

# Von Neumann's Quintessential Message: Genotype + Ribotype = Phenotype

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**Abstract** In this short article we argue that von Neumann's quintessential message with respect to self-replicating automata is genotype + ribotype = phenotype. Self-replication of his universal constructor occurs in analogy to nature: The description (genotype) written on the input tape is translated via a ribosome (ribotype) so as to create the offspring universal constructor (phenotype).

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structor

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In 1958, one year after John von Neumann's death, two major events took place in the history of molecular biology: First, Francis Crick, one of the discoverers of the DNA double helix, put forward what he called the *central dogma* of molecular biology: Proteins are not made directly from genes—there must be an intermediary between them, and this intermediary is RNA [2]. DNA (deoxyribonucleic acid) contains the information needed by a biological organism to carry out its functions. For example, in the case of a multicellular organism, this includes the information needed for the organism to differentiate, thereby growing from a single cell (the zygote) to a mature multicellular entity, to reproduce, and finally to die. This information is transcribed from DNA—by enzymes—to generate another class of molecules called ribonucleic acids (RNA). From there, it is translated to generate specific proteins, which are the molecules that underlie the cell's daily activities. Thus, DNA is the *carrier* of information, RNA is the *messenger*, and protein is the *executor* (with apparently but few exceptions).

In short, the central dogma prescribes that (Figure 1) DNA gives rise to RNA (transcription process), after which RNA gives rise to proteins (translation process). Second, Roberts [3] coined the term *ribosomes* to denote those elements that decode the genetic information, that is, translate the RNA string—a one-dimensional chain of nucleotides—so as to produce the appropriate protein—a three-dimensional structure of amino acids.

In his provocative book *The Semantic Theory of Evolution* [1], Marcello Barbieri made the following observations:

- The role of ribosomes in molecular biology has been significantly underestimated.
- In every cell the majority of nucleotides are devoted to the production of ribosomes.
- “Nature had to invent the most sophisticated molecular machine that has ever been assembled. The ribosomes are its crown jewels, the ultimate result of all the molecular engineering that Nature has put into life.” (p. 75)

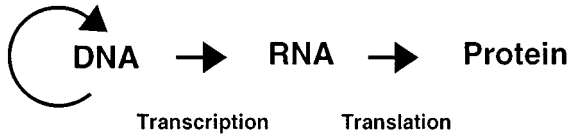


Figure 1. The central dogma of molecular biology.

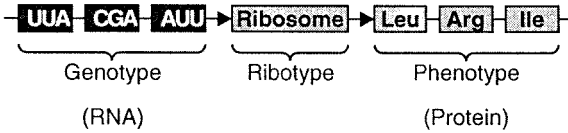


Figure 2. The trinity genotype-ribotype-phenotype.

- Finally, Barbieri proposed a new theory of evolution, based on the trinity genotype-ribotype-phenotype (Figure 2).

Ribosomes are capable, in general, of translating RNA chains of any length into proteins; in particular, they are capable of decoding a specific RNA string, the ribosomal RNA, producing an exact copy of the ribosome itself—an archetypical self-replication process (Figure 3).

Von Neumann’s visionary work [4], carried out in the late 1940s, predates that of Crick, Roberts, Barbieri, and other biologists. We hold that his basic message with respect to self-replicating automata concerns the underlying architecture of the *universal constructor*—which is none other than the artificial version of the biological ribosome. One can discern the genotype-ribotype-phenotype trinity in von Neumann’s cellular-automaton world (Figure 4a):

- The genotype is the (input) tape of the automaton, containing the description (genome) of the machine to be built.
- The ribotype is the universal constructor itself.
- The phenotype is the ultimate construction, in the cellular space, of the machine described on the tape.

Self-replication of the universal constructor occurs in analogy to nature (Figure 4b): The description (genotype) written on the input tape is translated via a ribosome (ri-  
botype) so as to create the offspring universal constructor (phenotype).

To conclude, we maintain that von Neumann’s quintessential message is

$$\text{Genotype} + \text{Ribotype} = \text{Phenotype.}$$

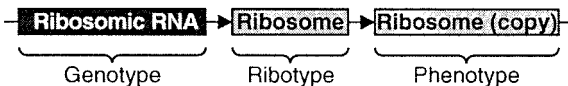


Figure 3. Self-replication of the ribosome.

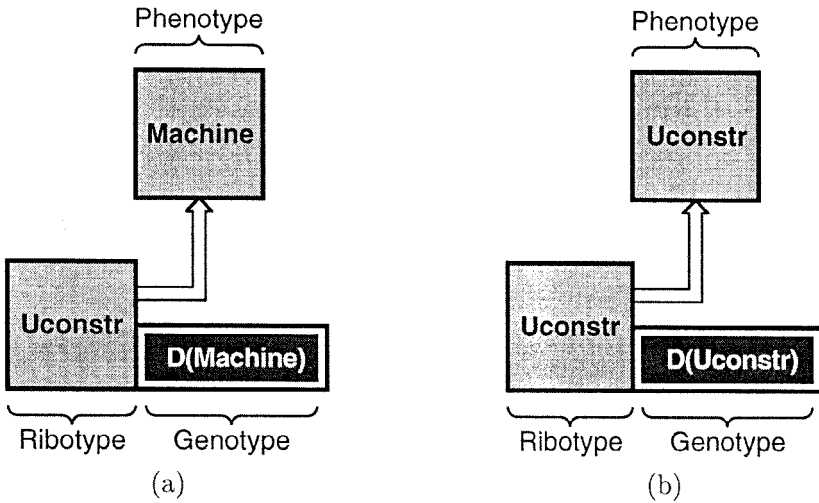


Figure 4. (a) Von Neumann's universal constructor within the genotype-ribotype-phenotype framework. (The universal constructor is a machine capable of constructing, through the use of a "constructing arm," any configuration whose description can be stored on its input tape.) (b) Self-replication of the universal constructor.

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