Practical Assignment of Advanced Topics in Databases

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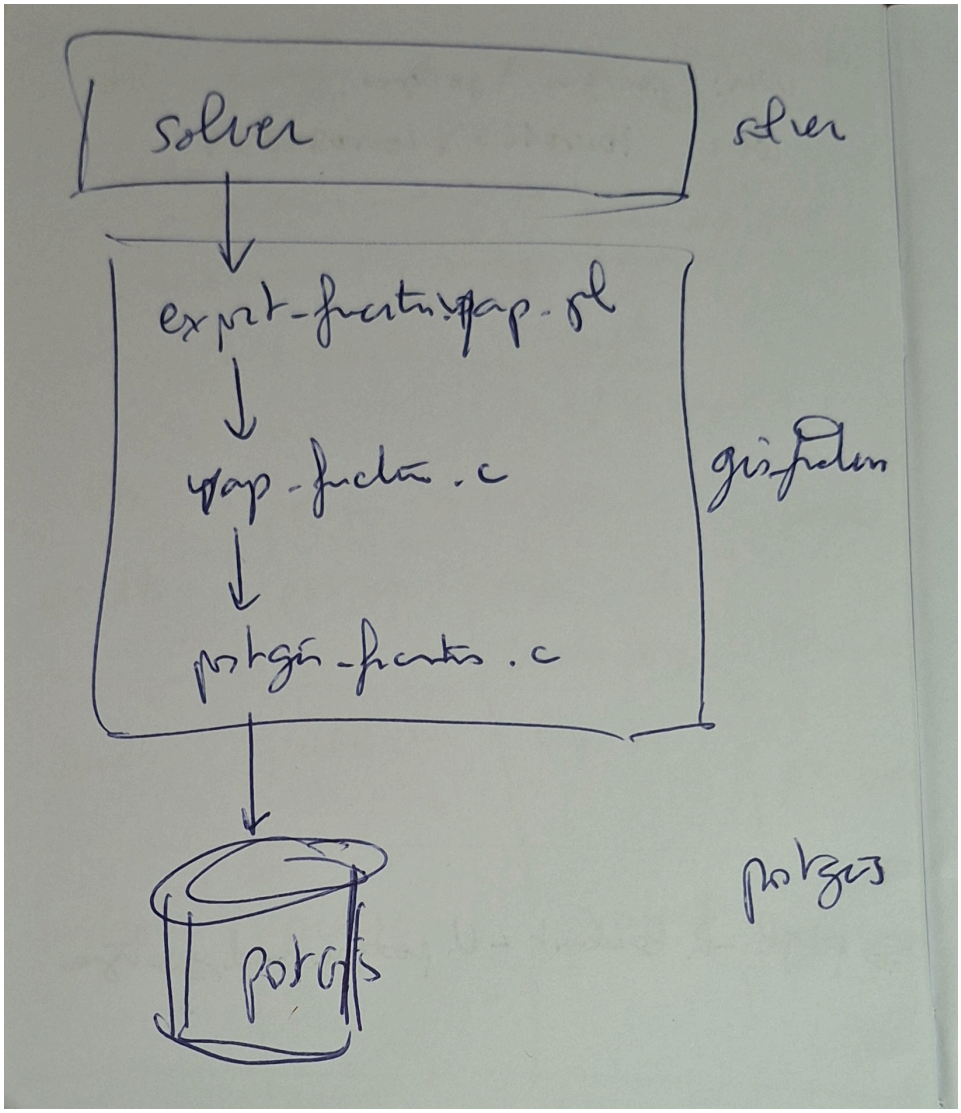
This report summarizes the design and implementation choices made during the “Practical Assignment: Advanced Topics in Databases” project. It provides a detailed overview of the database setup, data modeling decisions, and initial data population strategy, emphasizing the rationale behind key design choices.



Database Setup and Data Modeling

For the core database technology, PostgreSQL was selected primarily due to its robust and highly performance support for spatial data through the PostGIS extension. This was a critical factor given the geometric nature of the problem domain.

The following Entity-Relationship (ER) diagram (Figure 1) illustrates the implemented schema and its structural relationships:

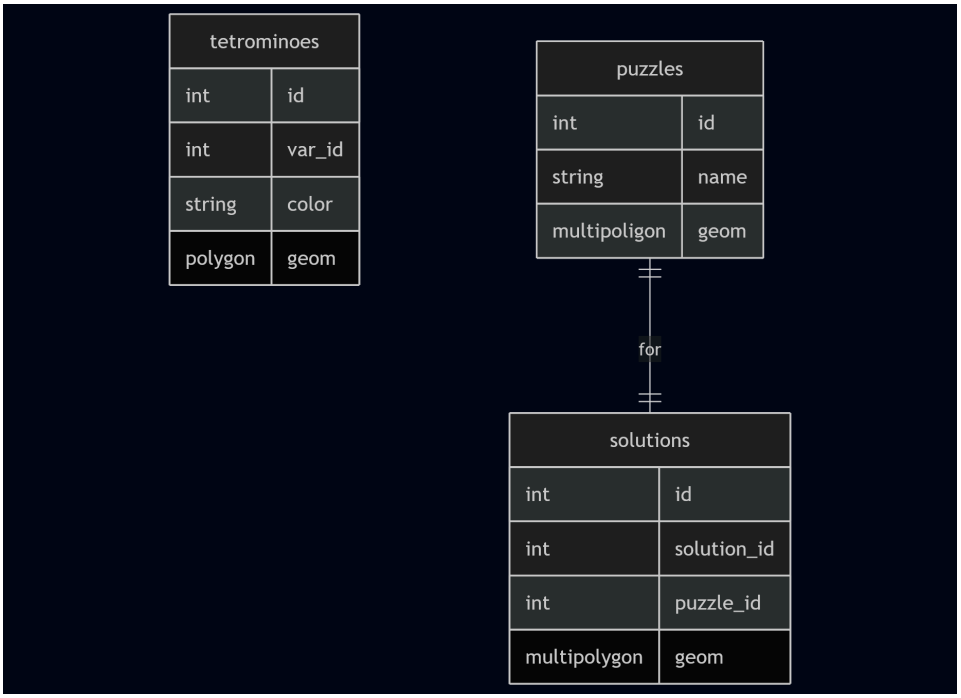


Figure 1: fig1: Entity-Relationship Diagram of the Database Schema

A significant design decision involved the representation of individual "solutions." Each solution was modeled as a composite of pre-defined tetromino configurations, each already possessing a specific rotation and spatial location. This was efficiently represented using a MULTIPOLYGON spatial data type within PostGIS.

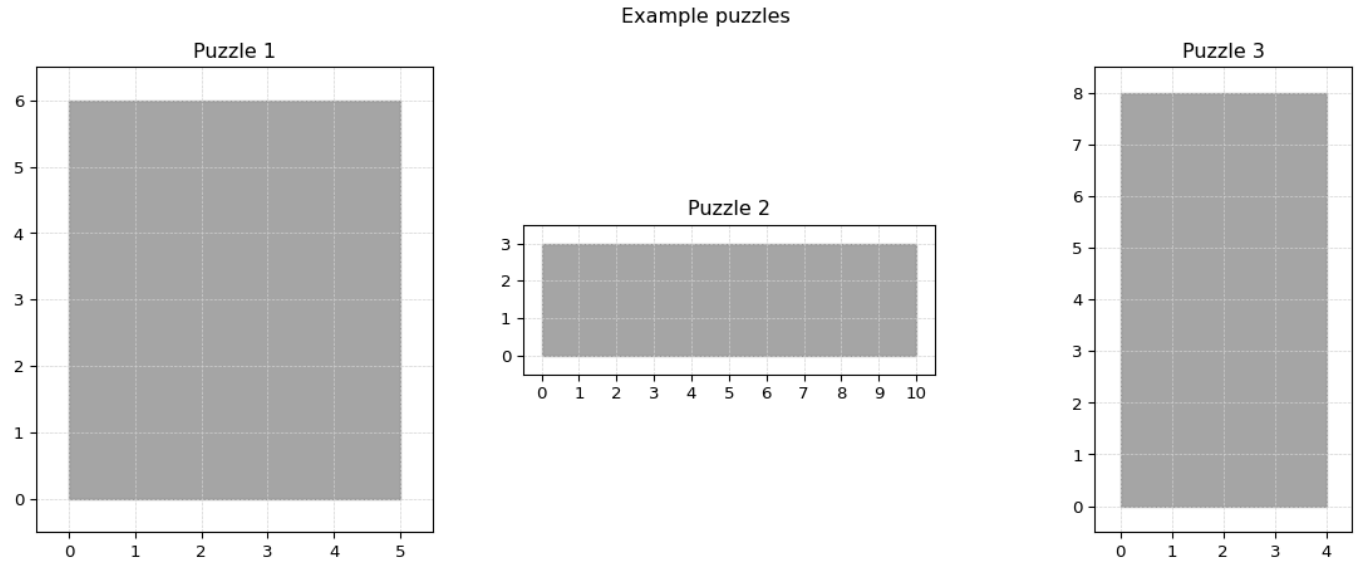
The initial plan for the database involved a **normalized 3NF structure** with a **bridge table** to ensure **data integrity** and **consistency** for tetromino instances and solutions. However, this approach was abandoned. The project team determined that the **added complexity** of such normalization wouldn't offer proportionate gains in **performance** or **solver efficiency** within the project's scope.

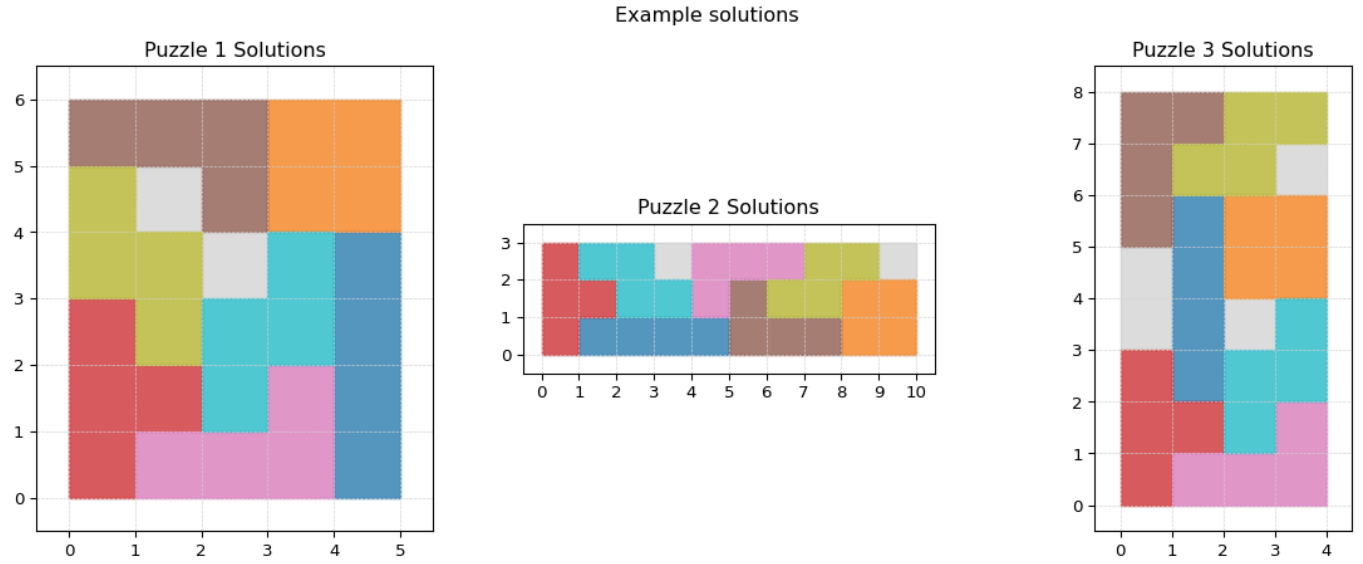
Furthermore, a deliberate choice was made to pre-represent all nineteen (19) distinct rotational and positional variations of each of the seven fundamental tetrominoes, as opposed to storing only the base seven shapes. This strategic decision offered several significant advantages:

- **Elimination of Runtime Rotation Calculations:** By pre-computing and storing all variations, the need to perform computationally intensive geometric rotation functions within the solver at runtime was entirely obviated. This directly contributes to improved solver performance and reduced computational overhead.
- **Predictable Initial Positioning:** This approach allowed for the precise prediction of the exact starting position for each pre-configured tetromino piece within a solution. This predictability significantly reduced the search space and the number of permutations the solver needed to evaluate, thereby minimizing backtracking and iteration cycles. This optimization was crucial for enhancing the efficiency of the solver's heuristic or algorithmic search process.

Initial Data Population

To facilitate testing and validation of the implemented solver, the database environment was populated with three distinct puzzle configurations and their corresponding verified solutions. These pre-defined data sets serve as crucial benchmarks and guidance for the subsequent development and rigorous testing of the solver's functionality and accuracy.





Solver Integration and Predicate Implementation

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Specifically, the following functionalities were implemented as predicates:

- **Intersection Detection:** To determine if a newly positioned tetromino overlaps with any previously placed pieces, a predicate utilizing the `ST_Touches` PostGIS function was employed.
- **Boundary Confinement:** To ensure that a tetromino remains within the defined bounds of the puzzle grid after transposition, a predicate using the `ST_Within` PostGIS function was integrated. This predicate verifies that the entire geometry of the tetromino is contained within the puzzle's boundary.
- **Solution Aggregation:** As the solver successfully places tetrominoes, their geometries need to be cumulatively stored to represent the evolving solution. For this, a predicate encapsulating the `ST_Collect* PostGIS function was implemented. The first interaction` theGEOMETRYCOLLECTION EMPTY` empty group is passed.

Solver solution

TThe solver's primary objective is to find a valid arrangement of tetrominoes that completely fills the predefined puzzle space without overlaps. The solver's logic is encapsulated in Prolog predicates, which leverage the pre-processed spatial data from the database.

A key optimization involves organizing the 19 distinct tetromino variations. Rather than treating them as an undifferentiated list, they are grouped by their fundamental tetromino type (e.g., all 'L' shaped variations, all 'T' shaped variations). **This is achieved by creating a YAP/ Prolog atom (function YAP_Term create_tetramino_list) that transforms the flat list of all variations into a structured list of group(Letter, Variations).** Once a valid placement for one variation within a group is found, the solver can avoid re-iterating over other variations of the same fundamental tetromino type in that specific branch of the search space, significantly pruning the search tree.

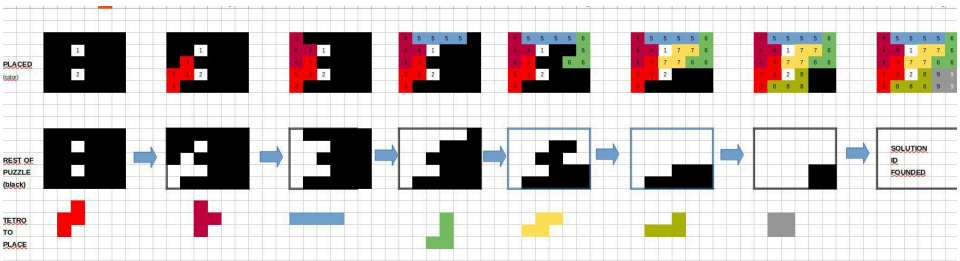

Figure 2: fig2: Solver Diagram

The solve/4 predicate orchestrates the placement process. It recursively iterates through these group lists. For each group, it attempts to place a tetramino(Letter, Seq, TetWKT) from its Variations list.

The actual placement logic resides within the try_place/4 predicate. This predicate employs a systematic grid-based search using grid_offset/2 to generate potential (Dx, Dy) translation coordinates. For each candidate position:

1. Transposition: The transpose_geometry predicate (an external function, likely calling PostGIS's `ST_Translate` functionality) is used to move the current TetWKT (Well-Known Text representation of the tetromino's geometry) to the new (Dx, Dy) offset, producing CandidatePlacedTetWKT.

2. Intersection Check: The disjoint_geometry predicate (corresponding to `ST_Touches` in PostGIS) verifies that the CandidatePlacedTetWKT does not intersect with OccupiedGeom, which represents the accumulated geometry of all already placed tetrominoes.

```
"SELECT" " CASE " " WHEN ST_IsEmpty(ST_GeomFromText($1, 4326)) " " OR ST_IsEmpty(ST_GeomFromText($2, 4326)) " " THEN true " " ELSE ST_Touches(ST_GeomFromText($1, 4326), ST_GeomFromText($2, 4326)) " " END;";
```

The above is used to test a location and st_touches to confirm if side by side tetrominos.

3. Boundary Confinement: The within_geometry predicate (mapping to PostGIS's `ST_Within` function) ensures that the CandidatePlacedTetWKT is entirely contained within the Puzzle boundary.

If all these conditions are met, the CandidatePlacedTetWKT is accepted as PlacedTet, and the solve predicate recursively calls itself, updating the AccGeom (accumulated geometry) by unifying the newly placed tetromino using the union_geometry predicate. This iterative process continues until all tetromino groups are successfully placed, leading to FinalPuzzle representing the complete solution.

Conclusion

This project successfully established a robust and efficient system by achieving several key objectives. We meticulously designed and implemented the optimal database structure, laying a solid foundation for data management. Furthermore, the seamless integration of the C API with PostgreSQL was accomplished, enabling powerful and direct interaction with the database. Finally, the translation of PostGIS functionalities into Prolog predicates represents a significant breakthrough, extending the system's analytical capabilities and facilitating complex spatial reasoning within the Prolog environment.

Due to lack of time some functions were not implemented and some code is not as clean as it should be. The next steps for refactoring are:

- Implement a 'fail safe' function when the solver does not find a solution.
- If the puzzle is too small or impossible to solve from the start (eg: 2x2 grid or 1x10 grid) the solver function shouln't even run the yap predicates and fail fast.
- Some functions are repeated or too long and should be refactored to be more readable and reusable.