Algorithmic Foundations of Programmable Matter Dagstuhl Seminar 16271

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Abstract

In July 2016, the Dagstuhl Seminar 16271 considered "Algorithmic Foundations of Programmable Matter", a new and emerging field that combines theoretical work on algorithms with a wide spectrum of practical applications that reach all the way from small-scale embedded systems to cyber-physical structures at nano-scale.

The aim of the Dagstuhl seminar was to bring together researchers from the algorithms community with selected experts from robotics and distributed systems in order to set a solid base for the development of models, technical solutions, and algorithms that can control programmable matter. Both communities benefited from such a meeting for the following reasons.

- Meeting experts from other fields provided additional insights, challenges and focus when considering work on programmable matter.
- Interacting with colleagues in a close and social manner gave many starting points for continuing collaboration.
- Getting together in a strong, large and enthusiastic group provided the opportunity to plan a number of followup activities.

1 Summary

Programmable matter refers to a substance that has the ability to change its physical properties (shape, density, moduli, conductivity, optical properties, etc.) in a programmable fashion, based upon user input or autonomous sensing. The potential applications are endless, e.g., smart materials, autonomous monitoring and repair, or minimal invasive surgery. Thus, there is a high relevance of this topic to industry and society in general, and much research has been invested in the past decade to fabricate programmable matter. However, fabrication is only part of the story: without a proper understanding of how to program that matter, complex tasks such as minimal invasive surgery will be out of reach. Unfortunately, only very few people in the algorithms community have worked on programmable matter so far, so programmable matter has not received the attention it deserves given the importance of that topic.

The Dagstuhl seminar "Algorithmic Foundations of Programmable Matter" aimed at resolving that problem by getting together a critical mass of people from algorithms with a selection of experts from distributed systems and robotics in order to discuss and develop models, algorithms, and technical solutions for programmable matter.

The aim of the seminar was to bring together researchers from the algorithms community with selected experts from robotics and distributed systems in order to set a solid base for the development of models, technical solutions, and algorithms that can control programmable matter. The overall mix worked quite well: researchers from the more practical side (such as Julien Bourgeois, Nikolaus Correll, Ted Pavlic, Kay Römer, among others) interacted well with participants from the theoretical side (e.g., Jennifer Welch, Andrea Richa, Christian Scheideler, Sándor Fekete, and many others). Particularly interesting to see were well-developed but still expanding areas, such as tile self-assembly that already combines theory and practice (with visible and well-connected scientists such as Damien Woods, Matt Patitz, David Doty, Andrew Winslow, Robert Schweller) or multi-robot systems (Julien Bourgeois, Nikolaus Correll, Matteo Lasagni, André Naz, Benoît Piranda, Kay Römer).

The seminar program started with a set of four tutorial talks given by representatives from the different sets of participants to establish a common ground for discussion. From the robotics and distributed system side, Nikolaus Correll and Julien Bourgeois gave tutorials on smart programmable materials and on the claytronics programmable matter framework, respectively. From the bioengineering side, Ted Pavlic gave a tutorial on natural systems that may inspire programmable matter. From the algorithmic side, Jacob Hendricks gave a tutorial on algorithmic self-assembly. In the mornings of the remaining four days, selected participants offered shorter presentations with a special focus on experience from the past work and especially also open problems and challenges. Two of the afternoons were devoted to discussions in breakout groups. Four breakout groups were formed, each with less than 10 participants to allow for intense interaction. Inspired by a classification of research questions in biology into " why?" and "how?" questions presented in Ted Pavlic's tutorial, the first breakout session was devoted to the "why?" questions underpinning programmable matter, especially also appropriate models of programmable matter systems (both biological or engineered) suitable for algorithmic research. The second breakout session towards the end of the seminar was devoted to a set of specific questions given by the organizers that resulted from the discussions among the participants, they included both research questions and organizational questions (e.g., how to proceed after the Dagstuhl seminar). After each of the two breakout sessions, one participant of each of the four breakout groups reported back the main findings of the discussions to the plenum, leading

to further discussion among all participants. One of the afternoons was devoted to a hike to a nearby village, where the participants also visited a small museum devoted to programmable mechanical musical devices.

The seminar was an overwhelming success. In particular, bringing together participants from a number of different but partially overlapping areas, in order to exchange problems and challenges on a newly developing field turned out to be excellent for the setting of Dagstuhl - and the opportunities provided at Dagstuhl are perfect for starting a new community.

Participants were enthusiastic on a number of different levels.

- Meeting experts from other fields provided additional insights, challenges and focus when considering work on programmable matter.
- Interacting with colleagues in a close and social manner gave many starting points for continuing collaboration.
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The latter include connecting participants via a mailing list, the planning and writing of survey articles in highly visible publication outlets, and a starting point for specific scientific workshops and conferences.

Participants were highly enthusiastic about the possibility of another Dagstuhl seminar in the future; organizers are keeping the ball rolling on this, so it is quite possible that there will be more to come.

2 Overview of Talks

Abstracts of all talks are available at
`http://drops.dagstuhl.de/opus/volltexte/2016/6759/`.

Claytronics: an Instance of Programmable Matter
Julien Bourgeois (FEMTO-ST Institute - Montbéliard, FR)

A Markov Chain Algorithm for Compression in Self-Organizing Particle Systems
Sarah Cannon (Georgia Institute of Technology - Atlanta, US)

Algorithm design for swarm robotics and smart materials
Nikolaus Correll (University of Colorado - Boulder, US)

Dynamic Networks of Computationally Challenged Devices: the Passive Case
Yuval Emek (Technion - Haifa, IL)

Algorithms for robot navigation: From optimizing individual robots to particle swarms
Sándor Fekete (TU Braunschweig, DE)

The Amoebot Model
Robert Gmyr (Universität Paderborn, DE)

Dances with Plants: Robot-supported Programmable Living Matter
Heiko Hamann (Universität Paderborn, DE)

Introduction to Modeling Algorithmic Self-Assembling Systems
Jacob Hendricks (University of Wisconsin - River Falls, US)

Advantages, Limitations, Challenges of Tendon-Driven Programmable Chains
Matteo Lasagni (TU Graz, AT)

Programmable Matter for Dynamic Environments
Othon Michail (CTI - Rion, GR)

Energy Harvesting in-vivo Nano-Robots in Caterpillar Swarm
Venkateswarlu Muni (Ben Gurion University of the Negev - Beer Sheva, IL)

Algorithmic design of complex 3D DNA origami structures
Pekka Orponen (Aalto University, FI)

Algorithmic Foundations of Biological Matter: Faster, Cheaper, and More Out of Control
Theodore P. Pavlic (Arizona State University - Tempe, US)

VisibleSim:Your simulator for Programmable Matter
Benoît Piranda (FEMTO-ST Institute - Montbéliard, FR)

On obliviousness
Nicola Santoro (Carleton University - Ottawa, CA)

Theory and practice of large scale molecular-robotic reconfiguration
Damien Woods (California Institute of Technology - Pasadena, US)

Distributed coordination of mobile robots in 3D-space
Yukiko Yamauchi (Kyushu University - Fukuoka, JP)