CS 764: Topics in Database Management Systems
Lecture 1: Introduction

Xiangyao Yu
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Who am I?

Name: Xiangyao Yu

Assistant professor in Computer Sciences, Database Group

Postdoc and PhD at MIT on databases and computer architecture

Research interests:

• Cloud-native databases
• New hardware for database
• Transactions and HTAP
Basic Information

Course website: https://pages.cs.wisc.edu/~yxy/cs764-f22/index.html

Instructor: Xiangyao Yu
Office hours:
  – Monday 2:30pm–3:30pm CS 4361
  – Or schedule by email

TA: Keren Chen
Office hours: schedule by email

Piazza for discussions and questions
Today’s Agenda

Database 101

Course logistics
**Database 101**

**Database**: A collection of data, typically describing the activities of one or more related organizations. For example:
- Entities: students, instructors, courses
- Relationships: students enroll in courses, instructors teach courses
Database: A collection of data, typically describing the activities of one or more related organizations. For example:
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Database management system (DBMS): Software designed to assist in maintaining and utilizing large collection of data.
A relational database is a collection of one or more relations, where each relation is a table with rows and columns.

An example relation:

<table>
<thead>
<tr>
<th>name</th>
<th>category</th>
<th>price</th>
<th>manufacturer</th>
</tr>
</thead>
<tbody>
<tr>
<td>iPad</td>
<td>tablet</td>
<td>$399.00</td>
<td>Apple</td>
</tr>
<tr>
<td>Surface</td>
<td>tablet</td>
<td>$299.00</td>
<td>Microsoft</td>
</tr>
</tbody>
</table>

…
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<td>tablet</td>
<td>$299.00</td>
<td>Microsoft</td>
</tr>
<tr>
<td>…</td>
<td>…</td>
<td>…</td>
<td>…</td>
</tr>
</tbody>
</table>
Relational Model

A relational database is a **collection of one or more relations**, where each relation is a **table with rows and columns**.

An example relation:

<table>
<thead>
<tr>
<th>Product</th>
<th>name</th>
<th>category</th>
<th>price</th>
<th>manufacturer</th>
</tr>
</thead>
<tbody>
<tr>
<td>iPad</td>
<td>tablet</td>
<td></td>
<td>$399.00</td>
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<td>tablet</td>
<td></td>
<td>$299.00</td>
<td>Microsoft</td>
</tr>
<tr>
<td>…</td>
<td>…</td>
<td>…</td>
<td>…</td>
<td>…</td>
</tr>
</tbody>
</table>

**table name**

**attribute/column**

**record/tuple/row**
SQL Queries

SELECT $a_1, a_2, \ldots, a_k$
FROM $R_1, R_2, \ldots, R_n$
WHERE conditions
A Database Template

\[
\begin{align*}
\text{SELECT} & \quad a_1, a_2, \ldots, a_k \\
\text{FROM} & \quad R_1, R_2, \ldots, R_n \\
\text{WHERE} & \quad \text{conditions}
\end{align*}
\]

```
answer = {}
for t_1 in R_1 do
    for t_2 in R_2 do
        ...
        for t_n in R_n do
            if conditions
                then answer = answer \cup \{(a_1,\ldots,a_k)\}
return answer
```

Vanilla query executor
A Database Template

SELECT \( a_1, a_2, \ldots, a_k \)
FROM \( R_1, R_2, \ldots, R_n \)
WHERE conditions

```
answer = {}
for t_1 in R_1 do
    for t_2 in R_2 do
        ...
        for t_n in R_n do
            if conditions
                then answer = answer U \( \{a_1,\ldots,a_k\}\)
return answer
```

Vanilla query executor
A Database Template

SELECT $a_1, a_2, \ldots, a_k$
FROM $R_1, R_2, \ldots, R_n$
WHERE conditions

answer = {}  
for $t_1$ in $R_1$ do  
  for $t_2$ in $R_2$ do  
    ...  
    for $t_n$ in $R_n$ do  
      if conditions  
      then answer = answer U \{(a_1,\ldots,a_k)\}  
return answer

Vanilla query executor

A DBMS can be heavily optimized beneath this simple interface
Optimizing the Template Implementation

```
SELECT a_1, a_2, ..., a_k
FROM R_1, R_2, ..., R_n
WHERE conditions

answer = {}

for t_1 in R_1 do
    for t_2 in R_2 do
        ...
        for t_n in R_n do
            if conditions
                then answer = answer U {(a_1, ..., a_k)}

return answer
```

Vanilla query executor

Cross products are expensive, can replace with joins
Optimizing the Template Implementation

```
SELECT a_1, a_2, ..., a_k
FROM R_1, R_2, ..., R_n
WHERE conditions

answer = {}

for t_1 in R_1 do
  for t_2 in R_2 do
    ...
    for t_n in R_n do
      if conditions
        then answer = answer ∪ {(a_1, ..., a_k)}

return answer
```

Vanilla query executor

Cross products are expensive, can replace with joins

Avoid scanning the entire table by accessing subsets of records through an index
Optimizing the Template Implementation

\[
\text{SELECT } a_1, a_2, \ldots, a_k \\
\text{FROM } R_1, R_2, \ldots, R_n \\
\text{WHERE } \text{conditions}
\]

\[
\text{answer} = \{\}
\]

\[
\text{for } t_1 \text{ in } R_1 \text{ do} \\
\quad \text{for } t_2 \text{ in } R_2 \text{ do} \\
\quad \quad \ldots \\
\quad \quad \text{for } t_n \text{ in } R_n \text{ do} \\
\quad \quad \quad \text{if } \text{conditions} \\
\quad \quad \quad \quad \text{then } \text{answer} = \text{answer} \cup \{(a_1, \ldots, a_k)\} \\
\text{return } \text{answer}
\]

Vanilla query executor

Cross products are expensive, can replace with \text{joins}

Avoid scanning the entire table by accessing subsets of records through an \text{index}

Query plan can be \text{optimized} to minimize the execution overhead
Optimizing the Template Implementation

SELECT $a_1, a_2, \ldots, a_k$
FROM $R_1, R_2, \ldots, R_n$
WHERE conditions

Data can be stored in disks for persistency and low cost and buffered in DRAM

answer = {}
for $t_1$ in $R_1$ do
  for $t_2$ in $R_2$ do
    ...
    for $t_n$ in $R_n$ do
      if conditions
        then answer = answer U \{(a_1, \ldots, a_k)\}
return answer

Vanilla query executor

Cross products are expensive, can replace with joins
Avoid scanning the entire table by accessing subsets of records through an index

Query plan can be optimized to minimize the execution overhead
Optimizing the Template Implementation

Perform **locking** at fine-granularity to enable parallel execution of transactions

Transactions

Database

Lock(DB)

Execute transaction

Unlock(DB)

Query Executor
Optimizing the Template Implementation

Perform locking at fine-granularity to enable parallel execution of transactions.

Ensure that parallel execution results are equivalent to serial execution.
Optimizing the Template Implementation

Perform locking at fine-granularity to enable parallel execution of transactions.

Ensure that parallel execution results are equivalent to serial execution.

Ensure the database can tolerate failures by providing durability and high availability.

Transactions

Database

Lock(DB)

Execute transaction

Unlock(DB)

Query Executor
Optimizing the Template Implementation

- Perform **locking** at fine-granularity to enable parallel execution of transactions.
- Ensure that parallel execution results are **equivalent to serial execution**.
- Ensure the database can tolerate failures by providing **durability and high availability**.
- Can **scale up** to multicore processors and **scale out** to distributed systems.
Topics in CS 764

Query processing and buffer management (Lectures 2–8)
  - Join
  - Buffer management
  - Query optimization
  - Column store
  - Parallel database

Advanced transaction processing (Lectures 9–20)
  - Two-phase locking
  - Isolation
  - Optimistic concurrency control
  - B-tree and radix-tree
  - Fault tolerance

Advanced topics in databases (Lectures 21–27)
  - Cloud-native databases
  - Database with new hardware technologies

Guest lectures from Oracle and TiDB
Topics in CS 764

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Course Logistics
Course Information


Canvas page: [https://canvas.wisc.edu/courses/309574](https://canvas.wisc.edu/courses/309574)

Piazza: [piazza.com/wisc/fall2022/cs764/](piazza.com/wisc/fall2022/cs764/)

Zoom: You can take the lectures online
- [https://uwmadison.zoom.us/j/93625999493?pwd=Si9PWEdpWnhNaTdxMG1zVXFFcXk0QT09](https://uwmadison.zoom.us/j/93625999493?pwd=Si9PWEdpWnhNaTdxMG1zVXFFcXk0QT09)
- passcode: 764

Prerequisite: CS 564

Reference textbooks:
- Red book
- Cow book
Grading

Paper review: 15%

Exam: 35%

Project proposal: 10%

Project presentation: 10%

Project final report: 30%
Paper Review (15%)

**Paper reading**: one classic/modern paper per lecture

- username: cs764  password: dbguru
Paper Review (15%)

**Paper reading**: one classic/modern paper per lecture
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**Upload review**: [https://wisc-cs764-f22.hotcrp.com](https://wisc-cs764-f22.hotcrp.com) (must submit before the lecture starts in order to be graded)
- Overall merit
- Paper summary
  - What main research problem/challenge did the paper address?
  - What is the key contribution of the paper?
- **Comments and questions**
  - Aspects you like or dislike about the paper
  - Questions about that paper that you wish to be discussed in the lecture
Paper Review (15%)

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- **Comments and questions**
  - Aspects you like or dislike about the paper
  - Questions about that paper that you wish to be discussed in the lecture

**Grading:** You can skip up to 2 reviews without losing points; otherwise 1% of total grade (up to 15%) is deducted for each missing review
Exam (35%)

In-class exam
  – Open-book, open-notes
  – You can use any material provided in this course or on the Internet

One lecture to review exams in previous years

Sample exam questions are available on course website
Course Project (50%)

In **groups of 2–4 students**

Project ideas will be provided but you are encouraged to propose your own ideas

- Project ideas for Fall 2020 and 2021 are available on the course website
- Three example projects are available on the course website (two papers based on course projects accepted to SIGMOD 2022 and SIGMOD 2023)
Course Project (50%)

In **groups of 2–4** students

Project ideas will be provided but you are encouraged to propose your own ideas

- Project ideas for Fall 2020 and 2021 are available on the course website
- Three example projects are available on the course website (two papers based on course projects accepted to SIGMOD 2022 and SIGMOD 2023)

**Important dates**

- **Create teams and submit proposal:** Oct. 24
- **Project meetings with instructor:** Nov. 21
- **Presentation:** Dec. 12 & 14
- **Paper submission:** Dec. 19
Computation Resources

CloudLab


Chameleon

https://www.chameleoncloud.org (project name: ngdb)
Lectures in Hybrid Mode

Each lecture will be streamed online on zoom
- https://uwmadison.zoom.us/j/93625999493?pwd=Si9PWEdpWnhNaTdxMG1zVXFFcXk0QT09 (passcode: 764)

Lectures will be recorded and the video recording will be available on canvas (canvas -> zoom)
Waitlist

Class size limited to ~60

If you are enrolled but don’t want to take the class, please drop ASAP

If you are on the waitlist, we will admit students first-come-first-serve
Before next lecture

Read the following paper and submit review

Email the instructor if you have problems registering for [https://wisc-cs764-f22.hotcrp.com](https://wisc-cs764-f22.hotcrp.com) after Friday

Enroll on Piazza
– [piazza.com/wisc/fall2022/cs764/](https://piazza.com/wisc/fall2022/cs764/)