von Hoerner lecture notes 2

Journal of the British Interplanetary Society, Vol. 28, pp. 691-712, 1975.

POPULATION EXPLOSION AND INTERSTELLAR EXPANSION*

SEBASTIAN VON HOERNER
NRAO, P. O. Box 2, Green Bank, West Virginia 24944, U.S.A.†

The growth of our human population is a problem much more serious than is realised by most of us; and starvation is certainly not the only, and probably not even the worst, threat from overcrowding. It is frequently mentioned by many science fiction writers (and by some scientists occasionally) that space travel and "populating other worlds" could be a future solution, maybe at least for some higher advanced civilisations. But it can be shown in general that the crisis of population growth cannot be solved by interstellar expansion, even if a perfect technology were assumed. We must look for internal solutions only, and must find one soon.

Another present crisis is self-destruction, and genetic degeneration will become a third one later. All three crises come in such a natural, predictable way that it seems reasonable to assume their general occurrence among emerging civilisations. Another feature common to all three crises is the sudden constraint to internal solutions, for problems which always before had been solved externally.

It could well be that civilisations, having survived these three crises, (and probably many more) must of necessity have developed such a high degree of stabilisation and regimentation that they will merge into the final crises of stagnation (the crises to end all crises) which even can be irreversible. Is this the reason why we do not see any sign of life and interstellar activity, among the billions of stars and galaxies we observe?

Interstellar communication could play a crucial role regarding the further development of civilisations, giving the advantage of competition without its danger, and preventing stagnation. Expansion then would be mental, not physical.

1. THE POPULATION PROBLEM

1.1 The Rate of Growth

How bad, actually, is the problem? At present (1972), there are 3730 million people here on Earth, and many of them have good reasons to feel that this number is already much too large. The density, in number of people per square mile, was in 1960: Africa 20, USSR 26, USA 49, Europe 221, India 332, and Japan 660. For a uniform distribution, this would mean a distance between neighbours of 1200 feet in Africa, 760 feet in the USA, 360 feet in Europe, and 210 feet in Japan. But we do not live uniformly distributed; a good fraction of the land is desert, rocks or forests, and in western countries most people live in cities. In a small university town like Charlottesville, Virginia (population 38,000),

* This paper, dedicated to C. F. von Weizsäcker on his 60th birthday, appeared in an earlier version, in 1972, in "Einheit und Vielheit", Scheibe and Süssmann (editors), Vandenhoeck and Ruprecht, Göttingen. Acknowledgement is made to the publishers for permission to present the paper here.

† The National Radio Astronomy Observatory is operated by Associated Universities, Inc., under contract with the National Science Foundation.

the average distance to neighbours is 93 feet, but it is only 23 feet in New York City. (And, as we all know, it is bumper-to-bumper during rush hours in all cities.) These numbers seem bad enough already.

But it gets worse all the time. At present, the human population increases by 74 million people each year (about as much as all of Germany, or 1/3 of the USA), which is 2.0% per year. This number, $\alpha = 0.02$/year, we call the relative growth rate, defined in general for a population N(t) by

$$dN/dt = \alpha N \tag{1}$$

If α were constant, the population would follow an exponential growth as

$$N(t) = N_o e^{\alpha t} \tag{2}$$

With $\alpha = 2\%$ per year, the population would double every 35 years, and be tenfold every 115 years. But other things increase even faster; following Basler [1971] we have given some examples in Table 1.

TABLE 1. Various Rates of Growth.

Quantity	Growth rate, α % per year	Doubling years	Factor 10 years
World population	2.0	35	115
Western construction activity	3.3	21	70
Number of scientists and engineers	4.6	15	50
Western energy consumption	7.0	9.9	33
Air freight (weight times distance)	11.0	6.3	21

Basler gives also a useful formula,

$$\tau_{cr} = \frac{230}{\alpha} \log(Q_{cr}/Q_o), \tag{3}$$

for the critical time τ_{cr} (in years) which it takes for a quantity Q to increase from its present value Q_o, to a critical or limiting value Q_{cr}, assuming exponential growth with a constant rate α (in % per year). We will make frequent use of this equation.

How we feel about something depends very much on the way we look at it; which, in our scientific age, means how we plot it. A nice illustration is shown in Fig. 1 (copied from Basler), where the same quantity Q(t), with exponential growth and with $\alpha = 3.3\%$ per year, is plotted first over the number of years, and second over the number of generations. If the only concern of some politician were the next election, he would plot Fig. 1a and would not find much to worry about right now; he would decide to worry about it later or let the next one in office do it. But if someone feels responsible for his children and grandchildren, he plots Fig. 1b, and his hair stands on end because the grandchildren don't even fit into the figure.

Actually, it is even much worse than that, because the population growth is *not* just exponential. This is clearly shown in Fig. 2, where an exponential growth would mean a straight line for N(t) and a constant value for α. But during the last 2000 years, α has increased by a factor of 40, just as much as N itself has, and indeed it always stayed $\alpha \sim N \pm 10\%$. Now, if

$$\alpha = \alpha_o N \tag{4}$$

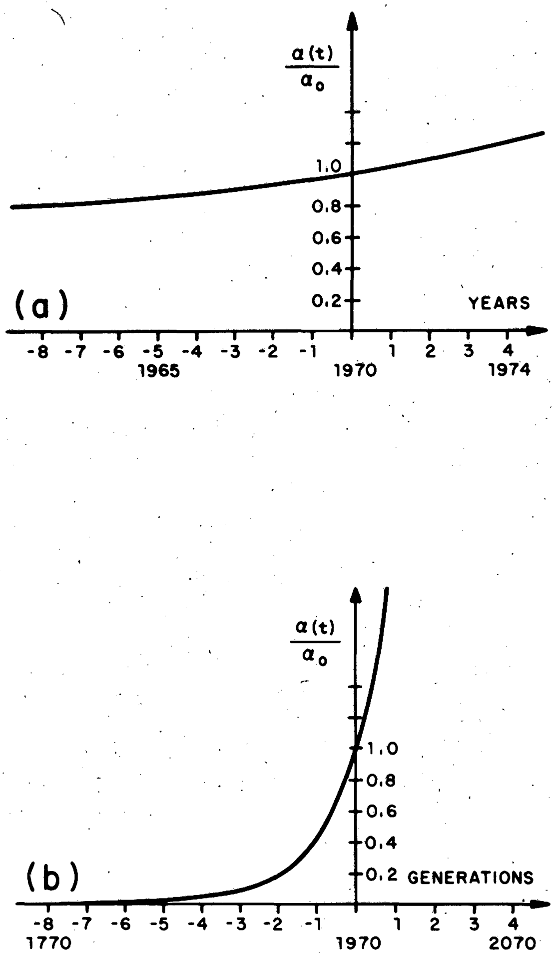

Fig. 1. The same exponential growth, with $\alpha = 3.3\%$ per year, plotted over (a) the number of years, (b) the number of generations.

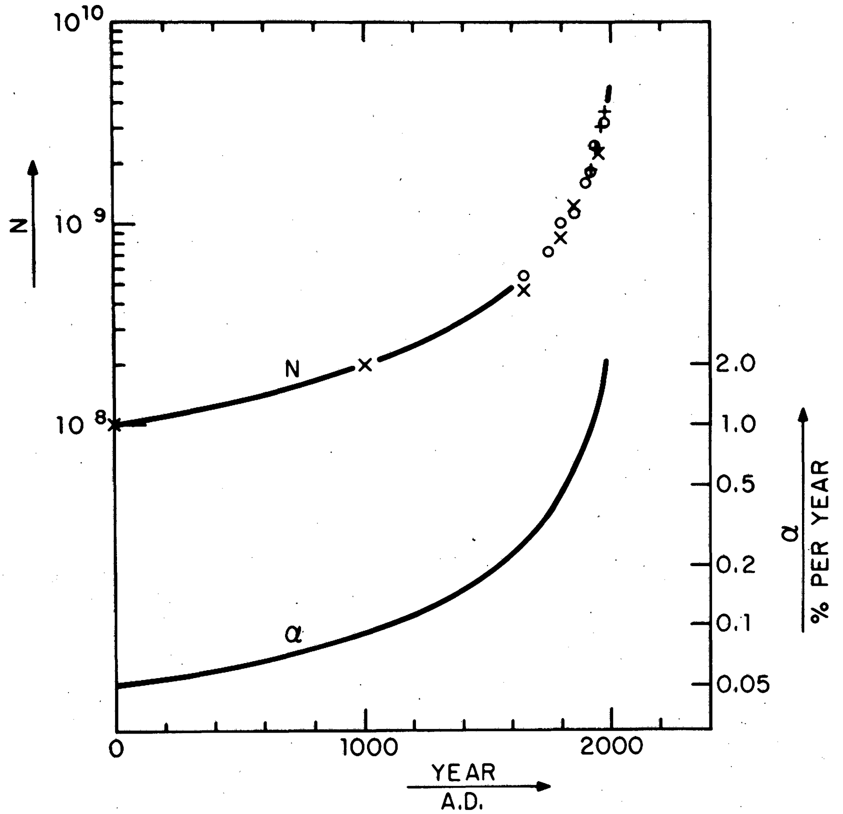

Fig. 2. World population N, and its growth rate α. X Mills [1959], O Rand McNally [1962], + VDW [1968].

with a_0 = const, then $dN/dt = a_0 N^2$ which is easily solved and yields

$$N(t) = \frac{1}{a_0 (t_\infty - t)} \tag{5}$$

This means that $N \to \infty$ for a finite time t_∞, to be found from

$$t_\infty = t_0 + 1/a_0 N_0 \tag{6}$$

With $a_0 = 5.0 \times 10^{-12}$ /year from Fig. 2, and with $t_0 = 1972$ and $N_0 = N(t_0) = 3.73 \times 10^9$, we obtain t_∞, the year of the true population "explosion", as

$$t_\infty = 1972 + 54 = 2026 \tag{7}$$

This result was obtained in a very good paper called "Doomsday: Friday, 13 November, A.D. 2026" by von Foerster, Mora & Amiot [1960], using a large and critically selected number of data, and with a general exponent $a = a_0 N^{1/k}$ to be solved for (with the best-fitting result $k = 0.990 \pm 0.009$ and t_∞ = A.D. 2026.9 $\pm$ 5.5 years); t_∞ was called "doomsday", and $\tau = t_\infty - t$ called "doomstime". At present, a doomstime of τ = 54 years is all we have left, just two more generations to go Fig. 3 shows clearly how straight we are headed for our disaster. Before we further discuss this result, let us first give it a precise formulation.

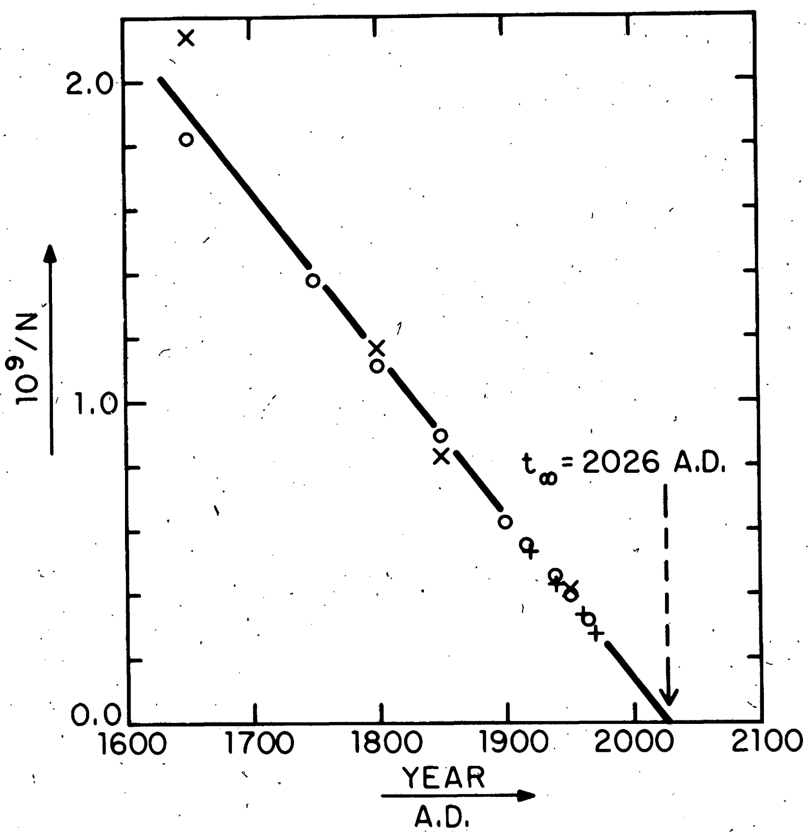

Fig. 3. Same data as Fig. 2 (last 300 years), but 1/N plotted over t. The straight line represents equation (5). Up to 1970, there is no indication of any beginning saturation.

> The best fitting curve for the past 2000 years, extrapolated into the future, predicts an infinite population after 54 years. (8)

But what does that really mean? Physical laws leading to a singularity usually are said to "break down" shortly before reaching it. In our case, too, we do not expect an infinite number of people, but we do seriously predict some drastic change within the next few decades; either achieved *by* us with great effort, or happening *to* us with deep suffering. Something is going to break down, and hopefully not mankind itself.

For almost all people, and during most of our past, the concept of *progress* has been an extremely positive one: a driving force in our actions, and a religious belief in our thoughts and feelings. Just listen to the positive sound of "progress, movement, going ahead", and the negative sound of "stagnation, stand-still, staying behind". It will be extremely difficult to change that.

When and why must we change it? The progress of our population number must soon turn into stagnation because our living space is finite. Or, quite in general: you better stop growing when you hit the ceiling. Some such ceilings will be discussed in the following.

1. 2 Some Material Limits

(a) *The Food Limit.* The danger of world-wide famines is frequently considered as the most urgent one. It actually is, but always has been, a severe problem in underdeveloped countries (whereas we have changed to exactly the opposite problem, dying of heart attacks from overfeeding). The numbers given in the next two paragraphs are taken from a thorough study by the Vereinigung Deutscher Wissenschaftler (VDW 1968).

At present, 70% of all people live in underdeveloped countries. And of these, 20% suffer from severe undernourishment and 60% from malnutrition of various kinds and degrees. The food per person is higher in the developed countries than in the underdeveloped ones by a factor 3.2. All four numbers given have been increasing (getting worse) during the last 10-20 years.

The present total food production would just suffice to provide all present people with a bare minimum supply, if it were equally distributed and if the present wastage of 20% could be avoided (mostly pests and bad storage). For a good, generally acceptable supply, the production should have been larger by about a factor two. But in addition to this factor, the future production must keep pace with the population growth. The VDW study sees no way for any fast improvement. But with a true (though difficult) effort on both sides, a catastrophic development could be avoided, and some small progress be made, at least for the near future.

But what about the far future? What should we consider as the ceiling, the final limit of food production? Let us use the following assumptions: (a) All land area of all continents were irrigated and cultivated, and planted with wheat or some similarly nutritious food. (b) A good yearly production of 3.0 tons/hektar = 800 tons/square mile, and no wastage. (c) Wheat yields 3.7 Cal/gram. (d) One person needs 2500 Cal/day. With these numbers, we obtain a final density of

$$3140 \text{ people/square mile} \tag{9}$$

or an average distance between neighbours of 94 feet, or a total world population of

$$N_{cr} = 1.8 \times 10^{11} \text{ people} \tag{10}$$

which, as compared to the present, is a factor

$$N_{cr}/N[1972] = 48.2 \tag{11}$$

If we just keep growing according to Fig. 2, this limit will be reached in A.D. 2025, or after only

$$\tau_{cr} = 53 \text{ years} \tag{12}$$

But if we soon get worried enough to do something and stop at least a from growing any further, it is of course anybody's guess (meditating a while over Fig. 2) at which value of a we might manage to keep it constant. Application of equation (3) then gives, anyway, only a few generations:

a	τ_{cr}
3% per year	129 years
4	97
5	77

(13)

(b) *The Energy Limit.* One of our main present energy sources is mineral oil. Its consumption has been increasing with $a = 6.9\%$ per year, and experts think we have used up about 4% of the oil available on Earth (Basler 1971).

With equation (3) this gives

$$\tau_{cr} = 47 \text{ years} \quad (14)$$

But of course we will soon change to nuclear energy. Maybe fusion (of hydrogen to helium) can be used in the future. Then 1 gram of hydrogen yields already 1.7×10^5 kWh of energy, and the tremendous amount of hydrogen in our oceans looks like an unlimited supply of energy. (Although, what do we do with all the helium?)

But now the limitation comes from a different side, independent of the source of energy. Energy consumption creates *heat*, and we must take great care not to upset the very delicate temperature balance of our planet, made up between the incoming solar radiation at the dayside (1.37 kW/m^2, or a total of 1.74×10^{17} W), and the temperature-dependent amount we radiate into space. Now, it seems we cannot increase the average temperature of the Earth by more than about 1°C without severe changes to ocean level, cloudiness and rainfall. This is 0.3% of the absolute temperature (300°K), and since our own radiation goes with T^4, we cannot afford any energy production larger than 1.2% of the solar radiation. This limit,

$$E_{cr} = 2.1 \times 10^{15} \text{W} \quad (15)$$

is only 317 times our present energy consumption of 6.6×10^{12} W. With $a = 7\%$ per year from Table 1, equation (3) then yields about three generations,

$$\tau_{cr} = 82 \text{ years} \quad (16)$$

This energy limit is a very crucial one. Somehow, most people feel that anything can be solved with just enough "push and energy", no matter what the problem. Well, that is true in many cases; but not in those requiring more than limit (15), and certainly not for the energy problem itself as expressed by (16). Furthermore, (15) also sets a final limit to any artificial production of food.

Actually, there are many more limits but we will not discuss them here: the diminishing supplies of iron, chromium and other natural resources, as well as the exactly opposite problems of garbage, wastes and pollution.

1. 3 The Territorial Limit

(a) *The Normal Situation.* Man is a social animal. But how much so and which type? According to Leyhausen (1969, p. 156) the only socially neutral mammal is a dead one. In general, there are two types of social behaviour: (1) The *pecking order,* within groups or herds belonging together, first discovered in 1922 by Schjelderup-Ebbe among hens in farm yards. This is a fixed and linear order of social rank. In the extreme case where nothing else matters, it is an "absolute hierarchy". (2) The *defense of a territory* which in the various species may belong to a single individuum, to a family, or to a larger group. It may be more complicated, like many small family territories within one large group territory, or sharing a place but dividing it by a fixed time schedule. Usually, the social dominance or rank of an animal is largest close to his home base (nest) and decreases with increasing distance; it is a "relative rank". The territorial behaviour was first carefully investigated with all its different varieties among birds, by Nice in 1941. (3) Many species have both patterns simultaneously, a *rank dualism* as Leyhausen calls it. In general, the pecking order dominates for animals living in larger herds, and the territorial claim is most pronounced for solitary animals or those living in small families.

Now, where do *we* stand? According to Morris [1967] the primates have a well pronounced leader and a pecking order, almost without fixed territories. But in the emergence of mankind, during the change to cooperative hunters, a fixed home base and hunting ground for the group was developed in addition; and the prolonged dependence of the young led to stronger family bonds and family defense, too. We thus have it both ways, the full dualism of pecking order plus territorial claim. Many drastic and typical examples for both ways are told by Lorenz [1963], Leyhausen [1969], and Morris [1967, 1969].

For dualistic animals, the balance between absolute and relative rank depends on the population density. Free-living wolves, for example, are mostly territorial; their pecking order is only mildly pronounced, and members of the same pack are friendly to each other and share their food. But in a zoo, with enough food but not enough space, a vigorous pecking order develops, with serious fights and little rest. This dependence on the density holds for the human animal, too. With plenty of space around us, as for the early settlers of the USA, there is a dominant territorial behaviour and very little absolute rank. Whereas the opposite case, the extreme pecking order of our crowded city life, is best described in the "Status Seekers" by Vance Packard [1959].

(b) *Overcrowding.* The effects of strong overcrowding can become very serious, even lethal. Leyhausen [1956, 1969] studies groups of cats in cages. (Cats are dualistic, too.) With increasing degrees of overcrowding, relative rank decreases. Finally, there is one despotic tyrant, while on the other social end there are some completely terrorised and despairing "pariahs", and in between there is a malicious mob with non-stop spitting and fighting. Calhoun [1962 a, b) found similar results with overcrowded rats neglecting their young and turning to cannibalism. Other animals have been studied, too, and many show a complete breakdown of their social patterns if heavily overcrowded.

It actually is the lack of space, the missing distance to the neighbours, which matters in all these cases, not the lack of food. Nor is it the real physical threat from strong close neighbours as one might think; von Holst [1970] reports that the weak animals suffer from overcrowding even if they are completely protected from the stronger ones by screens, and this suffering can go so far as to produce damaged kidneys and even death.

Lack of space means too short a distance between neighbours, not enough privacy, too high a density. It seems that each territorial or dualistic species has (a) an *optimum* density, somewhere between loneliness and overcrowding; and (b) a certain *adaptability,* for dealing with a higher density by somewhat changed patterns of behaviour; but (c) only up to some density limit, called *tolerance limit* by Leyhausen, beyond which all social patterns break down and where "uncontrollable aggressiveness" [Morris 1967] takes over.

All this applies to humans, too. As an optimum, I think, we want our neighbours close enough for a social life, but far enough for keeping them out of our family life. And in addition, we want plenty of wide empty ranges, of unbroken nature, for charging up our individualism once in a while, on weekends and vacations, as needed for good mental health. No doubt we have already passed this optimum and have adapted to considerably higher a density. More or less adapted, that is, and the less the higher the density. For example, Goldmark [1971, Fig. 8] shows that in the USA the rate of crime increases with the number of people in a city, about as $N^{1/4}$, which means by about a factor of 10 between a small village and a large city where it reaches the alarmingly high value of 7.0 crimes per year per 100 people. And humans also show the catastrophic breakdowns when crossing a tolerance limit. Riots and mass violence, slums, and utter despair and suicide, they all are typical for large cities; even revolutions used to start there. The most extremes maybe are prison camps; Leyhausen [1969] has spent 5 years as a prisoner of war and tells many drastic examples.

True social contact needs distance, as Leyhausen puts it. Also, democracy needs a sufficient amount of relative rank, and it cannot work beyond a certain density limit where the absolute rank of the pecking order starts dominating. With overcrowding comes tyranny, and frequently the tyrant is not a person but some organisation or government (acting always only in the common interest, of course). And with tyranny comes either mental crippling and neuroses, or some violent revolution mostly just replacing one tyrant by the other. We should keep in mind that most of our political problems and dangers, internally and worldwide, are closely connected with overcrowding.

And all this is not a matter of good will, of proper education, or of the right faith. More exactly: it is so, but only within our biological range of adaptability. There is a tolerance limit, inborn, part of our genetical heritage, which we cannot change.

Thus, our most urgent population problem is neither food nor energy which both still give us a critical time of two or three generations, short as that is. Most urgent is the territorial limit which we have passed already ($\tau_{cr} < 0$, so to say). Not only must we stop increasing our number, we should reduce it (by at least a factor of eight, if Leyhausen is right). Regarding the territorial limit, it is not the eleventh hour. It is far past midnight already.

(c) *Future Investigations.* Both Leyhausen and Morris agree that the territorial limit is our most urgent problem, that we have passed it already, but that we do not know its exact numerical value. Here, we know much more about cats, wolves, and rats than about humans. We badly need dependable objective investigations into this question so vital for us:

What exactly are optimum density and tolerance limit for the human being? (17)

But there is an additional problem. We certainly do not live as far away from our neighbours as we could; quite the contrary: we crowd into the big cities with considerable pressure. In 1960 in the USA, 53% of the nation's people lived on 0.7% of the nation's land, in 213 urbanized areas [Davis 1965]; which means in a density 76 times the average one. Thus I would like to see the question investigated:

Why do we crowd more than we have to? (18)

Some explanations may be, first, that efficiency increases with size (private workshop, factory, corporation, monopoly) which in a way applies to cities, too. Living standards increase with city size, maybe not much in the average but steeply so for the tempting upper end of the distribution, the more obviously seen wealthy people. Second, many things you may consider essential for your life have each a minimum city size below which they cannot exist (about in this order: tavern, church, high school, night club, university, football stadium, concert hall, opera house). Third, as with food, exercise and many other things: is it that we have lost our instincts, that we do not know what is good for us? This then would mean a lack of education.

2. POPULATING THE UNIVERSE

2.1 Multiply and Emigrate

In the previous sections we did extrapolate into the future, but only so for a few generations. We tried to "keep both feet on the ground". This constraint shall now be released.

First, let us consider a larger range of future, thousands of years, say. Second, since this cannot be done by extrapolation, we must argue on general grounds like basic laws of physics. Third, in case we kill each other shortly, let us talk about advanced civilisations more in general. Fourth and finally, since our population problem results from the limited size of our Earth, why on Earth should we stay?

When Europe got too crowded, and her pecking orders too tyrannical, we just in time discovered America and Australia, huge empty continents (never mind a few natives) with plenty of game and good land. We emigrated in large numbers and that solved the problem for a while. And now, after having crowded the whole planet even more, it may come as a most natural thought to just go on in the same way: the conquest of space, discovery of many lovely nice planets, emigration and settling. Isn't that the way to do it, and if not right now then at least in the future with a more advanced technology? And, quite in general: is it not obvious that many other civilisations far out in space, who advanced earlier than we did, must have faced exactly the same problem and solved it this way, by interstellar expansion?

This basic idea of interstellar expansion is one of the main themes of our past and present science fiction. It covers a vast variety of different occasions, means and results; sometimes it works peacefully and frequently with heroic fights. It goes both ways, too: daring humans setting out for populating other worlds, or hostile flying saucers trying to conquer our Earth (never mind a few natives). Science fiction has a very large audience, on all levels. The stories are frequently dull and stereotype, but some of them display a fascinating degree of imagination, intelligence and cunning. Now, regarding interstellar expansion, most readers may just dismiss it as some amusing fiction and utopia, educated readers may even detect a technical flaw or two; but somewhere back in our mind we still may have that feeling, consciously or not, that this exactly is the thing to do. After all, we see 3000 stars with the naked eye (or would, without air pollution); our Galaxy, the Milky Way, contains 200 billions of stars, about two billions of other similar galaxies can be seen with our largest telescopes. And here we sit on our little unimportant planet and worry about lack of space? Ridiculous. Stop crying and *do* something!

Well, it's no use. We increase by 74 million people per year (1972, that is, next year it will be 77), or 200,000 per day. Who could imagine shipping off 200,000 people each day into space, to other stars? All we have managed at present is two people at a time on the Moon for some hours, and Mars may follow after some years. But both are very inhospitable places, and even more so is the rest of our solar system. The nearest stars with "lovely nice planets" are probably 18 light years away, which is 500 million times farther than the Moon, and still a million times the distance to Mars. We get caught between extremes: here on Earth the distances between neighbours are getting much too short, but out in space the distances between stars are must too large.

No matter whether interstellar emigration could be solved by some highly advanced technology, we don't have it now nor do we have the time to develop it. We must solve our population problem here on Earth and very soon, no way out and no escape. It is the famous "here and now".

So much for our own present problem. But what about civilisations in general? First, maybe some emerging civilisations increase their knowledge much faster than their number, such that the means for interstellar mass emigration are available before overcrowding gets problematic. Second, even without the possibility of a real mass emigration, maybe just a rising population pressure could provide enough incentive to develop interstellar travel and to try some colonisation.

Personally, I do not think it will ever happen this way. Overcrowding results from discovering bacteria, interstellar travel (a million times farther than Mars) needs nuclear energy and a technology much further advanced than ours, and I think that medicine will always come before nuclear engineering, overcrowding long before any feasibility of interstellar flights. The population problem then must always be solved internally, without the help of interstellar emigration. There may be other reasons for interstellar travel, of course, but not the population pressure.

I feel rather sure about this, but I may be wrong. Thus, the following two sections investigate two general possibilities of expansion and their limits. Although the actual population growth is much faster than exponential, see Fig. 2, we will assume an exponential growth in the following.

2. 2 Interstellar Expansion

(a) *Possibility.* Our first question is whether interstellar travel, from star to star, is possible at all. Ten years ago [von Hoerner 1962] my answer was completely negative. First, the energy/mass ratio. Even with nuclear fission we reach at most 1/10 the velocity of light, and $v \leqslant c/5$ with nuclear fusion. Relativistic time-dilation then is negligible; travelling forth and back to explore the next habitable planets (18 light years) then takes at least 180 years per planet, about six generations onboard a spaceship. This still holds.

Second, the power/mass ratio. For a high efficiency one needs an exhaust velocity S close to the final travel velocity v; and the acceleration is $\dot{v} = 2P/S$, with P = (power of engine)/(total mass of rocket). Thus a short travel time needs a large v, which needs a large S for good efficiency, which then needs a large P for sufficient acceleration. With a numerical example, I derived the demand that $P \geqslant 3$ megawatt/gram = 4000 horsepower/gram. Which means that a nuclear power plant of, say 100 MW, enough for supplying a small city, should not have more weight than 33 gram, or about one ounce, or 50 paper clips. I thought that this demand was too high for ever being fulfilled. But this was wrong.

Freeman Dyson [1963] first suggested the use of "gravitational machines" exploiting the potential energy of close binary stars. In case of white dwarfs or neutron stars one could reach 2000 km/sec. = c/150. But later Dyson [1966, 1968] showed that even with our present technology we could build space ships achieving $v = c/30$ (within 10 days of acceleration with 1 G). His principle is amazingly easy: you throw out hydrogen bombs at the rear end of the ship, one at a time, let them explode 1 km behind it, catch about 10% of the explosion energy by a large screen about 1 km in diameter, and then convert this instantaneous thrust into a smooth acceleration by a shock absorber 75 m long. Thus, the power/mass ratio problem can be solved; but the energy/mass ratio together with a 10% efficiency gives a velocity of $v = c/30$, or 10,000 km/sec. This is about a thousand times faster than our present rockets, but still it would need over 1000 years for the 18 light years round trip, about 30 generations of crew on board the ship (and *no* population increase allowed on board).

This example shows two things. First, that interstellar travel is possible. Second, that it is extremely unlikely. Especially so for mass emigration.

(b) *Limit.* Even if we completely neglect and omit all technical problems and limits, there still is an absolute limit (private remark of F. Drake) given by one of our basic laws of physics, that nothing can travel faster than light.

Consider some advanced civilisation, with a "perfect technology" allowing them to travel almost as fast as light, who increase their population exponentially with $\alpha = 2\%$ per year, and who want to solve the problem by interstellar expansion. Then they must go and colonise all habitable planets within a sphere whose volume increases by 2% per year, and the absolute limit is reached when the radius of that sphere increases with the speed of light. From these two equations, $\dot{V}/V = 2\%$ per year and $\dot{R} = c$, we find that this limit is reached when

$$R \; = \; 50 \text{ parsec} \; = \; 150 \text{ light years} \tag{19}$$

which, at least for an astronomer, is an amazingly small limit.

But how long will it take to populate the whole sphere and actually reach the limit? With a density of 0.06 stars/pc^3 we have 500,000 stars within our sphere. A reasonable estimate says that about 6% of all stars have one habitable planet, which gives 30,000 planets to populate until the limit is reached. But with a growth rate of 2% per year, a factor of 30,000 takes only a time of

$$\tau \; = \; 500 \text{ years} \tag{20}$$

This means the following. If some day some civilisation considers their planet as being too crowded, and if their technology then were good enough for mass emigration with almost the speed of light, it takes them only 500 years to crowd 30,000 planets to the same extent, and from then on their growth rate is limited by the speed of light and must then be controlled anyway. Thus, interstellar expansion, even with perfect technology, cannot solve the population problem, it just delays it by 500 years.

2. 3 Circumstellar Shells

(a) *Possibility.* Dyson [1959] suggested that advancing civilisations finally would like to consume the maximum amount of energy, populate the largest possible area, and use for these aims whatever matter is available. In our case, for example, this would mean to take the largest (and otherwise rather useless) planet Jupiter apart, and to use its matter to build around the Sun a spherical shell somewhat larger than the Earth's orbit. This shell then catches all the energy produced by the Sun (nuclear fusion of one solar mass of hydrogen), and it yields an extremely large surface as "Lebensraum". Dyson even went into some details and showed that this task, tremendous as it may sound, is technically well solvable.

The energy produced by the Sun, and consumed by the population, must finally be radiated away at the outside of the sphere, at a temperature of about 300°K, which means at a spectral maximum of about 10 micron wavelength. Thus Dyson suggested looking our for "infrared stars" as possible seats of advanced civilisations.

(b) *Limit.* First, the total energy output of the Sun is 4×10^{33} erg/sec. = 4×10^{26} Watt. Our present energy production is 6.6×10^{12} Watt. The gain thus is a factor of 6×10^{13} which sounds a tremendous increase; but with a growth of 7% per year from Table 1, equation (3) just yields

$$\tau_{cr} = 450 \text{ years} \tag{21}$$

Second, the Earth's orbit is 23,500 times her radius. The gain in living area then is this number squared, or 5.6×10^8, again a very large factor. But with a population growth of 2% per year, equation (3) yields

$$\tau_{cr} = 1000 \text{ years} \tag{22}$$

Even the maximum use of a whole solar system cannot solve the population problem, it only delays it by 1000 years. And the energy must be rationed already after half that time.

3. SEVERAL CRISES

3. 1 Population Growth

Let us discuss the previous results in more general terms. The subsistence or growth of a species is a very delicate balance between average birth-rate and life-time. When a species develops intelligence and enough medicine to enhance the life-time, their number will increase unless or until they also decrease their birth-rate by the same factor, which can be done by medicine as well.

Our human population has been increasing drastically, much faster than exponentially, tending to a catastrophy within about two more generations. Although we see the problem and are afraid of its serious dangers, we feel rather helpless about it. Why?

The member of every surviving, successful species must have two strong biologically inherited urges: first, to maintain his personal life against all kinds of dangers, and second, to maintain the species against extinction. Which means to get old, and to raise many healthy children. Thus, all over the world a lot of pills are easily eaten for prolonging our life-time, whereas the use of "The Pill" for reducing our birth-rate is spreading only very gingerly. The first one agrees with our biological urge, the second one works against it.

If the problem can be stated in such general terms, then I would conclude that it must occur quite in general, that all emerging civilisations must face the population problem at some moment of their life. Every surviving civilisation then must have solved it somehow, and if our negative result about interstellar emigration holds in general, too, then they all must have solved it "internally".

3.2 Self-Destruction

Another crisis we are facing is self-destruction. How much destructive power do we have at present? The total world supply of nuclear bombs in 1960 was 30,000 Megatons of TNT [Lapp 1969], where TNT stands for trinitrotoluol which is a strong chemical explosive (4×10^{10} erg/g) similar to dynamite; a nuclear bomb of, say, 2 Megatons (Mt) then has the same explosive power as 2 million tons of TNT. If we estimate the further production as about

$$1000 \text{ Mt/year} \tag{23}$$

this would give at present a total supply of about

$$40{,}000 \text{ Mt} \tag{24}$$

And divided by the present total world population, this is about

$$10 \text{ tons of TNT per person} \tag{25}$$

This is an enormous supply, the famous "overkill", and difficult to visualise. Ten tons of TNT, for example, is a round ball of dynamite 7 feet (2 metres) in diameter, one such ball for each person in the world, grandmothers, babies and all. The energy of 10 tons of TNT is enough to lift a whole apartment house (10,000 tons, say) to a height of 500 metre (1500 feet). And let it fall down on you. Again, one for each living person. Maybe this illustrates on what kind of powder-keg we all sit.

Let us compare this destructive effort with our other activities. According to Lapp [1969], the USA used between 1950 and 1960 about 12% of its total electric power for separating uranium isotopes needed for A-bombs. Or, in terms of money (VDW-study 1968), all governments of the whole world paid in 1965 in total:

for the arms race	140 billion dollars	
education	116	(26)
health	46	

and Table 2 shows which fraction of our total efforts we spend on armament, as a good measure of human aggression although we usually call it "defense".

And nobody wants to stay behind, of course. The VDW-study finds that the underdeveloped countries in 1965, having a gross product of less than 160 dollars per year per person, received 7 billion dollars help from the industrial countries, but spent 18 billion dollars for armament; 2 billion more than the year before, which is an increase of 11% per year! There are exceptions, though, like Mexico which spent four times more on education than on armament, to be favourably compared with (26).

Thus, there is plenty of power to exterminate the whole race. Furthermore, we have no good means of a true defense but must rely on the ability to strike

TABLE 2. Fraction of the National Gross Product Spent on Armament in 1966 and 1967.

Country	per cent
Japan	1.1
Belgium	2.9
India	3.3
Germany	3.5
France	4.4
USSR	8.9
USA	9.2
China	10.0
Egypt	11.1
Israel	12.2

back after having been struck (second strike capability, or assured destruction capacity). If both sides have it (and know of both to have it) then this is a "stable" situation where none will strike. But many other situations are "unstable", where striking first may be considered better or safer than waiting. The present stable situation is also called: balance of power, stale-mate, peace by fear.

A good computer study into the question of stability, for many kinds of armament situations, has been done by Afheldt and Sonntag [1969, 1971]. It shows, for example, that the introduction of ABM (anti-ballistic missiles = defense against rockets) and MIRV (multiple independent re-entry vehicles = one rocket with many bombs for different targets) both have a strong influence toward instability.

A very dangerous feature of this kind of peace was pointed out by C. F. von Weizsaecker [1970]. Our present situation is stable because weapons, numbers and strategies are of a certain type. But technology makes progress, and weapon systems become obsolete after, say, seven years. With a new system, stability may not become possible, but even if it is, the transition in between has always a smaller degree of stability. Thus, about every seven years or so, there is a certain finite chance for a big war, and how many of such chances can we stand? Let us do it numerically. If q is the chance for a war every seven years, then the chance for a war within τ years is

$$Q(\tau) = 1 - (1 - q)^{\tau/7} \tag{27}$$

War gets more probable than peace when $Q \geqslant 1/2$. Some examples are given in Table 3, which shows that even a 10% chance for q gives us only two more generations, and that we probably have much less than that. If we don't find some better solution, and find it soon.

Let me quote Morris [1967]: "We are, to put it mildly, in a mess, and there is a strong chance that we shall have exterminated ourselves by the end of the century. Our only consolation will have to be that, as a species, we have had an exciting term of office. Not a long term, as species go, but an amazingly eventful one."

Again, we want to describe the problem in the most general terms. Morris [1969] lists 10 main reasons for our inter-group violence, from which I will repeat five here:

TABLE 3. Instability from improving weapon systems. If every seven years there is a small chance q for a nuclear war, then after τ years war will become more probable than peace.

q	τ
0.05	95.4 years
.10	45.6
.15	29.8
.20	21.7
.25	16.8
.30	13.6

1. The swelling of tribes into overcrowded super-tribes.
2. The invention of weapons that kill at a distance.
3. The removal of leaders from the front line of battle.
4. The creation of a specialised class of professional killers.
5. The exploitation of the cooperative urge to aid friends under attack.

And I would like to add another, very basic, reason for our problem:

6. Members of the species which finally dominate a planet must have a strong biologically inherited urge to fight for supremacy.

I think, again, that these reasons are of so general a nature that the problem of self-destruction must occur quite in general among emerging civilisations, very similar to the population problem. There is also some connection: the more overcrowded we get, with no emigration-escape, the more likely will we throw the bombs.

There is another similarity, too. During the past, any unification, agreement, merging-together (from families to tribes to little kingdoms to great nations) could always be achieved by pointing to some common enemy. Internal cooperation through external aggression. This exactly makes it so difficult to achieve the world-wide cooperation we need, that the problem now must be solved purely "internally". And common enemies like fighting cancer, or the population problem or other such things, will not be of much help; these enemies are much too abstract, they do not fit any of our biological enemy-patterns.

3. 3 Genetic Degeneration

There will be a third crisis which can easily be foreseen: genetic degeneration [von Hoerner 1961]. The first two crisis, population growth and self-destruction, are now our immediate urgent problems; the third one must come of necessity but only after some thousand years or so. Like the first problem, it results from discovering bacteria. It consists of three sub-problems.

The whole development of species, the growth and spread of life on our planet, up to what we think is intelligence, is brought forward by the (co- and counter-) action of two things: mutations and natural selection. Having many offspring, with several deviations from the norm, and survival only of the fittest; these are all very natural and easy principles, to be expected any other place, too.

But as soon as a species develops intelligence and medicine, the infant mortality will strongly be reduced, the average life-time prolonged, and not only the fittest can survive and multiply but almost everybody else. Also those will have children who without medicine would have died before maturity. Although medicine diminishes all contagious diseases, it enhances all hereditary ones. The better a treatment we develop for a hereditary disease, the larger will become the number of people who have it. This is sub-problem number one. It works without mutations just from the genetic spread already present in the species.

Sub-problem two makes it worse all the time. Medicine has eliminated natural selection, whereas mutations still go on as ever (if not amplified by nuclear tests, and by some pesticides and medicines). Mutations are chance-events, while a living being is something tremendously complicated, which means that almost all mutations are harmful ones. Thus, without natural selection, the genetic spread toward the "bad" side will get larger and larger. But also the past genetic accomplishments on the "good" side will gradually deteriorate when the so-called genetic pressure ceases to push.

In summary: medicine as we now have it improves the health of the present individuum, but it is very unhealthy for the future species. I think there is only one way out and some day we must do it: artificial or at least selective breeding.

But now comes the third sub-problem, the worst of all: who (or what) is going to decide which type of breed is desirable, into what kind of species do we want to evolve? And which of the present human types is "not to be continued"; which of our properties, our personal traits and our desires are to be eliminated? It is a terrible thought.

Again, I think that the problem is of so general a nature that it must occur quite in general. And again, the solution must be an "internal" one. When during our past history some empire got too old and degenerate, there were always enough healthy young barbarians around to take over. But the genetic crisis we now discuss will come after some thousand years and will affect the whole human species. There will be no healthy barbarians any more.

3. 4 Over-Stabilisation

We know the first two crises exist because we are right in them. The third one, I think, can be predicted with good certainty. All three come in such a natural way, that their general occurrence may be assumed. And I am sure there will be many more crises which we cannot yet foresee.

Each crisis can be met with success or with failure. But failure will eventually mean another chance, either given to the same species after a while in case of some smaller failure, or given to some other species after a longer time in case of a severe catastrophe. But even such longer times will probably be short in astronomical terms. Finally, then, all habitable planets are populated by civilisations which have mastered all crises, or, even better, have anticipated and avoided them. It is a process of repeated filtering.

What will these surviving civilisations look like, what type will they be? Of course, we do not know. The following is not a prediction. But I would like to discuss a possibility which may have some chance of being right, although I hope very much that it is wrong. Instead of proper derivations, I will use statements, overstatements, and slogans.

Competition is the driving force of development. Nobody evolves more than he has to. When on a planet some species "takes over", the competition with other species becomes unimportant; but this species now multiplies freely, and the competition between its groups and nations is an ever increasing driving force (certainly, no man on the Moon without the cold war). But then this must come to a complete halt. We cannot multiply any more, and further competition leads to self-destruction. We need a world-government, soon, and a strong one. Evolution is dangerous, our destructive powers are so huge that we cannot afford any mistakes. Not evolution is wanted, stability is.

Our whole way of thinking must change. At the end of Section I, 1 we found already that the progress of our population number must turn into stagnation, that we must stop growing when we hit the ceiling. The emotional connotations must be turned around: stagnation must become a well-sounding positive concept, progress a bad one.

Maybe one can master a crisis when it comes, and maybe not. It is better to anticipate a crisis and avoid it; but the only really safe way to survival is stagnation (we live now, if nothing changes then we live forever). Thus, all habitable planets are finally populated with stagnated civilisations. The reader now has a choice between two famous books; George Orwell's "1984" where stabilisation is reached by terror, which has a good chance at present, and Aldous Huxley's "Brave New World" which has an excellent chance in the future, because if artificial or selective breeding is needed anyway for avoiding degeneration, then why not breed a completely happy and content species? ("Better milk from contented cows" says one of our commercials.)

Well, those of us who have not yet managed to turn their emotional connotations around will instead turn up their nose and will call stagnation "the crisis to end all crises". They even may predict that the stagnated ones will die of boredom, and if die we must, there are more exciting ways. But who knows? Ants haven't died of boredom yet in spite of having not changed for a long time.

> We cannot tell how frequently it happens; but with selective breeding there is a non-zero chance for *irreversible stagnation.* (28)

4. WHERE IS EVERYBODY?

4. 1 The Question

Suppose the last section is wrong. How far, then, will civilisations evolve? We do not know how other activities evolve, but the evolution of technology can be measured in terms of the turnover of energy, in units of watts, or ergs per second ($1 \text{ W} = 10^7$ erg/sec.). The Russian astrophysicist Kardashev [1964] discusses three evolutionary phases of civilisations: Type I, with an energy turnover comparable to ours (7×10^{19} erg/sec.) using the chemical and nuclear energies available on their *planet*; Type II, who have harnessed the energy output of a *star* (4×10^{33} erg/sec. for our Sun), like Dyson's shells or in some other way; and Type III who use the energy production of a whole *galaxy* (4×10^{44} erg/sec. for our Galaxy).

As far as we know, all this is technically well possible. Interstellar activities of this scale do not violate any laws of physics. They just need determination and time: the travelling-time of light within a galaxy is ten thousands of years, between galaxies millions of years. Furthermore, Dyson argues that whatever *can* be done (with a given amount of energy and mass, within the laws of physics) sometimes *will* be done (given enough space and time for sufficient opportunity).

Why, then, do we see no interstellar activity, not a single sign of life, among the billions of stars in our own galaxy, among the billions of other galaxies visible in our telescopes? This, indeed, is a very serious question. And our ignorance of what to expect is rather unimportant. Like some still untouched natives would have no way of guessing what a city looks like; but if some day they would see one, they would immediately recognise it as something artificial, done by higher beings, not naturally grown. (But what about some ants seeing a city?)

4. 2 Three Answers

Many topics I will omit, like flying saucers, for example. Although some topics may have their merits, like the "Zoo Hypothesis" of Harvard scientist John Ball [1973] who suggests we may have been set aside in a wilderness area or a perfect zoo, one in which the animals do not see their waiters or spectators. Or like the "ants in a city" I just mentioned, which would mean that we do see a lot of activity, but it is beyond our mental horizon. I think that the most probable answer to our question are the following three, single or in combination:

(a) *Rarity of life* or intelligence. How many civilisations are there? We know of only one: us. Doing statistics with $n = 1$ yields an estimator of the *average:* us. Which means we should expect life on a planet of all stars which are "similar enough" to our Sun, about 6% of all stars; and half of these cases will be less advanced than we are, half of them more advanced. However, $n = 1$ does not yield an estimator of the mean *error.* Furthermore, there is a *bias,* since the question "how many" cannot have been asked on an empty planet.

Expecting plenty of advanced civilisations thus has the highest probability of being right, but we have not the slightest idea of how wrong that is (regarding both the statistical and the systematical error). Somehow we feel we should never expect to be something special, but maybe we are. It cannot be excluded that instead of being average, we are one of the first, and nobody else has developed the ability or had the time to do something being visible to us. On the other side, similar ideas in our past have always turned out wrong.

(b) *Change of Interest* [von Hoerner 1961]. We should never expect that our present interests, our present way of thinking, are the final goal of evolution; they will just be one link in a long chain. But we have no way of guessing what comes next and beyond.

This would mean there is plenty of advanced intelligence, but interest has changed to other fields (beyond our understanding). Technology, of course, is maintained to keep things going, but it has dropped out of the public interest, it attracts no ingenuity nor any big money, and thus never produces things visible to us. Could well be, I would say.

(c) *Stabilisation.* Section 3.4 says, in more reserved words, that surviving civilisations must have developed very efficient means of stabilisation against all possible crises and accidents. They also must have shifted the emphasis more and more from emotions to reason. Most motivations for interstellar expansion are more on the emotional side, like conquest of space, being the first one, the challenge of the difficult, and so on. But any surviving civilisation is, of necessity, so much stabilised and sober that no desire for any great enterprise is left or allowed.

As to the more sober or rational motivations, we showed already that the population problem cannot be solved this way. And travelling for mutual visits is not important, because contact to other civilisations can be achieved much easier and earlier by radio waves. Actually, mental contact is all that matters; our modern civilisation, for example, is strongly influenced by the ancient Greeks who never visited us but just left some books and pieces of art. Radio contact is much easier than travel; after having established the former, a sober civilisation sees no urgent need for the latter.

If stabilisation is the answer to our question, probably combined with a change of interest, it would mean:

> Interstellar expansion, though physically possible, has never occurred, because all sober reasons for expansion are terminated, and emotional reasons for anything are excluded, in any surviving civilisation, long before the technical ability for expansion has been reached. (29)

4.3 Critical Duration and Effort

Interstellar communication, by radio waves or other signals, is probably of crucial importance. Contact means stimulation and competition, it prevents stagnation. Interstellar expansion then is mental, not physical, and this is the reason why we do not see it. How probable is all this?

Maybe an interstellar network is already established, with beacons emitting "contacting signals" to be discovered by us, and maybe not. In any case, a general estimate can be made, by all those who want to establish the first contacts for a network, concerning the question "how long should we try?"

Call D_O = 3 light years the average distance between stars, and $T_O = 10^{10}$ years the age of the galaxy and oldest stars. Assume that the fraction f of all stars give birth to a civilisation which once in its development goes through a phase called "quest for communication", of duration τ, where they transmit signals and try to receive answers. The average distance between neighbours in this phase then is

$$D = D_O f^{-1/3} (T/\tau)^{1/3} \tag{30}$$

and 2D/c is the waiting time for an answer. Obviously, for having success, one must try during $\tau \geqslant 2D/c$. With a perfect method, that is, otherwise it may take a lot longer. This yields the minimum duration as

$$\tau \geqslant \tau_{cr} = (2D_O/c)^{3/4} (T/f)^{1/4} \tag{31a}$$

and the distance

$$D_{cr} = D_O^{3/4} (cT/2f)^{1/4} \tag{31b}$$

Fraction f is rather uncertain, but it enters only with the power ¼. If we are not too far from being average, we may expect $f = 10^{-1}$ to 10^{-3}, say, which gives the following range for duration and distance:

f	τ_{cr}	D_{cr}	
0.1	2000 years	1000 light-years =	300 parsec.
0.001	6000	3000	1000

(32)

Technically, these distances are not too large. If we had a partner already, knowing his direction and distance and having agreed about frequency and bandwidth, even with our present equipment we could reach about 200 light-years, and 2000 may become possible within 10 or 20 years. Of course, searching for a partner is much more difficult, but not hopelessly so. On the other side, if a network exists already, detection would be much easier. All these questions are discussed in detail in some good books by Drake [1962], Cameron [ed. 1963], Sullivan [1964], Shklovskii and Sagan [1966], and Schlemmer [ed. 1970].

Our first effort to detect signals from two near-by stars was done by Frank Drake in 1960, called "Project Ozma." In 1971, a very stimulating international conference, with scientists from all fields, was held in Byurakan (Armenia), USSR, called "CETI" = Communication with Extra-Terrestrial Intelligence. Also in 1971, a study-group in California, "Project Cyclops," investigated under B. Oliver the question of how much effort is needed to search for signals with a really good chance of success; the answer will probably be a compact array of 10,000 medium-sized radio telescopes, for 10 billion dollars. (For comparison, the 1970 USA budgets are, in billion dollars per year: NSF = 0.50, NASA = 3.8, "Defense" = 83; total budget = 210.)

Thus, we could try if we really wanted. And, I should admit, if we had a better understanding of what the "perfect method" might be. Generalising again, I would think that interstellar communication has a "fairly good chance" of existing.

4.4 Conclusion

Any further development, beyond the great crises, seems like a very delicate balance between two opposing dangers or temptations. On the first side the competitive and exciting but hectic development which leads into catastrophies if left unbridled. On the second side the stabilisation and regimentation needed for survival which leads to irreversible stagnation if given first priority.

There is only a "narrow path" in between, and the proper vehicle along this way may be interstellar communication, giving the advantage of competition without its danger (we may surpass and beat, but cannot kill, each other). But entering this vehicle takes a substantial effort, and a minimum time of a few thousand years.

Question: When a civilisation tries to avoid the first danger, and by doing so is going to plunge into the second temptation, is there enough time in between to establish interstellar contact? This needs already some stability, just sufficient to carry through a project lasting some thousand years, but it still needs a good deal of enthusiasm and zest for progress, just enough to get it started.

This, then, is the question. Let us hope that the answer is yes; but we will never know if we do not try; and in addition, we have Frank Drake's famous question: "Is there intelligent life on Earth?"

REFERENCES

Afheldt, H. A. and P. Sonntag [1969] "Analyse der Stabilität auf der Ebene der strategischen Kernwaffen", Vereinigung Deutscher Wissenschaftler.
Afheldt, H. A. and P. Sonntag [1971] transl. "Stability and Strategic Nuclear Arms", Occasional Papers, World Law Fund, Vol. **1**.
Ball, J. A. [1973], *Icarus* **19**, 347.
Basler, E. [1971], Analysen und Prognosen, Heft 18, p. 14.
Calhoun, J. B. [1962a], *Scientific American* **206**, 139.
Calhoun, J. B. [1962b], "Roots of Behaviour" (ed. E. L. Bliss); Harper & Brothers.
Cameron, A. G. W. [ed. 1963], "Interstellar Communication", Benjamin Inc.
Davis, K. [1965], *Scientific American* **213**, No. 3, p. 41. This issue contains 12 articles about cities; of the past, present and future, their types and their problems.
Drake, F. D. [1960], reprinted in Cameron [1963].
Drake, F. D. [1962], "Intelligent Life in Space", Macmillan.
Dyson, F. J. [1959], *Science* **131**, 1667.
Dyson, F. J. [1963], reprinted in Cameron [1963].
Dyson, F. J. [1966], Perspectives in Modern Physics; Interscience Publ. N.Y.
Dyson, F. J. [1968], *Physics Today* **21**, 41.
Foerster, H. von, Mora, P. and Amiot, L. [1960], *Science* **132**, 1291.
Goldmark, P. C. [1971], Analysen and Prognosen, Heft 18, p. 22.
Hoerner, S. von [1961], *Science* **134**, 1839. Reprinted in Cameron [1963].
Hoerner, S. von [1962], *Science* **137**, 18. Reprinted in Cameron [1963].
Hoerner, S. von [1970], in Schlemmer [ed. 1970].
Holst, E. von [1970], Tagung Gesellschaft Säugetierkunde, München.
Huxley, A. [1939], "Brave New World", Doubleday-Doran.
Kardashev, N. S. [1964], Soviet Astronomy, *A.J.* **8**, 217.
Lapp, R. E. [1969], "Kultur auf Waffen gebaut", Rütten & Loening.
Leyhausen, P. [1956], Zeitschr. Tierpsychologie, Beiheft 2.
Leyhausen, P. [1969], in: Lorenz and Leyhausen "Antriebe tierischen und menschlichen Verhaltens", Piper and Co.
Lorenz, K. [1963], "Das sogenannte Böse", Borotha-Schoeler.
Lorenz, K. [1966] transl. "On Aggression", Harcourt.
Mills, H. B. [1959] Trans. Illinois State Acad. *Science* **52**, 5.
Morris, D. [1967] "The Naked Ape", Delta Book.
Morris, D. [1969] "The Human Zoo", McGraw Hill.
Orwell, G. [1949] "1984", Harcourt, Brace & Co.
Packard, V. [1959] "The Status Seekers", McKay, Pocket Cardinal.
Rand McNally [1962] "Cosmopolitan World Atlas".
Schlemmer, J. [ed. 1970] "Sind wir allein im Kosmos?" Piper and Co.
Shklovskii, I. S. and Sagan, C. [1966], "Intelligent Life in the Universe", Holden-Day Inc.

Sullivan, W. [1964] "We are not Alone", McGraw-Hill.
VDW [1968]: Vereinigung Deutscher Wissenschaftler, "Welternährungskrise", Rowohlt.
Weizsäcker, C. F. von [1970] "Zugänge zur Friedensforschung", Bergedorfer Gesprächskreis, Protokoll Nr. 35, p. 8, 56, 57.

ADDENDUM TO SECOND EDITION

After this paper was written (early 1972), some older literature came to my attention which I regret not to have mentioned, some new books have appeared since, and there are some additional comments I would like to add.

1. There is an organisation "Zero Population Growth" with over 30,000 members and a monthly periodical (367 State Street, Los Altos, California).

2. Many good books should be recommended, dealing with the problems of population, resources and pollution, for example: Osborn, F. [1948, 1968]: "Our Plundered Planet", Pyramid Books; Hardin, G. [1959]: "Nature and Man's Fate", Rinehurst; Ehrlich, R. R. [1961]: "The Population Bomb", Ballantine Books; Carson, R. [1962]: "Silent Spring", Houghton Mifflin; Rienow, R. and L. T. [1967]: "Moments in the Sun", Ballantine Books; Singer, S. F., ed. [1971]: "Is there an Optimum Level of Population?", McGraw-Hill.

3. Computer studies about the interaction (in a finite world) between population growth, decreasing resources, and increasing pollution, and about the resulting catastrophies or possible stabilisations, are published by: Forrester, J. W. [1971]: "World Dynamics", Wright-Allen Press; Meadows, D. H. and D. L., J. Randers, W. W. Behrens [1972]: "The Limits to Growth", Potomac Associates.
The last-mentioned book, sponsored by the "Club of Rome", has stirred up a world-wide discussion and controversy; it has been attacked from both sides, for being only trivial as well as for being completely wrong. The book has certainly successfully served its main purpose: to bring these urgent problems to a wide public attention, and to make the experts as well as the general public much more concerned, worried and active. It was not so much meant as a prophesy but more as a warning; but if the warning is not taken soon, it well may become a prophesy. The weak point of this book is its neglect of the political and biological foundations and complications of our problems. How on Earth can a (theoretically possible) stability ever be actually reached, in our world of competitive egoistic nations fighting each other by all means, where saving face means more than hard facts, where glory is wanted and not weak compromises?

4. The political and moral aspects of our problems are discussed, and possible solutions mentioned, in two highly recommended books: Weizsäcker, C. F. von [1971]: "Kriegsfolgen und Kriegsverhütung", Carl Hanser, München; Hardin, G. [1972]: "Exploring New Ethics for Survival", Viking, New York. And the following headline "The population problem has no technical solution; it requires a fundamental extension in morality" summarizes an excellent paper: Hardin, G. [1968]: "The Tragedy of the Commons", *Science* **162**, 1243.

5. Regarding life in space and interstellar communication, we recommend: Dole, S. H. [1970]: "Habitable Planets for Man", Elsevier, New York; Oliver, B. M. [1971]: "Project Cyclops", NASA/Ames Research Center, Moffett Field, California; Sagan, C. ed. [1973]: "Communication with Extraterrestrial Intelligence" MIT Press.

6. The general awareness of the problems created by the finite size of our Earth has tremendously increased during the last few years. Pollution problems of land, water and air are not only discussed but get actually attacked, and the

oil crisis was badly felt by everybody. Maybe we can understand why productive solutions, and even international agreements, have only been achieved regarding pollution: we are assisted here by a general biological urge "to keep our nest clean". On the other side, our recent oil crisis was actually only a first warning shot; the real problem will arrive in a decade or two, with a much deeper and more brutal impact, and the needed international agreements regarding the distribution of resources are certainly not assisted by our urge "to fight each other for food".

7. It is not just chance that all our estimates of critical time scales give about two generations, where we might wonder why we have not worried about these problems long ago and worked out solutions meanwhile, when there was enough time left for doing something. Regrettable as it is, it makes sense. People start to worry seriously only if they are personally concerned, and the personal concern for most of us starts with our grandchildren.

8. Many suggestions and solutions presented in the literature and in private discussions can be turned down with the following argument. Contrary to common belief, just "egoism plus intelligence" does *not* lead to reasonable behaviour regarding our problems; because my egoism unfolds best if everybody else sticks to a moral code except me (and nobody knows the latter). Biologically speaking, the urge to maintain the individual cannot help us here, only the urge to maintain the species may do so. But this is not egoism; just as wisdom is not intelligence.