

Chapter 8

The Rapacious Hardscrapple Frontier

Robin Hanson

A hardscrapple life is one that is tough and absent of luxuries. It refers to the dish scrapple, made from whatever's left of the pig after the ham and sausage are made, the feet pickled, and the snouts soured.

Alix Paultre, 2003¹

The future is not the realization of our hopes and dreams, a warning to mend our ways, an adventure to inspire us, nor a romance to touch our hearts. The future is just another place in spacetime. Its residents, like us, find their world mundane and morally ambiguous relative to the heights of fiction and fantasy.

In this chapter we will use evolutionary game theory to outline the cycle of life of our descendants in one million years. What makes such hubristic conjecture viable is that we will (1) make some strong assumptions, (2) describe only a certain subset of our descendants, and (3) describe only certain physical aspects of their lives. I estimate at least a 5 percent chance that this package of assumptions will apply well to at least 5 percent of our descendants. Even if these assumptions are drastically violated, this analysis at least offers a simple and clear baseline for comparing other scenarios.

Our Assumptions

Five hundred million years ago brains appeared, and then doubled in size every thirty million years. About two million years ago, protohumans began to double in number every quarter million years, until ten thousand years ago, when with the advent of farming, our population began to double each millennium. With the Industrial Revolution about two hundred years ago, we began to double our economy every fifteen years. Statistics of prior transitions suggest that within this century we might somehow transition again, and then double (incredible as it might seem) *every two weeks*.

This rapid change is mainly the result of all the techniques, insights, and arrangements we accumulate. Since significant innovations are hard to anticipate, it is hard to forecast such abilities through even a few future doublings. So the only way we can see a *million* years in the future is to assume that, by that point, our descendants have long since run up against *hard* limits, limits even we can now foresee. Yes, such limits would defy our can-do, never-say-never spirit, but the future is not an inspirational story.

The situation we'll consider is a region of spacetime toward the edge, by contrast with the center, of a wave of interstellar colonization. We assume the speed of light is an absolute limit on moving matter and information, and that our descendants still won't have seen any hints of nearby intelligent aliens that might hinder their advance. We proceed as a wave of colonists steadily expanding out from Earth, hindered only by nature and each other.

Within this wave, our descendants would have access

to physical resources such as mass, energy, negentropy, and information, all of which are useful for colonization activities, such as making, maintaining, and transporting artifacts and our descendants themselves. We focus here on these activities, and will have little to say about resources not particularly useful for such activities. We assume that after a million years of searching for better ways to use such resources for such activities, technology no longer improves much, and is almost equally available to everyone.

We also assume that at least one key physical resource is highly concentrated somewhere in space, near relatively stable, identifiable oases such as stars, separated by a desert of near-empty space. And we assume that these oases are limited in two ways. First, each has a limited quantity of quickly usable physical resources. To quickly obtain more resources than a single oasis can offer, one must colonize many. Second, oasis resources have few economies of scale across oases. That is, there are few productivity gains from coordinating the development of resources at neighboring oases.

To colonize an oasis, our descendants will send a seed to the oasis, perhaps ranging in size between a grain of pollen and a battleship—a seed that then grows in its command of resources until it becomes capable of sending a new generation of seeds to other oases. (By analogy, picture a plant species adapted to distributing its seeds on the prevailing winds, slowly filling the oases of a lifeless desert.)

We assume that this seed-to-seed cycle is destructive, in the sense that resources used to support this process cannot be quickly reused for other purposes, and that long-distance interstellar travel is neither too hard nor too easy. That is, over the next million years our descendants will

not become extinct, but instead, within a half million years, will be capable of making seeds that can move from the near Earth oasis to oases several light-years away.

We make several more assumptions. Our descendants will *not* make a seed that can reliably and rapidly travel a million light-years in a single vast voyage. Most seeds are destroyed en route, but if not destroyed they probably arrive near their intended destination. All else being equal, seeds fail more often the farther they are sent, and so the fastest way to go a very long distance is to stop frequently to develop oases along the way. There are few benefits from earlier seeds clearing or finding safer paths through the desert. We assume instead that oases can see accurately a long way ahead and are very familiar with the kinds of objects they observe.

While it is possible to make predatory seeds that can travel between oases, such travel is usually too expensive to make invasion of occupied oases cost-effective in terms of resources gained, even for very patient invaders. That is, even moderately developed oases find the resource cost to defend themselves against invasion is much less than the cost to build and deploy seeds with a substantial chance of taking over an oasis at which a seed has had a moderate time to develop. Long-distance weapons to destroy oases and their in situ colonists might, however, be affordable.

How our descendants act in this situation will depend not only on the physical and technical constraints they face, but also on their “personalities”—that is, their strategies, goals, plans, and other behavioral tendencies. Some personalities might be inclined to gleefully rape their environment as fast as possible, while other personalities might seek minimal

disturbance and sustainable development. What will be the personality mix?

The answer depends on how strongly our descendants *coordinate* their behavior during a crucial era. The familiar biological world contains only local coordination. Genes can coordinate within a body, and creatures can coordinate within a tribe but, on larger scales, genes, creatures, and tribes compete for scarce resources with little coordination. This uncoordinated competition is what allows biologists to use hard limits and evolutionary selection theories to predict biology's rough outlines. If our descendants prove to be similarly uncoordinated, evolutionary analysis might accurately outline their behavior.

Compared to most creatures large and small, however, we humans today coordinate our actions on an unprecedented scale, via markets and governments. But even we do not have a strong planetary government; most of the dimensions in which we compete are not tightly constrained by the United Nations or by global contracts and treaties. Will our descendants coordinate more than we do?

At the extreme, imagine that a strong stable central government ensured for a million years that colonists spreading out from Earth all had nearly the same standard personality, with each colonist working hard to successfully prevent any wider personality variations in their neighbors, descendants, or future selves. In such a situation, the standard personality might control colonization patterns; if every colonist wanted colonization to be slow, for example, then colonization would be slow.

The crucial era for such coordination starts when competitive interstellar colonization first becomes possible. As long

as the oasis near Earth is growing or innovating rapidly, any deviant colonization attempts could be overrun by later, richer, more advanced reprisals. But as central growth and innovation slows, such reprisals would become increasingly difficult.

Why? Because with a common unchanging technology and a speed-of-light limit, the farther one falls behind a rapid colonization frontier, the harder it becomes to influence events on that frontier. For example, longer distance weapons are more easily evaded by unpredictable movements. Because of this circumstance, rapidly advancing frontier colonists could act largely independently of those far enough behind them. Thus, once enough colonists with a wide-enough range of personalities are moving away rapidly enough, central threats and rewards to induce coordination on frontier behavior would no longer be feasible. The competition genie would be out of the bottle.

This scenario, of an uncoordinated colonization wave, assumes that sometime after near Earth growth and innovation slows, enough colonists with behavioral variety will get sufficiently far away from the rest, fast enough, to prevent large-scale coordination from much influencing their behavior. And if that uncoordinated competition lasts long enough, an evolutionary analysis would then apply, allowing us to foresee now the outlines of our distant descendants' way of life. Let's find out what our assumptions imply. (The analysis method that produces these conclusions from these assumptions is given at the end of this chapter.)

Oases in the Desert

It seems hard to say much about what styles of music, art, or fiction, or what languages or operating systems, will be favored by our descendants in the Year Million. It is also hard to say much about the kinds of minds they will have. Distinct minds with their own sense of a coherent self, history, and personality might be far larger or far smaller than our own, perhaps broken into millions of parts that interact with trillions of other parts in unfamiliar ways.

Though these aspects are fuzzy, others are clearer. For example, “local” talk is much cheaper than distant talk. Thus, mental coherence is easier to obtain locally than over broad distances, and consequently more uncertainty exists about distant mental states. That is, even our Year Million descendants still have some relatively local beliefs, goals, and plans that have a privileged influence over local actions. And they have sharper memories of those local—by contrast with distant—activities that have led to current activities. Our descendants also suffer tensions between local and distant beliefs, goals, and plans, resulting in interactions analogous to what we call conflict, persuasion, promises, and deals.

Even more so than today, the spatial distribution of activity is highly uneven because of the highly uneven distribution of useful physical resources such as mass, energy, negentropy, and information. Such resources are highly concentrated at those small bountiful oases separated by vast “deserts” (or we could think of them as small islands separated by vast oceans). These oases might be comets, planets, stars, centers of star clusters,

galactic centers, or centers of clumps of as-yet-unknown types of dark matter; we cannot yet discern which oases will be important, or how.

The speed of light limits travel, and interstellar distances are so enormous that reliable travel is prohibitively expensive. Still, our descendants sometimes send seeds to cross the vast desert between oases. While the desert's density is very low on average, its total mass is immense; we can now only dimly imagine the dangers and obstacles such deserts might contain. Perhaps "here be dragons." Over such vast distances and times, seeds can suffer internal failures and collisions with stray desert matter—risks that increase with travel speed and distance.

A seed might contain just a single coherent mind, or information for constructing trillions of minds. It will not be a gigantic starship staffed by a human crew, the parochial *Star Trek* or *Battlestar Galactica* vision. At a minimum, each seed contains information and equipment sufficient to turn raw oasis resources into organized productive capital. Seeds can vary in their speed and capacity to carry cargo and fuel. Seeds can have eyes, ears, and scouts to identify and locate oases, other seeds, and obstacles. They might carry weapons to direct at obstacles, seeds, or oases, or shields to protect themselves from weapons and obstacles. They could also have maneuvering abilities, to evade weapons and approach targets.

Once a seed arrives intact at a virgin oasis, it begins to develop resources at that oasis into more usable capital. Such capital would support a largely self-sufficient local economy, and could take the form of mines, refineries, factories, roads, transports, generators, sensor grids, radiation collectors,

heat radiators, signal and power lines, construction and repair units, and command and control centers.

Such capital can be used to create more capital, as well as to increase oasis abilities to observe, talk with, hide from, and defend against outsiders. Even moderately developed oases have enough resources to defend themselves ably against invading seeds intent on displacing them. As noted, defense against long-distance weapons might be harder.

Importantly, the capital of an oasis can also be used to launch a new generation of seeds, the first of which might be the original seed refurbished. Capital would be used to construct the seeds themselves, and perhaps launchers to give them a push, or power and information transmitters to help seeds in transit. Oases might also create observatories and simulators to help refine plans for where seeds should land.

Descendants could ride in on seeds or be received later as signals [as Wil McCarthy speculates in Chapter 7—Ed.]. The rate at which capital can be created from oasis resources eventually slows down as oasis resources are exhausted. Different types of oases have different mixtures of resources and different points at which such resources become exhausted.

The Bleeding Edge

What sorts of lives will our descendants live, empowered by the most advanced technology possible and steadily domesticating the vast resources of the galaxy, as they develop oases and travel between them? Will they build

immense mansions with armies of servants to reenact famous battles on the south lawn? Will they isolate planets of primitive life to study their evolution, build vast Jupiter brains or MBrains to calculate more digits of pi, or shape molecular clouds into exquisite sculptures visible a billion light-years away?

Perhaps some settled descendants will do such things, but we are considering a realm near the edge of a wave of colonization hundreds of thousands of years after it began expanding away from Earth. Over this vast time, there has been a continuous race to see who can expand fastest, a race that has given the winner of each stage extra advantages in future stages.

This long competition has not selected a few idle gods using vast powers to indulge arbitrary whims, or solar-system-sized Matrioshka Brains. Instead, frontier life is as hard and tough as the lives of most wild plants and animals nowadays, and of most subsistence-level humans through history. These hard-life descendants, whom we will call “colonists,” can still find value, nobility, and happiness in their lives. For them, their tough competitive life is just the “way things are” and have long been.

Let us start by considering a wave of colonization with a locally flat wall or wave-front separating a colonized region from a fresh, uncolonized region. This is the sort of wave-front that might pass through any desert peppered uniformly with similar oases, such as the stars in a galaxy. The seeds all fly in nearly the same direction, away from the wall, and fly faster than the wall itself moves. Behind them, most of the good oases are occupied. Ahead, more and more virgin oases are available. A few lucky seeds find

themselves at the very leading edge of the wave, and have the luxury of picking a destination ahead with little fear that a competing seed will arrive first.

At the leading edge, all colonists follow similar strategies—that is, context-dependent behaviors. Colonists prefer similar oases, build similar colonies, and stay similar durations before launching similar numbers of similar seeds that move a similar speed and distance. These strategies are similar because they are close to the fastest possible way to move forward. By this time, recall, advanced technology is largely shared in common, and unchanging. Any slower strategies have, by definition, fallen behind and are no longer represented at the leading edge.

Though hardly noticeable to us, small strategy differences might loom large to our descendants. They might tie group identities to such differences, and obsess about whether variations in success are signs of random luck or of quality distinctions. The status ranking is clear; those closer to the leading edge rushing outward into the cosmos are more likely to have better strategies, and in any case will have more influence over future events.

It is not clear how many seeds an oasis typically sends out. But regardless of whether that number is ten or ten trillion, seeds certainly choose ambitious high-risk strategies so that, on average, only *one* seed survives the journey to colonize a new oasis. That is how plants today replicate, a strategy shaped by the pressures of natural selection. Of the thousands of seeds a plant might distribute, on average only one seed produces a new plant that lives to distribute more seeds.

To tolerate such a high failure rate, leading-edge colonists

are relatively tolerant of local risks. Any given seed might fail internally or hit a local obstacle. These risks tend to average out across a wide colonization frontier. Colonists might be less tolerant of correlated risks, such as uncertainty about a common characteristic of a larger region; correlated risks do not so easily average out.

Leading-edge descendants are rapacious and hardscrapple. That is, they devote few resources to luxuries that could instead be used to speed oasis growth or seed travel. Oasis colonies try to grow as fast as possible, neglecting long-term consequences for the oasis after seeds have gone, while seeds travel as fast as they reliably can, neglecting consequences for the desert they pass through. An oasis sends out new seeds only when its local capital growth rate is slowing down, and seeds in transit do not stop until the fraction that fail per distance traveled is increasing.

Interactions between leading-edge oases or seeds are probably minimal. However, if there were very fast and effective long-distance weapons, then seeds and colonies might try harder to hide and to choose unpredictable destinations.

When the wave-front is not flat but round, leading-edge strategies would adjust to prescribe slowing down, staying longer at oases and moving more slowly between them, to let more seeds survive and populate the larger volume ahead.

Leading-edge strategies would also adjust to a foreseeably nonuniform distribution of oases or desert obstacles. For example, outside the galaxy the density of useful oases probably falls by a larger factor than does the seed failure rate between oases. If so, the colonization wave would have to move more slowly outside the galaxy. To compensate, colonists would stay longer at oases and travel in slower

seeds. Strategies at the galaxy edge would also slow down, in effect building up resources during years of plenty in anticipation of years of famine ahead. Dwarf galaxies would be prized places to replenish resources.

Falling Behind

On average, colonists near the leading edge tend to slowly fall behind the lucky few who remain there as it rushes outward. How does behavior change as they fall behind? It depends on how intense (that is, how selective) was the colonization competition and race so far.

If competition was only moderate, then behind the leading edge we would see a mix of descendants, some who had suffered unlucky setbacks using pretty fast strategies, together with descendants using not quite as fast strategies. In this case, behavior behind the leading edge would look similar to that on the leading edge, but more random.

In the more likely case, wherein the competition has been more intense, it would select for colonists who adapt their behavior well to falling behind the leading edge. After all, the random factors that make one fall behind now might also help one to catch up later. So the best strategy for those who fall somewhat behind is to seek their best chance to return to the leading edge. Strategies that include giving up too easily would suffer on average and eventually fall so far behind that few seeds would be found anywhere near the leading edge.

In this case, seeds behind the leading edge would be not just risk-tolerant but actually risk-loving about their travel speed. That is, they would happily give up a middle

speed for a chance to either go much faster or much slower. Expect them to scour technical or terrain uncertainties for unlikely scenarios that might catapult them back to the leading edge.

Since the first colonists to an area grab the best oases, those arriving later must make do with lower-quality oases. Later arrivals must also suffer a larger chance that they will arrive at an oasis only to find another seed already settled in (and perhaps heavily defended). Seeds can try to compensate for such congestion by attempting to signal their intended destinations, by watching and replanning in flight, or by fighting over newly occupied oases.

To compensate for congestion and lower-quality oases, those that fall behind send out more seeds that travel more slowly and less far and invest more in observing, fighting, and maneuvering. Colonists would stay longer at each oasis to pay for all this, invest more in defense, and consider a wider range of oasis types. The net result is that those behind the leading edge move, on average, more slowly than the leading edge and fall even farther behind.

Congestion is a form of interaction, and it suggests other kinds of interaction behind the leading edge. We have so far considered the “lowest rung” of the local food chain; there might also be analogues of parasites and predators that “feed” on this basic colonization process. Working out the details of such a complex ecology is well beyond the scope of this chapter.

Congestion interaction also suggests the possibility of local coordination. A very intense colonization race might select for extreme local cooperation within local colonization “threads.” A thread of cooperation would be a volume in

space that follows a group of cooperating colonists and their descendants along a path of colonization, ending with a region of the colonization wave-front surface. Such colonists would cooperate to exclude predators and outsiders from their thread, and coordinate to avoid having their seeds target the same oasis. Threads thus avoid congestion costs except on the thread's surface. Better-performing threads would slowly increase their fraction of the surface of the colonization wave-front.

Staying Behind

Even among colonists who use the fastest possible strategies, a great many will find themselves far behind the leading edge and falling ever farther behind. Such colonists become increasingly desperate to find any long shot, however risky, that might move them closer to the leading edge. They would not accept just growing very slowly at poor oases; there is a limit to how slow an oasis growth rate they will tolerate.

So if all colonization behavior were devoted *entirely* to winning the race for the leading edge, the only things to be found a long way behind the leading edge at most but not all oases would be the wreckage of failed seeds, empty abandoned oasis colonies, and a notable absence of the prime resources. It would be as if a wildfire had passed through the area, converting the easy kindling to ash, but burning itself out while leaving slow-burning tree trunks largely untouched.

It is possible, however, to stay competitive at the lead-

ing edge for a long time even if from time to time one diverts a tiny fraction of resources at far-behind oases away from the task of chasing the leading edge. If the process of launching seeds sometimes does not quite exhaust all local capital, then the remaining colonists could give up on ever reaching the leading edge and instead devote themselves to staying put.

Such rare, diverted resources are likely, and would entirely change the character of far-behind regions from dead and empty to lively and full. For example, if a few colonists always remained at every occupied oasis, then in short order all such oases would become well developed. Alternatively, if colonists stayed at only a few rare oases, then once those oases developed enough, they could send out seeds to repopulate the local area. Under this second scenario, it would take only a bit longer for almost all local oases to be well developed.

Because seed travel is so expensive, it would cost far more to successfully conquer even a moderately developed oasis than could be gained from the invasion. There is thus a natural defensive advantage against oasis conquest. Long-distance destructive weapons might perhaps be cheap, but they would probably allow one to destroy an oasis, not to acquire its resources.

Because the first colonists at an oasis could repel invaders indefinitely, the distribution of colonist types in a region long after a colonization wave had passed would be determined mainly by the stay-put choices of the leading-edge colonists who had passed by long before. That is, the fraction of local oases dominated by any given type of colonist would depend

on the fraction of their ancestors on the leading edge of colonization, weighted by the fraction of oases at which those ancestors left behind colonists inclined to develop that oasis enough to resist invasion and to send seeds to similarly develop neighboring deserted oases. The earlier a colonist begins to stay put, the more of the local deserted oases it could colonize.

The competition for the leading edge selects against devoting resources to stay-put colonists, though only weakly. So to the extent that such stay-put behavior exists anyway, it is in defiance of that selection. Thus such strategies could be somewhat arbitrary (i.e., determined by hard to anticipate details of the way colonist behavior is encoded and varied). So for a long time after a colonization wave has passed, the activity in a region is determined largely by whatever arbitrary stay-put strategies have been chosen by such diverted colonists.

Eventually local selection effects might privilege certain kinds of stay-put behavior over others, but such effects, too, are well beyond the scope of this chapter. It is interesting to wonder whether the universe we see around us is consistent with such a scenario. That is, could a wave of alien interstellar colonization once have passed this way? Perhaps some combination of powerful weapons and oases in hiding from such weapons could be consistent with the virgin appearance of the universe we see.

Conclusion

The future is just another place in spacetime. We have used an evolutionary game-theory analysis to outline basic

physical aspects of the cycle of life toward the edge of a wave of interstellar colonization. I have estimated at least a 5 percent chance that this package of assumptions will apply close enough to at least 5 percent of our descendants in the Year Million. Given how very far away one million years is, that would be doing very well at forecasting.

The future is not the realization of our hopes and dreams, a warning to mend our ways, an adventure to inspire us, nor a romance to touch our hearts. I am not praising this possible future world to encourage you to help make it more likely, nor am I criticizing it to warn you to make it less likely. It is not intended as an allegory of problems or promises for us, our past, or our near future. It is just my best-guess description of another section of spacetime. I can imagine better worlds and worse worlds, so whether I am repelled by or attracted to this world must depend on the other realistic options on the table.

Analysis Method

When different personalities choose different colonization strategies, then those strategies effectively compete to see which of them produces a faster expansion out into the cosmos. Of course, from its own point of view, a personality might be happy to lose such a race, deeming the price of winning to be too high. Nevertheless, as we look farther out into the cosmos, we should tend to see the faster colonization strategies prevailing.

If the descendants and future selves of a personality tend to have similar personalities, then the competition

in each new colonization generation should select more for the faster strategies at the leading edge. Also, laggards who arrived after the first colonists to an area would have to make do with leftover resources, the resources the first colonists chose to not use, hide, destroy, or defend. Yes, in recent times humans well behind frontiers have competed effectively with frontier humans, but the scale economies that have made this possible are being assumed away for future oases.

After many generations, these advantages should increasingly select for and emphasize faster personalities on the frontier. Eventually, regions anywhere near the leading edge should be populated almost entirely by variations on, and descendants of, personalities that took the fastest winning colonization strategies. These fastest personalities dominate the “way of life” I describe in this paper.

To study these fastest strategies, I have elsewhere constructed a mathematical game-theoretic model to calculate optimal colonization strategies.³ In its most general form, the colonization problem is described via five key functions:

An *oasis* function gives the distribution of oases in spacetime by type.

A *growth* function says how the resources available to a colony depend on oasis type and the time since a seed landed at that oasis.

A *cost* function says how the resources needed to make and launch a seed vary with features.

A *mortality* function gives the rate at which seeds fail in transit, depending on the local oasis density as well as seed speed, hardness, and distance from source.

A *targeting* function says the chance a seed successfully gains and holds an oasis of a given type, given the local fraction of occupied oases, the rate of change of that fraction, and the seed's speed and targeting ability.

These functions are usually described abstractly in terms of the signs of various derivatives.

To analyze the optimal strategy in this game, I consider two functions across spacetime: a *density* function, giving the fraction of oases of each type that are occupied, and a *value* function, giving the value of having a new colony there. There are two key consistency equations.

First, a *flow* equation connects the oasis occupancy rate to the rate of arrival of seeds with various features.

Second, a *strategy* equation sets the value of a seed starting to colonize an oasis equal to the best possible sum of the expected value of seeds later launched from that oasis that end up successfully colonizing new oases one generation later. By “best possible” we mean considering all possible strategies for how long to wait at an oasis until sending out how many seeds of what type, how far and how fast. We consider colonist actions that are close to these best possible actions.

As usual in such analysis, to get concrete answers we must make a variety of “technical” assumptions of varying

plausibility. While the intent of such assumptions is to simplify the analysis without overly compromising realism, this intent is not always realized. Also as usual, we try to see how far we can get by making relatively weak assumptions, and then we add stronger assumptions as needed to get clearer pictures.

For example, my math analysis has so far always assumed that seeds travel many oasis spacings, that there is only one kind of oasis resource, and that oases are constantly and uniformly distributed in space. Sometimes this math assumes a flat colonization wave-front.

Surely the main question in many readers' minds is: how reasonable is our basic evolutionary modeling approach? This depends on how reasonable are its key modeling assumptions, of "enough" (1) stability of personalities across generations, (2) generations of colonization, and (3) variations of personalities. Whether there is enough personality variation depends in part on the level at which stable behavior tendencies are encoded.

For example, it might be that the stable tendencies are inclinations to build seeds a certain time period after landing at an oasis, or to make seeds of a given speed and hardness that travel a given distance, but with little tendency to *adapt* these behaviors to changing environmental features such as local colonization congestion or the types and density of local oases. If so, an evolutionary analysis might do well at describing average behavior, but poorly at describing how such choices *vary* with such environmental features.

On the other hand, there might be some colonist personalities that want to win at any cost the race to dominate the leading edge. Such personalities would calculate in far

more detail than we have done the best behavior to achieve this goal, assuming other independent competitors had a similar aim. With enough initial colonists like this, or with just one or two of them and enough generations of competition, optimal behavior models might do very well at describing behavior near the leading edge.

Chapter 8: “The Rapacious Hardscrapple Frontier” by Robin Hanson

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Chapter 9: “Do You Want to Live Forever?” by Pamela Sargent and Anne Corwin

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