Letters to the Editor

We invite readers of the *Journal of Space Philosophy* to send us letters referencing any past publication, to suggest subjects for future publication, or to submit information from anywhere in the Global Space Community. ***Bob Krone and Gordon Arthur***.

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Questions about a Lunar Colony

By Gordon Arthur, October 21, 2014

Dear Editor,

As I was reviewing and preparing David Schrunk's article for the Fall 2014 issue of the *Journal of Space Philosophy*,[1] the overriding question that stuck in my mind was how do we overcome the physiological effects of the low lunar gravity? Anyone staying on the moon for long enough will eventually be unable to return to Earth, even for a visit, as he or she will lose so much bone mass, particularly in the pelvis, that the Earth's gravity will crush his or her skeleton on landing. While I will take calculated risks under reasonable circumstances, my bottom line for any move into space would be a stable, breathable atmosphere, adequate food and water, and sufficient gravity (artificial or natural) to maintain the integrity of my skeleton. I wondered if he had any ideas on how the first and third of these might be achieved?

Later in the year, after the publication of this article, a research team from MIT led by Sydney Do produced an independent assessment of the technical feasibility of the Mars One mission plan, which they delivered at the 65th International Astronautical Congress in Toronto, Canada on September 30, 2014.[2] While this does not directly address the challenges of building a settlement on the moon, some of the problems Do et al. identify also seem to apply to a lunar settlement. They also address my second concern.

In particular, Do et al. found that if the crop-growing module shares the same atmosphere as the living area, after about 68 days the molar fraction of oxygen will become dangerously high, causing automatic venting, thereby reducing the atmospheric pressure to the point of inducing hypoxia in the crew and potentially leading to suffocation, unless a way can be found either to increase the nitrogen level at a comparable rate or to absorb or vent oxygen without reducing the atmospheric pressure.[3] In the Martian case, there are plans to recover nitrogen from the atmosphere, which may partially offset this problem, but this option will not be available on the moon.

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[1] David G. Schrunk, "The Planet Moon Project," *Journal of Space Philosophy* 3, no. 2 (Fall 2014): 47-56.
[2] Do, Sidney, Koki Ho, Samuel Schreiner, Andrew Owens, and Olivier de Weck, "An Independent Assessment of the Technical Feasibility of the Mars One Mission Plan," Paper Given at the 65th International Astronautical Congress, Toronto, Canada, September 30, 2014. web.mit.edu/sydneydo/Public/Mars%20One%20Feasibility%20Analysis%20IAC14.pdf (accessed October 19, 2014).
[3] Ibid., 10.

In addition, Do et al. found that the humidity is likely to approach 100% about a week earlier, making life very uncomfortable for the crew.[4] Finally, their analysis found that over time, the majority of the cargo transported to Mars will need to be spare parts.[5]

Their conclusions were as follows:

> Our integrated Mars settlement simulation revealed a number of significant insights into architecture decisions for establishing a Martian colony. First, our habitation simulations revealed that crop growth, if large enough to provide 100% of the settlement's food, will produce unsafe oxygen levels in the habitat. As a result, some form of oxygen removal system is required – a technology that has not yet been developed for spaceflight.
>
> Second, the ISRU [in-situ resource utilization] system sizing module generated a system mass estimate that was approximately 8% of the mass of the resources it would produce over a two year period, even with a generous margin on the ISRU system mass estimate. That being said, the ISRU technology required to produce nitrogen, oxygen, and water on the surface of Mars is at a relatively low TRL [technology readiness level], so such findings are preliminary at best. A spare parts analysis revealed that the mass of spare parts to support the ISRU and ECLS [environmental control and life-support] systems increases significantly as the settlement grows – after 130 months on the Martian surface, spare parts compose 62% of the mass transported to the Martian surface.…
>
> In general, technology development will have to focus on improving the reliability of ECLS systems, the TRL of ISRU systems, and either the capability of Mars in-situ manufacturing and/or the cost of launch. Improving these factors will help to dramatically reduce the mass and cost of Mars settlement architectures.[6]

I wonder how this paper affects his earlier argument.

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Response from David Schrunk, December 29, 2014

Thank you for the questions from Gordon Arthur regarding proposed Moon and Mars settlements. The subject matter has many facets and I expect that this dialogue will not end with a short discussion.

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[4] Ibid., 11.
[5] Ibid., 16-21.
[6] Ibid., 25

QUESTION/COMMENT (Arthur): **The overriding question that stuck in my mind as I read this was how do we overcome the physiological effects of the low lunar gravity? Anyone staying on the moon for long enough will eventually be unable to return to Earth, even for a visit, as he or she will lose so much bone mass, particularly in the pelvis, that the Earth's gravity will crush his or her skeleton on landing.**

RESPONSE (Schrunk): Two points. First, we don't yet know what the effects of the lunar gravity will be on humans. We will simply have to go to the Moon and take measurements of physiological effects over long periods of time. From my perspective as a physician, I believe that the deleterious effects of the Moon's 1/6th Earth gravity will be far less onerous than those experienced in the microgravity environment of the International Space Station (ISS) in low Earth orbit. The people who will live and work on the Moon will use the same bipedal posture and locomotion as they now use on the Earth (exhibit A = Apollo astronauts on the lunar surface). The result will be that the forces on their muscles, bones, tendons, and joints will be smaller but otherwise identical to those of the Earth, i.e., diminished in magnitude only – not completely absent as in microgravity. Cardiovascular degradation (and body fluid shifts/kidney function response) should be less pronounced on the Moon, for the same reason. In the best case scenario, we will not need to "overcome" the gravity of the Moon. We will lose some muscle/bone mass, but will otherwise experience little or no deleterious effects.

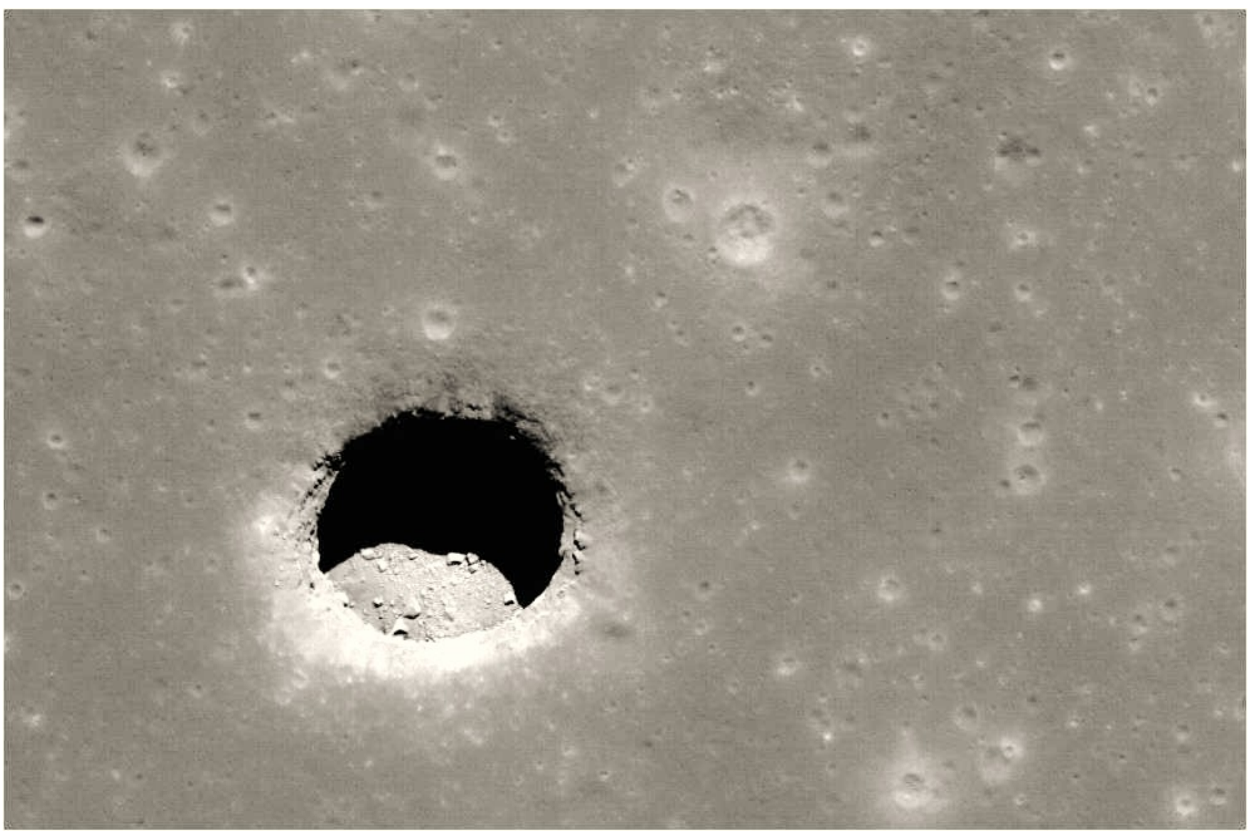
Second, the purpose for going into space is to become a spacefaring civilization, where humans will live permanently in space, on planets and moons in the solar system and eventually on planets of other star systems. The universe is the destiny of humankind. I envision a substantial permanent population of people on the Moon by the end of this century – people who appreciate their Earth heritage but who have adapted to their new home in space (at 1/6th gravity) and *who will never return to Earth*. They may lose bone mass and that will deter or prevent them from returning to the gravity well of the Earth. But that will be their choice. This may be particularly true for pioneers who have physical disabilities – they will contribute to the exploration and development of the Moon while enjoying the increased degree of freedom offered by the lesser gravity.…

QUESTION/COMMENT: **My bottom line for any move into space would be a stable, breathable atmosphere, adequate food and water, and sufficient gravity (artificial or natural) to maintain the integrity of my skeleton. Are there any ideas on how the first and third of these might be achieved?**

RESPONSE: The next stage of space exploration will involve the establishment of a *manufacturing base on the Moon* as explained in my article. With (virtually) unlimited material and energy (i.e., sunlight) resources, the manufacturing base (initially tele-operated from the Earth) will produce the means for sustaining permanent human settlements. The first objective of the lunar base will be to secure continuous power on the Moon and continuous communications with the Earth (I and coauthors Madhu Thangavelu and Burt Sharpe presented a concept for a lunar base configuration in the South Polar Region of the Moon that would accomplish these goals; Toronto IAC meeting, October 1, 2014).

When continuous power and communications are achieved on the Moon (within the coming decade), the lunar industrial base will produce the tools and equipment that are needed for the development and support of permanent human habitats and for scientific exploration – and the output and capability of that base will grow, *exponentially*, every year over the next century. In other words, the lunar base will be able to build completely regenerative life-support systems (with food, water, and stable atmospheres) that will supply the physiologic needs of thousands/tens of thousands of inhabitants.

Fortuitously, there are underground chambers (lava excavations) on the Moon that can protect large communities of people from the radiation, temperature extremes, and micrometeorite hazards of space (see photo below). All we need to do, during the initial phases of lunar development, is to deliver inflatable structures (such as those being developed by Bigelow Aerospace) to those chambers, supply them with power, communication, oxygen, water, and food, and we will have the beginnings of permanent human presence on the Moon. The next step is to tap into the vast resources of the Moon, cis-lunar space, and the asteroid belt, and we quickly evolve into a spacefaring civilization.



The photo depicts the opening (60-80 meters in diameter) of an underground chamber on the Moon. The chamber is 60-80 meters deep and its underground volume is unknown, but it may be thousands of meters in diameter. Inflatable habitats placed within this chamber will enable inhabitants to enjoy comfortable surroundings while being completely protected from the hazards of space – a new home in space that inaugurates the spacefaring future of humankind.

The answer to the second part of the question: If gravity augmentation is found to be necessary on the Moon (say, for the return of Moon residents to the Earth after a prolonged visit to the Moon), large centrifuges, in comfortable and safe underground environments, could be constructed for this purpose. For athletes on Earth, bone mass (in the tibia and femur, for example) increases dramatically over the course of a sports season (e.g., basketball, football) as the result of training and exercise. By existing temporarily in an artificially increased gravity field over a period of weeks, individuals could experience a physiological response of their musculoskeletal system that is sufficient for them to return safely to the gravity well of the Earth despite having lived on the Moon for a number of years.

QUESTION/COMMENT: Later in the year, after the publication of this (lunar development) article, a research team from MIT led by Sydney Do produced an independent assessment of the technical feasibility of the Mars One Mission plan, which they delivered at the 65th International Astronautical Congress in Toronto, Canada on September 30, 2014. While this does not directly address the challenges of building a settlement on the moon, some of the problems Do et al. identify also seem to apply to a lunar settlement. They also address my second concern.

In particular, Do et al. found that if the crop-growing module shares the same atmosphere as the living area, after about 68 days the molar fraction of oxygen will become dangerously high, causing automatic venting, thereby reducing the atmospheric pressure to the point of inducing hypoxia in the crew and potentially leading to suffocation, unless a way can be found either to increase the nitrogen level at a comparable rate or to absorb or vent oxygen without reducing the atmospheric pressure. In the Martian case, there are plans to recover nitrogen from the atmosphere, which may partially offset this problem, but this option will not be available on the moon. In addition, Do et al. found that the humidity is likely to approach 100% about a week earlier, making life very uncomfortable for the crew. Finally, their analysis found that over time, the majority of the cargo transported to Mars will need to be spare parts.… I wonder how this [Do's] paper affects his [Schrunk's] earlier argument.

RESPONSE The analyses and comments by Do et al., point out the significant advantages of near-term lunar development as opposed to Mars' exploration and development. The *KEY* to the next stage of space development is the establishment, in space, of a manufacturing base that taps into the material and energy resources of space and that produces the infrastructure needs of off-world human settlements and explorations. The distance from Earth to Mars precludes real time tele-operation of robotic devices on Mars from the Earth, and a practical manufacturing base on Mars is simply *not possible* at this time. In contrast, robotic devices on the Moon can be controlled (tele-operated) from the Earth with a round-trip speed-of-light time of less than three seconds. For lunar development, therefore, a number of ground stations around the Earth, with participants from virtually all nations on Earth, could conduct real-time mining, transportation, processing, manufacturing, and construction projects on the Moon continuously.

Infrastructure networks such as power, transportation, communication, and pipeline systems will be constructed on the Moon by the lunar manufacturing base that operates, via tele-operation from the Earth, continuously, and grows exponentially. Regenerative life support systems will be constructed with living quarters for humans separated from greenhouse modules, whose environment will be optimized for plant growth in terms of temperature, humidity, and atmospheric composition. Atmospheric gases in compartments for human occupation and for greenhouses will be monitored and controlled, and excess gases such as oxygen and carbon dioxide will be captured and diverted for other uses or stored. The growing need for spare parts at the Mars base, as mentioned by Do et al., will not be a problem on the Moon; spare parts will be manufactured at the lunar base on demand by tele-operated 3-D printing machines as needed.

As currently planned, Mars' missions will expose explorers to claustrophobia, dangerous levels of radiation, and limited means to exist at the end of a very tenuous supply line. In contrast, a Moon-first approach to space exploration will protect against all contingencies. The rapid growth of lunar manufacturing will enable humans to live and work on the Moon in comfortable and safe environments and enable the Moon to replace the Earth as the hub of space exploration and development efforts (with the advent of mass drivers that launch lunar-made spacecraft to all corners of the solar system). With proper planning, the Moon-based manufacturing facilities will produce and launch the essential elements of a Mars base to the surface of Mars in advance of human habitation. Then, when the first humans arrive at Mars, the infrastructure needed to support permanent human habitation will already be in place. In other words, the investment in a manufacturing capability on the Moon will enable Mars to be explored and developed on a much larger scale and shorter timetable than a Mars-first approach that bypasses the Moon.

Last word. I'm an optimist – and that attitude is justified by the accomplishments of humankind during my lifetime (breaking the sound barrier, deciphering the genetic code, defeating polio and smallpox, landing on the Moon, development of computers, CAT scanners, and the Internet, etc.). We are going to use that same "can do" attitude to become a spacefaring civilization, and the Moon is the key!

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Global Collaboration on Basic Space Science Research Is Needed

By Terry Tang, March 21, 2015

A Bay Area News Group Editorial of March 20, 2015 states that the "U.S. needs to get back into basic research." It goes on, "The United States is losing its edge.… China now performs more R&D than the United States, and South Korea and Germany have greater annual growth in R&D expenditures."[7] Competition among nations can be replaced with research collaboration benefitting everyone globally. Refer to the Space Renaissance International Congress soon to be held: it has adopted the theme, "Space, not War."

Now is the time for Global Basic Space Science Research, because human evolution has occurred since its beginning on Earth's environment. In the last couple of centuries, the industrial and post-industrial eras caused changes on Earth affecting human development, medical health, and psychological health. *Human interaction with the physical world during the last 300+ years has affected human biology*. Increases in longevity, skeleton size, muscle mass, population, city dwelling, use of artificial lighting and electric and carbon products, and travel across time zones and distances have also increased.

Science has found and is finding an increasing amount of knowledge on neurochemical processes in the brain and body that regulate health, performance, sleep, and mood that are affected by the quality of light and air, food and lifestyles on Earth. Now, men and women are living in Space where gravity is also different from that on Earth.

Chronobiology, part of space science, studies internal time regulated by a neurological mechanism, the circadian clock. It is connected to both the body's internal and external environments. These connections work in both directions with a feedback loop which, when running smoothly, leads to healthy life. Basic space science research needs now to be expanded to understand how the body's feedback loop from internal to external environments on Earth and in Space function. Currently the International Space Station's (ISS) program is a joint project among five participating space agencies of 16 nations: NASA, Roscosmos, JAXA, ESA, and CSA . Perhaps now is time to invite other nations such as India, Brazil (which has never had a war with another nation), China, etc., to join the ISS's program.

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Matter and Energy

By Peter Baker, April 19, 2015

Dear Editor,

Despite significant recent advances in cosmology, it appears that the fundamental questions of when time began, where our universe ends, and the origin of matter and energy remain unresolved. I feel that sometimes a contributing factor to this lack of progress is a failure to look beyond conventional concepts of our universe when searching for answers. This situation has, however, begun to alter in the past few years,

[7] http://www.mercurynews.com/opinion/ci_27736399/mercury-news-editorial-u-s-needs-increase-r

particularly with cosmologists such as Professor Sean Carroll of Caltech, whose work suggests that new ordered universes could be created spontaneously from the cold space of a previous universe. As alternate views, a number of physicists question the existence of time prior to the universe, while some others attempt to minimize its import to cosmological theories.

Firstly, although "Time" could be said to have started in the "Big Bang" 13.8 billion years ago as a function of the universe, and will cease when, or if, it disappears, this concept does not address the question of an ultimate beginning.

To consider this properly, it may be useful to think of whatever preceded the instant of creation of our universe as "Pretime". This suggests that it is not a fixed entity, and that its characteristics include the capability of supporting the creation of the creative instant, a two event process, following which everything within the universe became subject to time, with pretime continuing externally. Its beginning, however, appears impossible to determine.

There is general consensus that the Big Bang began as an infinitesimal entity and included both inflation and expansion components, the latter continually accelerating in rate. This enables conceptualisation of the entire universe, observable and unobservable, as a potentially finite, rather than infinite, entity, but does not address the fundamental question of where its creation occurred, and where the boundaries of that might be.

In the past few decades, however, it has been discovered that only 4.8% of the universe consists of normal atomic matter, the vast majority of it comprising dark matter (26.8%), and dark energy (68.4%), which is continually increasing in amount. The origin and role of dark matter and dark energy has remained unresolved, but if it is assumed the universe had to originate in something else, then dark matter and dark energy may be the embodiment of these surroundings, and the source of normal matter and energy. For convenience, it could be termed Dark Space. This concept could conceivably explain the continuing increase of dark energy within the universe as an ongoing permeation of its surroundings, but unlike the universe, it can neither be conceived as finite, nor its origins determined.

The beginning, structure, and boundaries of existence remain unresolved puzzles, and arguably creation was essentially their resolution. Our very existence proves, however, that this was achieved, and so the point I wish to make in this letter is that if we are to continue to search for answers, the consideration of different concepts, and posing new questions, as I have tried to do here, will be key to success. I welcome the recent trends towards this approach, and recognise their affinity with my own thinking. I hope to publish a detailed article on these matters later.

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Editors' Notes: We welcome Peter Baker's inclusion in the *Journal of Space Philosophy* his beyond universe musings about the unknown. He generated a dialogue among some of the Journal's members of the Board of Editors that will lead to more extensive future discussion on his thoughts. ***Bob Krone and Gordon Arthur*.**

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Recursive Distinguishing

By Joel D. Isaacson and Louis H. Kauffman, April 28, 2015

Dear Editor,

This letter is an advance statement about a paper that we (Joel Isaacson and Lou Kauffman) are in the process of writing. The work we are about to present is based on our mutual collaboration and is founded in the original work of Joel Isaacson[8] on recursive distinctions and the structure of character strings and on the work of Louis Kauffman[9] on recursion and distinction in cybernetics and in relation to the work of George Spencer-Brown.[10]

Everyone who works in science, mathematics, or computer science is familiar with the fundamental role of the concept of distinction and the making of distinctions in both theory and practice. For example, Einstein's relativity depends on a new distinction between space and time relative to an observer and a new unification of space and time that is part and parcel of this distinction. Every moment of using a digital computer

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[8] Joel D Isaacson, "Autonomic String-Manipulation System," U.S. Patent No. 4,286,330, Aug. 25, 1981, www.isss.org/2001meet/2001paper/4286330.pdf; Joel D Isaacson, "Steganogramic Representation of the Baryon Octet in Cellular Automata." Archived in 45th ISSS Annual Meeting and Conference: International Society for the System Sciences, Proceedings, 2001, www.isss.org/2001meet/2001paper/stegano.pdf; Joel D Isaacson, "The Intelligence Nexus in Space Exploration," in *Beyond Earth: The Future of Humans in Space*, ed. Bob Krone (Toronto: Apogee Books, 2006), Chapter 24, thespaceshow.files.wordpress.com/2012/02/beyond_earth-ch24-isaacson.pdf; Joel D Isaacson, "Nature's Cosmic Intelligence," *Journal of Space Philosophy* 1, no. 1 (Fall 2012): 8-16, bobkrone.com/sites/default/files/Nature%e2%80%99s%20Cosmic%20Intelligence%20%20By%20Joel%20Isaacson,PhD.pdf.

[9] Louis H Kauffman. "Sign and Space," in *Religious Experience and Scientific Paradigms: Proceedings of the 1982 IASWR Conference* (Stony Brook, NY: Institute of Advanced Study of World Religions, 1985), 118-64; Louis H Kauffman, "Self-reference and recursive forms," Journal of Social and Biological Structures 10 (1987): 53-72; Louis H Kauffman, "Special Relativity and a Calculus of Distinctions," Proceedings of the 9th Annual International Meeting of ANPA (Cambridge: APNA West, 1987), 290-311; Louis H Kauffman, "Knot Automata," Proceedings of the Twenty-Fourth International Conference on Multiple Valued Logic – Boston (Los Alamitos, CA: IEEE Computer Society Press, 1994), 328-33; Louis H Kauffman, "Eigenform," *Kybernetes* 34, no. 1/2 (2005): 129-50; Louis H. Kauffman, "Reflexivity and Eigenform – The Shape of Process," *Kybernetes* 4, no. 3, (July 2009): 121-37; Louis H Kauffman, "The Russell Operator," Constructivist Foundations 7, no. 2 (2012): 112-15; Louis H Kauffman, "Eigenforms, Discrete Processes and Quantum Processes," *Journal of Physics, Conference Series* 361 (2012): 012034; Marius Buliga and Louis H Kauffman, "Chemlambda, Universality and Self-Multiplication," in *Artificial Life 14 – Proceedings of the Fourteenth International Conference on the Synthesis and Simulation of Living Systems*, ed. Hiroki Sayama, John Rieffel, Sebastian Risi, René Doursat, and Hod Lipson (Cambridge, MA: MIT Press, 2014).

[10] George Spencer-Brown, *Laws of Form* (London: Allen & Unwin, 1969).

depends upon the myriad of distinctions that are handled automatically by the computer, enabling the production and recording of these words and the computation and transmission of information. Distinctions act on other distinctions. Once a new distinction is born, it becomes the object of further action. Thus grows all the physics that comes from relativity and thus grows all the industry of computation that grows from the idea and implementation of the Turing machine, the programmed computer.

And yet it is not usually recognized that it is through *recursive distinguishing* that all such progress is made. We will discuss recursive distinguishing both in its human and its automatic aspects. In the automatic aspect we will give examples of automata that are based on making very simple distinctions of equality, right/left, that then, upon allowing these distinctions to act on themselves, produce periodic and dialectical patterns that suggest what are usually regarded as higher-level phenomena. In this way, and with these examples, we can illustrate and speculate on the nature of intelligence, evolution, and many themes of fundamental science.

We give here an example of recursive distinguishing that is based on recursively rewriting strings of symbols where we use the special set of symbols {D, <, >, *} and can begin with any string of typographical symbols. The recursion is based on distinguishing the neighbors of a given character in the string. So if C is a character in the string S, we produce a string S' such that the end-points of the new string S' are unchanged and:

1 C' = < if C has a copy of C as a right-hand neighbor, but a different left-hand neighbor.
2 C' = > if C has a copy of C as a left-hand neighbor, but a different right-hand neighbor.
3 C' = * if both the right- and left-hand neighbors are equal to C.
4 C' = D if both the right- and left-hand neighbors of C are different from C.

Thus if S = * A B *, then S' = * D D * and S'' = * < > * and S''' = * D D *. This is a simple period two pattern. Now consider S = * ABA *. Then we have S' = * DDD *, S'' = * < * > *, S''' = * D D D * and again a period two pattern. But now examine Figure 1, and we see that there is a period three pattern for S = * A B A B *:

ABAB
DDDD
*<**>*
D<>D
DDDD
Figure 1: Period Three.

In Figure 2, we show a Mathematica program that instantiates these rules. In Figures 3 and 4, we show examples of higher periods.

```
    ZZ = " * A B R A C A D A B R A * ";
w = StringSplit[ZZ];
LL = Length[w]
Print[ StringJoin @@ w];
ww = w;
For[i = 0, i < 20,
    For[j = 2, j < LL,
        ww[[j]] = "D";
        If[ w[[j]] == w[[j - 1]], ww[[j]] = ">", ];
        If[ w[[j]] == w[[j + 1]], ww[[j]] = "<", ];
        If[ w[[j - 1]] == w[[j]] && w[[j]] == w[[j + 1]], ww[[j]] = "*"];
        j++];
    w = ww;
    Print[ StringJoin @@ ww];
    i++]
```

Figure 2: A Mathematica Program for the Recursive Discriminator

```
*ABABABAB*
*DDDDDDDD*
*<******>*
*D<****>D*
*DD<**>DD*
*<>D<>D<>*
*DDDDDDDD*
```

Figure 3: Period Five

```
*ABABABABABABABAB*
*DDDDDDDDDDDDDDDD*
*<**************>*
*D<************>D*
*DD<**********>DD*
*<>D<********>D<>*
*DDDD<******>DDDD*
*<**>D<****>D<**>*
*D<>DDD<**>DDD<>D*
*DDD<*>D<>D<*>DDD*
*<*>DDDDDDDDDD<*>*
*DDD<********>DDD*
*<*>D<******>D<*>*
*DDDDD<****>DDDDD*
*<***>D<**>D<***>*
*D<*>DDD<>DDD<*>D*
*DDDD<*>DD<*>DDDD*
*<**>DDD<>DDD<**>*
*D<>D<*>DD<*>D<>D*
*DDDDDDD<>DDDDDDD*
*<*****>DD<*****>*
*D<***>D<>D<***>D*
*DD<*>DDDDDD<*>DD*
*<>DDD<****>DDD<>*
*DD<*>D<**>D<*>DD*
*<>DDDDD<>DDDDD<>*
*DD<***>DD<***>DD*
*<>D<*>D<>D<*>D<>*
*DDDDDDDDDDDDDDDD*
```

Figure 4: Period 27.

The remarkable feature of these examples of recursive distinguishing is their great simplicity coupled with the complexity of behaviors that can arise from them. Notice that each successive string in the recursion can be regarded as *describing* its predecessor. It is remarkable that there should be such intricate structure in the process of description. Description is another word for making a distinction. The description of a given string is a string of individual distinctions that have been made. Each individual distinction is one that recognizes whether a given character in a string is equal to a left neighbor, a right neighbor, both, or neither. This elementary distinction becomes instantiated as a character in the new description string. The description string can be subjected to the same scrutiny and so the recursive process continues.

Note that this recursive process depends, at its base, on the most elementary distinctions possible for character strings. No mathematical calculations are performed. We should mention that distinction-making without mathematical computation is ubiquitous in natural neuronal processing. Joel Isaacson's collaboration with Eshel Ben-Jacob includes attempts to demonstrate RD in live neuronal tissue.[11] One can also point to the molecular interactions of DNA and RNA as natural RD automata. Finally, we can point to the notion of chemlambda computation of Buliga and Kauffman[12] as an abstract chemical combination computing that includes aspects of lambda calculus, but is based on direct and local action related to distinctions inherent in the system.

All these matters will be discussed in more detail in the longer paper. Note that in the RD system we use in this letter, the action is taken on the entire string before replacing it with a new string. Thus it is the distinctive structure of the string as a whole that is being described.

The epistemology behind this automaton is based directly on distinctions that can be made automatic. Other cellular automata are also based on distinctions. For example the well-known Wolfram line automata[13] are based on character strings with only two characters and the recognition of the eight possible triples of characters that can occur, including characters to the left and to the right of a given character. The automaton rule then replaces the middle character according to the structure of this neighborhood.

There is a crucial difference in epistemology between a Wolfram line automaton and our recursive distinction program. We do not replace according to an arbitrary rule. We place a character that describes the distinctive structure of the neighborhood of the predecessor character. *Our automaton engages in a meta-dialogue about its own structure.* This dialogue is then entered as a string for the automaton to examine and act upon once again. The patterns produced by this recursive distinction are part of a dialogue that the strings hold with themselves.

One can ask many questions about recursive distinguishing as presented here. The automaton we have demonstrated illustrates a concept that can be instantiated in many ways. We hope, in the paper to come, to demonstrate Turing universality for automata of this type. But in fact we feel that the paradigm of recursive distinguishing goes beyond the paradigm of the Turing machine, and we will discuss that issue as well.

There is another level to our automaton and *that is the level of examining with human eyes and minds* the output of the automaton, seeing patterns in the whole collection of strings and engaging in further design on this basis. This is where the recursive automatic distinctions meet the aware distinctions of the observers of the system, connecting the automatic with the aware process and design level that goes on in the larger network of science. We will stop here with our letter. We intend to discuss all these issues in more detail in our longer paper.

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[11] Personal communication.
[12] Buliga and Kauffman, "Chemlambda."
[13] Stephen Wolfram, "A New Kind of Science," (Champaign, IL: Wolfram Media, 2012).