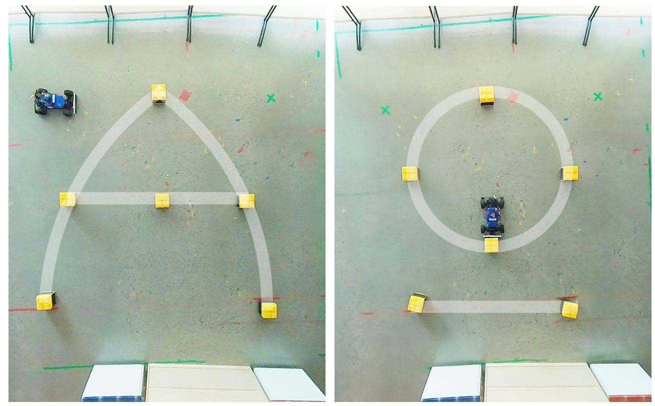
From A to Ω: Pixel Art with a Mobile Robot

Jeeho Ahn and Christoforos Mavrogiannis

***Abstract*— We describe an autonomous system that can create room-scale pixel art by guiding a mobile robot to rearrange a set of pixels via pushing. The technical foundation of our system is a planning framework for multiobject rearrangement that determines a sequence of robot pushes required to result in a desired pixel formation. This synergy of computational planning and artistic intent transforms a static studio floor into a dynamic canvas, where the arrangement and rearrangement of simple objects becomes a continuously shifting visual expression. Using our automated rearrangement system, we aim to express a visual performance of *infinity* by demonstrating a dynamic formation of the infinitely repeating generation of two Greek letters, Alpha, and Omega, representing respectively the beginning and the end. We demonstrate this performance using a 1/10th-scale robot racecar and a set of cubic pixels. A video demonstration of our pixel-art performance system can be found at https://youtu.be/WNWegHkDJ1Q.**



(a) Initial configuration: A. (b) Final configuration: Ω.

Fig. 1: Our autonomous system leveraging nonprehensile manipulation using a mobile robot to execute a tangible pixel-art installation. A rearrangement sequence is planned to iteratively transition between object formations corresponding to the Greek letters A and Ω, symbolizing respectively a cycle between the *beginning* and the *end*.

I. Introduction

The manipulation of physical objects as an artistic medium is as old as art itself. Sculptors, installation artists, and performance artists have long embraced the spatial arrangement of materials to express ideas and emotions. Today, robotics offers new avenues for artists to engage with physical space, enabling dynamic compositions that evolve over time. By blending the repeatability of a robotic system with the creative intuition of an artist, we can transform the placement of simple objects into a form of kinetic art. Forming patterns or letters through objects or robot formations has often been considered as a benchmark for robot planning algorithms. For instance, Alonso-Mora et al. [3] demonstrated their framework through the creation of artistic swarm formations like geometric shapes whereas Krontiris and Bekris [13] demonstrated their planning algorithm through the task of forming letter patterns on a tabletop.

Inspired by such prior work, we aim to develop a system capable of performing long-horizon rearrangement sequences, intended to support conceptual artistic projects. This concept is conceptually close to the practice of *pixel art*, which can be described as digital art involving images built using pixels as building blocks. While pixel art is typically instantiated in digital formats, here, we transfer its concept into a tangible form. However, implementing the automated orchestration of kinetic art in a confined space—especially works intended to evolve over long durations—is nontrivial. Ensuring that a robotic system can reliably rearrange objects while handling real-world uncertainties without human intervention involves technical complexity. Simultaneously accounting for physics constraints, limited maneuvering space, and the delicate interplay between robot and object presents challenges that go far beyond simply executing a single static arrangement.

To this end, we integrate kinematic, geometric, physics, and collision constraints into a unified graph representation. By planning on such a graph, we can extract a sequence of robot pushes resulting in the formation of a desired pattern (see Fig. 1). The execution of this plan becomes a choreographed performance: as the machine slides objects into new positions, lines become shapes, shapes become letters, and letters become patterns again. In this work, we demonstrate how a simple mobile pusher (see Fig. 4), guided by robust rearrangement methods, can produce evolving pixel-arts. Specifically, we visually show the impression of *infinity* by demonstrating a sequence of endlessly repeated rearrangements corresponding to the Greek letters, Alpha (A), and Omega (Ω), representing respectively the beginning and the end. The technical foundation of this work is based on our ReloPush framework for nonprehensile rearrangement planning for nonholonomic mobile robot pushers – please refer to the ReloPush paper [1] for additional technical details and experiments.

II. Related Work

Pixel Art using Robots. Prior instantiations of robotic pixel art typically involve robots assuming the role of pixels: multiple small-scale robots coordinate their motion to create desired art formations. Alonso-Mora et al. [4] introduced a swarm display in which differential-drive mobile robots equipped with LED panels make formations to reproduce

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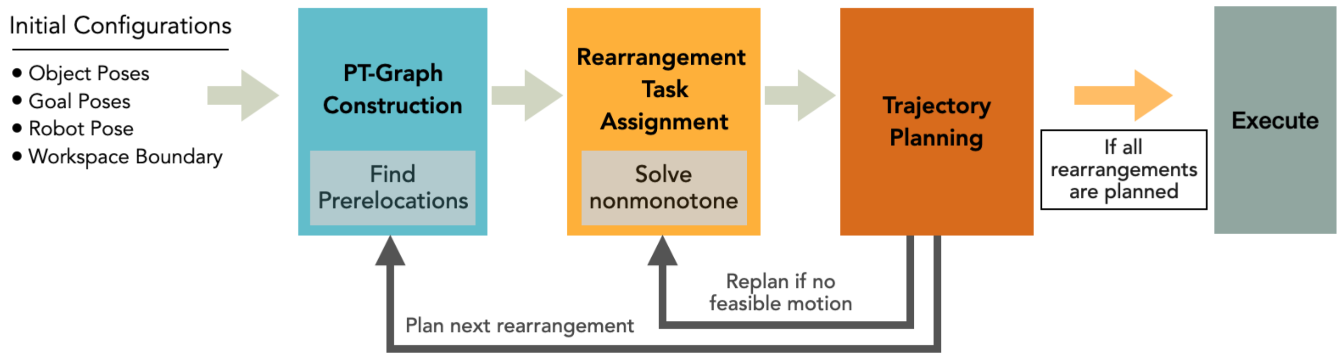


Fig. 2: Rearrangement planning architecture for pixel art, based on ReloPush [1]. For every object rearrangement, ReloPush generates a PT-graph as a spatial abstraction of the scene. Vertices represent poses that the robot can push objects from, whereas edges represent kinematically feasible transitions between them that respect object stability constraints while pushing. If an edge cannot be formed, ReloPush searches for potential *prerelocations* (i.e., intermediate object displacements) from which a collision-free push rearrangement path exists. Using graph search, ReloPush can return a robot path plan resulting in an optimal rearrangement of an object. When multiple objects need to be rearranged, ReloPush ranks them in order of lowest cost and generates corresponding robot plans resulting in the desired multi-object rearrangement. Once the plan is complete, the robot executes it using a model predictive controller.

artistic formations. This framework has been the foundation underlying follow-up works like *PIXELBOTS* [5], targeting the development of embodied display technologies. More broadly, in a time of reimagining display technologies [11, 15], robots capable of implementing pixel formations by design may offer a new concept of tangible, embodied user interfaces.

Mosaics by Robots. More densely arranged pixel formations are often referred to as a *mosaics* where all pixels are placed tangentially to to each other. As it often requires a large number of pixels, it is more commonly performed by a manipulator placing objects rather than mobile robots acting as pixels. For instance, Phooripoom and Koomsap [18] developed a system to assemble large-scale mosaics out of a large number of small-sized tiles using pick-and-place operations performed by a manipulator. Similarly, *Pixelbot 3000* [16], leveraging a generative AI system, first produces a mosaic image and then implements in the real-world using Lego pixels rearranged using a three-axes manipulator.

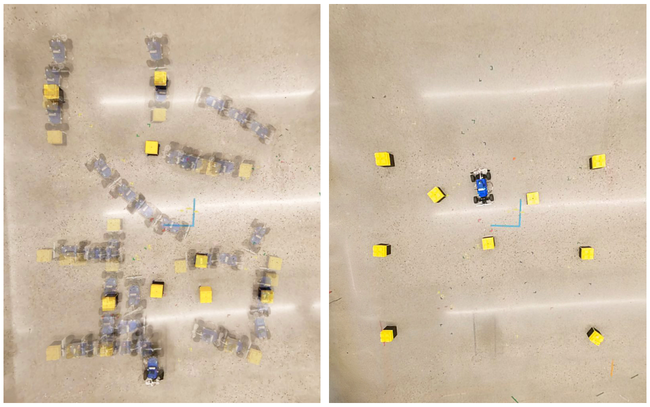
Object Rearrangement as Pixel Art. Rearrangement planning is a rich area of robotics research [1, 6, 7, 12–14, 21] involving the physical rearrangement of objects to goal poses. Prior research is generally motivated by practical applications like fulfillment, warehouse automation, and construction, but we see it as the foundation for empowering robots to support artistic performances like pixel art. Rearrangement planning is a challenging problem that is still under active research. Much of the prior work employs manipulator arms and uses prehensile grasping to complete rearrangement tasks [1, 6, 7, 9, 10, 12, 13, 13, 14, 21]. Such instantiations are limiting: prehensile grasping can only deal with a small range of object, constrained by the gripper's aperture and payload; static manipulators can only cover a small workspace; mobile manipulators can be bulky and can face especially narrow passages when assigned dense rearrangement tasks like the formations resulting in pixel arts. In contrast, scalable mobile robots can offer: superior mobility in dense workspaces thanks to their small footprint; increased object diversity when exploiting nonprehensile manipulation; increased power density, enabling higher payloads than available manipulator options when using mobile robots of car-like actuation. Talia et al. [20] demonstrated the practicality of this idea through a planning framework that enabled the parallel rearrangement of multiple objects by a team of car-like mobile robot pushers [19] whereas Ahn and Mavrogiannis [1] tackled challenging, nonmonotone rearrangement instances with the same hardware. This work demonstrates the potential of such frameworks in enabling the performance of pixel-art installations using mobile robots.

III. Technical Framework

The goal of our system is to orchestrate a series of robot pushing actions to rearrange scattered objects into a desired pixel-art formation. One example is forming a letter or symbol made of the given objects as if the robot solves a puzzle of completing an artwork. This can be extended to multiple letters or symbols in sequence to create a message, or it could repeat the creation of a set of letters in a loop. Here, we give an overview of our technical framework, **ReloPush** [1], and highlight preliminary results, relevant to performing pixel art.

A. Planning Robot Motion to Create Pixel Art

Planning for push-based rearrangement tasks requires accounting for a superposition of kinematic, geometric, physics, and collision constraints. This setting complicates planning and often results in infeasible instances. Our insight is that the world –especially in the setting of pixel art– is movable: enabling the robot to reconfigure its local workspace could simplify planning and even convert infeasible instances into feasible ones. To this end, we developed *PT-Graph*, an abstraction of rearrangement relationships between objects and goal locations that simultaneously integrates kinematic, physics, geometric, and collision constraints. Based on this graph, we developed **ReloPush** [1], a planning framework that uses graph-search techniques to plan efficient sequences of push-based rearrangements, harnessing temporary object relocations and removal of blocking



(a) Executing a rearrangement plan. (b) Resulting rearrangement.

Fig. 3: Our robotic pixel-art system is based on ReloPush, a planning framework for tackling multi-object rearrangement tasks with a nonholonomic mobile robot pusher [1].

objects to complete practical multi-object rearrangement tasks in constrained spaces. By taking as input the initial and final configurations of the pixels and the initial configuration of the robot, **ReloPush** [1] plans an object rearrangement sequence in the form of *transit* and *transfer* [2] robot paths. The framework is summarized in Fig. 2.

B. Prerelocation of objects

ReloPush leverages a strategy we refer to as *prerelocation* to respond to infeasible instances due to nonholonomic constraints of the pusher. In confined environments, a typical Dubins curve with a limited turning radius can often violate the workspace boundaries. *Prerelocation* searches for a temporary object configuration that: a) the robot can continuously push it to from its current pose; b) from which the robot can continuously push it to its goal pose. Using this strategy, even infeasible problem instances can often become executable. This is particularly relevant to our pixel-art setup because a transition from one formation to another often gives rise to nonmonotone rearrangement instances, requiring multiple manipulation actions.

C. Experimental Setup

The performing robot in our work is MuSHR [19], a 1/10th-scale, open-source mobile robot racecar, augmented with a 3D-printed flat bumper for pushing (see Fig. 4). The robot is deployed in a $4 \times 5.2m^2$ workspace. While it can push objects in various sizes and shapes, we use cubes with a side of $0.15m$ to make pixel-art formations at room-scale. To accurately track poses of the robot and the objects, we use a motion-capture system that covers the workspace.

D. Performance

In preliminary work [1], we demonstrated the ability of **ReloPush** to efficiently plan object rearrangements under the challenging conditions posed by nonholonomic kinematics of a robot and confined workspaces (see Fig. 3 and https://youtu.be/%5FEwHuF8XAjk). By incorporating Dubins-curve-based path planning, push-stability criteria, and *prerelocation* strategies to reposition objects through

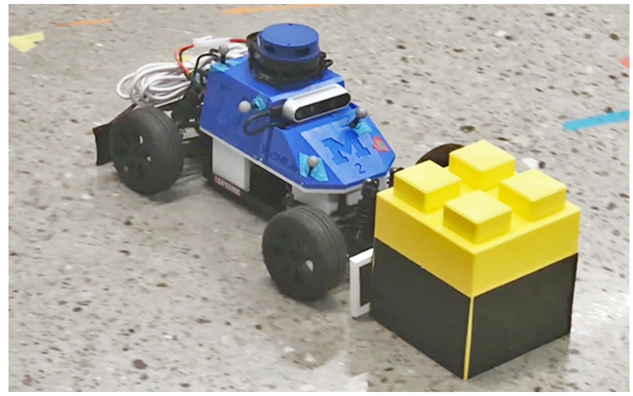


Fig. 4: Robot pushing an object to create a pixel-art.

intermediate configurations, this approach is able to find more solutions compared to other planning methods without these strategies. Table I shows comparisons in success rates for different planning scenarios. Each m represents the number of objects to rearrange in the scenario, and **NPR** and **MP** indicate respectively methods without *prerelocation* and *PT-graph*. All planning scenarios have the same workspace size, thus a higher m indicates higher congestion and thus task complexity as well.

IV. Pixel Art Performance: From A to Ω

Our artwork starts from a scene where multiple pixels are scattered within a bounded workspace. Using **ReloPush**, these blocks are systematically repositioned to form recognizable shapes: first the Greek letter Alpha (A), representing the *beginning*, and then Omega (Ω), representing the *end* (see Fig. 1). After displaying Omega, the system autonomously transitions back to Alpha, and then again to Omega, executing this cycle of rearrangements repeatedly.

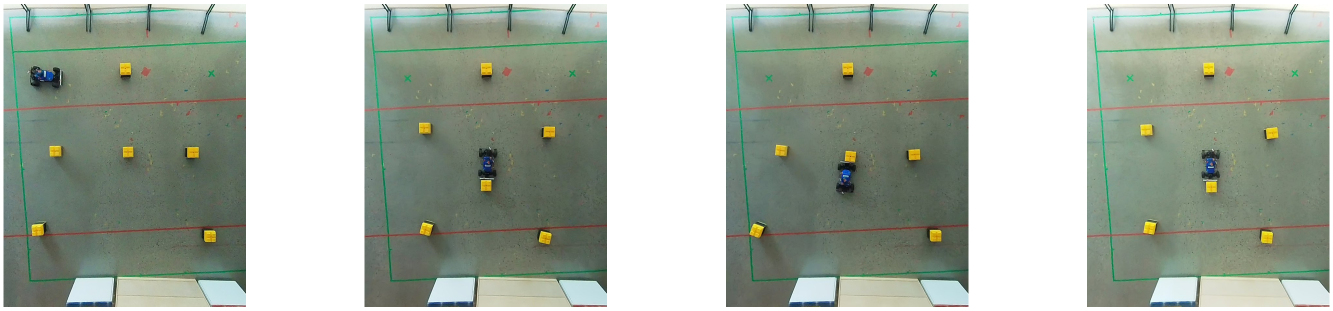
We instantiate the artwork using six objects for reconstructing each letter. At the beginning, we start our framework from the formation of A, planning the transition to Ω. At the end of the transition, the planner finds a new plan sequence to transition the configuration back to A. To demonstrate the message of cycling from beginning to end, the robot iterates between the rearrangements resulting in the A/Ω formations until the robot's battery is discharged. We demonstrate our robotic pixel-art performance in Fig. 5 and at https://youtu.be/WNWegHkDJ1Q. Our system was able to successfully iterate twice between the A and Ω patterns without human intervention. This performance illustrates the practical relevance of mobile robotics for assisting in the development of robotic pixel-art installations. It also motivates important future work on integrating robust object tracking and push modeling to enable more precise operation.

V. Future Work

ReloPush is an open-loop system that does not require tracking the movement of objects. By constraining robot steering to the stability limit [8, 17] during pushing, the robot will remain stuck to the robot, waiving the need for object tracking. While this is an effective strategy for one-shot rearrangement tasks like the ones tackled in our previous work (see Fig. 3), the proposed pixel-art performance

TABLE I: Success rates in planning for different scenarios. Each cell lists the mean and the standard deviation over 100 trials per scenario.

Scenario	$m=3$			$m=4$			$m=5$			$m=6$			$m=8$		
Algorithm	RELOPUSH	NPR	MP	RELOPUSH	NPR	MP	RELOPUSH	NPR	MP	RELOPUSH	NPR	MP	RELOPUSH	NPR	MP
S (%)	**100**	55	52	**100**	**100**	73	**80**	64	56	**89**	25	3	**86**	12	6



(a) Initial A (b) First Ω (c) Second A (d) Second Ω

Fig. 5: Pixel art "From A to Ω". The performance starts from a formation of letter A, moves on to complete a rearrangement to letter Ω, and continues iterating between the two. We demonstrate the robustness of our framework through the repetition of two cycles without human intervention.

involves the iterative execution of two rearrangement tasks, i.e., from A to Ω, impacting repeatability. In particular, robot path tracking errors, object rearrangement errors, and the creation of narrow passages due to object formations will often impact the ability of the system to keep the execution going. This motivates future work on closing the loop for object tracking errors, high-fidelity pushing models, and planning rearrangement sequences that account for future feasibility.

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