Techniques for Large-Scale Data: Exam

University of Gothenburg and Chalmers University of Technology
Department of Computer Science and Engineering
Period 4, 2018 (DIT871/DAT345)
Instructors: Dr. Alexander Schliep (Examiner) with Dr. Graham Kemp

Information:

- The exam takes place on Friday, June 1, 2018 from 14:00–18:00 in the SB building.
- The instructors will visit the exam room at 15:00 and 17:00 (Tel. 076-608 69 63).
- We expect that results will be published by June 17.
- Exam review: See the Canvas course website for details.
- You can earn are a total of 60 points in 6 questions in the exam.
- Grades for GU students (DIT851) are normally determined as follows: $\geq$ 70 % for grade VG; $\geq$ 40 % for grade G. Grades for Chalmers students (DAT345) are normally determined as follows: $\geq$ 80 % for grade 5; $\geq$ 60 % for grade 4; $\geq$ 40 % for grade 3.

Instructions:

- You may use one A4-sized sheet (back and front) of prepared formulas and notes, but all work must be your own. No photocopies or print-outs. It must be handed in with your exam questions. Please write the exam number on it. *Do not write your name*.
- Begin the answer to each question on a new page. Write page number and question on **every** page.
- Write clearly; unreadable = wrong!
- Fewer points are given for unnecessarily complicated solutions.
- Indicate clearly if you make any assumptions that are not given explicitly in the question.
- Show **ALL** your work. You will get little or no credit for an unexplained answer. Please indicate why a specific computation or transformation is appropriate. The points of each question appear in parentheses; use this for guiding your time.
- **No electronic devices of ANY kind!** Please store **all** your devices in your bag and not on your person. Any device found at your seat, **even if it is turned off**, will be considered cheating and reported!
- English language dictionaries are allowed.

Question 1 [*18 points total*]

Suppose we have the following relations:

$Persons(\underline{pid}, name)$

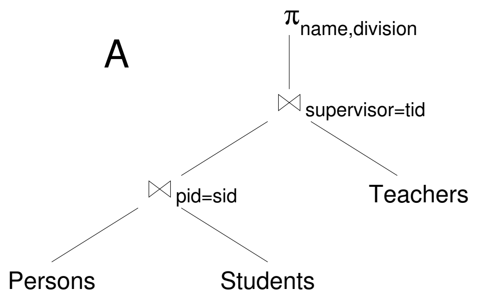
$Teachers(\underline{tid}, division)$
$tid \rightarrow Persons.pid$

$Students(\underline{sid}, supervisor)$
$sid \rightarrow Persons.pid$
$supervisor \rightarrow Teachers.tid$

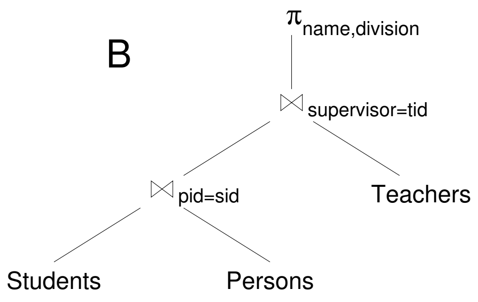
(a) [*6 pts*] A, B, C and D are four alternative logical query plans for the following SQL query:

```
SELECT   name, division
FROM     Persons, Students, Teachers
WHERE    pid=sid AND supervisor=tid
```

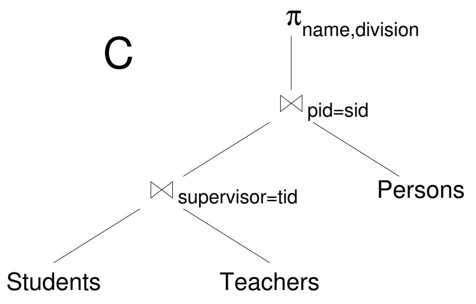
A



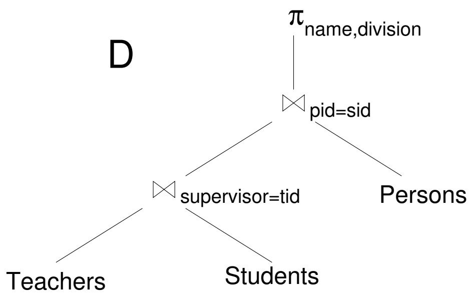
B



C



D



Assume that there are only indexes on the key attributes, and that relations Students and Teachers have approximately the same number of rows.

Discuss the efficiency of the logical query plans.

(b) [*4 pts*] Suppose we want to model these relations using Semantic Web technology. Give RDFS or OWL 2 statements that model the metadata. Students and teachers should be modelled as subclasses of persons.

(c) [*2 pts*] Based on the metadata in your answer to part (b), what RDF triples would be needed to implement the following data:

Persons

pid	**name**
p1	Smith
p2	Jones

Students

sid	**supervisor**
p1	p2

Teachers

tid	**division**
p2	DS

(d) [*3 pts*] Suppose that the triples in your answer to part (c) are stored in a Semantic Web database. Write a SPARQL query that computes the same result as the SQL query in part (a).

(e) [*3 pts*] Suppose that the triples in your answer to part (c) — and many other triples — are stored in a single relational database table with three columns. Translate the SPARQL query in your answer to part (d) to an SQL query that accesses this table to find the answer.

Question 2 [*6 points total*]

(a) [*3 pts*] In a concurrent database system, what is a *lock*? What is *deadlock*?

(b) [*3 pts*] Briefly describe the redo(T_i) operation in a database's recovery system. In what circumstance must transaction T_i be redone?

Question 3 [*8 points total*]

(a) [*4 pts*] Explain the main difference between document databases and key-value stores. In what circumstances are a document database and a key-value store essentially the same?

(b) [*4 pts*] The Neo4j web site states that: "Cypher uses ASCII-Art to represent patterns." Explain what this means. Give examples to illustrate your answer.

Question 4 [*3 points total*]

Suppose you are part of a university's IT team and have been asked to help improve campus safety by implementing automatic number plate recognition technology to monitor vehicles on campus.

Discuss whether there are ethical issues that need to be considered.

Question 5 [*11 points total*]

As a junior data scientist recently hired to Reynholm Industries you are tasked with overhauling and redesigning the IT infrastructure and accelerating existing computational workloads. The computational resources are mostly used by the following workloads for three departments at Reynholm Industries.

- The CEO has a team running a software to predict customer demand for the next month. The software, combining partial differential equations and Bayesian statistics in a large-scale, parallel Monte Carlo (MC) simulation running about two days, takes a few historical summary statistics and key economy indicators and outputs predicted demand and a confidence interval for the prediction.

- The COO's team runs daily analysis (DA) on orders, shopping baskets, online advertising, and website visits. The total amount of data is about 200GB per day collected in Reynholm Industries data center. The output are summary statistics (histograms, averages, etc.) and nice plots enabling monitoring the state of affairs.
- The marketing department runs advanced analytics (AA) aggregating primary data as used in the daily analysis over the span of several weeks to identify groups of customers and groups of website visitors. It also wants to identify factors which can help to predict when a website visitor becomes a customer. The output are models of groups and classifiers including features relevant to classification.

Provide a brief argument indicating key factors only when answering the following questions:

(a) [*3 pts*] If one were to reimplement software for the three workloads, which of the four paradigms for parallel computation we encountered—multi-threaded programming (MT), message passing (MP), map-reduce (MR), and Spark (SP) as an example of cluster computing—would you choose for the MC, DA, and AA workloads respectively.

Solution:

- MC can in principle be implemented in any of the four frameworks as the communication only occurs in the beginning and at the end of simulation run and only small amounts of data have to be transferred. MT or MP—depending whether all cores on one machine suffice or several machines are needed—is a natural answer, but MR and SP are certainly possible.
- DA is a data-intensive job. However, aggregating and computing summary statistics is sufficiently simple (and typically a one-pass operation) so that MR would be a natural model. As every MR job can also be expressed in SP, the latter would also be a legitimate answer. Note that SP would be unlikely to yield faster running times as caching in memory is irrelevant for one-pass jobs.

  MT/MP would be wrong due to handling big data.
- The likely iterative nature of the AA computations and the demands for data suggests SP as the natural framework.

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(b) [*3 pts*] If one were to acquire new hardware either in Reynholm Industries's data center or the cloud, which system architectures—distributed system with centralized disk storage (HPC), distributed system with local disk (DS), or a distributed system with local disks and large main memory (LM)—would be most appropriate for the workloads MC, DA, and AA respectively.

Solution:

- MC uses only small amounts of data so HPC is a natural answer. It would not benefit from DS, LM, but also run well on such system given equal number of cores and core speed.
- DA is not well-suited for HPC as bandwidth to the storage system is a likely bottleneck in contrast to the parallel IO-speed on multiple DS nodes and total amount of storage.
- The likely iterative nature of the AA computations suggests LM as the natural platform. Iterative computations benefit from caching data in RAM.

(c) [*5 pts*] Describe the questions you would ask yourself and the formal analysis you would perform when deciding whether moving the workload DA to the cloud would result in a desired speedup of the computation. Use variables for all relevant quantities.

Solution: The questions to ask are:

- Can increasing the number of nodes accelerate the computation to a desired speedup? In other words: is a sufficient proportion amenable to parallelization?
- Is data collected locally or can it be collected in the cloud?
- In how far are computational improvements negated by upload speeds to the cloud?
- Measure f, the proportion of a program which can be accelerated by parallelization.
- Use Amdahl's law to compute the total speedup s_{total} and its limit as the number of cores d goes to infinity.
- For computations in the cloud using locally collected data the transfer time have to be included. Let t_u be the time for upload and t_r the running time, then $t = t_u + t_r$ is the total time and $f' = \frac{f t_r}{t_u + t_r}$ is the proportion amenable to speedups, which can be analyzed with Amdahl's law.

  Note that there are other ways to formalize it. Partial credit for insight that upload speed bound computational speedup.

Question 6 [*14 points total*]

Bloom filters are data structures for set membership queries. The two main operations for standard Bloom filters are `insert(x)` and `query(x)` which insert an item x into a Bloom filter, respectively answer whether an item x is present in a Bloom filter.

(a) [*3 pts*] Bloom filters are probabilistic data structures, as in some circumstances an erroneous answer might be given. Describe those circumstances, the type of error which can occur, and how the probability of such an error occurring can be controlled (i.e. the main factor in the error probability assuming a constant number of items n).

Solution:

- Bloom filters cannot have false negatives: i.e. query yields a negative result for item x, although item x has been inserted.
- Bloom filters can have false positives: i.e. query yields positive result for item x, although item x has not been inserted. This occurs if the k bits $h_1(x), \ldots, h_k(x)$ for item x are set due to previous inserts.
- The dominant factor for the false positive error rate is the size of the Bloom filter. For a fixed number of items in the filter and fixed k, increasing the size will decrease the FPR and vice versa.

(b) [*3 pts*] Give an example how a Bloom filter can be used to accelerate computations.

Solution: Correct examples include

- Avoiding database lookups by having the keys in a Bloom filter (e.g. avoiding password lookup for mistyped user names)
- When using d servers to hold a distributed database (or a web cache), keep the keys in d Bloom filters to identify the server holding relevant information
- Identifying duplicate items
- Counting frequent items: Use a Bloom filter to identify when an item is seen a second time. Then count in a hash-map etc.

(c) [*8 pts*] Sketch an efficient parallel program for inserting all n items into a Bloom filter of size 2GB (two gigabytes). Assume that the nodes in your compute clusters are networked with very fast network connections, have at least 16GB RAM, and that the n items are stored in a distributed manner (e.g., in HDFS) on local disks of your cluster nodes. Your program should return the Bloom filter with all items inserted in one node (i.e, as if one would insert all items serially). *Hint: collecting all items in one node and inserting sequentially would not be efficient.*

Solution: The insertion of an item x can be viewed as computing the bitwise OR between the current Bloom filter of size b and an empty BF of equal size with only x inserted; i.e., containing a one at the k bits specified by $h_1(x), \ldots, h_k(x)$ and zero elsewhere. Note, bitwise OR is associative and commutative.

Consequently, partitioning items $x_1,\ldots,x_n$ into d sets, inserting each of the d sets into their own Bloom filter, and computing the bitwise-OR of the d bloom filters yields the same result as inserting all items into one Bloom filter.

Hence, one can insert all items stored locally in a node in a BF and compute the OR of all Bloom filters with a reduce operation, which causes $d-1$ transfers of size 2GB and $d-1$ OR operations.

Extra points for observing that bitwise OR on contiguous memory has very good cache behavior and can be performed with 512bit operations on modern CPUs.