**Phase 1 | What is "Synthetic Life"?**

**Preface**

Recently, we listened to the course on "Frontier Technology·Synthetic Biology" by young scientist **Dr. Li Teng**, which was deeply inspired. With Dr. Li’s clear explanation, we have a better understanding of synthetic biology. Next, let me make a brief summary of this course.

**What is "synthetic life"?**

The topic of resurrecting extinct species is not unfamiliar to us, but in real life, people still think it is impossible. But in fact, the first "artificial life" has been created.

In May 2010, American biology professor Craig Venter and his team synthesized a prokaryote, Mycoplasma mycoplasma. Mycoplasma, which is a pathogenic bacteria, consists of only one cell. Professor Venter used a computer program and four bottles of chemicals to synthesize a complete Mycoplasma DNA chromosome. Then the chromosome was implanted in an empty cell shell, creating life. And named it "Cynthia", which means "artificial".

However, many people will ask questions, is this a "synthetic life"? So how does it "synthesize life"?



**How to "synthesize life"?**

Not only that, although this research has received great attention from the media, it is not highly evaluated in the scientific community. But it is precisely because of this research that has truly confirmed the fact that has not been verified: "The essence of life is an information system." Simply put, if life is like a machine, then DNA is the software that controls it. If the software is modified, the machine will assemble its own hardware according to the new procedure.

For example, the cloning process of the cloned sheep "Dolly" involves 3 sheep. But Dolly looks exactly like the sheep that provided the nucleus, in fact, because the DNA in the nucleus provided the software for assembling Dolly this lamb.



**What is the use of "synthetic life"?**

After understanding the "synthetic life", you may still wonder, what can the "synthetic life" do?

In fact, human beings are a very ambitious race. Human beings always want to violate the laws of nature when it comes to their own destiny; but when dealing with the relationship between humans and nature, they hope that human civilization can be integrated with the laws of nature. It just so happens that synthetic biology can solve this.



**Phase 2｜Engineering Thinking: Synthesize life like Lego**

Hello, two exam weeks have finally passed! Our synthetic biology science can continue to be updated.This time, I will talk about one of the principles and methods of synthetic biology-engineering thinking.

**#Engineering Thinking**

We usually compare "engineering thinking" to "synthesize life like Lego."

Engineering thinking can be broken down into two cores: modularity and standardization.



**Modular**

**@Vol.1**

introduce

To put it simply, "modularity" means disassembling a complex system into small independent systems to build them separately, and then put them back together. It's like a programmer doesn't write all the code directly, but writes individual functional modules first, and then repeatedly tests and encapsulates them after writing, and the complete system assembles these independent modules. But synthetic biology is not just about changing a gene, because most biological functions are quite complex, and its realization depends on different genes, and there are many internal interactions.

**@Vol.2**

Genetic elements

Therefore, scientists have found "gene elements", which are the building blocks of genes. For example: synthetic insulin is composed of a gene, but this can be divided into functional elements (responsible for the synthesis of insulin protein) and regulatory elements (responsible for switching).

In terms of switching elements, different switching elements can respond to different signals.

**@Vol.3**

example

In 2017, Professor Ye Haifeng from East China Normal University added a gene to diabetic mice. The regulatory switch on this gene does not respond to signals in the body, but responds to infrared light. In other words, the gene for the synthesis of insulin in the mouse has not changed, but the logic that controls the synthesis of insulin has changed.



**standardization**

#introduce

In 2003, several Harvard and Massachusetts Institute of Technology (MIT) engineers established a genetic database. It is called "Registry of Standard Biological Parts". So far, Curry has used more than 20,000 genetic elements. It also designed a standard assembly process so that these genetic elements can be assembled like Lego.

The above-mentioned switch regulation actually comes from a bacteria that needs photosynthesis, so there are genetic elements in its body that respond to light. If there is no such gene bank, it may be more troublesome to find such genetic elements.



**Summarize**

Life can be divided in a modular way and assembled in a standardized way. In theory, the genetic elements can be sorted arbitrarily according to your wishes, and finally achieve unique functions. Of course, the complexity and diversity of natural life is often the biggest challenge in designing life. To solve these problems, computers and artificial intelligence are indispensable.

**Phase 3丨Data Driven: Improve the Success Rate of Synthetic Life**



If the logic mentioned above, as long as I accumulate enough genetic elements, I can spell out the shape I want like Lego. For example, I can install genetic elements with different functions of various organisms on the human body, so that a person can have bird wings and hairy claws. Of course, theoretically, it is possible, but it is impossible to predict in the future. Because even if it’s Lego, you still need to assemble instructions. So it is too difficult to reconstruct biological functions.



**Why is it so difficult to reconstruct biological functions?**

If we compare the genome to a book, the genetic elements are equivalent to a word, the composed genes are equivalent to a word, and each complex biological function is equivalent to a sentence. For example, insulin synthesis only requires one gene, but another specific drug for treating malaria, artemisinin, is troublesome. It requires more than a dozen genes, which is equivalent to a complicated sentence. As far as the synthesis of artemisinin is concerned, synthetic biologists used it for ten years and spent more than 4,000 US dollars in the end.



**Why use data-driven?**

If used in writing articles, synthetic biology is equivalent to writing poetry, because every word needs to be considered. Just like the Venter Synthetic Mycoplasma in the first lecture, the error rate of 1 in 1 million is already very low, but As a result, this life cannot survive normally. Synthetic life requires too much precision. To do a simple calculation, if you want to design a protein from scratch, suppose that there are only 100 amino acids that make up it, and there are as many combinations as 20 to the 100. This number far exceeds the number of atoms in the universe. Therefore, if you want to increase the success rate of synthetic life, you must use a computer to simulate life, which is data-driven.

**Simulate life with a computer.**

Due to limited technology, after scientists experienced many failures in the early stage, until the 1980s, only about 30 equations were needed to simulate the chemical processes of key cells. Up to now, almost the entire heart can be constructed, simulating the beating of billions of cells. In the future, before we create real cells, we can create a virtual cell through computer modeling, use it to test the conjecture, and then start experiments and tests, which can greatly shorten the development cycle. For example, artificial intelligence writes poems, as long as the more data accumulated, the more sufficient, the better the poems will be written.

Chris Voigt, a synthetic biologist at the Massachusetts Institute of Technology, has developed an automated design software called Cello. With this software, it is no longer necessary to consume a lot of manpower and directly send the data to Cello, and it can build a digital simulator to simulate the performance of metabolic pathways in cells. Because of the digital drive, the entire synthetic biology field has drastically reduced costs.

**Phase 4丨Accelerating Evolution: Acquiring Functions Not Available in Nature**

**Accelerate evolution**

**Methodology**



Compared with the engineering thinking and data driving mentioned in previous issues, the most difficult thing is that the function you want does not exist in nature. For example, if humans want to migrate to a new planet, the temperature difference between day and night of this planet is 100 degrees Celsius. This is a condition for human beings to not survive. At this time, it is necessary to evolve a protein that has never existed. This protein should not be sensitive to temperature. sensitive. This demand is "accelerated evolution."

**about it**

"Evolution" requires two conditions, one is "gene mutation" and the other is "natural selection". However, the probability of gene mutation is very low. Is there a lot of evolution in nature or mainly relying on natural selection. However, natural selection also has a fatal problem, which takes a long time. For example, bananas, wild bananas, which have less flesh and large seeds, have evolved into our current sweet, fleshy, seedless bananas, and it took a full 4000 years. In fact, there is another stupid method-mutation breeding, because the seeds are irradiated with radiation will accelerate the random mutation of genes. This method is like it has good computing power, but the method is relatively clumsy, and synthetic biology happens to improve this algorithm.

**method**

Accelerated screening

Dean-level synthetic biologist Professor George Church of Harvard University is mainly doing research on resurrecting mammoths, but the greatest thing is that he invented a method to accelerate evolution. He believes that a genome similar to a mammoth, such as an elephant, should be found, and then the characteristic genes of the mammoth should be added to this genome piece by piece, and it will be created by reverse engineering. Professor Church used this method to increase the production of lycopene, and it took only three days to increase the production of lycopene by five times.

**Create a mutation switch**

However, accelerated screening has a drawback. Only one DNA fragment can be introduced in each round, which can only cause mutations at one site, which usually has only a few bases. How to mutate multiple sites is to create a mutation switch. In 2012, there was a star project in synthetic biology. Scientists wanted to synthesize a complete set of yeast genome. An interesting design in this project is the insertion of 5,000 non-existent "mutant switches" into the genome. Such switches are special DNA sequences. When they meet certain catalytic enzymes, they can drive the surrounding area to become particularly unstable. So as long as the catalytic enzyme is turned on, 5,000 "earthquakes" can be triggered on the yeast's genome in an instant. In this way, it becomes very simple to obtain some extreme traits.

**Directed evolution protein**

Simply understand, this is a trial and error process. First predict the function of different regions of the protein, then try to change the DNA sequence corresponding to this function, and test to see if the function has changed. Of course, trial and error also requires data driving and data simulation to improve accuracy. DeepMind used thousands of known protein structures to train neural network algorithms, and then spent 2 weeks predicting the first protein structure. At the end of 2018, AlphaFold participated in the competition in the field of protein structure prediction and won the first place. So far, AlphaFold can only predict a limited number of types of proteins to a certain extent, and there is still a big gap between fully predicting the function of the protein.

**Phase 5丨Applications of Synthetic Biology**

**Applications of synthetic biology**

After learning the previous related knowledge, you should have a preliminary understanding of synthetic biology. To design life, the three most critical steps are to reconstruct biological functions with engineering thinking, use data-driven to increase the success rate of synthesis, and obtain new functions that are not available in nature through accelerated evolution.

**✿PART01✿**

**Why do artificial beef**

In 2019, Burger King, Subway, and KFC all launched artificial human meat one after another, and these artificial meat came from two American companies (Impossible Food\Beyond Meat). In fact, as early as five years ago, artificial meat was looked upon by the big tech giants from all walks of life, and they all invested in it. So why do these people want to produce artificial meat in a new way? Is something wrong with the meat? of course not. According to statistics, ground beef accounts for 60% of the meat consumed in the United States every year. Now a quarter of the non-icing land on the earth is used for grazing, and the total amount of farmland is only one-third. According to the United Nations, it is estimated that by 2050 70% more meat will be eaten than in 2005, and besides land, other associated resources, such as feed and water, will also be consumed greatly. Cattle also have a great impact on the environment. Now 15% of global greenhouse gas emissions are caused by cattle breeding. Instead of wasting a lot of resources to raise a cow, it is better to find a way to eat beef without raising a cow, so the artificial meat industry has been created.



**✿PART02✿**

**How is artificial meat made**

In fact, the cost of beef is very simple. A piece of ground beef patties, protein, fat, and water can basically constitute 100% of its quality. In terms of chemical composition, as long as you find a substitute for protein and fat, plus a small amount of trace elements, it is artificial meat. For example, Impossible Foods chose coconut oil instead of fat, and in order to satisfy the chewiness and aroma of beef, the company finally found a similar fibrous protein from wheat and potatoes to satisfy the chewiness of beef. For the heme in beef, Impossible Foods puts the heme gene element into yeast, synthesizes it with yeast, and adds it to the meatloaf. So an artificial beef made of wheat, coconut, and potatoes with beef taste and flavor came out.

Produced in this way, the same amount of beef can save more than 80% of the land and use more than 90% of water and fossil fuels.



**✿PART03✿**

**The most critical production material: genetic elements**

In fact, the artificial meat industry is not only advanced in technology, but also represents a change in the way humans use resources. Raising cattle is no longer the only way to obtain beef. We want to eat chicken wings. We should not raise chickens with eight wings, but synthesize chicken wings. Perhaps the most critical production material in the future is only one type, which is genetic elements. Because we can use the same bioreactor, the same raw materials, glucose and water, and the same microbe on the bottom plate, but with different genetic elements on it, the products produced are completely different.



Following this line of thinking, previously scarce resources, battles, wars, and commerce were all started by resources. But synthetic biology gives another set of ideas. As long as you have a general-purpose bioreactor, and you have thoroughly studied and enough genetic elements, you can hold a universal machine and produce whatever you want.

**Phase 6丨Applications of Synthetic Biology (2)**

**Bacteria that can cure pollution: a new solution to environmental problems**

In this new century, the most serious problem we encounter is environmental problems. In fact, in the final analysis, all environmental problems are essentially human activities disrupting the balance of the material cycle.

Environmental issues are essentially circular issues. Before the dinosaurs appeared, there was a period on the earth called the Carboniferous. Why is it called the Carboniferous? Because there was a dense and undecomposable "lignin" in the plants on the earth, the carbon cycle that should have been blocked at this step, so the living things on the earth will also become extinct. Fortunately, a fungus capable of decomposing "lignin" evolved in the late Carboniferous, which allowed the earth's carbon cycle to re-operate, and only then has the earthly homeland that is now thriving. We are no strangers to this truth. Plastic is actually "lignin", and it cannot be degraded in nature. The same goes for other environmental issues. The balance of nitrogen and phosphorus is broken, which leads to eutrophication of water bodies, and the balance of heavy metal elements is broken, which leads to soil pollution. How can the cycle be rebuilt? There are three ways to transform synthetic biology.

**01Replace with in-cycle products**

Find products that are originally in the cycle and replace products like industrial plastics.

According to the principle of "lignin", we can solve the carbon cycle problem as long as we find microorganisms that can decompose plastics, but because the appearance of plastics is too short, microorganisms have not yet evolved to that function. Moreover, it is impossible not to use plastic. Therefore, the best solution is to find a substitute, a material with plastic properties.

There is a kind of polymer material naturally in nature: PHA, which has the characteristics of plastics.

In fact, scientists discovered it as early as 1926, but because the production cost was too high to meet the requirements of industrial scale at all, so far there has been no result.

Synthetic biology can solve this problem, as long as the genetic elements are modified, the cost can be reduced.

PHA is a substance used by bacteria to store energy, which is equivalent to bacterial fat. Therefore, to reduce costs, we have to make bacteria fat.

The first thing to do is to modify the bacteria's decision-making mechanism, such as deleting some of its feedback control elements, so that the bacteria are not full of the concept, so that it will continue to eat. The second thing to change is the metabolic mechanism, because generally food enters the cell body for three purposes: it is converted into energy, converted into cell components, and stored into fat—that is, PHA. Therefore, in order to increase PHA, We have to increase the conversion rate of PHA and reduce the metabolism of the other two parts, so that the cells can maintain basic survival. In this way, we can breed "fat bacteria" that can produce PHA.

**02 accelerated evolution**

In fact, there are some bacteria that can degrade plastics, but the efficiency is very low. As long as you find the genetic elements corresponding to the degradation function, and then modify these originals, the degradation efficiency can be improved. This method has been discovered by many scientists, so the future can be expected.

**03Reconstruction engineering microorganisms**

The biggest difference between organics and inorganics is that inorganics cannot be degraded. The most extreme example is heavy metal pollution.

Why does the random throwing of batteries cause soil pollution? It is because heavy metals will stay in the soil and it is very difficult to separate them.

For example, metal cadmium, the cadmium in the soil is cadmium ions, and it is difficult to deal with the ions effectively. Rice especially likes to accumulate cadmium. When people eat this kind of rice, cadmium will accumulate in the body. If it is not metabolized, it will cause damage to the human internal organs.

In order to solve the problem of cadmium enrichment, scientists have tried to create an engineered microorganism, which is to create a new organism completely artificially to perform a specific function, just like a robot.

As long as this robot needs to find a soil microorganism, and then install two functions for it, one is to recognize cadmium ions and absorb it into the cells, and the other is to install a magnetotactic module for it so that it can be attracted by magnets. With these two functions, this engineered microorganism can complete the task of accumulating cadmium, and scientists can easily suck it out of the soil.

**Summarize**

Since human activities have interfered with the balance of natural cycles to complete serious environmental problems, then we use the materials that nature has prepared for us to rebuild natural cycles.

**Phase 7丨Applications of Synthetic Biology (3)**

A new solution for DNA information storage that can be used as a disk

After understanding food and environment

Next

Let's talk about

Strange and familiar

Mass data storage

**1 Why do we need DNA to store information**

If the sun exploded and the earth was destroyed, how would we escape? There are many settings in science fiction films. Humans build a super large spaceship, take away everything they need, and find another planet to rebuild their home. However, we must not only take away people, we must also take away human knowledge and scientific research results.

According to the aforementioned "As long as there is a DNA sequence, life can be restored", this theory is feasible. In other words, we only need to pack and take away the DNA.

In order to avoid the storage problem, scientists have provided a solution: store information in DNA.

**2 How to store information in DNA**

Everyone may think it’s weird to use DNA as a hard drive, but don’t forget that life’s information is stored by DNA, and it’s kept intact for billions of years, so DNA is definitely the oldest information storage tool on the planet.

In 1988, an artist converted a 35-pixel photo into 35 bases of DNA. As shown in the picture below, this picture looks like a fork and represents the earth. How is this done? In fact, DNA stores information and codes for the same reason. The computer can use the two characters 0 and 1 to represent all the information, and we can also use the 4 bases of ATCG to represent the same information.

If you want to store a picture, you can first restore the picture to 0-1 binary data, and then convert this data into an ATCG sequence, and then use DNA synthesis technology to synthesize this sequence, and the information will also be stored. In this piece of DNA. When you want to read it, sequence this piece of DNA.

In 2017, scientists have already said that a black-and-white movie exists on the DNA of E. coli. What's even more amazing is that E. coli not only grows normally, but also inherits normally. Each generation of E. coli is preserved intact.

Such research can provide us with a lot of imagination. In the future, spy films will transmit information, which may be hidden in bacteria in our intestines or skin.

But now there is less research on storing information in living cells. Because the cell will die and will continue to divide and replicate, there is still a risk of error. In order to ensure data security, in most cases DNA storing information is in the form of dry DNA powder.

**3 Why can't DNA replace hard drives**

Although the principle is simple, it is still very difficult to implement.

First of all, the speed of storage and reading is very slow. Disk storage is electromagnetic signals, but DNA synthesis relies on a series of chemical reactions. For 200MB of data, it does not take 1 second to write with disk, but DNA synthesis takes almost 2 weeks.

Moreover, DNA media cannot be reused. Once the information is saved, generally speaking, it cannot be modified. The U disk can be archived and read again and again at will. In DNA, if you want to read a document, you need to sequence all the information before transcoding, but you don’t want to read it from wherever you want.

**4 What are the advantages of DNA storage?**

Although DNA storage is slow, costly, and troublesome, it has three indispensable advantages: saving space, saving energy, and storing it for long enough.

Save space: In terms of physical space alone, DNA is smaller in size and has a three-dimensional structure, so the information density per unit space is much higher. Computer storage is binary, and DNA uses a quaternary system with a higher density than binary information. According to a study published in Science in March 2017, 1 gram of DNA can already store 215 million GB of data.

Save resources: Current storage tools, such as a data center, consume a large amount of monocrystalline silicon and also consume a large amount of electricity. DNA can be stored in a cool, dry place, and no additional manual maintenance is basically required. Even if the DNA needs to be frozen, the resources and energy consumed are almost negligible.

Long enough to store: No matter how high-density memory is, it will decay over time. The longest storage time is magnetic tape, which has a lifespan of 50 years. But DNA is not the same. As long as it is properly stored, it will not expire. There is no problem in storing it for 500 years. So, what is more suitable for storing big data information than DNA?

**5 Summary**

The storage space is running out immediately, what should I do? The solution to synthetic biology is to use DNA to store data.

Although compared with disks, this technology is not yet mature, with high cost and slow speed. However, DNA storage density is high, stability is high, and it is more energy-saving and environmentally friendly. When it is placed on a longer time scale, it has its unique advantages under greater space pressure.

**Phase 8丨Applications of Synthetic Biology (4)**

**Living medicine: new ideas for disease treatment**

I talked about many applications of synthetic biology, but it is mainly to get rid of traditional production methods for various products, or to modify microorganisms themselves. So, you may ask, what are the benefits of synthetic biology for living organisms? Next, I will introduce you to a new trend in disease treatment-living biological medicine.

**01What is a living biological medicine?**

Living biological medicine literally means a living, alive medicine.

The vaccines, antibodies, penicillins, and insulins that we come into contact with are all biological drugs, but they are all extracted from the active ingredients of organisms, but living biological drugs are directly alive to cure diseases.

Don’t think it’s illusory. Living biological medicine is very common in daily life. Isn’t yogurt? Drink yogurt, drink probiotics into your stomach, and strengthen gastrointestinal motility. These probiotics are alive.

Living biological medicine is not mysterious at all. It is particularly important, and it is becoming more and more important because it can help us reduce the risk of treatment.

**02How to treat metabolic diseases?**

Adults have many metabolic diseases, the most common of which is drunkenness, which may not be considered a disease, but it is indeed related to genes. Many people will blush when drinking alcohol. This means that people cannot metabolize alcohol normally. The harmful metabolite acetaldehyde will continue to accumulate in the body, so they will blush. This is actually a danger signal.

So how should we solve this problem? Drunkenness is controlled by genes, so let's do all the genes, change that gene? Although this line of thinking fits well with synthetic biology, it has a high risk factor. What's more, editing genes because of drunkenness is indeed a little fuss.

Therefore, there is a new method. The scientific community has discovered that the human body and skin are full of microorganisms, and we have a symbiotic relationship with these microorganisms. And the role of human microbes is much more important than originally thought, especially the intestinal microbes. Intestinal microbes not only metabolize food, resist germs, and synthesize nutrients, but can even affect a person's weight, stimulate the brain, and affect people's emotions.

There is a synthetic biology company (Zbiotics) in the United States, and they have made a microbial agent that can hangover. Its principle is to modify a kind of intestinal microbe, adding the genetic elements of the anti-alcoholic enzyme in the liver. In this way, after you take this microbial agent, it can help you digest before your digestive tract absorbs alcohol. If you take this medicine, you may never get drunk again, and you will become a person empowered by microorganisms.

Whether it is alcohol metabolism or hyperammonemia, it is actually a digestive system disease caused by a gene defect. In the past, we had no good way to deal with this type of disease. Gene defect, then modify the gene. However, living biological medicine gave a four-two-stroke idea. There is no need to move human genes, just change the microbes in the intestinal flora.

**03How to become a cancer targeted drug?**

As early as 1890, he discovered that cancer was clearly incurable, and many patients healed on their own. For example, a cancer patient who had undergone many operations, the doctor said that he had no medicine to cure, but at this time he was infected with another type of bacteria (erysipelas: Streptococcus pyogenes infection), which made the situation worse. But the magic is that after a while, the patient's cancer has healed on its own. Dr. Colley speculated that the bacterial infection triggered an immune response, allowing the patient's immune cells to attack the bacteria while also attacking the cancer cells incidentally, which instead killed the cancer cells.

Since accidental infection can cure cancer, why not create some bacteria to treat cancer? This is his original intention to develop a cancer vaccine, and it is also the starting point for immunotherapy.

For example, Salmonella is the main culprit of food poisoning. If Salmonella is injected into the human body, it can induce immune cells to kill cancer cells. However, because Salmonella is toxic and the treatment effect is not guaranteed, it has not developed.

In 2017, South Korean researchers published a study in Science that transformed Salmonella into a more powerful "spy". Their approach is to delete part of the genome and make Salmonella completely harmless. But retaining its ability to sneak into cancer cells allows Salmonella to sneak into cancer tissues silently, take root and multiply, and continue to grow the size of the spy organization. Secondly, give Salmonella a signal flare function to attract macrophages in our body to eat cancer cells. The study found that within 3 days, this "spy" Salmonella can spread all over the tumor tissues of mice. After 4 months of continuous observation, half of the mice were cured by this "spy therapy". At present, this research has entered the stage of cell experiments.

**04Summary**

For living biological drugs, there are generally these two ideas, but now it is still a relatively new type of drug, and people are cautious about the use of new drugs. So far, no non-natural living biological medicine has been approved to enter the market.

**Phase 9丨Conclusion: How far is it to create life**

**How far are we from creating life**

Through the previous study, we have learned that synthetic biology has many technologies, but it is not yet free to create life. So, how far are we from creating life?

**01 The power of stepping on the accelerator: cutting-edge technology development**

The latest technology now is that scientists have been able to artificial bases. You know, for 4 billion years, all life on earth has shared the same life code at the DNA level, which is the four bases of ATCG. However, scientists synthesized another pair of completely different bases and named it X and Y. Even in different laboratories around the world, more new bases are being synthesized. This means that proteins that may not have appeared in nature will be produced, which is a brand new expansion of life. Maybe one day, this is the "alien" we meet, but it was not found on another planet, but was born in the laboratory of a synthetic biologist.

There is also another trend in biological computing. Science fiction is called DNA computer, which uses DNA and biological enzymes to do calculations. In June 2011, the California Institute of Technology produced a biochemical circuit composed of 74 DNA molecules, which can calculate the square root of an integer less than 15. Such calculations are already very complicated. While DNA has amazing storage density and extremely low energy consumption, it also has extremely high parallel computing capabilities. Perhaps in a specific scenario in the future, DNA computers will have unique value.

**02The power to step on the brakes: safety risks and ethical challenges**

In fact, synthetic biology does have great safety risks. Synthetic biology has modified microorganisms on a large scale and created many unnatural genes. These species did not originally exist in nature. If we release these unnatural genes into nature, what will be the consequences? Scientists are not entirely clear. This has the same meaning as species invasion. For example, Australia experienced some weird things many years ago when they introduced a toad from the United States. The original intention is to control a native beetle and protect sugarcane. As a result, after the introduction of this toad, it reproduced wildly and quickly swept the entire Australian continent. And these toads produce a toxin that kills predators, killing many animals.

So the consequences of all new things are unknown, and these people who step on the brakes play a very important role.

**03The future of life**

From another perspective, technological progress will inevitably bring new problems, and new problems will stimulate the production of new technologies. This is an inevitable law of technological development.

Rather than worrying, it is better to care about how to redefine boundaries after technological development. For example, perhaps soon, the new challenge we will face is how to deal with the relationship between artificial life and humans.

If you get a person’s genome, you can print that person in another place, or even print it on another planet, such as Mars. So, if the organs are all replaced a little bit, I am still not the same as my discussion, and it may really have practical significance.