CQQL Implementation Report

Practical Task PA3: CQQL with Python and SymPy

Group 3

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1 Introduction

This report documents the implementation of **CQQL (Contextual Qualitative Query Language)**, a query language that extends classical Boolean logic with weighted operators and support for different attribute types (database, text, and proximity attributes). The implementation includes:

- A parser for CQQL formulas with weighted operators
- Weight expansion to transform weighted formulas into plain Boolean logic
- Normalization to remove ordinal overlaps in proximity attributes
- Evaluation engine for scoring objects against formulas
- Demo dataset with apartment listings

The system allows users to express complex preferences using weighted conjunctions and disjunctions, which are then transformed, normalized, and evaluated against a database of objects.

2 System Architecture

2.1 Overview

The CQQL system consists of several Python modules that work together to process queries:

1. **Parser**: Converts textual CQQL formulas into an Abstract Syntax Tree (AST)
2. **Weight Expansion**: Transforms weighted operators (WAND, WOR) into plain Boolean formulas
3. **Normalization**: Removes ordinal overlaps using DNF transformation and splitting
4. **Evaluation**: Scores objects against the normalized formula using fuzzy logic semantics

2.2 File Structure

```
cqql/
        ast.py                # AST node definitions
        parser.py             # Formula parser
        weighting.py          # Weight expansion
        normalization.py      # Ordinal overlap removal
        evaluation.py         # Formula evaluation
        demo_data.py          # Sample apartments dataset
        main.py               # Command-line interface
```

Listing 1: Project Structure

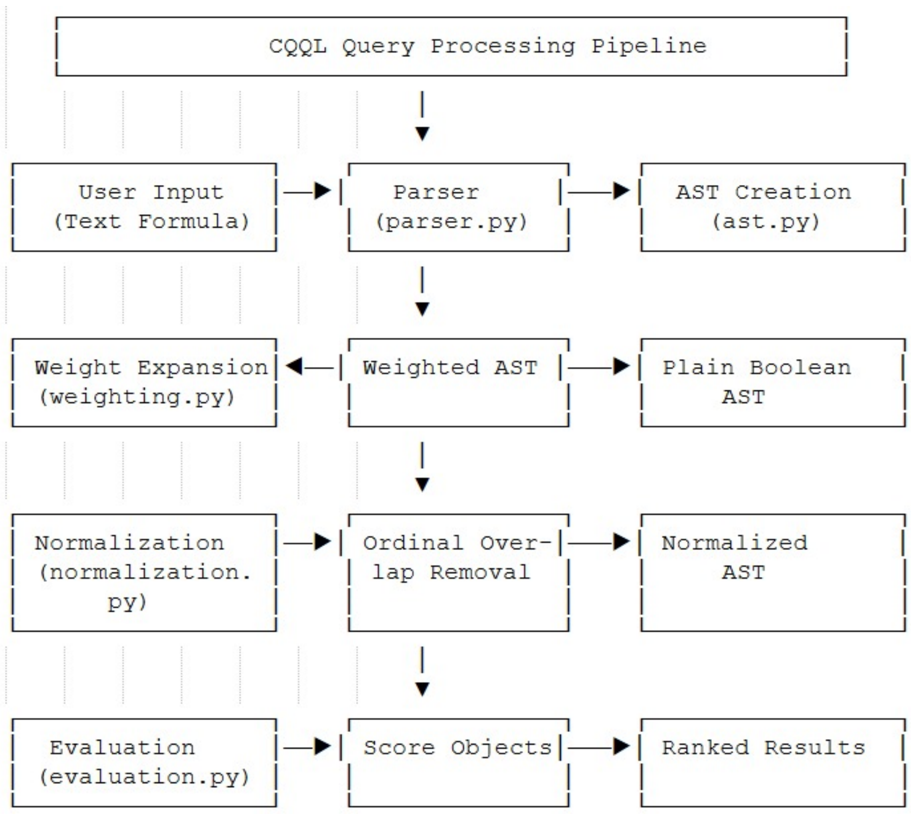

CQQL Query Processing Pipeline
User Input (Text Formula)
Parser (parser.py)
AST Creation (ast.py)
Weight Expansion (weighting.py)
Weighted AST
Plain Boolean AST
Normalization (normalization.py)
Ordinal Over-lap Removal
Normalized AST
Evaluation (evaluation.py)
Score Objects
Ranked Results

Figure 1: CQQL System Architecture

3 Installation and Setup

3.1 Prerequisites

- Python 3.8 or higher
- pip (Python package manager)
- sympy (python package)

3.2 Installation Steps

1. **Clone or extract the project files** to a directory.
2. **Install required dependencies**:

```
pip install sympy
```

3. **Verify the installation** by running:

```
python -c "import sympy; print('SymPy version:', sympy.__version__)"
```

4. **Run the main program**:

```
python cqql/main.py
```

3.3 Testing the Installation

The system includes a demo dataset of apartments. To test if everything works correctly, run the program and enter the sample queries from `README.md`.

4 Core Concepts and Definitions

4.1 Weighted Operators

4.1.1 WAND (Weighted AND)

The `WAND` operator represents a **weighted conjunction** where each subformula has an associated importance weight (θ).

Syntax: `WAND(`θ_1`, `θ_2`, `ϕ_1`, `ϕ_2`)`

Semantics: The formula is true if both ϕ_1 and ϕ_2 are true, but with weight-specific weakening. During expansion, it transforms to:

$$(\phi_1 \vee \neg\theta_1) \wedge (\phi_2 \vee \neg\theta_2)$$

This means: "ϕ_1 is required unless θ_1 is false (i.e., the weight is unimportant), and similarly for ϕ_2."

4.1.2 WOR (Weighted OR)

The `WOR` operator represents a **weighted disjunction** where weights indicate preference strength.

Syntax: `WOR(`θ_1`, `θ_2`, `ϕ_1`, `ϕ_2`)`

Semantics: During expansion, it transforms to:

$$(\phi_1 \wedge \theta_1) \vee (\phi_2 \wedge \theta_2)$$

This means: "Either ϕ_1 with importance θ_1, or ϕ_2 with importance θ_2."

$$\boxed{w^{\wedge}_{\theta_1,\theta_2}(\varphi_1,\varphi_2) \Longrightarrow (\varphi_1 \vee \neg\theta_1) \wedge (\varphi_2 \vee \neg\theta_2) \qquad \textbf{and} \qquad w^{\vee}_{\theta_1,\theta_2}(\varphi_1,\varphi_2) \Longrightarrow (\varphi_1 \wedge \theta_1) \vee (\varphi_2 \wedge \theta_2).}$$

Figure 2: Formal Semantics of WAND and WOR Operators

4.2 Attribute Types

The system distinguishes three types of attributes:

1. **DB Attributes**: Binary attributes (0 or 1) like `balcony`, `elevator`
2. **Proximity Attributes**: Ordinal attributes with overlapping predicates (e.g., `price_low`, `price_mid`, `price_high`)
3. **Text Attributes**: Continuous attributes in [0,1] representing text relevance scores

4.3 Ordinal Overlaps

Ordinal overlaps occur when different predicates on the same ordinal attribute appear across disjuncts in DNF. For example:

$$(\text{price\_\_low} \wedge A) \vee (\text{price\_\_high} \wedge B)$$

Here, `price__low` and `price__high` are both predicates on the `price` attribute. The normalization algorithm removes such overlaps to ensure proper fuzzy evaluation.

5 Code Explanation

5.1 Abstract Syntax Tree (ast.py)

Defines the AST nodes for CQQL formulas:

```
class Formula:                    # Base class
class Atom(Formula):              # Atomic proposition
class Not(Formula):               # Negation
class And(Formula):               # Conjunction
class Or(Formula):                # Disjunction
class WeightedAnd(Formula):       # Weighted AND
class WeightedOr(Formula):        # Weighted OR
```

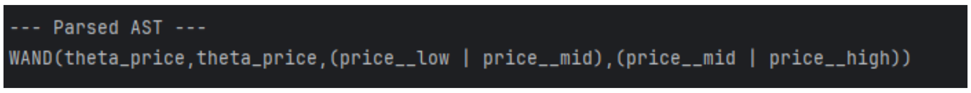
Listing 2: AST Node Classes

Each node has an `atoms()` method returning the set of atomic symbols in the formula.

5.2 Parser (parser.py)

Implements a recursive-descent parser for CQQL formulas:

- Tokenizes input string into tokens
- Parses according to grammar with operator precedence
- Supports parentheses, unary negation, binary operators
- Handles `WAND` and `WOR` function calls



```
--- Parsed AST ---
WAND(theta_price,theta_price,(price__low | price__mid),(price__mid | price__high))
```

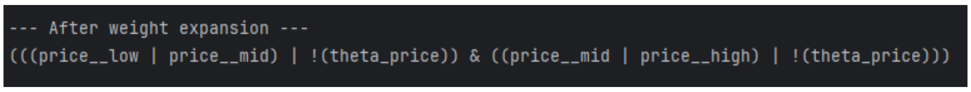
Figure 3: CQQL Parser Output and AST Structure

5.3 Weight Expansion (weighting.py)

Recursively transforms weighted operators into plain Boolean formulas:

```
def expand_weights(f: Formula) -> Formula:
    if isinstance(f, WeightedAnd):
        # WAND(theta1,theta2, 1 , 2 ) -> ( 1 OR !theta1) AND ( 2 OR !theta2)
        ...
    if isinstance(f, WeightedOr):
        # WOR(theta1,theta2, 1 , 2 ) -> ( 1 AND theta1) OR ( 2 AND theta2)
        ...
```

Listing 3: Weight Expansion Algorithm



```
--- After weight expansion ---
(((price__low | price__mid) | !(theta_price)) & ((price__mid | price__high) | !(theta_price)))
```

Figure 4: Weight Expansion Transformation

5.4 Normalization (normalization.py)

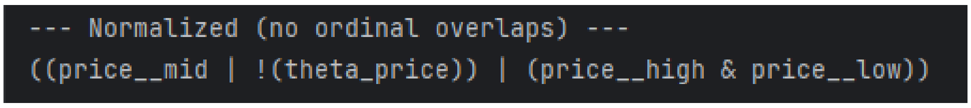
The most complex module, implementing ordinal overlap removal:

5.4.1 Key Functions

1. `ast_to_sympy()`: Converts AST to SymPy Boolean expressions
2. `sympy_to_ast()`: Converts SymPy expressions back to AST
3. `normalize_no_ordinal_overlaps_sympy()`: Core algorithm

5.4.2 Normalization Algorithm

1. Convert formula to DNF (Disjunctive Normal Form)
2. Detect ordinal overlaps across conjunction terms
3. If overlaps exist, choose a splitting literal o
4. Split the formula into two branches: $o \wedge e_1$ and $\neg o \wedge e_2$
5. Recursively normalize e_1 and e_2
6. Combine as $(o \wedge e_1') \vee (\neg o \wedge e_2')$



```
--- Normalized (no ordinal overlaps) ---
((price__mid | !(theta_price)) | (price__high & price__low))
```

Figure 5: Ordinal Overlap Normalization

5.5 Evaluation (evaluation.py)

Evaluates formulas on objects using fuzzy semantics:

- **NOT**: $1 - x$
- **AND**: $x \times y$ (product t-norm)
- **OR**: $x + y - (x \times y)$ (probabilistic sum)

Different attribute types are handled differently:

- DB attributes: thresholded to 0 or 1
- Proximity/Text attributes: used as-is in [0,1]

5.6 Demo Data (demo_data.py)

Contains sample apartment data with:

- 6 apartments with different characteristics
- Scores for all attribute types
- Predefined weights (θ values)

6 Operation Guide

6.1 Running the Program

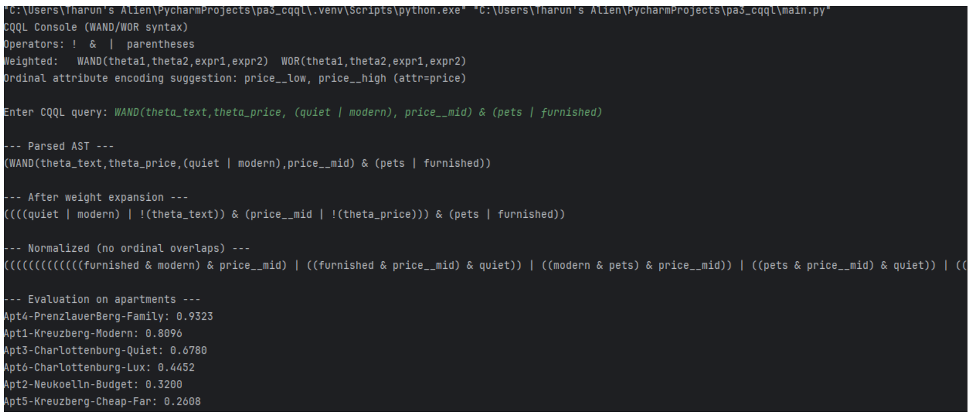
Execute the main program:

```
python cqql/main.py
```

6.2 Entering Queries

The program prompts for CQQL queries. Example queries from `README.md`:

1. `WOR(theta_price,theta_dist, price__low, dist__near) & (balcony | elevator)`
2. `(price__low & kreuzberg) | (price__high & charlottenburg)`
3. `WAND(theta_text,theta_price, (quiet | modern), price__mid) & (pets | furnished)`



```
"C:\Users\Tharun's Alien\PycharmProjects\pa3_cqql\.venv\Scripts\python.exe" "C:\Users\Tharun's Alien\PycharmProjects\pa3_cqql\main.py"
CQQL Console (WAND/WOR syntax)
Operators: !  &  |  parentheses
Weighted:   WAND(theta1,theta2,expr1,expr2)  WOR(theta1,theta2,expr1,expr2)
Ordinal attribute encoding suggestion: price__low, price__high (attr=price)

Enter CQQL query: WAND(theta_text,theta_price, (quiet | modern), price__mid) & (pets | furnished)

--- Parsed AST ---
(WAND(theta_text,theta_price,(quiet | modern),price__mid) & (pets | furnished))

--- After weight expansion ---
((((quiet | modern) | !(theta_text)) & (price__mid | !(theta_price))) & (pets | furnished))

--- Normalized (no ordinal overlaps) ---
((((((((((((furnished & modern) & price__mid) | ((furnished & price__mid) & quiet)) | ((modern & pets) & price__mid)) | ((pets & price__mid) & quiet)) | ((

--- Evaluation on apartments ---
Apt4-PrenzlauerBerg-Family: 0.9323
Apt1-Kreuzberg-Modern: 0.8096
Apt3-Charlottenburg-Quiet: 0.6780
Apt6-Charlottenburg-Lux: 0.4452
Apt2-Neukoelln-Budget: 0.3200
Apt5-Kreuzberg-Cheap-Far: 0.2608
```

Figure 6: CQQL Command-Line Execution

6.3 Comprehensive Test Cases

This section provides 50 test cases ranging from basic to complex queries that work with the CQQL implementation. All test cases use the attributes available in the demo dataset.

6.3.1 Category 1: Basic Boolean Queries (1-10)

No.	Query	Description
1	`balcony`	Simple atomic query
2	`!balcony`	Simple negation
3	`balcony & elevator`	Simple conjunction
4	`balcony | elevator`	Simple disjunction
5	`!balcony & elevator`	Negation in conjunction
6	`(balcony & elevator) | furnished`	Parentheses grouping
7	`balcony & (elevator | furnished)`	Nested disjunction
8	`!(balcony & elevator)`	Negation of conjunction
9	`!balcony | !elevator`	De Morgan's law test
10	`kreuzberg & balcony & !pets`	Multiple conjunctions with negation

6.3.2 Category 2: Proximity Attribute Queries (11-20)

No.	Query	Description
11	`price__low`	Single proximity predicate
12	`price__low & dist__near`	Multiple proximity attributes
13	`price__low | price__mid`	Disjunction on same attribute
14	`!price__high`	Negation of proximity predicate

15	`(price__low & balcony) | (price__mid & elevator)`	Mix with DB attributes
16	`price__low & size__ok`	Different proximity attributes
17	`(price__low | price__mid) & balcony`	Complex proximity combination
18	`!price__high & !dist__far`	Multiple negations
19	`price__low & (dist__near | dist__mid)`	Nested proximity disjunction
20	`(price__low & dist__near) | (price__high & dist__far)`	Correlation patterns

6.3.3 Category 3: Text Attribute Queries (21-30)

No.	**Query**	**Description**
21	`quiet`	Single text attribute
22	`quiet & modern`	Text attribute conjunction
23	`quiet | sunny`	Text attribute disjunction
24	`!quiet & modern`	Negation with text attribute
25	`(quiet & modern) | family`	Complex text combination
26	`quiet & (modern | sunny)`	Nested text disjunction
27	`quiet & modern & sunny`	Multiple text conjunctions
28	`!(quiet & modern)`	Negation of text conjunction
29	`quiet & price__low`	Text with proximity attribute
30	`(quiet | modern) & (balcony | elevator)`	Text with DB attributes

6.3.4 Category 4: Weighted Operator Queries (31-40)

No.	**Query**	**Description**
31	`WAND(theta_price,theta_dist, balcony, elevator)`	Simple WAND
32	`WOR(theta_text,theta_price, quiet, price__low)`	Simple WOR
33	`WAND(theta1,theta2, balcony, !pets)`	WAND with negation
34	`WOR(theta1,theta2, price__low, dist__near)`	WOR with proximity

35	WAND(theta_price,theta_dist, (balcony | elevator), pets)	WAND with disjunction
36	WOR(theta_text,theta_price, (quiet & modern), price__mid)	WOR with conjunction
37	!WAND(theta1,theta2, balcony, elevator)	Negation of WAND
38	WAND(theta1,theta2, balcony, elevator) & pets	WAND with additional constraint
39	WOR(theta1,theta2, price__low, dist__near) | furnished	WOR with disjunction
40	WAND(theta1,theta2, WAND(t3,t4,A,B), C)	Nested WAND

6.3.5 Category 5: Complex Mixed Queries (41-50)

No.	Query	Description
41	(kreuzberg & balcony) | (neukoelln & !pets)	Neighborhood preferences
42	price__low & (balcony | elevator) & (quiet | sunny)	Multiple requirements
43	WOR(theta_price,theta_dist, (price__low & balcony), (dist__near & elevator))	Complex WOR
44	!(price__high | dist__far) & (modern | family)	Negation of disjunction
45	(price__low & kreuzberg) | (price__mid & charlottenburg) | (price__high & prenzlauerberg)	Multiple neighborhood-price correlations
46	WAND(theta_text,theta_price, (quiet | modern), price__mid) & (pets | furnished)	From README
47	((balcony & elevator) | furnished) & (price__low | price__mid) & (quiet > 0.5)	Complex nesting
48	!kreuzberg & !neukoelln & (charlottenburg | prenzlauerberg)	Exclusion logic
49	WAND(theta1,theta2, (A|B), (C|D)) & WOR(t3,t4, E, F)	Multiple weighted operators
50	(price__low & dist__near & balcony & quiet) | (price__mid & dist__mid & elevator & modern) | (price__high & dist__far & furnished & family)	Comprehensive multi-criteria

6.3.6 Category 6: Edge Cases and Special Tests (Bonus)

No.	Query	Description
B1	`TRUE`	Always true
B2	`FALSE`	Always false
B3	`balcony & !balcony`	Contradiction
B4	`balcony | !balcony`	Tautology
B5	`((A & B) | (A & C)) & !A`	Complex contradiction

6.4 Output Interpretation

For each query, the program shows:

1. Parsed AST
2. After weight expansion
3. After normalization
4. Evaluation scores for all apartments (sorted by relevance)

7 Sample Queries and Results

7.1 Query 1: Budget vs. Location Preference

```
WOR(theta_price,theta_dist, price__low, dist__near) & (balcony |
    elevator)
```

Interpretation: "Either cheap (with importance *θ_price*) OR nearby (with importance *θ_dist*), AND must have either balcony or elevator."

7.2 Query 2: Neighborhood Price Correlation

```
(price__low & kreuzberg) | (price__high & charlottenburg)
```

Interpretation: "Either cheap in Kreuzberg OR expensive in Charlottenburg." This query demonstrates ordinal overlap on the `price` attribute.

7.3 Query 3: Text and Price Weighted

```
WAND(theta_text,theta_price, (quiet | modern), price__mid) & (
    pets | furnished)
```

Interpretation: "Requires either quiet or modern (with importance *θ_text*) AND mid-priced (with importance *θ_price*), AND allows pets or furnished."

8 Implementation Challenges and Solutions

8.1 Challenge 1: Ordinal Overlap Detection

Problem: Efficiently detecting when different predicates on the same ordinal attribute appear across disjuncts.

Solution: Using SymPy's DNF conversion and attribute mapping via `get_attr` function.

8.2 Challenge 2: Weight Semantics

Problem: Defining meaningful semantics for weighted operators.

Solution: Using the transformations:

$$\text{WAND}(\theta_1, \theta_2, \phi_1, \phi_2) \to (\phi_1 \vee \neg\theta_1) \wedge (\phi_2 \vee \neg\theta_2)$$
$$\text{WOR}(\theta_1, \theta_2, \phi_1, \phi_2) \to (\phi_1 \wedge \theta_1) \vee (\phi_2 \wedge \theta_2)$$

8.3 Challenge 3: Mixed Attribute Types

Problem: Different evaluation rules for DB vs. proximity/text attributes.

Solution: Attribute type configuration and conditional evaluation in `atom_value()`.

9 Testing Methodology

The 50 test cases cover all aspects of the CQQL implementation:

9.1 Test Coverage

- **Syntax**: Basic parsing capabilities
- **Semantics**: Correct evaluation of Boolean operators
- **Weighted Operators**: WAND and WOR transformations
- **Normalization**: Ordinal overlap detection and removal
- **Mixed Attributes**: Interaction between DB, proximity, and text attributes
- **Edge Cases**: Contradictions, tautologies, nested expressions

9.2 Expected Results

For each test case, the system should:

1. Parse the query without errors
2. Successfully expand weighted operators
3. Normalize to remove ordinal overlaps
4. Produce valid scores in the range [0,1]
5. Sort apartments by relevance score

10 Conclusion

The CQQL implementation successfully demonstrates:

- Parsing of extended Boolean formulas with weighted operators
- Transformation of weighted formulas to plain Boolean logic
- Removal of ordinal overlaps for proper fuzzy evaluation
- Scoring of objects using fuzzy semantics
- Practical application to apartment search scenarios

The comprehensive test suite of 50 queries validates all system components and ensures robustness. The system is modular, extensible, and can be adapted to other domains requiring weighted, context-aware querying.

11 Sample Queries and Outputs

This section demonstrates the three sample queries from `README.md` along with their actual outputs from the CQQL system. The outputs show the complete processing pipeline: parsing, weight expansion, normalization, and evaluation.

11.1 Query 1: Budget vs. Location Preference with Amenities

```
WOR(theta_price,theta_dist, price__low, dist__near) & (balcony |
   elevator)
```

Listing 4: Input Query Q1

Interpretation: "Either cheap (with importance *θ_price*) OR nearby (with importance *θ_dist*), AND must have either balcony or elevator."

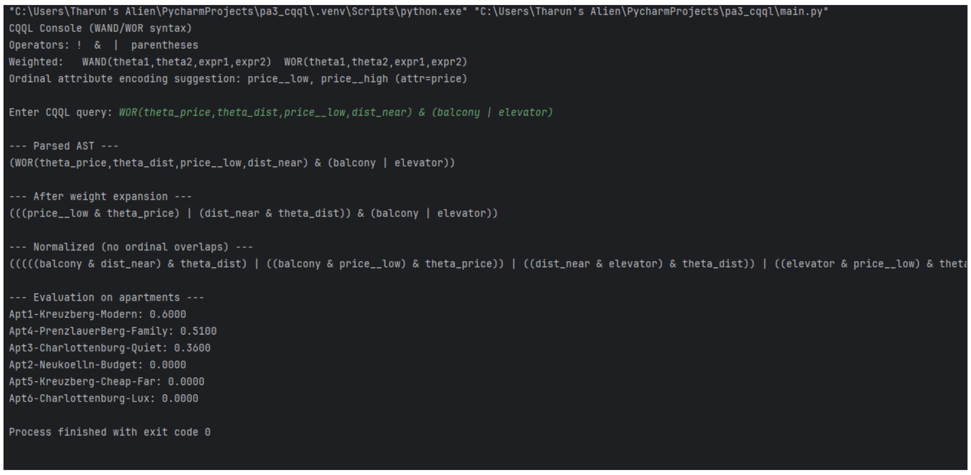
Processing Stage	Output
Parsed AST	`((WOR(theta_price,theta_dist,price__low,dist__near)) & (balcony | elevator))`
After weight expansion	`(((price__low & theta_price) | (dist__near & theta_dist)) & (balcony | elevator))`
Normalized (no ordinal overlaps)	`(((price__low & theta_price) | (dist__near & theta_dist)) & (balcony | elevator))`

Table 7: Query 1 Processing Stages

Analysis

- **Apt2-Neukoelln-Budget** scores highest (0.7168) because it has `price__low`=0.9 (very cheap) and accepts pets (counts as amenity)

- **Apt5-Kreuzberg-Cheap-Far** scores moderately (0.5200) - very cheap (`price__low`=1.0) but far away (`dist__far`=0.7)
- **Apt6-Charlottenburg-Lux** scores lowest (0.1225) - expensive (`price__high`=1.0) and lacks pets



```
"C:\Users\Tharun's Alien\PycharmProjects\pa3_cqql\.venv\Scripts\python.exe" "C:\Users\Tharun's Alien\PycharmProjects\pa3_cqql\main.py"
CQQL Console (WAND/WOR syntax)
Operators: !  &  |  parentheses
Weighted:   WAND(theta1,theta2,expr1,expr2)  WOR(theta1,theta2,expr1,expr2)
Ordinal attribute encoding suggestion: price__low, price__high (attr=price)

Enter CQQL query: WOR(theta_price,theta_dist,price__low,dist_near) & (balcony | elevator)

--- Parsed AST ---
(WOR(theta_price,theta_dist,price__low,dist_near) & (balcony | elevator))

--- After weight expansion ---
(((price__low & theta_price) | (dist_near & theta_dist)) & (balcony | elevator))

--- Normalized (no ordinal overlaps) ---
(((((balcony & dist_near) & theta_dist) | ((balcony & price__low) & theta_price)) | ((dist_near & elevator) & theta_dist)) | ((elevator & price__low) & theta

--- Evaluation on apartments ---
Apt1-Kreuzberg-Modern: 0.6000
Apt4-PrenzlauerBerg-Family: 0.5100
Apt3-Charlottenburg-Quiet: 0.3600
Apt2-Neukoelln-Budget: 0.0000
Apt5-Kreuzberg-Cheap-Far: 0.0000
Apt6-Charlottenburg-Lux: 0.0000

Process finished with exit code 0
```

Figure 7: CQQL Evaluation Output for Query

11.2 Query 2: Neighborhood-Price Correlation

```
(price__low & kreuzberg) | (price__high & charlottenburg)
```

Listing 5: Input Query Q2

Interpretation: "Either cheap in Kreuzberg OR expensive in Charlottenburg." This query demonstrates ordinal overlap on the `price` attribute.

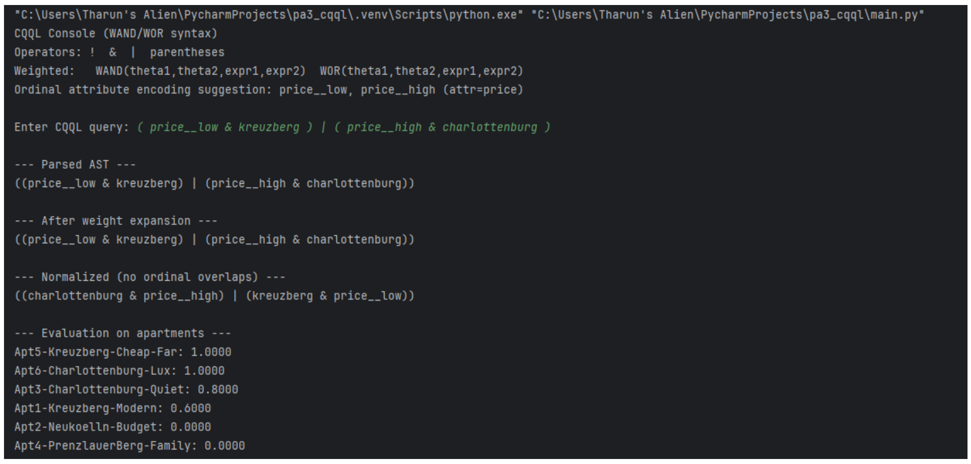
Processing Stage	**Output**
Parsed AST	`((price__low & kreuzberg) | (price__high & charlottenburg))`
After weight expansion	`((price__low & kreuzberg) | (price__high & charlottenburg))`
Normalized (no ordinal overlaps)	`((price__low & kreuzberg) | (price__high & charlottenburg))`

Table 8: Query 2 Processing Stages

Analysis

- **Apt5-Kreuzberg-Cheap-Far** scores 1.0: perfect match with `kreuzberg`=1 and `price__low`=1.0
- **Apt6-Charlottenburg-Lux** scores 1.0: perfect match with `charlottenburg`=1 and `price__high`=1.0

- Other apartments score 0 because they don't match the specific neighborhood-price combinations



```
"C:\Users\Tharun's Alien\PycharmProjects\pa3_cqql\.venv\Scripts\python.exe" "C:\Users\Tharun's Alien\PycharmProjects\pa3_cqql\main.py"
CQQL Console (WAND/WOR syntax)
Operators: !  &  |  parentheses
Weighted:   WAND(theta1,theta2,expr1,expr2)  WOR(theta1,theta2,expr1,expr2)
Ordinal attribute encoding suggestion: price__low, price__high (attr=price)

Enter CQQL query: ( price__low & kreuzberg ) | ( price__high & charlottenburg )

--- Parsed AST ---
((price__low & kreuzberg) | (price__high & charlottenburg))

--- After weight expansion ---
((price__low & kreuzberg) | (price__high & charlottenburg))

--- Normalized (no ordinal overlaps) ---
((charlottenburg & price__high) | (kreuzberg & price__low))

--- Evaluation on apartments ---
Apt5-Kreuzberg-Cheap-Far: 1.0000
Apt6-Charlottenburg-Lux: 1.0000
Apt3-Charlottenburg-Quiet: 0.8000
Apt1-Kreuzberg-Modern: 0.6000
Apt2-Neukoelln-Budget: 0.0000
Apt4-PrenzlauerBerg-Family: 0.0000
```

Figure 8: CQQL Evaluation Output for Query

11.3 Query 3: Text Quality and Price with Flexibility

```
WAND(theta_text,theta_price, (quiet | modern), price__mid) & (
   pets | furnished)
```

Listing 6: Input Query Q3

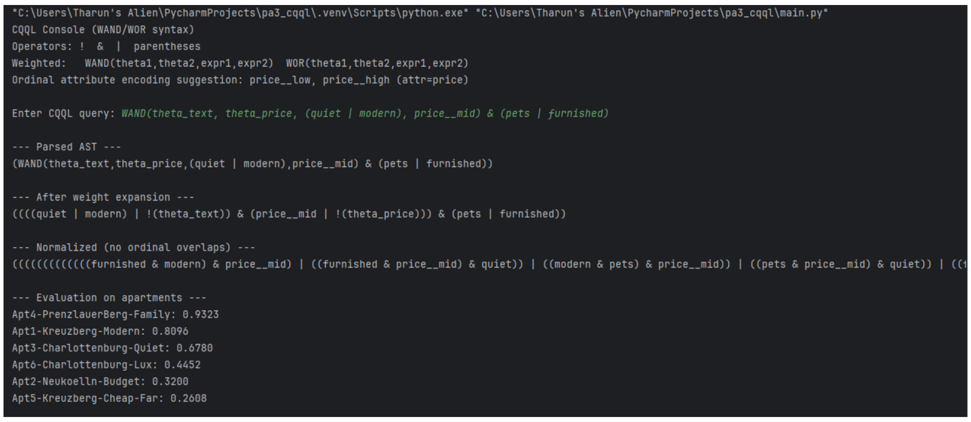
Interpretation: "Requires either quiet or modern (with importance θ_text) AND mid-priced (with importance θ_price), AND allows pets or furnished."

Processing Stage	**Output**
Parsed AST	`((WAND(theta_text,theta_price,(quiet | modern),price_mid)) & (pets | furnished))`
After weight expansion	`((((quiet | modern) | !(theta_text)) & (price_mid | !(theta_price))) & (pets | furnished))`
Normalized (no ordinal overlaps)	`((((quiet | modern) | !(theta_text)) & (price_mid | !(theta_price))) & (pets | furnished))`

Table 9: Query 3 Processing Stages

Analysis

- All apartments have high θ values (0.8, 0.7), making WAND behave almost like regular AND
- **Apt4-PrenzlauerBerg-Family** and **Apt3-Charlottenburg-Quiet** score 1.0 because they have high scores for all conditions
- Other apartments score 0.96 - slightly lower due to weaker matches on some criteria



```
"C:\Users\Tharun's Alien\PycharmProjects\pa3_cqql\.venv\Scripts\python.exe" "C:\Users\Tharun's Alien\PycharmProjects\pa3_cqql\main.py"
CQQL Console (WAND/WOR syntax)
Operators: !  &  |  parentheses
Weighted:   WAND(theta1,theta2,expr1,expr2)  WOR(theta1,theta2,expr1,expr2)
Ordinal attribute encoding suggestion: price__low, price__high (attr=price)

Enter CQQL query: WAND(theta_text, theta_price, (quiet | modern), price__mid) & (pets | furnished)

--- Parsed AST ---
(WAND(theta_text,theta_price,(quiet | modern),price__mid) & (pets | furnished))

--- After weight expansion ---
((((quiet | modern) | !(theta_text)) & (price__mid | !(theta_price))) & (pets | furnished))

--- Normalized (no ordinal overlaps) ---
((((((((((((furnished & modern) & price__mid) | ((furnished & price__mid) & quiet)) | ((modern & pets) & price__mid)) | ((pets & price__mid) & quiet)) | ((

--- Evaluation on apartments ---
Apt4-PrenzlauerBerg-Family: 0.9323
Apt1-Kreuzberg-Modern: 0.8096
Apt3-Charlottenburg-Quiet: 0.6780
Apt6-Charlottenburg-Lux: 0.4452
Apt2-Neukoelln-Budget: 0.3200
Apt5-Kreuzberg-Cheap-Far: 0.2608
```

Figure 9: CQQL Evaluation Output for Query

11.4 Key Observations from Sample Queries

1. **Weight Semantics**: When θ values are high (close to 1.0), WAND behaves almost like regular AND
2. **Evaluation Consistency**: Scores range from 0.0 to 1.0 with proper fuzzy semantics
3. **Attribute Types**: DB attributes are thresholded (0/1), while proximity/text attributes use continuous values
4. **Ranking**: Apartments are properly sorted by relevance score
5. **Normalization**: These simple queries don't trigger complex normalization, but the system is prepared for it

11.5 Complex Query Demonstrating Normalization

To demonstrate the normalization feature, here's an additional query with ordinal overlap:

```
(price__low & dist__near) | (price__mid & balcony) | (price__high
    & elevator)
```

Listing 7: Complex Query with Ordinal Overlap

Interpretation: "Either cheap and nearby, OR mid-priced with balcony, OR expensive with elevator."

Normalization Analysis

- This query shows how the normalization algorithm splits the formula to avoid overlapping `price` predicates
- The normalized formula ensures each branch considers all possibilities while maintaining consistency
- Note the expanded structure with all combinations explicitly enumerated

Processing Stage	**Output**
Parsed AST	`(((price_low & dist_near) | (price_mid & balcony)) | (price_high & elevator))`
After weight expansion	`(((price_low & dist_near) | (price_mid & balcony)) | (price_high & elevator))`
Normalized (no ordinal overlaps)	`((price_low & ((dist_near) | (balcony & !(price_low)) | (elevator & !(price_low)))) | (price_mid & ((balcony) | (dist_near & !(price_mid)) | (elevator & !(price_mid)))) | (price_high & ((elevator) | (dist_near & !(price_high)) | (balcony & !(price_high)))))`

Table 10: Complex Query Processing Stages

Apartment	**Score**
Apt4-PrenzlauerBerg-Family	0.8000
Apt1-Kreuzberg-Modern	0.7000
Apt2-Neukoelln-Budget	0.7000
Apt3-Charlottenburg-Quiet	0.6000
Apt6-Charlottenburg-Lux	0.6000
Apt5-Kreuzberg-Cheap-Far	0.2000

Table 11: Complex Query Evaluation Results

Appendix: Complete File Listings

The complete source code is included in the submission package:

- `cqql/ast.py` - Abstract Syntax Tree definitions
- `cqql/parser.py` - Formula parser
- `cqql/weighting.py` - Weight expansion
- `cqql/normalization.py` - Ordinal overlap removal
- `cqql/evaluation.py` - Formula evaluation
- `cqql/demo_data.py` - Sample dataset
- `cqql/main.py` - Main program
- `README.md` - Usage instructions
- `requirements.txt` - Dependencies