SFU

Database Systems I

CMPT 354 Summer 2024

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21 June 2024

Announcements (Fri. June 21)

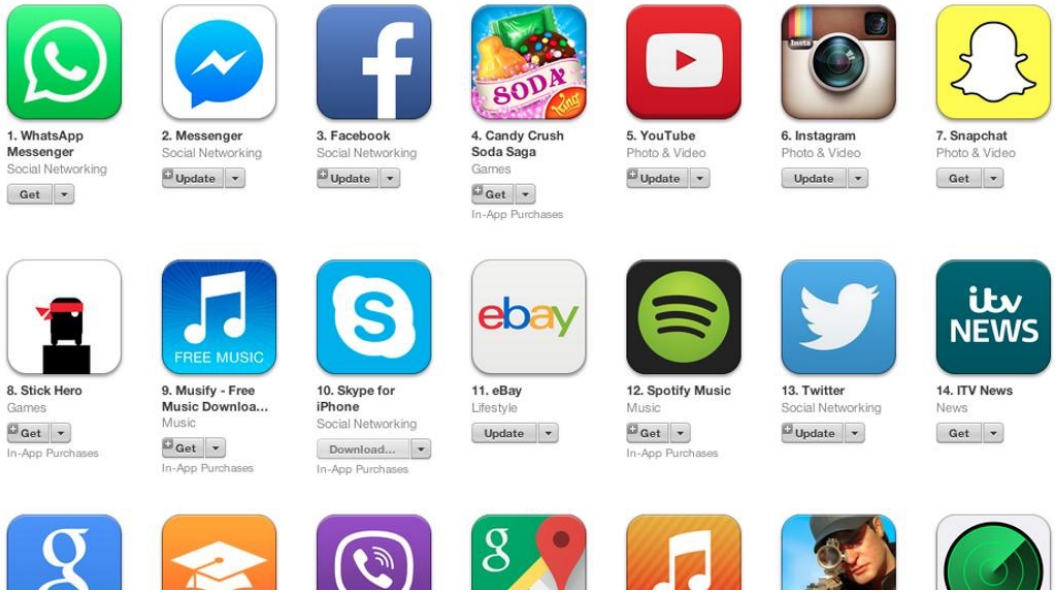
- Exam I
  - Solution & grade released
- Schedule
  - Some review lecture?

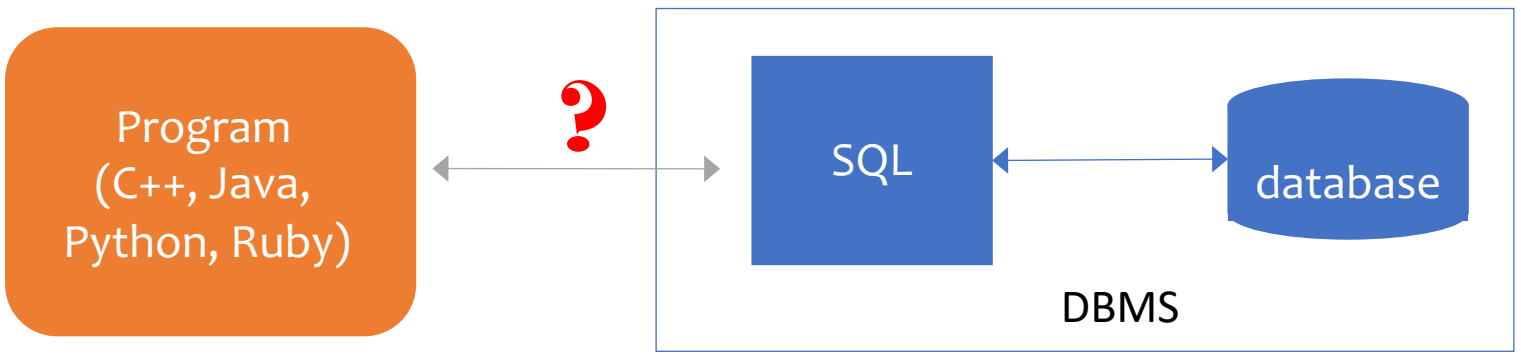
Why this lecture

- **DB designer:** establishes schema
- **DB administrator:** tunes systems and keeps whole things running
- **Data scientist:** manipulates data to extract insights
- **Data engineer:** builds a data-processing pipeline

- **DB application developer:** writes programs that query and modify a database

Application development





Outline

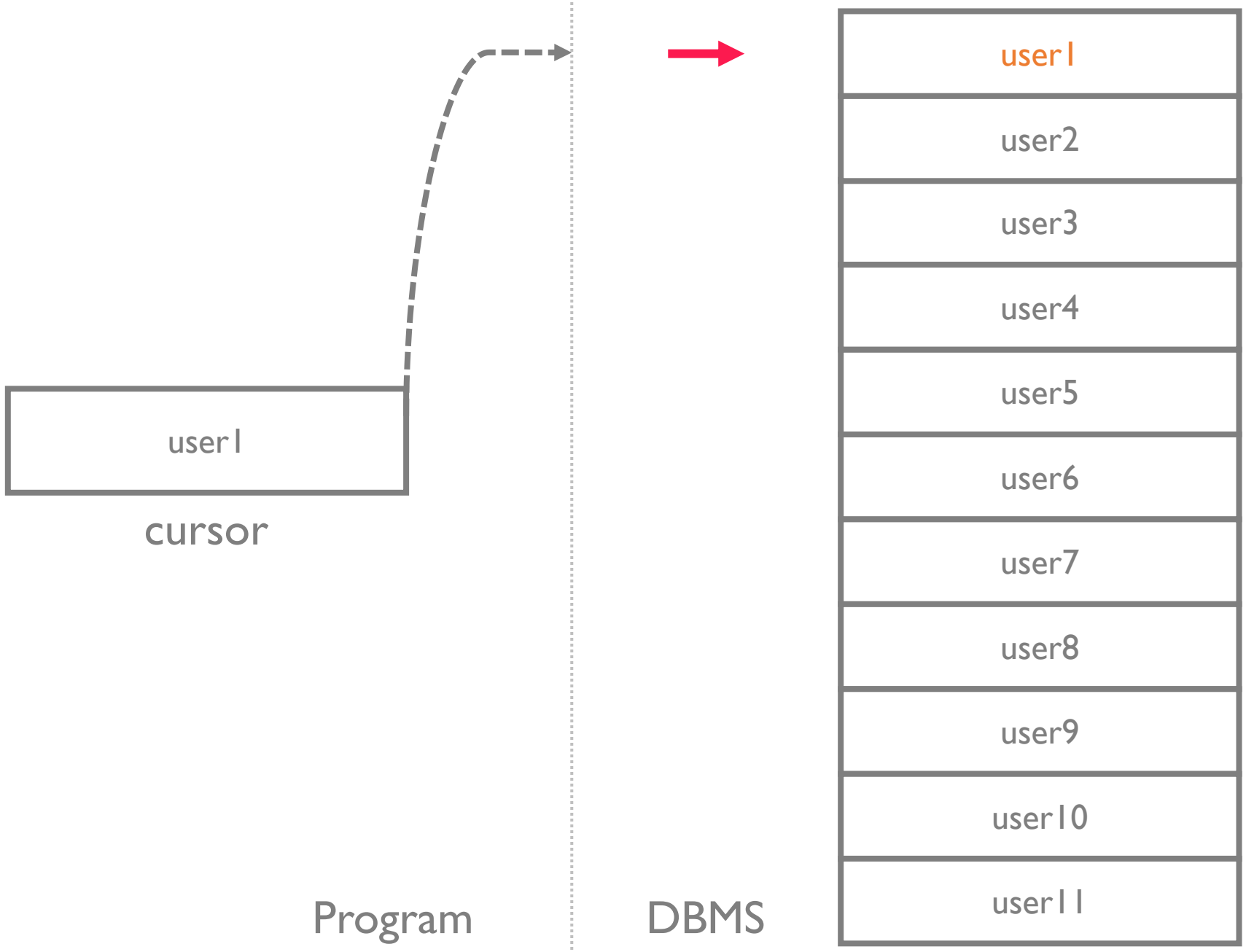
- **SQL Programming**
- Application Architecture

Motivation

- Pros and cons of SQL
  - Very high-level, possible to optimize
  - Not intended for general-purpose computation
- Solutions
  - Augment SQL with constructs from general-purpose programming languages
    - E.g.: SQL/PSM
  - Use SQL together with general-purpose programming languages: many possibilities
    - Through an API, e.g., Python psycopg2 or SQLAlchemy
    - Embedded SQL, e.g., in C
    - Automatic object-relational mapping, e.g.: Python SQLAlchemy
    - Extending programming languages with SQL-like constructs, e.g.: LINQ

An "impedance mismatch"

- SQL operates on a set of records at a time
- Typical low-level general-purpose programming languages operate on one record at a time
  - Less of an issue for functional programming languages
- Solution: cursor
  - Open (a result table): position the cursor before the first row
  - Get next: move the cursor to the next row and return that row; raise a flag if there is no such row
  - Close: clean up and release DBMS resources
  - Found in virtually every database language/API
    - With slightly different syntaxes
  - Some support more positioning and movement options, modification at the current position, etc.


user1
cursor
user1
user2
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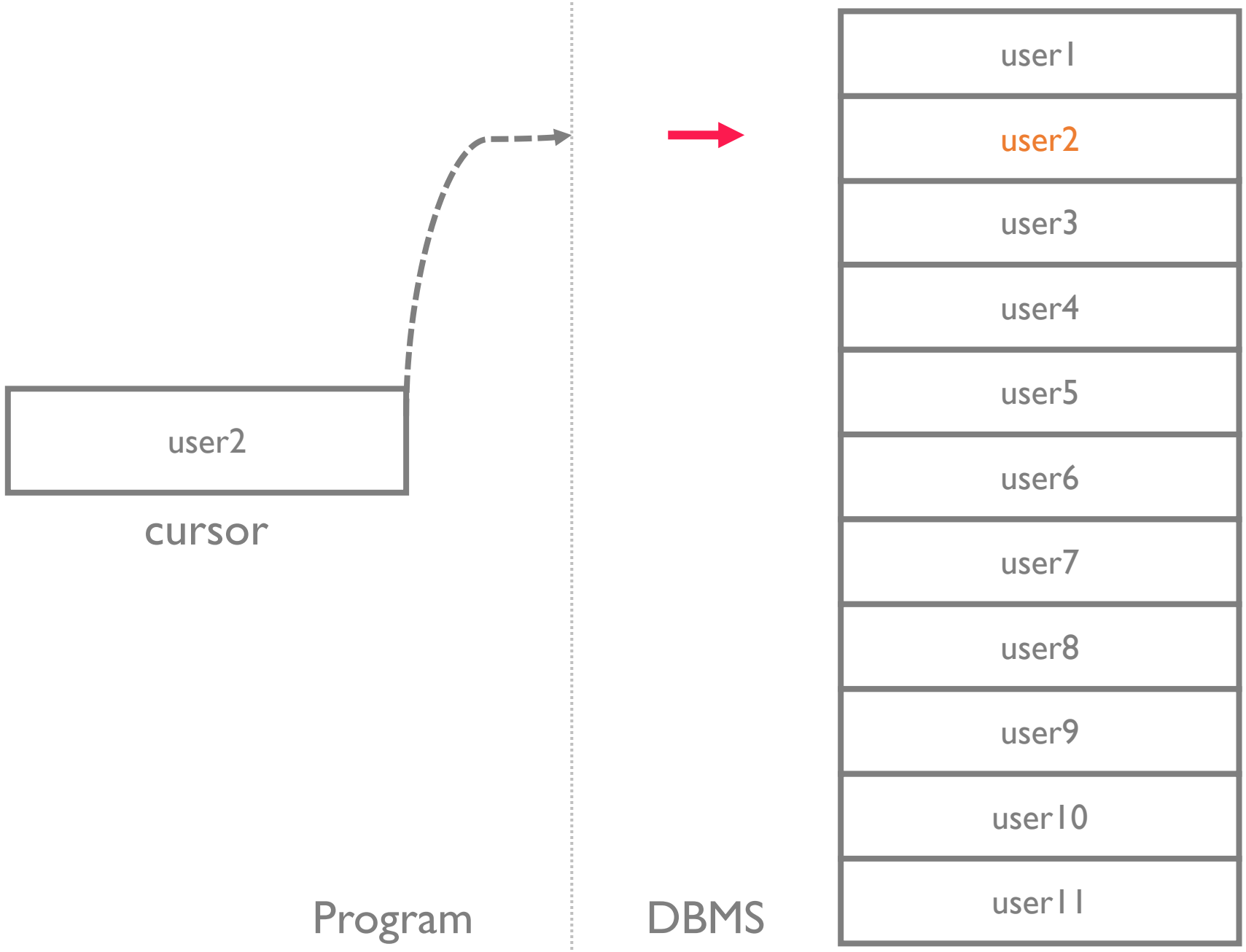
user4
user5
user6
user7
user8
user9
user10
user11
Program
DBMS


user1
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user10
user11
user2
cursor
Program
DBMS

Augmenting SQL: SQL/PSM

- PSM = Persistent Stored Modules
- `CREATE PROCEDURE` *proc_name*(*param_decls*)
  local_decls
  proc_body;
- `CREATE FUNCTION` *func_name*(*param_decls*)
  `RETURNS` *return_type*
  local_decls
  func_body;
- `CALL` *proc_name*(*params*);
- Inside procedure body:
  `SET` *variable* `=` `CALL` *func_name*(*params*);

SQL/PSM example

```
CREATE FUNCTION SetMaxPop(IN newMaxPop FLOAT)
  RETURNS INT
  -- Enforce newMaxPop; return # rows modified.
BEGIN
  DECLARE rowsUpdated INT DEFAULT 0;
  DECLARE thisPop FLOAT;
  -- A cursor to range over all users:
  DECLARE userCursor CURSOR FOR
      SELECT pop FROM User
  FOR UPDATE;
  -- Set a flag upon "not found" exception:
  DECLARE noMoreRows INT DEFAULT 0;
  DECLARE CONTINUE HANDLER FOR NOT FOUND
      SET noMoreRows = 1;
  … (see next slide) …
  RETURN rowsUpdated;
END
```

SQL/PSM example continued

```
-- Fetch the first result row:
OPEN userCursor;
FETCH FROM userCursor INTO thisPop;
-- Loop over all result rows:
WHILE noMoreRows <> 1 DO
    IF thisPop > newMaxPop THEN
        -- Enforce newMaxPop:
        UPDATE User SET pop = newMaxPop
        WHERE CURRENT OF userCursor;
        -- Update count:
        SET rowsUpdated = rowsUpdated + 1;
    END IF;
    -- Fetch the next result row:
    FETCH FROM userCursor INTO thisPop;
END WHILE;
CLOSE userCursor;
```

Other SQL/PSM features

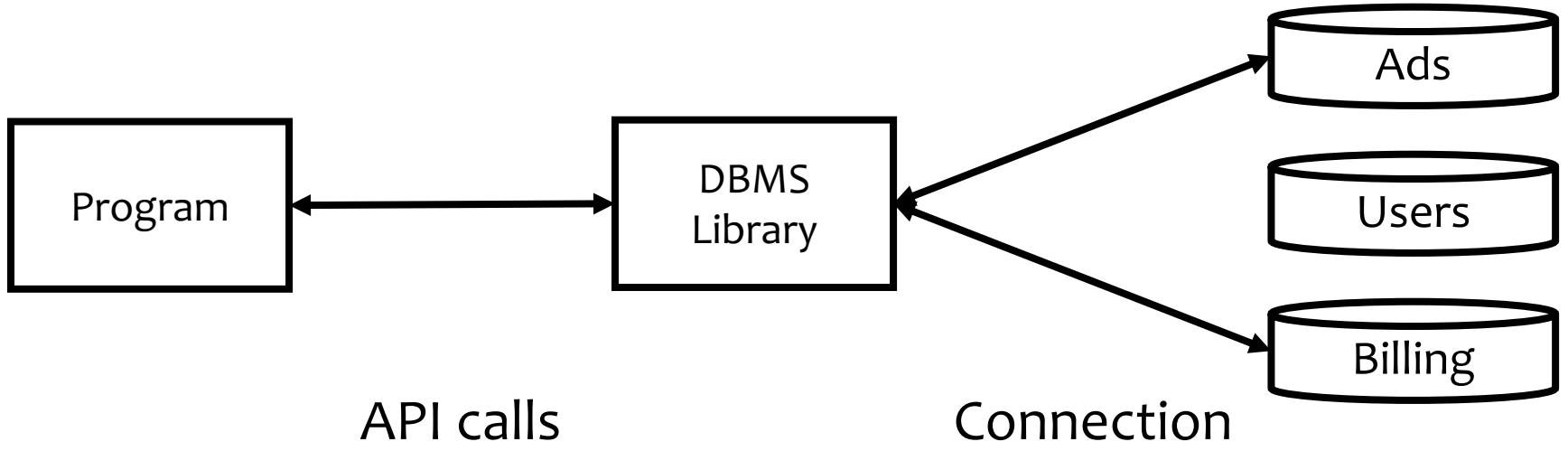
- Assignment using scalar query results
  - `SELECT INTO`
- Other loop constructs
  - `FOR, REPEAT UNTIL, LOOP`
- Flow control
  - `GOTO`
- Exceptions
  - `SIGNAL, RESIGNAL`

…

- For more PostgreSQL-specific information, look for “PL/pgSQL” in PostgreSQL documentation

Working with SQL through an API

- E.g.: Python psycopg2, JDBC, ODBC (C/C++/VB)
  - All based on the SQL/CLI (Call-Level Interface) standard
- The application program sends SQL commands to the DBMS at runtime
- Responses/results are converted to objects in the application program



Example API: Python SQLAlchemy

```
from sqlalchemy import create_engine, text
engine = create_engine(…)
with engine.begin() as conn:
    # list all drinkers:
    result = conn.execute(text('SELECT * FROM Drinker'))
    for drinker, address in result:
        print(drinker + ' lives at ' + address)
    # print menu for bars whose name contains “a”:
    result = conn.execute\
        (text('SELECT * FROM Serves WHERE bar LIKE :pattern'),
         dict(pattern='%a%'))
    for bar, beer, price in result:
        print('{} serves {} at ${:,.2f}'.format(bar, beer, price))
```

You can iterate over result one tuple at a time

Placeholder for query parameter

Dictionary of parameter values, one for each placeholder

More SQLAlchemy examples

```
with engine.connect() as conn:
    # “commit” each change immediately in this session
    conn.execution_options(isolation_level='AUTOCOMMIT')
    # …
    bar = input('Enter the bar to update: ').strip()
    beer = input('Enter the beer to update: ').strip()
    price = float(input('Enter the new price: ‘))
    try:
        result = conn.execute(text('''
UPDATE Serves SET price = :price
WHERE bar = :bar AND beer = :beer'''),
                              dict(price=price, bar=bar, beer=beer))
        if result.rowcount != 1:
            print('{} row(s) updated: correct bar/beer?'\
                  .format(result.rowcount))
    except Exception as e:
        print(e)
```

# of tuples modified

Exceptions can be thrown
(e.g., if positive-price constraint is violated)

More SQLAlchemy examples

Are there any cases where you want reads to be transactions?
Since writes use transactions, does that mean that reads are automatically protected and do not need to use transactions?

One alternative (and recommended) for `index()` in app.py in Assignment 3, Problem 2

```
def index():
    res = []
    with db.engine.begin() as conn:
        query_result = conn.execute(text("SELECT * FROM Stock WHERE sym =
:sym ;"), dict(sym='AAPL'))
        for sym, price in query_result:
            res.append([sym, price])
    return jsonify(res[0])
```

Parameters and placeholders

May throw exceptions after checking the # tuples returned

Type Mismatch

- SQL standard defines mappings between SQL and several languages

SQL types	C types	Python types
CHAR(20)	char[20]	str
INTEGER	int	int
SMALLINT	short	int
REAL	float	float

Prepared statements: motivation

```
while True:
    # Input bar, beer, price…
    result = conn.execute(text('''UPDATE Serves SET price = :price
                                  WHERE bar = :bar AND beer = :beer'''),
                          dict(price=price, bar=bar, beer=beer))
    # Check result...
```

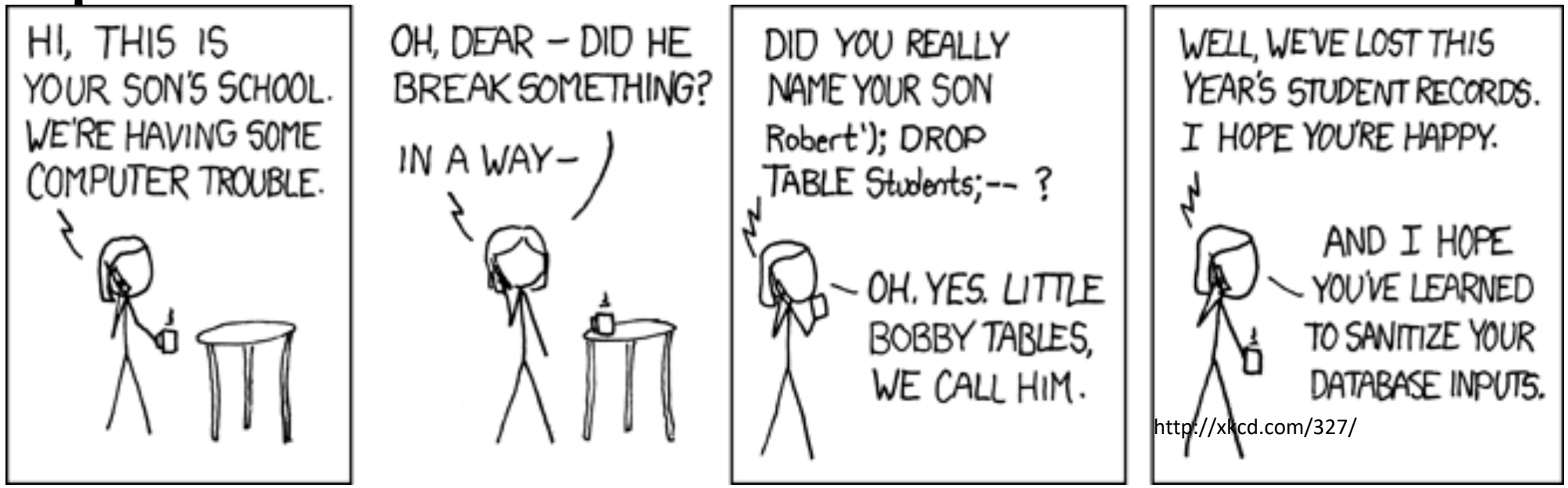
- Every time we send an SQL string to the DBMS, it must perform parsing, semantic analysis, optimization, compilation, and finally execution
- A typical application issues many queries with a small number of patterns (with different parameter values)
- Can we reduce this overhead?

Prepared statements: example

```
conn.execute(text('''                    # Prepare once (in SQL)
PREPARE update_price AS                  # Name the prepared plan
UPDATE Serves
SET price = $1                           # and note the $1, $2, … notation for
WHERE bar = $2 AND beer = $3'''))        # PostgreSQL parameter placeholders
while True: # Input bar, beer, price…
    conn.execute(text('EXECUTE update_price(:bar, :beer, :price)'),
                 dict(price=price, bar=bar, beer=beer))
                # Note the switch back to : for parameter placeholders
    # Check result...
```

- The DBMS performs parsing, semantic analysis, optimization, and compilation only once, when it "prepares" the statement
- At execution time, the DBMS only needs to check parameter types and validate the compiled plan
- Most other backends/API's have better support for prepared statements
  - E.g., they would provide a conn.prepare() method

"Exploits of a mom"



- The school probably had something like:

```
conn.execute(text("SELECT * FROM Students " + \
                  "WHERE (name = '" + name + "')"))
```

  where name is a string input by user
- Called an SQL injection attack

Guarding against SQL injection

- Escape certain characters in a user input string, to ensure that it remains a single string
  - E.g., ', which would terminate a string in SQL, must be replaced by '' (two single quotes in a row) within the input string
- Luckily, most database API's provide ways to "sanitize" input automatically (if you use them properly)
  - E.g., pass parameter values in sqlalchemy through :'s
- Do NOT rely non-DB API/language's string support
  - E.g., ~~"name = '" + **name** + "'"~~ or ~~f"name = '{name}'"~~

If one fails to learn the lesson…

… P.S. To Ashley Madison's Development Team: You should be embarrased [sic] for your train wreck of a database (and obviously security), not sanitizing your phone numbers to your database is completely amateur, it's as if the entire site was made by Comp Sci 1XX students.

— Creators of CheckAshleyMadison.com

http://www.washingtonpost.com/news/the-intersect/wp/2015/08/19/how-to-see-if-you-or-your-spouse-appear-in-the-ashley-madison-leak/

Augmenting SQL vs. API

- Pros of augmenting SQL:
  - More processing features for DBMS
  - More application logic can be pushed closer to data
    - Less data "shipping," more optimization opportunities ⇒ more efficient
    - Less code ⇒ easier to maintain multiple applications
- Cons of augmenting SQL:
  - SQL is already too big—at some point one must recognize that SQL/DBMS are not for everything!
  - General-purpose programming constructs complicate optimization and make it impossible to guarantee safety

A brief look at other approaches

- "Embed" SQL in a general-purpose programming language
  - E.g.: embedded SQL
- Support database features through an object-oriented programming language
  - By automatically storing objects in tables and translating methods to SQL
  - E.g., object-relational mappers (ORM) like Python SQLAlchemy
- Extend a general-purpose programming language with SQL-like constructs
  - E.g.: LINQ (Language Integrated Query for .NET)

With embedded SQL, the compiler checks

Embedding SQL in a language

Example in C

```
EXEC SQL BEGIN DECLARE SECTION;
int thisUid; float thisPop;
EXEC SQL END DECLARE SECTION;
```

Declare variables to be "shared" between the application and DBMS

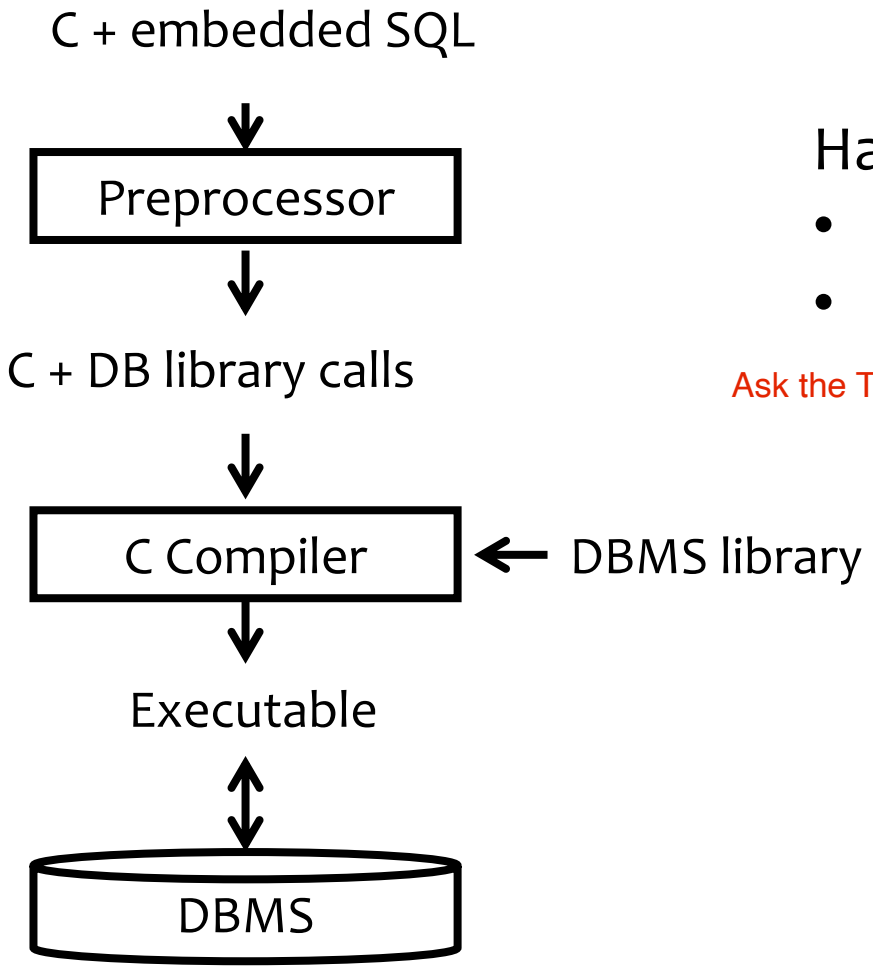
```
EXEC SQL DECLARE ABCMember CURSOR FOR
    SELECT uid, pop FROM User
    WHERE uid IN (SELECT uid FROM Member WHERE gid = 'abc')
    FOR UPDATE;

EXEC SQL OPEN ABCMember;
EXEC SQL WHENEVER NOT FOUND DO break;
```

Specify a handler for NOT FOUND exception

```
while (1) {
    EXEC SQL FETCH ABCMember INTO :thisUid, :thisPop;
    printf("uid %d: current pop is %f\n", thisUid, thisPop);
    printf("Enter new popularity: ");
    scanf("%f", &thisPop);
    EXEC SQL UPDATE User SET pop = :thisPop
        WHERE CURRENT OF ABCMember;
}
EXEC SQL CLOSE ABCMember;
```

Embedded SQL



Hard to maintain

- What if SQL evolves?
- What if Compiler evolves?

Ask the TA about these points

Object-relational mapping

- Example: Python SQLAlchemy

```
class User(Base):
  __tablename__ = 'users'
  id = Column(Integer, primary_key=True)
  name = Column(String)
  password = Column(String)
```

```
class Address(Base):
  __tablename__ = 'addresses'
  id = Column(Integer, primary_key=True)
  email_address = Column(String, nullable=False)
  user_id = Column(Integer, ForeignKey('users.id'))
```

```
Address.user = relationship("User", back_populates="addresses")
User.addresses = relationship("Address", order_by=Address.id, back_populates="user")

jack = User(name='jack', password='gjffdd')
jack.addresses = [Address(email_address='jack@google.com'), Address(email_address='j25@yahoo.com')]
session.add(jack)
session.commit()

session.query(User).join(Address).filter(Address.email_address=='jack@google.com').all()
```

- Automatic data mapping and query translation
- But syntax may vary for different host languages
- Very convenient for simple structures/queries, but quickly get complicated and less intuitive for more complex situations

Deeper language integration

- Example: LINQ (Language Integrated Query) for Microsoft .NET languages (e.g., C#)

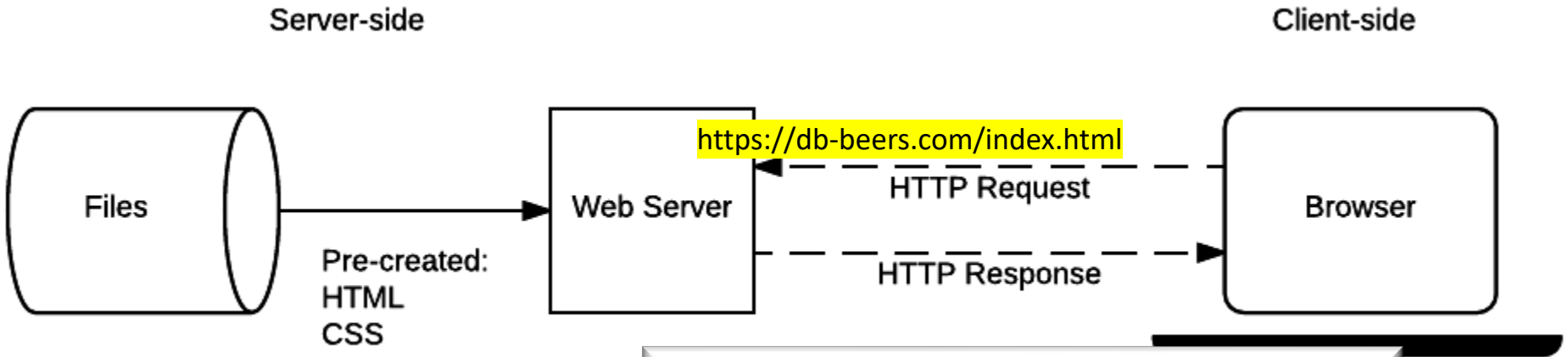
```
int someValue = 5;
var results = from c in someCollection
              let x = someValue * 2
              where c.SomeProperty < x
              select new {c.SomeProperty, c.OtherProperty};
foreach (var result in results) {
  Console.WriteLine(result);
}
```

- Again, automatic data mapping and query translation
- Much cleaner syntax, but it still may vary for different host languages

Outline

- SQL Programming
- **Application Architecture**

A static website




```
<html>
<head><title>DB-Beers Example</title></head>
<body>
<h1>DB-Beers</h1>
<h2 id="heading">All Drinkers</h2>
<ul>
<li><a href="/drinker/Amy">Amy</a></li>
<li><a href="/drinker/Ben">Ben</a></li>
<li><a href="/drinker/Coy">Coy</a></li>
<li><a href="/drinker/Dan">Dan</a></li>
<li><a href="/drinker/Eve">Eve</a></li>
</ul>
</body>
</html>
```


https://developer.mozilla.org/en-US/docs/Learn/Server-side/First_steps/Client-Server_overview/basic_static_app_server.png

Towards a dynamic website

- Imagine a function that dynamically generates the HTTP response
  - Visiting the URL leads to calling the function
  - The function returns the HTML page (as a string)
  - The function can query the database for content!

```
def all_drinkers():
    html_out = '<html>\n'
    # more HTML...
    html_out += '<ul>\n'
    with engine.begin() as conn:
        result = conn.execute(text('SELECT * FROM drinker'))
        for name, address in result:
            html_out += '<li><a href="/drinker/{}>{}</a></li>\n'.format(name, name)
    html_out += '</ul>\n'
    # more HTML...
    html_out += '</html>\n'
    return html_out
```

Tedious, ugly code though!

"Refactor" that function!

- Separate data from presentation, e.g.:
  - Data: list of drinker names
  - Presentation: a HTML template, with some processing directives to embed data items

Template for all-drinker listing

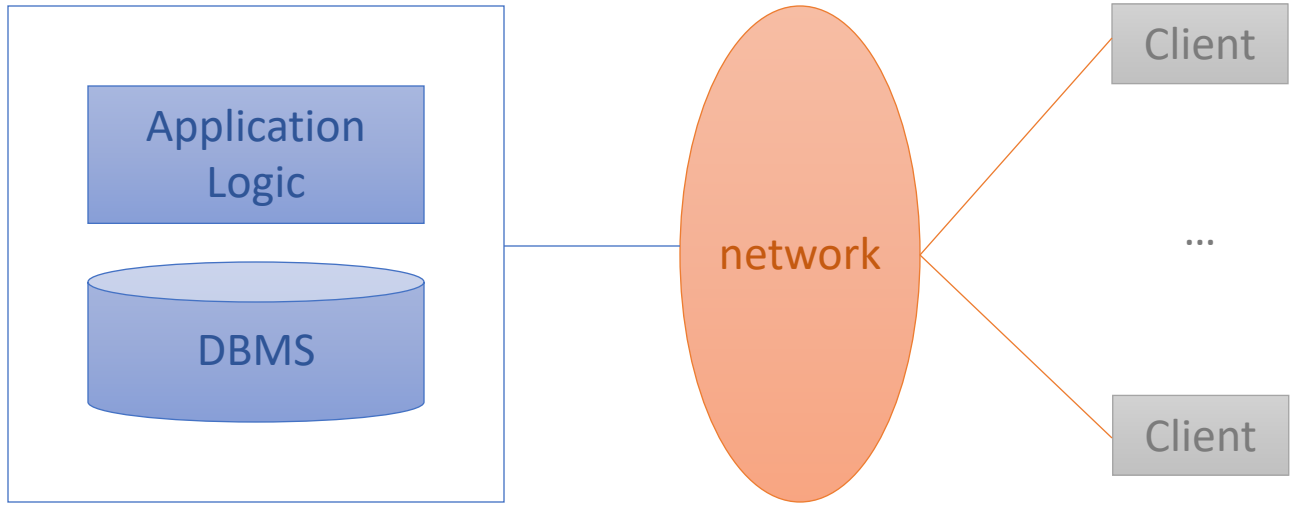
```
<html>
<head><title>DB-Beers Example</title></head>
<body>
<h1>DB-Beers</h1>
<h2 id="heading">All Drinkers</h2>
<ul>
{% for drinker in drinkers %}
  <li><a href="{{ url_for('drinker', name=drinker) }}">{{drinker}}</a></li>
{% endfor %}
</ul>
</body>
</htmi>
```

Much simplified code/logic

```
def all_drinkers():
    with engine.begin() as conn:
        result = conn.execute(text('SELECT * FROM drinker'))
        drinker_names = [name for name, address in result]
        return render_template('index.html', drinkers=drinker_names)
```

Two-Tier Architecture

- Client/ server architecture
  - The server implements the business logic and data management
- Separate presentation from the rest of the application



Presentation Layer

- Responsible for handling the user's interaction with the middle tier

- One application may have multiple versions that correspond to different interfaces
  - Web browsers, mobile phones, …
  - Style sheets can assist in controlling versions

Calling these functions

- URL in the HTTP request specifies the function to call
  - AKA routes, endpoints

```
@app.route('/')
def index():
    """
        an alternative implementation of the index() function
        with query parameter and placeholder
    """
    res = []
    with db.engine.begin() as conn:
        query_result = conn.execute(text("SELECT * FROM Stock WHERE sym = :sym ;"),
                                    dict(sym='AAPL'))
        for sym, price in query_result:
            res.append([sym, price])
    return jsonify(res[0])
```

Calling these functions

- URL in the HTTP request specifies the function to call
  - AKA routes, endpoints
- HTTP request also encodes any input parameter values to call the function with
  - Can be part of the URL (GET) or the request body (POST)

A page showing the details about one drinker

```
@app.route('/drinker/<name>')
def drinker(name):
    with engine.begin() as conn:
        result = conn.execute(text('SELECT * FROM drinker WHERE name = :s'),
                              dict(s=name))
        name, address = result.fetchone()
        return render_template('drinker.html',
                               drinker_name=name,
                               drinker_address=address)
```

But who calls these functions?

- User usually don't type specific URLs themselves
- Calls are typically embedded in your HTML pages

Template for all-drinker listing

```
<html>
<head><title>DB-Beers Example</title></head>
<body>
<h1>DB-Beers</h1>
<h2 id="heading">All Drinkers</h2>
<ul>
{% for drinker in drinkers %}
  <li><a href="{{ url_for('drinker', name=drinker) }}">{{drinker}}</a></li>
{% endfor %}
</ul>
</body>
</htmi>
```

Setting up the URL for showing a specific drinker

```
<html>
<head><title>DB-Beers Example</title></head>
<body>
<h1>DB-Beers</h1>
<h2 id="heading">All Drinkers</h2>
<ul>
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<li><a href="/drinker/Dan">Dan</a></li>
<li><a href="/drinker/Eve">Eve</a></li>
</ul>
</body>
</html>
```
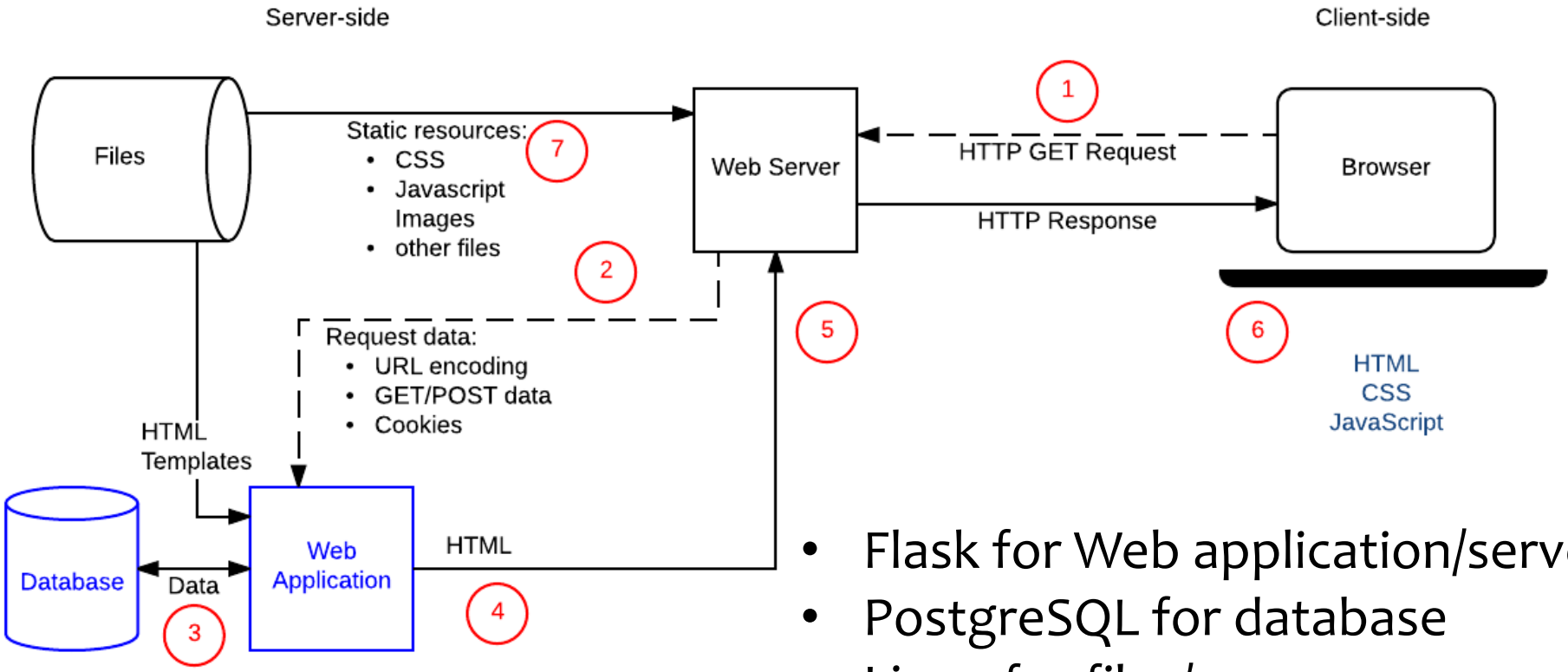

Full-stack

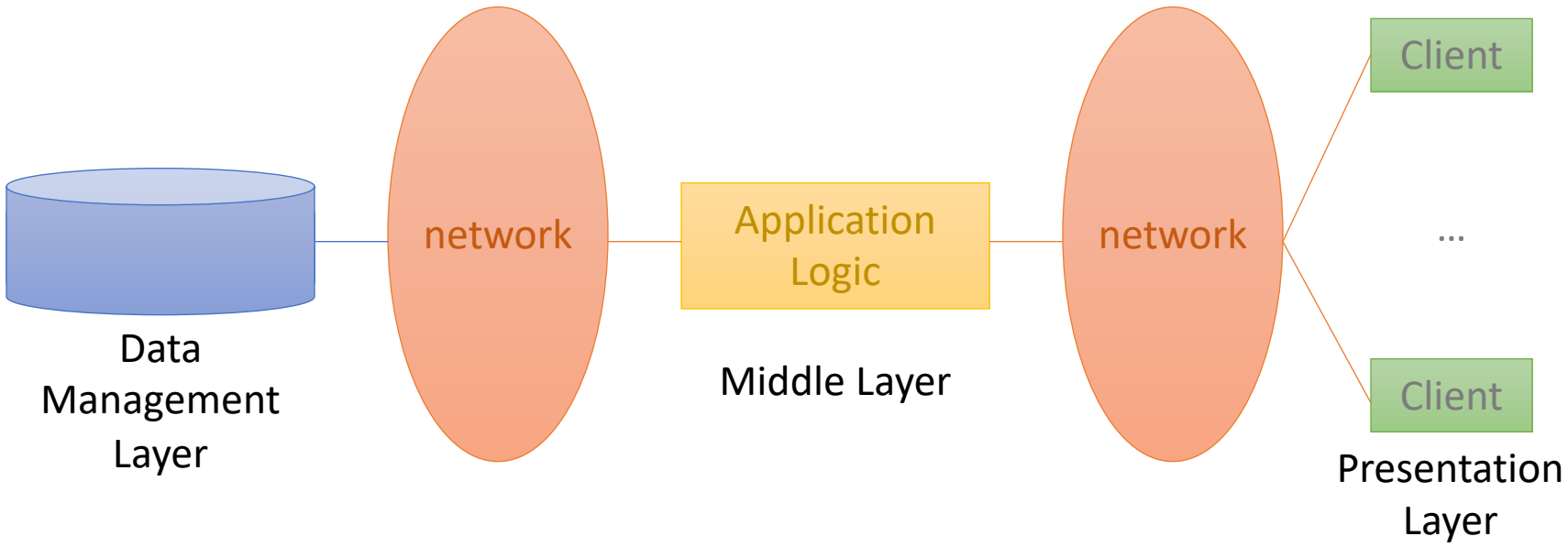


- Flask for Web application/server
- PostgreSQL for database
- Linux for files/server

https://developer.mozilla.org/en-US/docs/Learn/Server-side/First_steps/Client-Server_overview/web_application_with_html_and_steps.png

Three-Tier Architecture

- Separate presentation from the rest of the application
- Separate the application logic from the data management



Business logic Layer

- The middle layer is responsible for running the business logic of the application which controls
  - What data is required before an action is performed
  - The control flow of multi-stage actions
  - Access to the database layer

- Multi-stage actions performed by the middle tier may require database access
  - But will not usually make permanent changes until the end of the process
    - e.g. adding items to a shopping basket in an Internet shopping site

Data Management Layer

- The data management tier contains one, or more databases
  - Which may be running on different DBMSs
- Data needs to be exchanged between the middle tier and the database servers
  - This task is not required if a single data source is used but,
  - May be required if multiple data sources are to be integrated
  - *XML* is a language which can be used as a data exchange format between database servers and the middle tier

Example: RATest

- Consider the three tiers in the RATest website
- Database System
  - Student info, questions, solutions, submissions…
- Application Server
  - Logic to consent recording the history, submit queries
- Client Program
  - Display queries, outputs, and query trees

Example: Course Enrollment

- Student enrollment system tiers
- Database System
  - Student information, course information, instructor information, course availability, pre-requisites, etc.
- Application Server
  - Logic to add a course, drop a course, create a new course, etc.
- Client Program
  - Log in different users (students, staff, faculty), display forms and human-readable output

Summary

- SQL Programming
  - Augmenting SQL
  - DB API

- Application Architecture
  - Three Tier Architecture