

In fact, my beliefs empower institutions to make me do things

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I tried to write a book for children.¹ It introduces natural forces as magical forces. This speech is an elaboration on it.

[1. Reductive Freedom & Emergence]

2. The Logic of Physical Life (Bejan)

The constructal law in fact is 'the' 'law of life'; of *physical* life. The *persistence* of physical life comes about through feedback. If life is stressed, to change or to being killed, then internal feedback will *resist* that, and *stabilize* the system. But life also needs to *evolve* in order to get ever better.

3-6. The Logic of Reductive Freedom

Feedback not only creates life, it also creates, what I call, *reductive freedom*... A system is reductively free, or has reductive freedom, in as far as its parts (more or less) submit themselves to a whole. ([J. C. Smuts](#), the inventor of holism, writes: "Parts are bound, the whole is free.") This automatically happens when there is *feedback*.

Persistence means that, if you *try* to destabilize a living system, it *self-corrects*; but this correcting also is a 'reaction' or 'behavior.' This way, the 'reaction' or 'output' is (at least partly) dependent on 'input', and *not* on reducible, 'material' causes.

This combination of input and output, I call reductive freedom. This freedom may not be perfect, but, *through top-down processes*, the slightest freedom may evolve into ever more freedom.

Then this freedom becomes ever more *recognizable* as input and output, such as with neurons.

Reductive freedom is *the building block of higher level life*—it is its 'matter' and 'energy', like what micro-controller instructions are to software. "*For a living system to emerge, reductive freedom must arise.*" That makes the whole *strongly emergent* (even though emergence is rarely perfect; lower level systems may 'brake into' higher level systems).

Out of reductive freedom, ever again, neighboring wholes form a higher level '*superwhole*,' which, next, may *thrive* or *die*. For example: *If you have certain beliefs, then a group (as a higher level) can use you to their benefit*—but you still feel that its use of you, is your choice and freedom. At the lowest level, i/o is about force, energy, and matter; heat *in*, expanding gasses *out*, is the basis of thermodynamics. (From these, following the constructal law, more complex living systems naturally arise, which again create their own i/o and reductive freedom).

(In fact, by definition a whole is anything that has reductive freedom.)

(Things that have the same reductive freedoms are, semantically and categorically, the same (kind of) things.)

(This, in fact, our brains, as neural network, knew all along.)

Some other examples...

- heat and pressure are 'made' from the movement of particles;
- the mind consists of 'things' like 'experiences';
- gravity maybe 'arises' out of the 'bending' of space-time;
- computer-software is made out of micro-controller instructions.

Dead configurations may behave as having input and output too, but I do not want to make that a topic today.

(The main difference between life and death is: evolution.)

The Logic of Physical Life (Bejan)

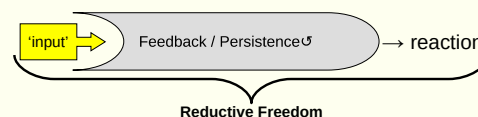
- Constructal Law = Law of **Life**:
For life to persist in time it must evolve with freedom such that it provides easier and greater access to what flows.
- **Life** = Self-stabilizing and evolving from freedom.

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The Logic of Reductive Freedom



- {input → reaction} is the building block of higher level life → **strong emergence**
- "*For a living system to emerge, reductive freedom must arise.*"

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1 In 5 languages: NL: Eigenlijk; Toveren uitgelegd aan onze kinderen; DE: Eigentlich; Zaubern erklärt für unsere Kinder; FR: En Fait; La magie expliquée à nos enfants; ES: En Realidad; La magia explicada a nuestros hijos; EN: In Fact; Magic explained to our children.

7. Degrees of Freedom $\hat{=}$ Reductive Freedom

There is a relation between reductive freedom and degrees of freedom, but at this moment they are not the same. reductive freedom is often *complex* — so, it may not have a number; and reductive freedom is often partial or *imperfect* — for instance, ‘lower level’ emotions can ‘brake into’ ‘higher level’ (cognitive) thoughts. Above all, degrees of freedom are not yet seen as *reductive* freedom; they somehow fit into a reductionist worldview.

8. Emergence: Subverse & Superverse

Neighboring systems together form a *supersystem*.

Supersystems again form a *supersupersystem*, etc...

The emergent structure all the way up, I call a system's ‘*superverse*.’ (In the past I called this an *extraverse*, but that is unclear.)

At a lower level, there is a *subsystem*. The structure, all the way down to the quantum realm, I call a system's ‘*subverse*.’ (earlier I called this an *intraverse*.)

So, each living system (each life) has its *own* subverse and superverse. With *natural* life, each part on every level of emergence, is alive. That is why it is almost impossible to *make* living things. (Also, that is why mathematics is the language of nature.) Our consciousness has this structure this too; probably in order to *mirror* reality ever better. For this it uses *attention*. (whatever you look at, it is always something both in itself and in its surroundings.)

When there is *emergence*, one enters a new realm; a new universe. The subverse is not non-existent, but, because of reductive freedom, it is *absent*. The mind knows nothing about the brain it ‘runs’ in. The mind is largely independent of its ‘hardware’; just like a computer is *made to make software causal*. The other way round, no part of the brain can oversee the brain either.

[II. Energy, Entropy, Exergy, Anexergy]

9. The Logic of Entropy Generation

All these systems, that I speak of, run on *energy*, and they must generate *entropy*.

How can the *effect* or *product*, ‘entropy,’ be a *cause*?

1) In fact the 2nd law implies that forces are *non-stoppable causes*, and thereby everything tends to be explosive or implosive.

2) This will generate heat that, *ultimately*, cannot be converted to other energy. Nature can only *slow down* this entropy generation, through, what I call, *configurational inaccessibility*.

10. Configurational (in)accessibility

The moon ‘wants’ and tries to fall on earth. The earth tries to fall on the sun. That *would* generate an enormous amount of heat and entropy; ...but they cannot do so.

Configurational inaccessibility means that (at macro-level) there arise ever more structures or configurations that *hinder the generation of entropy*. Examples are solar-systems, but, also, plants and animals.

For a chemical process in a solution, an insoluble solid puts itself outside of this system. Such inaccessibility determines the direction of this process.

So, configurational inaccessibility is about *irreversibility*; about configurations becoming *inaccessible* to other configurations.

11. The Logic of Relevant Configuration

At micro-level, a system, as a configuration, consists of *forces* and *relevant differences* (or ‘energy differentials’). ‘Relevant’ refers to *differences* that are relevant to the *forces at hand*. The relevant difference for gravity is distance or height; for electrical charge it is voltage; and for heat or entropy it is temperature.

Emergence: Subverse & Superverse

- etc...
- Supersupersystem
- Supersystem
- **System / Life**
- Subsystem
- Subsubsystem
- etc...



‘**Superverse**’ (Extraverse)

Subverse & Superverse are largely absent

‘**Subverse**’ (Intraverse)

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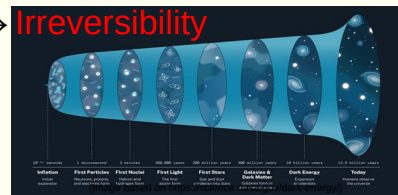
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Configurational (in)accessibility

= Energy or matter *outside* (or *leaving*) a configuration

→ **Irreversibility**



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The Logic of Relevant Configuration

Relevant Configuration



Forces & **Relevant Differences** d_R

Force	Relevant Difference d_R
heat / entropy	temperature
gravity	distance / height
electrical charge	voltage
??? c^2	mass

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Entropy is the classical example for *lack of configuration*; it is *chaos* and *disorder* at micro-level. But, paradoxically, this means that entropy is something 'configurational', because entropy is *energy per absent difference* in temperature, given in J/K; (it has a temperature, but there is nothing with a differing temperature.)

Configurational inaccessibility means that the forces exist, but no energy can be retrieved from them, and no entropy can be generated. (Like a weight can be at a different height, entropy can be at a different temperature. And when its difference (in temperature or height) is zero, then its energy is gone; then, there is no heat-(or-height)-as-energy, even if it has a temperature (or height)! Yet, there still is heat-as-a-force.)

12, 13. General Relative 'Entropy': Anexergy

Any force can be expressed as *energy per relevant difference*, (1 Newton equals 1 Joule per meter, etc.). Any force can *become relatively inaccessible*; think of the orbiting moon (or static electricity, or entropy).

But the word "entropy" refers to *chaos*... Even if I would say 'general entropy', many physicists will think of heat. So, applying "entropy" to any force is confusing.

Another difference is that classical entropy, *ultimately*, is *absolutely inaccessible*; other inaccessibilities are more *relative*.

Accessible energy is called "*Exergy*", so, I shall call these *relatively inaccessible* forces: "*anexergy*", given in *Joule per relevant difference*. And I use "\$" ("*S*"-slash) to denote it. Anexergy is energy *per a relevant difference* that is *relatively inaccessible here and now*. The difference with *potential* energy is this inaccessibility; that the forces are *not within a configuration*. Without inaccessibility, the universe would be a big bang with little structure. Anexergies are like single poles of a battery; when they meet, something happens; in the children's book I compare it to love:-)

Absolutely inaccessible energy, that is, Clausius' entropy, may then be called "*inexergy*".

Inaccessibility can be *relative* in many ways; if a process is even a little more difficult in one direction than in another; then 'an arrow of time' arises. When *relevant* differences become relatively inaccessible, things keep changing almost forever instead of fast & once.

14, 15. Entropy & Kinetic / Internal / Subversal Energy

Entropy is considered to be the only natural force that can be *generated*. (For instance, when you rub your hands they get warm.) By contrast, elementary forces remain forever. But, 'under the hood', heat is *kinetic* energy; moving particles; then, *what, energetically, is the difference between a moon, orbiting its planet, and heat?* Both are a form of anexergy generation! The same is true for other kinds of 'higher level' energy, such a chemical or bio-chemical energy.

The *generation* of entropy or anexergy, is about *making* internal energy *inaccessible*. From the outside, this energy is 'gone'. (except that it is a kind force; entropy may meet entropy with a differing temperature, and then energy is released.) What, inside, is exergy, is anexergy outside.

Since, 'internal' and 'external', in fact, are often metaphors for 'sub' and 'super', we could also speak of *subversal energy*.

I will use this to get at a mathematical definition of the constructal law, but first something else...

16. Intermezzo: Fred Spier: Big History & Flow

The table below is made by [Fred Spier](#). In it, he combines data from [Eric Chaisson](#) (2001) and [Earl Cook](#) (1971). Here, configurations are arranged according to their (internal) power density, which allows for an interesting comparison. (Power density is exergy flow per second through a certain mass; for this, a relevant difference (or "energy differential") must exist. Remark that the raising *human* power density, refers ever more to energy flows *external* to our bodies.)

Notice that *specific configurations only emerge, within a certain range of energy flow and -level*.

Configurations (or complexity) emerge when energy flows through matter. At the start of the Big Bang (first 15 minutes), entropy was at a maximum. Then there hardly was any *difference* in temperature (i.e., no relevant configuration), thus hardly any power per kilogram.

The continuing expansion of the Universe can take up entropy. This alone allows for energy to keep flowing.

General Relative 'Entropy': Anexergy

- **Exergy** = Accessible Energy (J)
- **Anexergy** \$ = Inaccessible Force (J/Δ)
Metaphor: The Single Pole Battery.
- **Inexergy** S = Entropy (J/K)
= Absolutely Inaccessible Heat-as-a-force

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Subversal Energy

Heat
Chemical energy
A moon orbiting
... } **Subversal Energy**

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Historically, the price for a growing complexity is a shorter life span (due to vulnerability). This, according to Spier, raises the question of whether we will become so complex as to drive ourselves to extinction.

Table 1: Energy levels and flows

	Energy levels (temperature, in: K or C)	Power Density Φ_m in: watt/kg		Energy levels (temperature, in: K or C)	Power Density Φ_m in: watt/kg
Our Galaxy	Almost 0 K (interstellar space) up to 3×10^9 K (supernovae)	.00005*	Humanity	20 C up to 30 C (African savanna)	2 (proto-humans)*
Sun	15×10^6 K (core) up to 6000 K (surface)	.0002*		-20 C up to +50 C	5 (advanced gatherer-hunters)**
Earth	150 K (upper atmosphere) up to 7000 K (core)	.0075*			16 (early agriculturists)**
Life	0 C up to 90 C	.05 (plants)*			26 (advanced agriculturists)**
		2 (animals)*			77 (industrial society)
		15 (human brains)*			230 (technological society c.1970)**
					50 (all humankind on average)*

[Fred Spier, How Big History Works: Energy Flows and the Rise and Demise of Complexity, Evolution: Cosmic, Biological, and Social, 2011, 30–65.](#)

[Chaisson E. J. 2001. Cosmic Evolution: The Rise of Complexity in Nature. Cambridge, MA: Harvard University Press.](#)

[Cook E. 1971. The Flow of Energy in an Industrial Society. Scientific American 224: 134–147.](#)

[Christian D. 1991. The Case for 'Big History'. Journal of World History 2/2: 223–238.](#)

[III. The Constructal Law]

17. Disruptive Evolution

In 1990, in his book “The Innovator’s Dilemma”, Clayton Christensen describes, what he calls, “*disruptive innovation*”. Disruptive Innovation describes the process by which a new product or service, that has a new quality, but scores worse at established qualities, eventually displaces established competitors.

In analogy to this, I want to add disruptive evolution to the constructal law.

In terms of Bejan, Christensen in fact says: “There is not only a flow, but there may also be a *potential, new flow*.” For this flow + potential flow, physics already has a term, namely: *Energy*.

Remark: *Before* finding it, the new flow is *anexergy*, not potential energy; the moment you see the configuration, or that the configuration has formed, anexergy (in Joule per absent relevant difference) becomes potential energy (in Joule). A natural example is the 1st arrival of photosynthesis on our planet. It caused oxygen to be generated. This caused much, then existing life to be *extinguished*. Finding a new flow, generally is very successful.

Remark; disruption is possible *because of* anexergy.

Thus, a system may evolve through creating a new flow. Then the constructal law should read: For life to persist in time it must evolve such that it provides easier and greater access to energy, that is, to what flows or can flow.

18. Physical Trying

Life is *persistent* both to *external* pressure and to *internal* disturbances such as *quantum-fluctuations*. But, although persistent, life will *react* to the disturbances or fluctuations. Thus, changes or ‘mutations’ (maybe caused by quantum-fluctuations), in fact, are *tried out* in its *superverse*, such as an ecosystem. This trying itself goes with ups and downs, which is OK since the process of dying gives time for errors.

Trying operates in a ‘super’-hierarchical structure; that is, a structure having a subverse and a superverse. *Trying* is that (the working and *the output of* a system *fluctuates*, while it is able to *evolve* through *feedback*, both (1) superversal or

Disruptive Evolution

- Clayton M. Christensen: *Disruptive innovation*
- **Finding a new flow can be very successful.**
- Flow + Potential Flow = **Energy**
- *For life to persist in time it must evolve such that it provides easier and greater access to **energy**, i.e., to what flows or **can** flow.*

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Physical Trying

- Quantum-fluctuations $\Rightarrow$ reaction $\Rightarrow$ changes (‘mutations’) $\Rightarrow$ **tried out** in or ‘by’ the superverse.
- **Trying is that (the working and output of a system fluctuates, while it is able to evolve through feedback;**
both superversal or ‘top-down’ feedback,
and subversal or ‘bottom-up’ feedback;
 - *superversally like (not) being killed or like (neural) adaption;*
 - *subversally like (not) being exhausted.*

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'top-down' feedback, and (2) subversal or 'bottom-up' 'feedback'; superversally, for example, like (not) being killed or like (neural) adaptation; subversally like (not) being exhausted. (This is a physical definition of trying.)

I think we have to add the notion of "trying" to the constructal law.

19. The Constructal Law Mathematically

Of course, life, as defined by Bejan, runs on exergy, and it needs to dump entropy, but life also has *persistent*, 'internal' (or subversal) energy (U). So, life itself is a form of *anexergy*, just like the orbiting moon and entropy are, and this anexergy is given in Joule per 'made inaccessible', relevant difference (J/Δ). (Bejan and Wagstaff wrote an article on how the formation of solar-systems is a living process.) (The Physics Origin of the Hierarchy of Bodies in Space, 2016, [doi:10.1063/1.4941986](https://doi.org/10.1063/1.4941986))

(At higher levels of emergence these differences do not look like physical differences anymore.)

Thus, we can give a *mathematical* definition of the constructal law: For life not to die, *each of its anexergies must grow*, much like ordinary entropy, but less strict. Dying usually is a process, so it gives time (to turn thing around). This dying has nothing to do with misery; it may be good. Creation needs destruction — like with scientific revolutions.

To, more clearly, allow for *trying* (and for reality), we can include a *maximum allowable dying*. For life to persist, for each of its anexergies, *their lowering must not exhaust their subversally available energy*.

Life uses differences between forces; it annihilates them in external configurations and 'stores' that energy within its own configuration.

In computers and neural networks, information and consciousness are *energetically separated* from their subsystems. That makes these superversa, and their 'energy,' *non-physical*. Subversally, information and consciousness are not without energy, but there is more than enough energy for neurons to work.

20. Smuts: Holism and Evolution (1926)

In 1926, the inventor of "holism", J. C. Smuts wrote his book "[Holism and Evolution](#)."

(The opening quote in his book is from Plato: "That which comes to be, always does so as a whole; so that if a man does not count the whole among realities, he ought not to speak of substance, or of coming-to-be, as real.")

Conform Smuts, life that kills its superverse (he says: 'superstructure'), kills itself.

The deadliest Coronaviruses died out because of killing their living environment; us.

Further more, life that kills its subverse, kills itself too, for instance, if you overwork yourself (or a country at war that is wearing itself out).

21-23. To be Subverse or to be Superverse

The constructal law will be much *more predictive* if it entails the sub- and superverse *explicitly*. It is not enough that the (constructal) law holds for the supersystem; of course it does. The point is, that the superverse matters to the system at hand. This relation is complex. For instance, considering our climate, a 'dead' climate (i.e., no wind, no rain) will kill us, but a too energetic climate will kill us too.

In general, superversal energy must stay within a certain

range (conform Fred Spier); superversal energy must be ever more optimal, and its subsystem must be ever more flexible.

Taken strictly, I think that Bejan's constructal law, only applies in as far as systems are independent. But one may apply the law to the subverse and superverse of a system, as a whole,—that is, to everything, but from the perspective of the system at hand: "For a system and its subverse and superverse (for life) to persist in time (to live) it must regularly try to evolve (with freedom) such that its access to energy is optimal, free, and flexible.

Through cooperation, humans form a superverse. If we act *responsible*, that is, if we account for *reality* and for the existence of our *differences*, and if we *transcend* our ideas again and again, (that is, if we keep *evolving*), then our ideas can form a strong, living supersystem; (with, in fact, no one at the top); a freely evolving cultural system. That could even handle the earths climate. That's the *force of altruism*. The constructal law itself could become part of this supersystem—our culture.

The Constructal Law Mathematically

- life has internal or subversal energy, U (J);
- **!** Outside itself, this life is anexergy, $\$$ (J/Δ).
- **Constructal Law:** $\{\forall \$ \mid \Delta \$ > 0 \Rightarrow \text{not dying}\}$, change of each anexergy must be positive but dying gives time.
- **Constructal Law:** $\{\forall \$ \mid \Delta \$ > -\$ \Rightarrow \text{alive}\}$ ($\Leftrightarrow \{\forall \$ \mid d_{\text{e}} \Delta \$ > -U \Rightarrow \text{alive}\}$).
For life to persist, for each of its anexergies their lowering must not exhaust their subversal energy.

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To be Subverse or to be Superverse

- **!** Life that kills its "superstructure," kills itself.
- Life that kills its subverse, kills itself too.
- **For a system and its subverse and superverse (for life) to persist in time (to live) it must regularly try to evolve such that its access to energy is ever more optimal and flexible.**
- **Responsibility** → we form a strong superverse.
- **Irresponsibility** → we will be in the subverse.
- **For humans to survive, cooperative responsibility must grow.**

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If we are overwhelmed by *méconnaissance*, disinformation, stealing, and force (as is common), then our superverse will be overwhelmed too; *then we are in the subverse*, for instance: in the hands of our climate, or a dictator, or ignorant policy makers.

Beware, that *in predicting when things live, the Constructal Law also predicts their extinction*. For humans to survive they must evolve toward cooperative responsibility. (Our climate will hold us responsible for 7 generations.)

The *logic* of the constructal law itself (working on different levels of emergence) shows how our survival is becoming ever more complex!

(For the moment, unlike viruses, human institutions are good in having someone else pay the price. The constructal law should not be part of their reasoning.)

24. Smuts: Physical Creativeness

J. C. Smuts points to an interesting fact: When complex life reacts to a stimulus or to some internal disturbance, then, in its reaction, one does not so much recognize this stimulus, *but the living complex itself*, as 'personality'.

This is certainly true for our reaction to climate change; we, and our blindness and inflexibility are the problem, not the climate change.

(Inaccessibility and independence are much the same.)

25. An Evolved Constructal Law...

I think evolution can be described in terms of the development of reductive freedom. Then, 'my' constructal laws, *at the moment*, read: "For a system and its subverse and superverse (for life) to stay alive (to persist in time), it must regularly try to evolve its freedom (external, usable freedom (or behavior), and internal freedom (or working)), such that its access to energy is ever more optimal and flexible."

This said, *if* one clearly takes into account a system's subverse and subverse, *then* the original constructal law still is correct. *But this is not clear at all from the law itself*. In fact, to the system at hand, its sub- and superverse is often the most important; its superverse must be as optimal as possible, and its subverse as flexible as possible.

(I think, we have to keep for ever evolving ourselves and society, so as to gain ever more internal energy and freedom, and ever more external flexibility and usability.)

[IV. End]

36. Math & Questions?

The math to the right is, mostly, an experiment to define time and 'speed of change' from entropy and anexergy. It probably is useless, but maybe it inspires someone...

The top equations are the constructal laws.

The next equation is about mass as energy, thus, ultimately as being entropy. In fact, in Einstein's equation, mass is the relevant difference that is used to release energy. This places c^2 in the position of force ! ? ? ?

Next follow the equations about time.

(1) *If* the sum of all anexergies could be 0, then change would go with maximum speed; and

(2) *if* the sum of all anexergies could equal maximum ordinary entropy then time would come to a standstill and nothing would change.

So... maximum possible entropy generation minus all anexergy combined (including the 'generation of' mass), is a measure for 'speed of change.'

Its inverse, then, is a base of time. Taking this (in the superverse) as unit of time, the speed of change does not change.

(On screen is the movie that is on every page in the children's book.)

Smuts: Physical Creativeness

To Smuts an important characteristic of the whole is its creativeness: '... only in wholes does the new emerge ... If an external "cause" is applied ... the organism appears clearly as the real cause, and the stimulus merely as a minor condition or excitation ... the whole process of Evolution is largely a continuous growth towards organic independence and self-regulation; in other words, towards wholeness ... creative movement in time, so different from what one would expect on the second law of thermodynamics ...'

— Holism and Evolution, p139-145

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An Evolved Constructal Law...

- *For a system and its subverse and superverse to stay alive, it must regularly try to evolve its freedom, such that its access to energy is ever more optimal and flexible.*
- *For life to persist in time, it must regularly try to evolve its superversal, usable freedom (or behavior), and its subversal freedom (or working), such that its access to energy is ever more optimal and flexible.*

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$$\forall \$ \Delta | \$ > 0 \Rightarrow \text{not dying}$$

$$\forall \$ \Delta | \$ > -\$ \Rightarrow \text{alive}$$

$$\left. \begin{aligned} S_{m_{\max}} &= E = m c^2 = d_R F \\ \{m \rightarrow 0\} &\Rightarrow d_R = m \end{aligned} \right\} \Rightarrow F_m = c^2$$

$$\text{SpeedOfChange} = \Delta S_{\max} - \sum \Delta \$ \Rightarrow$$

$$\Rightarrow \begin{cases} \Delta \$ = 0 & \rightarrow \text{SpeedOfChange} = \text{maximal} \\ \Delta \$ = \text{maximal} & \rightarrow \text{SpeedOfChange} = 0 \end{cases}$$

$$\text{TimeBase} = \frac{1}{\text{SpeedOfChange}} = \frac{1}{\Delta S_{\max} - \sum \Delta \$}$$