Databases

Normalisation

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What Makes a Good Data Model?

- **Minimal Modification Anomalies:** A robust model ensures that data remains consistent and accurate through all insertions, updates, and deletions.
- **Efficient Data Usage:** Optimizes data storage and retrieval, preventing unnecessary duplication.
- **Flexibility and Scalability:** Adapts easily to evolving data requirements and scales with growing data volumes.

What Must Be Done: Reduce Redundancies

- **Identify and Eliminate Duplication:** Reducing redundancies in a database prevents data inconsistencies and lowers storage needs. It involves ensuring each piece of information exists only once, eliminating duplicates.

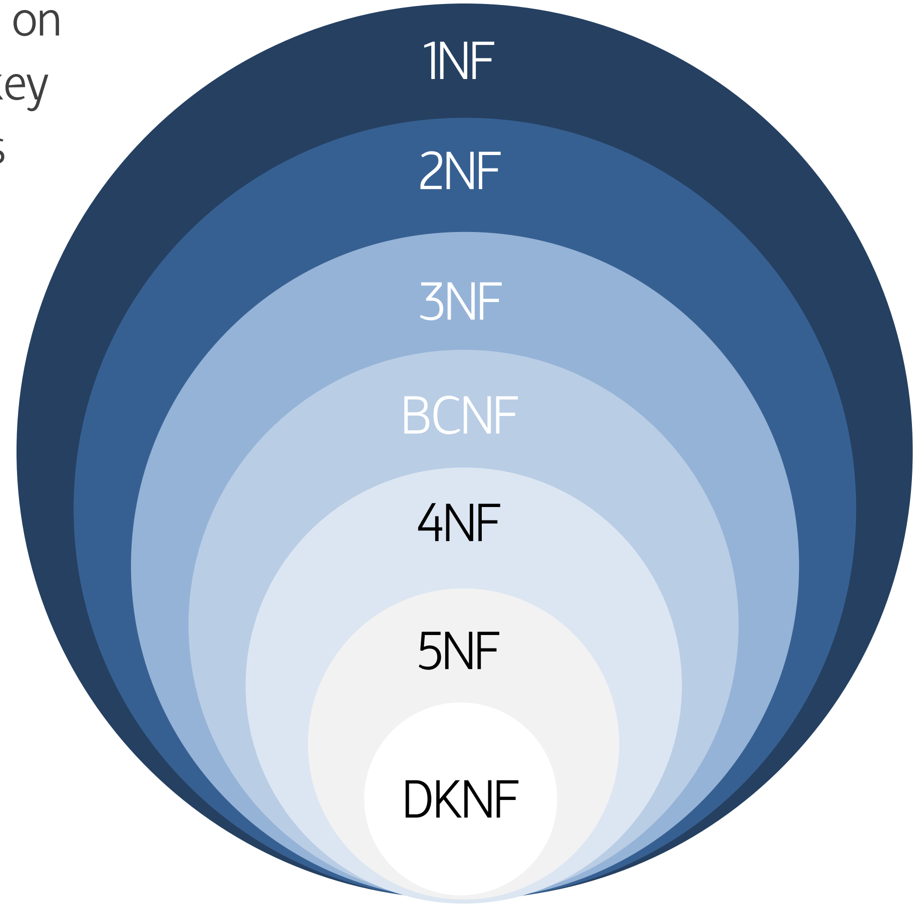
- **Streamline Data Relationships:** By organizing data to ensure that each item is stored in the most logical and efficient way, databases are structured for better accessibility and clearer understanding.

Normalisation: The How-To Process

- **Systematic Organization:** Normalization is a process to organize data in databases, minimizing redundancy and anomalies through structured stages, or 'normal forms'.
- **Staged Refinement:** The process progresses through stages from First Normal Form (1NF) to more advanced forms like BCNF, each stage reducing data duplication and enhancing integrity and efficiency.
- **Practical Balance:** Normalization balances data integrity with database performance, tailored to specific needs and scenarios.

Normal Forms

- **Clumaltive Nature:** Each normal form adds rules to further refine the database structure. Achieving a higher normal form (like BCNF) implies compliance with all lower forms' criteria.
- **Pracitcal Usage:** In current industry practices, emphasis is often on achieving BCNF due to its effectiveness and clarity in resolving key anomalies. 2NF, while historically significant, is less a focus as its requirements are naturally met on the path to 3NF and BCNF.



Staged Refinement

1NF

Redundancy Target: Eliminates multiple values in a single cell and duplicate rows.
Focus: Ensuring that each cell contains a single value and each record is unique.

Staged Refinement

2NF

Redundancy Target: Addresses partial dependencies on a composite key.
Focus: Making sure every non-key attribute is fully dependent on the entire primary key.

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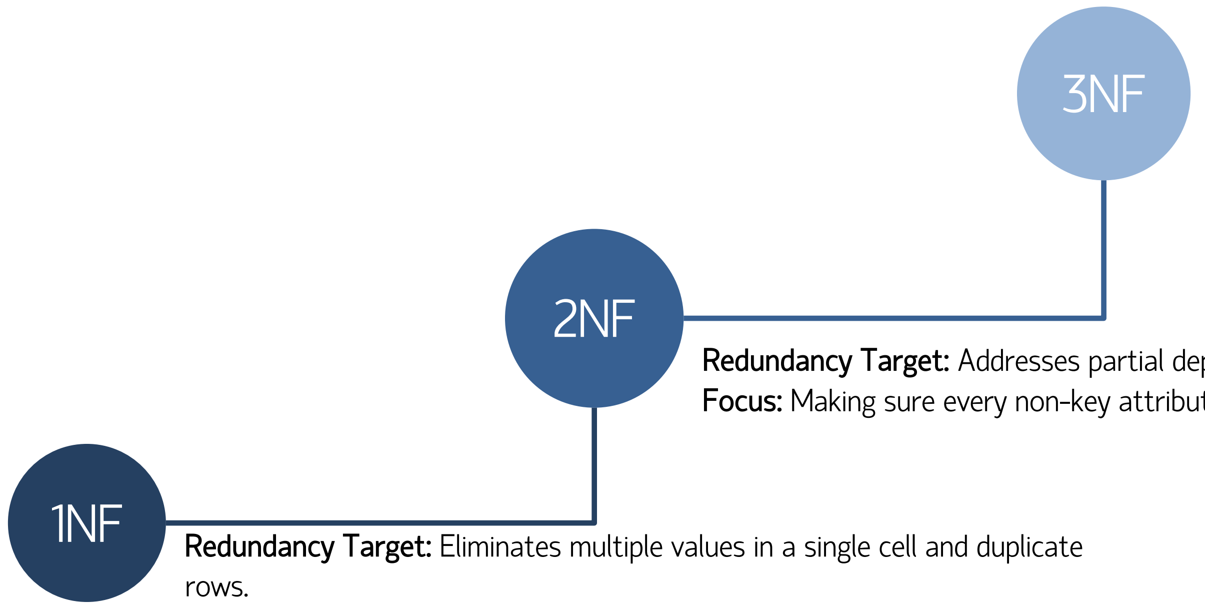

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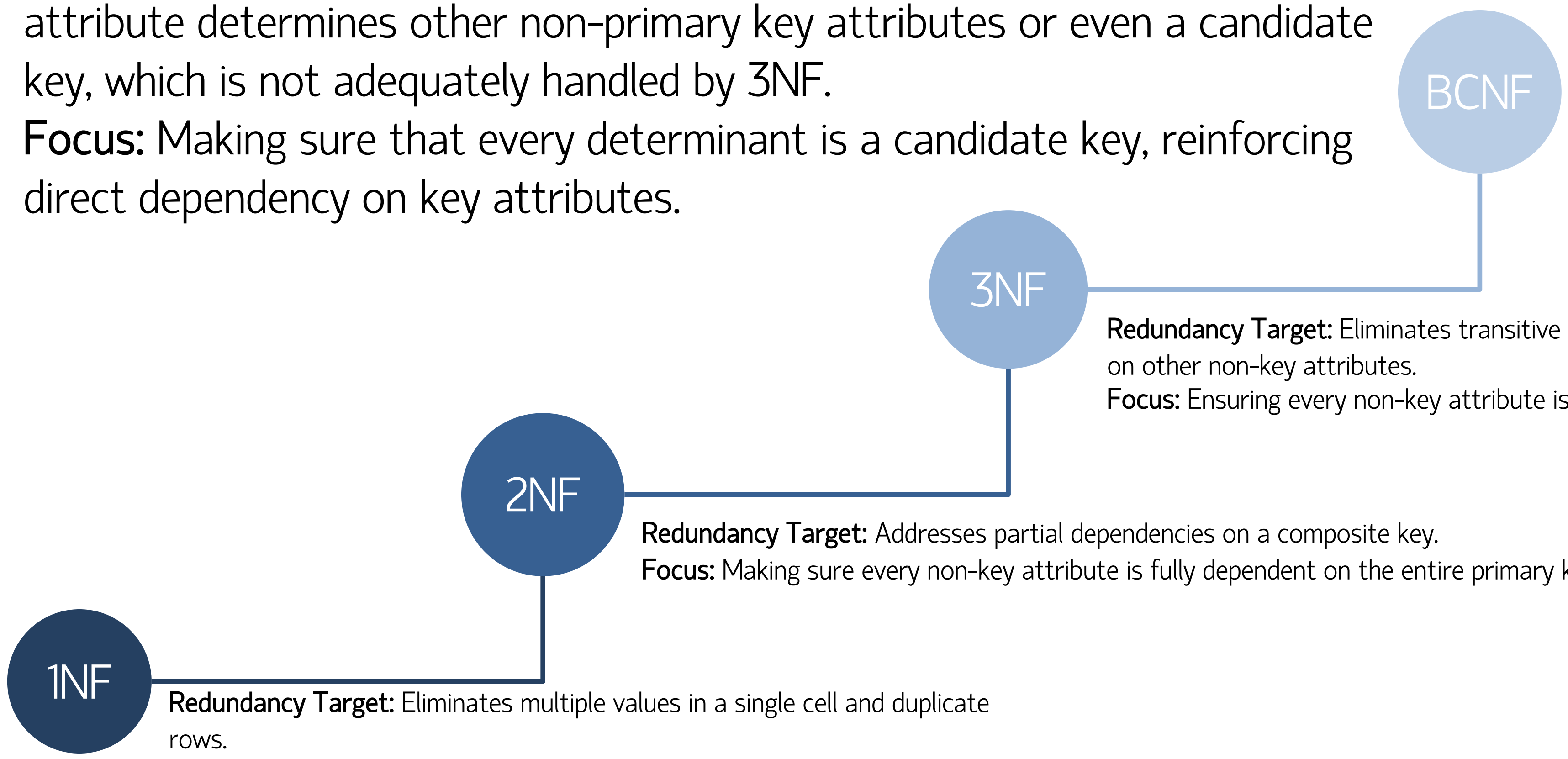
Focus: Making sure that every determinant is a candidate key, reinforcing direct dependency on key attributes.



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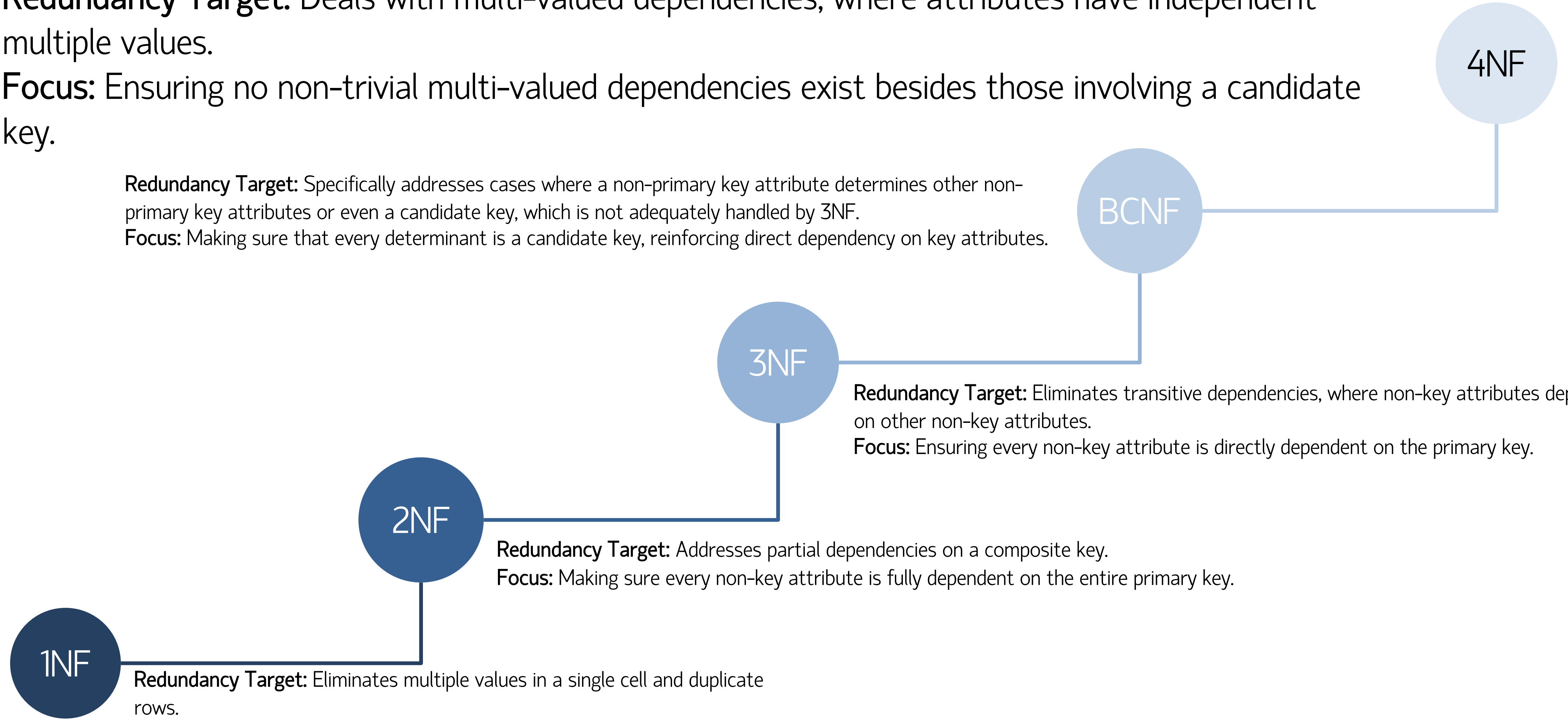

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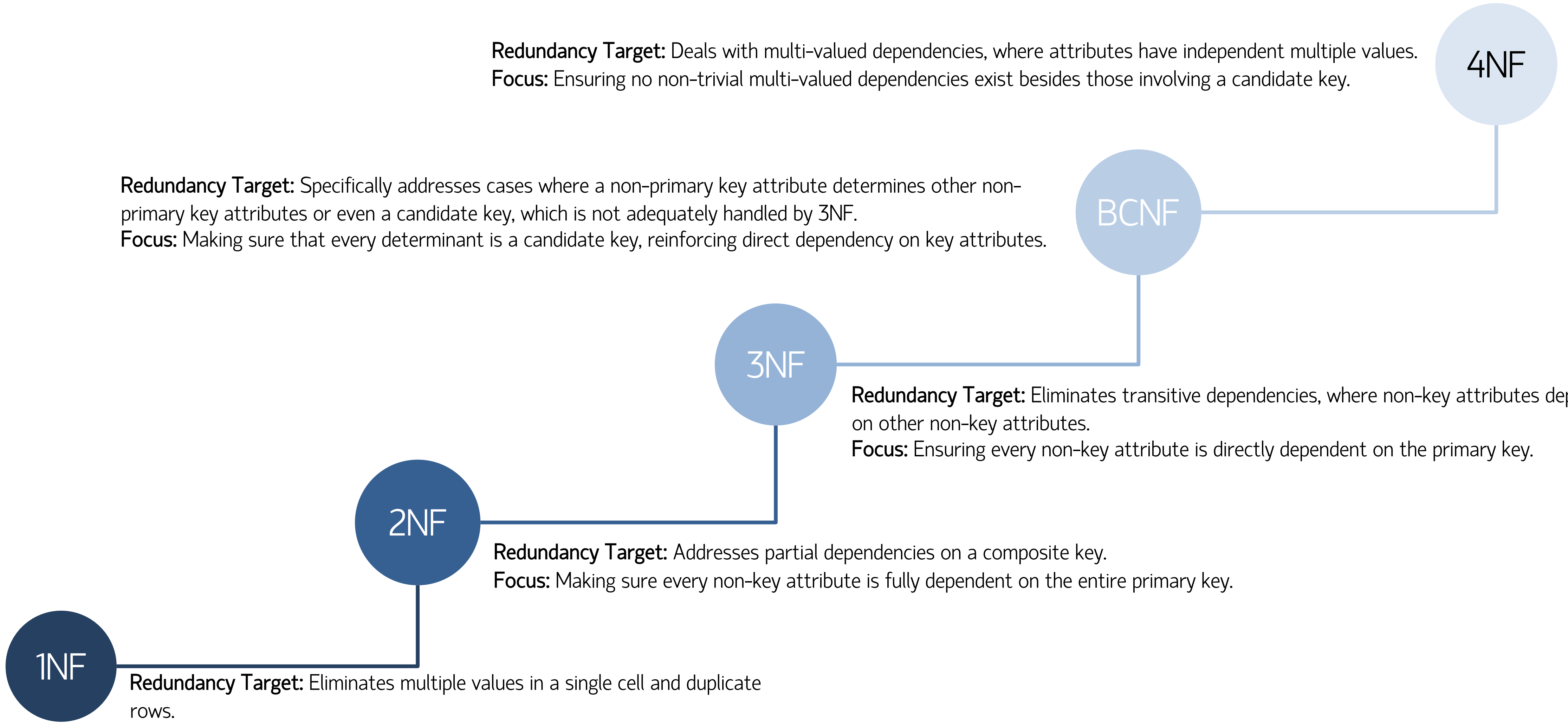

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Staged Refinement

1NF

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Understanding First Normal Form (1NF)

What is 1NF?

- 1NF requires that each cell in a table has a unique, atomic value and that each record is distinct. It's the first step in ensuring data is well-structured and unambiguous

Spotting the Problem

- Look for columns containing multiple values. In our example, 'Courses' and 'Textbooks' hold lists, violating the 1NF rule.

Sample Data (Not in 1NF)

```
| StudentID | Courses                 | Textbooks                |
|-----------|-------------------------|--------------------------|
| 101       | Math, Science           | Math101, Science201      |
| 102       | Literature, Math        | Lit101, Math101          |
```

Breaking Down Complexity

- 1NF aims to simplify database records. Instead of storing multiple values in a single cell, 1NF requires splitting these into individual, atomic items. This reduces complexity and enhances data clarity.

Transitioning to First Normal Form (1NF)

Normalisation

- To meet 1NF, multi-valued fields are split into separate rows, creating a one-to-one relationship between key and value in each cell.
- This leads to a more organized table where each data point is distinctly represented in its own row, complying with the atomicity principle of 1NF.

Transformed into 1NF

```
| StudentID | Course     | Textbook    |
|-----------|------------|-------------|
| 101       | Math       | Math101     |
| 101       | Science    | Science201  |
| 102       | Literature | Lit101      |
| 102       | Math       | Math101     |
```

Understanding the Change

- The table now clearly represents each piece of information in separate, atomic units, laying the groundwork for more advanced data structuring and integrity.

Staged Refinement

2NF

Redundancy Target: Addresses partial dependencies on a composite key.
Focus: Making sure every non-key attribute is fully dependent on the entire primary key.

1NF

Redundancy Target: Eliminates multiple values in a single cell and duplicate rows.
Focus: Ensuring that each cell contains a single value and each record is unique.

Understanding Second Normal Form (2NF)

What is 2NF?

- Second Normal Form (2NF) builds upon 1NF by addressing partial dependencies. In 2NF, every non-key attribute must fully depend on the entire primary key, not just part of a composite key.

Sample Data (1NF but not in 2NF)

```
| StudentID | Course     | Textbook    |
|-----------|------------|-------------|
| 101       | Math       | Math101     |
| 101       | Science    | Science201  |
| 102       | Literature | Lit101      |
| 102       | Math       | Math101     |
```

Functional Dependencies

```
(StudentID, Course) → Textbook
Course → Textbook
```

Eliminating Partial Dependencies

- In 2NF, we target the elimination of these partial dependencies. In our example, if 'Textbook' is related to 'Course' but not to the combination of 'StudentID' and 'Course', it represents a partial dependency.

Transitioning to Second Normal Form (2NF)

Normalisation

- The goal is to restructure data so that all information in the table is fully dependent on the complete primary key.
- In our 1NF table, the 'Textbook' is dependent only on 'Course', not the composite key of 'StudentID' and 'Course'. This is a partial dependency, which 2NF aims to resolve.

Transformed into 2NF

- StudentCourses

```
| StudentID | Course     |
|-----------|------------|
| 101       | Math       |
| 101       | Science    |
| 102       | Literature |
| 102       | Math       |
```

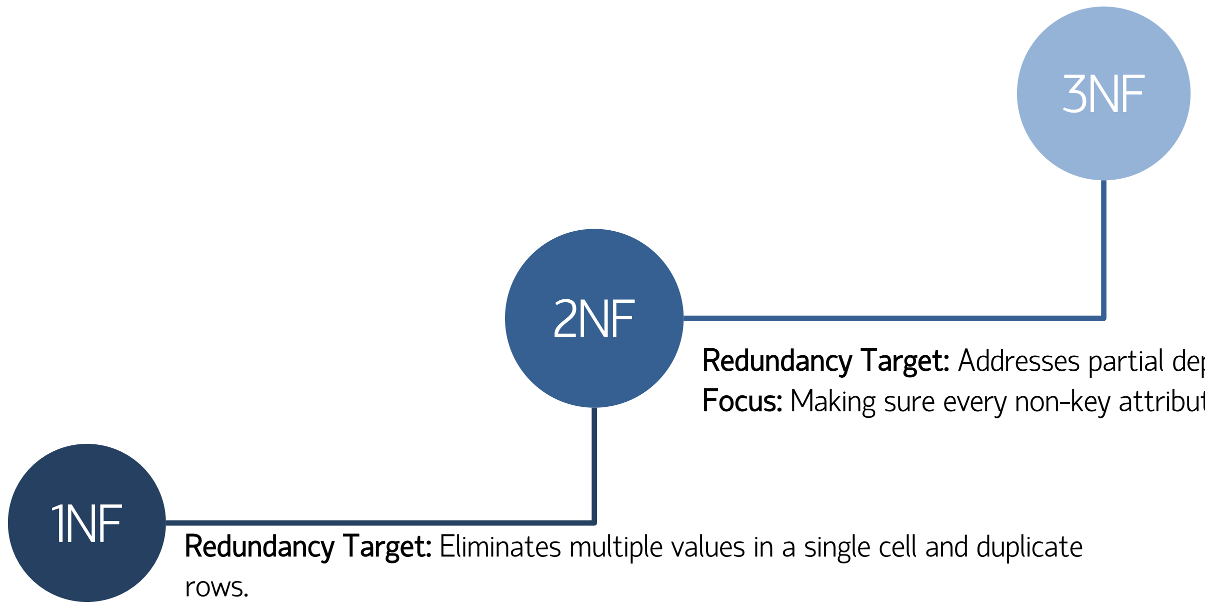
- CourseDetails

```
| Course     | Textbook    |
|------------|-------------|
| Math       | Math101     |
| Science    | Science201  |
| Literature | Lit101      |
```

Understanding the Change

- By dividing the original table into 'StudentCourses' and 'CourseTextbooks', we have removed partial dependencies, aligning the database with the principles of 2NF.

Staged Refinement



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Understanding Third Normal Form (3NF)

What is 3NF?

- Third Normal Form (3NF) builds upon the foundation of 2NF by eliminating transitive dependencies. In 3NF, every non-key attribute must be directly dependent on the primary key, not through another attribute.

Sample Data (2NF but not in 3NF)

```
| EmployeeID | EmployeeName | Department   | DepartmentLocation |
|------------|--------------|--------------|--------------------|
| E001       | Alice        | HR           | New York           |
| E002       | Bob          | Marketing    | Chicago            |
| E003       | Charlie      | HR           | New York           |
| E004       | Dana         | Engineering  | San Francisco      |
```

Functional Dependencies

```
EmployeeID → EmployeeName, Department, DepartmentLocation
Department → DepartmentLocation
```

Eliminating Transitive Dependencies

- In 3NF, we target the elimination of these transitive dependencies. For instance, DepartmentLocation' is dependent on 'Department', which in turn is dependent on 'EmployeeID'.

Transitioning to Third Normal Form (3NF)

Normalisation

- The goal is to eliminate transitive dependencies in a database table, ensuring that all non-key attributes are not only fully functionally dependent on the primary key but also non-transitively dependent.
- In our 2NF table, 'DepartmentLocation' should not depend on 'EmployeeID' through 'Department'. To align with 3NF, we need to remove this transitive dependency by restructuring the data into separate tables.

Transition into 3NF

- EmployeeDepartment

```
| EmployeeID | EmployeeName | Department  |
|------------|--------------|-------------|
| E001       | Alice        | HR          |
| E002       | Bob          | Marketing   |
| E003       | Charlie      | HR          |
| E004       | Dana         | Engineering |
```

- DepartmentLocations

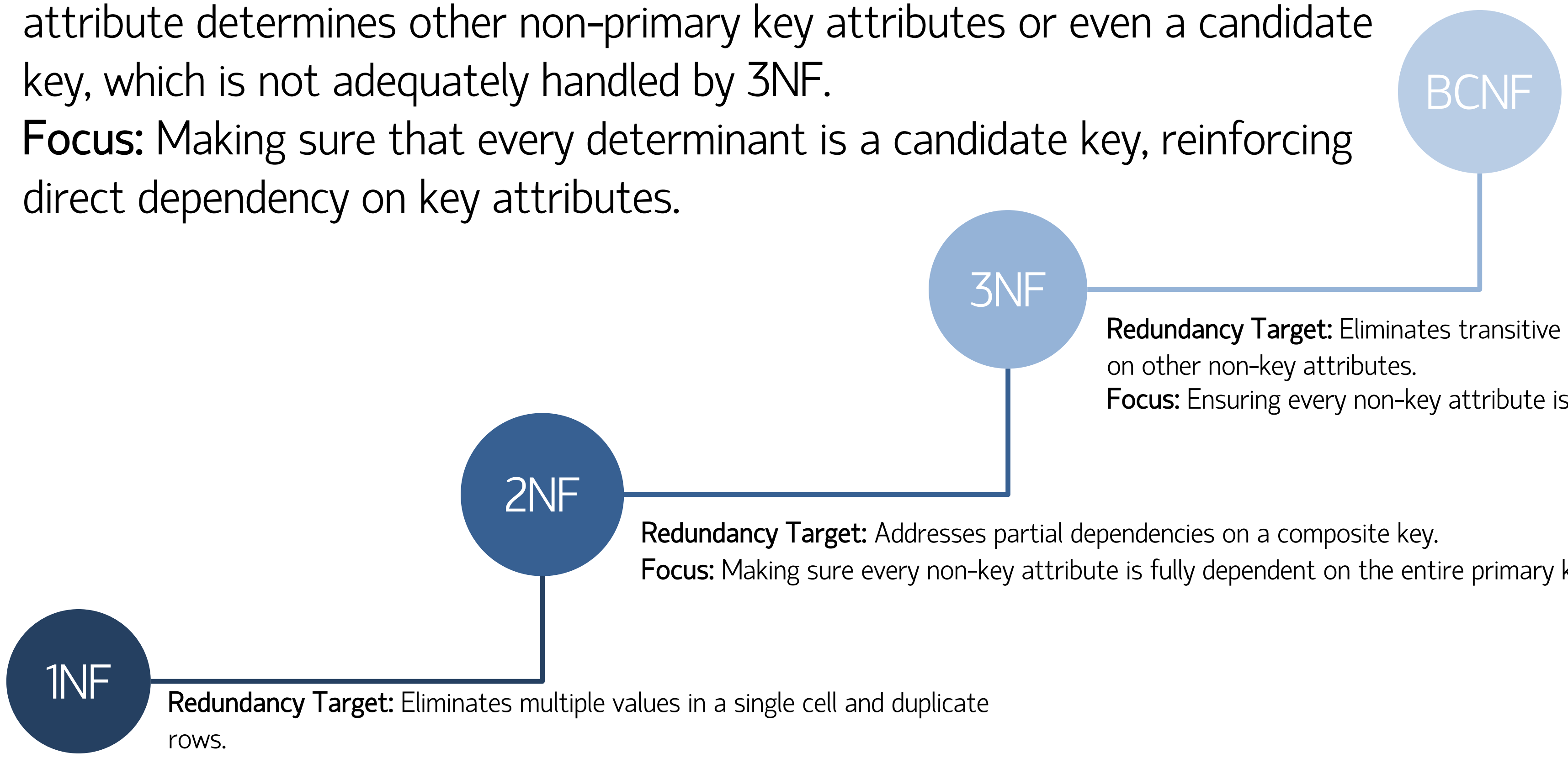
```
| Department  | DepartmentLocation |
|-------------|--------------------|
| HR          | New York           |
| Marketing   | Chicago            |
| Engineering | San Francisco      |
```

Understanding the Change

- In the EmployeeDepartment table, each employee's details directly depend on their unique EmployeeID, exemplifying 3NF's requirement for direct dependency between the primary key and non-key attributes.
- The separation into EmployeeDepartment and DepartmentLocations tables resolves transitive dependencies. Department locations are now independently determined.

Staged Refinement

Redundancy Target: Specifically addresses cases where a non-primary key attribute determines other non-primary key attributes or even a candidate key, which is not adequately handled by 3NF.
Focus: Making sure that every determinant is a candidate key, reinforcing direct dependency on key attributes.



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Understanding Boyce-Codd Normal Form (BCNF)

What is BCNF?

- A relation is in Boyce-Codd Normal Form (BCNF) if, and only if, every determinant in a functional dependency is a candidate key.
- This prevents any situation where a non-candidate-key column determines another column, a scenario that can lead to anomalies.

Sample Data (Not in BCNF)

```
| EquipmentID | EmployeeID | EmployeeDept |
|-------------|------------|--------------|
| EQ101       | E001       | HR           |
| EQ102       | E002       | Marketing    |
| EQ103       | E001       | HR           |
```

Functional Dependencies

```
EquipmentID → EmployeeID, EmployeeDept
EmployeeID → EmployeeDept
```

Eliminating Transitive Dependencies

- In BCNF, the focus is on removing dependencies where a non-superkey determines another attribute. For example, in the original EquipmentAllocation table, EmployeeID determined EmployeeDept but wasn't a superkey. BCNF demands restructuring to ensure that all determinants are candidate keys.

Transitioning to Boyce-Codd Normal Form (BCNF)

Normalisation

- Our focus is to ensure that every determinant is a candidate key, reinforcing direct dependency on key attributes.
- To adhere to BCNF, we must decompose the EquipmentAllocation table, separating the 'EmployeeDept' information into its own structure.

Transition into BCNF

- EquipmentAssignment

```
| EquipmentID | EmployeeID |
|-------------|------------|
| EQ101       | E001       |
| EQ102       | E002       |
| EQ103       | E001       |
```

- EmployeeDepartment

```
| EmployeeID | EmployeeDept |
|------------|--------------|
| E001       | HR           |
| E002       | Marketing    |
```

Understanding the Change

- We split 'EquipmentAllocation' into 'EquipmentAssignment' (links equipment to employees) and 'EmployeeDepartment' (maps employees to departments). This separation addresses the BCNF issue by ensuring 'EmployeeID' is a superkey in 'EmployeeDepartment'.
- The restructuring led to clearer and more efficient management of equipment and departmental data. Each table now has a singular focus, reducing redundancy and potential anomalies,

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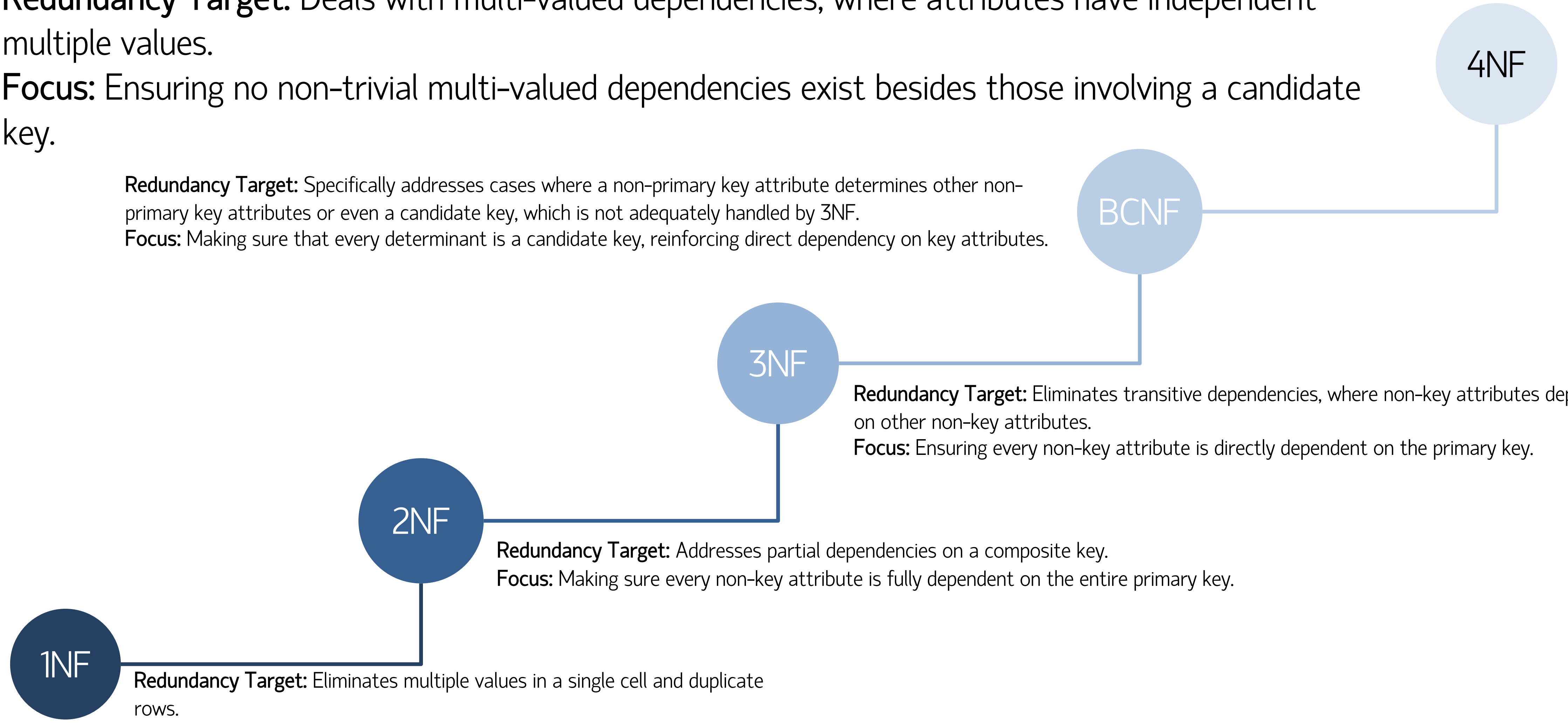

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Understand Fourth Normal Form (4NF)

What is 4NF?

- A table is in 4NF if, for every one of its non-trivial multi-valued dependencies, each attribute is independent of the others, except for the primary key.

Sample Data (Not in 4NF)

```
| EmployeeID | TrainingID | ProjectID |
|------------|------------|-----------|
| E001       | T101       | P201      |
| E001       | T101       | P202      |
| E001       | T102       | P201      |
| E001       | T102       | P202      |
| E002       | T103       | P203      |
| E002       | T104       | P203      |
| E002       | T104       | P204      |
| E003       | T105       | P205      |
```

Functional Dependencies

```
(EmployeeID, TrainingID, ProjectID) → (None)
```

Eliminating Multi-Valued Dependencies

- In the 'EmployeeTrainingProjects' table, the multi-valued dependencies (employees to training sessions and to projects) were jumbled together, which is not ideal in database design. This structure could lead to redundancy and make updates or queries more complex than necessary.

Transitioning to Fourth Normal Form (4NF)

Normalisation

- Our goal is to remove multi-valued dependencies that are independent of the primary key.
- We create two separate tables: one for employee training 'EmployeeTraining' and another for employee projects 'EmployeeProjects'.

Transition into 4NF

- EmployeeTraining

```
| EmployeeID | TrainingID |
|------------|------------|
| E001       | T101       |
| E001       | T102       |
| E002       | T103       |
```

- EmployeeProjects

```
| EmployeeID | ProjectID   |
|------------|-------------|
| E001       | P201        |
| E001       | P202        |
```

Understand the Change

- By dividing the data into two focused tables, we align with 4NF by eliminating non-trivial multi-valued dependencies. Each table has a clear, singular purpose, reducing complexity and potential for data anomalies.
- This separation improves the database's scalability and adaptability. It becomes easier to add new training sessions or projects, and the data structure is more resilient to changes in one aspect of the employees' records.

Practice Problems (1 of 6)

Question: The following shows a data table in a school library tracking student book borrowings. To what stage is this table normalised?

```
| StudentID | StudentName | Courses                         |
|-----------|-------------|---------------------------------|
| 1001      | Alice       | Math, Science                   |
| 1002      | Bob         | History; Literature             |
| 1003      | Clara       | Math, Science, Literature       |
| 1004      | Dave        | Physics, Chemistry              |
| 1005      | Ellen       | Biology, History                |
```

Answer: The table is not in 1NF because the Courses column contains multiple values in a single cell. 1NF requires that each cell contain only atomic (singular) values.

Practice Problems (2 of 6)

Question: A university maintains a record of students and the courses they're enrolled in, along with the instructor's details. To what stage is this data normalized?

```
| StudentID | CourseID | StudentName | InstructorName
|
|-----------|----------|-------------|----------------
|
| 1001      | C101     | Alice       | Dr. Smith
|
| 1002      | C102     | Bob         | Dr. Jones
|
| 1003      | C103     | Clara       | Dr. Williams
|
| 1004      | C104     | Dave        | Dr. Taylor
|
```

Answer: It is in 1NF as each cell contains atomic values, and there are no partial dependencies on a composite primary key.

- Is it in 2NF? 2NF requires that all non-key attributes be fully functionally dependent on the entire primary key.
- (StudentID, CourseID) is a composite primary key.
- **2NF Violation:** 'StudentName' is only dependent on 'StudentID' and not on the entire composite key ('StudentID', 'CourseID'). This means 'StudentName' can be determined solely by 'StudentID', irrespective of 'CourseID'.

Practice Problems (3 of 6)

Question: The data table keeps track of its employees and their departmental affiliations. The table also records the locations of these departments. At what stage of normalisation is this table?

```
| EmployeeID | DepartmentID | DepartmentLocation |
|------------|--------------|--------------------|
| E001       | D101         | New York           |
| E002       | D102         | Los Angeles        |
| E003       | D101         | New York           |
| E004       | D103         | Chicago            |
```

Answer: 'EmployID' is the primary key. The table is in 2NF because it does not have any partial dependency. Each non-key attribute ('DepartmentID', 'DepartmentLocation') is fully functionally dependent on the entire primary key ('EmployeeID').

- Is it in 3NF? In 3NF, all non-key attributes should be directly dependent on the primary key and not on another non-key attribute.
- **3NF Violation:** The table is not in 3NF due to the presence of a transitive dependency. 'DepartmentLocation' is not directly dependent on 'EmployeeID' (the primary key) but is indirectly dependent 'through DepartmentID'.

Practice Problems (4 of 6)

Question: An online store keeps track of orders and customer details in separate but related tables. What normal form are these tables in?

```
| OrderID | ProductName   | ProductPrice |
|---------|---------------|--------------|
| 0101    | Widget        | $10          |
| 0102    | Gizmo         | $15          |
| 0103    | Doodad        | $20          |
| 0104    | Thingamajig   | $25          |
```

```
| OrderID | CustomerName  | CustomerAddress       |
|---------|---------------|-----------------------|
| 0101    | Alice         | 123 Maple St, Denver  |
| 0102    | Bob           | 456 Oak St, Boston    |
| 0103    | Clara         | 789 Pine St, Seattle  |
| 0104    | Dave          | 101 Birch St, Austin  |
```

Answer: The tables are not in 3NF. If 'ProductPrice' can be determined by knowing 'ProductName', and 'ProductName' is dependent on 'OrderID', then 'ProductPrice' is transitively dependent on 'OrderID' through 'ProductName'. Similarly for 'CustomerAddress'.

- **3NF Violation:** This transitive dependency violates the rules of 3NF. In a 3NF-compliant table, 'ProductPrice' should depend solely on the primary key ('OrderID') and not through another non-key attribute ('ProductName'). Similarly for 'CustomerAddress'.

Practice Problems (5 of 6)

Question: The data table records each doctor's specializations along with the various locations where they practice. At what stage of normalization is this table?

```
| DoctorID | Specialization   | Location       |
|----------|------------------|----------------|
| D001     | Cardiology       | New York       |
| D001     | Cardiology       | Boston         |
| D001     | Endocrinology    | New York       |
| D002     | Pediatrics       | Chicago        |
| D002     | Pediatrics       | Los Angeles    |
```

Answer: The table is in 3NF as each attribute is only dependent on the primary key (DoctorID), and there are no transitive dependencies. Each row is a unique combination of a doctor, their specialization, and location.

- Is it in 4NF? In 4NF, the table has no multi-valued dependencies other than trivial ones.
- **4NF Violation:** The table is not in 4NF due to the presence of multi-valued dependencies. A doctor has multiple specializations and works at multiple locations, but these two attributes are independent of each other.

Practice Problems (6 of 6)

- For a given DoctorID, there are multiple values for Specialization and Location that are unrelated to each other. This is a characteristic of non-trivial multi-valued dependencies, which violates the requirements of 4NF.
- To bring this table into 4NF, you would need to remove the multi-valued dependencies. This can be achieved by splitting the table into two:

```
| DoctorID | Specialization  |
|----------|-----------------|
| D001     | Cardiology      |
| D001     | Endocrinology   |
| D002     | Pediatrics      |
```

```
| DoctorID | Location       |
|----------|----------------|
| D001     | New York       |
| D001     | Boston         |
| D002     | Chicago        |
| D002     | Los Angeles    |
```

- In these two new tables, each attribute is either fully functionally dependent on the primary key or is a primary key itself, meeting the requirements of 4NF by resolving the multi-valued dependencies.

Recap and Key Takeaways

- Normalisation directly addresses data redundancy and consistency, relying on functional dependencies. This systematic process reduces anomalies, ensuring data is organised logically and efficiently.
- Normal forms in database design impose stricter structural rules for higher levels, from 1NF through BCNF to 4NF. However, designers can bypass sequential progression and target higher normal forms directly, tailoring the approach to the specific needs and efficiency requirements of the database.

```
| EmployeeID | DepartmentID | DepartmentLocation |
|------------|--------------|--------------------|
| E001       | D101         | New York           |
| E002       | D102         | Los Angeles        |
| E003       | D101         | New York           |
```

- This transitive dependency means that DepartmentLocation is indirectly dependent on EmployeeID through DepartmentID. This setup can lead to data inconsistencies if DepartmentLocation changes for a specific department but isn't updated across all records, creating redundancy and potential errors.

Preparing for Design Case Studies:

- Next Lecture Preview:
  - We transform denormalized data into efficient database schemas using ERD techniques, focusing on logical data representation and "one fact per table" design principles.
  - We'll perform a detailed analysis to identify the achieved normal form, emphasising the transition towards BCNF or 4NF.

Can you think of a scenario where normalisation might actually hinder database performance or usability?