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by Mr Adnan

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Optimizing Irregular Tiling Patterns for Spatial Coverage: A Symbolic Framework for Design Efficiency

Abstract

In many real-world situations like paving, designing layouts, or cutting materials, people need to cover space using shapes that aren't regular. These shapes don't fit together easily, especially when the area is limited and the edges matter. This project looks at how to tile space more efficiently using irregular shapes, and how symbolic logic can help guide the process.

I'll test different tiling strategies, grid-based, greedy-fit, and random placement, using shapes like L-forms and trapezoids. I'll measure how much space gets covered and how much is wasted. To make the method clearer and easier to repeat, I'll create a symbolic trigger sheet and a scoring system called the **Tiling Efficiency Index (TEI)**. The weights in the TEI formula will be tuned based on pilot results to balance coverage, gap area, and runtime.

As a high school student exploring symbolic modeling, this project is also a learning experience in applying abstract logic to real-world design. The goal is to build a simple but useful framework that helps improve design efficiency when working with tricky shapes and limited space.

Introduction

Tiling is everywhere, from the way floors are paved to how solar panels are arranged on rooftops. It's a basic idea: covering a surface with shapes. But behind that simple concept is a deep mathematical challenge, especially when the shapes aren't regular. Unlike squares or hexagons, irregular shapes don't fit together easily, and that makes it harder to cover space without gaps or waste.

In design and architecture, this problem shows up often. Whether it's cutting materials efficiently or laying out patterns in limited areas, the goal is to use space wisely. That's where tiling becomes more than just geometry, it becomes a question of optimization. And while many mathematical models focus on perfect shapes and infinite space, real-world situations are messier. Shapes often have odd angles, holes, or don't fit neatly, making layout harder.

This proposal explores that challenge: how to tile space efficiently using irregular shapes, and how symbolic logic can help guide the process.

Literature Review

The domain of 2D irregular packing and tiling has expanded in recent years, especially in manufacturing and layout optimization. Guo et al. provide a comprehensive review of 2D irregular packing methods, observing that heuristic and metaheuristic approaches dominate due to NP-hardness of exact solutions [1]. Leão et al. survey mathematical modeling for nesting and layout, distinguishing linear, nonlinear, integer, and constraint programming models [2]. Liu et al. propose a hybrid GA-LP algorithm, combining genetic algorithms with linear programming and no-fit-polygon techniques to improve utilization in irregular packing benchmarks [3]. More advanced work, such as GFPack++, uses attention-based gradient field learning to infer continuous placement and rotation for irregular shapes, improving space utilization and inference speed compared to existing baselines [4]. In the graphics and mosaic domain, Hu et al. demonstrate methods for synthesizing surface mosaics using irregular tiles, combining continuous optimization and combinatorial selection to maximize coverage without overlaps [5]. Liao presents a graph-based compaction algorithm for VLSI layouts with mixed constraints, which illustrates the broader applicability of constraint-based symbolic methods [6]. From pure tiling theory, Laczkovich shows that only finitely many rational-angle triangles can tile polygons beyond certain conditions [7]. Frettlöh explores non-edge-to-edge hexagon tilings, showing that convex tiles can form irregular tilings with complex adjacency [8]. Despite these advances, few approaches integrate declarative symbolic rules explicitly as first-class elements within irregular tiling simulations. The gap lies in combining symbolic logic with empirical evaluation, which this project addresses.

Research Questions and Hypotheses

Research Question

How can symbolic modeling (trigger sheets encoding placement rules) improve tiling efficiency and stability when placing irregular shapes under spatial constraints?

Hypotheses

H1: Layouts guided by symbolic trigger sheets will yield higher Tiling Efficiency Index (TEI) than layouts produced by baseline greedy or stochastic heuristics. H2: The symbolic approach will produce lower variance across trials (i.e., more reproducible results) compared to heuristics without symbolic guidance. H3: As constraint complexity increases (e.g., adjacency rules, margin constraints, orientation limits), the performance advantage of symbolic methods will grow, demonstrating robustness under stricter conditions.

Methodology

Shape Library & Preprocessing: A dataset of irregular polygons (concave, holed, varying complexity) will be collected. Shapes will be normalized by area for consistency. Algorithmic Strategies: Three baselines will be implemented: (1) grid alignment, (2) greedy placement, and (3) stochastic sampling. Each will be compared with symbolic-trigger-driven variants. Symbolic Trigger Sheet: Encodes orientation options, adjacency rules, fallback placements, and margin checks. This acts as a decision tree guiding placement. Evaluation Metric: A Tiling Efficiency Index (TEI) defined as TEI = w1 * Coverage – w2 * GapArea – w3 * log(Time+1). Experimental Protocol: For each shape set and constraint level, strategies will be run 30 times. Metrics collected will include TEI mean, variance, and runtime. Statistical comparisons will evaluate hypotheses.

Reproducibility: All code and triggers will be published with seeds logged for exact replication.

Timeline

Phase 1 (Weeks 1-2): Literature survey and dataset selection.

Phase 2 (Weeks 3-5): Implement baseline strategies.

Phase 3 (Weeks 6-8): Integrate symbolic triggers, define TEI, pilot runs.

Phase 4 (Weeks 9-10): Full-scale testing, analysis, and reporting.

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