Physical Database Design for Relational Databases

Logical *v*. Physical Database Design

- Sources of information for physical design process includes logical data model and documentation that describes model.

- Logical database design is concerned with the *what*, physical database design is concerned with the *how*.

Physical Database Design

- Process of producing a description of the implementation of the database on secondary storage.

- It describes the base relations, file organisations, and indexes used to achieve efficient access to the data, and any associated integrity constraints and security measures.

Overview Database Design Methodology

- Step 1 Build conceptual data model.
- Step 2 Build and validate logical data model.
- Step 3 Translate logical data model for target DBMS.
- Step 4 Design file organisations and indexes.
- Step 5 Design user views.
- Step 6 Design security mechanisms.
- Step 7 Consider the introduction of controlled redundancy.
- Step 8 Monitor and tune the operational system.

Overview of Physical Database Design Methodology

- Step 3 Translate logical data model for target DBMS
  - Step 3.1 Design base relations
  - Step 3.2 Design representation of derived data
  - Step 3.3 Design general constraints

Overview of Physical Database Design Methodology

- Step 4 Design file organisations and indexes
  - Step 4.1 Analyse transactions
  - Step 4.2 Choose file organisations
  - Step 4.3 Choose indexes
  - Step 4.4 Estimate disk space requirements

Overview of Physical Database Design Methodology

- Step 5 Design user views
- Step 6 Design security mechanisms
- Step 7 Consider the introduction of controlled redundancy
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Step 3 Translate Logical Data Model for Target DBMS

Objective: To produce a relational database schema from the logical data model that can be implemented in the target DBMS.

- Need to know functionality of target DBMS such as how to create base relations and whether the system supports the definition of:
  - Primary Keys, Foreign Keys, and Alternate Keys;
  - required data – i.e. whether system supports NOT NULL;
  - Domain definition;
  - relational integrity constraints;
  - general constraints.

Step 3.1 Design base relations

Objective**:** To decide how to represent base relations identified in logical model in target DBMS.

- For each relation, need to define:
  - the name of the relation;
  - a list of simple attributes in brackets;
  - the Primary Key and, where appropriate, Alternate Keys and Foreign Keys;
  - referential integrity constraints for any Foreign Keys identified.

Step 3.1 Design base relations

- From data dictionary, we have for each attribute:
  - its domain, consisting of a data type, length, and any constraints on the domain;
  - an optional default value for the attribute;
  - whether it can hold nulls;
  - whether it is derived, and if so, how it should be computed.

Step 3.2 Design representation of derived data

Objective**:** To decide how to represent any derived data present in logical data model in target DBMS.

- Recall a derived attribute is an attribute whose value can be found by examining the values of other attributes (or performing some calculation).
- Examine logical data model and data dictionary, and produce list of all derived attributes.
- Derived attribute can be stored in database or calculated every time it is needed.

Step 3.2 Design representation of derived data

- Option selected is based on:
  - additional cost to store the derived data and keep it consistent with operational data from which it is derived;
  - cost to calculate it each time it is required.

- Less expensive option is chosen subject to performance constraints.

PropertyforRent Relation and Staff Relation with Derived Attribute noOfProperties

PropertyForRent

propertyNo	street	city	postcode	type	rooms	rent	ownerNo	staffNo	branchNo
PA14	16 Holhead	Aberdeen	AB7 5SU	House	6	650	CO46	SA9	B007
PL94	6 Argyll St	London	NW2	Flat	4	400	CO87	SL41	B005
PG4	6 Lawrence St	Glasgow	G11 9QX	Flat	3	350	CO40		B003
PG36	2 Manor Rd	Glasgow	G32 4QX	Flat	3	375	CO93	SG37	B003
PG21	18 Dale Rd	Glasgow	G12	House	5	600	CO87	SG37	B003
PG16	5 Novar Dr	Glasgow	G12 9AX	Flat	4	450	CO93	SG14	B003

Staff

staffNo	fName	lName	branchNo	noOfProperties
SL21	John	White	B005	0
SG37	Ann	Beech	B003	2
SG14	David	Ford	B003	1
SA9	Mary	Howe	B007	1
SG5	Susan	Brand	B003	0
SL41	Julie	Lee	B005	1

Step 3.3 Design general constraints

Objective: To design the general constraints for target DBMS.

- Some DBMS provide more facilities than others for defining enterprise constraints. Example:

```
CONSTRAINT StaffNotHandlingTooMuch
    CHECK (NOT EXISTS (SELECT staffNo
                       FROM PropertyForRent
                       GROUP BY staffNo
                       HAVING COUNT(*) > 100))
```

Step 3.3 Design general constraints

- If you cannot implement the constraint in the DBMS chosen you could use *Triggers* or implement the constraint in the application used as a front end to the DBMS.

Step 4 Design File Organisations and Indexes

Objective: To determine optimal file organisations to store the base relations and the indexes that are required to achieve acceptable performance; that is, the way in which relations and tuples will be held on secondary storage.

- One of the main objectives of physical database design is to store and access data in an efficient way.

- Must understand the typical *workload* that the database must support.

Step 4.1 Analyse transactions

Objective: To understand the functionality of the transactions that will run on the database and to analyse the important transactions.

- Attempt to identify performance criteria, such as:
  - transactions that run frequently and will have a significant impact on performance;
  - transactions that are critical to the business;
  - times during the day/week when there will be a high demand made on the database (called the *peak load*).

Step 4.1 Analyse transactions

- Use this information to identify the parts of the database that may cause performance problems.

- Also need to know high-level functionality of the transactions, such as:
  - attributes that are updated;
  - search criteria used in a query.

Step 4.1 Analyse transactions

- Often not possible to analyse all transactions, so investigate most ‘important’ ones.

- To help identify these can use:
  - *transaction/relation cross-reference matrix*, showing relations that each transaction accesses, and/or
  - *transaction usage map*, indicating which relations are potentially heavily used.

Step 4.1 Analyse transactions

- To focus on areas that may be problematic:
  1. Map all transaction paths to relations.
  2. Determine which relations are most frequently accessed by transactions.
  3. Analyze the data usage of selected transactions that involve these relations.

Step 4.1 Analyse transactions
Map all transaction paths to relations

- Sample transactions:
  A. Enter the details for a new property and the owner.
  B. Update/delete the details of a property.
  C. Identify the total number of staff in each position at branches in Glasgow.
  D. List the property number, address, type, and rent of all properties in Glasgow, order by rent.
  E. List the details of properties for rent managed by a named member of staff.
  F. Identify the total number of properties assigned to each member of staff at a given branch.

Cross-referencing transactions and relations

Cross-referencing transactions and relations.

Transaction/ Relation	(A)				(B)				(C)				(D)				(E)				(F)			
	I	R	U	D	I	R	U	D	I	R	U	D	I	R	U	D	I	R	U	D	I	R	U	D
Branch										X				X								X		
Telephone																								
Staff		X				X				X								X				X		
Manager																								
PrivateOwner	X																							
BusinessOwner	X																							
PropertyForRent	X					X	X	X						X				X				X		
Viewing																								
Client																								
Registration																								
Lease																								
Newspaper																								
Advert																								

I = Insert; R = Read; U = Update; D = Delete

Step 4.1 Analyse transactions
Map all transaction paths to relations

- The matrix shows that both the *Staff* and *PropertyForRent* relations are accessed by five of the six transactions, and so efficient access to these relations may be important to avoid performance problems.

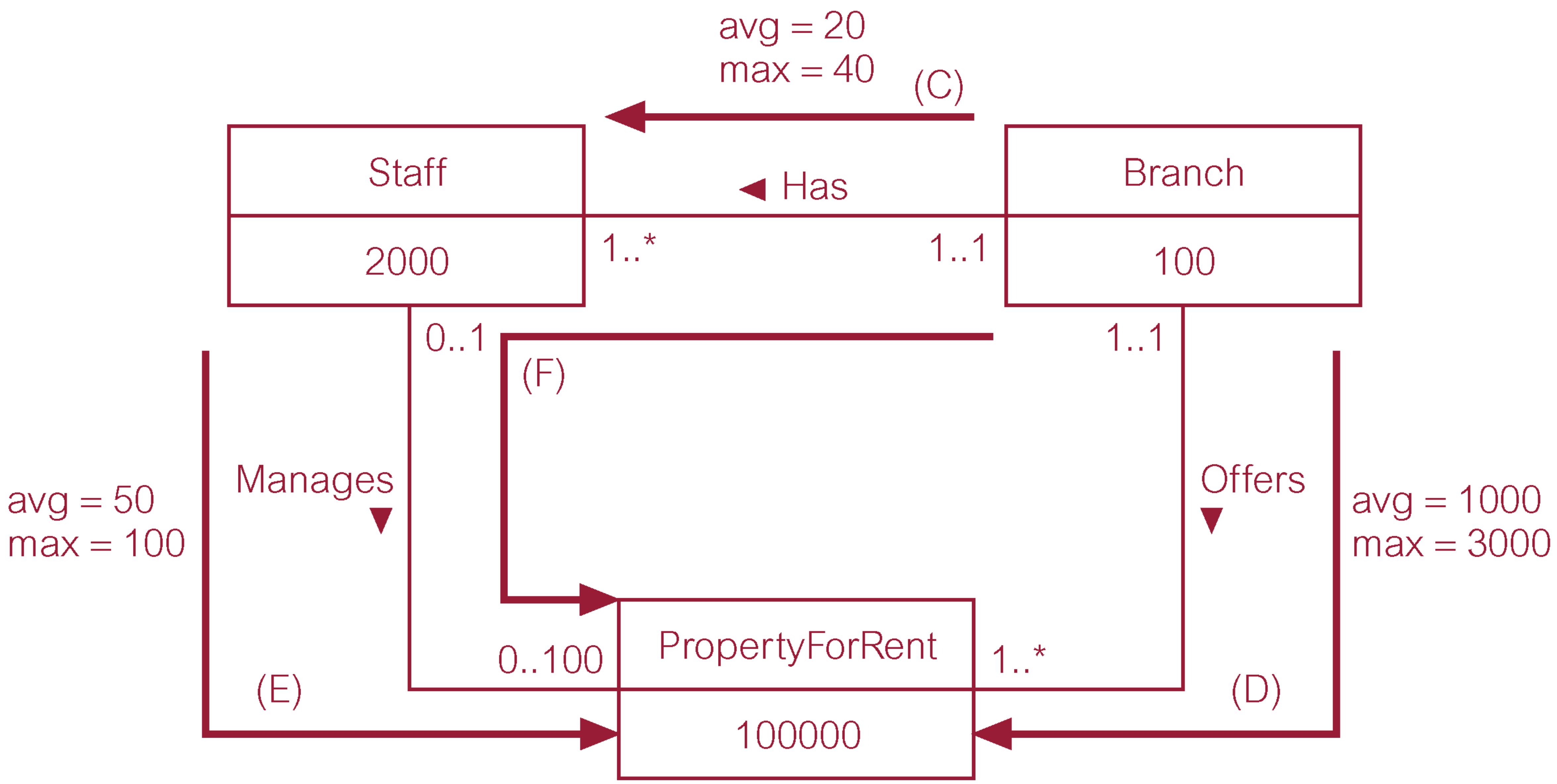
- A closer inspection of these transactions and relations are necessary.

Step 4.1 Analyse transactions
Determine which relations are most frequently accessed by transactions

- Suppose we know that there are 100,000 properties for rent and 2000 staff distributed over 100 branch offices, with an average of 1000 and a maximum of 3000 properties at each branch.

- The following transaction usage map is for transactions C, D, E, and F, which all access at least one of the Staff and PropertyForRent relations, with these numbers added.

Example Transaction Usage Map



Step 4.1 Analyse transactions
Analyze the data usage of selected transactions that involve these relations

- Having identified the important transactions, we now analyse each one in more detail. For each transaction, determine
  - The relations and attributes accessed by the transaction and the type of access; (i.e. insert, update, delete, select transaction).
  - The attributes used in any predicates/conditions. Check whether predicates involve:
    - Pattern matching;
    - Range searches;
    - Exact-match key retrieval.

Step 4.1 Analyse transactions
Analyze the data usage of selected transactions that involve these relations

- For each transaction, determine (continued):
  - For a query, the attributes that are involved in the join of two or more relations.
  - The expected frequency at which the transaction will run.
  - The performance goals for the transation; for example, the transaction must complete within 1 second.
- The following image shows an example of a transaction analysis form for transaction D. It shows the average frequency of this transaction, and peak loading. It also shows the SQL statement and the transaction usage map.

Example Transaction Analysis Form

Transaction Analysis Form **1-Sept-2004**

Transaction (D) List the property number, address, type, and rent of all properties in Glasgow, ordered by rent

Transaction volume

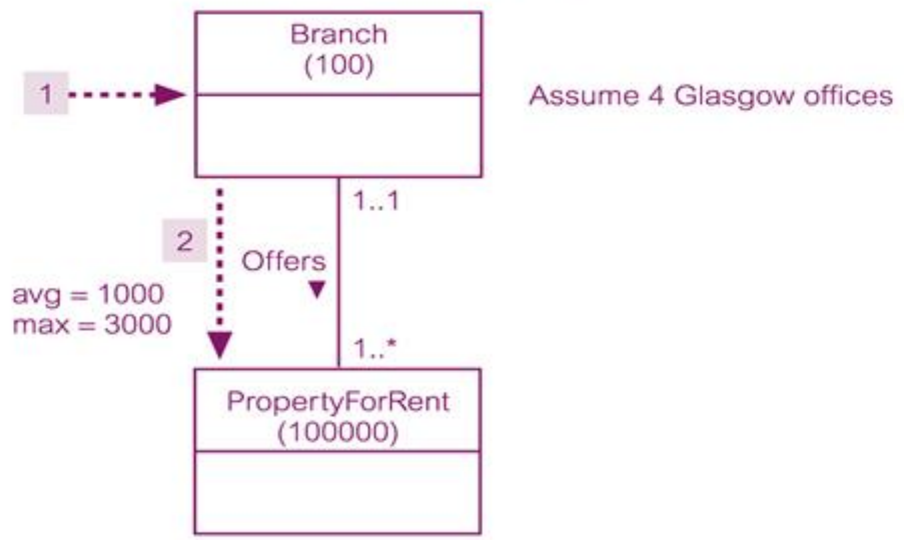
Average: 50 per hour

Peak: 100 per hour (between 17.00 and 19.00 Monday–Saturday)

SELECT **propertyNo**, **p.street**, **p.postcode**, **type**, **rent**
FROM **Branch b** INNER JOIN **PropertyForRent p** ON
b.branchNo = **p.branchNo**
WHERE **p.city** = 'Glasgow'
ORDER BY **rent**;

Predicate: **p.city** = 'Glasgow'
Join attributes: **b.branchNo** = **p.branchNo**
Ordering attribute: **rent**
Grouping attribute: none
Built-in functions: none
Attributes updated: none

Transaction usage map



Access	Entity	Type of Access	No. of References		
			Per Transaction	Avg Per Hour	Peak Per Hour
1	**Branch** (entry)	R	100	5000	10000
2	**PropertyForRent**	R	4000–12000	200000–600000	400000–1200000
Total References			**4100–12100**	**205000–605000**	**410000–1210000**

Example transaction analysis form.

Step 4.2 Choose file organisations

Objective: To determine an efficient file organisation for each base relation.

- Store and access data in an efficient way.
- File organisations include Heap, Hash, Indexed Sequential Access Method (ISAM), B+-Tree, and Clusters.
- Some DBMSs may not allow selection of file organisations.

Step 4.2 Choose file organisations

- InnoDB is a general-purpose storage engine that balances high reliability and high performance. InnoDB is the default MySQL storage engine in MySQL 8.0.

- InnoDB tables arrange your data on disk to optimise queries based on primary keys. Each InnoDB table has a primary key index called a clustered index that organises the data to minimise I/O for primary key lookups.

- InnoDB data and indexes for a given table are stored in the same physical tablespace file.

Step 4.3 Choose indexes

Objective: To determine whether adding indexes will improve the performance of the system.

- One approach is to keep tuples unordered and create as many *secondary indexes* as necessary.

Step 4.3 Choose indexes

- Another approach is to order tuples in the relation by specifying a *primary* or *clustering index*.

- In this case, choose the attribute for ordering or clustering the tuples as:
  - attribute that is used most often for join operations - this makes join operation more efficient, or
  - attribute that is used most often to access the tuples in a relation in order of that attribute.

Step 4.3 Choose indexes

- If ordering attribute chosen is key of relation, index will be a *primary index*; otherwise, index will be a *clustering index*.

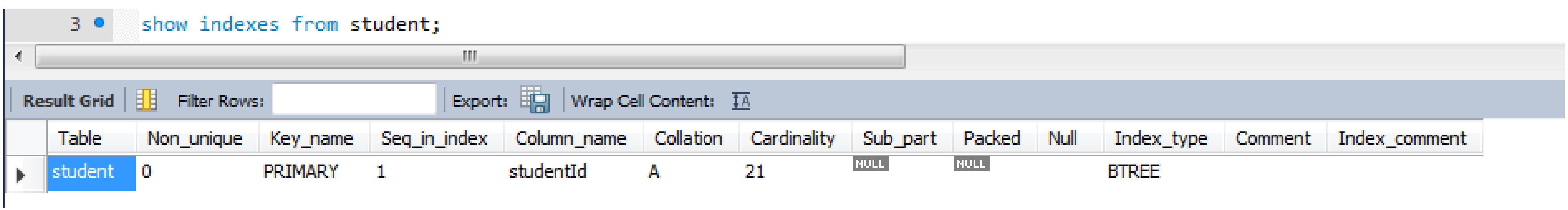
- Each relation can only have either a primary index or a clustering index.

- Secondary indexes provide a mechanism for specifying an additional key for a base relation that can be used to retrieve data more efficiently.

Step 4.3 Choose indexes

- Every InnoDB table has a special index called the clustered index where the data for the rows is stored. Typically, the clustered index is synonymous with the primary key.

- A clustered index (MySQL/InnoDB) is a table stored in an index B-Tree structure.



```
3 show indexes from student;
```

Result Grid | Filter Rows: | Export: | Wrap Cell Content:

Table	Non_unique	Key_name	Seq_in_index	Column_name	Collation	Cardinality	Sub_part	Packed	Null	Index_type	Comment	Index_comment
student	0	PRIMARY	1	studentId	A	21	NULL	NULL		BTREE		

Step 4.3 Choose indexes

- All indexes other than the clustered index are known as secondary indexes. In InnoDB, each record in a secondary index contains the primary key columns for the row, as well as the columns specified for the secondary index. InnoDB uses this primary key value to search for the row in the clustered index.

Step 4.3 Choose indexes

- Have to balance overhead involved in maintenance and use of secondary indexes against performance improvement gained when retrieving data.

- This includes:
  - adding an index record to every secondary index whenever a tuple is inserted;
  - updating secondary index when the corresponding tuple is updated;
  - increase in disk space needed to store secondary index;
  - possible performance degradation during query optimisation to consider all secondary indexes.

Step 4.3 Choose indexes – Guidelines for choosing ‘wish-list’

1. Do not index small relations.
2. Index Primary Key of a relation if it is not a key of the file organisation.
3. Add secondary index to a Foreign Key if it is frequently accessed.
4. Add secondary index to any attribute heavily used as a secondary key.
5. Add secondary index on attributes involved in: selection or join criteria; ORDER BY; GROUP BY; and other operations involving sorting (such as UNION or DISTINCT).

Step 4.3 Choose indexes – Guidelines for choosing ‘wish-list’

6. Add secondary index on attributes involved in built-in aggregate functions.

7. Add secondary index on attributes that could result in an index-only plan.

8. Avoid indexing an attribute or relation that is frequently updated.

9. Avoid indexing an attribute if the query will retrieve a significant proportion of the relation.

10. Avoid indexing attributes that consist of long character strings.

Step 4.4 Estimate disk space requirements

Objective: To estimate the amount of disk space that will be required by the database.

- For each table, add up the field sizes for each record and multiply the total field size by the estimated number of records/tuples in the table.

Step 5 Design User Views

Objective**:** To design the user views that were identified during the Requirements Collection and Analysis stage of the database system development lifecycle.

Step 6 Design Security Measures

Objective: To design the security measures for the database as specified by the users.