Self-replicating machine

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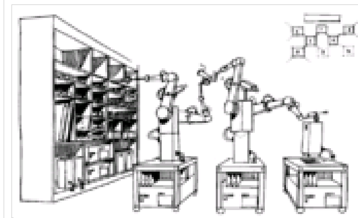

A simple form of machine self-replication

A **self-replicating machine** is an artificial construct that is capable of autonomously manufacturing a copy of itself using simpler components or raw materials taken from its environment. The concept of self-replicating machines has been most notably advanced and examined by, Homer Jacobsen, Edward F. Moore, Freeman Dyson, John von Neumann and in more recent times by K. Eric Drexler in his seminal book on nanotechnology, *Engines of Creation* and by Robert Freitas and Ralph Merkle in their landmark review *Kinematic Self-Replicating Machines*[1] which provided the first comprehensive analysis of the entire replicator design space. The future development of such technology has featured as an integral part of several plans involving the mining of moons and asteroid belts for ore and other materials, the creation of lunar factories and even the construction of solar power satellites in space. The possibly misnamed von Neumann probe[2] is one theoretical example of such a machine. Von Neumann also worked on what he called the Universal Constructor, a self-replicating machine that would operate in a cellular automata environment.

A self-replicating machine is, as the name suggests, an artificial self-replicating system that relies on conventional large-scale technology and automation. Certain idiosyncratic terms are occasionally found in the literature. For example, the term "clanking replicator" was once used by Drexler[3] to distinguish macroscale replicating systems from the microscopic nanorobots or "assemblers" that nanotechnology may make possible, but the term is informal and is rarely used by others in popular or technical discussions. Replicators have also been called "von Neumann machines" after John von Neumann, who first rigorously studied the idea. But this term ("von Neumann machine") is less specific and also refers to a completely unrelated computer architecture proposed by von Neumann, so its use is discouraged where accuracy is important. Von Neumann himself used the term Universal Constructor.

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Basic concept

A self-replicating machine would need to have the capacity to gather energy and raw materials, process the raw materials into finished components, and then assemble them into a copy of itself. It is unlikely that this would all be contained within a single monolithic structure, but would rather be a group of cooperating machines or an automated factory that is capable of manufacturing all of the machines that make it up.

The factory could produce mining robots to collect raw materials, construction robots to put new machines together, and repair robots to maintain itself against wear and tear, all without human intervention or direction. The advantage of such a system lies in its ability to expand its own capacity rapidly and without additional human effort; in essence, the initial investment required to construct the first self-replicating device would have an infinitely large payoff with no additional labor cost.

Such a machine violates no physical laws, and we already possess the basic technologies necessary for some of the more detailed proposals and designs.

If proof were needed that self-replicating machines are possible, the simple fact that all living organisms are self replicating by definition should go some way towards providing that proof, although most living organisms are still many times more complex than even the most advanced man-made device.

History of the concept

The general concept of artificial machines capable of producing copies of themselves dates back at least several hundred years. An early reference is an anecdote regarding the philosopher René Descartes, who suggested to Queen Christina of Sweden that the human body could be regarded as a machine; she responded by pointing to a clock and ordering "see to it that it reproduces offspring."[4] Several other variations on this anecdotal response also exist. Samuel Butler proposed in his 1872 novel *Erewhon* that machines were already capable of reproducing themselves with the assistance of the humans that operated them, and analogized this to flowering plants that were only capable of reproducing with the assistance of pollinating insects.[5]

In 1802 William Paley formulated the first known teleological argument depicting machines producing other machines,[6] suggesting that the question of who originally made a watch was rendered moot if it were demonstrated that the watch was able to manufacture a copy of itself.[7] Scientific study of self-reproducing machines was anticipated by John Bernal as early as 1929[8] and by mathematicians such as Stephen Kleene who began developing recursion theory in the

1930s.[9]
Much of this latter work was motivated by interest in information processing and algorithms rather than physical implementation of such a system, however.

von Neumann's kinematic model

A detailed conceptual proposal for a physical non-biological self-replicating system was first put forward by mathematician John von Neumann in lectures delivered in 1948 and 1949, when he proposed a kinematic self-reproducing automaton model as a thought experiment.[10][11] Von Neumann's concept of a physical self-replicating machine was dealt with only abstractly, with the hypothetical machine using a "sea" or stockroom of spare parts as its source of raw materials. The machine had a program stored on a memory tape that directed it to retrieve parts from this "sea" using a manipulator, assemble them into a duplicate of itself, and then copy the contents of its memory tape into the empty duplicate's. The machine was envisioned as consisting of as few as eight different types of components; four logic elements that send and receive stimuli and four mechanical elements used to provide a structural skeleton and mobility. While qualitatively sound, von Neumann was evidently dissatisfied with this model of a self-replicating machine due to the difficulty of analyzing it with mathematical rigor. He went on to instead develop an even more abstract model self-replicator based on cellular automata.[12] His original kinematic concept remained obscure until it was popularized in a 1955 issue of *Scientific American*.[13]

Moore's artificial living plants

In 1956 mathematician Edward F. Moore
proposed the first known suggestion for a practical real-world self-replicating machine, also published in *Scientific American*.[14][15]
Moore's "artificial living plants" were proposed as machines able to use air, water and soil as sources of raw materials and to draw its energy from sunlight via a solar battery or a steam engine. He chose the seashore as an initial habitat for such machines, giving them easy access to the chemicals in seawater, and suggested that later generations of the machine could be designed to float freely on the ocean's surface as self-replicating factory barges or to be placed in barren desert terrain that was otherwise useless for industrial purposes. The self-replicators would be "harvested" for their component parts, to be used by humanity in other non-replicating machines.

Dyson's replicating systems

The next major development of the concept of self-replicating machines was a series of thought experiments proposed by physicist Freeman Dyson in his 1970 Vanuxem Lecture.[16][17] He proposed three large-scale applications of machine replicators. First was to send a self-replicating system to Saturn's moon Enceladus, which in addition to producing copies of itself would also be programmed to manufacture and launch solar sail-propelled cargo spacecraft. These spacecraft would carry blocks of Enceladean ice to Mars, where they would be used to terraform the planet. His second proposal was a solar-powered factory system designed for a terrestrial desert environment, and his third was an "industrial development kit" based on this replicator that could be sold to developing countries to provide them with as much industrial capacity as desired. When Dyson revised and reprinted his lecture in 1979 he added proposals for a modified version of Moore's seagoing artificial living plants that was designed to distill and store fresh water for human use[18] and the "Astrochicken."

Advanced Automation for Space Missions

In 1980, inspired by a 1979 "New Directions Workshop" held at Wood's Hole, NASA conducted a joint summer study with ASEE entitled *Advanced Automation for Space Missions* to produce a detailed proposal for self-replicating factories to develop lunar resources without requiring additional launches or human workers on-site. The study was conducted at Santa Clara University and ran from June 23 to August 29, with the final report published in 1982.[19] The proposed system would have been capable of exponentially increasing productive capacity and the design could be modified to build self-replicating probes to explore the galaxy.

An artist's conception of a "self-growing" robotic lunar factory

The reference design included small computer-controlled electric carts running on rails inside the factory, mobile "paving machines" that used large parabolic mirrors to focus sunlight on lunar regolith to melt and sinter it into a hard surface suitable for building on, and robotic front-end loaders for strip mining. Raw lunar regolith would be refined by a variety of techniques, primarily hydrofluoric acid leaching. Large transports with a variety of manipulator arms and tools were proposed as the constructors that would put together new factories from parts and assemblies produced by its parent.

Power would be provided by a "canopy" of solar cells supported on pillars. The other machinery would be placed under the canopy.

A "casting robot" would use sculpting tools and templates to make plaster molds. Plaster was selected because the molds are easy to make, can make precise parts with good surface finishes, and the plaster can be easily recycled afterward using an oven to bake the water back out. The robot would then cast most of the parts either from nonconductive molten rock (basalt) or purified metals. A carbon dioxide laser cutting and welding system was also included.

A more speculative, more complex microchip fabricator was specified to produce the computer and electronic systems, but the designers also said that it might prove practical to ship the chips from Earth as if they were "vitamins."

Much of the design study was concerned with a simple, flexible chemical system for processing the ores, and the differences between the ratio of elements needed by the replicator, and the ratios available in lunar regolith. The element that most limited the growth rate was chlorine, needed to process regolith for aluminium. Chlorine is very rare in lunar regolith.

Lackner-Wendt Auxon replicators

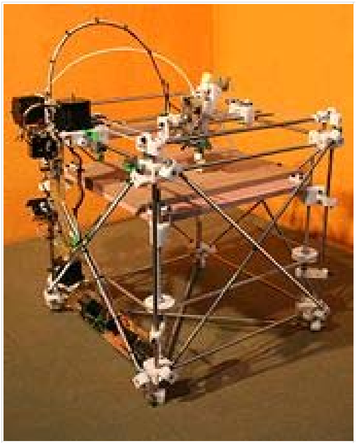
In 1995, inspired by Dyson's 1970 suggestion of seeding uninhabited deserts on Earth with self-replicating machines for industrial development, Klaus Lackner and Christopher Wendt developed a more detailed outline for such a system.[20][21][22]
They proposed a colony of cooperating mobile robots 10-30 cm in size running on a grid of electrified ceramic tracks around stationary manufacturing equipment and fields of solar cells. Their proposal didn't include a complete analysis of the system's material requirements, but described a novel method for extracting the ten most common chemical elements found in raw desert topsoil (Na, Fe, Mg, Si, Ca, Ti, Al, C, O_2 and H_2) using a high-temperature carbothermic process. This proposal was popularized in Discover Magazine, featuring solar-powered desalination

equipment used to irrigate the desert in which the system was based.[23] They named their machines "Auxons", from the Greek word *auxein* which means "to grow."

Recent work

Self-replicating rapid prototypers

Early experimentation with rapid prototyping in 1997-2000 was not expressly



RepRap 1.0 "Darwin" prototype

oriented toward reproducing rapid prototyping systems themselves, but rather extended simulated "evolutionary robotics" techniques into the physical world. Later developments in rapid prototyping have given the process the ability to produce a wide variety of electronic and mechanical components, making this a rapidly developing frontier in self-replicating system research.[24]

In 1998 Chris Phoenix informally outlined a design for a hydraulically-powered replicator a few feet in volume that used ultraviolet light to cure soft plastic feedstock and a fluidic logic control system, but didn't address most of the details of assembly procedures, error rates, or machining tolerances.[25][26]

In 2005, Adrian Bowyer of the University of Bath started the RepRap Project to develop a rapid prototyping machine which would be able to manufacture most of its own components, making such machines cheap enough for people to buy and use in their homes. The project is releasing its designs and control programs under the GNU GPL.[27] The RepRap approach uses fused deposition modeling to manufacture plastic components, possibly incorporating conductive pathways for circuitry. Other components, such as motors and discrete electronic components, would be supplied externally. As of 2006 the project has produced a basic functional prototype.

NIAC studies on self-replicating systems

In the spirit of the 1980 "Advanced Automation for Space Missions" study, the NASA Institute for Advanced Concepts
began several studies of self-replicating system design in 2002 and 2003. Four phase I grants were awarded:

- Hod Lipson (Cornell University), "Autonomous Self-Extending Machines for Accelerating Space Exploration"[28]
- Gregory Chirikjian (Johns Hopkins University), "Architecture for Unmanned Self-Replicating Lunar Factories"[29]
- Paul Todd (Space Hardware Optimization Technology Inc.), "Robotic Lunar Ecopoiesis"[30][31]

- Tihamer Toth-Fejel (General Dynamics), "Modeling Kinematic Cellular Automata: An Approach to Self-Replication"[32][33]
  The study concluded that complexity of the development was equal to that of a Pentium 4, and promoted a design based on cellular automata.

F-Units

Self-replication
has been achieved by man within a complex and systematic method by self-replicators known as F-Units (for "Fabricating Units"). The system must be initialized and set up first as follows. Such is achieved by first using excimer lasers at ultraviolet wavelengths of usually about 193 nanometers that evoke a 1 micron "spot size" cutting path to carve out microscopic tiles that are electrically conductive and nonconductive. Aluminum and polycarbonate are usually used initially. After first providing the tiles to already existing F-Units they will fashion the tiles into vertical layers constructing another identical F-Unit within the "block" of tiles so fabricated. The F-Units independently move about the surface of the structure that they are fabricating much like a trolley car while receiving data and electrical power up through the columns of tiles through the block it fabricates upon from a computer
and power source attached to the base of the block. The power and data pass up through the conductive tiles to the F-Units through their feet and is utilized. The F-Unit slides up on skids to each next layer upon completion of the prior once the next layer is well started. Once this initial "scaffolding" is intact about this electrically "charged" block, more advanced self-replicating constructions can thereafter commence beyond as liquids, gasses, energies and more complex materials can further be utilized in high resolution to provide a means to fabricate more tiles and other devices including the computer and power supply closing the loop.

"Dabbing" of hard drying liquids such as polymers
are performed upon each finished tile layer as well to complete the process to evoke needed finer details and further fuse the block. A tile manufacturing process, to attain further tiles then commences within this tile structure, mostly from further dabbing. Thereafter, fabrication of the system's own computing means from the additional tiles can be had along with further locating of resources independently once the system spans out for further fabrication and propagation bringing the system to its full self-replicating real world scope. The computing means that is assembled by the F-Units exists about a central "data track" consisting of a path of intermittent electrically conductive and nonconductive tiles usually twenty or more tiles wide. The data track is read like a commutator by the F-Units through contact with their feet as they walk upon it. The data track makes up the F-Unit's "DNA" so to speak consisting of its primary instruction code. As one foot goes down closing a conductive path on a conductive tile another foot feeds the signals back down into the block which is picked up by other worker F-Units nearby to be utilized to build objects so instructed from the data track's data including other F-Units or other parts of the system, all made of tiles. These off and on signals are utilized by the F-Units by using them to charging electromagnetic coil actuators upon the F-Units thus animating them. The device's own ecosystem at this point can be firmly established. The initiating computer and power source can, thereafter be disconnected. Each tile location being addressed and tracked or "indexed" with error correction much like a hard drive tracks its clusters effects highly accurate high resolution constructs. Such digitally addressed areas that the F-Units utilize as their ecosystems and fabricate within while maintaining direct control, at direct cause over are called "Digital Referenced Areas" (DRA).

The F-Unit system has the capacity to exist on a planet far away from any sun or star and fulfill its functions by only chemosynthesis (energy attained by chemical reactions only) if raw resources are present. This system, therefore expresses closed independent self-replication in its purest paradigm.

The F-Unit fabrication process successfully fabricates all of the primary mobile fabricating tool's smallest parts and support system parts and of particular note its simple actuators (motors) which have no bearings and other similar small parts that would be impossible to fabricate like has been the stop point in most past attempts at executing real

world independent self-replication. The special technique assembles the primary unit module and all the other support structures in situ
(in place) having all been particularly configured for such an assembly. Further, a highly refined and well planned system is used with different fabrication techniques for different sized parts that evokes wining results in the self-replication. Tiles are placed for the larger areas with the larger tiles for very large areas and smaller ones for medium sized areas and the slower "dabbing" or paint-on techniques are employed with liquid polymers for only the very small parts or fine edges with both processes working freely and simply together interactively which all can be executed solely by the F-Units themselves. These well structured and coordinated functions culminate into a process that greatly increases the efficiency of detail so attained as well as the rate of the fabrication collectively.

One upcoming goal is to effect evolution processes. To arrive at this the DRA will allow for imposed or random tile placement variations (mutations) and evaluations
thereof under constant scrutiny of the controlling computer employing error corrections to a high order, perfect in any practical sense within a "digitally locked" DRA system. This evolution state, the next ladder in the advanced Mechagenics development stage only requiring the simplest, slowest, lowliest DRA immersed self-replicator to start, once achieved and now in the works will target improvements of not only the F-Units but the objects they fabricate and the systems they fabricate to exist within. Once achieved, such will not only ultimately provide all that is necessary in a physical universe
oriented DRA but arrive at the shortest paths toward that goal, being all that is necessary. That threshold will no doubt be absolute in terms of resolution, structural efficiency for all known human needed structures and associated fabrication rates. With the speed of present day computers that threshold will be found very quickly once the internal computer evolution experiment commences.

Other extended projects in the works include a safe, first line consumer product consisting of a fabricating chamber (12" x 12" x 12" cubic shaped "box") with 12,000 or more electrical contact points situated on the floor of the box upon which the tiles are placed by the F-Units. The contact points abut and make electrical contact with the conductive tiles within the "block" of material being built on top of it. The F-Units fill the box with different shaped and sized tiles of varying materials and dab or paint fine details with various hard drying liquids upon each finished tile layer as needed. Such liquids also serve as adhesive to assist in binding the materials so situated together. The F-units lay down the tiles, one layer then another on top of that, layer by layer leaving unattached or partially unattached tiles for support around the object, say a vase being fabricated. Electrically conductive tiles within and throughout the block provide a network of electrical power to run the F-Units and as well activate their tile grabber and placement features. The power is used to actuate other devices in addition to the F-Units built within the matrix such as robotic arms and gantries to assist in the tile placements and move liquid reservoirs, tiles, large blocks of tiles and completed objects about as needed.

The tiles and liquid reservoirs will be supplied to the matrix affixed upon tightly wound rolls of release paper similar to a paper towel roll though somewhat larger which is mounted to the side of the "box" and rolled off of a motorized spindle. The various tiles are laser
cut out of the top layer of sheet material affixed to the rolls upon release paper. The material that the tiles are cut from upon the rolls has two layers and the bottom layer is more resistive to the laser light providing a means of lasering out reservoirs like miniature bath tubs that can be filled with the liquid polymers or other liquids for dabbing and are sealed into the rolls when they are tightly rolled up at the laser plant where they are made. Compressed gases are delivered within blocks made of substances that dissolve when subjected to electrical power delivering mixed gasses precisely where needed. The tiles and factory completed F-Units and further other finished tools and devices can be delivered and be thereafter "picked" off the surface of the sheet release material on the rolls and then utilized by the existing F-units in the box. The F-Units achieve this with their tweeze means on their forward tips (tweezers). Liquids can also be supplied by a side tank and individual tiles can be fed as well by hand through shoots if preferred. Once the box is full and fabrication complete the vase is simply grabbed by the customer and pulled out of the top of the open box and the supporting tiles fall away like loose sand.

To accommodate fabricating a large continuous system instead of a single object like the vase, the four walls of the

box are hinged on the bottom and can be released from latches at their tops by the F-Units or the customer and fall down like a landing craft's to allow propagation
growth of the DRA ecosystem outside the box along DRA charged "roads" and onto floors, walls etc. to bring about a large area DRA or a "mechahouse". Various objects can be ordered over the Internet and the customer thereafter picks up the order at the local hardware store in the form of automatically completed rolls or otherwise packed as needed tiles after his or her order is placed by the computer in the home. If you need a vase, bowl and a plate, silverware, glasses etc. you pick them out on-line, click the execute button in the computer's software and you pick up the roll next time you're out shopping and affix it upon the box when you get home, turn it on before bed at night and get up the next day and pull your dinnerware set out of the box with your name inscribed on each and of the type material, color and shape that you personally wanted.

The software with the computer is configured as a simple CAD/CAM operation with individual tiles in the software depicted as different colors representing various substances used to build with in the software operated like a 3D paint program. When you zoom out they appear as continuous colors to designate respective materials used in various areas and can be moved around en masse with your mouse pointer. Stretching and scaling of various starter objects or "primitives" (like a 12" high vase) will be available along with other tools needed. Double-clicking on a tile or area will give instructions in pop-up windows
on strengths of various materials and suggest laying patterns of defined and classified "lattice structures" thereof etc.

Another aspect of the system employs verbal control of the fabrication process. Verbal commands spoken by the system user can automatically evoke various wanted hard objects or actions by the F-Units upon request by verbally asking for the program or nested (linked together) programs by name. This is done after numerous transducers (microphones) made out of the tiles are strategically replicated within the system, positioned to receive the verbal commands with corresponding speakers to communicate back to the user. The language that the F-Unit System uses consists as follows: *nouns* are spoken to represent the *objects* to be fabricated (and what they are made of) and *verbs* and *adjectives* etc. to indicate the *actions* done with and to the objects and *how* etc. (this is simplified here).

"Closed loop", independent self-replicating F-Units, though very important as they were developed for pure science research
purposes are far less useful than the much faster "limited" proposed replicators or "mixed" self-replicator and simple fabricator combinations as set forth above as a useful fast self-replicating product line. Their capabilities are highly extended by using previously man configured aspects which simply assist in the rate of self-replications and fabrications of the devices and products. The independence of the F-Units and the DRA aspect are far more useful and important than the independent self-replicating aspects. Independent self-replicators that self-replicate within a very sheltered factory environment for the narrow
purpose of fabricate F-Units to deliver them thereafter upon the rolls to the home will be the most optimum way to utilize such independent, closed loop self-replicator capability but only within a broader domestic and industrial system. Such a system, overall can truly be defined as "self-replicating", "independent" and further expressing "digitally locked" "Digital Referenced Areas" (DRA).

The first self-replicating, device, the F-Unit was first made operable in 1998. It did indeed fulfill the requisite requirements to hold it as a genuine "self-replicator" in pure scientific terms for demonstration thereof. However, it was found to be exceedingly slow to self-replicate (over 6 months) due to the time needed for dabbing liquids and actuator speeds and wait times to prevent overheatings. This was due to the necessary tradeoff of efficiency for self-replicating capability built into the actuator design. The same was true with the F-Unit replicator that replicated a copy of itself that, thereafter could lay tiles and dab liquids upon command of the computer or "Data Tracks" it made but with a high error rate. Further, it had no continuous serial capability due to errors that were cumulative in a serial self-replication attempt (serial self-replication means multigenerational self-replications). Such is the same with many life forms as they exist presently. Newer designed F-Units will overcome such drawbacks. Two patents were filed in 1997 and 1998 setting forth all herein.

The scientist that designed the system predicts the tiles, liquids and gasses and the F-Units themselves may someday be delivered encapsulated and through plumbing
into the home for automatic fabrication of pretty much all household objects of any reasonable resolution and very high resolution (detailed) objects can be had but at considerable slower build rates (four or five months for a computer chip for example). There would be no need to go out shopping and driving and using gasoline as products are evolutionarily perfected to customer's explicit orders on-line. He envisioned a large planet wide, fully autonomous system where huge industrial plants housing hundreds of laser banks and E-Beam (electron beam) cutters and other cutting devices work endlessly and autonomously to cut tiles and deliver them through plumbing networks to each and every home as ordered. Individual "mother" F-Units which are made of diamond and titanium that fabricate the "worker" F-Units when they wear out are actually fabricated at their requisite slow rate at the plants, precision cultivated
to replace other "mother" F-units that eventually wear out as well. Such will present complete industrial autonomy at a viable rate of production.

Such will present the long sought autonomous "closed loop" scenario in a way that is actually useful presenting the true full scope of the replicator's power in a completely autonomous, self perfecting, self-replicating, digitally referenced system. Frozen foods that are sliced into tiles or cubes with cold cutting (ablating) lasers could be delivered through insulated
plumbing as well and thereafter reassembled, thawed and eaten. In fact he predicts soon the entire planet's surface including homes, buildings, roads and sidewalks may be made up of mostly "DRA-Stuff". He is certain it is absolutely inevitable because it is too useful and important and most likely the only option for a populated planet whose populations seem to never decrease and whose industrial aspects pose ecological hazards in their present forms. Overall, in situ fabrication is far more petrol efficient than any means existing widespread today. A physical Internet will be effectively had, accessed anywhere by verbal command and the system will provide the most optimum and safe fabrication solution in terms of efficiency and waste emissions and recycling. Future systems may even be able to assist flora and fauna persist in their natural habitats.

In the past, tissue-engineering has had some problems. The main one was placing living cells accurately upon a three dimensional structure where they could fuse and grow. Of late, employing thermo-reversible gels color printers [1] (http://www.newscientist.com/article.ns?id=dn3292) have been used to attain the accuracy but such is limited to only liquid biological depositions in the gel suspension medium and limited, further because no scaffolding exists to support the liquids before they gel, at least automatically and particularly on a microscopic construct. Further, the ability to place individual cells and mix individual cells (or at least close to that) was not extant like is capable with the F-Unit fabricating system. The F-Unit system has the capacity to do the above on any level and further facilitate precision control of placement of such products amongst other hard grown structures, such as bone and interact with the construct during and after initial forming. It as well can effect post fabrication mixing of chemicals both hard and soft and further, hitherto unhad gaseous mixing. Further, the F-Unit system effects a form of precision, near single cell resolution placement process and interaction and transfer of technology between life processes that have been commandeered by the system in the form of individual cells (or larger) and its own or man's synthetic constructs.

Further, F-units present the capability of doing it "on the fly" or in "real time" while employing evolution processes thus closing the loop on all parameters possible for self-replicating biotics or bionics in any configuration. The F-unit system turns computing power and direct precision tooling power downward and inward focusing it to full resolution on all parameters of biological and non-biological self-replication and fabrication of mass structure. Designs for biotic and bionic F-Units and biotic and bionic materials for use in fabrications or other uses as well are designed and are being prepared for development constituting new life forms and new bionic life forms. Software implementations
for evolution development are designed and ready that as well employ all mixes of the above. System, planet, and galactic wide evolution imposed improvement software are an experimental project contemplated in the macro areas. With above provided, the F-Unit system will yield all that is necessary in man's technological advancement.

An F-Unit which is the primary tooling means within the DRA system can be viewed at the scientist's MySpace site here:

[2] (http://www.myspace.com/mechagenics) (click on "pics" within)

Self-replicating spacecraft

The idea of an automated spacecraft capable of constructing copies of itself was first proposed in scientific literature in 1974 by Michael A. Arbib,[34][35] but the concept had appeared earlier in science fiction such as the 1967 novel *Berserker* by Fred Saberhagen or the 1950 novellette trilogy *The Voyage of the Space Beagle* by A. E. van Vogt (see self-replicating machines in fiction, below). The first quantitative engineering analysis of a self-replicating spacecraft was published in 1980 by Robert Freitas,[36] in which the non-replicating Project Daedalus
design was modified to include all subsystems necessary for self-replication. The design's strategy was to use the probe to deliver a "seed" factory with a mass of about 443 tons to a distant site, have the seed factory replicate many copies of itself there to increase its total manufacturing capacity, and then use the resulting automated industrial complex to construct more probes with a single seed factory on board each.

Other references

- A number of patents have been granted for self-replicating machine concepts.[37] The most directly relevant include U.S. Patent 4,734,856 (http://patft.uspto.gov/netacgi/nph-Parser?patentnumber=4734856) "Autogeneric system" Inventor: Davis; Dannie E. (Elmore, AL) (March 1988), U.S. Patent 5,659,477 (http://patft.uspto.gov/netacgi/nph-Parser?patentnumber=5659477) "Self reproducing fundamental fabricating machines (F-Units)" Inventor: Collins; Charles Michael (Burke, VA) (August 1997), U.S. Patent 5,764,518 (http://patft.uspto.gov/netacgi/nph-Parser?patentnumber=5764518) " Self reproducing fundamental fabricating machine system" Inventor: Collins; Charles Michael (Burke, VA)(June 1998), and U.S. Patent 6,510,359 (http://patft.uspto.gov/netacgi/nph-Parser?patentnumber=6510359) " Method and system for self-replicating manufacturing stations" Inventors: Merkle; Ralph C. (Sunnyvale, CA), Parker; Eric G. (Wylie, TX), Skidmore; George D. (Plano, TX) (January 2003).

- Macroscopic replicators are mentioned briefly in the fourth chapter of K. Eric Drexler's 1986 book *Engines of Creation*.[3]

- In 1995, Nick Szabo proposed a challenge to build a macroscale replicator from Lego(tm) robot kits and similar basic parts.[38]
  Szabo wrote that this approach was easier than previous proposals for macroscale replicators, but successfully predicted that even this method would not lead to a macroscale replicator within ten years.

- In 2004, Robert Freitas and Ralph Merkle
  published the first comprehensive review of the field of self-replication (from which much of the material in this article is derived, with permission of the authors), in their book *Kinematic Self-Replicating Machines*, which includes 3000+ literature references.[1] This book included a new molecular assembler design,[39] a primer on the mathematics of replication,[40]
  and the first comprehensive analysis of the entire replicator design space.[41]

Self-replicating machines in fiction

In fiction, the idea dates back at least as far as Karel Čapek's 1920 play *R.U.R. (Rossum's Universal Robots)*.[42] A fundamental obstacle of self-replicating machines, how to repair the repair systems, was the critical failure in the automated society described in *The Machine Stops*.

A. E. van Vogt
used the idea as a plot device in his story "M33 in Andromeda" (1943), which was later combined with four other General Semantics stories to became the novel, The Voyage of the Space Beagle. The story describes the creation of self-replicating weapons factories designed to destroy the Anabis, a galaxy-spanning malevolent life form bent on destruction of the human race.

An early treatment was the short story *Autofac* by Philip K. Dick, published in 1955, which precedes von Neumann's original paper about self-reproducing machines.[43][44] Dick also touched on this theme in his earlier 1953 short story *Second Variety*. Another example can be found in the 1962 short story *Epilogue* by Poul Anderson, in which self-replicating factory barges were proposed that used minerals extracted from ocean water as raw materials.[43]

In his short story "Crabs on the Island" (1958) Anatoly Dneprov speculated on the idea that since the replication process is never 100% accurate, leading to slight differences in the descendants, over several generations of replication the machines would be subjected to evolution similar to that of living organisms. In the story, a machine is designed, the sole purpose of which is to find metal to produce copies of itself, intended to be used as a weapon against an enemy's war machines. The machines are released on a deserted island, the idea being that once the available metal is all used and they start fighting each other, natural selection will enhance their design. However, the evolution has stopped by itself when the last descendant, an enormously large crab, was created, being unable to reproduce itself due to lack of energy and materials.

Stanisław Lem has also studied the same idea in his novel *The Invincible* (1964), in which the crew of a spacecraft landing on a distant planet finds a non-biological life-form, which is the product of long, possibly of millions of years of, mechanical evolution. This phenomenon is also key to the aforementioned Anderson story.

John Sladek used the concept to humorous ends in his first novel *The Reproductive System* (1968, also titled *Mechasm* in some markets), where a U.S. military research project goes out of control.[45]

NASA's Advanced Automation for Space Missions study directly inspired the science fiction novel *Code of the Lifemaker* (1983) by author James P. Hogan.

The movie *Screamers*, based on Dick's short story *Second Variety*, features a group of robot weapons created by mankind to act as Von Neumann devices / berserkers. The original robots are subterranean buzzsaws that make a screaming sound as they approach a potential victim beneath the soil. These machines are self-replicating and, as is found out through the course of the movie, they are quite intelligent and have managed to "evolve" into newer, more dangerous forms, most notably human forms which the real humans in the movie cannot tell apart from other real humans except by trial and error.

The concept is also widely utilised in science fiction television. The TV series Lexx featured an army of self replicating robots known as Mantrid drones. Similarly the Replicators are a horde of self-replicating machines that appear frequently in Stargate SG-1, and Star Trek's Borg could also be considered as self-replicating machines.

Other notable works containing replicators

- "The Necessary Thing" by Robert Sheckley, in which the Universal Replicator is unwittingly tricked into replicating itself
- The Berserker series of books and short stories by Fred Saberhagen

- *The Forge of God by Greg Bear*
- *2010: Odyssey Two by Arthur C. Clarke*
- *The World at the End of Time* by Frederik Pohl
- *Recursion* by Tony Ballantyne ISBN 0-330-42699-0
- *Evolution* by Stephen Baxter
- *Spin* by *Robert Charles Wilson*
- *Prey* by Michael Crichton

Prospects for implementation

As the use of industrial automation has expanded over time, some factories have begun to approach a semblance of self-sufficiency that is suggestive of self-replicating machines.[46] However, such factories are unlikely to achieve "full closure"[47]
until the cost and flexibility of automated machinery comes close to that of human labour and the manufacture of spare parts and other components locally becomes more economical than transporting them from elsewhere. Fully-capable machine replicators are most useful for developing resources in dangerous environments which are not easily reached by existing transportation systems (such as outer space).

An artificial replicator can be considered to be a form of artificial life. Depending on its design, it might be subject to evolution over an extended period of time.[48] However, with robust error correction, and the possibility of external intervention, the common science fiction
scenario of robotic life run amok will remain extremely unlikely for the foreseeable future.[49]

See also

- Conway's Game of Life
- Grey goo
- Ecophagy
- Computer virus

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External links

- The Clanking Replicator Project: Bootstrap your own self-replicating, rapid prototyping machine (http://www.3dreplicators.com)
- Cornell's Self-replicating machine (http://ccsl.mae.cornell.edu/research/selfrep/)
- The RepRap Project: Creating wealth without money... (http://reprap.org)
- Terraforming Mars and Venus using machine self-replicating systems (SRS) (http://www.rfreitas.com/Astro/TerraformSRS1983.htm)
- Green Goo - Life In The Era Of Humane Genocide (http://www.archive.org/details/NickSzabosEssayGreenGoo-LifeInTheEraOfHumaneGenocide) by Nick Szabo

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