**Extract from http://jli.di.unimi.it/**

**Courtesly from G.Prini**

**Observation** - ***Evolutionism*** (ital. ***evoluzionismo***) has a multimillenial history. It's well known that ideas similar to those attributed to Darwin (1859) had been independently developed by Wallace (1855). Conversely, it's less known that the evolutionary theory as currently taught in schools (which we call "orthodox", in the sense that it does not consider the issues referred to in the Observation at the end of this page) is not due to Wallace-Darwin alone. In the first edition of his *opus magnum,* Darwin didn't provide a solution to the problem of the ***blending*** (ital. ***mescolamento***) of the inherited characteristics, which over time would tend to produce increasingly similar individuals -- and no evolution whatsoever can exist without differentiation. In one of the book's subsequent editions, Darwin tried to overcome this problem by introducing the controversial (and discredited) theory of ***gemmulae*** (ital. ***gemmule***), which -- according to Darwin -- were capable of transmitting the characteristics acquired by the individuals over time, thearby recovering some of the ideas put forward by Lamarck (1809) several years previously. It was only when the works of Mendel (1865) were rediscovered by DeVries (1901) that the conceptual gaps in Darwin's theory were filled. Therefore, the resulting theory, which is now called ***neo-Darwinian synthesis*** (ital. ***sintesi neodarwiniana***), should be (more appropriately) called "Wallace-Darwin-Mendel-DeVries' synthesis". [For a recent development of neo-Darwinism, which again recovers some of Lamarck's ideas, see the already-cited Observation ath the end of this page.]

**Question** - Is it possible to manufacture ***evolutionary*** (ital. ***evolutivi***) artificial systems patterned after the mechanisms of the neo-Darwinian synthesis?

**Observation** - The main characteristics of the neo-Darwinian synthesis are the following:

- two main factors allow innnovations to be introduced into the individuals' genome
    - at the individual's birth
        - synthesis of new chromosomes that inherit (*pro rata*) the characteristics of the mother's and the father's genome
    - during the individual's lifetime
        - duplication (copying) errors of the genome during cell reproduction
        - mutations of the genome induced by exogenous factors (e.g. cosmic rays, radiations generated inside/outside the body, etc.)
- two factors influence the survival of a gene over time
    - genetic factors
        - the higher or lower probability for the gene bearers to reach the reproduction age (with respect to the other individuals of the same species)
        - the higher or lower number of offsprings of the gene bearer (with respect to other individuals of the same species)
    - environmental factors
        - the higher or lower probability of the gene bearer to survive in the environment it lives in

An **unavoidable statistical consequence** of the above factors is the phenomenon known as ***natural selection*** (ital. ***selezione naturale***), also known as ***selective survival*** or ***survival of the fittest*** (ital. ***sopravvivenza selettiva*** or ***sopravvivenza del piu' adatto***). The result is that some genes (those belonging to individuals with the highest survival probability) are transmitted to the individual's descendants generation after generation, while the others are lost at the death of their last bearer (although they can be "recreated" later on in some individual, thanks to copying errors or exogenous mutations, etc).

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**Observation** - The fact that selective survival is an "unavoidable statistical consequence" of the above factors does not necessarily imply that it is the only evolutionary mechanism at work. In particular, selective survival is perfectly compatible with a creationist hypothesis, whether of natural or supernatural

("divine") origin. Also, there might be some additional mechanism at work that hasn't yet been discovered -- or that is just being discovered (see the cited Observation at the end of this page for a plausible candidate).

**Exercise 1** - Compare the (illogical) inference "*natural selection exists, hence it is unique*" -- meaning that it's the only evolutionary mechanism at work -- with the (illogical) Galilaean inference "*such is what I see, therefore such the world is*". Compare this (illogical) Galilaean inference with Bellarmino's objection "*such is what I see, but not necessarily such the world is*", and devise a "Bellarminian" objection to the above (illogical) inference about the uniqueness of natural selection.

**Exercise 2** - In "*Life of Galileo*" by Bertold Brecht, at some point Cardinal Bellarmino asks Galileo: "*Before I look through your telescope, answer this question: are those stars necessary?*" Discuss this sentence in the context of Exercise 1.

**Warning** - The problems introduced with Exercise 1 and Exercise 2 should be discussed in a purely logico-formal context, disregarding any aspects related to religion or philosophy (except for the fact that Bellarmino's position assumes the existence of "a" metaphysics -- a philosophical concept).

**Observation** - A modern "Galilaean" scientist would probably set aside the problem of the existence of "a" metaphysics by stating: "*In my physicist's job, I limit myself to theorize about what I happen to see: I'm not supposed, nor do I intend, to theorize about anything else*".

**Warning** - Not every self-poclaiming "Galilaean" scientist is truly "Galilaean" (in fact most scientists are not...).

**Exercise 3** - Analyze Osiander's introduction to Micolaj Kopernik's "*De revolutionibus orbium coelestium*" from the perspective of Exercise 1 and the subsequent Observation.

***Genetic programming*** (ital. ***programmazione genetica***) provides a positive answer to the question asked at the beginning of this lecture ("*Is it possible to manufacture evolutionary artificial systems patterned after the mechanisms of the neo-Darwinian synthesis?*").

**Example** - Consider a robotized vacuum-cleaner capable of cleaning "all those little corners" (i.e. all the tiles next to a wall) in an idealized, unfurnished room (Figure 1). Consider the problem of writing a computer program (satisfying this requirement, to be executed by the robotized vacuum-cleaner) in a language where the following "sensor" functions are defined

- (nw) = 1 if sensor $s_1$ detects a free tile, 0 otherwise
- (n) = 1 if sensor $s_2$ detects a free tile, 0 otherwise
- (ne) = 1 if sensor $s_3$ detects a free tile, 0 otherwise
- (e) = 1 if sensor $s_4$ detects a free tile, 0 otherwise
- (se) = 1 if sensor $s_5$ detects a free tile, 0 otherwise
- (s) = 1 if sensor $s_6$ detects a free tile, 0 otherwise
- (sw) = 1 if sensor $s_7$ detects a free tile, 0 otherwise
- (w) = 1 if sensor $s_8$ detects a free tile, 0 otherwise

along with the following "actuator" functions

- (north) = move the robot one tile northwards, if such a move is feasible (i.e. if no wall obstructs the move), otherwise leave the robot where it currently is
- (east) = move the robot one tile eastwards, if such a move is feasible (i.e. if no wall obstructs the move), otherwise leave the robot where it currently is
- (south) = move the robot one tile southwards, if such a move is feasible (i.e. if no wall obstructs the move), otherwise leave the robot where it currently is
- (west) = move the robot one tile westwards, if such a move is feasible (i.e. if no wall obstructs the move), otherwise leave the robot where it currently is

and the following Boolean functions

- (AND x y) = 0 if x=0, otherwise y
- (OR x y) = 1 if x=1, otherwise y
- (NOT x) = 0 if x=1, otherwise 1
- (IF x y z) = y if x=1, otherwise z
- (0) = 0 (constant function with no arguments)
- (1) = 1 (constant function with no arguments)

**Example** - A program whose repeaded ***execution*** (ital. ***esecuzione***) makes the robot move according to the given specifications is shown in Figure 2.

**Exercise 4** - Why is it that in the above sentence the indeterminative article "a" has been used, instead of the determinative article "the"?

**Observation** - By combining the above functions in all possible ways, an infinite quantity of programs can be created. Most of them would be completely "meaningless", but some of them (at least the one shown in Figure 2) can make the robot move in a "meaningful" way.

For any given program, let's define its ***fitness degree*** (ital. ***grado di adeguatezza***) as the number of tiles next to a wall that the robot will visit in a predefined number (e.g. 10) of ***runs*** (ital. ***corse***), starting from a corresponding number of initial positions taken at random, where by "run" we mean a predefined number (e.g. 60) of "moves" (i.e. successive executions of the given program).

**Observation** - The maximum attainable adequacy in the case of Figure 1 is 320 (a maximum of 32 tiles -- next to a wall -- visited for each of the 10 runs).

Let us now build a sequence of sets $G_0$, $G_1$, ... , $G_n$, that we call ***generations*** (ital. ***generazioni***), as follows:

- $G_0$ = a set containing a number (e.g. 5000) of programs taken at random among all the infinitely many programs one can write
- $G_{n+1}$ = a set given by the union of the three sets $S_{n+1}$, $C_{n+1}$ e $R_{n+1}$, where:
  - $S_{n+1}$ = a number of programs (a fixed percentage $s$ with respect to $G_n$) chosen by means of an equivalent number of ***tournaments*** (ital. ***tornei***) between a given number $t$ of programs in $G_n$, wherefrom the "winner" is chosen as the most adequate program found in each group (i.e. tournament)
  - $F_{n+1}$ = a number of programs (a fixed percentage $f$ with respect to $G_n$), obtained by ***crossover*** (ital. ***incrocio***) starting from an equivalent number of pairs of programs in $G_n$, whose members, the ***father*** and the ***mother*** (ital. ***padre*** and ***madre***), are each selected by means of a tournament as above, and where by "crossover" we mean the replacement of a fragment (taken at random) of the mother program by a fragment (also taken at random) of the father program (Figure 3)
  - $R_{n+1}$ = a number of programs (a fixed percentage $r$ with respect to $G_n$), obtained by ***mutation*** (ital. ***mutazione***) of an equivalent number of programs chosen by means of tournaments as above, where by "mutation" we mean the replacement of a fragment (taken at random) of each program by a new fragment generated afresh (at random)

**Observation** - Some suggested values for the fixed percentages mentioned in the definition above are $s$=0.1 ($s$=10%), $r$<0.01 ($r$<1%) e $f$=(1-$s$-$r$), with $t$=7 for the number of "participants" in each tournament.

For each generation $G_n$, the adequacy of all programs (belonging to that generation) is computed. The process terminates if and when a program is generated which attains the maximum possible adequacy.

**Example** - The "most adequate programs" in generations $G_0$, $G_2$, $G_4$ and $G_{10}$ obtained by putting the previous mechanisms at work (one of the infinitely many possible outcomes, due to the fact that there are many random processes/choices going on) are respectively found in Figure 4, Figure 5, Figure 6 and Figure 7, while the adequacy of the "best" program for each generation is mapped in Figure 8.

**Observation** - Note that an (apparent) risk of incurring an "evolutionary dead-end" is found between $G_4$ e $G_7$, (perhaps) due to a sort of ***genetic drift*** (ital. ***deriva genetica***). The smaller the population, the higher the risk of incurring a "dead-end" (i.e. reduced genetic diversity).

**Observation** - According to some authors, the neo-Darwinian synthesis does not fully explain the origin and evolution of life (as we know it) in such a "short" time period as the estimated age of the earth (4.5 billion years). See e.g. McFadden (2000) and McFadden & al-Khalili (2014) -- the latter also available in a (highly accurate) Italian translation (2015) -- for a (controversial) theory that resorts to quantum phenomena to explain some ***preferred mutations*** (ital. ***mutazioni preferenziali***) observed in *Escherichia coli* (*E. coli*). For the time being, there does not seem to exist an extension of genetic programming aimed at incorporating preferential mutation mechanisms into its core techniques (a theme that someone might be willing to explore in a course-end paper, or perhaps in a master's thesis)