Problem statement: Given a shape (e.g., a triangle), transform any initial set of tiles into this given shape. Refer to shape [1, 2].

Observation 1: From a given set of tiles it is not always possible to find a tile that does not disconnect the tile set. Therefore, the approach to start removing tiles and building a required shape is not always going to work. We need an intermediate step!

Observation 2: If a robot can always find a safely removable tile, it can build simple shapes layer by layer.

Theorem 1. A single robot cannot find a safely removable tile.

Proof idea: It cannot distinguish between these two scenarios:

- **Line** is a simple structure that takes \(O(n\ell)\) steps to build.
  - Idea: move locally a most NW tile to the bottom of the column to the right.
  - Block has at most the diameter of the input tile set, can be built in \(O(n\ell)\) steps.
  - Tree is a more involved structure that stays inside the convex hull of the input tiles and takes \(O(n\ell)\) steps to build.

Theorem 2. A robot with a pebble can always find a safely removable tile.

Motivated by the problem of manipulating nanoscale materials by nanoscale active matter, we introduce a new theoretical hybrid model for programmable matter.

**Tiles:** passive agents

**Robots:** active agents

Robots act as deterministic finite automata and operate in look-compute-move cycles.

In the look phase each robot can observe its local neighborhood.

In the compute phase a robot can change its state and determine its next move.

In the move phase a robot can either

1. pick up a tile,
2. place a tile it is carrying, or
3. move to an adjacent node while possibly carrying a tile.

In this project we have considered three types of problems:

- shape formation,
- shape recognition, and
- sealing.

**Model**

**Form**: a single robot without any pebbles cannot decide whether the tile configuration is a parallelogram with \(\ell = f(h)\), where \(h\) is its height, for any given polynomial \(f(\cdot)\) of constant degree.

**Proof idea:**

- \(p(x) = a_n x^n + a_{n-1} x^{n-1} + \ldots + a_0\), where \(a_i = \pm 1/2^n\) for any constants \(a_i \in \mathbb{Z}\).
- The robot will move the pebble from the leftmost to the rightmost column in phases, by \(a_0 \mod 2\).

In each phase, the robot can observe its local neighborhood.

Intermediate structures: before assembling the final shape, the robots reshape the tiles to form a simply connected set. We describe three structures:

- Line is a simple structure that takes \(O(n\ell)\) steps to build.
- Block has at most \(\ell\) diameter of the input tile set, can be built in \(O(n\ell)\) steps.
- Tree is a more involved structure that stays inside the convex hull of the input tiles and takes \(O(n\ell)\) steps to build.

Theorem 3. A line can be built in \(O(n\ell)\) steps, a block in \(O(n\ell)\) steps. (Feedback)

Towards Hybrid Programmable Matter: shape recognition, formation, and sealing algorithms for finite automaton robots

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**Model & extension**

We extend the robot model with a capability of expansion and contraction, analogous to [2].

**Idea:**

- A leader can maintain \(6\) distances to the boundary of the object, maintaining the distances to the vertex.

- A robot with one pebble can decide whether the tile configuration is a parallelogram with \(\ell = f(h)\).

- A robot with two pebbles can decide whether a tile is carrying a tile.

- A robot without any pebbles cannot decide whether the tile configuration is a parallelogram with \(\ell = f(h)\).

**Proof idea:**

In the look phase each robot can observe its local neighborhood.

In the compute phase a robot can change its state and determine its next move.

In the move phase a robot can either

1. pick up a tile,
2. place a tile it is carrying, or
3. move to an adjacent node while possibly carrying a tile.

In this project we have considered three types of problems:

- shape formation,
- shape recognition, and
- sealing.

**Theorem 2.** A set of robots can form a convex hull of an object in \(O(B = H \log H)\) asynchronous rounds in the worst case, where \(B = \ell\) is the length of the perimeter of the object, and \(H = \ell\) is the height of its convex hull.

**Problem statement:** Given a shape (e.g., a triangle), transform any initial set of tiles into this given shape. Refer to shape [1, 2].

References
