From information to mortality

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Work in progress

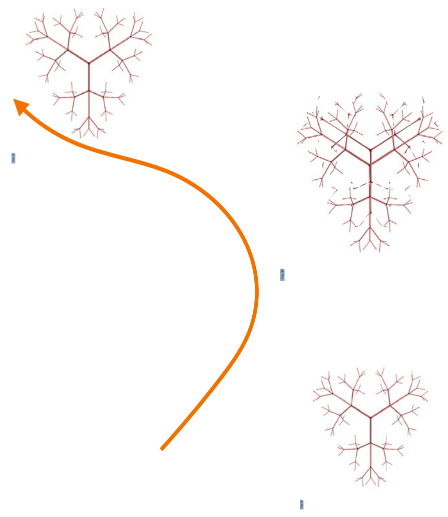
Rate of (endogenous) aging

Denote $I' \equiv \frac{\frac{dI}{dt}}{I}$ as relative change in functional information.

I' can be interpreted as the rate of endogenous aging

Represents the relative intrinsic change in the ability to resist death/destruction, i.e., mortality.

How functional information changes along a world-line



Gompertz-Makeham Mortality Model

Rate of aging determines increase of mortality over age:

$$\mu(I, E, x) = f(I_0 - I_*)\exp\left(-I' x\right) + c(E)$$

Rate of (endogenous) aging

For e.g., a company, c could be more involved

With

- Age $x \equiv t - t_0$
- Environment E
- Functional information at Birth $I_0 \equiv I_{t_0}(A; E)$
- Functional information at (endogenous) age at death $I_* \equiv I_{t_*}(A; E)$
- Functions f and c could be constant functions to set the system's time scale

Gompertz-Makeham Mortality Model

$$\mu(I, E, x) = f(I_0 - I_*)\exp\left(-I^{\prime} x\right) + c(E)$$

In (long-lived) human populations

- $c(E)$ negligible <1/10.000
- $f(I_0 - I_*)$ infant mortality (if modeled from birth); in e.g. DK around 3/1000
- Vaupel's hypothesis: For humans, primates, and maybe mammals and beyond **rate of aging for the individual across time and age is constant.**
- Note on Phase IV (see David): As I approaches I_* it can be assumed that $I^{\prime}$ for the individual accelerates and may approach infinity. Phase IV might stretch over the time it takes from $I^{\prime}$ to accelerate from its constant level to ultimate death

Note on limit to lifespan

$$\mu(I,E,x) = f(I_0 - I_*)\exp(-I' x) + c(E)$$

- Lower limit of minimum mortality not yet reached (Ebeling 2018 Demography) →
- reduction in minimum mortality facilitates persistent lifespan extension because we start aging at constant rate from ever lower minimum mortality (currently reached around age 10 in ”best” places)
- Upper limit of mortality (not lifespan!) given by mortality plateau at $\mu(x) = 0.7$ for x>= 105
- Barbi et al. 2018 Science. Indication that humans approach the plateau at later ages

Individual vs population aging: heterogeneity in individual frailty

Frailty model of mortality

$$\mu(I,x) = f(I_0 - I_*)\exp\left(-I' x\right)$$

Assumes I, I_0, I_* pertain to standard agent *A* in *E*

Assumes individuals differ proportionally w.r.t. this standard agent (Vaupel et al 1979).

Then mortality for individual with frailty z

$$\mu(I,x,z) = z\, f(I_0 - I_*)\exp\left(-I' x\right)$$

Parameter z: frailty, e.g. , gamma distributed; z=1 standard frailty

Average mortality in population with average frailty $\bar{z}$

$$\bar{\mu}(I,x) = \bar{z}\, f(I_0 - I_*)\exp\left(-I' x\right)$$

Frailty model of mortality

Missov and Vaupel (2015) SIAM find that the only model that fits the data at ages above 90 for humans is exponentially rising individual mortality with gamma distributed frailty.

Frailty model of mortality: best guesses for the rate of aging given current results

Mortality for individual with frailty z

$$\mu(I, x, z) = z\, f(I_0 - I_*) \exp\left(-I' x\right)$$

- I' at any t constant across ages at about -0.16 for the individual
- I' for a cohort constant across ages at about -0.14 for the individual (note: continuous improvement in conditions over time, so E changes)

Mortality for population with population frailty $\bar{z}$

$$\bar{\mu}(I, x) = \bar{z} f(I_0 - I_*) \exp\left(-I' x\right)$$

- I' changes over time and age. Today it is about -0.12 between ages 30 to 90. Levels off and approaches 0 at around 105 with mortality=0.7.

Relative change in functional information, $\boldsymbol{I}'$

From David: Functional information for agent A in environment E at time t.

$$I_t(E;A) = H_t(E) - H_t(E|A)$$

With

$$H_t(E|A) = H_t(E,A) - H_t(A)$$

Inserting for the conditional entropy above gives

$$I_t(E;A) = H_t(E) + H_t(A) - H_t(E,A)$$

The change in I over time is given by

$$\frac{d\,I_t(E,A)}{dt} = \frac{dH_t(E)}{dt} + \frac{dH_t(A)}{dt} - \frac{dH_t(E,A)}{dt}$$

Assume E does not change over time, then dH(E)/dt=0

If E changes to a new level E', treat it as a discrete shift, after which E' again is constant. Then similar equations just for different regimes of E.

$$\frac{d\, I_t(E,A)}{dt} = \frac{dH_t(A)}{dt} - \frac{dH_t(E,A)}{dt}$$

Functional information rises during Phase I, as the change in $H_t(A)$ outpaces the change in $H_t(E,A)$.

$\frac{dH_t(A)}{dt}$ Repair, Regeneration, Growth, Development $\equiv R(I)$

$\frac{dH_t(E,A)}{dt}$ Damage, Decay, Disalignement $\equiv D(I)$

How does I_t change during phases II and III?

$$\frac{dI_t(E;A)}{dt} = R(I) - D(I)$$

If loss of information is proportional to information, one may assume that

$$D(I) = \delta I$$

If $R(I) = 0$, then information decays exponentiall$y$ at a constant rate

$$\frac{\frac{dI_t(E;A)}{dt}}{I} = -\delta$$

Similarly, if $R(I) = r\ I$, then information decays exponentiall$y$ at a constant rate

$$\frac{\frac{dI_t(E;A)}{dt}}{I} = r - \delta$$

Constant rate of aging hypothesis in humans, primates, and likely other species

How does I_t change during phases II and III?

If repair is not proportional to I and $R(I) > 0$, then system decays slower than exponentially or improves

If system decays faster than exponentially, then cascading failure may cause violation of proportionality assumption, initiating Phase IV.

The order balance

How R and D relate to I depends on the system.

In organisms, I might closely relate to size and structure, but also includes cognitive functioning, learning, hierachy etc.

What are reasonable assumptions about $R(I)$ and $\mathrm{D}(I)$ being proportional to $I^{(-?)n}$ with $n =, <, or > 1$ for what system?

…work to do