Coordinating Amoebots via Reconfigurable Circuits*

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Programmable matter is a physical substance consisting of tiny, homogeneous robots (also called *particles*) that is able to dynamically change its physical properties like shape or density. Such a substance can be deployed, for example, for minimal invasive surgeries through injection into the human body (detecting cancer cells, repairing bones, closing blood vessels, etc.). Programmable matter has been envisioned for 30 years [2] and is yet still to be realized in practice. However, theoretical investigation on various models (such as the nubot model [3] or the geometric amoebot model [1]) has already been started and is still continuing in the distributed computing community.

Shape formation algorithms are of particular interest. Algorithms of polylogarithmic complexity are known for the nubot model [3]. However, these assume particles on the molecular scale since it requires the rotation of entire substructures. Due to the acting forces, this would not be possible on the micro or macro scale. In contrast, many problems for the geometric amoebot model come with a natural lower bound of $\Omega(D)$, where D is the diameter of the structure formed by the amoebots. The main goal of our research is to formulate a model that is able to break this lower bound while still being reasonable on the micro or even macro scale.

Many of the various models for programmable matter take their inspiration from nature. For example, the particles of the nubot model resemble molecules, and the locomotion of the particles of the amoebot model are inspired by amoeba. However, many more fascinating forms of locomotion can be found in nature. Our model is motivated by the muscular system. Muscles are composed of muscle fibers, which can be stimulated to perform coordinated contractions. These contractions (and their counterpart relaxations) allow for fast locomotion. The stimuli are inflicted by the nervous system. The nervous system consists of highly connected nerves. These are able to rapidly transmit primitive signals (the stimuli) over long distances. Our aim is to come up with a model for programmable matter incorporating both concepts: the muscular system and the nervous system.

Instead of proposing an entirely new model, we build our model on top of the geometric amoebot model (see Figure 1a). This model is tailor-made for

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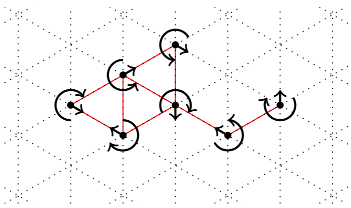
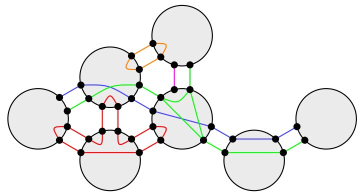
our purpose since it already provides contractions (and expansions) on a small scale of single particles. Inspired by the nervous system described above, in a first step, we introduce reconfigurable circuits to the geometric amoebot model. Each particle is allowed to create a constant amount of circuits with a subset of the particle structure (see Figure 1b). A circuit formed by particles allows for the instantaneous transmission of primitive signals to all of these. Table 1 shows an overview over our algorithmic results. The realization of the muscular system is the subject of future work.



(a)



(b)

Fig. 1: (a) shows a particle structure. (b) shows the same particle structure with reconfigurable circuits. Each color indicates another circuit.

Table 1: An overview over our algorithmic results.

Problem	Minimum Required Pins	Common Chirality	Runtime
Leader election	1	No	$\Theta(\log n)$ w.h.p.
Consensus	1	No	$O(1)$
Compass alignment	1	Yes	$O(\log n)$ w.h.p.
Chirality agreement	2	No	$O(\log n)$ w.h.p.
Shape recognition			
Parallelograms	1	No	$O(1)$
Parallelograms with linear side ratio	1	No	$\Theta(\log n)$ w.h.p.
Parallelograms with polynomial side ratio	2	No	$\Theta(\log n)$ w.h.p.
Universal shape recognition	2	Yes	$O(1)$

References

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