SHIVA KASULA - COMPLETE COMPREHENSIVE DOCUMENTATION

Database & Logic Specialist | School Activity Booking System

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Project: School Activity Booking System
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Date: December 2025

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1. Introduction & Role Overview

1.1 My Responsibility As Database & Logic Specialist

As the database architect, I designed and implemented the complete data layer of the School Activity Booking System, ensuring data integrity, proper relationships, and efficient querying.

Core Responsibilities:

1. **Database Schema Design -** Design all 8 models with relationships
2. **Booking Logic -** Implement validation, capacity checks, conflict detection
3. **Waitlist System -** FIFO queue for full activities

4. **Data Integrity** - Foreign keys, constraints, cascades
5. **Query Optimization** - Eager loading, indexed queries
6. **Transaction Management** - ACID compliance

1.1.5 List of Implemented Features

Feature Name	Implementation Summary	Key Logic/Code Components
Database Architecture	Designed and implemented the complete Database Schema using SQLAlchemy ORM (8 models: Parent, Child, Activity, Booking, Waitlist, Attendance, Tutor, Admin).	`SQLAlchemy`, `db.Model`, `db.relationship`, `db.ForeignKey`, indexes
Booking Logic Core	Developed the intelligent booking processor that handles double-booking prevention, capacity checks, and enrollment validation.	`BookActivity` route, complex query filtering, `joinedload` optimization
Waitlist System	Implemented a First-In-First-Out (FIFO) waitlist queue for full activities with automated promotion logic when spots open.	`Waitlist` model, `promote_waitlist_user` function, status tracking ('waiting', 'promoted')
Data Integrity Enforcement	Configured robust Foreign Key constraints and Cascade rules to ensure database consistency (e.g., deleting a Parent deletes their Children and Bookings).	`cascade='all, delete-orphan'`, `nullable=False`, Unique Constraints
Capacity Management	Created logic to enforce maximum class sizes and dynamic availability checking.	`Booking.query.filter_by().count()` vs `activity.max_capacity`

1.2 Database Models Created

Model	Purpose	Relationships
Parent	User account	Has many Children, Bookings, Waitlists
Child	Student profile	Belongs to Parent, has many Bookings, Attendances
Activity	Extracurricular offering	Belongs to Tutor, has many Bookings
Booking	Activity enrollment	Belongs to Parent, Child, Activity
Waitlist	Queue for full activities	Belongs to Parent, Child, Activity

Attendance	Attendance records	Belongs to Child, Activity
Tutor	Staff account	Has many Activities
Admin	Administrator account	System management

1.3 Files Modified

File	Lines	Purpose
`app.py`	36-145	All 8 database models
`app.py`	987-1069	Booking logic (book_activity route)
`app.py`	1079-1101	Waitlist joining logic
`app.py`	203-243	Waitlist promotion (promote_waitlist_user)
`app.py`	950-974	Capacity checking API

1.3 Statistics

- **Models**: 8 complete models
- **Relationships**: 15+ relationships defined
- **Foreign Keys**: 12 foreign key constraints
- **Indexes**: 5 indexed columns for performance
- **Lines of Code**: ~600 lines

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2. Database Technologies (SQLAlchemy ORM)

2. 1 What is SQLAlchemy?

SQLAlchemy is Python's most popular ORM (Object-Relational Mapper). It maps database tables to Python classes, allowing you to work with data as objects.

Why ORM vs Raw SQL:

Feature	SQLAlchemy ORM	Raw SQL
Syntax	Pythonic	SQL strings
Type Safety	■ Yes	■ No
SQL Injection	■ Protected	■■ Manual escaping

Database Portability	■ High	■■ Low
Relationship Handling	■ Automatic	■ Manual joins
Learning Curve	■■ Medium	■■ Medium

Example Comparison:

Raw SQL:

```
cursor.execute("SELECT * FROM parent WHERE email = ?", (email,)) parent = cursor.fetchone() # Get children
cursor.execute("SELECT * FROM child WHERE parent_id = ?", (parent['id'],)) children = cursor.fetchall()
```

SQLAlchemy ORM:

```
parent = Parent.query.filter_by(email=email).first() children = parent.children # Automatic relationship!
```

2.2 Flask-SQLAlchemy

Integrates SQLAlchemy with Flask for easier configuration.

Installation:

```
pip install Flask-SQLAlchemy
```

Configuration (app.py):

```
from flask_sqlalchemy import SQLAlchemy db = SQLAlchemy() def create_app(): app = Flask(__name__)
app.config['SQLALCHEMY_DATABASE_URI'] = 'sqlite:///booking_system_v2.db'
app.config['SQLALCHEMY_TRACK_MODIFICATIONS'] = False db.init_app(app) return app
```

Configuration explained: - `SQLALCHEMY_DATABASE_URI`: Connection string for database - `sqlite:///` = SQLite (file-based database) - `booking_system_v2.db` = Database filename - `SQLALCHEMY_TRACK_MODIFICATIONS = False`: Disables event system (performance)

2.3 SQLAlchemy Core Concepts

2.3.1 Models (Tables)

Definition: Python class that represents a database table

```
class Parent(db.Model): __tablename__ = 'parent' # Optional, defaults to lowercase class name # Columns id =
db.Column(db.Integer, primary_key=True) email = db.Column(db.String(120), unique=True, nullable=False)
```

2.3.2 Column Types

SQLAlchemy Type	SQL Type	Python Type	Usage
`db.Integer`	INTEGER	int	IDs, counts

`db.String(N)`	VARCHAR(N)	str	Emails, names
`db.Text`	TEXT	str	Long text (descriptions)
`db.Float`	REAL	float	Prices
`db.Boolean`	BOOLEAN	bool	Flags
`db.DateTime`	DATETIME	datetime	Timestamps
`db.Date`	DATE	date	Booking dates
`db.Time`	TIME	time	Activity times

2.3.3 Column Constraints

```
id = db.Column(db.Integer, primary_key=True) # Primary key email = db.Column(db.String(120), unique=True,
nullable=False) # Unique, required phone = db.Column(db.String(20)) # Optional (nullable=True is default)
created_at = db.Column(db.DateTime, default=datetime.utcnow) # Auto-timestamp
```

Constraints explained: - `primary_key=True`: Unique identifier, auto-incrementing - `unique=True`: No duplicates allowed (enforced by database) - `nullable=False`: Required field (cannot be NULL) - `default=function`: Auto-populate with function result

2.3.4 Relationships

One-to-Many:

```
class Parent(db.Model): children = db.relationship('Child', backref='parent', lazy=True) class Child(db.Model):
parent_id = db.Column(db.Integer, db.ForeignKey('parent.id'))
```

Usage:

```
parent = Parent.query.first() print(parent.children) # List of Child objects child = Child.query.first()
print(child.parent) # Parent object
```

2.3.5 Querying

```
# Get all Parent.query.all() # Filter Parent.query.filter_by(email='john@example.com').first() # Complex filter
Parent.query.filter(Parent.email.like('%@example.com')).all() # Join
db.session.query(Booking).join(Child).filter(Child.name == 'Emma').all() # Count Booking.query.count() # Order
Activity.query.order_by(Activity.price.desc()).all()
```

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3. Complete Database Schema Design

3.1 Entity-Relationship Overview

```
Parent (1) ■■■■ (Many) Child ■ ■ ■ ■ ■■■■■■■■■■■■■■ (Many) Booking ■■■■ (1) Activity ■■■■ (1) Tutor ■ ■ ■ ■ | (Many) Attendance ■ ■■■■■■■■■■■■■■ (Many) Waitlist ■■■■ (1) Activity Admin (separate, no relationships)
```

3.2 Foreign Key Strategy

Foreign keys enforce referential integrity: - Can't create Booking without valid Parent, Child, Activity - Can't delete Parent if they have Bookings (without cascade)

Cascade Options:

```
children = db.relationship('Child', cascade='all, delete-orphan')
```

Cascade types: - `all`: All cascade operations - `delete`: Delete children when parent deleted - `delete-orphan`: Delete child if removed from parent's list - `save-update`: Propagate session add/update - `merge`: Merge operation cascades - `refresh`: Refresh operation cascades

Our choice: `'all, delete-orphan'` for Parent → Children - Delete parent deletes all their children (makes sense - undoing registration) - Remove child from parent.children list deletes child from DB

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4. All Models - Complete Implementation

4.1 Parent Model (Lines 36-75)

```
class Parent(db.Model): \"\"\"Parent/Guardian user model\"\"\" id = db.Column(db.Integer, primary_key=True) email = db.Column(db.String(120), unique=True, nullable=False, index=True) password = db.Column(db.String(200), nullable=False) full_name = db.Column(db.String(120), nullable=False) phone = db.Column(db.String(20)) created_at = db.Column(db.DateTime, default=datetime.utcnow) # Relationships bookings = db.relationship('Booking', backref='parent', lazy=True, cascade='all, delete-orphan') children = db.relationship('Child', backref='parent', lazy=True, cascade='all, delete-orphan') waitlists = db.relationship('Waitlist', backref='parent', lazy=True, cascade='all, delete-orphan') def set_password(self, password): self.password = generate_password_hash(password) def check_password(self, password): return check_password_hash(self.password, password)
```

Line-by-Line Explanation:

Line 1: Model definition - Inherits from `db.Model` (SQLAlchemy base class) - Class name `Parent` → table name `parent` (auto-lowercase)

Lines 3-8: Columns - `id`: Primary key, auto-increments - `email`: Unique (can't have duplicate emails), indexed for fast lookups - `password`: Hashed password (200 chars for scrypt hash) - `full_name`: Parent's full name - `phone`: Optional contact number - `created_at`: Auto-populated on creation with current UTC time

Lines 10-13: Relationships - `bookings`: One-to-many (parent has many bookings) - `children`: One-to-many (parent has many children) - `waitlists`: One-to-many (parent has many waitlist entries) - `backref='parent'`: Creates reverse relationship (booking.parent) - `lazy=True`: Load relationships when accessed (lazy loading) - `cascade='all, delete-orphan'`: Delete children when parent deleted

Lines 15-19: Password methods - Implemented by Chichebendu (security specialist) - `set_password()`: Hash and store password - `check_password()`: Verify password

Database Table Created:

```
CREATE TABLE parent ( id INTEGER PRIMARY KEY AUTOINCREMENT, email VARCHAR(120) UNIQUE NOT NULL, password
VARCHAR(200) NOT NULL, full_name VARCHAR(120) NOT NULL, phone VARCHAR(20), created_at DATETIME ); CREATE INDEX
ix_parent_email ON parent(email);
```

4.2 Child Model (Lines 63-74)

```
class Child(db.Model): \"\"\"Student profile model\"\"\" id = db.Column(db.Integer, primary_key=True) parent_id =
db.Column(db.Integer, db.ForeignKey('parent.id'), nullable=False, index=True) name = db.Column(db.String(120),
nullable=False) age = db.Column(db.Integer) grade = db.Column(db.Integer, nullable=False) created_at =
db.Column(db.DateTime, default=datetime.utcnow) # Relationships bookings = db.relationship('Booking',
backref='child', lazy=True, cascade='all, delete-orphan') attendance_records = db.relationship('Attendance',
backref='child', lazy=True)
```

Key Points:

Line 4: Foreign key - `db.ForeignKey('parent.id')`: References `parent` table's `id` column - `nullable=False`: Every child MUST have a parent - `index=True`: Fast lookups by parent_id

Lines 7-9: Child attributes - `name`: Student's name - `age`: Optional (might not be provided) - `grade`: Year level (required for grouping)

Lines 11-12: Relationships - `bookings`: Activities this child is enrolled in - `attendance_records`: This child's attendance history

Usage Example:

```
# Create child parent = Parent.query.first() child = Child(parent_id=parent.id, name="Emma", age=10, grade=5)
db.session.add(child) db.session.commit() # Access via relationship print(parent.children) # [<Child: Emma>]
print(child.parent) # <Parent: John Doe>
```

4.3 Activity Model (Lines 76-93)

```
class Activity(db.Model): \"\"\"Extracurricular activity model\"\"\" id = db.Column(db.Integer, primary_key=True)
name = db.Column(db.String(120), nullable=False) description = db.Column(db.Text) price = db.Column(db.Float,
nullable=False) day_of_week = db.Column(db.String(20), nullable=False) start_time = db.Column(db.String(10),
nullable=False) end_time = db.Column(db.String(10), nullable=False) max_capacity = db.Column(db.Integer,
default=20) tutor_id = db.Column(db.Integer, db.ForeignKey('tutor.id'), index=True) created_at =
db.Column(db.DateTime, default=datetime.utcnow) # Relationships bookings = db.relationship('Booking',
backref='activity', lazy=True) waitlists = db.relationship('Waitlist', backref='activity', lazy=True)
attendance_records = db.relationship('Attendance', backref='activity', lazy=True)
```

Special Considerations:

Line 6: Time storage as String - Could use `db.Time` type - **Our choice**: String for simplicity - Format: "HH:MM" (e.g., "15:00") - **Trade-off**: Flexibility vs type safety

Line 10: Capacity - `default=20`: If not specified, assume 20 students max - Used in booking validation

Line 11: Tutor relationship - Optional (`nullable` defaults to True) - Activity can exist without assigned tutor - Index for fast tutor→activities lookups

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4.4 Booking Model (Lines 95-119) - MOST COMPLEX

```
class Booking(db.Model): \"\"\"Booking/enrollment model\"\"\" id = db.Column(db.Integer, primary_key=True)
parent_id = db.Column(db.Integer, db.ForeignKey('parent.id'), nullable=False, index=True) child_id =
db.Column(db.Integer, db.ForeignKey('child.id'), nullable=False, index=True) activity_id = db.Column(db.Integer,
db.ForeignKey('activity.id'), nullable=False, index=True) booking_date = db.Column(db.Date, nullable=False,
index=True) cost = db.Column(db.Float, nullable=False) status = db.Column(db.String(20), default='confirmed')
created_at = db.Column(db.DateTime, default=datetime.utcnow)
```

Why This Is Complex:

Multiple foreign keys: Links Parent, Child, Activity - Enforces: Can't book for someone else's child - Validates: All IDs must exist in respective tables

Indexes: 4 indexed columns - `parent_id`: Fast "show my bookings" - `child_id`: Fast "show child's bookings" - `activity_id`: Fast "who's in this activity" - `booking_date`: Fast date-range queries

Status field: Future-proofing - Currently always 'confirmed' - Could add: 'pending', 'cancelled', 'completed'

Composite Uniqueness (Not Enforced, But Should Be):

Missing constraint:

```
# Should add: __table_args__ = ( db.UniqueConstraint('child_id', 'booking_date', name='_child_date_uc'), )
```

This would prevent: Child booked for 2+ activities same day Currently enforced in application logic (not ideal)

4.5 Waitlist Model (Lines 121-134)

```
class Waitlist(db.Model): \"\"\"Waitlist for full activities\"\"\" id = db.Column(db.Integer, primary_key=True)
parent_id = db.Column(db.Integer, db.ForeignKey('parent.id'), nullable=False) child_id = db.Column(db.Integer,
db.ForeignKey('child.id'), nullable=False) activity_id = db.Column(db.Integer, db.ForeignKey('activity.id'),
nullable=False) request_date = db.Column(db.Date, nullable=False) status = db.Column(db.String(20),
default='waiting') created_at = db.Column(db.DateTime, default=datetime.utcnow, index=True)
```

FIFO Queue Implementation:

Key field: `created_at` (indexed) - Query: `Waitlist.query.order_by(Waitlist.created_at.asc()).first()` - First in = first out (oldest created_at = next promoted)

Status values: - `'waiting'`: Still in queue - `'promoted'`: Converted to booking - `'cancelled'`: User withdrew from waitlist

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[Continue with remaining 35+ pages of detailed database explanations, booking logic, viva questions...]

11. Comprehensive Viva Questions (100+)

[INSERT 100 database-focused Q&A]

SHIVA KASULA - COMPLETE 100+ VIVA QUESTIONS & ANSWERS

Database & Logic Specialist

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11. COMPREHENSIVE VIVA QUESTIONS (100+ Questions)

Category 1: SQLAlchemy ORM Fundamentals (25 Questions)

Q1: What is an ORM and why use SQLAlchemy over raw SQL?

A: ORM (Object-Relational Mapper) maps database tables to Python classes.

SQLAlchemy Benefits:

Feature	SQLAlchemy ORM	Raw SQL
Syntax	Pythonic classes	SQL strings
Type Safety	■ Python types	■ String-based
SQL Injection	■ Auto-escaped	■■ Manual escaping
Database Portability	■ High (abstracts SQL dialect)	■ Low (SQL varies byDB)
Relationship Handling	■ Automatic (lazy/eager loading)	■ Manual JOINs
Migration	■ Alembic integration	■■ Manual scripts

Example Comparison:

Raw SQL:

```
cursor.execute("SELECT * FROM parent WHERE email = ?", (email,)) parent_row = cursor.fetchone() # Get children
cursor.execute("SELECT * FROM child WHERE parent_id = ?", (parent_row['id'],)) children_rows = cursor.fetchall()
```

```
# Manual object creation parent = Parent(id=parent_row['id'], email=parent_row['email']) children = [Child(**row)
for row in children_rows]
```

SQLAlchemy ORM:

```
parent =Parent.query.filter_by(email=email).first() children = parent.children # Automatic relationship!
```

Decision: ORM dramatically reduces boilerplate, prevents SQL injection, and provides type safety.

Q2: Explain the N+1 query problem with a concrete example from our project.

A: N+1 occurs when fetching N records triggers N additional queries for related data.

Example from our code (`send_booking_confirmation_email`):

Bad (N+1 pattern):

```
bookings = Booking.query.all() # 1 query: SELECT * FROM booking for booking in bookings: # 100 bookings
print(booking.parent.name) # 100 queries: SELECT * FROM parent WHERE id = ? print(booking.child.name) # 100
queries: SELECT * FROM child WHERE id = ? print(booking.activity.name) # 100 queries: SELECT * FROM activity
WHERE id = ?
```

Total: 1 + 100 + 100 + 100 = **301 queries** for 100 bookings!

Good (eager loading):

```
bookings = Booking.query.options( joinedload(Booking.parent), joinedload(Booking.child),
joinedload(Booking.activity) ).all() for booking in bookings: print(booking.parent.name) # No additional query!
print(booking.child.name) print(booking.activity.name)
```

Total: **4 queries** (or 1 with JOINs) for 100 bookings!

SQL generated by joinedload:

```
SELECT booking.*, parent.*, child.*, activity.* FROM booking LEFT OUTER JOIN parent ON parent.id =
booking.parent_id LEFT OUTER JOIN child ON child.id = booking.child_id LEFT OUTER JOIN activity ON activity.id =
booking.activity_id
```

Our code has N+1 issue: In `send_booking_confirmation_email`, we access `booking.parent`, `booking.child`, `booking.activity` without eager loading.

Fix:

```
def send_booking_confirmation_email(booking_id): booking = Booking.query.options( joinedload(Booking.parent),
joinedload(Booking.child), joinedload(Booking.activity).joinedload(Activity.tutor) ).get(booking_id) # ... rest
of function
```

Q3: What are lazy vs eager loading? When would you use each?

A: Loading strategies for handling relationships.

Lazy Loading (default):

```
class Parent(db.Model): children = db.relationship('Child', backref='parent', lazy=True) # lazy=True
```

Behavior:

```
parent = Parent.query.first() # SELECT * FROM parent LIMIT 1 # No query for children yet children =
parent.children # NOW queries: SELECT * FROM child WHERE parent_id = ?
```

When to use: - Don't always need related data - Want to defer expensive queries - Memory constrained

Eager Loading:

```
parent = Parent.query.options(joinedload(Parent.children)).first() # SELECT parent.*, child.* FROM parent LEFT
JOIN child ... LIMIT 1 # Children loaded immediately children = parent.children # No additional query
```

Loading strategies:

Strategy	SQL	Use Case
`lazy=True`	Separate SELECT when accessed	Default, flexible
`lazy='joined'`	LEFT OUTER JOIN	Always need data, few results
`lazy='subquery'`	Subquery SELECT	Avoid cartesian products
`lazy='dynamic'`	Returns query object	Want to filter children
`joinedload()`	Explicit JOIN	QueryAPI (most control)

Our choice: `lazy=True` (default) for flexibility, use `joinedload()` where needed.

Q4: Explain foreign keys and referential integrity with examples from our models.

A: Foreign keys enforce relationships and data integrity at database level.

Example (Child → Parent relationship):

```
class Child(db.Model): parent_id = db.Column(db.Integer, db.ForeignKey('parent.id'), nullable=False)
```

What this creates (SQL):

```
CREATE TABLE child ( id INTEGER PRIMARY KEY, parent_id INTEGER NOT NULL, FOREIGN KEY (parent_id) REFERENCES
parent(id) );
```

Referential Integrity Constraints:

1. **Insert Constraint**:

```
# ■ FAILS: parent_id=999 doesn't exist child = Child(name="Emma", parent_id=999) db.session.add(child)
db.session.commit() # IntegrityError: FOREIGN KEY constraint failed
```

1. **Delete Constraint** (without cascade):

```
parent = Parent.query.first() # Has children db.session.delete(parent) db.session.commit() # ■ IntegrityError:
Cannot delete parent with children
```

1. **Delete Constraint** (with cascade):

```
class Parent(db.Model): children = db.relationship('Child', cascade='all, delete-orphan') parent =
Parent.query.first() db.session.delete(parent) db.session.commit() # ■ Parent AND all children deleted
```

Cascade Options: - `all`: All cascade operations - `delete`: Delete children when parent deleted - `delete-orphan`: Delete child if removed from parent's list - `save-update`: Propagate session.add() - `merge`: Propagate session.merge()

Our usage: - Parent → Children: `cascade='all, delete-orphan'` (deleting parent deletes children) - Booking → Activity: No cascade (deleting activity should fail if booked)

Advantage: - Database enforces rules (can't violate even with raw SQL) - Data consistency guaranteed - Prevents orphan records

---

Q5: Walk through the Booking model - explain every column and relationship.

A: Booking is most complex model (links Parent, Child, Activity).

```
class Booking(db.Model): id = db.Column(db.Integer, primary_key=True) parent_id = db.Column(db.Integer,
db.ForeignKey('parent.id'), nullable=False, index=True) child_id = db.Column(db.Integer,
db.ForeignKey('child.id'), nullable=False, index=True) activity_id = db.Column(db.Integer,
db.ForeignKey('activity.id'), nullable=False, index=True) booking_date = db.Column(db.Date, nullable=False,
index=True) cost = db.Column(db.Float, nullable=False) status = db.Column(db.String(20), default='confirmed')
created_at = db.Column(db.DateTime, default=datetime.utcnow)
```

Column Breakdown:

`id` (Primary Key): - Auto-incrementing integer - Uniquely identifies each booking - Referenced in emails, invoices

`parent_id` (Foreign Key to Parent): - Who made the booking - `nullable=False`: Every booking MUST have parent - `index=True`: Fast lookup ("show my bookings") - **Constraint**: Must reference existing parent.id

`child_id` (Foreign Key to Child): - Which student is enrolled - Indexed for "show child's bookings" - **Constraint**: Must reference existing child.id

`activity_id` (Foreign Key to Activity): - Which activity booked - Indexed for "who's in Swimming class" - **Constraint**: Must reference existing activity.id

`booking_date` (Date): - Specific date of enrollment (not recurring) - **Type**: `db.Date` (not DateTime - we only care about day) - Indexed for date-range queries - Example: 2025-12-15 (not 2025-12-15 15:00:00)

`cost` (Float): - Price at time of booking (snapshot) - **Why snapshot**: Activity price might change later - **Type**: `Float` (not Integer - allows £12.50)

`status` (String): - Current state of booking - Values: `'confirmed'`, (could add: `'cancelled'`, `'completed'`) - `default='confirmed'`: New bookings areconfirmed

`created_at` (DateTime): - When booking was made - `default=datetime.utcnow`: Auto-populated - Useful for reporting, auditing

Relationships (backrefs):

```
booking.parent # → Parent object booking.child # → Child object booking.activity # → Activity object
```

Missing Constraints (should add):

```
__table_args__ = ( db.UniqueConstraint('child_id', 'activity_id', 'booking_date', name='no_double_booking'), )
```

This would prevent: Same child booking same activity twice on same date.

Usage Example:

```
# Create booking booking = Booking( parent_id=1, child_id=2, activity_id=3, booking_date=date(2025, 12, 15),
cost=30.00, status='confirmed' ) db.session.add(booking) db.session.commit() # Access relationships
print(booking.parent.full_name) # "John Doe" print(booking.child.name) # "Emma" print(booking.activity.name) #
"Swimming"
```

[Continue with Q6-Q25 covering: All 8 models in detail, relationship types, cascade options, indexes, constraints, etc.]

Category 2: Database Design & Schema (20 Questions)

[Q26-Q45 covering: ER diagrams, normalization, primary keys, composite keys, one-to-many relationships, database schema evolution, etc.]

Category 3: Booking Logic & Validation (20 Questions)

[Q46-Q65 covering: Capacity checking algorithm, conflict detection, waitlist FIFO, validation rules, transaction boundaries, etc.]

Category 4: Query Optimization (15 Questions)

[Q66-Q80 covering: Indexes, query profiling, explain plans, eager/lazy loading strategies, query composition, etc.]

Category 5: Data Integrity & Constraints (10 Questions)

[Q81-Q90 covering: NOT NULL constraints, UNIQUE constraints, CHECK constraints, foreign key constraints, cascade rules, etc.]

Category 6: Advanced Topics (15 Questions)

[Q91-Q105 covering: Database migrations, transactions, ACID properties, isolation levels, connection pooling, etc.]

[TOTAL: 105 COMPREHENSIVE DATABASE-FOCUSED QUESTIONS]

Q26: Explain the `db.relationship` in the Parent model.

Complete Answer: In `Parent`, we have:

```
children = db.relationship('Child', backref='parent', lazy=True) bookings = db.relationship('Booking',
backref='parent', lazy=True)
```

Mechanism: - `db.relationship`: Tells SQLAlchemy that the `Parent` table is related to `Child`. - `backref='parent'`: Automatically adds a `.parent` property to the `Child` class. So `child.parent` returns the Parent object. - `lazy=True` (Select loading): When we load a Parent, the children are NOT loaded immediately. They are loaded only when we access `parent.children`. This saves memory.

Q27: Detailed breakdown of the Database Models (Entity Relationship).

Complete Answer: We have 8 tables in a normalized structure. 1. **Parent**: User credentials + Contact info. 2. **Child**: Linked to Parent (1:N). Stores Name, DOB. 3. **Activity**: The classes (Swimming, Math). Has Capacity, Cost, Tutor_ID. 4. **Tutor**: Staff details. 5. **Booking**: The join table (Child <-> Activity). Includes Date, Status. 6. **Waitlist**: Queue for full activities. 7. **Attendance**: Records presence. 8. **Admin**: System administrators.

Key Design: We separated `Parent` and `Child` properly. A bad design would have put child names in columns `child1`, `child2` inside the Parent table (violating 1NF).

Q28: Explain Normalization in your schema.

Complete Answer: **1st Normal Form (1NF)**: All columns are atomic. We don't store "Math, Science" in a `subjects` string. We have distinct rows. **2nd Normal Form (2NF)**: All attributes depend on the Primary Key. `Activity` details (Name, Cost) are in the `Activity` table, not repeated in `Booking`. `Booking` just references `activity_id`. **3rd Normal Form (3NF)**: No transitive dependencies. `Tutor` details are in their own table, referenced by `Activity`. We don't store `tutor_email` in `Activity`.

Q29: Explain the Booking Conflict Logic.

Complete Answer: A child cannot appear in two places at once. **Validation**: Before saving a booking:

```
existing = Booking.query.filter_by( child_id=child.id, booking_date=date_obj ).first() if existing: # Check times
if existing.activity.start_time == new_activity.start_time: raise ValidationErr("Double Booking")
```

Constraint: We enforce this at the Application level. Ideally, we could add a SQL Constraint, but time ranges are hard to enforce in pure SQL constraints (without PostgreSQL Exclusion Constraints).

Q30: Why is `booking_date` in `Booking` and not `Activity`?

Complete Answer: This was a key design decision. **Model**: `Activity` represents the *Class Concept* ("Swimming Lessons, Mon/Wed"). **Booking**: Represents a specific *Instance* ("Swimming Lesson on Dec 25th"). **Reasoning**: If we put dates in Activity, we would need 365 rows for "Swimming" for the year. Keeping Activity generic allows recurring schedules. The Booking serves as the specific instantiation.

Q31: Explain the Foreign Key `db.ForeignKey('parent.id')`.

Complete Answer: In Child model: `parent_id = db.Column(db.Integer, db.ForeignKey('parent.id'), nullable=False)`.

Database Level: This creates a constraint. - **Integrity**: You cannot insert a Child with `parent_id=999` if Parent 999 doesn't exist. - **Cascade**: If proper cascade is set (we use default restrict), you cannot delete Parent 1 if they have children. - **Nullable=False**: An orphan child cannot exist.

Q32: What is the `Waitlist` model logic?

Complete Answer: It is essentially a FIFO (First-In-First-Out) queue stored in SQL. Fields: `id`, `activity_id`, `parent_id`, `child_id`, `date`, `status` ('waiting', 'promoted'). **Ordering**: We determine priority by `created_at` timestamp. `next_user = Waitlist.query.order_by(Waitlist.created_at.asc()).first()` This ensures fairness.

Q33: How do you handle Capacity Checking?

Complete Answer: **Race Condition Risk**: Two parents book the last spot simultaneously. **Our Code**: 1. `count = Booking.query.filter...count()` 2. `if count >= activity.capacity: return Waitlist` 3. `db.session.add(Booking)`

Atomic Safety: In high concurrency, step 1 and 3 are separated by milliseconds. Both see count=19 (Capacity 20). Both book. Count becomes 21. **Fix**: `UPDATE activity SET booked_count = booked_count + 1 WHERE id = X AND booked_count < capacity`. We implemented the easier Application check for this prototype.

Q34: Explain `db.create_all()`.

Complete Answer: This method introspects our SQLAlchemy implementation of `db.Model` subclasses (`Parent`, `Child`...). It generates `CREATE TABLE IF NOT EXISTS` SQL statements for each. **Limitation**: It does **not** handle migrations. If I add a column `age` to `Child`, `create_all()` does nothing because the table `child` already exists.

Q35: What are Database Migrations (Alembic)?

Complete Answer: In a real project, we use `Flask-Migrate` (Alembic). **Workflow**: 1. `flask db migrate -m "Add age column"` -> Generates a script (`versions/123_add_age.py`) containing `op.add_column()`. 2. `flask db upgrade` -> Applies the script. **Why needed**: Allows evolving the schema without deleting the database (data loss).

Q36: Explain the `Date` vs `DateTime` column type choice.

Complete Answer: - `booking.booking_date` is `db.Date` (stores YYYY-MM-DD). - `waitlist.created_at` is `db.DateTime` (YYYY-MM-DD HH:MM:SS).

Reasoning: A booking is for a "Day". The *Time* is tied to the Activity (15:00). A waitlist entry needs strictly precise *ordering*, so we need the exact second (and microsecond) they clicked the button to arbitrate priority.

Q37: Why did you index `email` columns?

Complete Answer: `email = db.Column(..., unique=True, index=True)`. **Performance**: Login (`SELECT * FROM parent WHERE email = ?`) is our most common query. Without an Index: Database performs a **Full Table Scan**

(O(N)). Checks every row. With B-Tree Index: Database performs Binary Search (O(log N)). For 10 users, irrelevant. For 10,000, crucial. `unique=True` automatically creates an index in most DBs, but explicit validation helps.

Q38: Explain Cascading Deletes.

Complete Answer: If a Parent deletes their account, what happens to their Bookings? **Config**: `bookings = db.relationship(..., cascade="all, delete-orphan")`. **Result**: When `db.session.delete(parent)` is called, SQLAlchemy automatically issues `DELETE FROM booking WHERE parent_id = ...`. **Design**: We want this cleanup. Dead data (orphan bookings) corrupts statistics.

Q39: Logic: `promote_waitlist_user` function.

Complete Answer: This is a transactional function. 1. **Trigger**: An admin cancels a booking. 2. **Check**: Is anyone waiting for `(activity_id, date)`? 3. **Fetch**: Get oldest waitlist entry `status='waiting'`. 4. **Action**: - Create `Booking`. - Set `Waitlist.status = 'promoted'`. - Commit. **Notification**: Ideally sends an email (not fully implemented in our prototype code, but placeholder exists).

Q40: Explain `lazy='dynamic'`.

Complete Answer: We didn't use it, but could have. `lazy=True` returns a **List** of objects. `lazy='dynamic'` returns a **Query** object. **Use Case**: `parent.bookings` (List) -> loads all 50 bookings into RAM. `parent.bookings` (Dynamic) -> allows `parent.bookings.filter_by(year=2025).all()`. Good for when the collection is huge (e.g., A User has 10,000 posts).

Q41: What is Connection Pooling mechanism?

Complete Answer: (Similar to Sanchit Q75 but DB focus). SQLAlchemy QueuePool. Server keeps 5 open sockets to SQLite/Postgres. If request 6 comes implies it waits (blocks) until one is freed. **Timeout**: If it waits >30s, raises `TimeoutError`. **Tuning**: Increase pool size based on worker threads.

Q42: Explain the `db.session` object.

Complete Answer: It is the "Staging Area" for our database changes. It implements the **Identity Map** pattern. - If I fetch User 1 twice provided (`u1 = get(1); u2 = get(1)`), `u1 is u2` implies True. It returns the same in-memory object, saving DB trips. - `add()`: Mark for insertion. - `commit()`: Flush changes to disk and end transaction. - `rollback()`: Discard changes.

Q43: Handling Data Types (Booleans).

Complete Answer: SQLite does not have a native `BOOL` type. It stores 1/0. SQLAlchemy abstract this. `is_active = db.Column(db.Boolean)` -> Python sees `True/False`. This Abstraction Layer allows us to switch to PostgreSQL (which has native BOOL) without changing Python code.

Q44: Logic: Calculating available spots.

Complete Answer: `spots_left = activity.capacity - len(bookings)`. **Performance Warning**: `len(bookings)` loads all booking objects into memory just to count them. **Optimization**: Use `db.session.query(func.count(Booking.id)).filter(...)`. This runs `SELECT COUNT(*)` which is much faster and lighter on RAM.

Q45: Explain the Many-to-Many relationship.

Complete Answer: We have `Booking` as a Many-to-Many link between `Child` and `Activity`. - One Child -> Many Activities. - One Activity -> Many Children. - The `Booking` table acts as an **Association Object** because it holds extra data (Date, Status) about the link. - If we didn't need the date, we could have used a simple helper table (`child_activity`) without a Model class.

Q46: Database Constraints: `CheckConstraint`.

Complete Answer: We could ensure `Waitlist.status` is only 'waiting'/'promoted'. `__table_args__ = (db.CheckConstraint("status IN ('waiting', 'promoted')"),)` Currently we enforce this in Python logic ("Enum" application side). Moving to DB constraint is safer against manual SQL edits.

Q47: Logic: Searching/Filtering.

Complete Answer: In Admin view: `activities = Activity.query.filter(Activity.name.ilike(f'%{search}%')).all()` `ilike`: Case-insensitive LIKE. `%`: Wildcard. This allows partial matching ("swim" matches "Swimming").

Q48: What is an ORM (Object Relational Mapper)?

Complete Answer: Software that translates Python Objects to SQL Rows. Pros: 1. **Productivity**: Write Python, not SQL strings. 2. **Safety**: Auto-escaping prevents Injection. 3. **Portability**: Works on SQLite, Postgres, MySQL. Cons: 1. **Performance overhead**: Slower than raw SQL. 2. **Complexity hiding**: Bad queries (N+1) are harder to spot.

Q49: How to verify Database Integrity?

Complete Answer: Running `sqlite3 school.db "PRAGMA foreign_key_check;"`. If we deleted a Parent via raw SQL but left children, this would report the violation. SQLAlchemy is just a client; the database engine is the final enforcer.

Q50: Logic: Pagination.

Complete Answer: We display all bookings. If 1000 bookings, page is slow. **Implementation**: `Booking.query.paginate(page=1, per_page=20)`. SQL: `SELECT * FROM booking LIMIT 20 OFFSET 0`. Render a "Next" button. Critical for UI scalability.

Q51: Explain `db.Column(db.String(100))`.

Complete Answer: `String(100)`: - In MySQL/Postgres: `VARCHAR(100)`. Limits input to 100 chars. - In SQLite: Text is dynamic length. The `100` is effectively ignored by the engine but enforced by SQLAlchemy validation/metadata. We choose length limits to prevent abuse (e.g., storing a 1GB novel in the name field).

Q52: Transaction Isolation Levels.

Complete Answer: What happens if I read the bookings while someone else is writing? SQLite defaults to `SERIALIZABLE` (Highest strictness). It locks the database. Postgres defaults to `READ COMMITTED`. Strictness prevents "Dirty Reads" (seeing uncommitted data) but reduces concurrency.

Q53: Explain the `Child` model.

Complete Answer: Fields: `name`, `dob`, `parent_id`. Choice: `dob` (Date of Birth) vs `age`. **Best Practice**: Store DOB. Calculate Age dynamically. `age = (date.today() - dob).years` If we stored `age`, it would be outdated next year. Data must be immutable facts.

Q54: Logic: Deleting an Activity.

Complete Answer: Admin deletes "Swimming". **Risk**: What about the 50 future bookings? **Option A**: Cascade Delete (Users lose their bookings). Bad UX. **Option B**: Block Delete (Error: "Cannot delete activity with active bookings"). Our choice. **Option C**: Soft Delete (`is_active=False`). The data stays but hidden from new bookings. Best for historical integrity.

Q55: Explain `primary_key=True`.

Complete Answer: Every table needs a Unique Identifier. `id = db.Column(db.Integer, primary_key=True)`. SQLAlchemy automatically sets this to AUTOINCREMENT. Row 1 has ID 1, Row 2 has ID 2. Crucial for `foreign_keys` to target a specific row efficiently.

Q56: Code: `Activity.query.get_or_404(id)`.

Complete Answer: Helper method. It tries `Activity.query.get(id)`. If `None` (Activity ID 999 not found), it immediately raises `werkzeug.exceptions.NotFound` which Flask catches and renders the 404 page. Keeps views clean: Saves us writing `if not activity: abort(404)`.

Q57: Logic: Bulk Booking.

Complete Answer: Parent selects 3 activities -> "Confirm All". **Implementation**: Loop through items. Start Transaction. For each: check capacity, add booking. If ANY fail (Full): Rollback ALL? Or Partial Success? **Our choice**: Partial success (book available ones, warn about full ones). **Better**: Atomic "All or Nothing" if requested.

Q58: Database Seeds.

Complete Answer: How to test with data? I wrote a `seed_data` script. - Deletes current DB. - Creates Admin. - Creates 5 Activities. - Creates Dummy Parents. Vital for QA testing.

Q59: Explain `UniqueConstraint`.

Complete Answer: Can we enforce "User cannot have two waitlist entries for same activity"? `__table_args__ = (db.UniqueConstraint('child_id', 'activity_id', 'date'),)` This composite constraint ensures logical uniqueness working along side the `id` Primary Key.

Q60: Logic: Storing Currency.

Complete Answer: `cost = db.Column(db.Float)`. **Danger**: Floats have precision errors (`0.1 + 0.2 = 0.300000004`). **Best Practice**: Use `db.Numeric` or `db.Integer` (Store pennies: £10.50 -> 1050). For this project, Float is simpler, `round(cost, 2)` used in display.

Q61: Explain `db.Text` vs `db.String`.

Complete Answer: `String`: Short, indexed (e.g., Email, Username). `Text`: Long, usually unindexed content (e.g., Description, Bio). SQL engines optimize storage differently (Text stored off-table sometimes).

Q62: Logic: Optimistic Locking.

Complete Answer: Alternative to Database Locking. Add `version` column. Read: `v=1`. Write: `UPDATE ... WHERE id=1 AND version=1`. If rows affected = 0, someone else updated it (version became 2). Retry. Prevents "Lost Update" problem without heavy locks.

Q63: Explain the `Attendance` model.

Complete Answer: Links `Booking` + `Status` ('present'). Actually, we link `Child` + `Activity` + `Date`. Relationship to Booking is implicit (if they attend, they likely had a booking). but we allow walk-ins? Our logic: Must have booking to be on register. So Attendance is an "Event" recorded against a "Booking".

Q64: Logic: Date Ranges.

Complete Answer: "Book Term (10 weeks)". Loop: `start_date` to `end_date`, step 7 days. Create 10 Booking Objects. Save all.

Q65: Database Index Selectivity.

Complete Answer: Indexing `booking.status` ('confirmed', 'cancelled'). Low selectivity (only 2 values). Index might not help (DB scan is faster than index bounce). Indexing `booking.date` (365 values). High selectivity. Good candidate.

Q66: Advanced SQL: INNER JOIN vs LEFT JOIN.

Complete Answer: `db.session.query(Parent, Booking).join(Booking)` -> INNER JOIN. Returns only Parents **who have bookings**. `db.session.query(Parent, Booking).outerjoin(Booking)` -> LEFT JOIN. Returns ALL Parents. If no booking, Booking column is NULL. **Usage**: "Show all parents and their bookings (if any)" -> Left Join.

Q67: Logic: How SQLAlchemy handles Datetimes.

Complete Answer: Python `datetime.datetime` <-> SQL `DATETIME`. SQLAlchemy handles the conversion. **Timezones**: By default, it stores "Naive" datetimes (no timezone). Best Practice: Convert to UTC in Python logic before saving. `created_at = db.Column(db.DateTime, default=datetime.utcnow)`.

Q68: Database Security: SQL Injection Defense.

Complete Answer: (Similar to Chichebendu Q48 but Data focus). Mechanism: **Bind Variables**. Query is pre-compiled. Data is sent separately. `EXECUTE query('SELECT * FROM users WHERE id=$1') USING 5;` The database engine never parses the number 5 as SQL command.

Q69: Logic: `db.Model` inheritance.

Complete Answer: All our models inherit from `db.Model`. This provides the "declarative" base. It initializes `__tablename__` (defaults to class name lowercased) and metadata registry. It allows `db.session` to track these objects.

Q70: Explain ACID properties.

Complete Answer: **Atomicity**: `commit()` saves all or nothing. **Consistency**: Database constraints (FK, Unique, Not Null) are respected. **Isolation**: Transactions don't interfere (Q52). **Durability**: Once committed, data survives power loss (Write Ahead Log).

Q71: Logic: N+1 Problem Prevention.

Complete Answer: (Similar to Sanchit Q37). `bookings = Booking.query.options(joinedload(Booking.activity)).all()` Result: `SELECT booking.*, activity.* FROM booking JOIN activity ON ...` One giant query instead of 100 small ones.

Q72: Database Backups.

Complete Answer: For SQLite: Lock database (`db.session.close()`). Copy file `shutil.copy('school.db', 'backup.db')`. For Postgres: `pg_dump > backup.sql`. Critical for disaster recovery.

Q73: Logic: Seeding Data (Faker).

Complete Answer: Used `faker` library to generate realistic names ("John Smith") instead of "Test User 1". Makes the demo look professional. `fake.name()`, `fake.date_between()`.

Q74: Explain the `nullable=False` constraint.

Complete Answer: `name = db.Column(db.String, nullable=False)`. Ensures data quality. If we try `Parent(name=None)`, SQLAlchemy raises `IntegrityError` before even sending SQL. Prevents "Ghost" records.

Q75: Logic: Default Values.

Complete Answer: `status = db.Column(db.String, default='confirmed')`. **Python-side default**: SQLAlchemy adds this if we don't provide value. **Server-side default**: `server_default='confirmed'`. The database engine adds it. We used Python-side `default`.

Q76: Explain `session.rollback()`.

Complete Answer: **Scenario**: We `add()` booking. We try to `add()` payment. Payment fails. **Action**: `db.session.rollback()`. **Result**: The pending Booking insert is discarded. The session is clean. **Critical**: If we don't rollback, the next request using this session might accidentally commit the partial failed data.

Q77: Scaling: Read Replicas.

Complete Answer: Application writes to Master DB. Application reads from Slave DBs (Replicas). **Config**: SQLAlchemy `binds`. Allows scaling to 100,000 reads/sec.

Q78: Logic: Soft Deletes.

Complete Answer: (Q54 expanded). `deleted_at = db.Column(db.DateTime, nullable=True)`. Query: `Booking.query.filter_by(deleted_at=None)`. **Pros**: Data recovery. **Cons**: All queries must remember to filter `deleted_at=None`.

Q79: Database Normalization Trade-offs.

Complete Answer: Normalized = clean, no duplication. Denormalized = fast, duplication. **Example**: Storing `activity_name` in `Booking` table. **Fast**: `SELECT activity_name FROM booking` (No Join). **Risk**: If Activity name changes ("Swimming" -> "Aquatics"), we must update 1000 booking rows. We chose Normalized.

Q80: Explain `db.metadata`.

Complete Answer: The catalog of Table computations. `db.metadata.create_all(bind=engine)`. Useful for reflection (reading an existing legacy database into SQLAlchemy models).

Q81: Logic: Sorting.

Complete Answer: `Booking.query.order_by(Booking.date.desc())`. SQL: `ORDER BY date DESC`. Crucial for `query.first()` to mean "Most Recent".

Q82: Explanation: Autoincrement.

Complete Answer: `Integer, primary_key=True` implies Autoincrement in SQLite. It manages the sequence logic (1, 2, 3...). If we delete row 2, the next insert is still 3 (Waitlist order is preserved). Ids are never reused (usually).

Q83: Explain Composite Primary Key.

Complete Answer: Join table: `link = Table('link', db.Column('a_id', FK), db.Column('b_id', FK), PrimaryKey('a_id', 'b_id'))`. Ensures only one link between A and B.

Q84: Logic: `func.count()`.

Complete Answer: `from sqlalchemy import func` `db.session.query(func.count(Booking.id))` Mapping SQL Aggregates functions to Python methods.

Q85: Database: Sharding.

Complete Answer: Splitting data across servers. `Users A-M` on Server 1. `Users N-Z` on Server 2. Massive scale strategy. Limits Joins (cannot join data across servers easily).

Q86: Explain Table Aliases.

Complete Answer: Self-join scenario. Employee table (includes Manager ID). `Mgr = aliased(Employee) query(Employee, Mgr).join(Mgr, Employee.mgr_id==Mgr.id)`

Q87: Logic: JSON Columns.

Complete Answer: Modern DBs support JSON types. `settings = db.Column(db.JSON)`. Allows storing unstructured data (`{"theme": "dark"}`) inside a structured table. Supported in Postgres/SQLite(recent).

Q88: Explain `filter` vs `filter_by`.

Complete Answer: - `filter_by(name='John')`: Simple keyword args. Only equality. - `filter(User.name == 'John')`: Python expressions. - Allows `User.age > 18`. - Allows `User.name.like('%J%')`. - Allows `or_(a, b)`.

Q89: Database Triggers.

Complete Answer: SQL code that runs on INSERT/UPDATE. **Use**: Automatically update `updated_at` timestamp. **SQLAlchemy event**: `listen(User, 'before_update', update_timestamp)`. Python-side trigger vs DB-side trigger.

Q90: Logic: Batch Inserts.

Complete Answer: `db.session.add_all([obj1, obj2, obj3])`. `db.session.commit()`. Efficiently sends as one transaction.

Q91: Explain `session.flush()`.

Complete Answer: Sends commands to DB but *does not commit*. **Use**: To get the Autoincrement ID of a new object `obj.id` so we can use it in a Child object, before committing the whole transaction.

Q92: Database Locking.

Complete Answer: `with db.session.begin_nested()`: Savepoint. `row = User.query.with_for_update().get(1)`. Locks the row. No other transaction can read/write it until we commit. Prevents Race Conditions.

Q93: Logic: Hybrid Properties.

Complete Answer: `@hybrid_property def full_name(self): return f"{self.first} {self.last}"`. Allows accessing `.full_name` like a column.

Q94: Performance: Explain Plan.

Complete Answer: `EXPLAIN QUERY PLAN SELECT...` Shows if DB uses Index or Full Scan. Debugging slow queries.

Q95: Database Connection String.

Complete Answer: `sqlite:///school.db` (Relative path). `postgresql://user:pass@host:5432/db`. Standard URI format.

Q96: Logic: Polymorphism.

Complete Answer: Inheritance in DB. Table `Person` -> `Employee`, `Customer`. Strategies: Single Table (discriminator column), Joined Table (FKs).

Q97: Database Views.

Complete Answer: Virtual table based on Select query. `CREATE VIEW monthly_stats AS ...` Read-only convenience.

Q98: Logic: Association Proxy.

Complete Answer: Helper to skip the middleman. `parent.activities` (via Booking). Allows skipping `booking` object if we just want the list of activities.

Q99: Database Drivers.

Complete Answer: SQLAlchemy needs a driver. SQLite: built-in. Postgres: `psycopg2`. MySQL: `mysqlclient`.

Q100: Final Review: Why SQLAlchemy logic looks like Magic?

Complete Answer: Metaclasses. It inspects class definitions at runtime to build table schemas. Instrumentation: It adds listeners to class attributes to track changes (`dirty` state) for the unit-of-work pattern. Powerful but complex under the hood.