A New Porous Structure for Modular Robots

Extended Abstract

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ABSTRACT

In this paper, we propose a new self-reconfiguration method based on organizing modules in meta-modules that form a 3D porous structure allowing modules to flow in parallel inside of it without blocking. We first propose a new meta-module model which can be used to fill in its internal volume an additional number of modules and describe the structure that can be built with our meta-modules which allow it to be compressible and expandable. We then show how to self-reconfigure the structure from an initial shape to a given goal shape.

KEYWORDS

Porous Structure; Meta-Modules; Autonomous Robots

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1 INTRODUCTION

Programmable matter gives new properties to the matter that surrounds us, it can change color or even shape, which is called self-reconfiguration. In order to create this programmable matter, we propose to replace the atoms that constitute the real matter by autonomous and communicating robots, which ensures at the same time the physical presence of the matter and brings a capacity of distributed calculation to the core of the object.

The self-reconfiguration algorithms [3, 5] reorganize the modules forming an initial shape into a given goal shape using motions coordinated by communications. Self-reconfiguration is known to be an intricate task since the number of possible configurations increases drastically when the size of the ensemble increases.

This work defines a new type of meta-module that offers new assumptions to create an object with programmable matter. The object consists of an internal scaffolding structure and borders formed by solid meta-modules that close the volume. Some excess modules are stored in the internal volume of a meta-module of the scaffold to get more modules available for a reconfiguration or to accelerate the delivery of matter in a free space. Using this new structure, self-reconfiguration algorithms will be able to both reduce the distances covered by the robots and to parallelize their movements.

Our solution uses quasi-spherical robots able to move by rolling on their neighbors: the *3D Catoms* [4]. We propose to define a porous structure formed by meta-modules grouping several *3D Catoms*. Usually meta-modules are used to facilitate the movement of modules by pre-planning unitary moves [1]. Thus with these meta-modules we obtain lattices at the meta-module scale composed of cells that can be empty, sparse or full.

The meta-modules provide a new functionality: they are a reserve of material or storage places. Their presence in the grid allows to reduce the distances covered by the modules during the self-reconfiguration, either by proposing a place to store incoming modules or to propose outgoing modules close to their delivery place.

2 META-MODULES ANATOMY

Our proposed meta-module can be in two states: "FULL" or "SPARSE" (cf. Figure 1). A "SPARSE" meta-module is composed of ten *3D Catoms* placed in a 3D hexagon like shape in a FCC lattice. Each "SPARSE" meta-module can fit in its internal empty volume a set of ten additional modules. A "FULL" meta-module is a meta-module storing in its internal volume ten modules, i.e. grouping twenty *3D Catoms*, twice the size of a meta-module. The size of the meta-module have an impact on the granularity of the system since the shape description will be done at the meta-module level. The size of 10 modules is chosen in a way for the meta-module to be able to store the size of another one and to keep enough space between it and its neighbor meta-modules to allow the modules to flow between them without blocking. In addition, 10 is the smallest size that allows modules to flow in parallel through the empty internal volume of a "SPARSE" meta-module without being blocked by the modules forming the "SPARSE" meta-module that they are traversing.

The meta-modules are arranged in a 3D regular cubic lattice as shown in Figure 1. A cell in the grid can be "EMPTY" or present. A present cell contains a meta-module that can be "SPARSE" or "FULL". Each meta-module is attached to an adjacent one with at least one module. The left, right, front and back adjacent meta-modules in the XY plane have the positions of their modules flipped vertically and the top and bottom adjacent meta-modules in the XZ plane are attached to the front or the back of the two top or the two bottom modules according to the $\overrightarrow{Z}$ axis to facilitate modules transportation and to preserve the symmetry of the structure.

In order to change the shape of the whole structure, we define three basic operations that can be executed by a meta-module to change the state of its cell:

(1) *Dismantle* operation changes the state of an occupied cell from "SPARSE" to "EMPTY" or "FULL" to "SPARSE". It breaks or empty the meta-module and transports its modules to an adjacent cell.

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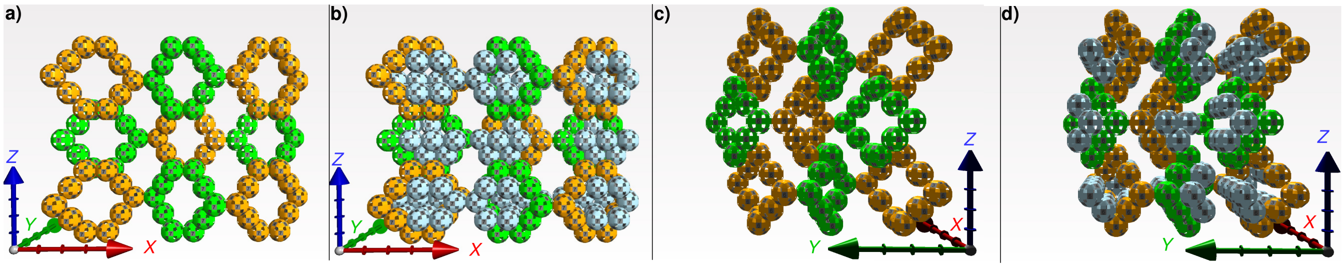

Figure 1: Meta-modules structure in a 3D cubic lattice. a) "Sparse" meta-modules in the XZ plane. b) "Full" meta-modules in the XZ plane. c) "Sparse" meta-modules in the YZ. d) "Full" meta-modules in the YZ plane.

(2) *Transfer* operation does not change the state of a cell. It is only used to transport the modules through a "Sparse" cell.
(3) *Assemble* operation changes the state of a cell from "Empty" to "Sparse" or "Sparse" to "Full".

Each operation can be executed in the six directions (left, right, up, down, back and front) in the cubic meta-module scale lattice. An operation is defined as a sequence of hand-coded movements to navigate the modules of a meta-module from one position to another. These operations can be exploited by a self-reconfiguration planner whose purpose will be to specify what operation to execute on which meta-module and at what time.

2.1 Use Case

In this section, we show an example of self-reconfiguration from an initial shape to a goal one of the same size using our meta-module structure. The algorithm is mainly divided into three steps repeated until the result configuration corresponds to the goal shape:

1. Determining sources and destinations meta-modules. Sources are meta-modules that do not belong to the goal shape and that when removed do not disconnect the structure. Destinations are meta-modules adjacent to "Empty" positions in the goal shape and can handle the *Assemble* operation at its adjacent "Empty" position.
2. Finding the maximum number of possible disjoint streamlines connecting sources and destinations using a distributed version of max-flow algorithm [2].
3. Dismantling sources meta-modules and transporting their composing modules to destinations.

All simulations are done in *VisibleSim* [6]: a discrete-event simulator for modular robots. Figure 2 shows snapshots of simulation during the reconfiguration of an L shape made of 48 meta-modules placed in the XZ plane to a C shape in the YZ plane. At each iteration, sources meta-modules are dismantled then transported along streamlines to be built at an empty goal position.

3 CONCLUSION AND FUTURE WORK

In this paper, we propose a new meta-modules anatomy that can be exploited to expand or compress the structure by filling it with a reserve of modules and improve the self-reconfiguration process in terms of parallelism of motions.

Our structure model allows to store excess modules in "Sparse" meta-modules. Future work will exploit this powerful capability to propose algorithms that can reconfigure a shape into another one of different size. In addition, we aim to study the expandability and compressibility property of our structure and how it can be exploited to enhance the self-reconfiguration process. For instance, during an iteration, empty meta-modules near the goal shape can be filled then the filling modules are transported during the next iteration so the distance from source meta-modules to the goal shape is reduced. Furthermore, we aim to provide a solution to better represent the goal object. Perhaps, we can change the shape of boundary meta-modules to better mimic the boundary of the goal shape and use filling modules for coating it.

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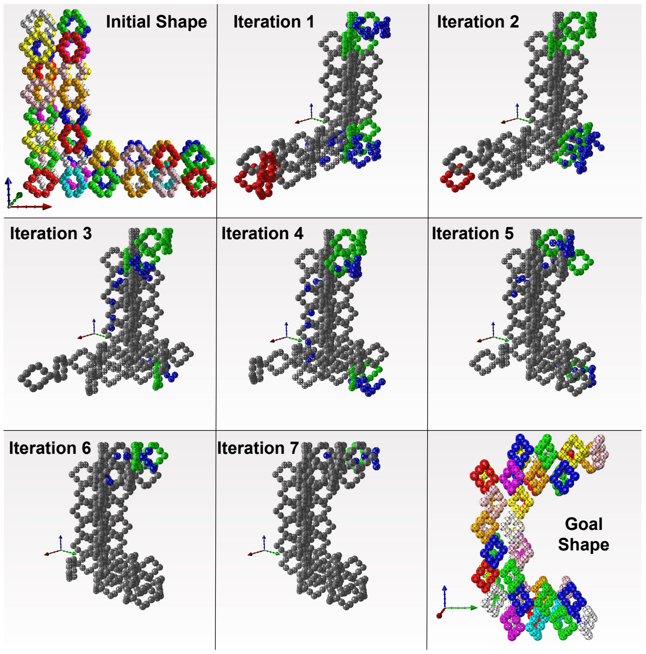

Figure 2: Simulation snapshots for the 7 iterations during the reconfiguration of 48 meta-modules in an L shape to a C shape.

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