for suffering in other animals is not enough of a reason to just allow humans to eat anything they want to eat. These animals at least deserve our moral consideration, just as a human being—even with severe brain damage—would deserve consideration to avoid suffering. Regardless of species, all life with a long-term memory, a capacity for suffering, and awareness of pain deserves to have that considered and ideally reduced. Just as being racist has been found to be an abhorrent, fallacious viewpoint, someday perhaps the same will occur for speciesism.

But, what if "matter-ism" is the next logical and moral fallacy that we cannot see today? If robots or artificial species that we have engineered or that come to exist take over our role as Guardians, we could not declare that "these pieces of matter are not the same as us, and thus can be disregarded." Using the same syllogism as above, it is likely that we cannot morally discriminate against matter (carbon-based or otherwise) either.

Even the mechanical life of the future, if truly sentient and aware of extinction, would have a prerogative and self-sustained imperative to preserve its own, and others', existence. For it, too, "existence precedes essence." Thus, at this point in the ten-phase plan, we would have no preference for organic versus inorganic matter as the stewards and protectors of the sentience of the universe. The Guardian species by then may all be mechanical in nature, or biological, or even a combination of both within a singular being. At this point, all existing Guardians will hopefully look out to the horizon and feel that sense of duty to all self-replicating and sentient entities across the universe. For any Guardians to survive, they must work together and expand throughout the solar system (and universe) and support each other.

Once this vision is achieved, the final stages of preparation for becoming interstellar entities can begin. Self-reliant, mobile cities can now be engineered, packaged, and sent to the best candidate planets to ensure our—or our inheritors'—survival. For the first time in the history of life, life itself will choose its own sun to orbit.

11

PHASE 9: LAUNCH TOWARD THE SECOND SUN (2401–2500)

> If we stay here, we'll all change. The air. Don't you smell it? Something in the air. A Martian virus, maybe; some seed, or a pollen.
>
> —Ray Bradbury, "Dark They Were, and Golden-Eyed"

The full, multisystem backup plan of Earth's life will initiate with the launch of the first generation ship around 2401. Beyond prolonging the existence of Earth's life, this initiative may even lead to the identification of new life unlike anything we have ever seen (similar to unnatural base pairs, UBPs, discussed in Phase 5). Through the identification of new findings on different worlds, we can look, again, into the universe with new lenses—such as new biosignatures and emission spectra in distant stars and planets. This will be the beginning of a sustainable presence of life in the universe, one that isn't at the mercy of the collapse of a single system (be it rogue asteroids, solar output, or ecosystem collapse) and, further, not defined by the limited window of life on only one planet.

However, every time humans have expanded into a new place, a drive for independence has erupted and often led to bloodshed, suffering, and death (e.g., the American Revolutionary War). Given this history, it is likely that a new settlement, colony, or outpost of humanity would eventually want its own rights, power, and governance—and could we blame them? The society that leaves Earth to settle new

worlds must eventually be as independent socioeconomically as they are with the production of their own required resources. They must not be exploited as a means to gain remote resources.

However, these societies shouldn't be cut off from the rest of life, either—that would only hinder the advancement of technological, biological, and ethical discoveries. Trade and autonomy between systems must be planned for, expected, and engineered into its initial design. Goods may come in digital form, such as point-to-point biology trade between ships, planets, and stars, as well as the creation of rare physical goods derived and created in new locations. Ideally, there will be a rich exchange of ideas, products, and knowledge between systems fulfilling the deontogenic duty as humans (or subsequent form of sentience) across a whole society.

A DEONTOGENIC SOCIETY

The potential deontogenic society of 2401 will feature the end of planned-obsolescence products (e.g., car parts purposefully engineered to fail after a year), enhance the widespread use of durable and efficient multipurpose machines, and optimized processes spanning across biology, genomics, and medicine. Rather than a simple, short-term capitalist drive to maximize dollars per unit on cheap devices, the new economic drive will be focused instead on maximization over the long term, including long-lasting products and investments that last generations. This will not only be a more ethical way to operate, but will actually be required to operate in a multiplanet state, where technology must last for long trips and with limited or no repair capacity. In space, there is no instant gratification or next-day shipping to replace something.

To adapt to this new era, companies will have to be built to last for the long term, with the best companies having multigenerational track records of reliable research and durable products capable of handling extremes across multiple planets. While companies that lasted for hundreds of years were rare in the twenty-first century on Earth, there were some examples. For example, Kongō Gumi, a manufacturing company in Japan, has been running since 578 CE. Similarly, experiments will be planned that span hundreds, thousands, and eventually even

tens of thousands of years, enabling the study of complex heritability of loci selected through directed evolution, as well as planetary-scale terraforming.

By 2401, the majority (or potentially all) of genetic disease will no longer cause human suffering. DNA sequencers (readers) and synthesizers (writers) will be both accurate and common. Technologies will enable the seamless mixing and synthesis of genetic networks in easy, accurate, and cheap ways, akin to DJs mixing and making music with a beat sampler. As noted by music critic Nate Harrison, both the sampler and the turntable were key tools largely responsible for the birth and development of hip hop. With the sampler, any sound that could be recorded could be used as part of a new composition.

The DNA sequencer is the "sampler" of genetics; the DNA synthesizer is the turntable. This means that any DNA fragment can be sequenced, and then used as part of a context of genome design. With the turntable, musicians can mix and match components to create new musical compositions. With the synthesizer, any DNA fragment can be combined to create new genetic compositions.

In this era, humans have the ability to control their underlying genetic code, controlling for how their molecules fundamentally change in response to stimuli and enabling new abilities. This will enable an unprecedented ability to build, edit, and transplant cross-kingdom combinations of genomes, which we will need to survive on new worlds. The majority of other diseases or causes of human death on Earth will also largely decrease, including those associated with birth, cancer, and even accident. These advances will go beyond the Guardian species and be implemented to improve the quality of life for other animals as well. There will no longer be an excuse for animal suffering, caused by humans or even parasites. The continual engineering of animals, plants, and single cell organisms will enable them to thrive in previously unimaginable conditions.

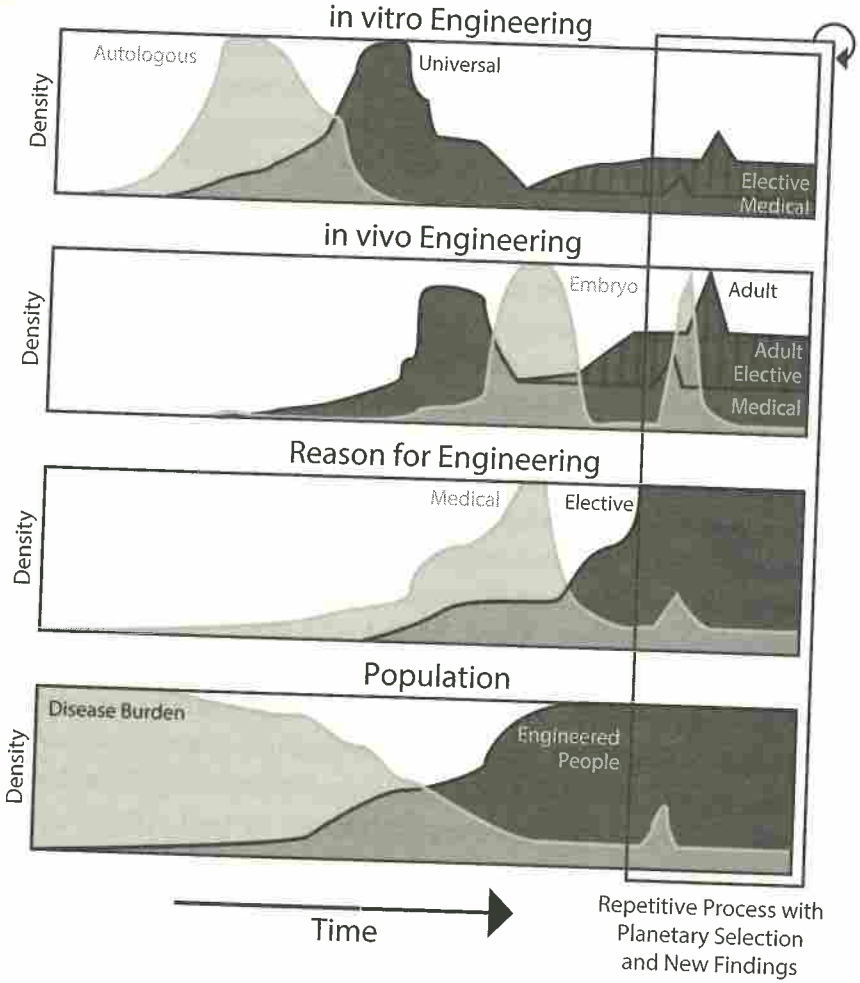
UBIQUITOUS AND CONTINUAL BIOLOGICAL ENGINEERING

The merger of two key events will fundamentally change human society forever, both of which are under active investigation with

promising results in the twenty-first century. First, the successful engineering, clinical validation, and broad utilization of exowombs. This process will start slowly, initially used only to finish the development of children born prematurely. Over time, these processes will improve, the fundamental laws of human development will be uncovered, and these technologies will be used earlier in human development. Eventually, they will be capable of bringing an embryo to a fully developed and perfectly healthy baby. Second, cellular engineering (including genome and epigenome editing) will continue to improve over time, enabling the editing, incorporation, or removal of any level of cell biology in accurate, inexpensive, and easy ways. Once these have been vetted within in vitro therapies, they will then be tested as adult in vivo applications and, eventually, within embryos.

However, the safest and most ethical way to incorporate these technologies within an embryo or fetus will be before it is developing within an exowomb, as opposed to its mother (or *one* of its mothers as previously discussed). In this way, the developing baby can be constantly monitored, and if/when issues arise, they can be quickly addressed and fixed. Eventually, it may be *more* ethical to have your child develop within an exowomb rather than its native mom, for both the health of the woman and the child. Reproduction would be further decoupled from sex, as new technologies to "engineer out" diseases will be developed, and highly specific, largely automated, monitoring technologies will be developed to further ensure the birth of a healthy child.

Moving from the embryo to the adult, here, too, the number of genetically engineered people will continue to rise over time (figure 11.1). This process already started in the twentieth century through the usage of ex vivo derived autologous (using the patient's own cells) and allogenic (using donor cells) cellular therapies, as described in chapters 3 and 4 (e.g., CAR-Ts). These technologies have been further under active development in the twenty-first century to derive "universal" cellular therapies, which can be picked out of a freezer and used to treat anyone regardless of their genetic background (HLA type) without the fear of graft versus host disease (GVHD). These universal cells will, for the first time, enable the widespread usage of cellular therapies by overcoming three of their main hurdles simultaneously: (1) the economic



11.1 Proportion of humans that could be edited over time. The number of genetically engineered people (top) would increase first for therapeutic purposes and then for enhancement reasons, until it would become unethical to not do any edits, and then another round of edits would appear that would reduce the disease incidence a second time (bottom) within a repetitive process.

burden of deriving a product of each person, every time they need it; (2) the amount of time it takes to derive a patient's own therapy; and (3) the unpredictability of how a patient's cells will respond to the engineering or act once engineered. Finally, these genetic engineering

therapies could be integrated into nanoparticles with engineered tropism to enable highly specific and precise engineering within a given person. These universal cells and in vivo engineering capabilities will work in synergy, creating customized cells to address more diseases for more people. These will eventually become the standard of care, leading to more cures and fewer treatments.

Indeed, assuming exowombs are shown to be safer than carrying a child full-term, it would be considered "poor parenting" to not include exowombs within a human's pregnancy plan, assuming you had the means. Or, future mothers might be viewed as "romantic" for doing gestation "the old-fashioned way." Further, once it has been shown that genetic editing can be done safely and improve long-term health, it would actually be recommended by geneticists and pediatricians where appropriate. As such, to *not use* it would be akin to refusing to use vaccines in the twentieth century and, appropriately, result in scorn and derision of the parents. This idea is just an extension of the same "herd-immunity effect" that is granted with widespread vaccination efforts, except now applied to heritable diseases.

The convenience of an exowomb and the empowerment for women notwithstanding, these will give us the greatest chance to develop healthy babies and even adults with lower medical risks. Through the efforts of The Online Mendelian Inheritance in Man (OMIM) database (even though it is a misnomer; diseases affect women too), which annotates genetic disorders, and ClinVar, the clinical variation database, a road map could be followed to correct mutations associated with single-gene disorders (e.g., cystic fibrosis), multifactorial disorders (e.g., diabetes and asthma), and even risk of infections (e.g., malaria).

However, this type of engineering would not only be applicable for familiar genetic diseases such as Down's syndrome, but would also improve immune, circulatory, and neurological systems. As an example, an optimized immune plan could be integrated to improve antigen-presentation and cellular differentiation to better identify foreign or unwanted pathogens while reducing the incidence of the destruction of one's own cells, as commonly happens in autoimmune and rheumatoid diseases. Further, OMIM contains over 25,000 entries as of 2021, some of which are genetic variations that lead to "abnormal laboratory

test values" (such as dysalbuminemic euthyroidal hyperthyroxinemia). These, too, could be improved.

THE GENE TRUST

The widespread application of these genetic therapies, and their adoption into society, will eventually blur the distinction between enhancements and therapies—from the first cell onward. The use of some genetic engineering strategies will likely require development in exowombs, while at the same time people will choose to do more engineering because they are already planning to use an exowomb—driving an increased usage and demand for both technologies.

There would likely be campaigns that promote the most, best, and healthiest options for embryos, using slogans like "From the first cell you get, to the first cell you choose." Eventually, *not performing* cellular optimization and *not using* exowombs would only lead to increased risks and endangerment for the child, their to-be mothers, members of the society, and even future generations. Performing cellular optimizations would be perceived as a duty that spans parental, social, intergenerational, and deontogenic dimensions, and fulfilling this duty will transform communities, countries, planets, and eventually all of humanity.

However, as is the case with any major update to code, in this case our shared genetic code, creating a backup is strongly encouraged. A "genetic backup" of unedited humans will likely exist, living in a separate society of their own, based on groups of some people's disdain for change across human history. However, given enough technological progress, this society is not a requirement for our backup. If necessary, we could simply undo our editing, reverting back to a previous version in our genetic library, using the same engineering technology—an even easier feat than the de-extinction of entire species. There is even an example of this in the twenty-first century, the Svalbard Global Seed Vault "Crop Trust" in Norway. Storing data and cells across human generations would result in a similar "Gene Trust," further maximizing our chance of long-term survival and protecting against extinction caused either by our own hubris or by accident.

UPRIGHT GENETICS

The idea of selecting and modifying entire human populations, while controversial and the basis of horrific Nazi experiments, has actually already been deployed successfully for ensuring health. The simplest example of this has already occurred in the twenty-first century, in the Ashkenazic and Sephardic Jewish communities. These religious groups (and especially Orthodox Jews) usually marry and have children only within their religion. Because of this selectivity, there has been a historically high rate of several genetic disorders, including Tay-Sachs disease, which is both painful and fatal. Tay-Sachs symptoms often appear in the first year of life as a loss of motor skills, seizures, vision and hearing loss, and muscle weakness. In almost all cases, when children carry both copies of the defective gene, they die by the age of four. There is no treatment or cure.

In 1983, Josef Ekstein, a rabbi in Brooklyn, New York, had an idea to stop the spread of these diseases: identify a potential couple's risk *before* they even meet or have children. In modern genetics, this is called "carrier screening," where potential parents have their genetic risk factors examined to reduce the risk of passing on a disorder to their would-be children. If potential mates were identified as being "carriers" for a set of diseases, they could avoid children with other carriers. This idea would decrease the incidence of Tay-Sachs and other diseases *without* the need for abortion, IVF, or PGD—an important requirement for the Orthodox Jews, given the opposition of such elective treatments, their complications, and expense in the 1980s.

Rabbi Ekstein started a project called *Dor Yeshorim*, meaning "upright generation," taken from an Old Testament verse (Psalms 112:2). This service set up genetic testing to identify if an individual carried mutations that could cause Tay-Sachs disease and saved this information into a database. People were then given a random code which they could use to call a number and find a mate, so that their offspring would be unlikely to have the disease. Over time, these systems became more sophisticated, and by 2021, one could simply order a relatively inexpensive ($225) test to check for a number of different diseases,

including cystic fibrosis and Canavan disease. Further panels may even be added depending on background risks.

Did love hit you hard and fast? Good news, there's even an "emergency test" for just this case ($450). As an extraordinary demonstration of the power that genetic planning can bring, there was a 90 percent reduction in the incidence of Tay-Sachs in ultraorthodox Brooklyn Jewish community after implementing this approach. Due to the widespread uptake of these approaches, a previously haunting and awful death sentence for children has been mostly removed from the world's Jewish population.

Indeed, the Dor Yeshorim project has been so successful that it has moved on to addressing other diseases. The "standard panel" of genetic testing for Dor Yeshorim now includes cystic fibrosis, Canavan, Niemann-Pick types A and B, familial dysautonomia, Fanconi's anemia, glycogen storage type 1A, Bloom syndrome, mucolipidosis type 4, and spinal muscular atrophy, among other diseases. Some of the testing is also specific to the Jewish background of each person, and there are specific gene panels for each possible genetic mixture. For example, Sephardic Jews are tested for twenty-three monogenic diseases, whereas Ashkenazi Jews are tested for ten.

The incredible decrease of devastating diseases has not gone unnoticed. Inspired by these stories, additional services have emerged to enable broader access to carrier screening technologies. One such example is a dating app called Digid8, spun out of George Church's lab, which enables people to share their genetic data and match with others, to decrease the chance that their offspring will inherit any number of severe diseases. If such a method were implemented for all severe diseases, there could be a dramatic reduction in disease burden and suffering around the world.

As genetic engineering treatments and enhancements become more common and broadly adopted, there will likely also be a strong social drive for genetic selection, similar to the carrier-screening methods of the twenty-first century. However, this selection process would have to be balanced by continuously examining and weighing the risk and reward associated with any genetic, epigenetic, or cellular alteration.

There will further need to be a clear characterization of what actually constitutes a *disease* or, more appropriately, once enhancement and therapies begin to be blurred, a *limitation*.

INDIVIDUAL, INTERGENERATIONAL, AND INTERPLANETARY RISK SCORING

Genetic risk factors of the twentieth century were driven by ancestry and historical patterns of human migration. For example, cystic fibrosis is the most common autosomal recessive disease among people of Northern European heritage, but is less common in Asian populations. Similarly, sickle cell anemia is more common in people with sub-Saharan African ancestry, but less common elsewhere in world. As with carrier-screening technologies, different methods could be implemented to decrease the overall global burden and suffering caused by these diseases through informing individuals of their to-be children's risk susceptibility. Over time, as these burdens decrease, their ancestral associations would also change, resulting in continually altered risk profiles.

As such, the population- and genetic-mapping tools employed in 2400 for disease or phenotype likelihood will need to continually reassess the associated risks and rewards of interventions to diseases, limitations, and enhancements. As such, a combined score could be derived for a specific disease with a specific treatment, in a specific location (including the current or pending planet), which weighs the impact these factors have for an individual, society, and economy. This score would then enable the comparison of one treatment to another for a specific disease or the severity of one disease with its best-possible treatment against another disease, thereby focusing research efforts to improve overall well-being.

Such a score did not exist in the twentieth century, since it depended on many factors that were hard to quantify. However, much like the Drake equation, whose formulation was useful as a guide to laying out the driving factors related to the question of intelligent life in the universe (vs. the exact answer), a similar genetic quotient of risk across one's life can be a useful guide and thought experiment. For such a

metric, the elements' impact and relevance would change over time, as society, technology, and treatments would continue to develop. Such factors would need to include those which weigh on the inflicted individual, those around them, the current population, and the future impact that a given treatment (or lack of one) could have on the economy and society, which would all be planet specific.

Indeed, at least thirteen factors would comprise such a "Lifetime Risk Score" for given phenotype (figure 11.2). These factors include:

1. The "background" population life expectancy;
2. Age of symptom onset;
3. The expected age of death;
4. Treatment success likelihood;
5. The overall quality of life (1 means no decrease in the quality of life, 0 absolute suffering or death);
6. Proxy suffering (suffering of loved ones or those around them, causing a negative feedback loop on patient's suffering);
7. The function of onset (relative to background population and as such location-specific);
8. Penetrance and the risk to develop the disease (1 if the patient already shows symptoms);
9. Pleiotropy (1 no pleiotropy, >1 complex negative phenotypic associations, <1 if associated treatment helps other phenotypes, such as comorbidities);
10. Balancing selection (1 if no evidence of balancing selection, >1 if evidence of selection, which may confer worse outcomes elsewhere, <1 if positive outcomes);
11. Heritability of condition;
12. Anticipation (the altered severity of disease over generations (1 if evidence of no worsening);
13. The economic burden (taking into account the cost of treatment, supportive care, and prevalence for current and future generations).

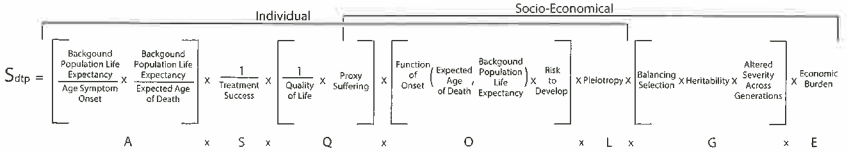
The values associated with this risk score (S) will depend on three things: the disease (d) or condition being examined; the treatment (t), or lack of one; and the place (p) of context, including new planets (p). To put this into a formula, this risk (S_{dtp}) could be represented as shown

in figure 11.2, as the aggregate score of combined disease-treatment-place risk (S_{dtp}).

The equation is designed such that a larger relative value would result in a worse outcome and therefore something that would need to be addressed. As an example, the earlier the onset relative to the background-population life expectancy, and the less time the person is expected to live, the larger this score will scale (age: A). The treatment success would be the chance that the treatment will work for the individual, such that a lower chance of success would result in a higher overall risk score (success: S). As treatment success tends toward zero, the overall score will approach infinity—making the usage of the treatment highly unlikely, unless it is the only option and results in a better outcome than no treatment at all.

Similar to treatment success, quality of life will further move this score, such that if quality of life is extremely low, approaching zero, the overall score will approach infinity. Proxy suffering further increases the score when a patient's quality of life is not maximized, expected age of death is not that of the background population, and there are others around who may suffer. This may then further increase the suffering of the individual, seeing their loved ones suffer on their behalf, which would need to be accounted for (quality: Q). However, if the quality of life is maximized and expected age of death is equal to background-population life expectancy, then proxy suffering would be equal to one, resulting in Q equal to one.

If a treatment is capable of extending the expected age of death beyond that of the background-population, then the age term (A)



11.2 This score allows for the comparison of how a disease, condition, or enhancement risk changes depending on treatment and location. This further allows for the relative ranking of the severity of a disease given limitations at the time, which can then direct future research.

will decrease. However, the overall well-being of the individual would depend on the amount of additional suffering they may experience in their additional time. As such, the overall score must be a function of the onset of the disease; for example, if their disease will get extremely worse for the majority of the additional time they have acquired from the treatment or location, then they may actually be worse off. The output from this function of onset is then further weighted by the risk to actually develop the disease or condition (onset: O), which is the "penetrance" of the allele—the proportion of people who get the disease if carrying a risk allele. If the risk to develop is close to zero for the individual, then the overall score would be low (approaching an asymptote of zero), whereas this term would be equal to one if symptoms already exist.

The overall pleiotropy will further play into both the individual and generational risks as well as the complexity of treating the condition (L, pLeiotropy). This value would be one if no pleiotropy is identified, and could actually be less than one in cases where there are overall positive associations or the treatment reduces comorbidities. Similarly, many effects which span generations would need to be tracked and analyzed (G, generational value), such as balancing selection, which may further result in additional pleiotropic effects. Also, if/how a condition may worsen over generations (anticipation), as with Huntington's disease, would be a key attribute that will likely strongly favor gene editing therapies which remove diseases from the population. Finally, economic burdens (E) would be a major factor including both the monetary and social strain of not only the therapy, but the continuation of a therapy across generations, if not corrected.

Such a score has the ability to simply compare the impact of one therapy versus another on a given disease or phenotypes, for a given person, in a given society. But beyond that, these scores could inform someone on how their life might change depending on where they live—whether on Earth or on different worlds. As an example, say a disease only starts to present itself at 80 years of age, but has a function of onset that rapidly causes a poor quality of life and death within a year (making the expected age of death 81). This disease would have

a much lower risk if the background-population life expectancy was only 50 (say, on board a ship), relative to a location with an average life expectancy of 100 (say, on future Earth), given that the person may likely never reach the age where symptoms develop. Therefore, the risk score of this disease, even if given the same treatment options at both locations, will be dramatically lower for the individual if they lived on the ship relative to Earth. The same idea can be applied to positive evolutionary selection pressures on one planet which can serve as risk factors on another. As such, these values will need to be analyzed and readily available for any combinations of interventions across different planets.

As seen with carrier-screening, it is likely that the first wave of genome engineering decisions based on S_{dtp} would start in a singular community, to address a given disease, which causes a large amount of burden and suffering. Once overall benefit is realized, these techniques would then be broadened to additional populations, and eventually span the globe for a multitude of ailments. The number of genetically engineered people would reach its peak, and the incidence of disease would fall (see figure 11.1).

Then, in vivo, embryonic engineering would replace the usage of somatic engineering, since it will decrease the economic burden, heritability, and any potential increased severity of the disease over generations, while offering the same improvements in quality of life. It is also likely that a "burst" of more subtle diseases or phenotypes would emerge after widespread adoption due to our own ill-defined understanding of the diseases and alleles, or even from new diseases that we face, as we gain the ability to explore new locations and worlds.

Once we pass the "postediting burst" of cryptic diseases, most editing would then be for adult cells, because the previous embryonic editing would be inherited and embryos would only need to be further edited for newly emerging or previously missed diseases. This could not only resolve the genetic risks for many diseases and disorders, but could lead to a world where any trait, from any organism, can be "toggled" on and off, as needed or simply wanted (such as recreational, low-oxygen living on the top of Mount Everest).

THE DANGER OF ABLEISM

However, this ostensibly beneficial plan to get rid of "bad genes" has several issues. First, as the extremely long yet oversimplified equation reveals, it will be no simple feat. While laudable in application to eliminate diseases, such as Tay-Sachs, it is this very same rationale that was used to lay the foundation of eugenics in the early 1900s. Eugenics has been the folly of many geneticists, including "councils of experts" in the 1920s who championed their enthusiasm to avoid disease and to imagine a world without suffering. They quickly started to think about mapping and quantifying "underperforming" traits beyond just severe diseases. The idea would be to essentially to put "chlorine in the gene pool" and remove any trait deemed "undesirable." Then, as now, there are councils of geneticists who annotate, quantify, and stratify diseases based on their own measures of severity, creating well-meaning metrics like S_{dtp}.

Yet, this ideology has historically had a devastating effect on society and the field of genetics. The eugenics movement of the twentieth century and its geneticists ended up eviscerating the liberty of individuals rather than safeguarding it, especially reproductive liberty. Laws were drafted and passed across the United States that required forced sterilization of any member of society who possessed a low intelligence quotient (IQ) or was deemed "retarded" by metrics from the *Diagnostics and Statistical Manual of Mental Disorders* (*DSM*). Such IQ metrics led to an estimated >70,000 sterilizations in the United States and the theft of the ability of those individuals' ability to have their own children. Importantly, the *DSM* itself changes over time, which means that "disease" and our definition is not just a matter of pure empiricism, but can be (and almost always is) influenced by society at the time, as discussed above. For example, homosexuality was listed as a disease in 1952 in the first edition of the *DSM*, but the listing was removed in the second edition in 1973, and has not returned since.

Another issue with the goal of removing "bad genes" is that it can promote "ableism," which is the prejudice or discrimination against individuals with disabilities. Work from Jacqueline Mae Wallis, among

others in disability studies, has shown that some reject the idea that deafness is a disability because it can enable an entire world of experiences, culture, and language that is unique and distinct from that of "the hearing." Moreover, deafness can also lead to new sensitivities of touch and tactile "feeling," especially for subtle vibrations, that may not readily be available for hearing people.

The unique physiological, cultural, social, or cognitive abilities that people experience due to their specific genetics, whether it is a disability or not, have led some couples to express an interest in editing or selecting IVF embryos so that their children will have similar experiences—including some deaf couples wanting to ensure that their child is deaf. In a 2008 survey taken in the United States, Susannah Baruch and colleagues found that 3 percent of IVF–PGD clinics provided PGD to couples who wanted to use it to select an embryo for the *presence* of a "disease or disability," such as deafness or dwarfism.

The selection of any trait, whether for or against it, is complicated. Removing one *disability* may also accidentally remove an *ability*—as is often the case with pleiotropy and complex traits. Just as removing CCR5 to resist HIV also increased the risk of West Nile virus infection, tampering with one gene and one phenotype can increase the risk of exacerbating others. Imperfections in human knowledge and historical errors in the application of genetics to "fix" diseases are often at odds with the disability-rights movement, which aims to secure equal opportunities and rights for all people with disabilities, rather than removing these aspects of their identities.

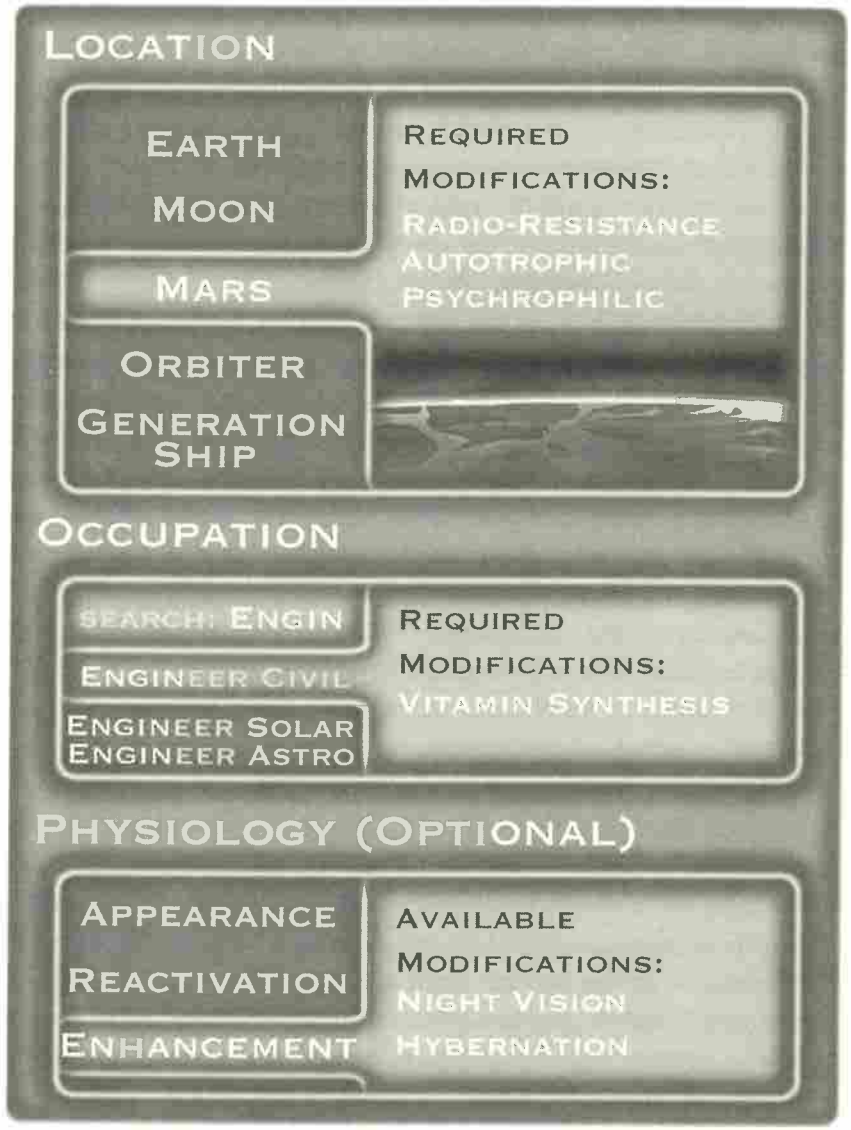
Many people with disabilities view themselves as, and are, functional, active, and vibrant members of their communities, because of—*not in spite of*—their disabilities. While self-assessment of one's own abilities and status can certainly be a complicated and imperfect process, there are obvious challenges with assuming that another group of nondisabled (or differently abled) people can judge the internal states of others. A prominent researcher in the field, Elizabeth Barnes, noted quite correctly in *The Minority Body* that "the intuitions of the privileged majority don't have a particularly good track record as reliable guides to how we should think about the minority, especially when the minority is a victim of stigma and prejudice."

Indeed, the imperfect use of this genetic knowledge leads some to conclude that widespread carrier screening or genome engineering to avoid disease should not be done at all. Instead, some argue we should stick to the status quo and more "natural" methods of mate selection and procreation. However, this argument unnecessarily limits humankind's ability to safeguard life, reduce suffering, and to fulfill our deontogenic duty as Guardians. The goal is not, and should not, be the removal of liberty or freedom, but instead the addition to it.

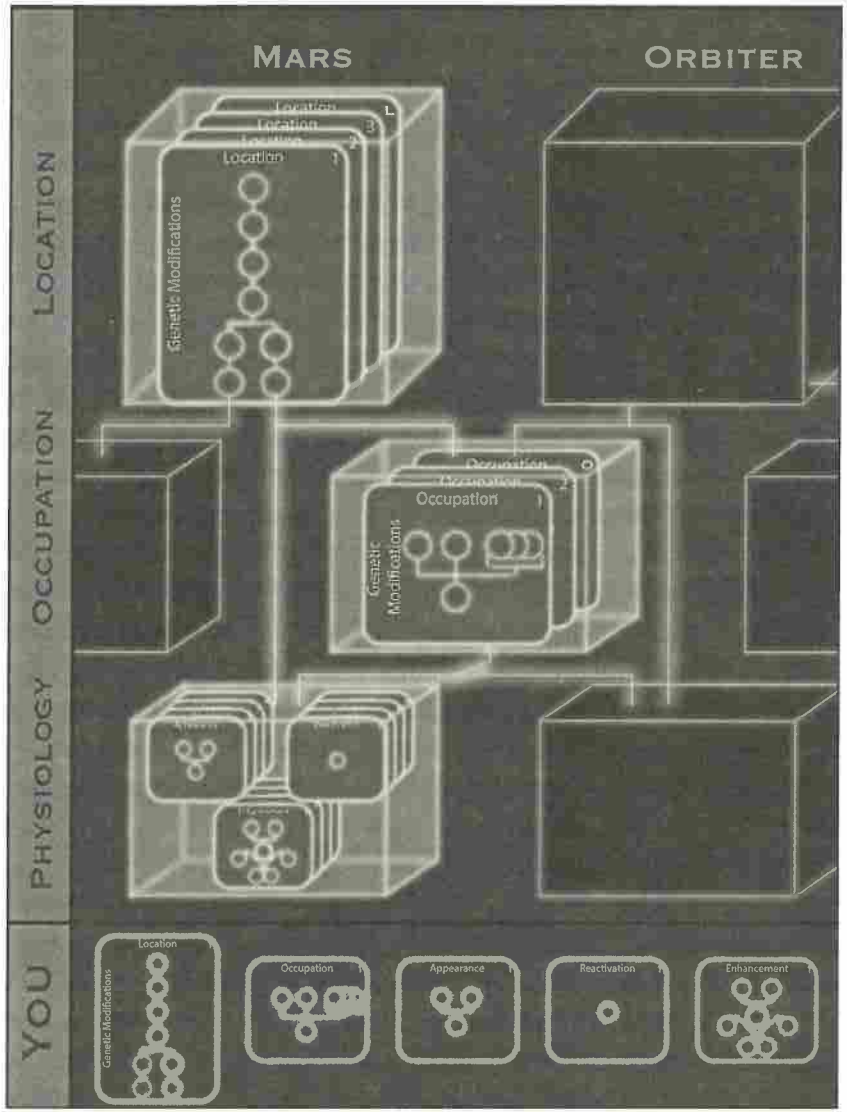
Whenever given two options, there are always two more: both and neither. On a new planet, and also on Earth, it may be good to have the best of both options. We can actually have both the benefits that may come with a previously designed disease (e.g., enhanced senses), as well as the benefits of not having that disease (additional abilities or not having to live in constant pain). The overall goal, rather than forcing mutually exclusive choices, should be to drive technologies and safe methods that can create the greatest amount of cellular, reproductive, and planetary liberty, including the ability to not only choose a world to visit, but to be able to thrive once there (figure 11.3).

PLANETARY AND CELLULAR LIBERTY

So how can there possibly be a "both" option when discussing removal or selection of traits? This ability will likely depend on the specific traits, themselves, but it can be possible. Instead of only acquiring new abilities, such as enhanced vibration detection for the hearing impaired, at the expense of others, such as hearing, it could be possible to engineer both abilities within the same person. This question can be addressed by the S_{dtp} score, to determine how it would impact someone's quality of life, potential proxy suffering, and overall economic burden. Again, these values will be both time and location dependent. Within space, it may make more sense to have a better ability to sense vibration, communicate without the need to hear, and even think in more abstract ways. The ability to selectively turn on genes, redirect cells, and recreate tissues of interest within the body can have a profound impact on the places to which a body can travel and the degree of self-control over one's own cells. Some level of this cellular liberty is, to a degree, already



11.3 The Genetic Programming Interface. In the future, both jobs and recreational work could employ a paradigm for editing certain genes, pathways, and networks, as needed.



present in the twenty-first century in the form of sex-reassignment therapies and surgeries.

But will every "ability" that accompanies a disease or condition be engineerable? At first, the answer is likely no. For example, hardship from a disease or the experiences gained from it are not purely negative—going through such hardship can, in turn, strengthen the individual. It can give them drive to then want to be a part of how the world operates. Such resolve can cause them to work toward solving a missing link in science that is required to make the generation ship a reality, but one that was only born out of the struggle with an ailment.

Many people living with such a disease, even those without hypersensitive abilities, may say that, even if they were given the chance to go back in time and never have the disease, they would not. However, this is typically for one of two reasons: (1) one cannot go back in time, so why crave an impossible state, or (2) they truly like who they have become and know a large part of what made them who they are is what they experienced (including the disease). But the reality is—there will be hardships in other forms, through unrequited love, the loss of a family member, trying your hardest but still not succeeding. There is no evidence that having any given disease is the causative reason they are resilient—as opposed to people who already were, or would become, resilient anyway. As Guardians, we should minimize the suffering of all subsequent species and individuals while maximizing their liberty and knowledge. While it may not be possible, at least at first, to engineer the resilience and optimism that can come from dealing with fighting a disease, it undoubtedly can be acquired through other means.

One such means to create the inspiration of resilience could, again, be an individual's choice to "turn a disease on," such as wanting to feel a brief, targeted destruction of a tissue or the pounding and simultaneous stabbing of their brain in response to light during a migraine. Even though this ability would take time to develop, it could also potentially be acquired through advanced virtual reality—experiencing an entire life in the shoes of hardship, all while, in reality, being unknowingly safe in bed.

Perhaps most importantly, there is one thing that this deontogenic society and advanced cellular and planetary liberty will in fact remove:

helplessness. The dread of a pending death sentence from birth, at least for most diseases, could vanish. Moreover, the new technologies can enable altering of previously immutable, genetic traits, giving a malleable path to a new sense of belonging or role. This belonging will no longer be forced—it will be chosen. Some may choose to live on Mars, others may choose to turn off their hearing, and others may choose completely different traits; all get to choose their traits and features.

Ideally, the best combination of genes and traits would be selected for each specific exoplanet, and then integrated into the genomes for long-term use. Here, too, there is a question of how much cellular or personal liberty is gained or lost by predefining the traits of a person going to a specific world or on a specific mission. Denotogenic ethics would argue, however, that the package of edits that enables the most people to survive on the greatest number of worlds would be the ideal option for "preloading" the human genome and surviving as long as possible. Even economically, this would make the most sense, as it would minimize the number of elective operations an individual may want. The best option for any embryo, anywhere, is that which enables the greatest cellular and planetary liberty.

EMBRYOS IN SPACE

The main challenge of "spacefaring embryos" is their safe development. It is simply not clear whether embryogenesis will function for human embryos in space as well as it has on Earth. As of 2020, no embryo has gone through the entire process of fertilization, development, and birth while in space. It is perhaps worrisome that several mice studies have shown that having just a part of fetal development take place in space can disrupt the vestibular system's development, causing issues when they were born on Earth. All of Earth's life has depended on, and developed under, the pressure of 1g gravity. The lack of gravity in space, on the ISS, and on potential ships to Mars, is the primary reason for this developmental concern.

However, this is by no means impossible to address. The answer is further engineering, although not necessarily genetic. If there is a rotating section of the spacecraft or generation ship that creates 1g,

or even just partial gravity, it is likely that the embryos would develop just fine. However, any mechanical issues relating to this section of the ship pausing for any period of time could also be detrimental to the developing embryo. Medical interventions leveraging the previously discussed mechanisms of diapause could be used here to give the mother (or exowomb) and her developing child more time.

But there is at least some evidence that the early stages of embryogenesis can successfully occur in space. In 2016, a Chinese research team used a microgravity satellite to send 6,000 mouse embryos into space to observe their gastrulation, taking photos every four hours of development. The team, led by Duan Enkui, Professor of the Institute of Zoology at the Chinese Academy of Sciences, found that most of the embryos developed into blastocysts, indicating that this early stage of development is possible in space (at least for mice).

If space embryogenesis turns out to be too complicated, there are many other ideas which could be put into action, many of which require large improvements to twenty-first-century technology (genetic and mechanical), as previously discussed. One such idea (first proposed by Adam Crowl in "Embryo Space Colonization to Overcome the Interstellar Time Distance Bottleneck") would be to send frozen embryos directly to an exoplanet of interest. Once a spacecraft arrives at (or near) the new planet, automated robotics, artificial intelligence, and artificial uteruses (exowombs) would be deployed to create, raise, and teach the new human beings. Most of the technology for autonomous raising of children does not yet exist—much to the chagrin of tired parents—so it remains to be seen if this would be a viable childrearing method. Thus, it is likely that some people, potentially multiple generations, would need to be alive on the ship to aid in its navigation as it heads toward a new star.

PLANETARY DATING APPS

Even after the extensive planning and analyses conducted on Earth, and even with the aid of probes, the exoplanet we set off toward may not fit our needs as perfectly as we had hoped. This may force the ship and its crew to switch to their plan B, and further possibly even plan

C, and so on. To aid this contingency plan, generation ships would ideally be sent to multiplanet systems, containing multiple potentially habitable planets or, at least, multiple potential moons to live on. The uncertainty of when a mission will actually end, and where the crew might one day call home, further underscores the need for generation ships to be as self-reliant as possible.

Before we can start to think about what system we want to target, we first need to be able to score and rank potential exoplanets based on their similarity to Earth and their overall habitability. Both metrics received a specific formulation in 2011 from Dirk Schulze-Makuch and colleagues, published in *Astrobiology*. They proposed a two-tiered classification system for exoplanets, the Earth Similarity Index (ESI) and the Planetary Habitability Index (PHI). The ESI is composed of both an "interior ESI" for a planet—including its density and radius—and a "surface" ESI, based on the likely surface temperature and escape velocity. The PHI is built upon the presence of a "stable substrate," or place to land, available energy, life-related chemistry, and the potential for holding a liquid solvent. Though the PHI may give a more accurate representation of what planet would be best for the habitability of known life, the ESI offers an estimate using more readily available metrics:

$$ESI = \prod_{i=1}^{n} \left(1 - \frac{x_i - x_{i0}}{x_i + x_{i0}}\right)^{\frac{w_i}{n}}$$

Where x_i and x_{i0} are specific properties of the extraterrestrial body and of Earth, respectively, w_i is the weighted exponent of each property and n is the total number of properties being measured. The PHI is similar to the Bray-Curtis Similarity Index, which is also used in microbiome studies of diversity. This index constrains the planet's similarity score between 0 and 1, with identical to Earth (based on all analyzed metrics) being 1, and the most divergent from Earth possible (in terms of ESI) being 0. This metric can further be expanded to include additional features of a planet (such as using mass, radius, escape velocity, flux, density, and temperature all together) and even simplified by allowing each feature to weigh evenly.

Mars has the second-highest ESI in the solar system, clocking in at a value of 0.70. Venus, often called Earth's "twin," comes in at a measly

0.44. Venus's low ESI is due to the high solar flux (irradiation from the sun) and the impact of the high levels of carbon dioxide on the planet, which led to its having a runaway greenhouse effect; it is likely even too hot for most life-forms to exist, at least relative to the profiling complete by the twenty-first century. In planetary-science terms, this means that Venus is beyond its Komabayasi-Ingersoll limit, defined as the maximum solar flux a planet can handle without a runaway greenhouse effect. Once the planet gets too hot, its ESI decreases and is less desirable.

It is worth noting that the ESI, by its very nature, is biased toward Earth. Other researchers, including Madhu Jagadeesh, have defined Mars Similarity Indices (MSIs), and posit that the search for life and potentially habitable planets could also have MSI as a secondary metric (especially if Mars once had life). This metric could readily be made for any planet or moon as long as we have enough information on it—such as a Venus Similarity Index or a Titan Similarity Index. However, given that all understanding of life is based on what has developed on Earth, the best chance for a generation ship's mission to succeed would be through the use of the ESI and PHI metrics. Once we validate our plans to inhabit other worlds and create self-sustaining societies, then these planets' initial characteristics could be used to widen the net of possible worlds to which we could travel. These metrics will essentially allow us to "swipe left" on a planet that is not quite right, or "swipe right" on a planet that matches or piques our curiosity. Of course, additional probes and data would be required before starting anything long term.

OUR PLANETARY MATE(S)

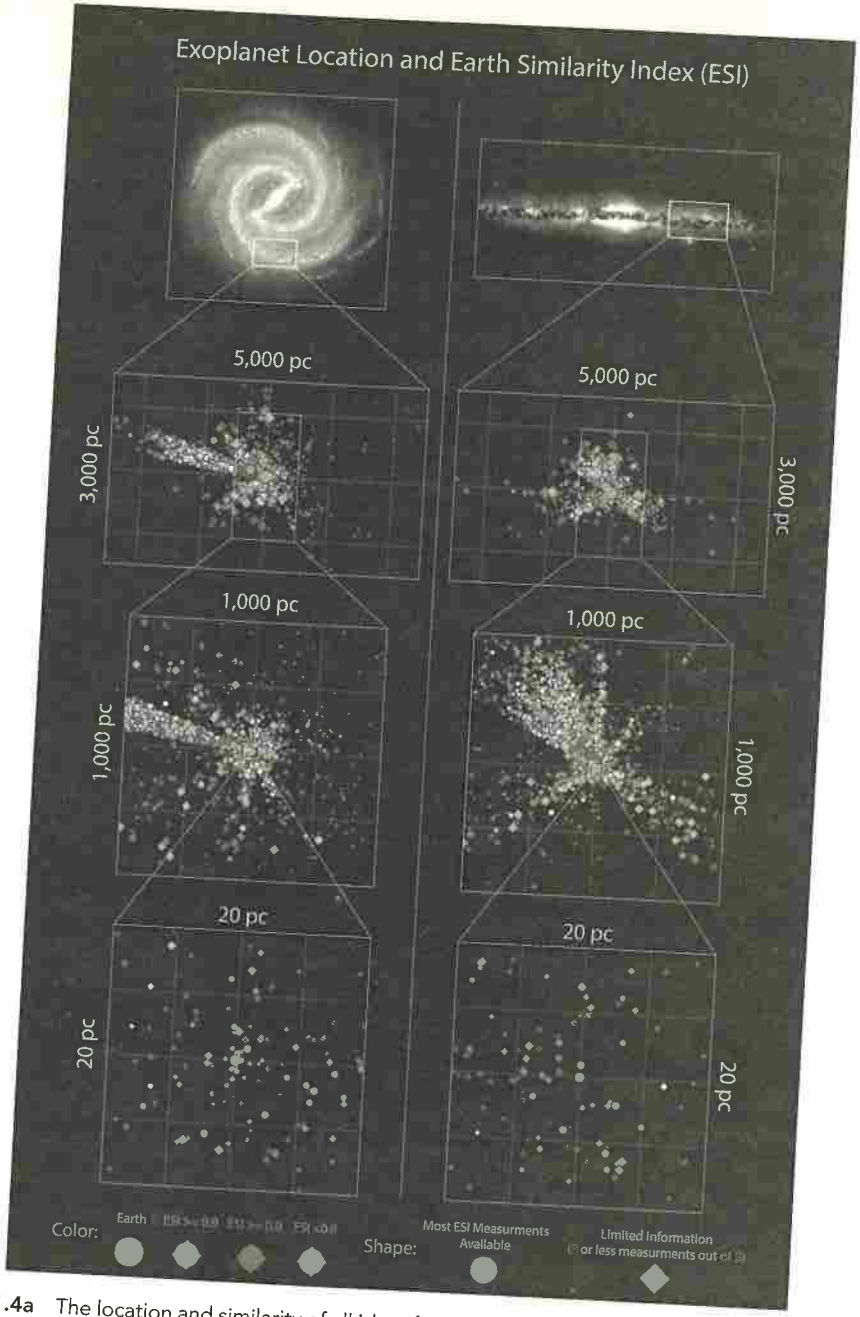
So, then, where should we send the newly engineered humans and other organisms? Fortunately, as described earlier, we have rapidly progressed from finding no Earthlike planets, in 2014, to finding thousands, with far more lying in wait for our discovery by 2500. Perhaps most strikingly, almost all the high-ESI and high-PHI planets discovered so far have been found in one very narrow and short view of the Milky Way (figure 11.4a). Far more planets will be found, some of which will

likely even be closer than the majority of planets currently found, making the generation ship's travel time even more palatable.

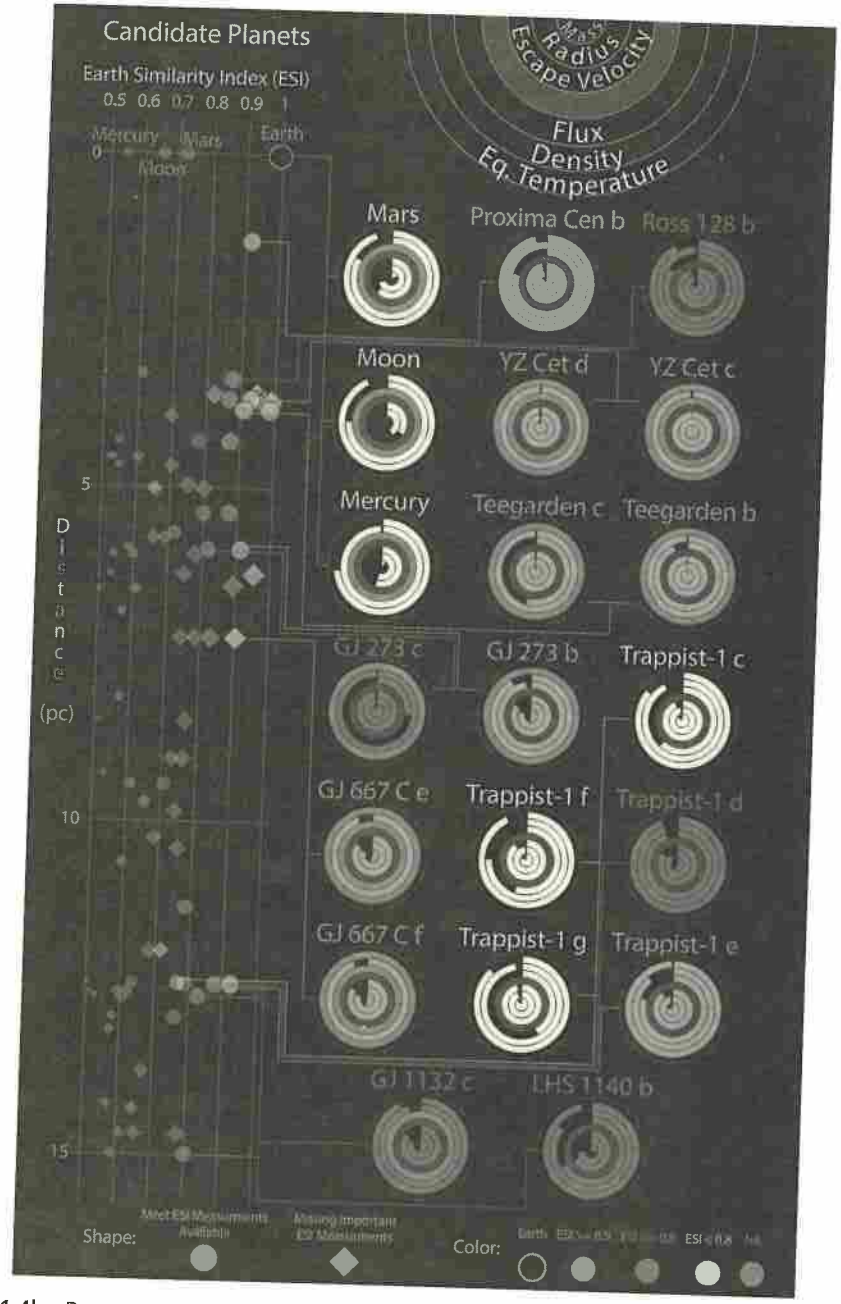
Though these new findings may not even be needed, as many exoplanets cataloged in the twenty-first century could serve as potential human homes. The aptly named website Planetary Habitability Laboratory (PHL), kept at the University of Puerto Rico, tracks each new discovery that is either Subterran (Mars-size), Terran (Earth-size), or Superterran (Super-Earth/Mini-Neptunes). For many of the planets, there are only guesses at the actual surface temperature or atmosphere, making the PHI hard to measure, but at least the ESI has already given us some great candidates. Based on PHL's calculations at the time of publication, there are seventeen candidate planets greater than or equal to 0.8 ESI, and forty-two greater than or equal to 0.7.

A great candidate system is the seven-planet, TRAPPIST-1 system (planets a, b, c, d, e, f, g, and h). This system was analyzed through a collaboration between the scientists working on the Hubble, Kepler, and Spitzer space telescopes and the European Southern Observatory's SPECULOOS (Search for habitable Planets Eclipsing Ultra-cOOl Stars) telescope. Data collected, refined, and finally published in 2018 showed that the seven planets have masses of 0.3–1.2-fold that of Earth's, with similar densities, indicating their gravity would be tolerable, and even useful, for twenty-first-century humans. Some planets (c and e) seem to be mostly rocky, while others (b, d, f, g, and h) likely have some kind of watery, icy, or atmospheric exterior similar to Earth's. Excitingly, there is evidence that Planet d has a liquid-water ocean that makes up about 5 percent of its mass (Earth's water content only accounts for <0.1 percent of its mass). Further, most of the planets have evidence of a possible iron core, which bodes well for their magnetosphere. Our own ESI calculations on the TRAPPIST system and other close (relatively) exoplanets which could be potential homes for future life are visualized in figure 11.4b.

Though the TRAPPIST-1 system may be the best candidate if a generation ship were launched in the twenty-first century, it is not perfect. From the data collected thus far, all seven planets appear to be "tidally locked," just like Earth's moon and Titan with Saturn, where one side



11.4a The location and similarity of all identified exoplanets: Most putative exoplanets that could be used for settlement by generation ships are within dozens or hundreds of parsecs (3.26 light-years) of Earth, either when examined from the top of the Milky Way (left) or the side-view of the Milky Way (right). The ESI for a variety of planets can be calculated based on the metrics of equilibrium temperature, density, solar flux, radius, and escape velocity. The highest-quality candidates are ≥0.9 (gray), secondary candidates are <0.9 but ≥0.8, and the lower-quality candidates are <0.8 (white). Exoplanets with only 3 or less metrics for ESI calculation



11.4b Best extracellular worlds based on location and similarity: ESI for candidate planets is shown relative along with their distance to Earth (y-axis). The ESI for a variety of planets can be calculated based on the metrics of equilibrium temperature, density, solar flux, radius, and escape velocity. The highest-quality candidates are ≥0.9 (gray), secondary candidates are <0.9 but ≥0.8, and the lower-quality candidates are <0.8 (white). Relative values are displayed as filled-in rows within the circular plots; light gray

of the planet is permanently facing its star. This means that these planets probably have very drastic and sharp differences in temperature between their permanently lit "light sides" and their ever-night "dark sides," which may also create unwanted stormy weather. The twilight regions which exist between these extremes, called the "terminator line," may therefore be the best regions to land and set up a new home. The Earth's terminator line is constantly in motion, appearing as sunset and sunrise, but the fixed TRAPPIST-1 planets' terminator lines may actually be an advantage. Crews could keep exploring in the "hotter" or "colder" parts of a planet, until they find the Goldilocks zone and a site that seems stable.

Our data are still very limited, both in the percentage of space that we have observed, and in the granularity of what we know about exoplanets we have found. Missions such as the "Project Starshot" will drastically aid in our understanding of what nearby solar systems and exoplanets actually look like by enabling us to analyze them closer up. Astronomers of the twenty-first century are much like an ophthalmologist trying to examine their patient's eyes from across the street amid traffic. We will know much more once we get closer. These missions will produce more reliable information on exoplanets and systems of interest—including data on surface chemistry, planetary activity, and data for PHI calculations. This information will be crucial to have well before the launch of any generation ship to maximize their success and minimize their need to go to plan B, C, D, or move to a new system.

PLANETARY ENGINEERING

In an ideal scenario, the generation ship would find an exoplanet that is immediately habitable. However, as with most of biology, survival is a question of access to resources, and there are many, many planetary or system conditions which can put this accessibility in jeopardy. If a planet is too hot, it might be impossible to survive at all. The extreme cold of a planet might be manageable—but even this would have limits on practicality and feasibility. The challenges of generation ship's mission will be compounded by the distance, bringing humans farther away from where they grew up, and the uncertainty which accompanies

trying to analyze worlds that are full of unknown variables. The majority of how we plan this mission, what we bring with us, and how we set up our first exoplanet will be based on the success and challenges from inhabiting Mars, Titan, and even remote areas of Earth.

All of the technologies needed for mapping, monitoring, and adjusting Earth's atmosphere will be the basis for adjusting the atmosphere of new worlds. Even long-forgotten processes that once plagued Earth could be brought back to help. For example, chlorofluorocarbons (CFCs) are incredible greenhouse gases capable of making a new world hotter. This idea was first proposed in *The Greening of Mars* (by Michael Allaby and James Lovelock) as a way to heat Mars. Even though CFCs once destroyed the protective ozone in Earth's upper atmosphere, their future application in new worlds may provide us with the exact heat retention we need to survive, like a large blanket in the winter. The generation ship could even manufacture them, further improving its self-reliance and ability to have multiple backup plans.

If the planet is not yet habitable, next up will be engineering its atmosphere. This process could take hundreds, thousands, or tens of thousands of years, resulting in the generation ship being in orbit for many more generations beyond arrival. However, some small outposts would likely be built while waiting for complete touch down and further used for testing new chemistry and atmospheric engineering. An important step for the success of any large-scale engineering challenge, whether genetic or planetary, is to catalog and understand the accessibility, modularity, and interactions of all of its components. Ideal technologies would be ones capable of addressing multiple limitations of the world with few ingredients.

First, small biomes could be sent down to the surface. These could be used to help test new combinations of chemistry, as well as for atmospheric engineering. Fortunately, plants from Earth are an ideal model for planetary technology development. But how can you convert their consumption of sunlight and CO_2 to produce required reagents, such as energy and O_2, for the use on other worlds? This has been a long-standing question for the US Department of Energy, which now supports three Clean Energy Hubs (Nuclear Energy Modeling and Simulation, Energy Storage Research, and Critical Materials Institute), as

well as the Joint Center for Artificial Photosynthesis. These initiatives have propelled the work of many scientists, including Harvard professors Pam Silver and Daniel G. Nocera, who first made a "bionic leaf" in 2011, capable of performing five to ten times better than non-bionic plants. Their "leaf" is a simple wafer of silicon and solid substrates that, when exposed to sunlight and water, split the water into hydrogen and oxygen.

Deployment of such bionic leaves in new worlds would enable quick fuel and air production, by creating hydrogen and oxygen simultaneously. However, these will rely on the availability of both light and water. While water is scarce on Mars, the red planet does have water in places as shallow as 2.5 cm (about one inch), based on a water "treasure map" published by NASA in 2019. Using such scanning technology would likely constrain the selection of exoplanets to those with accessible water, though that will likely be the case anyway since (Earth's) life seems to enjoy it.

Even though one of the primary jobs of plants on Earth is to photosynthesize, they actually aren't that good at it (about 1 percent efficient). Similar to the improvement seen with synthetic leaves, other biological life has been shown to actually do this better. Microalgae grown in bioreactors can sometimes reach 3 percent efficiency; and a maximum of 5–7 percent efficiency has been observed for microalgae in very specific conditions (called "bubble bioreactors"). Professor Nocera and other biologists, including Pam Silver, wanted to see just how far they could push this. Basing their work on that of Anthony Sinskey (at MIT), they took the unique bacterium *Raistonia eutropha*, which is capable of consuming hydrogen and CO_2 to produce ATP, and inserted new genes, which enabled it to further convert this ATP alcohol and a cobalt-phosphorus water-splitting catalyst, and even excrete its products in aerobic conditions.

This artificial photosynthesis system was far more efficient than that of natural photosynthesis and reached an impressive 10 percent. Beyond this advance, they even produced petrochemicals—including isopropanol, isobutanol, and isopentanol—which could be used in engines of the twenty-first century. This 2016 work was published to much fanfare because their system uses CO_2 in a carbon-neutral

manner. Although it does not serve as a carbon sink to help with the excess carbon, it can help with the entire petrochemical industry that is "burning carbon to find more carbon to burn," continually exacerbating the greenhouse effect of CO_2 on Earth. On future planets, the degree of efficiency and types and proportion of gases released could be altered to help accelerate the changes of an atmosphere or a settlement into one that is more amenable to the crew.

Similarly, the NASA project Ecopoiesis Test Bed aims to use this exact idea of kick-starting a planetary engineering plan (terraforming) with "ecopoiesis" (from the Greek for "house" and "production") on Mars and eventually other worlds. The Ecopoiesis Test Bed project proposes to land at a site close to liquid water, completely seal itself off from the rest of the planet (for planetary protection), and then release extremophiles capable of surviving in their new home while sensing the presence or absence of metabolic products. Data generated from this project could then be captured by an orbiting satellite, and reports would aid in improving the chemical and biological composition of future probes and life. Over time, this will enable the engineering of strong and adaptive pioneering organisms capable of building entire ecosystems in the harshest of environments.

The biggest challenge in deep space exploration, especially generation ships where the destination may not be guaranteed, is the renewal of required resources. The farther we get from the sun, the more it will become just like any other star in the sky, and the less we will receive its nurturing light. Even if we have the ability to deploy these continually learning organism seedings on a planet, we would still need the materials required to synthesize the organisms and all other materials required to stay in orbit for how ever long such a project would take. As previously stated, the recycling and reuse ability on these ships will need to be extremely well designed, but the synthesis of materials will have to come from somewhere.

One solution to this would be extremely large ships, capable of storing the required raw building blocks the rest of the system feeds off of—which, of course, would still mean these cannot last indefinitely and would be much more challenging to build. Another solution, however, would be detailed planning on scavenging whatever is in interstellar

space. This could be in the form of harvesting and actually using the constant barrage of radiation for the better or, likely, mining materials from asteroids and other space debris. The overall mission could be planned to maximize these encounters and restock materials whenever possible. If this plan were built into the generation ship missions, then the crew would not be despondent about a delay; rather, they would view it as part of the mission and their duty.

INTERSTELLAR, DIRECTED EVOLUTION

Over time, evolutionary changes will inevitably occur. Some rapid selection pressures (like with the silver fox) could quickly distinguish new humans or Guardian species from others, which itself would depend on what planet or ship their ancestors were from. Once this emerges, it will represent the first interstellar tracking system of life. Through molecular profiling and DNA sequencing of these changes, we will develop a catalog of how life changes around various stars and build a vast catalog of the panoply of life's adaptations. This vast genetic library can be continually compared to what we know about evolution on Earth, as well as to anywhere else humans and other life-forms will live, such as the moon, Mars, Titan, orbiters around different planets, and any world outside of our solar system.

Once identified, these specific molecular changes could further be analyzed, characterized, and examined for the ability to move into new biological systems. Those shown to be beneficial to living in specific locations (e.g., a moon in the TRAPPIST-1 system) could then be preemptively engineered into people before they visit (as discussed above and in figure 11.3). This would start a positive-feedback loop of undirected *and* directed evolution, which spans multiple worlds, stars, and eventually even galaxies. Eventually, these world-specific, engineered protocols could be preemptively engineered into the first settlers of new worlds by using a world similarity index (WSI), similar to ESI but without bias, to find what currently cataloged world it most resembles, further increasing mission success. Then, by extension, there would be a solar system similarity index (SSSI) and eventually galactic similarity index (GSI) for the best match for known life, and we could exquisitely

discern those life-forms that are specific to any area of the mapped universe.

However, technology can be a double-edged sword. For any good a new discovery can bring, it could also be twisted in the wrong hands for a malicious purpose. As an example, imagine we find a specific type of nucleotide, or group of biological substrates, which is uniquely associated with living on a different world. This could inspire learning and continual improvements on directed evolution to ensure people can thrive under different conditions, but it can also lead to nefarious events whereby a "planetary terrorist" may engineer a virus that specifically attacks humans who have evolved to only live on this world in a specific chemical context. While the logistical and economic hurdles to such an effort are vast, they are not insurmountable, and history has shown that marginalized and suppressed groups, or even just those with different ideologies, can resort to drastic measures to fight for what they think is right. This potential biological warfare would need to be carefully monitored and safeguarded to ensure the safety of each world and its inhabitants.

Nonetheless, by 2401, we will have several generations of directed evolution, spanning human, fungal, bacterial, and planetary adaptations across multiple systems, orbiters, and ships. Combining this information with characteristics of known planets and moons will drive the positive-feedback loop between undirected and directed evolution. Given enough time, we will go beyond the planets and moons in our own solar system, exploring other stars, and someday even exploring other galaxies. We could potentially even engineer organisms capable of surviving space, not just persisting but even thriving in the void, including some being able to migrate between planets, as easily as flying within Earth's atmosphere. We might even have migrating species, such as tardigrades with solar wings, that move between newly settled planets like interstellar monarchs. The engineered life would be a new kind of poetry that moves between stars.