DB at FI – Steps to take

B. Connecting via Web UI pgAdmin

- Using FI's VPN
  - Host name: db.fi.muni.cz
  - Port: 5432
  - Database: pgdb
  - Username is your login name at FI
  - Password can be set/changed here.
- All done here!

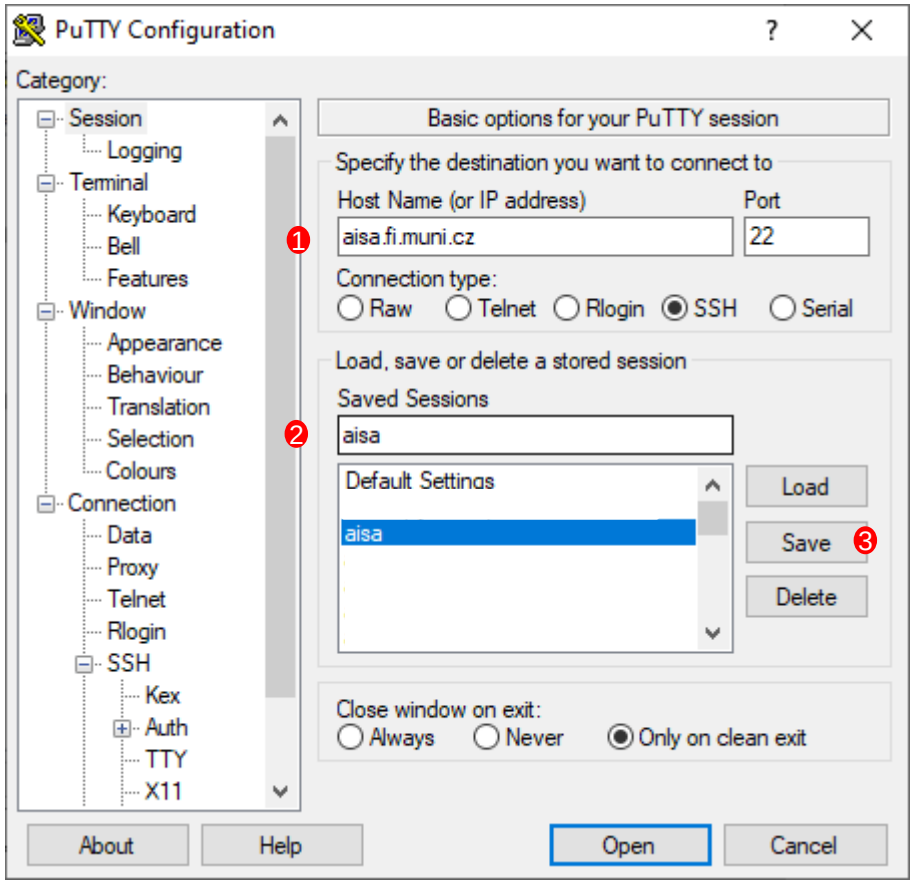


Student's DB at FI – Steps to take

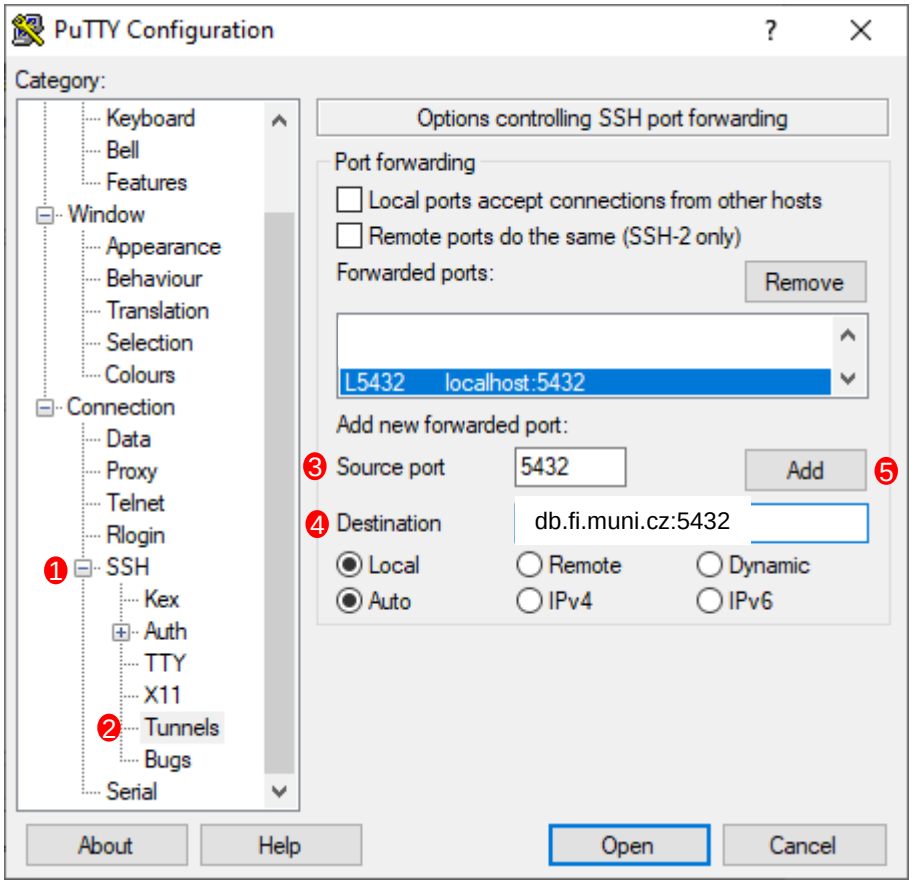
B. Connecting via Web UI pgAdmin

- Forwarding a local port to db.fi.muni.cz, e.g., using Putty

1. Create a session to aisa.fi.muni.cz



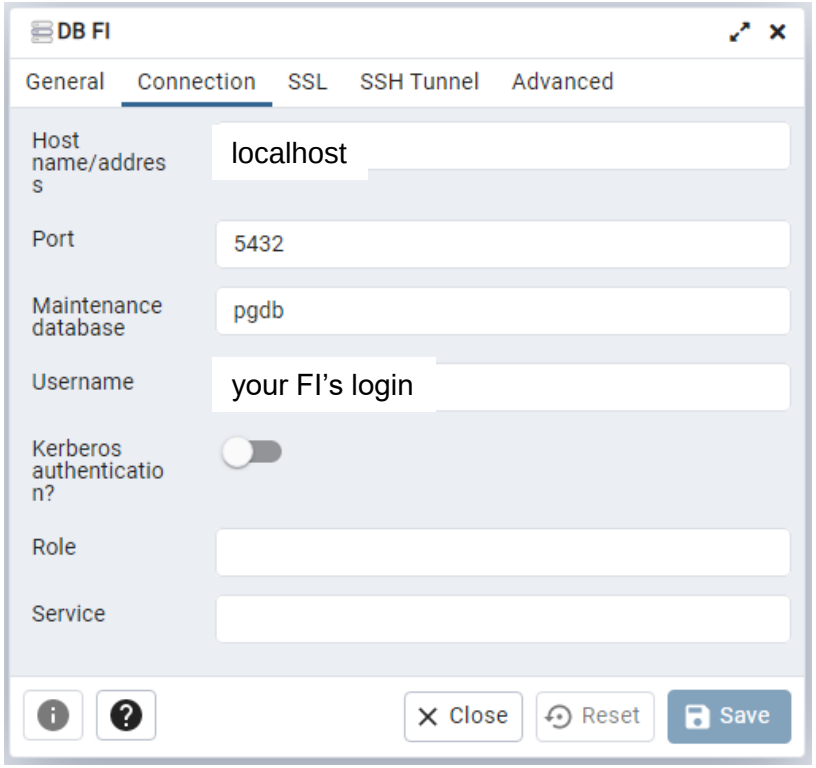
2. Modify the session (and save as in the left figure)



Student's DB at FI – Steps to take

B. Connecting via Web UI pgAdmin

- Forwarding a local port to db.fi.muni.cz, e.g., using Putty
- 1st: Connect via Putty (select the item Aisa, click the Open button)
- 2nd: Use pgAdmin
  - **Host name: localhost**
  - Port: 5432
  - Maintenance database: pgdb
  - Username: your login name at FI
  - Password can be set/changed here.



- All done here!