Negative two (-2) Generation Programmable Matter: A Road Map Into The Future

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Boring Legal Stuff

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Executive Summary

Programmable matter is the ability to enter a request into a system and have particles create the requested form or design. An example would be a request to create a chair. The components would assemble themselves in the form of a chair that could actually be used as a chair.

This paper proposes and lays out the road map to create negative two generation programmable matter. Negative two generation programmable matter has components that are can range from the size of a baseball to the size of a softball. First generation programmable matter will be the size of a pea.

Programmable matter, as proposed in this paper, consists of three components: the worker, the manager, and the master. The worker is the component which is greatest in quantity and is a ‘dumb’ component that only carries out commands it receives. Managers provide workers with commands and take high-level direction from masters. Masters take user input and translate them into the directions required to create the design or pattern.

The specific physical parts of programmable matter components are the skeleton, skin, magnets, and chargers. The skeleton and skin need to be researched and developed. The magnets may require advanced technology that is not yet widely available. Wireless charging already exists and it is expected this technology can be adapted.

The artificial intelligence (AI) required may be able to leverage the advancements in AI that have been seen in drone AI technology. Drone AI has demonstrated the ability to manage many devices in near synchronous fashion. There are limitations with this idea though, the main limitation being that drones can fly and programmable matter has no flight capability.

The author is under the impression this technology will be created independently and in isolation but is open to accepting any outside participation. The author acknowledges limitation is knowledge, technology, and finances that could limit and delay the production of this negative two generation programmable matter.

Ultimately, programmable matter will be created. Whether the author creates it, another entity creates it independently prior the author's completions of this road map, or if it is created sometime later there will be a future when furniture and other designs and patterns will only exist when they are convenient for the beneficiary.

Assumptions

The assumptions at the time of writing this document include:

- No person or entity that reads this document will have the appetite to participate in the creation of programmable matter.
- No person or entity that reads this document will have the appetite to independently develop programmable matter.
- The author has the personal capability to overcome knowledge gaps.
- The author has the personal capability to outsource any issues where there is a lack of personal ability to overcome knowledge gaps.
- None of the steps will be financially infeasible based on the ten year timeline to develop the proof-of-concept.
- The 10 year goal is independent of any outside participation or financing.
- None of the technology suggested in this paper are substantially different from existing technologies.
- The author's assertions are correct and current research has not negated the author's previous education, experimentation, and understanding.
- Engineering and physical principles will not be violated.

Introduction

Many people who hear the term 'programmable matter' immediately begin to think of ways to use computer commands to force electrons, protons, neutrons, or maybe atoms and molecules, into desired structures. That is the wrong understanding. That is replication of matter and not programmable matter. Programmable matter is microscopic, or near microscopic, colonies of machines. These 20 faced polygon (Icosahedron) machines are capable of very basic on and off commands for each of their 20 faces. This on and off functionality enables these machines to attach to neighbor machines. A small set of machines is controlled by a manager that issues orientation and positioning commands to each machine in a hive. A group of hives is controlled by a master. The master is responsible for orientation and positioning of groups of hives, known as a swarm. An entity (human, robot, external artificial intelligence (AI)) can issue a command to the master such as “Chair”. The master will use its AI to architect the placement and orientation of managers. The managers will issue orientation and positioning commands to its workers. The workers will turn on and off their electromagnetic sides to ‘roll’ into position. Thus a chair is created.

Form Factor

Shape

The selected shape is the regular Icosahedron (polyhedr.com/icosahedron.html) or twenty-sided polygon. There are two reason for choosing the Icosahedron as the form factor: reduction of force required to create movement and strength of shape.

Reduction of Force for Movement

When two Icosahedron have faces that are in contact the faces surrounding are about 86 degrees away from each other. This means is both Icosahedron move they need to shift less than 45 degrees to reach the new position. In most cases though, a single worker will be moving about fixes placement workers. In this scenario the worker still must rotate less than 90 degrees to reach the new position. These acute angles are not present in polygons with less sides which substantially increases the required force for movement. For comparison, a cube would need to overcome 180 degrees of rotation.

Strength of Shape

It has been proven numerous times geodesic domes are capable of withstanding external forces that far surpass the forces traditional buildings can withstand. These same principles seem to both scale and apply to fully formed polygons, not just half-polygons. This is understood to be related to the idea that these polygons have very limited surfaces areas that are perpendicular to any given external force. While this is an over simplification the basic premise is applicable.

Skeleton

The Icosahedron skeleton is going to be a little difficult to get right. The skeleton used for the prototype will not be optimized for longevity and efficiency. This is because of the requirement for something that is light weight, slightly flexible, but not too flexible. The light weight is required to reduce the burden on the electromagnets. The slight flexibility is required to permit the worker to manages forces without being brittle and breaking easily. The skeleton cannot be too flexible either to prevent structural failure when a load is applied. The skin will assist in maintaining the structural integrity though so skeletal flexibility has some malleability.

Skin

Some form of fabric polymer may be the first choice when testing potential skins. This is due to their flexibility and strength. There should not be a single skin that covers the entire polygon. Each face should have its own skin that is connected to each of the three sides in a sipper pattern with the skin the touching side. This multi-skin design that is connected to the skeleton on every edge increases structural stability while reducing the opportunity for full failure from a single puncture.

Physical Components

The shape, skeleton, and skin of the Icosahedron are not considered physical components. They are sub-components of the vessel. As the vessel is a common component of all types of programmable matter units they were described in the preceding section. This section will cover the components that are unique to each of the three types of programmable matter Icosahedron: the worker, the manager, and the master.

Worker Icosahedrons

Worker Icosahedrons are the most rudimentary of the three types. The technologies in these vessels are present in the remaining two, the manager and master. No technologies in those two are present in the worker. The two physical components in the worker Icosahedron are are electromagnets and the brain.

Electromagnets

The worker has twenty sides, thus each worker has twenty dynamic magnets. These magnets have three settings: off, high, and low.

Off

The off setting provides full magnetic capability by providing no electric current. This is designed to permit the workers to maintain macro structures long after all power has been drained.

High

The high setting removes all magnetic capability to permit full freedom of movement.

Low

To ensure the greatest reduction of impact by external forces there is a low setting. The low setting assists in the movement of the worker in opposition to external forces. How this works is explained in the “Rolling” section below.

Brain Units

The brain units are the central processing units of the Icosahedron but they are not what one may consider when hearing the term CPU. They are miniature, specialized CPUs with extremely limited functionality. They consist of communications, magnet management functions, and power and charging.

Communications

Each worker communicates using near field communication (NFC) technology. The workers will receive arrays of commands directing the workers the setting level of each magnet along with which workers should be partnered with each of its faces.

Magnet Management

Magnets will be managed using a very simple central power switching mechanism. The switching mechanism will provide half-power to create the ‘low’ setting. Full power will be used to ‘turn off’ the magnet. Removing all electrical power to a magnet will ensure the magnet is operating at full strength.

Power and Management

There are several ideas on how to provides and manage power for programmable matter. The author believes the idea with the most merit for the technology being presented here is external power only. Each Icosahedron would be fitted with wireless power receivers but no batteries. This means programmable matter could only be programmed if a power supply is actively transmitting wireless power within range and with enough power to reach every Icosahedron.

Manager Icosahedrons

Managers have most of the technologies of workers and some of the technologies of masters. Managers have static magnets that have between 65 and 75% of the power of workers. This permits workers the ability to overcome the magnetic force of managers for freedom of movement. Additionally, managers will have AI. The AI in the managers will determine the position of the workers, the positions where the workers should be located, and the path required to get the workers into the proper position. These “paths” will be transmitted to the workers wirelessly.

Master Icosahedrons

The masters have the same physical characteristics of managers but have different AI characteristics and capabilities.

Artificial Intelligence Components

However, the commands they receive will determine how they roll and partner with other workers. Managers develop the paths required for workers to get into the correct positions with the correct partners while receiving orders from masters. Masters develop the macro-architecture of the entire shape or design being created, issuing command designed to move managers and workers into the correct positions.

Worker Icosahedron Intelligence

The workers do not have any artificial intelligence. They simply act on the long string of commands they receive. The long strings of commands have two parts: the roll path and the partnering identifiers.

Roll Paths

The roll path is a series of commands received from the manager. Essentially it is a list of face names with associated power levels. Due to the shape of an Icosahedron, the workers will not be able to roll in a ‘straight’ line so even the simplest of repositioning will require multiple roll commands. To overcome eternal forces (such as gravity) the “low” command will need to be used in conjunction with other power levels to increase the “upward pull” in a way that overcomes such forces.

Partner Identifiers

The second portion of commands sent to workers are partner identifiers. These are a list of face names of the receiving worker with the identifier of the worker that should be connected to that face. This is essentially an error correction command. Once the roll path commands have been executed the partner identifiers report the orientation and location of the worker compared to the desired orientation and location. This permits the manager to provide additional roll paths if required.

Manager Icosahedron Intelligence

The AI in the managers will determine the position of the workers, the positions where the workers should be located, and the path required to get the workers into the proper position. These “paths” will be transmitted to the workers wirelessly.

Hive Mapping

In hive mapping the manager builds a three-dimensional map of the current position of its workers. Using that map it identifies the most economic routes for workers to move into the desired hive shape. The manager uses a center-outward approach. The manager identifies itself as the center of the hive and assigns paths to workers in a layered approach working to the outermost edge of the intended hive design.

Hive Partnering

Hive partnering is the concept that discrete small groups (possibly 100 or less) groups of workers do not present great enough numbers to create meaningful designs. Hives will be required to partner with other hives to make swarms. Much like workers receive path and partnering commands managers receive partnering commands to ensure they are oriented and fixed in the correct location.

Master Icosahedron Intelligence

Masters are the highest form of intelligence in this proposed iteration of pre-programmable matter. The master is responsible for interpreting and creating the requested design patters.

Swarm Architecting

When the master receives a request for a design or pattern it request location and orientation data from hive managers. With this data received the master determines the most efficient movement and orientation of hives to achieve the desired pattern or form, (for instance, a chair). The master uses the same technique as the manger, work from the center outward to ensure proper swarm placement.

Swarm Placing

Programmable matter is not magic. It cannot magically violate physics to assemble itself several meters or yards off the ground without some external force acting upon it. Thus, the swarm or group of hives does need to placed with purposefully. The master will be the center of the 'bottom' layer of the design. If the bottom layer is a flat surface on a floor that is great; however, if the bottom most layer is on a pitted, slightly inclined forest floor there is more complexity. It is the master that must 'talk' with managers to compensate for and overcome these nuances.

Path to Victory

The path to actually creating all of the above mentioned glory is based on the ability to source and build each of the specified technologies in both the hardware and software layers. The requirements of the most basic unit, the worker, will set the pace and expectation of ability and timeline for the remaining components. This section strives to provide the generic description of components that need to be sourced. This section does not provide how or from where components should, or could, be sourced.

Icosahedron Workers

As the most basic programmable matter component the worker is considered the most crucial piece to develop correctly. The main components are the skeleton, the skin, the processor, and the wireless electricity receiver.

Sourcing Components

The sources of hardware and software components for the worker are quite disparate but both require technologies that are just beyond current capabilities.

Hardware

The skeleton will be produced and reproduced using a variety of substances on a 3D printer for testing and prototyping purposes. The final skeleton design and source will be subject to cost, availability, and durability. The skin will be subject to a similar set of testing and may include tests with carbon fiber, 2DPA-1, graphene, and kevlar among others. The processor will need to be a fairly simplistic, very small, unit. Smart phone processors will be the first to be evaluated for this need but they may be too large.

Software

The software in a worker is very simplistic. It is simply responsible for adjusting power levels, receiving commands, identifying itself to neighbors, and transmitting neighbors' identifiers to the managers. This software can be created by leveraging and modifying current SCADA or other operational software systems that are freely available.

Building the Prototype

The prototype will consist of three components. The first two are fully assembled and completed workers. The third is the 'top' half of a worker that has been mounted to a surface. This third component ensures a single complete worker is able to interact independently and to verify full functionality during testing.

Testing the Prototype

The testing will consist of the single worker test and the multi-worker test. The goal of the single worker test is verify a single worker is able to receive and act upon paths then return the neighbor ID once the path has been completed. The multi-worker test is designed to ensure a second worker can move about the first without tainting its position, orientation, or structural integrity.

Single Component Test

Once the prototype is ready for testing the test should follow a series that looks similar to the following set of steps.

1. Bring the wireless electrical source within range of the worker.
2. Bring the complete worker in range of the static half worker.
3. Give commands for worker to turn off all magnets.
4. Pull worker away from static half worker while measuring force required.
5. Turn power back on for all magnets of worker.
6. Observe if worker rolls to static half worker.
7. Observe if worker transmits face and partner ID information after connecting to static half worker.
8. Provide worker with a single move path.
9. Observe if worker moved correctly and transmitted appropriate information.

10. Provide worker with multi move path.
11. Observe if worker responds appropriately and transmits the appropriate information.

Multi-Component Test

The multi-component test will build on the single component test. However, the multi-component test will provide more complex commands such as having a worker move from the static half worker to the other whole worker, move vertically (climb) atop the other worker, and have one worker travel a complex path over and around both the other worker and the static half worker.

Icosahedron Managers

The managers will use the same skeletons and skins as the workers but the processor and AI may be required to have advanced features.

Sourcing Components

The processor for the manager will also examine the possibility of using smart device processors for this iteration of programmable matter. If those technologies are not feasible development or potential sourcing of other technologies will need to be explored. To build the AI current drone swarm AI will be examined for feasibility and potential adaptation.

Hardware

The processor for managers must be more sophisticated than the ones used for workers. This suggests they will create substantially more heat. Therefore, it will be imperative to identify processors that are small in forms, capable of managing the data load, and which do not create substantial ambient heat.

Software

The AI used for creating maps, calculating paths, and maintaining hives must be sophisticated. Thankfully similar technology already exists in the form of drone swarm AI. Drone swarm AI is not the same thing and does not have the same limitations because drones are much larger and can fly. There are portions of the drone AI technology that appear promising though because of the intricate management of many dynamic components in near synchronous time.

Creating the Prototype

The manager prototype will be a fully assembled manager vessel which includes all components and technology.

Testing the Prototype

Testing of the manager prototype will leverage the two prototype workers that were tested above. In this scenario the tester issues commands to the manager and observes the results to determine if they are complete and appropriate.

Single Component Test

In the single component test a single manager will be tested with a single worker. Once that has reached full success the manager will be tested using two workers. Once that has been successfully completed the multi-component test can begin.

Multi-Component Test

The multi-component test will leverage two managers with one worker each. The tester will issue a series of simplistic designs to the managers. The results will be observed, recorded and scored to ensure appropriate paths have been created, the final design matches the requirement, and communications are complete and appropriate.

Icosahedron Masters

The masters are the most advanced form of programmable matter to be included in this iteration. The processors should not need to be any more advanced than those used in the managers. This is because the masters are effectively managing the same number or potentially less numbers of components than that of the managers. The same AI roots from drone technology will also be evaluated for applicability and usability for the masters.

Testing the prototype

Testing the master will build upon the testing of previous prototypes with the addition of requesting the master to design a number of programmed designs.

Potential Limitations and Roadblocks

It would be dishonest not to acknowledge the limitations of the author and potential roadblocks that could prevent the creation of this programmable matter technology. The author is not omniscient, does not have access to unlimited technology, and is not without financial limitations. These issues will be discussed here.

Educational

The author has some knowledge of all topics presented in this paper but has significant knowledge gaps in some of the major areas required to create this technology. Although those knowledge gaps can be overcome it may take an extended duration at times due to competing priorities.

Technological

The author is at the mercy of industry for any technologies that need to be advanced to create these prototypes. An example would be electromagnetic devices small enough to build workers. There are small electromagnetic devices; however, the author (based on a very limited search) did not see any devices of sufficiently small size to meet the proposed need.

Financial

The author is not independently wealthy, has no partners, and is not funded. Financial constrains will be a factor that limits the progress that can be accomplished in finite intervals.

Future Iterations

The currently proposed iteration is a negative two generation of programmable matter. Negative two generation programmable matter is somewhere in the range between the size of a baseball and a softball. This is not programmable matter, only a precursor. Negative one generation programmable matter will (or should be) no larger than the size of a golf ball. Zero generation programmable matter should be no larger than a standard sized marble. Only when micro-sizing is achieved can there be a claim that that the first generation of programmable matter has been achieved.

Micro-Sizing

There are some ideas about how generation one programmable matter will look. The skin and skeleton may be graphene with microprocessors and micro dynamic magnetism.

Dynamic Movement

Once programmable matter is assembled into its design or shape it seems to be a static assembly. There may be a time when the ability to create dynamic movement will be reasonable. The author does not anticipate that capability withing generations negative two, negative one, or generation zero due to friction and other external forces.

Summary

Generation negative two programmable matter is hardly programmable matter but it is a good start. It will be developed (possibly in complete isolation) by the author. Any entity on earth has permission to create this technology using the ideas, concepts, and technologies in this paper while conforming to the legal requirements and agreements. The worker is the heart of programmable matter that literally does all of the work. Managers give directions to hives or groups of workers to ensure their portion of the programmed design is completed efficiently and accurately. Masters take input from users and interpret the request into instruction for managers to perform. Programmable matter can leverage existing technologies as starting points such at drone swarm AI, operational control systems technology, smart device processors, and wireless charging technology. Programmable matter, it isn't just something with a cool name.