Multilevel Strategy for Personal Immortality:

Plan A – Fighting Aging,

Plan B – Cryonics,

Plan C – Digital Immortality,

Plan D – Big World Immortality

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**Abstract**: The field of life extension is full of ideas but they are unstructured. Here we suggest a comprehensive strategy for reaching personal immortality based on the idea of multilevel defense, where the next life-preserving plan is implemented if the previous one fails, but all plans need to be prepared simultaneously in advance. The first plan, plan A, is the surviving until advanced AI creation via fighting aging and other causes of death and extending one’s life. Plan B is cryonics, which starts if plan A fails, and assumes cryopreservation of the brain until technical capabilities to return it to life appear. Plan C is digital immortality in the sense of collecting data about the person now so future AI will be able to recreate a model of a person. Plan D is the hope based on some unlikely scenarios of infinite survival, like so-called “quantum immortality”. All these plans have personal and social perspective. The personal aspect means efforts of the increasing chances of personal survival via taking care about one’s own health, signing cryocontract or collecting digital immortality data. The social aspect means the participation in collective work towards creation and increase of the availability of life extension technologies, which includes funding scientific research, promotion of life extension value and direct performing of research and implementation, as well as preventing global catastrophic risk. All plans converge at the end, as their result is the indefinite survival as an uploaded mind inside an ecosystem, created by a superintelligent AI.

**Highlights**:

* By combining plans for survival in the correct order, a person could get maximum chances to the personal immortality.
* Survival strategy could be structured as a multilevel defense: Plan A – fighting aging, Plan B – cryonics, Plan C – digital immortality, plan D – “big world immortality”.
* All survival plans depend on the creation of advanced friendly AI at the end.
* Indefinite life extension cannot be reached without cooperation between many people.
* Funding of life extension research depends on the popularity of the idea of life extension.

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# Introduction

The idea of life extension is gaining traction. Several methods how to reach *potentially indefinite life extension* (which we here use as a synonymous for “immortality” as it was suggested by B. Goertzel, as the word “immortality” may have religious connotations for some and also “indefinite life extension” doesn’t imply philosophical problems of actual numeric infinity or of the freedom to end one’s life) were suggested, including cryonics, mind uploading and digital immortality. But most proponents support just one of such methods and think that this method is the best and most effective way for living forever.

However, the future is very uncertain and we don’t know what will work in life extension and when. It is easy to be overoptimistic or over-pessimistic. Our ability to predict and, moreover, influence the speed of technological progress is limited. Also, we cannot say how complex the problems of aging and of AGI are.

Another type of uncertainty is personal. Some people may live naturally until 90, others will die young. People also have different ages now, which affect their chances to survive until the bright future.

The last type of uncertainty is connected with risks of civilizational discontinuity, that is different collapses, global catastrophic risks and existential risks which could kill most people or at least stop technological progress. Here we assume that all needed efforts are undertaken to prevent them.

To counter this complex uncertainty, we suggest multilevel “death-prevention” plan. We could think about death as an enemy, which attacks the fortress of our survival from different sides. Thus, we need to protect all the sides.

The idea of “multilevel defense” is used in engineering safety, for example, to ensure safety of nuclear plants, where failure on one level of the defense means that the next level of the defense starts to act. There are four such levels in nuclear safety: normal regulating rods, emergency shutdown rods, containment building and exclusion zone.

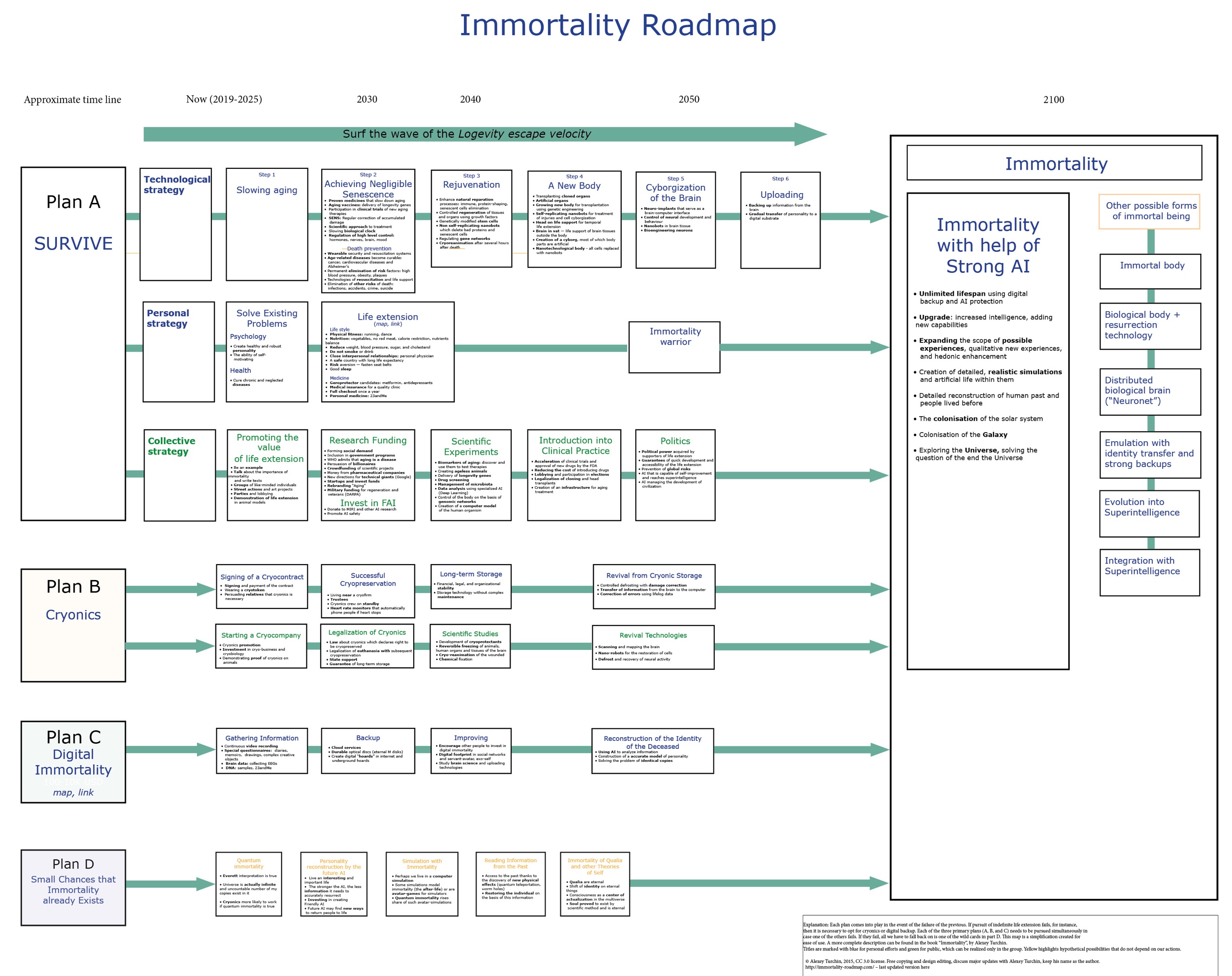
The main uncertainty is timing of my death relative to the timing of the creation (and availability) of technologies, which could provide indefinite life extension. I need either to extend my life until the moment of such technologies creation, or, if I die before, to ensure the possibility of my resurrection. Here two exponential processes are competing: the growth of my personal probability of death because of aging and the exponential growth of the computer and medical technologies by Moore’s law analogues which could extend my life.

Also, the solution for “personal” immortality, despite misconceptions, may be cheap, available for most people and thus altruistic: for example, some antiaging medicine, like metformin has very low bulk price, and future solutions may be as cheap as vaccination, antibiotics or smartphones. But developing such solution may require large concentration of capital and effort.

The prevention plans are presented by order of implementation. If one starts plan B, it means that plan A fails. But it doesn’t mean that plan A is strongest for everybody – for some very old people plans B and C may be the only options.

The whole roadmap is presented in Figure 1, and the reasons behind its construction as well as the details of each block will be discussed in the next sections.

*Figure 1. The roadmap to immortality (see full size in* [*here*](http://immortality-roadmap.com/IMMORTEN2.pdf)*)*

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# 1. Plan A: surviving until AI

## 1.1. Fighting aging as the main instrument to reach “Longevity escape velocity”

The main idea of this plan is to surf the wave of technological progress in order to reach “longevity escape velocity” (LEV) and later reach immortality. LEV was defined by Aubrey de Grey as a moment in history when the increase of the personal life expectancy is more than 1 year in each year. But this is not equal to full immortality, as some people will still die every year, and thus personal probability of survival is not 1. (China [increased life expectancy](http://www.china-profile.com/data/fig_WPP2010_L0_Boths.htm) by 15 years in only five years of calendar time, but people still died) Full immortality will be reached only when the technology of indefinite life extension appears and is widely distributed.

Stopping aging is not enough to reach indefinite life extension, as other accidents will take a toll. The minimum risk of death for a human being is typically at the age of 10, and is a result of the combination of the absence of aging, high quality parent control and low-level engagement in risk activities, such as drugs, driving etc. Even in that case, life expectancy – if it could be fixed at this level – would be no more than a few thousand years. If we exclude the age-dependent component of mortality by extrapolating the minimal probability of death for 10-year-old white American girls, which is 0.000084 for a year (Actuarial Life Table, 2017), calculated life expectancy is 5925 years. Increasing the probability of death by including the factor of age, though, lowers it to 81.

It could be proved that anything which exists, cannot exist forever, using [Poincaré recurrence](https://en.wikipedia.org/wiki/Poincar%C3%A9_recurrence_theorem) theorem. The line of reasoning is the following: imagine a box, perhaps the size of the Universe. Initially it was in a chaotic state, and later a mind (or whatever object: atom, planet, star, black hole) appeared in it. According to the Poincaré theorem, this universe must return into the its initial state after some – may be infinitely long – time. Thus, any object which appeared in it, will stop existing. Contemporary science also tells us that all known objects disappear: even black holes evaporate after 10100 years; all complex atoms will decay, and even elementary particles could turn into other particles. The observable universe also will likely end in a Big Rip or Heat Death. These seem like unsurmountable obstacles to constant linear immortality, but the same recurrence theorem is claiming that anything will appear again in the infinite universe (but much rarer than return to chaotic state, as chaotic state is fact much more probable). While it all seems purely theoretical, the practical conclusion is that one cannot create an immortal body, but digital resurrection from some backup, may provide an instrument of almost infinite existence in the universe (at least as long as the universe exists). This theory of digital preservation of information by many backups was explored by Eubanks (Eubanks, 2008). Thus, to become actually immortal in this world, one’s mind needs to be transferred from a biological carrier into a digital carrier, as digital information is easy to copy and backup, and digital copies could exist as long as some future analogue of the Internet exists – that is, if one is uploaded into a computer, one could exist as long as civilization exists, which could be billions of years.

To make the risk of death equal to zero and reach “potentially indefinite life extension”, we need to combine brain uploading and creation of some resurrection technology, which – in the case of an uploaded mind – is just reconstruction from a back-up copy. In that case a mind could exist as long as civilization exists. Moreover, there some reasons to believe that a civilization could survive the end of the universe in some way or another (Dvorsky, 2015; Tipler, 1997; Alexey Turchin, 2019).

But for now, aging is the main killer, which causes directly and indirectly up to 95 per cent of deaths in developed countries. Thus, there are two major steps in reaching immortality:

1. Stop aging
2. Create mind uploading technologies

But for better comprehension, we will break up the plan into more steps in the next sections.

## 1.2. Stakeholders and actors

To effectively fight death, three types of strategies are needed:

* Personal strategy to extend one’s own life,
* Personal altruistic strategy to increase collective probability of survival, and
* Technological strategy for the whole civilization

Personal efforts to take care of one’s life expectancy are needed, as a person is in the best position to take care of one’s own life. But many technological changes require funding, testing and legal support, so they could be created only through collective actions of many people. Finally, life extending technologies will evolve through a series of steps in technological development, which we could envision and prepare for now via our collective efforts, and which will not happen if nobody works on them.

We will explore all three strategies below, but keep in mind that all 3 are needed for success.

## 1.3. Plan A, personal strategy

Personal strategy is a strategy for a person who want to live forever, and is describing what kind of efforts she should make to extend her own life. Thus, she has to put herself in the best position for survival, given her own situation and accounting for all the uncertainty about the speed of progress.

Here we will not go into all details about what a person could do now (as of 2019) to decrease her probability of death (for more advice-level recommendations, see Appendix A), but we will just outline the main principles.

### 1.3.1. Making a decision about radical life extension: immortality warrior

A person has to make a decision to actively fight for life extension. Obviously, some people could survive for a long time because of pure luck and genetics, or because of high quality care by relatives or institutions. But as our understanding of aging is growing, the power of personal choices is also growing.

To make a decision to actively work for life extension, one should probably know about such probability and have a preference to live, that is love to life. There are people who know about the possibility of technological life extension, but they expect that the technological progress will solve all their problems, and they even take risky behavior like smoking, expecting that the future technologies will take care of their possible cancer. This strategy may work for young and technologically optimistic people, not interested in cooperation.

But the decision is not enough. Many people are unable to implement good decisions because of lack of will or other psychological problems, or because they have even stronger preferences, like money making, pleasure seeking, family caring, and helping others.

I would suggest a term of “immortality warrior” as a person who has the primary goal of reaching indefinite life extension, balancing egoistic and altruistic behavior for it. That is, he doesn’t try to survive by lowering other’s life expectancy, but he also doesn’t completely ignore his need. His behavior could be understood in terms of decision theory: if everybody “defects” and tries only egoistic survival strategies, then the global life extension project would fail because of the lack of cooperation, scammers etc. However, if everybody does not care about their own health, while helping others, then also collective survival will not work.

There are many psychological obstacles to becoming a perfect “immortality warrior”, as everybody who tried to quit smoking or become physically active everyday knows.

An immortality warrior also should be rational and should take care of his mental health and debiasing.

An immortality warrior also should care about preventing global catastrophic risks, as they will end any chance of indefinite life extension.

The important conclusion is that an immortality warrior should take most care about preventing his own brain aging and damage, as it would prevent him from act rationally in the future.

### 1.3.2. Using existing instruments to lower probability of death and slow down aging

An immortality warrior should search for low hanging fruits in personal life extension (as well as altruistic collective options which will be discussed later). Such options include getting rid of dangerous addictions including smoking, drinking and overeating, and investing in prophylaxis of diseases which includes regular medical check-ups, putting under control existing chronic conditions like diabetes-2 and hypertension, vaccination etc.

An immortality warrior could calculate how many “millimorts” he prevents by installing carbon monoxide detectors, not riding a motorbike, wearing light reflection clothes while walking at night as well fastening the seat belt.

After all such low hanging fruits are identified, the main survival probability depends mostly on aging (and genetics), and thus all efforts should go on slowing down aging as well as preventing personal risks following from genetic analysis.

Here is a few instruments now (as of 2019) available to slow down aging, which include fast mimic diet, sport, hot bathing, dancing and some potential generally safe geroprotectors, which should be evaluated individually, like vitamin D and metformin (see also *Polypill*). There are also some experimental geroprotectors, which may be risky, so one should choose them only if one employs a riskier strategy, which will be discussed below (e.g. rapamicine).

Aging could affect different systems non-uniformly, and thus special blood work is needed to make the decision about needed interventions, which could be called “diagnostic of aging” and which include measuring of many parameters connected with life expectancy, as well as genetic like the 23andMe test.

### 1.3.3. Putting oneself in the best place to get the new technologies

All listed above known methods of life extension may give no more than 10-20 years of increase of life expectancy, and not guarantee them, as survival is a probabilistic process (even a completely healthy person could die earlier).

The best chance to survive is to be an earlier adopter of new life extension technologies, as soon as they appear (assuming risks are low). There are several factors to be such an adopter:

*Knowledge* – knowing about the progress in aging research, and general science background. This may also include access to future advanced AI which will play major role in life extension.

*Creation* – be the one who actually works on the life extension technology development, and thus knows them better than everybody else and has access to them. This means scientific or venture investor.

*Trials* – participate in clinical trials. Most life extension technologies have to undergo long trials on humans before they will reach the market. The trial gives may be 10 years advantage, but could have risks of being in a control group or failure with negative health effects.

*Country* – living in some countries may have effect on life expectancy, because they have higher like expectancy (Italy and Spain, for example), better health care and advanced science (Silicon Valley). But being an immigrant is stressful and could not translate into higher life expectancy.

*Funding* – a richer person could have access to better medicine or to buy expensive new life extension instruments, when they first appear and before they become cheaper in a mass market. A very rich person, like a billionaire, may fund research in areas related to his health problems or fund the field in general finding most effective interventions.

*Membership* – It is important to be a member of a group of likeminded people to have access to the new technologies, to get feedback and for motivation.

*Biohacking* – this is self-experimentation and building one’s own tools for life extension. However, self-experimenting with genetic technology, like viruses for gene delivery, has non-negligible risk of causing a global catastrophe. This is especially true if many people create many viruses, as some viruses may be able to replicate in the wild and will be able to affect humans. Thus, responsible biohacking should eshew experiments with self-replicating entities, and concentrate on collecting personal data and non-replicating self-experimentation.

An important part of the personal life extension strategy is to fight brain-aging first, because if the brain is aging, it has lower ability to adapt to changes and thus actively participate in testing new life extending technologies.

## 1.4. Plan A, technological strategy

Technological strategy is the strategy for the whole humanity to fight aging and death. It could become a strategy for one large corporation which is aimed at indefinite life extension if it ever appears.

Technological strategy is based on the idea of accelerated technological development and on an assumption, that – if no global catastrophe or other unexpected things happened – the technologies for radical life extension will appear in 2100 with 90 per cent probability, and will be connected with advanced in AI, nanotech and synthetic biology. This assumption is optimistic but conservative, as it excludes the chance of the earlier appearance of some very advance technology, like self-improving superintelligent AI somewhere in 2030 or 2050.

We also assume that advances of biotechnology will eradicate other causes of death, besides aging, that is infectious diseases, and that global social situation will improve thus helping to fight external causes of death like poverty, wars, crime, suicide. So, we will concentrate on fighting aging.

The discussed below technological plan is the set of research directions and experiments which should be undertaken. This plan should be staffed and funded via some social mechanisms discussed in the next section.

The steps are presented in the “logical time sequence”, similar to the space exploration logical sequence of artificial satellite, animal in space, human in space, human on the Moon and robots and human on Mars. Actual realization in time may be somewhat different.

Also, we expect that initial steps are simpler and earlier in physical time, as well as cheaper and safer and require less expensive and long-term experiments on humans, as well as less regulator’s approval to prove that they actually work, but they will provide less increase in life expectancy. This assumption about the correlation of the speed of implementation and weakness of the results may be challenged by some unexpected discoveries.

### Step 1. Weak slowdown of aging

“Weak slowdown of aging” are methods which:

a) Work on animals.

b) Could be transferred on humans without large risks or too long of experiments.

с) Could be implemented now.

d) Are based mostly on empirical patterns observed in animals or human cohort studies but not on the exact understanding of the nature of aging.

Slowing down aging will be presented in the form of increased life expectancy and lower incidence of age-related diseases. Blagosklony defines aging as pre-pre-disease (Blagosklonny, 2018).

The reason that we call these methods weak is that even if all combined they will give a less than 10 years increase of human life expectancy. The reason for this pessimistic estimation is that even the most well-proved and thoroughly analyzed methods like metformin are expected to give between 1 and 3 years human life expectancy increase. This is based on hyperexponential nature of aging (half-life period is declining with age according to Hompertz law from 7 years around 70 years old to around 1 years at 100 years old, where the decline of half-life stops), and because of this significant lowering of mortality translate in only modest increase in life expectancy. A famous example is that if cancer will be totally eliminated, total life expectancy would grow only 3 years (gwern, 2015).

This hyper-exponential nature of aging does not allow us just to sum up gains from different life extending therapies. Another reason for it is that often very different empirically observed life extending therapies are in fact acting on the same molecular pathway associated with increased life expectancy, like mTOR or insulin-like growth hormone. Also, evolution already optimized humans for longer survival; thus, many low hanging fruits have been taken.

Now we quickly overview main empirical principles.

#### Removing other risks of death besides aging

Educated rational people in rich countries have much longer life expectancy and much high chances to die from aging, not from other causes. The last thing could be measure by share of people who survived until 60. Even in the US different social groups have much different changes survive to 60. For example, black males have only 70 per cent probability to survive until 60, while white females have 95 per cent probability.

The obvious reasons ways to escape earlier death are:

* Vaccination
* Hygiene
* Prophylaxis and regular medical checkup to find diseases on early stages
* Safe life style
* Rational approach to own health
* Control of chronic diseases

#### Removing factors of accelerated aging

There are also activities and factors which act as if they are accelerating aging, which include:

* Smoking
* Alcohol overconsumption
* Obesity
* Sedimentary life style
* Drug addiction
* Milk? Fructose? Trans-fats?? Red meat
* Air pollution
* Nutrient toxins
* Stress
* Nutrient deficiencies (of some vitamins, first of all vitamin D)

Removing them may act as much stronger life extending intervention than the initial steps of fighting aging. For example, smoking is associated with 10 years of life expectancy reduction (CDC, 2017).

Interestingly, most of them are connected with addictions to some pleasure-seeking activity.

#### Diets

There is enormous research into diets which may help in life extension. One important observation is the Mediterranean diet which presumably correlates with high life-expectancy in this region, which happens despite large incidents of smoking.

One possible explanation is large amount of olive oil, fish and greens in this diet. The attempt to explain its effects through resveratrol in wine mostly failed as the resveratrol alone was not able to show life extending effects, despite all hype about it.

One possible explanation of effectiveness of diets is coevolution of humans and some agricultural plants, which were both interested in mutual survival. Candidates for such natural life extending “symbionts” are olive trees, wine grape and green tea.

Another direction of the research is the fasting-mimicking diet (FMD), which was designed to create the same effects as lowering of calories intake.

Lowering calorie intake is one of the most confirmed on animals ways to extend life; it is also supported on humans by cohort studies of Copenhagen mortality research for WW1. But most people cannot constantly implement it, because of lack of will and there also problems with performance at low calories intake.

*Open Longevity* is undertaking research on diet during its Life extension school as part of patients organisation’s performed clinical trials.

#### Sport

Not all but some types of physical activity are associated with life extending benefits. The most effective are slow running and dancing, and some other social sports. See e.g. “Reduced Disability and Mortality Among Aging Runners. A 21-Year Longitudinal Study” (Chakravarty, Hubert, Lingala, & Fries, 2008). A new study [here](https://bjsm.bmj.com/content/early/2019/09/25/bjsports-2018-100493).

#### Social activity

Having family, friends, work and social sport increase expected life expectancy.

#### Geroprotectors

Experiments of animals may give clues about possible “geroprotectors”, that is, the drugs and interventions which slow down aging.

Geroprotectors are also the safest type of drug interventions. Typically, they are well known drugs, which safety is already tested in other fields. However, even known potential geroprotectors need long tests on humans to prove that they actually lower mortality and increase life expectancy.

One of the useful ideas to get the biggest benefit from potential geroprotectors is to choose alternatives which are associated with increasing life expectancy. For example, only one group of antihypertensive drugs demonstrated life extension benefits, that is *sartans*, while calcium channels blockers don’t show this effect.

The most studied geroprotectors are metformin and rapamycin; however, there are many (from tens to hundreds) geroprotector candidates which demonstrated some life extending properties.

An interesting task is screening of all existing medical drugs on mice in a life-long experiment to find the ones which extend life. Such experiments were performed by Chikunov and Gladishev?? in 2010s but results were not published. They tested around 1000 compounds on mice for a few years.

#### Combinations of geroprotectors

An obvious idea is to combine different geroprotectors and find if they have synergy in life extension. However, such experiments will quickly be impeded by combinatorial explosion. A narrow AI, biomarkers and some understanding of antiaging pathways may help to escape such explosion. We discussed this deeper in the article “AI in life extension”.

Current best results were achieved by the combination of rapamycin, rifampicin and alantoine, where the life span of nematodes was extended almost 1.5 times (Dessale et al., 2017). Metformin surprisingly did not show itself well in this combination, as it possibly affects the same metabolic pathway as other drugs.

#### Hormesis

Hormesis is the effect of small stress on organisms which results in activation of reparation systems. One of such systems is heat-shock proteins, which start to repair the cell after it is affected by excess heat. Such reparation overshoots and repairs even other damages in the cell resulting in its rejuvenation. This may explain why Finnish sauna is associated with life extending benefits.

http://roguehealthandfitness.com/hormesis-for-health-and-longevity-a-guide/

#### Parabiosis

Parabiosis is the effect of the rejuvenation of older animals if they are getting the blood of the younger ones. The startup in California funded by Peter Thiel provides the plasma of blood of teenagers to older clients.

There are several theories why this may work, probably the blood of younger ones has some combination of the regulatory factors, may be similar to the “Yamanaka cocktail”, which is the combination of 4 drugs which reload epigenetic clock of a call and return it to stem-cell condition. The lower concentration of these drugs resulted in life extension effects in mice, but higher concentration killed them.

#### Biomarkers of aging

To properly demonstrate that some intervention works on humans, we need a life-long experiment with a control group, which requires decades of very stable conditions. This is very expensive, and even unfeasible as human conditions are changing and completely stable conditions are impossible. Such long experiments also mean that their results will be unavailable to currently living people.

To solve the problem of very long experiments, biomarkers of aging should be developed, that are the instruments which predict the outcome of the life extension experiment. One of the best possible such biomarkers is lowering of age-related mortality, but some effects of interventions may be long-term. For example, if some hormone therapy makes people feel younger but in 10 years horizon increases probability of cancer, it is not good life extension instrument.

There is some progress in developing different biomarkers. For example, some pre-disease conditions like hypertension, obesity, or intima-media thickness of arteria could be used to estimate the effects of the experiments. The amount of physical activity is also well correlated with mortality. However, not all correlations are good predictors, as some of them may be just side effects of aging like grey hair, and intervention which change this color hair (like wigs), will not help in life extension. So, the problems described by Goodhart’s law (Goodhart, 1984) are arising here.

One could find the list of the ongoing antiaging experiment in the <https://www.lifespan.io/the-rejuvenation-roadmap/>.

AI could be used to evaluate biomarkers and combinations of geroprotectors, as well as personal medicine, based on personal genomics and big data about the body.

All such low-tech interventions may give ~10 years of life expectancy, but even a small gain in life expectancy means that hundreds of millions of people will survive until he next life extending technology and ultimately until immortality. So, we do not speak just about healthy aging, but about a chance to win in a lottery where millions years of future life could be won.

There are several drugs and interventions currently researched for slowing down aging.

### Step 2. Strong slowdown of aging

The main idea of the step 2 is that it is based on some understanding of the mechanisms of aging and uses this understanding to directly attack underlying molecular pathways. This understanding may not be a complete model of aging, but may only contain some the important mechanisms.

These may be unable to completely “solve aging”, but may slow it down significantly. These methods were used to reach 10 times increase life expectancy in worms and almost 2 times on mice, via genetic manipulation of single genes. This gives us hope that such methods could result in human life expectancy increase of decades, something like 10-50 years.

If these technologies appear in less than 10 years after some combination of geroprotectors from step 1, which presumably would max out at 10 years life expectancy, then this will be in line with longevity escape velocity.

#### Fundamental research of the mechanisms of aging

The necessary condition to significantly slow down aging is the fundamental research on its mechanisms. This includes not only testing of prospective geroprotectors but creating an entire model of biological processes. The first outcome here is finding new metabolic pathways related to aging. These pathways may be then targeted via specific interventions.

Each theory about the nature of human aging has a corresponding idea of which intervention could slow down aging. There are tens of different theories of aging. The most prominent ones – and corresponding interventions – are:

* Oxidative stress – powerful antioxidants
* Programmed aging – find and turn off genes of the program
* Hayflick limit – add telomerase (and prevent cancer)
* Damage accumulation – increase reparation

#### Gene delivery

There were several experiments on mice when genes were delivered via viral vectors in already living organisms. It is not currently possible to deliver genes into all cells of the body, but in many cases changing only some cells is enough. Such changes are obviously risks as they could damage some cells and make them cancerous.

There are two genes associated with life extension in experiments: gene of telomerase, which increase telomeres in cells, and the gene of muscle mass. Lis Parrish claimed to inject herself with this combination.

Systems like CRISPR will surely play the role in future gene editing of the living beings. The specific genes may be also targeted by regulation their expression via epigenetics, or by direct insertion of the proteins which they code for.

In 2019 Church has claimed to reverse 4 age-associated diseases via genetic therapy with adenovirus vector (Davidsohn et al., 2019).

#### Stem cell replacement

It is possible to rejuvenate the whole immune system, if all hematopoietic cells are replaced with their younger clones, maybe taken from the same donor when he was younger and cryopreserved. The idea was tested on mice (Kovina, Zuev, Kagarlitskiĭ, & Khodarovich, 2012). When a person is aging only a few hematopoietic stem cells survive and they accumulate a lot of damage. Brain stem cells also rejuvenated mice (Zhang et al., 2017).

#### Personal medicine

As aging (according to one of the main theories) is an accumulation of damage, such damage is unique to every person. Personal medicine is the idea to adjust therapy based on all the big data about the person. Amounts of personal data is quickly growing with full genome sequencing and availability of different “omics”. Narrow AI is needed to read these data and find related research and provide recommendations.

Thus “personal medicine” becomes synonymous to the antiaging therapy, as both are based on the deep understanding of pre-pre-diseases.

#### Microbiotic replacement

It is known that microbiota changes with age and becomes less diverse. Microbiota creates many important vitamins and precursors of neurotransmitters and could even control human behavior via producing signaling molecules like pheromones.

Now we have “fecal transplants” aimed at improving personal microbiota. Maybe some instruments like coevolution could be used to create or find already exiting microbiota which increases human lifespan.

The idea of using kefir as a source of correct microbiota exists for 100 years and was suggested by Mechnikov.

Genetically reprogrammed E.Coli could become an alternative to nanorobots. For example, Eligio Bioscience (<https://eligo.bio/>) is working of what they call “biological nanobots” to combat antibiotic resistance.

#### Senescent cell removal

Experiments on mice show that killing senescent cells – which are old and non-functional cells which did not go into apoptosis but create toxic chemicals – are extending the lifespan of mice. *Unity Biotechnology* startup is trying to find drugs which could stimulate apoptosis of such cells.

#### Extracellular matrix rebuilding

There is more and more evidence that stability of this matrix is the key to successful natural regeneration.

### Step 3. Achieving Negligible Senescence

When we have a complete theory of aging, we could reach negligible senescence, that is completely stop the aging process. Such a model probably will be not just one theory or molecular pathway, but incredibly complex net of interaction, which could only be modeled inside a computer.

#### Vaccine against aging

Theoretically, embryo editing technologies could be used for creating an almost non-aging organism, if we add many genes which are associated with life extension, increase the number of anticancer genes like P53. Such editing maybe akin to a vaccine against aging, and may increase human life span a few times. Such editing will preserve some traits from parents, as the child will still carry most of their genes. Human embryo editing experiments are now becoming legal in China and Japan, but given the need for experiments on animals and getting regulators’ approval, a human aging vaccine may be decades away.

Also, it will not help directly currently living people, but could help indirectly: ageless new animals could provide better understanding of the nature of aging, and ageless humans could be a source of transplantable cells, blood or organs, which will rejuvenate even currently living humans.

#### Reprogrammed cell therapy

Stem cells combined with effective gene engineering technology could become something akin to nanobots which rejuvenate the body from inside.

Currently, a person could receive IPS (induced pluripotent stem cells) stem cells from another person for treatment of muscular degeneration, but not genetically modified ones (Mandai et al., 2017).

#### Stopping pre-diseases and the main causes of death

Not only fighting aging as a pre-pre-disease, but slowing down and stopping other pre-disease like high blood pressure, dieabetes-2, atherosclerosis, HIV, and “inflammation” will contribute to significant reduction of mortality, and results of treating pre-diseases will be quicker and more obvious. Such pre-diseases may be viewed as branches from the main trunk of the aging tree.

Preventing immediate causes of death will also contribute to global growth of life expectancy. This include thrombosis prevention, powerful therapy of cancer; cure for ALZ etc.

#### SENS

The main idea behind SENS is complete control over age damage, perhaps via regular interventions, the same way as a car gets maintenance. SENS includes 7 sub-projects:

|  |  |  |
| --- | --- | --- |
| **Aging Damage** | **Year Discovered** | **Rejuvenation Biotechnology** |
| Cell loss, tissue atrophy | 19551 | Stem cells and tissue engineering: [RepleniSENS](https://www.sens.org/research/introduction-to-sens-research/cell-loss-and-atrophy) |
| Cancerous cells | 19592, 19823 | Removal of telomere-lengthening machinery: [OncoSENS](https://www.sens.org/research/introduction-to-sens-research/cancerous-cells) |
| Mitochondrial mutations | 19724 | Allotopic expression of 13 proteins: [MitoSENS](https://www.sens.org/research/introduction-to-sens-research/mitochondrial-mutations) |
| Death-resistant cells | 19655 | Targeted ablation: [ApoptoSENS](https://www.sens.org/research/introduction-to-sens-research/deathresistant-cells) |
| Extracellular matrix stiffening | 19586, 19817 | AGE-breaking molecules; tissue engineering: [GlycoSENS](https://www.sens.org/research/introduction-to-sens-research/extracellular-crosslinks) |
| Extracellular aggregates | 19078 | Immunotherapeutic clearance: [AmyloSENS](https://www.sens.org/research/introduction-to-sens-research/extracellular-junk) |
| Intracellular aggregates | 19599 | Novel lysosomal hydrolases: [LysoSENS](https://www.sens.org/research/introduction-to-sens-research/intracellular-junk) |

<https://www.sens.org/research/introduction-to-sens-research>

Many of these ideas are based on genetic engineering, like moving mitochondrial genes into cell’s nucleus or deleting telomerase gene to eliminate possibility of cancer. Others require special enzymes which will destroy some intercellular and extracellular junk.

### Step 4. Rejuvenation

The idea of rejuvenation is to return parameters of the body and probability of death to a younger age, presumably to the best age of a person, somewhere below 20 years old.

#### Non-replicating nanobots inside the body: targeted drug delivery systems with logic

[*Ligandal*](https://www.ligandal.com/) created a system of delivery with precision of exact organelle of a cell based on multilayer lipid spheres.

DNA-origami is also used for drug-delivery nanorobots with simple logic. It could be used to kill senescent cells and cancer cells.

#### Regulating a gene’s expression: Yamanaka factors

Yamanaka cocktail is used to convert normal cells into the induced pluripotent stem (iPS) cell condition via set of epigenetic changes induced by several drugs. The cocktail initially consisted of 24 chemicals but now it has been reduced to 4.

It was also shown that it is capable – if administrated in lower concentration which are not producing full reprogramming – to extend mice lifespan up to 30 per cent. (Ocampo et al., 2016)

#### Internal rejuvenation factors: Klotho, hormones

It is possible that organisms could regulate their rejuvenation capabilities, which could explain the effects of parabiosis. One of such rejuvenation regulators may be a Klotho protein, which overexpression increases mice lifespan of 19-30 per cent (Kurosu et al., 2005)

#### Promoting regeneration process inside tissues

Some complex animals like Salamanders preserve the ability of regeneration of limbs. This regeneration is proliferation of stem cells and correct differentiation and localization: the task which was already done in embryotic stage, but is turned off in most animals.

Scientists are now capable of starting regeneration inside bodies of animals which lost this capability. They partly regenerate a frog leg via application of progesterone patch (Herrera-Rincon et al., 2018).

#### Replacing cells via genetically modified stem cell injections

Replacing of depots of stem cells with younger ones or genetically modified ones

#### Replacing body parts via therapeutic cloning

Therapeutic cloning is controlled cloning of cells in order to get more material for transplantation. Such cells could be used to grow organs out of body, and also for transplantation. Organs could be grown inside animals or on a artificial substrate. Cell matrix of the donors’ organs could be filled with new cells to create biocompatible organs.

#### Use of advanced AI for complex interventions: large data streams in and out of body

See more in our about AI in life extension article (Batin, Turchin, Markov, Zhila, & Denkenberger, 2018)

#### Advanced “death protection”

We could reach lower mortality in case of accidents by adding additional protection measures, like pockets of artificial blood somewhere inside the body with high oxygen content – which would help the brain to survive in case of unexpected heart arrest.

### Step 5. A New Body

Ideal solution of the problem of aging is not body repairmen, but body replacement technology, the same way as at some moment it is simpler to buy a new car than to fix the old one. The main problem is not the lack of bodies – we theoretically could use animal bodies, but the difficulty of the replacement process, because of:

a) organ rejection risk

b) difficulty of neural connection in spinal cord

с) risks of the surgery – clots, brain damage.

в) body replacement is not solving the problem of the brain aging, including ALZ and risks of head and brain cancer, so even absolutely successful body replacement technology will give only 10-30 years of life extension.

We need robotic and biotech solution to quickly replace body parts.

There are at least 4 possible types of the new body: head on life support, new biological body, new cyborg body, and nanotechnological body, where all cells are replaced with nanorobots.

#### Head on life support

Currently a very small amount of research, even on animals, was done on the topic of the supporting of the head out of body or head transplants. The main reason is mostly ethical commission are not giving approval on such experiments even on rats. There were some Soviet experiments about dog head transplants by Brukhonenko at 1930s and in 1950s Demihov reached 29 days survival time in of the dog’s head transplant (Lamba, Holsgrove, & Broekman, 2016).

There is a planned experiment on head transplant in China, but they also want to solve the problem of neural connection in spinal cord, which is known to be extremely difficult. Without such connection, the patient will not be able to move his body, but could remain alive and control computer via eyes, which in our society is enough to live a full life, as Hawking did.

If the head could be supported out of the body, may be on donor blood pumped by artificial heart, it will be the first step to the full body cyborgization. Such head-on-life-support is obviously a temporary solution, but many our cancer therapies are also temporary. But it could give a something like 10 years boost to someone’s life expectancy, which could be enough to survive until full body regeneration.

The experiments like “Brain in a Vat” were recently performed on the pig brains (again with absurd public backlash as hundreds of millions pigs are slaughtered every year). If a head is damaged, but the brain is not this could be a temporary solution. Also, there are some head diseases which are excluded this way, first of all: different types of head and neck cancers.

Head-to-animal bodies transplantation may also help to extend life to seriously ill people. There is now a lot of research to create human-compatible animals, mostly pigs, as a source of organs for transplantation. However, the bodies of such animals could be also used to support head transplants. But most human diseases may be better treated without head transplantation. For example, such transplantation will not help in case of metastatic cancer as it may appear also in brain.

Theoretically, a human donor could carry additional head on his shoulders and be well paid for this, but it is not a scalable solution which could provide life extension for everybody. Alternatively, a head could live on a donated blood, which is oxygenated via some pomp; if artificial blood will be developed, it will be much simpler.

#### Creation of a cyborg, most of which body parts are artificial

If supporting systems of the head-transplant could be made small and reliable enough, it opens the way to full cyborgization of the body.

#### Cultivating a new body for transplantation using genetic engineering

Theoretically speaking, the best transplantation would be on the person’s own cloned body, but this raises significant moral question, as we cannot kill a clone (especially as such clone will be a child). The possible solution is suppressing the brain development in order to create “Artificial Anencephaly” (it could be done by damage to neural tube of the embryo at 26 days after conception. The ethical problems of donor donation from Anencephalic babies are very complex and unlikely to be solved soon.

Thus, it is better to find a way to control stem cell development so only a large part of the body will grow, but not the brain. Such large part of the body, as limbs, or a group of internal organs grown in a vat could be as effective as whole body cloned transplant, but this would require non-natural ways to control regulatory gene expression and possible genetic modification.

#### Nanotechnological body

To tackle all small damages of aging, we need an instrument able to reach any cell in the body. As was suggested by Drexler and later R. Freitas in the book “Nanomedicine” (Freitas Jr, 2003), such an instrument is nanotechnology, or molecular manufacturing.

The main direction of evolution of such system are:

* From larger to smaller
* From reparation to replacement
* From simple logic to full autonomous with elements of AI
* From single bots to swarms
* From manufactured to self-replicating.
* From biologically inspired to fully mechanical.

It is expected that nanobots will have lower level of errors and high capabilities to self-repair than cells, and thus will not be affected by aging.

This nanotech medical intervention could be implemented in several steps:

• *Medical small robots*: Constantly circulating nanorobots in the blood.

Nanobots for treatment of injuries, senescent cells and cancer cells.

• *Self-replicating nanobots:* Nanobots for repairing extracellular matrix and other errors. They could also be bionanobots, that is, based on some augmented cells.

• *Cyborgization of cell*: Small nanobots replace organelles inside cells. In some sense, viruses are already capable of doing this.

• *Nanotechnological body*. All cells are replaced with nanobots. In some sense, such body will be like a liquid metal from the movie Terminator-2, as new “cells” do not need to have the same positions and roles as original cells, but they have to replace also brain neurons to reach this stage.

At an earlier stage, most cells will be artificial but some structure, like extracellular matrix or neurons will be from previous biological body. At the end, even neurons will be replaced by nanobots, which is equal to uploading.

### Step 6. Cyborgization of the Brain

In fact, we need only the human brain for immortality, and thus all efforts in life extension should concentrate in the preservation of the life of the brain. Moreover, we do not need the brain itself, but the human mind as “program” which runs on the brain. This all means that connection of the brain with computer is important step toward uploading and immortality.

#### Non-invasive brain scans: reading data from the brain and recording it back

The [*Openwater*](https://www.openwater.cc/technology) startup suggested to use infrared light for wearable brain imaging technologies. It also uses a holographic principle to increase spatial resolution of the system.

The system could also be used to write back information into the brain via creation of something like “3D hologram” which has a spike only in one pre-determined place to affect selected group of neurons.

#### Brain implants for data exchange

*Electrode arrays***.** DBS via a single electrode is a rather unsophisticated way to get pleasure, as such stimulation does not take into account the complex structure of the human reward center and stimulates the whole area. Thus—presumably—it cannot reach the maximum level of pleasure. However, a more powerful system might include many smaller electrodes in many parts of the brain connected to specific groups of neurons. This approach may be more difficult: science does not yet know the structures of these pleasure centers; smaller electrodes degrade more quickly, losing electric connections with the brain tissue or killing neurons around them; and such surgery is also currently difficult.

*Neural prosthesis.* The most common current implants are cochlear implants. They are connected to nerve tissue, not brain tissue, have up to 22 electrodes (Van Besouw, 2013) and cost up to 100 000 USD. A more advanced neural prosthesis has been researched for the hippocampus (Gonzalez, 2018) as memory improvement implants. In DBS, no direct current is used, but instead a combination of pulses of some frequency (like 100 Hz) which is regulated by a signal processor (Fagundes, Rieder, da Cruz, Beber, & Portuguez, 2016). For most effective reward stimulation, a special digital processor is needed which would create different signals for different parts of the brain. It could be put inside the brain together with electrodes, creating something like a reward-stimulating implant.

#### Genetically modified neurons as connectors

There are two main ideas for GM neurons for the brain implants. One is [optogenetics](https://www.eurekalert.org/pub_releases/2018-02/aaft-anw020518.php), that is insertion of luminescent genes in the neurons, which code luminescent protein which emits light when the neuron is activated. Hypothetically such genes could be delivered via viral vectors into a human brain, and flashes of light could be read by detectors on the brain surface. The same way, information could be sent back via photo sensible genes insertion. However, it seems risky to infect all live neurons in the brain by viruses.

Another idea is artificial genetically modified new neurons, which could migrate inside brain tissue, or, at least send its axon connection through the tissue and connect to existing neurons, thus either reading their internal states or affecting them.

Some viral vectors could be used to deliver genes (Ramos, Hunter, & Wolfe, 2017) that code for light-sensitive proteins into specific neurons, and such neurons could later be stimulated by sending infrared laser light in their direction.

*Artificial biological neurons as implants.* If humanity’s understanding of biological tissue becomes sufficiently advanced, we could harness the implanting mechanism used during the early embryonal development of the human brain. This is the ability of new neurons to travel through the brain, find a specific location, and from there, send axonal connections to other brain regions. Axons from live neurons could grow into remote regions of the brain and be used as relatively safe brain implants (Adewole et al., 2018). This technology would have important applications, like restoring brain function, creating non-degradable brain–computer interfaces, and ultimately, uploading brains, but it could be also used for wireheading (reward center stimulation) (Alexey Turchin & Denkenberger, 2018).

#### Nanobots in the brain tissue

*Neural dust.* This idea is to create small self-sufficient electric machines which could be injected in the brain where they would exchange information and recharge wirelessly. The idea is explored in Musk’s project Neuralink (Templeton, 2017).

### Step 7. Mind uploading

The goals of the mind uploading are backing up information from the brain and gradual transfer of personality to a digital substrate.

We have to solve the complex problem of the nature of human consciousness, which is out of the scope of this article. We assume that advances in AI, experimental neural science and philosophy will help us to answer the question: “Is it possible that human mind will have conscious experiences if it is simulated by a computer?” Even if “Turing computers” turn out to be not capable of supporting human consciousness, as it, say, has quantum nature, as Penrose suggested, the special type of artificial quantum computers may be used to simulate neurons in the way that will ensure existence of this quantum consciousness.

There are several ways of mind uploading, which differ from relatively low-tech and destructive, to high-tech, non-destructive and preserving continuity of consciousness. (It should be noted that the “continuity of consciousness” is something like a “soul” for atheists – it is postulated as very important but cannot be measured.)

In fact, there are two problems: “Can a computer model of a human mind be conscious at all?” and “will such model of my mind have *my* conscious?” We here assume that some copy-friendly and computer-friendly theory of human consciousness is created and accepted, that is, both questions could be answered “yes”. If not, we assume that some more complex machinery will still solve both problems, like artificial quantum computers for consciousness and gradual uploading technology.

#### Scanning of the brain slices

The simplest way of full brain uploading is the [scanning of brain slices](https://io9.gizmodo.com/see-the-first-ultra-high-resolution-3d-scan-of-the-ent-514395280) postmortem. This, however, requires immediately dead patient, so cryopreserved brains are not the best candidates for the first uploading, as the “fresh brain” needs some preparation for scanning. The scanning itself is slicing of the brain into thin slices which when are photographed by the methods of microscopy.

The [advances of tomography](https://www.medgadget.com/2015/12/siemens-simultaneous-multi-slice-mri-technology-fast-brain-scans.html) may also help as for a non-moving object, much higher resolution could be reached.

Moreover, slices of human brain tissue could be cultivated, currently up to two weeks (Schwarz et al., 2019).

#### Merging of the brain and computer via deep integration of implants

Neural implants described in the previous section could produce a situation where a computer will become a part of the mind (this would be similar to current smartphones being inseparable from some people). As a result, the computation process will gradually migrate into a computerized exo-self, which will become more “me” than my “wetware”.

Another consequence of effective neuroimplants is the deeper connection between human minds which could produce something as global hive mind called by some “Neuralnet”. In that case an individuality will merge with other minds, and this may or may not be regarded as a form of immortality. From my point of view, it is not, as do not want to coalescence with other minds which I may not like.

#### Nanorobots will read the brain structure

A possible advance of nanotechnology, where ubiquitous nanorobots could be smaller than human cells, create another route to uploading: these nanobots will connect to all neurons of the brain, read their electrical activity, trace their connectome connections and even read the synapse weights.

In that case, the brain model could be created from a living person, so it is non-destructive uploading. But this model will be only a copy of the person’s mind at some moment.

Finally, if nanobots are used to gradually replace neurons in the brain, this will result in gradual uploading, similar to a thought experiment by Chalmers against “fading qualia” (Chalmers, 1995), where gradual replacement of biological neurons with their mechanical analogs were demonstrated to not capable of interrupt the stream of consciousness (without assuming that there is one special neuron which creates consciousness).

If all neurons are replaced with nanobots, which only exchange information according to some digital rules, it would be equivalent to the uploading into a computer, as the physical location of these nanobots will be not relevant and they could be then replaced by computer programs presenting the same calculations.

If some quantum theory of consciousness turns out to be true, it still could be continuously uploaded by adding artificial “microtubes” (“microtubes” are cell elements which constitute elements of the quantum mind according to Penrose), and then making them coherent with natural microtubes. This will stretch the “quantum mind” from natural carriers to artificial. The elements of this “quantum field” could them be distributed over the Earth via some quantum communication channels, and thus the whole quantum state will become uploaded, backed up and virtually indestructible.

If the quantum mind state is unclonable (as it is implied by the [no-cloning theorem](https://en.wikipedia.org/wiki/No-cloning_theorem)), it can’t be distributed over many elements of mind (as it suggests some form of state-cloning), but should be concentrated only in one neuron and also cannot participate in any processes in mind, as there cannot be changes. But even if the “quantum mind” is just quantum uncertainty of the state of electric potential of just one neuron, in this case such neuron could be located and its state could be transferred to an artificial neuron.

## 1.5. Plan A, social changes strategy

The main goal of the social strategy is to attract money to the scientific experiments, but also to ensure the needed changes in regulations. The amount of money which could be effectively used for longevity research is large and could be estimated in around 100 billion dollars a year (which is still smaller than public spending on unproved snake oil antiaging solutions of around 300 billion a year). A 100 billion will be significant share of total global spending on biotech R&D, but it will not “over-flood” the field. There is only a limited number of scientists and labs, so too much money will have diminishing returns eventually.

Moreover, such money should be committed long-term (for decades-long experiments) and without obligation to provide “success”; so it is better to spend them through universities than through startups, which has higher incentives to commit fraud (which is especially easy in life extension field as the final result – longer human life – is far away and not measurable).

The social strategy is based on the interaction of two “engines”.

One is a *social demand engine*, which consists of the increase of the popularity of the idea of life extension, growing number of supporters and increase of funding of honest scientific projects. There is a big problem with science scam in anti-aging research as quarterly reports require getting quick profit, and most of life extension research will produce only probabilistic results which cannot be verified for a single person – in something like 20 years from now.

The global market of scam interventions in fighting aging is around 300 billion USD a year, while vital fundamental research is severely underfunded and gets only a few hundred million at best. Many important experiments have been underfunded for years, like the test of metformin as a life-extending drug.

The second enemy is religion – and general human unwillingness to live longer. The problem of why the idea of life extension is so unpopular despite its obvious rational grounding requires additional scientific research.

The third problem is FDA not accepting aging as a disease and thus big pharmaceutical companies do not have legal grounds to pursue research in this direction.

The funding engine should not only provide money, but also ensure that they are spent on honest and important research.

*The second engine* is scientific research and development which consists of the normal cycle:

* Theoretical idea
* In vitro tests
* Experiments on animals, from worms to flies to mice to monkeys
* 3 stages of clinical trials on humans,
* FDA approval
* Marketing and implementation

The engine of the social demand is needed to move on the scientific research. But success in demonstrating feasibility of fighting aging via high quality research may also help to attract more funds. Such an experiment may be the creation of a non-aging animal, or significant extension of mice life span.

There are several ways that the funding engine may work:

* Political parties, like a Party for Medical Research in Germany, which got around 1 per cent in local elections
* Crowdfunding
* Influencing billionaires or former presidents
* Patient organizations of aging people, who organize clinical trials
* Lobbying international organizations and in Parliaments, like International Longevity alliance is doing.
* Increase the number of followers of the idea of life extension via art, books, movies
* Pension funds
* Church and charities: Fighting aging should be recognized as a cause of effective altruism
* Startups
* Personal influence in one-to-one conversations
* Scientific career
* Creating a Longevity university territory, may be based on *longevity schools*, like the ones which was created by *Open longevity.*

A person interested in life extension should probably chose the most impactful area where s/he could contribute to the global success. By participating in collective efforts, the person will have better knowledge of the field and he will be more likely to have access to new life extending technologies first.

#### 1.5.2 What-strategy and how-strategy

What-strategy is about technologies which we should develop to reach immortality. How-strategy is about the ways how to get money and other social resources for that. Here is mostly presented what-strategy.

#### 1.5.3. Is it possible to accelerate the technological progress?

If changing the speed of the progress is not possible, then any technological strategy is futile. All the things will come in their time. Some historical cases, like nukes and transplantations, indicate that the change of the speed of the progress is possible for around 10 years in the direction of acceleration, but more than 50 years in the opposite direction. Accelerating right tech in right time for 10 years could provide us with the ladder of technologies. This could remind the reader about the idea of differential technological development by Bostrom (Bostrom, 2002) as a way to prevent global risks.

There are three ways to accelerate progress: creation of a superhuman AI, large money infusions or the situation of urgency like in the case of war. The field of longevity research is rapidly growing now because of startup bonanza, so “money infusions” seems to be the most practical way to accelerate progress in life extension, while perusing superhuman AI is dangerous approach and the “urgent measures” could be implemented by some older dictator or in the case of political changes.

## 1.6. Safety problem and the duration of scientific experiments

If interventions are applied to younger and healthier people, they should be extremely safe long-term. But it is not easy to prove the safety on some completely new therapies. What if genetic therapy of aging will increase cancer rate in 10-20 years from its start? It rather possible that telomerase treatments could produce initial rejuvenation, but eventually will help cancers to grow. To prove safety of genetic therapy we need a very long time.

However, some other therapies of aging are less effective but relatively safe, as they were tested by decades, and their safety profile is well known. These are some of old known potential geroprotectors, like metformin, vitamin D or green tea, as well as their combinations. So, they could be much quicker approved by regulators or used over the counter.

Some antiaging mechanisms, which could be applied to very old people, do not need such long-term testing (like head transplantation), as these old people has much smaller life expectancy and its increase will be proved in shorter time. This is especially true if we save people from close inevitable death, and in that case, it can’t be called “fighting aging”.

Also, very powerful interventions will be able to correct their own negative consequences, e.g. nanotech.

# 2. Plan B. Cryonics

The chance of surviving until 2100 may not be high, even if a global catastrophe does not happen, and strongly depends on current age. Most currently living people likely will not survive. This also depends on the longevity escape velocity curve: if life extension technologies advance slowly, more people will die.

But biological death is not information-theoretical death. We could preserve the human brain hoping that future advanced AI and nanotechnology will be able to resurrect the person. There are several possible ways for such preservation:

* Cryonics: cooling the brain to very low temperature, while preventing ice formation in the process called vitrification.
* Chemical preservation. Use of chemicals to fix brain structure. One variant is called plastination.
* Slicing and preserving of slices on glass with some chemical preservation. This is how Lenin’s brain was preserved (Adrianov, Bogolepova, Blinkov, & Kukuev, 1993).

Only cryonics is currently commercially available, but not very popular: only around 250 people are cryopreserved in three facilities, two in the US and one in Russia. Because the idea is surprisingly unpopular (more people’s bodies are eaten by birds according to Zoroastrian funeral tradition in Mumbai), the prices have remained high, legal status is unclear in most of the world, except Arizona, and the amount of scientific research is small in the field, which has existed for around 50 years.

Plan B, by definition, takes over when the plan A fails. But for this to work, one should be prepared for it, so the preparation for all plans should be simultaneous.

## 2.1. Plan B, technological strategy

Cryonics requires research in reversible tissue cryopreservation. One direction of the research is the search for new cryoprotectors (which prevent ice formation in cells). Another approach here is promoted by Organ Preservation Alliance, that is, the idea that we should start from cryopreserving organs for transplantations.

Experiments on reversible cryopreservation of small animals are needed to demonstrate the feasibility of cryonics. For example, Natasha Vita-More demonstrated that a C. Elegans worm could retain its learned memories after liquid nitrogen preservation.

## 2.2. Plan B, personal strategy

The personal cryo-strategy is rather straightforward:

* Sign up for cryonics! One can fund it through life insurance, so it is not as expensive as one may think. You may need to make a will with instructions about cryopreservation
* Wear the cryotoken, so in case of accidental death, the people around you will know what to do.
* Have a trusted relative, who may organize the process of cryopreservation and funeral.
* Live near a cryofacility, especially when older, and contact it immediately in case of life threatening situation.

## 2.3. Plan B, social changes strategy

If there are no new people signing up for cryonics, the companies will probably die off before the possible resurrection – so one should be interested in promoting cryonics. Wearing a cryotoken openly helps to start discussions. A conference for young cryonists is held regularly in the US.

Another important direction is increasing “legal stability” of cryonics. Cryonics is illegal in many countries, like France and Germany, or is in the grey legal zone in most others. Different companies use different legal tricks to continue business. For example, new Spanish company Cecryon <https://www.cecryon.com/en/> declared its facilities as “morgue” where bodies can stay indefinitely according to Spanish law. Kriorus keeps bodies as part of scientific research project in cryopreservation.

Ideally, we need laws about cryonics, in which suspended bodies would have the same protection as people in a coma (that is, their destruction would be equal to murder). But to pass such a law, transhumanists need a good representation in parliament, that is, we need some form of a Longevity Party, or proponents of life extension in other parties.

If cryonics were more popular, it would be cheaper, and there will be more chances that a law in support of it will be signed.

A failure for cryonics to become mass movement is a failure of marketing. There are several good texts about cryonics like by [Wait but why](https://waitbutwhy.com/2016/03/cryonics.html), but the number of subscribers is still small.

# 3. Plan C. Digital immortality, or indirect mind uploading

Obviously, cryonics could fail too. Maybe I will be not cryopreserved, or my body will thaw or important information will be lost. There are different estimates of the probability of personal success of cryonics, but given all uncertainty, it is reasonable to estimate the chances of cryonics around 10 per cent. See more in my article about digital immortality (A. Turchin, 2018a).

In that case, there is another option for immortality, which is called “digital immortality”, but the name is ambiguous, as it could also mean mind uploading via brain implants and scanning of live brain, but in such situation, it is part of plan A, as one needs to survive until such technologies.

Here we mean digital immortality as an idea that we could collect data about a person now, hoping that future superintelligent AI will be able to create a model of the person based on this data. There are two difficult questions here: what is the needed level of fidelity of such a model, and will such model be me at all, even if it will be conscious?

This is known as the “personal identity problem” which is notoriously difficult. We do not know how to solve it now, but we could expect that future progress in brain science, philosophy and AI will help to understand it better. Based on this ignorance, we choose a conservative approach to the personal identity problem: try to save as much information as possible about a person, hoping that something will help.

However, it is obvious that some types of information about personality are more important than others. We need information which complies with all three criteria:

* *Unique* (The fact that I have 2 legs in not unique for humans; name is unique)
* *Valuable* (But the pincode of my credit card is not part of my personality, despite its objective importance, so “valuable” means that the data is connected with my preferences)
* *Predictive* (There is a lot of noisy information, which I heard, but which will not affect my future behavior)

There are two main approaches to data collection for digital immortality: passive recording of everything I do and active running of psychological tests, writing memoirs, taking EEG, creating objects of art, declaring my own properties as I understand them.

Digital immortality is plan C, not B, as it is better to be reconstructed from cryopreservation, than have just a model of personality. However, the end stage of all three plans A, B, and C is the same: the human mind is uploaded into a computer controlled by some advanced AI.

Cryonics and digital immortality seem to be able to help each other: some information could be lost during cryopreservation but could be restored via digital immortality data.

Proper digital immortality is even less popular than cryonics, but a lot of information is now collected automatically in social networks, personal computers and surveillance systems.

## 3.1. Plan C technological strategy

The instruments to record and cheaply preserve large amounts of data are evolving very quickly. A person could record almost everything one does, at least in audio.

But technologies for active digital immortality are evolving much slower most because of lack of interest.

Another part of technological strategy for DI is the progress in AI and its ability to create human mind models based on observations and data analysis.

## 3.2. Plan C personal strategy

Personal digital immortality strategy consists of two equally important parts: data collection and data storage.

Passive collecting requires recording as much data as possible, first of all, record conversations with other people, and all other interesting and unique activity. A diary would also help.

Active data collection requires a period of full concentration of the task, perhaps for 1-3 months, during which several important activities will help to collect as much viable data as possible. This includes:

* Write a story of your life, perhaps based on some prompts of good questions.
* Create unique objects of art which will be something like hash-function or unique signature of your personality, as well as a portrait of your values (this may include verses, songs and most importantly drawings or a novel).
* Archive significant data from social networks.
* Scan or photograph all your historical documents and home environments.
* Run a battery of psychological tests.
* Collect EEG data during all this
* Videorecord different types of your behavior (public talks, having fun with friends, etc.)

## 3.3. Plan C, social changes strategy

While theoretically it would be better to wait until full fruition of the reconstructing technologies to create digital models of dead people, the market demand as well as emotional structure of love requires us to try as soon as possible. Because of this, even now (as of 2019) we have attempts to digitally reconstruct people in form of the non-perfect chat-bots. This could fuel more research in reconstruction and encourage more people to collect the data.

If nobody is interested in proper digital immortality, there will be no cheap and effective instruments in data collection and preservation. Moreover, future AI may be not interested in the resurrection of the dead based on such data. Because (friendly) AI will likely represent aggregation of collective human will, and if some human values are underrepresented, they could get less attention by the AI, especially given computational and moral costs of complex resurrection. Therefore, promotion the idea of digital immortality is needed to get more people inside the project.

Broadly speaking, the idea of the resurrection of the dead as a moral good should be accepted. Now some rational utilitarians think that it would be enough to create new happy people to increase global good, and naturally unhappy and expensive to recreate people of the past will spoil such statistics. But the same way we could kill old people as money for their medical care and pensions could be used to raise many new kids and the kids are naturally more happy beings, so this would increase total utilitarian good. But here we see an example of the Goodhart’s law failure: something (happy observer-moment) which was a good measure of social well-being, becomes not a measure but a goal, and *repugnant conclusion* (Parfit, 1984) and *utility monster* appears.

# 4. Plan D

Plan D is a set of ideas, where immortality appears without any of our conscious actions, but which have very low probability. For most religious people, it is plan A because they are sure that some form of immortality already exists in the form of afterlife or reincarnation. But for us it cannot be plan A, as there is very little evidence for the afterlife, and there are some theoretical problems in the idea. However, there are several more rational ideas for already existing immortality which do not require soul, afterlife and God, but still have some conceptual difficulties.

## 4.1. Big world immortality known as “Quantum immortality”

The first such idea of rational immortality which exists without any human interventions is so called “quantum immortality” or multiverse immortality. See more in my article (A. Turchin, 2018b).

The original quantum immortality idea is based on Everettian many world interpretation of quantum mechanics, where the world is constantly branching. Such branching means that at the moment of a person’s death where will be always a branch where the person didn’t die. It is formulated on the level of quantum events (like a bomb controlled by quantum random generator which either kill me or not) but could be extrapolated on macroscopic events, like death by a car accident.

It could be formulated as for any observer *O* at any moment of her existence *t* exists the same observer in the next moment t+1.

The idea is known to be controversial and most authors who wrote about it were critical. We do not know if the universe is actually infinite (or if Everett interpretation is true), could we count my remote copies as me, and what to do with declining “share of existence” problem. Also, such immortality is egoistic – and if I value something except my own future feelings, like wellbeing of my relatives, it is completely useless. Finally, there is nothing good in this type of immortality, as it means survival on barely above conscious level, probably as infinitely old and very ill, strongly suffering being.

However, it could be used to augment other types of immortality. For example, it work very well with cryonics, and increases subjective chances that it will work as well cryonics helps make the default outcome of quantum immortality positive – the share of the worlds where I will be cryopreserved and successfully resurrected is much larger than the share where I will be extremely old but not dying man.

## 4.2. Resurrection by the future superintelligent AI

We could imagine that future superintelligent AI will find ways to resurrect the dead even without properly done cryonics or digital immortality data collection. Maybe it will create time travel or ways to read information from the past. More about this idea in my articles (A. Turchin, 2019; A. Turchin & Chernyakov, 2018).

Another idea is the use of quantum randomness generator to create a random mind in a computer simulation. In the Everettian multiverse this will be equal to the resurrection of all the dead and even all possible beings, as any combination of 0 and 1 will appear in one of timelines.

There are a few patches which make this idea more plausible and helps to overcome possible undesired outcomes, like excess creation of damaged suffering beings. One patch is to take into account that in other branches of the multiverse where there will be many other such experiments, and if we properly calculate the total “quantum measure” (that is, the share of all timelines), then there will be no decline in this measure. In other words, for any person who had died will be exactly one his copy in one of the worlds, but maybe not in the same world where he died.

Another patch is the use of the digital immortality data there available to create a person who is adapted to our world and complies with expectations of his relatives.

The third patch is to use “resurrection simulations”. In that case, the AI runs one simulation of all human past to resurrect everybody, but replaces all unknown data with random bits. This helps to make proper distribution between more and less possible minds and to exclude random fantastic minds which would never appear naturally and which are most likely just invalids. This trick also nicely combines digital immortality and randomness resurrection.

Obviously, it is now just a sketch of what could be done, and future superintelligent AI – if it will be benevolent – could find much better ways to resurrect the dead.

## 4.3. Alien resurrection

If humanity goes extinct, the earth could be visited by an extraterrestrial civilization in the remote future, and they – using their own advanced AI – could resurrect the dead, the same way as we now thinking about mammoth or Neanderthals resurrection.

## 4.4. We are in a simulation

Famous simulation argument claims that we are with high probability (like 0.9999…) located in computer simulation created either by our descendants or by some other advanced civilization, because such simulation would be cheaper than real world and thus more numerous (Bostrom, 2003; A. Turchin, Yampolskiy, Denkenberger, & Batin, 2019) The argument itself may suffer from some form of circularity, as if we are in simulation, we cannot tell much about the world outside, but doesn’t kill the simulation argument completely as in this case it is assumed that we are in the simulation.

There are other possible solutions of the simulation argument, as was shown by Bostrom: may be our civilization will become extinct with high probability or it will decide never to create past simulations – or simulations and AI are impossible. But analogues to universal Doomsday argument, it is possible universal Simulation argument, which applies to all possible civilizations, and it is very unlikely that all of them will go extinct or decide not to create simulations.

If we are in a simulation, the computer which runs it has technical capabilities to resurrect anyone after death as it could record any mind states. But we do not know in which type of simulation we are and thus whether it would actually include resurrection. One type is already discussed above “resurrectional simulation”, which is designed exactly to calculate the state of mind of a person at the moment of his/her death in the original world.

Another type is recreational simulations where a person is just an avatar of a more advanced being who chose to forget about herself in order to enjoy the game – but which will retain the full memories of the game after it will be over.

The third hypothetical type consists of simulations which simulate the world according to the set of human beliefs and thus include an afterlife similar to, say, Christian, expectations.

## 4.5. What if the soul exists?

From theoretical point of view, an eternal soul requires the existence of God which would guarantee the soul’s eternal existence. But from the practical point of view, God is not different from the superintelligence discussed above which creates a simulation. Thus, there is not much reason to discuss the existence of absolute God, as even if does not exist, but a mundane superintelligent AI exists as a creator of our simulation, it would have for us the same observational consequences.

If a human soul exists, but only as some unknown part of the physical world, like a part of brain which consists of an unknown form of matter, this does not guarantee immortality as any material things tend to decay. Thus, all possible evidence like contacts with soul of the dead, haunting of apparitions etc. does not prove eternal “immortality”, but may hint at some process of data preservation at the moment of physical death – if there is anything real in them.

The topic is so deep into pseudoscience and scams that it is difficult to find any grain of truth if there is any, and more over such attempts will come with reputational costs.

There is not much to hint us about possible existence of anything unknown in the human brain except existence of qualia, that is subjective experience.

If some form of “qualia panpsychism” is true, and ontology of our world is much different than we think, then some other instruments for reaching immortality become possible. For example, it was recently suggested that there is no real world, but only chains of states of mind following from one to another (the theory is also known as “dust theory” and is similar to idea of the Boltzmann brains).

# 5. Navigating the life extension strategy depending on the personal situation

In the sections above we presented a map of the life extension landscape. But it is not enough to have a map for navigating. One need also to know her location on the map. There are several paths through this map, which are different for different people.

## Age dependent strategy

The younger is the person, the bigger her chances to survive until radical life extension. Thus, plan A is the most natural choice for the younger person. Moreover, children now have life expectancy of ~80 years and thus may expect to survive until longevity escape velocity and even to immortality, without implementing any special measures, except, obviously, escaping risky activities and taking reasonable care of their own health.

Some interventions are especially easy in younger age, like sport or not forming dangerous habits, like smoking.

Younger people could have bigger impact on global projects via career choices. They could become scientists, entrepreneurs or activists.

Plans B and C for them is more like a protection against accidents than the main survival strategy.

For older people, there is only a small chance to survive until radical life extension, and cryonics is a higher priority. Also, it may be a time to write memoirs for plan C.

## Financially dependent strategy

Life expectancy grows very slowly with wealth: Indian miners live just a few years less than American billionaires (lower life expectancy in Africa mostly connected with AIDS epidemic and child morality because malaria.) Despite popular belief, life extension therapies will not be just for the super rich, because in order for them to be reliable, they need to be tested on many thousands of people and thus relatively cheap. Even the most expensive medical interventions rarely cost more than a million dollars.

For even richer people, an option is investing their money in their own life extension by financing of scientific research, which may be related to their expected diseases or funding of the cryonics organizations. An important caveat here is the risk of encountering scammers, whose concentration in the life extension field is very high. Thus, before investing in life extension, a person has to have relatively high level of understanding of the field. Investing in scammers would have a negative effect as they will try to stop good research which could expose their fraud.

For old and poor people cryonics is almost unavailable option (but actually, one may pay from either insurance, or from remaining assets after death, so the actual burden will be not as high; Head preservation in Kriorus is 15 000 USD. If you are interested in cryonics, contact the nearest cryocompany and ask if they have any special suggestions for you: cryocompanies may be interested in increasing the number of clients and publicity, while getting funding from a few main sponsors).

Anyway, for old and poor person the most realistic option is Plan C, that is collecting data about oneself. This may require only access to a computer with a videocamera (or even paper and pen).

## All-in strategy?

Preparation for all three plans may look for someone with limited resources as too demanding. She may choose to go all-in into one of the plans, and in one of the substrategies: personal or altruistic. For example, older or ill person may invest only in personal cryopreservation, or young entrepreneur may bet on success of his anti-aging startup.

# 6. Different types of final immortality

*Ems*. If I will become uploaded, I will live as an emulation (em) inside a very large ecosystem of other ems, controlled by some advanced superintelligent AI. This world was described in detail by Hanson (Hanson, 2016). An emulated mind could be loaded back into a robotic body, so it could act in the real world, as if she were human, enjoying an indestructible body and a constantly updated backup copy (ies) on some remote server, which could enable immediate resurrection if the robotic body were destroyed. In that case one superintelligent AI could become a Singleton and play the role of global operation system, which combines features of world state and Internet.

But this may be not the only solution.

*Merge with Singeton.* One could evolve into AI or merge with other minds, in that case he will be not a separate mind, but the Singleton itself, which implies much larger transformation of individuality.

*Monocosm* – this a very advance being, which is not however, a ruler of the world, but could act independently in space and exist for billion years.

*Neuronet* – it that case, merging with other minds becomes the main way of personal evolution, which implies dissolution of individuality. This could be reached even on the level of advanced neuroimplants.

Non-destructible nanotechbological body, may be of very small size. Downloading the mind into a new biological body, and after its “death,” would be resurrection in a new biological body from the last saved point. This is also could be called “resurrection dominated immortality”.

All listed above ideas are in some sense interchangeable and are based on the technological paradigm of 3 supertechologies: biotech, nanotech and AI, which will provide complete control over biological objects, matter and information.

The more hypothetical or speculative ideas are “artificial soul” and “multidimensional body”.

# Conclusion

In this article are explored several currently available ways to reach personal immortality and suggested a structure of their implementation which gives maximum probability of success. This structure consists of the four main plans, which are constructed as levels of defense and ordered by their order of the implementation.

# Literature

Actuarial Life Table. (2017). *Actuarial Life Table*. Retrieved from https://www.ssa.gov/oact/STATS/table4c6.html

Adewole, D. O., Struzyna, L. A., Harris, J. P., Nemes, A. D., Burrell, J. C., Petrov, D., … Cullen, D. K. (2018). Optically-Controlled “Living Electrodes” with Long-Projecting Axon Tracts for a Synaptic Brain-Machine Interface. *BioRxiv*, 333526. https://doi.org/10.1101/333526

Adrianov, O. S., Bogolepova, I. N., Blinkov, S. M., & Kukuev, L. A. (1993). [The study of V. I. Lenin’s brain]. *Uspekhi Fiziologicheskikh Nauk*, *24*(3), 40–52.

Argonov, V. Y. (2012). Neural Correlate of Consciousness in a Single Electron: Radical Answer to “Quantum Theories of Consciousness.” *NeuroQuantology*, *10*(2). Retrieved from http://neuroquantology.com/index.php/journal/article/view/548

Batin, M., Turchin, A., Markov, S., Zhila, A., & Denkenberger, D. (2018). Artificial Intelligence in Life Extension: from Deep Learning to Superintelligence. *Informatica (Slovenia)*, *41*, 401.

Blagosklonny, M. V. (2018). Disease or not, aging is easily treatable. *Aging (Albany NY)*, *10*(11), 3067.

Bostrom, N. (2002). Existential risks: Analyzing Human Extinction Scenarios and Related Hazards. *Journal of Evolution and Technology, Vol. 9, No. 1 (2002).*

Bostrom, N. (2003). Are You Living In a Computer Simulation? *Published in Philosophical Quarterly (2003) Vol. 53, No. 211, Pp. 243-255.*

CDC. (2017, May 15). *Tobacco-Related Mortality*. Retrieved from https://www.cdc.gov/tobacco/data\_statistics/fact\_sheets/health\_effects/tobacco\_related\_mortality/index.htm

Chakravarty, E. F., Hubert, H. B., Lingala, V. B., & Fries, J. F. (2008). Reduced Disability and Mortality Among Aging Runners: A 21-Year Longitudinal Study. *Archives of Internal Medicine*, *168*(15), 1638–1646. https://doi.org/10.1001/archinte.168.15.1638

Chalmers, D. J. (1995). Absent qualia, fading qualia, dancing qualia. *Conscious Experience*, 309–328.

Davidsohn, N., Pezzone, M., Vernet, A., Graveline, A., Oliver, D., Slomovic, S., … Church, G. M. (2019). A single combination gene therapy treats multiple age-related diseases. *Proceedings of the National Academy of Sciences*.

Dessale, T., Batchu, K. C., Barardo, D., Ng, L. F., Lam, V. Y. M., Wenk, M. R., … Gruber, J. (2017). Slowing ageing using drug synergy in C. elegans. *BioRxiv*, 153205.

Dvorsky, G. (2015). *Will Our Descendants Survive the Destruction of the Universe?* Retrieved from https://io9.gizmodo.com/will-our-descendants-survive-the-destruction-of-the-uni-1744169933

Eubanks, D. A. (2008). Survival Strategies. *ArXiv:0812.0644 [q-Bio]*. Retrieved from http://arxiv.org/abs/0812.0644

Fagundes, V. de C., Rieder, C. R. M., da Cruz, A. N., Beber, B. C., & Portuguez, M. W. (2016). Deep Brain Stimulation Frequency of the Subthalamic Nucleus Affects Phonemic and Action Fluency in Parkinson’s Disease. *Parkinson’s Disease*, *2016*. https://doi.org/10.1155/2016/6760243

Freitas Jr, R. A. (2003). Nanomedicine, Vol. IIA: Biocompatibility. *Landes Bioscience, Georgetown, USA*.

Gonzalez, R. (2018, April 6). A Brain-Boosting Prosthesis Moves From Rats to Humans. *Wired*. Retrieved from https://www.wired.com/story/hippocampal-neural-prosthetic/

Goodhart, C. A. (1984). Problems of monetary management: the UK experience. In *Monetary Theory and Practice* (pp. 91–121). Springer.

gwern. (2015, June 1). Life Extension Cost-Benefits - Gwern.net. Retrieved March 17, 2018, from https://www.gwern.net/Longevity

Hanson, R. (2016). *The Age of Em: Work, Love, and Life when Robots Rule the Earth*. Oxford University Press.

Herrera-Rincon, C., Golding, A. S., Moran, K. M., Harrison, C., Martyniuk, C. J., Guay, J. A., … Levin, M. (2018). Brief local application of progesterone via a wearable bioreactor induces long-term regenerative response in adult Xenopus Hindlimb. *Cell Reports*, *25*(6), 1593–1609.

Kovina, M. V., Zuev, V. A., Kagarlitskiĭ, G. O., & Khodarovich, I. M. (2012). [Life extension study on high-yield non-myeloablating bone marrow transplantation from young to old mice]. *Tsitologiia*, *54*(12), 883–886.

Kurosu, H., Yamamoto, M., Clark, J. D., Pastor, J. V., Nandi, A., Gurnani, P., … Kuro-o, M. (2005). Suppression of Aging in Mice by the Hormone Klotho. *Science (New York, N.Y.)*, *309*(5742), 1829–1833. https://doi.org/10.1126/science.1112766

Lamba, N., Holsgrove, D., & Broekman, M. L. (2016). The history of head transplantation: a review. *Acta Neurochirurgica*, *158*(12), 2239–2247. https://doi.org/10.1007/s00701-016-2984-0

Mandai, M., Watanabe, A., Kurimoto, Y., Hirami, Y., Morinaga, C., Daimon, T., … Takahashi, M. (2017). Autologous Induced Stem-Cell–Derived Retinal Cells for Macular Degeneration. *Http://Dx.Doi.Org/10.1056/NEJMoa1608368*. https://doi.org/10.1056/NEJMoa1608368

Ocampo, A., Reddy, P., Martinez-Redondo, P., Platero-Luengo, A., Hatanaka, F., Hishida, T., … Beyret, E. (2016). In vivo amelioration of age-associated hallmarks by partial reprogramming. *Cell*, *167*(7), 1719–1733.

Parfit, D. (1984). *Reasons and persons*. OUP Oxford.

Ramos, L., Hunter, J. E., & Wolfe, J. H. (2017). Viral Vector Gene Delivery to the Brain for Treating Neurogenetic Diseases. In *Drug and Gene Delivery to the Central Nervous System for Neuroprotection* (pp. 89–125). Springer.

Schwarz, N., Uysal, B., Welzer, M., Bahr, J. C., Layer, N., Löffler, H., … Koch, H. (2019). Long-term adult human brain slice cultures as a model system to study human CNS circuitry and disease. *ELife*, *8*, e48417. https://doi.org/10.7554/eLife.48417

Templeton, G. (2017). Elon Musk’s NeuraLink Is Not a Neural Lace Company. Retrieved February 14, 2018, from Inverse website: https://www.inverse.com/article/30600-elon-musk-neuralink-neural-lace-neural-dust-electrode

Tipler, F. J. (1997). *The physics of immortality: Modern cosmology, God, and the resurrection*.

Turchin, A. (2018a). *Digital Immortality: Theory and Protocol for Indirect Mind Uploading*. Retrieved from https://philpapers.org/rec/TURDIT

Turchin, A. (2018b). *Forever and Again: Necessary Conditions for the “Quantum Immortality” and its Practical Implications*.

Turchin, A. (2019). *You only live twice: resurrection of the dead in computer simulations*.

Turchin, A., & Chernyakov, M. (2018). Classification of Approaches to Technological Resurrection. *Under Review in Post-Humans Studies*. Retrieved from https://philpapers.org/rec/TURCOA-3

Turchin, A., Yampolskiy, R., Denkenberger, D., & Batin, M. (2019). *Simulation Typology and Termination Risks*.

Turchin, Alexey. (2019). *How to survive the end of the universe*.

Turchin, Alexey, & Denkenberger, D. (2018). Wireheading as a Possible Contributor to Civilizational Decline. *Under Review in Futures.* Retrieved from https://philpapers.org/rec/TURWAA

Van Besouw, R. (2013). Implanting Awareness |. Retrieved August 13, 2018, from Sound on sound website: https://www.soundonsound.com/sound-advice/implanting-awareness

Zhang, Y., Kim, M. S., Jia, B., Yan, J., Zuniga-Hertz, J. P., Han, C., & Cai, D. (2017). Hypothalamic stem cells control ageing speed partly through exosomal miRNAs. *Nature*, *548*(7665), 52–57. https://doi.org/10.1038/nature23282

# Appendix A. Personal strategy for life extension for 2018

Figure 2. Currently available methods of life extension, download high res image here: <http://immortality-roadmap.com/lifeexteng.pdf>

