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Irreversible Dynamics.
Productivity, Quality, Technology, Well-Being and Artificial Intelligence Combinatory Systems

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ABSTRACT

This study examines the dynamics of five irreversible phenomena — the continuous increase in Productivity, Quality, Technology, Well-being, and Artificial Intelligence— which, having begun at the dawn of civilization, are still active today after millennia and are accelerating through mutual interaction. These phenomena both derive from and drive scientific and technological progress, which in turn accelerates the improvement and enhancement of Artificial Intelligence systems and the spread of Robots. To explain these irreversible dynamics — which could also be defined as "natural" — I will draw upon *Combinatory Systems Theory*, which I have developed (Mella, 2017, 2025) and, in my view, offers a logical simplicity and a convincing explanatory framework grounded in observation. Indeed, Combinatory Systems Theory provides effective models for representing and interpreting "collective" phenomena and their effects (macro-effects), which, on the one hand, are the consequence of individual behavior (micro-behavior) and, on the other hand, influence individual decisions, encouraging individuals to persist in — if not intensify — their micro-behavior. One of the most notable examples can be observed in collectivities when an expansion of "collective progress" occurs, as the result of the "individual improvement" pursued by the individuals composing that same collectivity. Among the many interesting dynamics produced by various kinds of Combinatory Systems, I would emphasize the logic underlying increasing productivity, quality, technological progress, well-being", and "artificial intelligence, AI". To make the understanding of these systems easier, it is appropriate to briefly recall both the principles underlying Combinatory Systems Theory and the simple heuristic graphical models used to represent (and compare) them according to a common framework.

Questo studio esamina la dinamica di cinque fenomeni irreversibili — l'aumento continuo della Produttività, della Qualità, della Tecnologia, del Benessere e dell'Intelligenza Artificiale — che, essendo iniziati all'alba della civiltà, sono ancora attivi oggi dopo millenni e stanno accelerando attraverso l'interazione reciproca. Questi fenomeni derivano e guidano il progresso scientifico e tecnologico, il che a sua volta accelera il miglioramento e il potenziamento dei sistemi di intelligenza artificiale e la diffusione dei robot. Per spiegare queste dinamiche irreversibili — che potrebbero anche essere definite "naturali" — attingerò alla *Teoria dei Sistemi Combina-tori*, che ho sviluppato (Mella, 2017, 2025) e che, a mio avviso, offre una semplicità logica e un quadro esplicativo convincente basato sull'osservazione. Infatti, la Teoria dei Sistemi Combinatori fornisce modelli efficaci per rappresentare e interpretare fenomeni "collettivi" e i loro effetti (macro-effetti), che, da un lato, sono la conseguenza del comportamento individuale (micro-comportamento) e, dall'altro, influenzano le decisioni individuali, incoraggiando gli individui a persistere — se non intensificare — il proprio micro-comportamento. Uno degli esempi più notevoli si può osservare nelle collettività quando avviene un'espansione del "progresso collettivo", come risultato del "miglioramento individuale" perseguito dagli individui che compongono quella stessa collettività. Tra le molte dinamiche interessanti prodotte dai vari tipi di Sistemi Combinatori, sottolineerei la logica alla base dell'aumento della produttività, qualità, progresso tecnologico, benessere" e "intelligenza artificiale, IA". Per facilitare la comprensione di questi sistemi, è opportuno ricordare brevemente sia i principi alla base della Teoria dei Sistemi Combinatori sia i semplici modelli grafici euristici utilizzati per rappresentarli (e confrontarli) secondo un quadro comune.

Keywords: Combinatory System, Synergetics, cellular automata, allelomimesis, stigmergies, agent-based systems, combinatory automaton, break the record, increasing productivity, increasing quality, scientific and technological progress, survival and evolution, expansion and spread of AI and Robots

1 – Theoretical framework. The modus operandi of Combinatory Systems

From the moment Thomas Schelling, in his famous *Micromotives and Macrobehavior* (1978), attempted to provide a logical explanation for the collective macro-behavior displayed by supposedly intelligent agents, and John Conway discovered the fascinating world of *Life*, described and popularized by Martin Gardner (1970), the study and simulation of the behavior of collectivities has become a fruitful field of research.

It is sufficient to observe the world around us "from a certain height" to become aware of the presence of "collectivities" of individuals (more generally, of entities); that is, sets of "agents" of some kind which, although displaying specific differences and operating autonomously, without direct connections or organization, generate collective phenomena that persist over time, as if directed by an "invisible hand" acting to produce an emergent collective phenomenon.

Such collectivities and the emergent phenomena connected with them can be described or explained — and therefore understood — through the Combinatory Systems model, which is as simple as it is general. *Combinatory Systems Theory* represents a new tool for the observation of collective phenomena, a new form of *Systems Thinking* (Mella, 2012) that applies to all fields: biology, medicine, ecology, economics, social and political action, education, and the professions, to mention only a few.

A combinatory system is a collection of relatively similar, unorganized agents — such as people, animals, or bacteria — that individually perform comparable small-scale actions (micro-behavior) and produce corresponding local effects (micro-states). When these individual actions combine, they generate a larger, emergent macro-behavior at the collective level. This overall behavior is not pre-programmed into the individual agents but arises from the group as a whole, which can therefore be treated as a unified system, and thus as a Combinatory System.

The collective behavior then influences the future actions (micro-behavior) of the individual agents. This ongoing two-way interaction between individual (micro) behavior and collective (macro) behavior is called *micro-macro feedback*. This interaction is both necessary and sufficient for a combinatory system to exist because it preserves the system's macro-behavior over time while continuously reshaping the actions of its individual components.

Combinatory Systems generally begin "*by chance*", but once activated they sustain their dynamics through the "*necessity*" of agents to modify their individual behaviors, thereby producing — through the recombination of these behaviors — the dynamics of the collectivity itself.

Combinatory Systems can produce many significant phenomena, including the following four: the accumulation of objects, the spread of features or information, the pursuit or exceeding of a limit, and the attainment and maintenance of an order among the agents' micro-behaviors. These are different phenomena that appear to originate *randomly* yet develop into an inevitable and often irreversible dynamic through the combined action of "chance and necessity", in the sense described by Jacques Monod in his celebrated work *Chance and Necessity (*1970). There is a very relevant fifth effect that includes the others: the *interdependent dynamics of individual improvement and collective progress* in the collectivity's overall state (defined appropriately). Between the micro- and macro-behaviors there exists a *micro-macro feedback* that produces joint growth in the micro- and micro- behaviors.

The action of *micro-macro feedback* transforms these collectivities into genuine *autonomous systems*, which can be observed as unified entities despite the multiplicity of their constituent agents. *Micro-macro feedback* arises and persists over time through the action of "*necessitating factors*", which compel agents to adapt their micro-behavior to the macro-behavior of the system. The feedback is maintained through the work of "*recombining factors*", which lead the collectivity to recombine individual micro-behaviors, or micro-effects, in order to generate and preserve the macro-behavior, or macro-effect (Mella, 2025, Sect. 1.1.3).

The operational logic of Combinatory Systems can be easily understood through the simple yet emblematic example of the class of *Systems of Pursuit*, which produce a behavior consisting in the gradual movement of the system toward an objective, as if the system, considered as a single entity, were pursuing a goal or attempting to move toward increasingly "advanced" states.

We have all experienced the annoying buzz that forms in an enclosed space: in restaurants, during conferences, and sometimes even in cinemas or theaters while a performance is taking place. It is a general phenomenon generated by the volume of the voices (micro-effect) of the many individuals present when they talk to one another (micro-behavior). In a closed environment, voices are not dispersed as they would be in an open space; instead, they are "recombined", thus producing a more or less intense "buzz". This buzz can be amplified or dampened by the distance between speakers, the shape of the room, the covering of the walls, or other environmental factors (*recombining factors*).

But why do people begin speaking more loudly (micro-behavior)? Because the *buzz* itself — which represents a *global* source of information directed at every speaking agent — prevents them from being heard (*necessitating factor*). Consequently, they must speak at a number of decibels higher than the buzz in order to be understood. This becomes the *minimum threshold* that must be exceeded for communication to occur. At this point, *micro-macro feedback* begins to operate. If an individual's vocal level is insufficient (communication gap), each agent, in order to communicate, must *raise the volume of his or her voice*. This inevitably results in an *increase in the overall buzz* (macro-systemic dynamic), which in turn forces everyone present, if they wish to be heard, to raise their voices even further (*necessitating factor*).

The action of the *micro-macro feedback* continuously intensifies the buzz, compelling people to speak louder, which further increases the buzz, which again forces people to raise their voices, and so on, as part of a "reinforcement loop". This process drives the noise level toward the maximum limit of tolerance (constraint). Once this limit is reached, everyone stops talking, at least for a few moments. After that, the buzz gradually begins to rise again, as most of us have personally experienced at least once. It almost appears as though all the speakers are acting together to adjust their vocal levels, as if the *global information*—the *buzz* itself—were forcing them to "synchronize" their micro-behavior.

2 – A brief review of the literature

Combinatory Systems do not lend themselves to *representation and interpretation* through the logic of "traditional" systems — that is, the logic of *organized systems* — but can instead be studied and understood according to the new theory proposed here. Many of these collective systems are usually examined within the framework of *complex systems theory*, as developed by Murray Gell-Mann (1994, 1995), or through simulations (Gilbert & Doran, 1994), often with the aid of cellular automata, such as those discussed by Thomas Schelling (2006) and Martin Gardner (1970).

Complex systems, composed of a multiplicity of elements interacting without centralized coordination (Mella, 2026), are also the subject of study in *synergetics*, a discipline founded by Hermann Haken (1977, 1983). Haken describes synergetic systems as systems whose various components become ordered as if guided by an "invisible hand", while at the same time it is precisely the individual systems themselves that create this invisible hand, which Haken calls the "order parameter" (Haken, 1983, p. 17). The study of complex systems can be approached by analyzing the process behind the formation and evolution of "patterns". A pattern is, in fact, a property of the system as a whole, but not a property of its individual components; it allows the global description of the system to be abbreviated in comparison with a complete listing of the descriptions of all its parts (NECSI online; Stacey, 1995).

Such studies provide an *external* description of the behavior of collective systems but do not bring to light the conditions, factors, and rules that generate the *feedback* between the *micro- and macro-behavior*. The Theory of Combinatory Systems, by contrast, offers an *internal* interpretation, emphasizing the operational mechanisms that "justify" the behavior of such systems. In particular, this theory interprets, incorporates, and generalizes the *allelomimesis* and *stigmergy* approaches to the ordered behavior of biological collectivities, especially in the attempt to explain *systems of diffusion and order*. The *allelomimesis* approach (Juanico et al., 2003) is especially relevant for the study of systems composed of "social animals", such as bees, ants, and termites, which behave as agents within combinatory systems.

> For example, one bird takes off, those near it also take off, and very quickly the whole flock has taken off. Recruitment in social insects is another classical example, in which one forager discovers an important food source, recruits inactive foragers in the nest to go to it, which in turn recruit still more foragers. Allelomimesis is by definition autocatalytic, in that if I do as others, then others do as I, and we all end up doing the same thing. Another term for this is positive feedback, and we shall use the three terms rather indiscriminately. … [They] all refer to the idea that the probability of an individual adopting a particular behaviour or state is an increasing function of the number of individuals already exhibiting that behaviour or state (Deneubourg & Goss, 1989, p. 296).

The *stigmergy* approach, introduced by Pierre-Paul Grassé (1960), interprets the coordination observed in social animals — particularly termites and ants — as the result of their own micro-behavior, which lead to the release of "pheromones" as micro-effects. The combination of these micro-effects, understood as the accumulation of the quantity of pheromones released (after subtracting the portion that disappears over time), represents the self-produced global information that guides the insects' subsequent *micro-behavior*, which together generate the corresponding macro-effects (Dorigo et al., 2000, p. 852). Note: for a more extensive biological review, see Mella, 2025, Section 1.2.

3 – Models to understand the modus operandi of a Combinatory System

To understand collective phenomena, it is necessary to construct a model capable of representing, in a simple and clear way, the operational mechanisms of the combinatory systems that generate those phenomena and how the *micro-macro feedback*, on which both the micro- and macro-behavior depends, develops and operates.

Combinatory systems can be represented through models of different kinds and increasing levels of complexity.

DESCRIPTIVE MODELS. The simplest are *descriptive models*, which identify — in lexical language — the fundamental elements necessary for understanding the operational logic of the combinatory system, as outlined in the preceding sections. In particular, such models must specify what is meant by micro- and macro-behavior, the initial impulse, the micro- and macro-effects, the necessitating factors, and the recombining factors. Above all, they must highlight how micro-macro feedback operates. Finally, they may also indicate different forms of reinforcement or weakening, as well as possible mechanisms of control.

The model in Figure 1 represents the *general structure* of any Combinatory System.

HEURISTIC MODELS. *Heuristic models* are more interesting, as they seek to simulate the system's dynamics by explicitly — or by constructing *ad hoc* — some simple *operating rules* that must be followed by both the *basic elements* of the system, to carry out their micro-behaviour (*micro* rules or *necessary* rules), and the *system* as a whole, in terms of its *macro* or *recombining* rules. These rules must be necessary and sufficient, in the sense that their combined action must generate the micro–macro feedback that allows the system to develop its own dynamics, thereby producing the observed phenomena. The individual elements that make up the system's *base* do not necessarily need to be aware of these rules; nevertheless, they must simulate the system's modus operandi as closely as possible. In particular, heuristic models must specify the following elements:

– *MICRO-BEHAVIOR* = *NECESSITATING FACTOR*

– *MACRO- BEHAVIOR* = *RECOMBINING FACTOR*

–*MICRO-MACRO FEEDBACK*

– *CONTROL* = *STRENGTHENING AND WEAKENING ACTIONS*

The HEURISTIC MODEL (as well as the verbal one) should always be accompanied by a graphical one that describes all the characteristic elements that justify the behavior of the system and of its component agents..

> Heuristic approaches to system modelling include methods and techniques that, even without definitive validation, can help identify, uncover, or suggest the qualitative and quantitative features of real systems. Although these approaches may not be fully verifiable or empirically proven, they can still play an important role in developing practical and reliable system models. Their defining characteristic is the absence of a solid theoretical foundation, which means they often rely heavily on intuition, judgment, and subjective interpretation. (Sandquist 1985, p. 269).

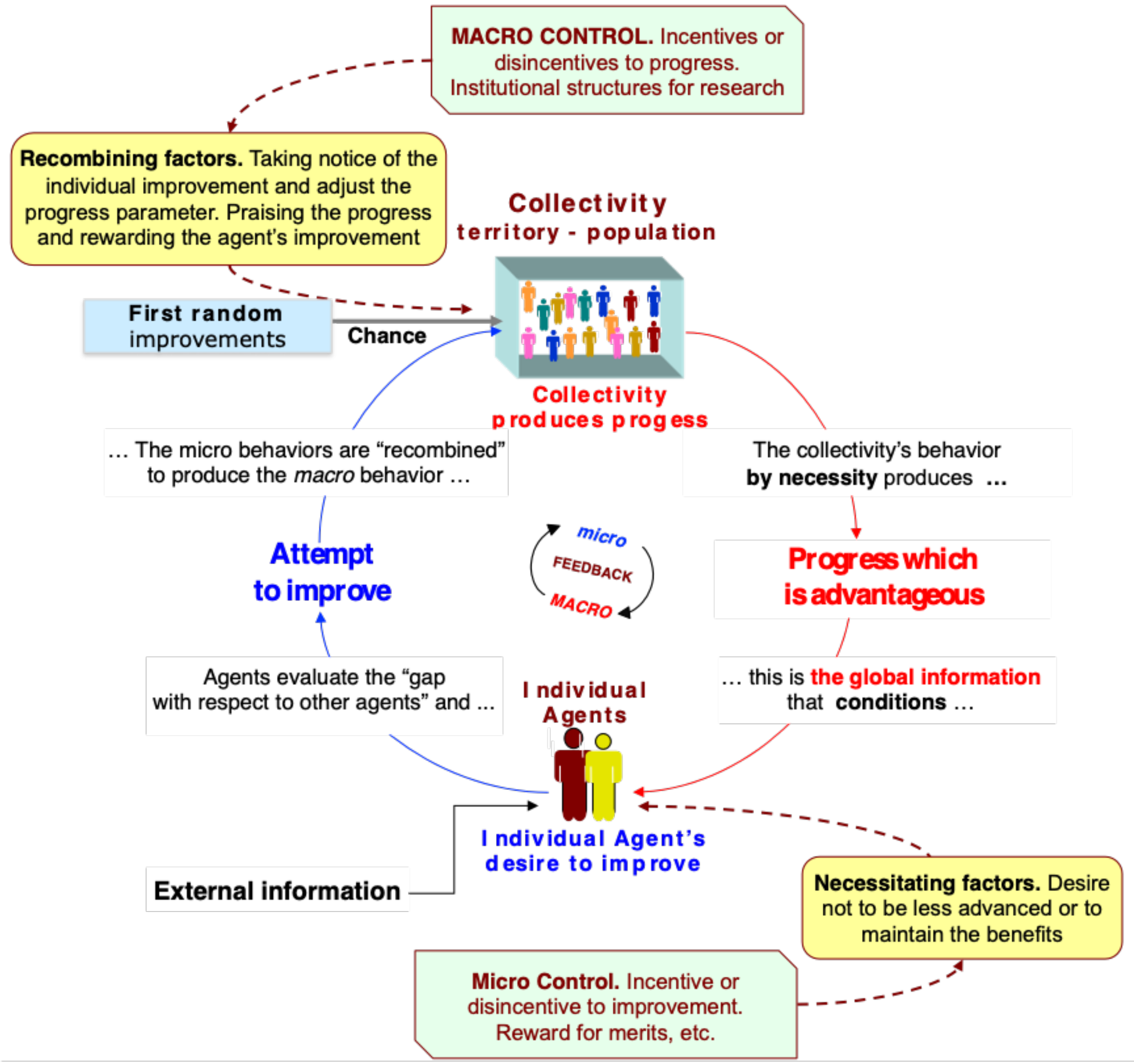

Fig. 1 – General structure of a "Combinatory System"

COMBINATORY AUTOMATA. Finally, it is possible to construct *mathematical and statistical simulation models* which, by providing a formal representation of Combinatory Systems, make it possible to simulate — also in probabilistic terms — the *dynamics* of the macro- and micro-behavior and/or the macro- and micro-effects.

Among the various *mathematical-statistical models*, particularly effective are the Combinatory Automata ones, the simplest of which represent Combinatory Systems through a *matrix arrangement* in which, in the **N** cells — at a given instant t_h — the micro-states of the **N** agents, $x_i(t_h)$, are represented, with **i** assuming values from 1 to **N**, and/or the micro-effects, $e_i(t_h)$, corresponding to those individual states.

The combination of the $x_i(t_h)$, according to *recombination* rules, makes it possible to quantify the macro-state, $X(t_h)$, of the collective considered as a whole, and/or a *global macro-effect*, $E(t_h)$. The macro-state $X(t_h)$, when perceivable by the agents — or, more often, the macro-effect $E(t_h)$ — may be interpreted as self-produced global information, on the basis of which the agents determine their new micro-state, $x_i(t_{h+1})$, from which the new macro-state $X(t_{h+1})$ derives, together with the corresponding micro- and macro-effects.

Figure 2 illustrates the logic of a generic combinatory automaton and the micro- and macro-values it produces.

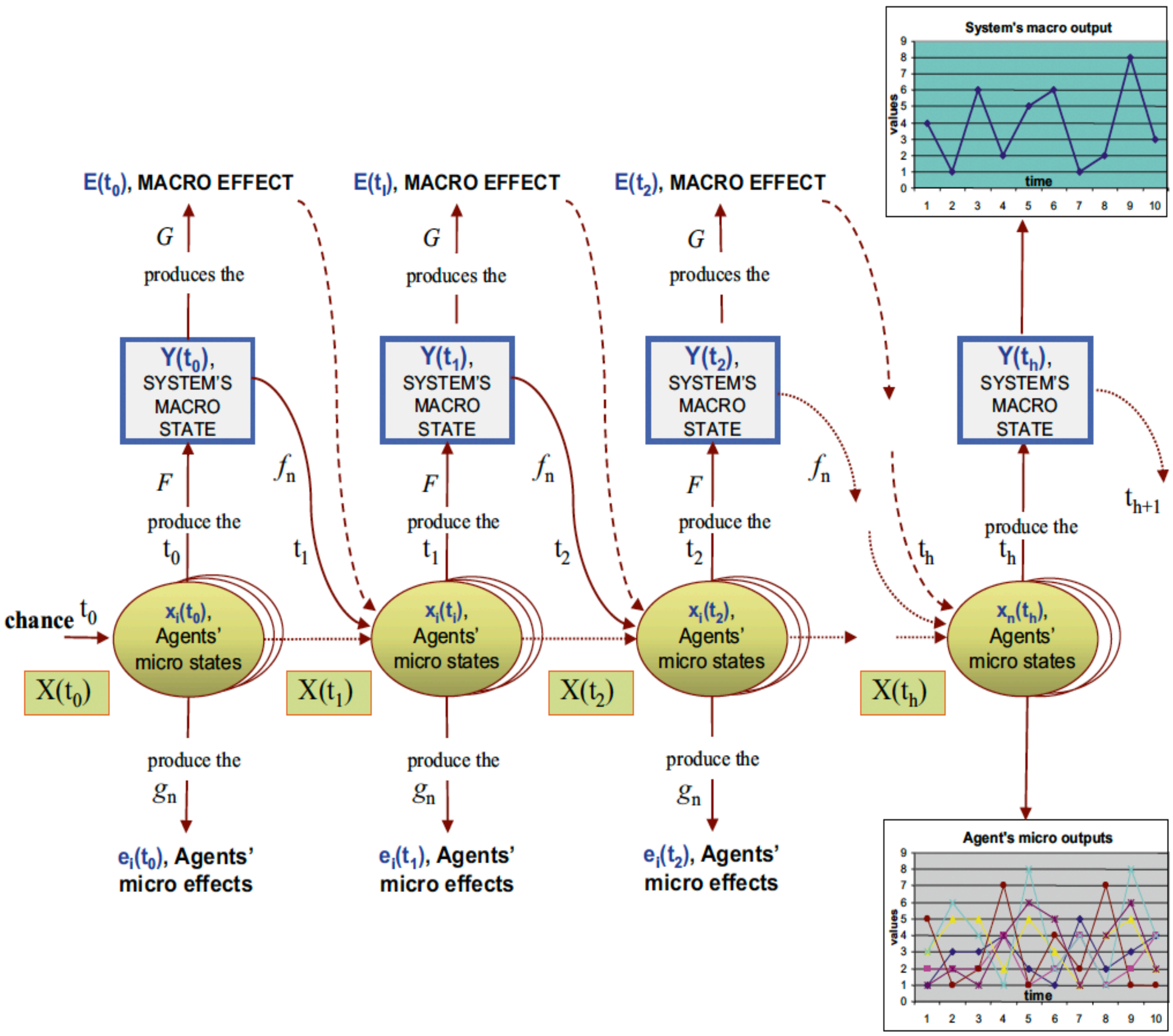

Fig. 2 – Model of the dynamics of a combinatory automaton
(Mella, 2025, Section 1.3.3)

Combinatory automata make it possible to determine the dynamics of the micro- and macro-variables that define the behavior of the system, as more clearly specified in the model shown in Figure 3. The figure highlights how the *micro–macro feedback* — the "engine" of Combinatory Systems — connects the micro- and macro-dynamics produced, respectively, by the agents and by the collective as a whole.

Figure 4 highlights the results of the probabilistic Combinatory Automaton through which the simulation of a system (composed of 20 agents) was carried out that produced and maintained the *murmur/buzz* within a closed space, as described in Sect. 1.

The automaton shown in Figure 4, for example, is a typical "medial" *combinatory automaton*, since the values representing the macro-effect (the *murmur*) are determined as the average (with adjustments) of the values indicating the micro-effects (the voice levels of the individual speakers) (for details, see Mella, 2025, Sect. 2.4.1).

This combinatory automaton belongs to the class of *Combinatory Automata simulating Improvement and Progress* (see Mella, 2025, section 3.5). If., for examples of alternative situations that the automaton can represent). The following section will focus on the class of Systems of *Improvement and Progress*.

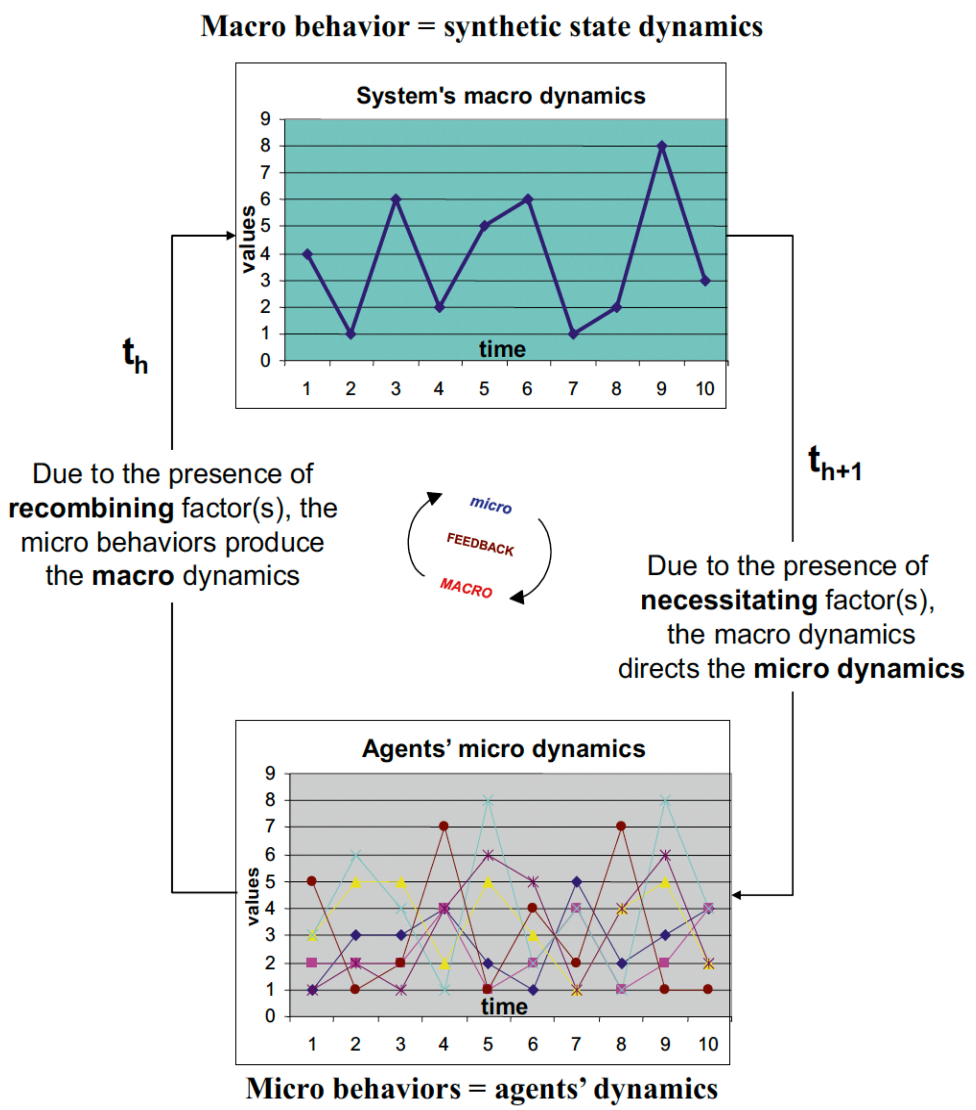

Fig. 3 – Interaction between the micro-dynamics of the agents and the macro-dynamics of the collectivity

4 – The theoretical framework of COMBINATORY SYSTEMS OF IMPROVEMENT AND PROGRESS

A significant type of combinatory system is what may be called the IMPROVEMENT & PROGRESS COMBINATORY SYSTEM. Its defining macro-effect is the generation of *progress*, understood as the enhancement of the overall condition of a collectivity achieved through the improvement of its *individual members*. These systems may be included within the broader categories discussed earlier.

More specifically, they are systems oriented toward pursuit and capable of generating processes of accumulation or diffusion. They are treated here as a distinct class because of their special importance within social collectivities. In such systems, individual improvements contribute to increasing the parameter that measures collective progress. This parameter acts as *global information*, enabling individuals to perceive positive or negative gaps that motivate them either to improve so as to widen the gaps (if positive) or eliminate the gaps (when they are negative).

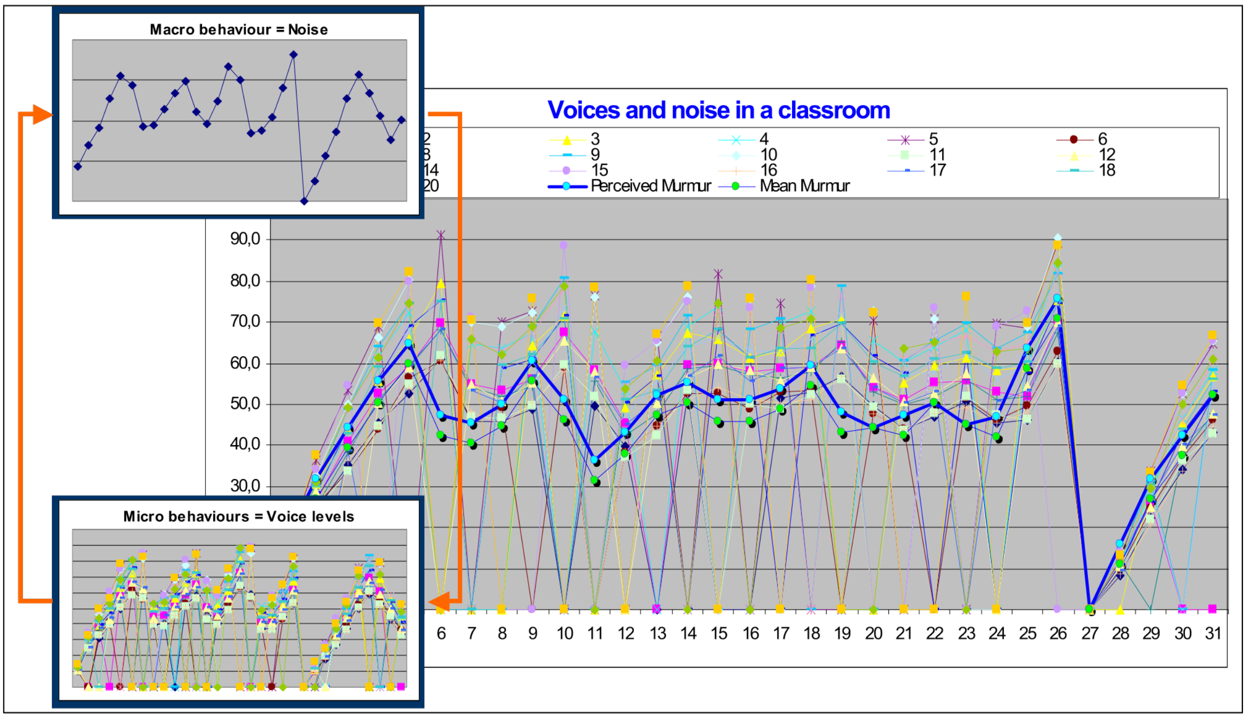

Fig. 4 – Combinatory automaton simulating the murmur/buzz system formed in a closed space (reference: section 3)

In addition to being powerful, these systems are also quite widespread. For example, Adam Smith was the first to theorize the economy as a typical Improvement and Progress Combinatory System. Interpreting his thinking through Combinatory Systems terminology, Smith viewed "progress" as the diffusion of the "wealth" produced by economic agents pursuing their own personal interests.

> Every individual is continually exerting himself to find out the most advantageous employment of whatever capital he can command. It is his own advantage [individual improvement], indeed, and not that of the society, which he has in view. But the study of his own advantage naturally, or rather necessarily leads him to prefer that employment which is most advantageous to society [necessitating factor]. He generally, indeed, neither intends to promote the public interest nor knows how much he is promoting it. By preferring the support of domestic to that of foreign industry, he intends only his own security [limited information]; and by directing that industry in such a manner as its produce may be of the greatest value [micro-effect], he intends only his own gain, and he is in this, as in many other cases, led by an invisible hand [*micro-macro* feedback] to promote an end which was no part of his intention [recombining factor]. Nor is it always the worse for the society that it was no part of it. By pursuing his own interest [individual improvement], he frequently promotes that of the society [collective progress] more effectually that when he really intends to promote it. I have never known much good done by those who affected to trade for the public good. It is an affectation, indeed, not very common among merchants, and very few words need be employed in dissuading them from it (Adam Smith, 1776) [*the parts in brackets were added by me*].

Ludwig von Mises was more decisive. He clearly described the idea of "progress" as deriving from "*the fact that people are motivated by the impulse to improve the material condition of their existence*".

> The term progress is nonsensical when applied to cosmic events or to a comprehensive world view. We have no information about the plans of the prime mover. But it is different with its use in the frame of ideological doctrine. The immense majority strives after a greater and better supply of food, clothes, homes, and other material amenities. In calling a rise in the masses' standard of living progress and improvement, economists do not espouse a mean materialism. They simply establish the fact that people are motivated by the urge to improve the material conditions of their existence. They judge policies from the point of view of the aims men want to attain. He who disdains the fall in infant mortality and the gradual disappearance of famines and plagues may cast the first stone upon the materialism of the economists (von Mises, 1998, p. 192).

> With the progress of time society will more and more become the society of free men, aiming at the greatest happiness of the greatest number (von Mises, 1998, p. 192).

In social systems, Improvement and Progress Systems effectively lead to the emergence of institutions (Caldas & Coelho, 1999). In the life sciences, we may adopt the hypothesis that human beings naturally tend toward individual improvement and collective progress, as argued in Stephen Jay Gould's theory of options (2000, 2001).

> After testing many pathways to account for human peculiarity, we arrive at an unusual principle. Humans appeared to evolve along a fitness pathway that maximized the options of behavior for the least cost to adapt. […] The suggestion here is to examine the issues not with answers, but as a way to ask questions. If we study an attribute of human physiology or behavior and ask 'why did it evolve this way?' we might ask that forever. But if we ask, 'how would evolving this way maximize options?' we see old problems from a fresh perspective (Gould 2001, online).

Improvement and Progress Systems can, in general, be represented by the following heuristic and graphical models shown in Figure 5.

<u>HEURISTIC MODEL OF THE SYSTEM THAT PRODUCES "IMPROVEMENT AND PROGRESS"</u>

MICRO-BEHAVIOR AND NECESSITATING FACTOR: if you perceive that the level of your *improvement* parameter (to be specified at the individual level) is lower than the level of the system's *progress* parameter (to be specified at the collective level) — that is, if there is a *negative gap* between your state and what you perceive in others — and, for various reasons, you do not wish or are unable to "fall behind" (necessitating factors), then you should try to *improve* your micro-behavior to reduce the gap and, if possible, achieve a *positive one*. If instead you perceive a *positive gap*, either do nothing or attempt to *improve* further to widen the favorable difference.

MICRO-BEHAVIOR AND RECOMBINING FACTOR: *the presence of recombining* factors leads the system/collectivity to detect the *improvements* of individual agents and to determine the *collective progress parameter* as a combination (according to the most appropriate forms for the nature of the phenomenon) of the single *measures of individual improvement*.

MICRO-MACRO FEEDBACK. CHANGE AND NECESSITY: THE individual improvement produced by each agent (micro-effect) raises the parameter that measures collective progress (macro-effect). This leads to the emergence of positive and negative welfare gaps perceived by individuals, which in turn push agents either to further improve themselves in order to widen these gaps (if positive) or to eliminate them (if negative). Initial improvements may occur by *chance*, but once a minimum number of agents have improved their position, collective progress becomes evident and, if evaluated positively, necessarily spreads throughout the entire collectivity.

CONTROL STRENGTHENING AND WEAKENING ACTIONS: IF individual improvement leads to clear advantages for those who achieve it and increases gratification, then the system is *reinforced* through the creation of instruments such as schools, craft and trade associations, patents, awards, and various forms of facilitation that enable individuals to improve. If, instead, the pursuit of actions or processes of individual improvement causes accidents, harm, or social envy, then collective improvement is weakened and, in the worst cases, may come to a halt.

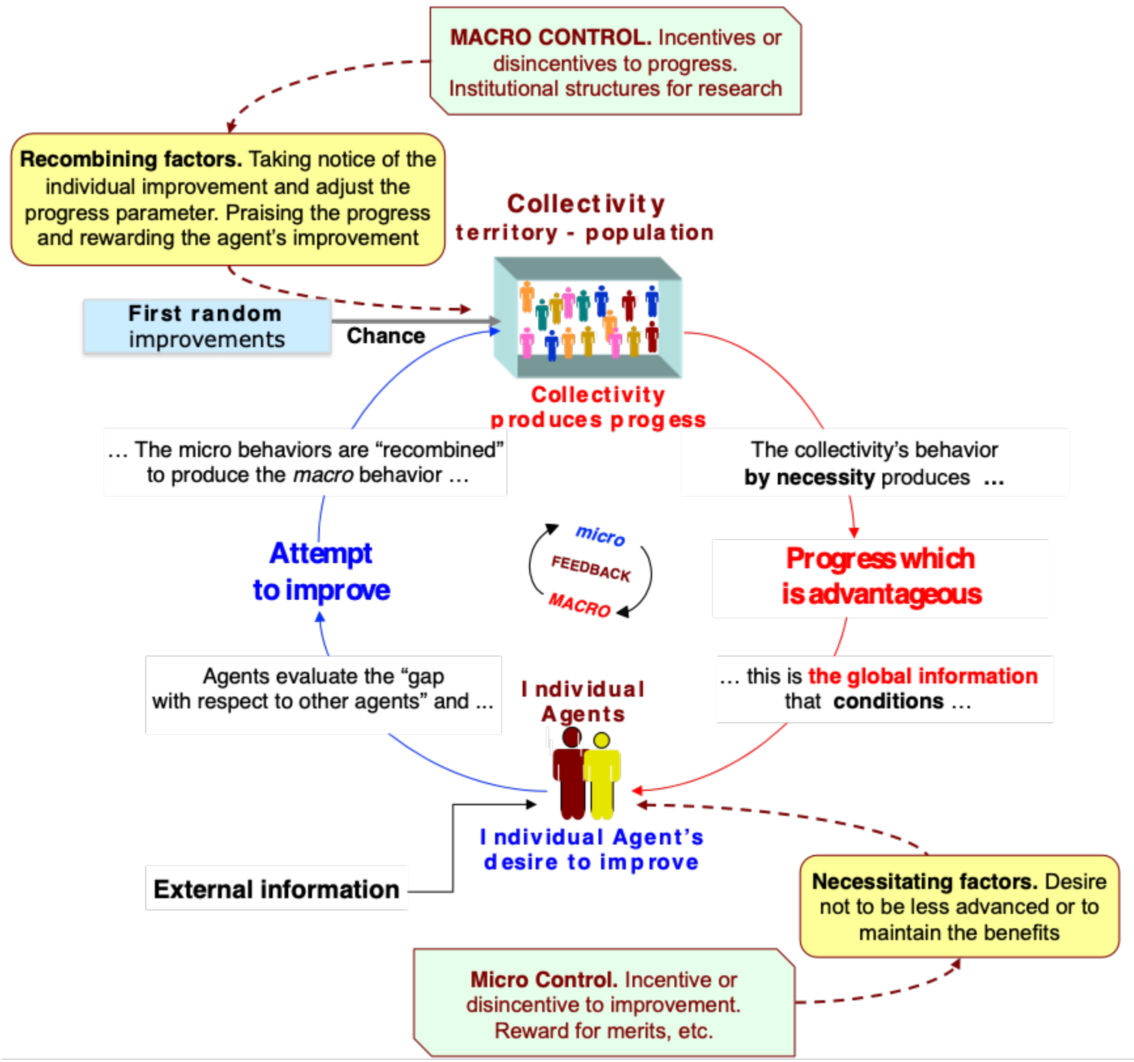

Fig. 5 – General graphic model of systems of "Improvement and Progress"

To make the general operating logic of Improvement and Progress Systems more evident, it is useful to describe the "breaking the record" system, which leads to a progressive increase in records (Mella, 2025, Sect. 2.4.2)". Its operational logic is described by the following HEURISTIC MODE. Figure 6 presents the corresponding graphical model.

<u>HEURISTIC MODEL OF THE "BREAKING THE RECORD" SYSTEM</u>

MICRO BEHAVIOR AND NECESSITATING FACTORS: if a record exists and you wish to distinguish yourself — by demonstrating that you are "the" best — then you must compete in order to win and surpass the record. Participation in such competitions brings recognition, and in the case of victory, it results in the awarding of a prize.

MACRO BEHAVIOR AND RECOMBINING FACTORS: THE record is valued by the collectivity, and the widespread effort to surpass it strengthens the motivation "to achieve the record" while also raising average performance levels. As a result, successful competition requires increasingly intensive training, which ultimately leads both to the record being broken and to an overall improvement in the average standard of performance within the competition.

MICRO-MACRO FEEDBACK. CHANCE AND NECESSITY: improving the record and increasing the average competitive performance are a consequence of the athletes' results; however, the athletes themselves are influenced by the record they are trying to surpass. The initial record emerges "by chance" once a minimum number of athletes willing to compete is attained. The record is then maintained "by necessity" for as long as the collectivity favorably values it.

STRENGTHENING, WEAKENING AND CONTROL ACTIONS: if the record-holder is highly honored and victory is associated with substantial prize money, the system is strengthened through the resulting increase in gratification. Conversely, if attempts to set new records lead to accidents and casualties, the system is weakened. Another weakening factor is the cost of competitions: the higher the cost, the more difficult it becomes to pursue a record-breaking performance. Control mechanisms for the system include publicity surrounding the record and the establishment of venues where the sport can be practiced. A typical micro-level control is the existence of a supportive sporting culture.

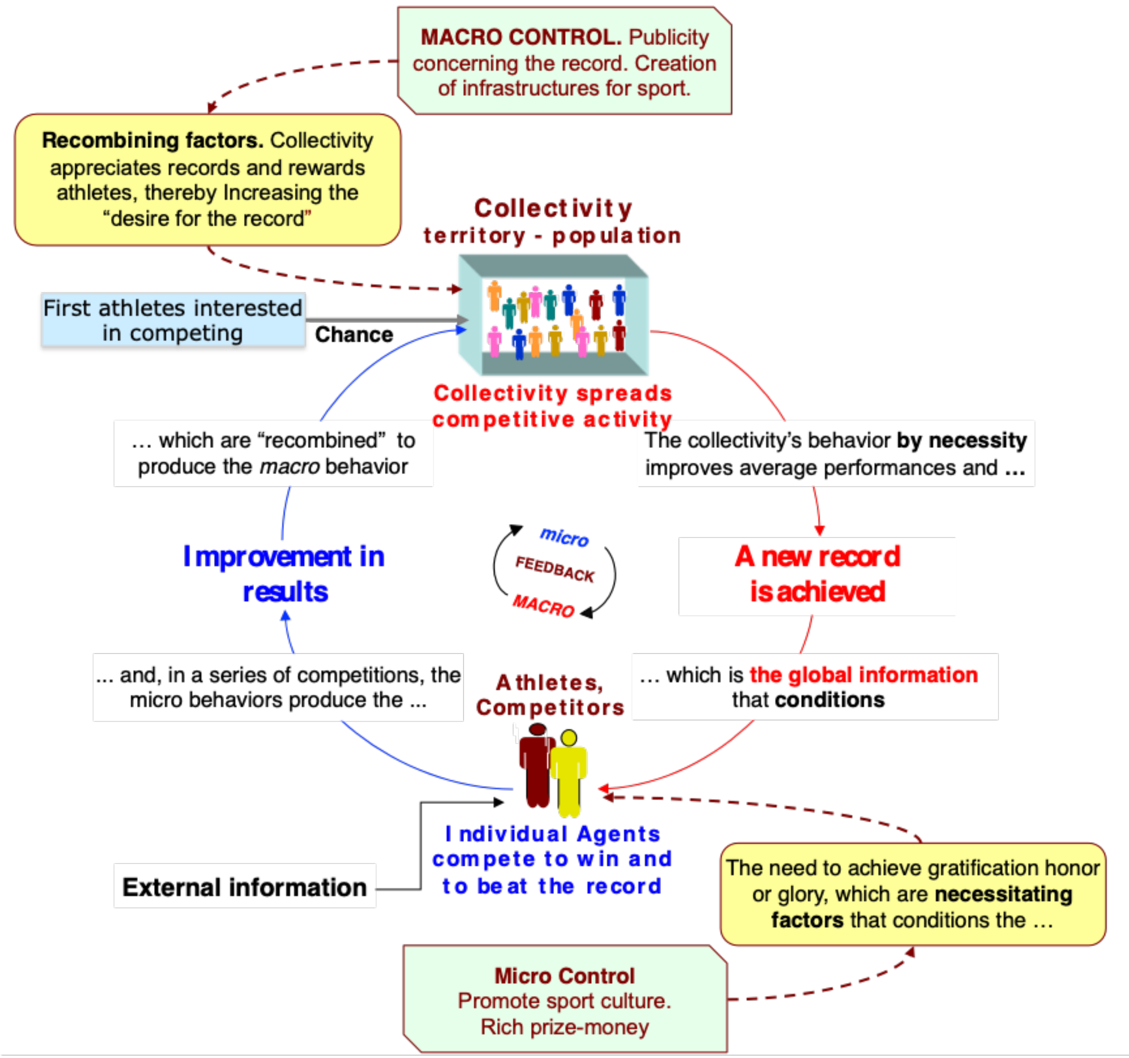

Fig. 6 – Graphic model of the "Breaking the Record" system

The system just described is widely generalizable, as it applies within the same framework to all cases in which a limit — for example, a speed limit — or a rule in general is set and this limit or rule is then disregarded, giving rise to micro-behavior that exceeds the limit and ultimately leads to the abandonment of the limit itself. The model also applies to sports in which results are measured on a quantitative scale (time, distance, weight, etc.), which defines and transmits over time the measure of the achieved record. In such cases, a combinatory system emerges that leads to *record-breaking* (through micro-improvements from individual athletes) and raises the overall level of the collectivity in that sporting activity, as evidenced by the Olympic Games and national and world championships. The model in Figure 6 also applies to competitive sports in which the "record" is expressed as the number of victories achieved over an athlete's career or by teams.

5 – The system of "Growing Productivity"

Productivity is the efficiency with which humans produce. It can be observed either at the individual producer level (usually a firm or a division) or with reference to a sector, a region, or the overall economic system (see Mella, 2018a).

At the *business* level, the degree of average productivity is measured by the *ratio* between the *quantity of output obtained* from a given production process (or the time required to obtain it) and the *amount of labor employed* in that process during a given observation period. It may also be measured by the *inverse ratio*, which indicates the *average labor requirement per unit of output*. At the territorial level or with reference to the economic sector, many statistics present productivity data as the ratio between GDP and the number of hours worked. However, this measure is not fully indicative of productive efficiency within business processes, since GDP is influenced by factors such as capital and rents, which may increase productivity even with limited labor input. In any case, it is evident that some economic systems enjoy very high levels of productivity compared with others in which average productivity remains rather low, as shown, for example, by the data reported by TRADING ECONOMICS (online).

But one thing is certain: whenever competition among producers is possible within an economic system, average productivity — both at the level of the firm and of the system as a whole — tends to increase continuously and becomes difficult to halt. When productivity rises within a given company or sector, the average productivity of other firms and other economic systems also tends to expand, even if growth rates are uneven.

Productivity depends on various "drivers" (or factors) of productivity which, although interacting with one another, may be divided into different categories to facilitate analysis. This is illustrated by Adam Smith's well-known example of *pin* manufacturing, which highlighted the productivity advantages generated by the division of labor.

> This great increase in the quantity of work, which, in consequence of the division of labor, the same number of people are capable of performing, is owing to three different circumstances; first, to the increase of dexterity in every particular workman; secondly, to the saving of the time which is commonly lost in passing from one species of work to another; and lastly, to the invention of a great number of machines which facilitate and abridge labour, and enable one man to do the work of many (Smith, 1776, p. 5).

Generalizing Adam Smith produces the following typology:

A. *Passive drivers*: these factors increase the amount of output generated for each unit of labor employed in production. They are closely linked to fertility in its various forms, including the fertility of land, water, and subsoil resources, whether natural — such as the fertile banks of the Nile — or artificially enhanced through irrigation and fertilization.

B. *Active drivers*: these factors reduce the amount of labor required for production while keeping fertility constant. Three main types of active productivity drivers can be identified: skill, equipment, and specialization. Through the division of labor, each worker contributes specialized skills supported by appropriate equipment to perform a specific task, and this specialization — combined with the available tools and technologies — further enhances productivity (Smith 1776, p. 3-5).

C. *Endogenous or psychological drivers*: these entail the psychological conditions that drive workers to supply their labor to an organization, and they can be divided into *Motivation* and *Satisfaction*.

D. *Extrinsic drivers*, which are so called because they concern the organization of productive systems, the environment in which work is performed, and, ultimately, the firm's policies aimed at increasing productivity. The following represent the most important of these policies (Schmitz 2005):

1. The continuing *mechanization trend*
2. Processes involving on-line *automatic control systems*
3. Enhancing efficiency by *optimizing logistics and the handling of materials* (Bowersox et al. 2005)
4. *Standardizing designs* and adopting *new materials*
5. Progress in *scientific and technological research* — especially in energy supply systems and in the productive use of energy — has had a major impact on economic advancement, as emphasized by Carlo Cipolla in *The Economic History of World Population* (1962).
6. Advances in the productive application of *Artificial Intelligence systems* to design, execute, and control production processes (see section 10).

The main challenge facing developed economies will be the creation of endogenous drivers of productivity; that is, the ability to motivate and satisfy workers, as argued by William J. Baumol and his collaborators (1989). Indeed, the crucial issue for the future — already a central one today — will be to improve productivity through higher product quality and better working conditions.

Growth in productivity increases *welfare* (Coyle, 1999), not only through the diffusion and accumulation of wealth among consumers, but also, and perhaps above all, through the gradual reduction of working hours and the improvement in the conditions of workers (Blank and Shapiro, 2001).

If we consider the level of productivity as a *parameter of progress*, we can posit the following:

HYPOTHESIS OF INCREASING PRODUCTIVITY: *the network of productive firms* (Mella, 2018a, 2019) *tends to achieve ever-higher productivity, while at the same time being governed by the continuous increase in productivity (and quality), following a typical micro–macro feedback mechanism of a particular Combinatory System.*

Let us suppose that, within a given environment, several producers operate by manufacturing goods that are directly or indirectly substitutable. If, "*by chance*", one of these producers were to increase its average productivity — thereby reducing average unit production costs — it would create advantages for itself and a threat to competitors, since it would increase profits, enable greater investment, attract customers, and reduce the selling price. In order to survive in the "economic arena", the other producers would "*by necessity*" be forced to increase their own productivity, in a typical feedback process of the combinatory system. The result of these micro-level behaviors is an increase in the average productivity of the system, which denotes *economic progress* — an increase that becomes continuous because of the relentless competition among producers and the need for each producer to maintain profit margins sufficient to remain in business. If, "*by chance*", a producer were to introduce a new technological or information-based invention — for example, *production robots*, *3D printers*, *vision systems*, *optical fibers*, or interactive systems driven by *artificial intelligence* — then the Combinatory System would "*by necessity*" ensure the diffusion, across all sectors, of the adoption of those or similar inventions. The increase in average productivity at the level of the productive system — that is, progress in the efficiency of production — is the macro-effect resulting from the combination of individual micro-behavior aimed at the IMPROVEMENT of corporate productivity and the constant search for new productivity factors (micro-effects). The "history" of humanity can be "read" as the history of increasing productivity, that is, of the emergence and operation of the combinatory system we are observing, which can be described by the following HEURISTIC model and Figure 7.

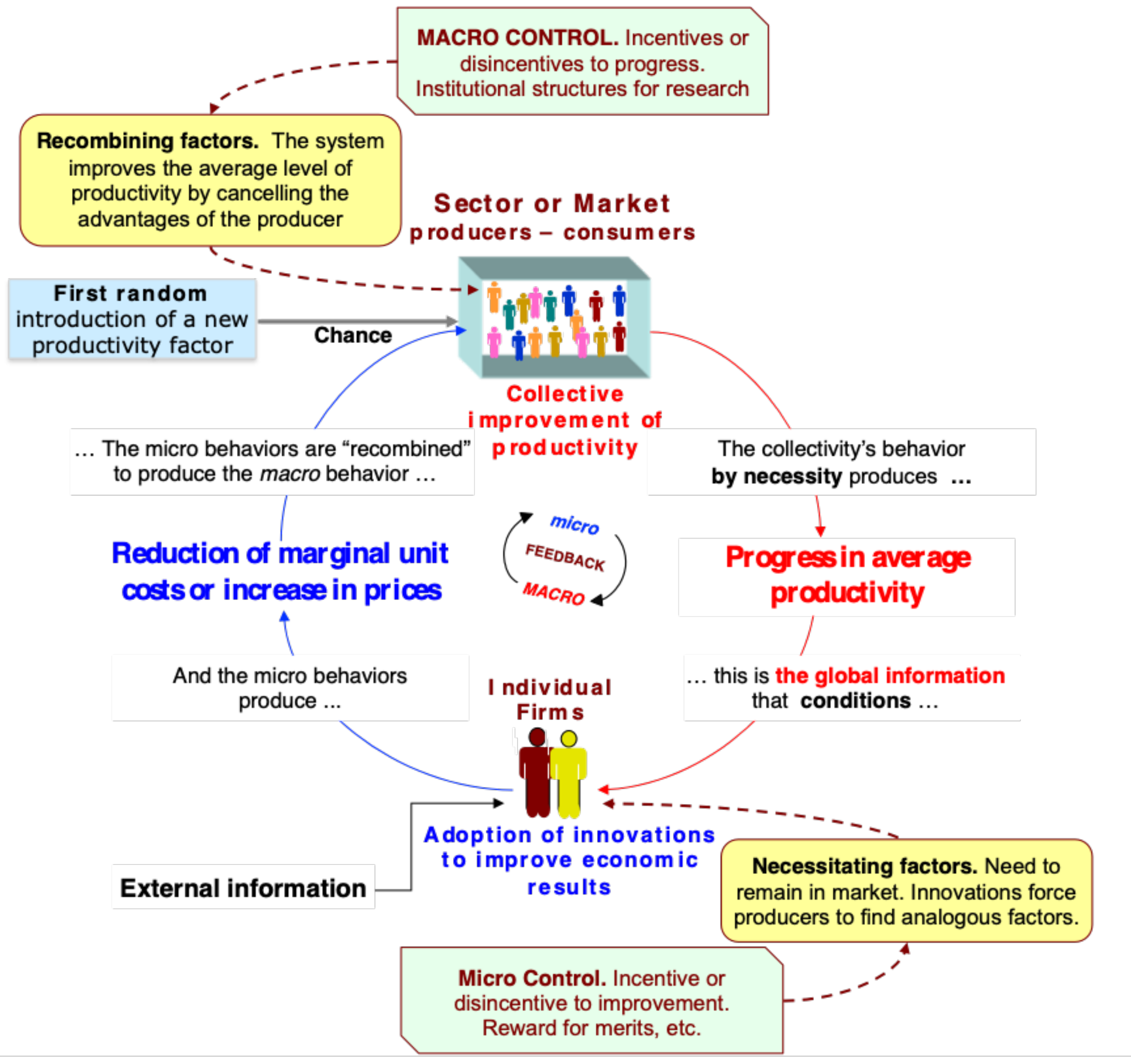

Fig.7 – Graphic model of the system of "Increasing Productivity"

HEURISTIC MODEL OF THE SYSTEM OF "INCREASING PRODUCTIVITY"

MICRO- BEHAVIOR = NECESSITATING FACTOR: IF you are an entrepreneur and your unit profit decreases — and you cannot influence the selling price — then, to remain in the economic system as a producer,, you must reduce your average unit production cost by increasing productivity to a level equal to or higher than the average level of the other competing producers by enhancing some productivity factor. This will also enable you to reduce prices in order to counter competition.

MACRO-BEHAVIOR = RECOMBINING FACTOR The generalized introduction of some productivity factor improves the average productivity level of the system, thereby reducing the advantages of the individual producer; producers therefore strive to match, or preferably surpass, the average productivity level of the system.

MICRO-MACRO FEEDBACK. CHANCE AND NECESSITY: THE macro-effect represented by the increase in the average productivity level of the productive system is the result of past micro-behaviors, but it also influences the search for new productivity factors by individual producers. A productive innovation — or, more generally, a new productivity factor — is introduced or adopted "*by chance*", but the new productivity factor adopted affects production costs (and often prices as well), forcing other producers "*by necessity*" to find similar factors, sometimes simply by imitating the innovation (we are all familiar with industrial espionage), and at other times through a substitutive innovation.

STRENGTHENING, WEAKENING, AND CONTROL ACTIONS: *incentives* for innovation, the existence of specialized research centers, and strong profit motivations are all examples of factors that reinforce the system. Conversely, monopolistic conditions and limited consumer awareness represent factors that weaken it. Macro-level control can be exercised through laws and policies that either encourage or hinder the introduction of innovations, as well as through interventions in the

6 – The system of "Increasing Quality"

A particularly important combinatory system, operating in a manner similar to that of the system of increasing productivity and contributing to progress in both the production and use of goods, is the one concerned with the *quality* of goods produced. The concept of quality, however, is difficult to define, often being considered "elusive", and its understanding is generally entrusted to intuition. Many scholars have suggested abandoning the attempt to formulate a precise definition, instead regarding quality as an intuitive, indefinable, almost primitive or philosophical notion associated with ideas such as differentiation, excellence, perfection, and consistency. In his 1974 book titled *Zen and the Art of Motorcycle Maintenance: An Inquiry into Values*, Robert Pirsig introduces the concept of the "Metaphysics of Quality", according to which quality is a direct experience that exists independently of, and prior to, intellectual abstractions.

I propose three distinct, although interconnected, notions that summarize most of the definitions found in the literature and allow us to focus on quality from a threefold perspective: the customer, the product, and the environment — namely, *functional quality*, *design quality*, and *environmental quality* (Mella, 2018b, 2021, Chapter 10).

A. Functional quality (or *market quality*, or *quality in use*) defines the set of characteristics that, from the consumer's/customer's point of view, make the product suitable *for use*, that is, capable of satisfying a specific *function of use or utility* of the good or service, while taking into account a desired standard of *reliability* (the product must allow a use that is not interrupted because of imperfections or lack of *safety*).

B. Design quality (*intrinsic* quality, or *production* quality) is the set of characteristics that, from an internal perspective (in terms of production processes), make all *product units* conform to a reference *standard* (prototype, sample, model, or design). This form of quality refers not so much to the product itself as to the *production process*; that is, to the flows of production units generated within a given process.

C. Environmental quality (or contextual quality) is the set of characteristics that, from the perspective of external impact, make the product compatible with the environment, both in terms of pollution, waste disposal, and environmental risks, as well as its suitability for being "introduced" into the surrounding environment.

These notions of quality ultimately define *quality products* as those that are fit for a *purpose*:

> One of the possible criteria for establishing whether or not a unit meets quality is its accordance with what is seen to be the goal of the unit" (Campbell & Rozsnyai, 2002, p. 132). "Fitness for purpose sees quality as fulfilling a customer's requirements, needs or desires (Harvey & Green, 1993).

In 1983, the American Society for Quality Control (ASQC) put forth a specific definition in line with the aforementioned tripartition.

> [Quality is a] subjective term for which each person or sector has its own definition. In technical usage, quality can have two meanings: 1) the characteristics of a product or service that bear on its ability to satisfy stated or implied needs; 2) a product or service free of deficiencies. According to Joseph Juran, quality means "fitness for use"; according to Philip Crosby, it means "conformance to requirements" (ASQ 1991, online).

"Quality", together with "productivity," is an essential element for assessing the efficiency and effectiveness of a production process of material goods or services, and it is a fundamental objective in the production and sales strategies of every company (Mella, 2021, Sect. 8.7). Every improvement in the quality of a product provides the producer with a *temporary competitive advantage*, which lasts until the qualitative improvement is offset by the imitative effects of other producers. The history of humanity — as we can observe through a simple "reading" of the economic and technological environment in which we live — does not appear to be solely the history of increasing "productivity" but also of the *continuous improvement* in the quality of goods and services produced. It is enough to consider the recent "history" of automobiles, weapons, computers, smartphones, and especially AI, to appreciate the rapid progress in the quality of their *design* and *performance*.

The logic of "Combinatory Systems" that lead to the "Continuous Increase in Quality" can be summarized as follows: when a producer introduces a qualitative improvement in a product that is appreciated by consumers, thus giving them a competitive advantage in terms of price and sales volumes, the improvement is sooner or later also adopted by competitors. This dynamic leads to a continuous increase in the average quality of the goods that are produced and sold, so that the competitive advantage gradually weakens and requires further interventions to sustain quality.

The improvement in the average quality of the production system is the macro-effect from the "combination" of the micro-behavior of producers/agents and their related micro-effects; however, this macro-effect, in turn, influences the search by individual producers for new qualitative improvements.

When, "*by chance*", an innovation is introduced that produces an increase in quality, giving the producer an advantage in sales and therefore economic benefits, other producers are "forced", "*by necessity*", to find the means and ways to improve the quality of their own products as well. Such a system can be synthesized by Figure 8.

Fig. 8 – Graphic model of the system of "Increasing Quality"

7 – System of "Scientific-and-Technological-Progress"

At the basis of the behavior of the systems of Increasing Productivity and Quality is another fundamental system that leads to the continuous growth of scientific and technological progress. Every new discovery — new law, scientific theory, technological invention, technical application — becomes part of a cultural heritage that contributes to new discoveries, thanks to the wealth of knowledge accumulated up to that moment. These new discoveries enrich the stock of knowledge which, in turn, contributes to additional new discoveries, following a typical micro-macro feedback process of combinatory systems.

A scientific or technological discovery usually arises "by chance", although it also often results from teamwork at the end of a research program undertaken specifically to reduce the gap in scientific or technological knowledge. However, if the discovery is useful, it inspires further research by other researchers and manufacturers, thus triggering *micro-macro feedback*.

The graph in Figure 9 uses Combinatory Systems of Improvement and Progress to illustrate the process behind the incessant *growth of scientific and technological knowledge*.

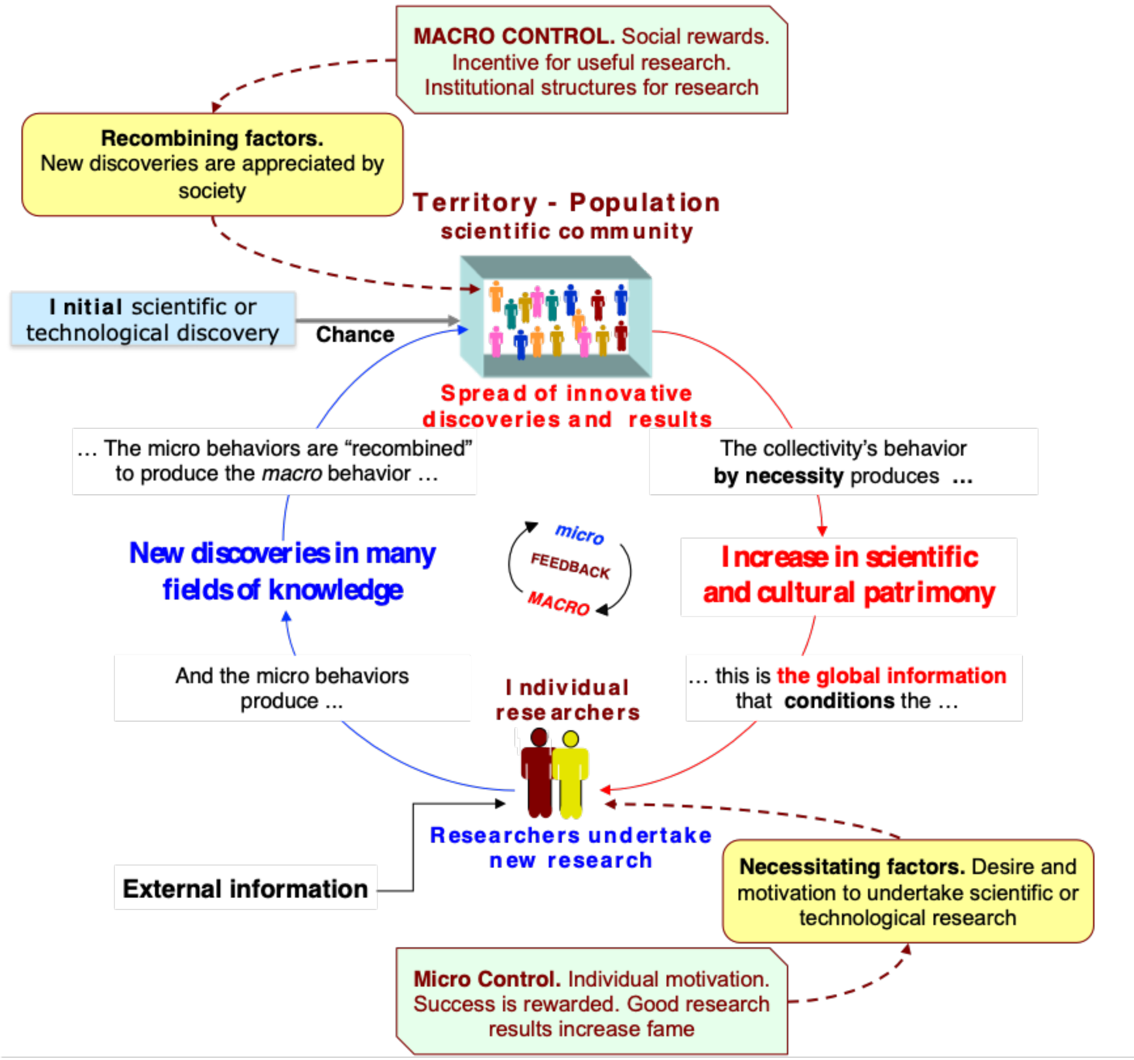

Fig. 9 – Graphic model of the system of "Scientific and Technological Progress"

The same process is operationally explained in the subsequent HEURISTIC MODEL.

<u>HEURISTIC MODEL OF THE "SCIENTIFIC AND TECHNOLOGICAL PROGRESS" SYSTEM</u>

MICRO-BEHAVIOR AND NECESSITATING FACTORS: at the micro level, scientific and technological research is driven by the recognition of gaps in existing knowledge. Whenever researchers encounter limits in their understanding or identify missing elements in the current body of science and technology, they are motivated to investigate further and pursue new discoveries.

MACRO-BEHAVIOR AND RECOMBINING FACTORS: each advance expands the collective stock of knowledge, but at the same time reveals new unanswered questions and unexplored areas. In this way, scientific development continuously generates fresh demands for research, creating a micro-macro feedback loop between individual inquiry and the broader evolution of science and technology.

MICRO-MACRO FEEDBACK. CHANCE AND NECESSITY: our knowledge patrimony results from the accumulation of scientific and technological research. The micro–macro feedback mechanism is shaped by both chance and necessity. Many discoveries emerge unexpectedly or accidentally, yet once they prove useful, they are incorporated into humanity's knowledge base. Their integration then makes further investigation necessary, since every new achievement exposes additional gaps and possibilities for innovation.

STRENGTHENING, WEAKENING, AND CONTROL ACTIONS: innovations in areas considered socially valuable — such as computers, lasers, energy, Artificial Intelligence, space exploration, medicine — are a fundamental strengthening force. By contrast, areas perceived as ethically controversial, such as human genetic engineering, are often subject to strong weakening pressures from social resistance.

8 – System of "Increasing Well-Being"

The combined action of the combinatory systems of Productivity and Increasing Quality influences the well-being of populations and leads to another evident combinatory system: Increasing Well-Being. Upon reflection, it is immediately clear that the increase in productivity and quality leads to an increase in the quantity and quality of the goods available to people, and therefore to an increase in the needs and aspirations that can be satisfied; in other words, to an increase in their "well-being", both as individuals and as a community.

The psychologist Abraham Maslow (1943, 1954) suggested that human beings, by their nature, tend to continuously elevate the satisfaction they derive from fulfilling needs and aspirations.

> It is quite true that man lives by bread alone — when there is no bread. But what happens to man's desires when there is plenty of bread and when his belly is chronically filled? At once other (and "higher") needs emerge and these, rather than physiological hungers, dominate the organism. And when these in turn are satisfied, again new (and still "higher") needs emerge and so on. This is what we mean by saying that the basic human needs are organized into a hierarchy of relative prepotency' (Maslow,1943, p. 375).

Maslov proposed a hierarchy, or pyramid, of needs that he extended during the 1960s and 1970s, positing an *eight*-level model (McLeod, 2007):

(1) *biological and physiological needs*

(2) *safety needs*

(3) *love and belongingness needs*

(4) *need for esteem*

(5) *cognitive needs* (knowledge, meaning, culture, etc.)

(6) *aesthetic needs* (search for beauty, balance, form, etc.)

(7) *self-actualization needs*

(8) *transcendence needs* (helping others to achieve self-actualization)

We are all aware that the quality of life, that is, our "well-being", manifests "continuous progress", the dynamics of which depend on the number and types of needs and aspirations we can satisfy, and above all on the way in which we achieve this satisfaction. Until a few decades ago, we could only satisfy our basic needs for food, clothing, and protection from disease, and only a few people were able to satisfy their aspirations for culture, art, and entertainment, which today are within everyone's reach in the so-called "advanced" regions. This is a general phenomenon: in all eras, in all civilizations, in every area of the world we observe a double transition: from low-level needs to high-level ones, from needs to aspirations, activating the combinatory systems of Increasing Productivity and Quality.

The micro-behavior is represented by the search for individual improvement in the "agents"— understood as an increase in the degree of satisfaction of needs and aspirations — by the desire for greater wealth and better working conditions, together with the demand for ever greater quantities of goods of ever higher quality or for new goods, all of which are capable of satisfying aspirations. The micro-effects are identified with greater satisfaction regarding our existence. The macro-effect of the system is a given perceived average level of quality of life, in the context of a given community.

The individual elements of the system *base* — i.e., households and consumers — compare their quality of life with the average level; if they perceive it as below average, they act to reduce the gap; if, on the other hand, they perceive it as superior, they act to further increase that gap (micro-behavior). As a result, the system tends to raise its state even further, "directing" the subsequent micro-behaviors; the micro-macro feedback continually produces new improvements in the "general quality of life", which translate into improvements in the productivity and quality of goods.

Il System of "Increasing Well-Being" can be represented by the GRAPHIC MODEL in Figure 10.

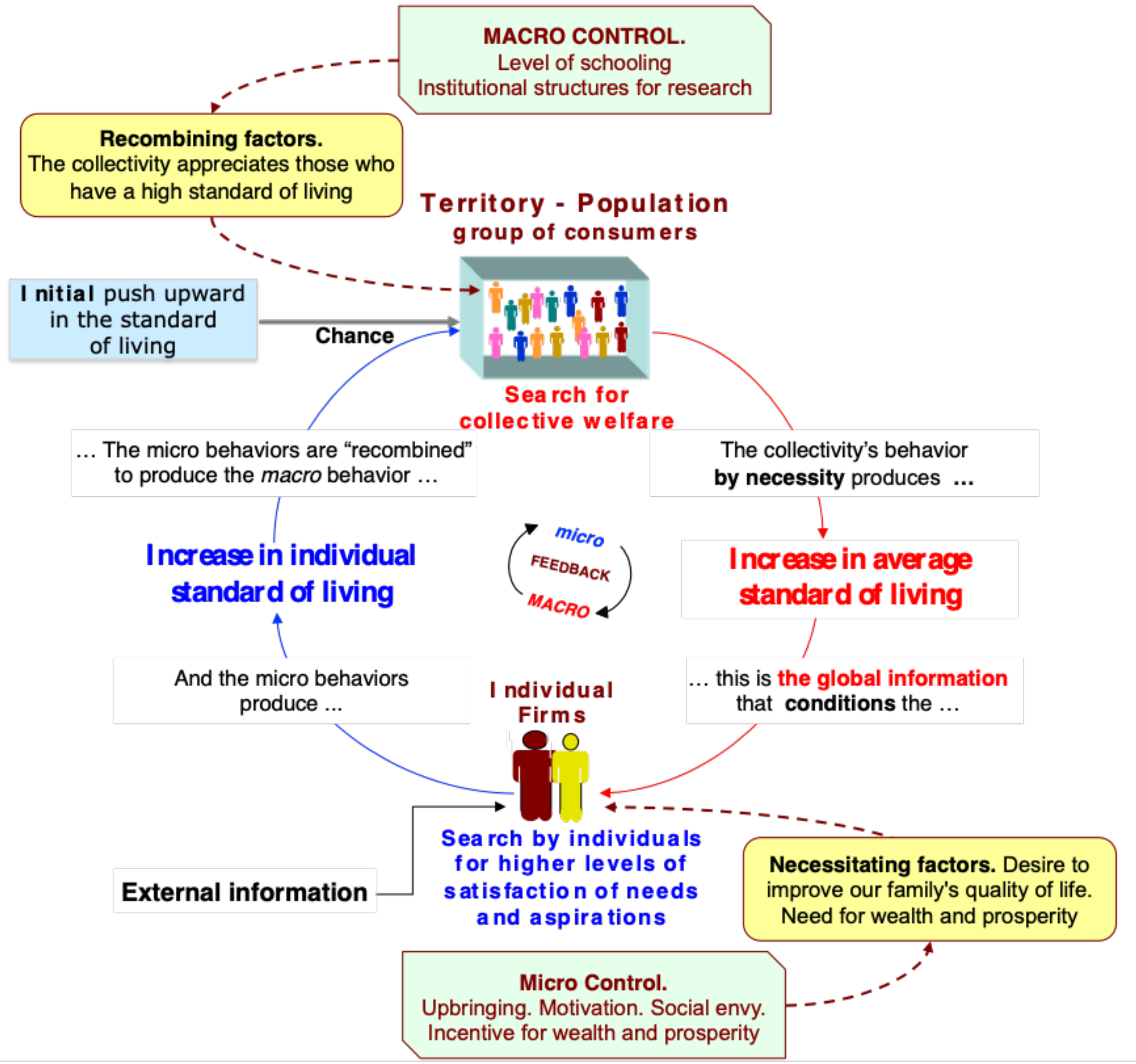

Fig. 10 – Graphic model of the system of "Increasing Well-Being"

9 – Combinatory Systems of *evolution in* AI and *robotic interaction.* A look at the future

It is not possible, in a brief paper, to fully examine the meaning and modus operandi of Artificial Intelligence (AI) and its connections with robotics. It is nevertheless evident that the dynamics of all the systems of improvement and progress examined in the previous sections find new momentum and acceleration in the dynamics of AI and robotics, two technological sectors which, on the one hand, drive progress and, on the other, are themselves driven by it, thus forming two interrelated combinatory systems.

The first is the combinatory system producing the improvement and progress of AI and of robots that are "intelligent" in the common sense of the term; the second is the system that produces the diffusion of such tools, offering very interesting prospects whose realization in terms of timing and methods nevertheless remains unpredictable.

To simplify, we may consider *Artificial Intelligence* as a specialized branch of computer science concerned with creating systems (logical or mechanical) capable of performing tasks similar to those carried out by human intelligence (Russell & Norvig, 2016): that is, systems capable of simulating, even surpassing, human cognitive abilities in *reasoning*, *learning*, *planning*, and creativity (Szeliski, 2022).

Unlike traditional software, whose outputs derive from what may be considered "rigid" instructions designed to provide solutions for learning, programming, and control, Artificial Intelligence uses *machine learning*, which enables automatic learning through the analysis of large volumes of data, identifying patterns and making decisions with minimal human intervention (Mnih et al. , 2015). Rather than being equipped with specific programs capable of providing responses for every individual circumstance, AI — through the hardware systems that support it — uses machine learning to analyze vast amounts of data in order to identify patterns and thus "learn" how to perform a task autonomously. In other words, AI itself creates models that it can subsequently use to make decisions or predictions about new data (Dabija & Vătămănescu, 2023).

The previous general considerations concern the overall characteristics of AI; in reality, however, there are different forms of AI with evolving and diverse capabilities. It should be recalled that AI systems may be classified according to the complexity of the capabilities and tasks for which they were designed, distinguishing among:

1. *Weak* AI (ANI, or *Artificial Narrow Intelligence)*, which is specialized in carrying out a single specific task, but with no consciousness. Examples include Siri, Netflix recommendation algorithms, and spam filters.

2. *Strong* AI (AGI, or Artificial General Intelligence) *(Hypothetical)*. At present, this form of Artificial Intelligence remains hypothetical and represents mainly a theoretical objective of research aimed at developing an AI capable of understanding, learning, and attempting to solve any intellectual problem that a human being can face. In theory, AGI systems should possess the ability to reason abstractly, plan, and solve problems in *previously unseen* contexts, eventually achieving cognitive flexibility equal or even superior to that of humans and, in a more science-fiction-oriented vision, possibly even a form of self-awareness.

3. *Generative* AI. This is a subgroup of AI systems capable not only of answering questions on virtually any subject, but also of creating new content on the basis of specific human requests, including texts, images, and videos (Sengar et al. (2025). Among the many widely used non-

specialized AI systems are OpenAI (USA), Google (USA), Microsoft (USA, partner of OpenAI), Anthropic (USA), Meta (USA), Mistral AI (France), and DeepSeek (China).

It is useful to remember that the forms of AI considered thus far are also defined as "Horizontal AIs" (such as the standard ChatGPT or Gemini), which are designed to respond to a very wide range of requests but do not have a particular specialization. However, the so-called "vertical AIs" are also widespread in specialized domains, and they can be considered as "domain experts", operating in, among other areas, medicine, industrial control, micro-processor design, social, economic, and accounting control, chemicals and pharmaceuticals, advanced programming, the supply chain, and the space and military sectors. In addition, Natural Language Processing also adopts AI with applications that permit computers and human language to interact.

As a result, machines are capable of understanding, interpreting, and responding to natural language. AI is also employed to develop strategies and discover optimal solutions to complicated problems, for example, *logistics* and *urban planning*.

The term "AI" is a general category that designates the multiple specific software created for particular tasks or functions; it can be considered a rapidly expanding and evolving non-biological species that is continuously improving and becoming more sophisticated.

In the context of Combinatory Systems Theory, it is useful and meaningful to think of a "population" of specific AIs, each of which has "its own behavior" and is aimed at the needs of specific users identified by the creator and the manufacturer. In just a few years, AI has spread this "population" to every sector of society and in every technological field such as automatic control, autonomous driving, traffic optimization, educational support, financial and professional analysis and control, early diagnosis in medicine, precision surgery, pharmacological research, prosthesis design, simultaneous translation, voice reproduction, and the recognition of errors and bank fraud in real time (see Sect. 10). Other sectors in which AI operates are equally relevant. Among the many that stand out for their enormous economic and social impact are robotic control in industrial sectors, the optimization of logistics routes and information flows, and laser printing in many materials.

In short, AI is no longer an objective for "the future" but a particular population of entities that interact with humans and thus represent an integral part of our present.

Using the terminology of the Combinatory Systems of Improvement and Progress", AI can be interpreted as a *collectivity* of individual forms of (applications of) AI that are increasingly widespread and continuously maintain themselves, improve in power and efficiency, and expand in number. The individual AIs, *combining* their behaviors and their micro-dynamics, give rise to a *macro-behavior* that, in turn, conditions the *micro-behavior*, in a typical *micro-macro feedback* that, persisting over time, produces *progress*, i.e., the qualitative *improvement* of the performance of individual AIs and their *dissemination*, or quantitative *expansion*.

The Combinatory System of AIs is driven by *necessitating factors* that derive, in fact, from the needs generated by the other Combinatory Systems of Improvement and Progress examined above.

The *necessitating factors* for the *progress* and *dissemination* of AI can be identified as follows:

A – The need to increase productivity in all sectors, typical of the *Combinatory System of Increasing Productivity*.

B – The desire for ever higher quality in products, working conditions, and consumer safety, which gives rise to the *Combinatory System of Increasing Quality*.

C – The Need for “Increasing Well-Being" to increase the satisfaction of material and intellectual needs.

D – The need to advance "scientific and technological progress".

The *necessitating factors* are joined by the *recombining factors*, represented by the tendency of the research and user communities to develop studies and applications of all kinds with some form of AI incorporated.

We need only consider commercial advertisements to realize that most technological applications boast the incorporation of some form of Artificial Intelligence, not only in mobile phones and computers but also in refrigerators, home ovens, gardening tools, even home automation. AI is widespread today in schools of all kinds, making it attractive to students, and it is used in laboratories to experiment with the results achieved. AI users also collaborate to produce increasingly advanced applications. Finally, consider the high regard that Universities place on theses and papers dealing with some aspect of AI.

The HEURISTIC MODEL of this system can be summarized as follows:

HEURISTIC MODEL OF THE SYSTEM PRODUCING THE “EXPANSION AND SPREAD OF AI”

MICRO-BEHAVIOUR AND NECESSITATING FACTOR: if you are a producer of a specific AI and you perceive that the performance of your AI (*improvement* parameter to be specified for each individual AI) is lower than the level of the system's *progress* parameter (whose functions or functionalities are to be specified) — that is, if there is a *negative gap* between the *state* of your AI and what you perceive in others; and, to prevent your AI from being replaced by other AIs, you do not want/cannot "fall behind" (necessitating factors), try to *improve* the performance of your product to reduce the gap and, if possible, achieve a *positive gap* with respect to the performance of other equivalent products. If you perceive a positive gap do nothing, or try to further *improve* your AI to increase the favorable gap.

MACRO-BEHAVIOR AND RECOMBINING FACTOR: *recombining factors* induce the collectivity of operators that form the system to detect *improvements* in the individual AIs and to determine the *collective progress parameter* as a combination (according to the most appropriate forms given the nature of AIs) of the single measures of *individual improvement*.

MICRO-MACRO FEEDBACK. CHANCE AND NECESSITY: individual improvement in the efficiency of the single AIs (micro-effect) raises the parameter that measures collective progress (macro-effect). This leads to positive and negative efficiency gaps perceived by the users, which drive producers to improve the performance of their products to increase the gap (if positive) or eliminate it (if negative). The first AIs can be designed and produced “by chance”, but when a minimum number of AIs in operation is reached, collective progress is evident and “of necessity” is disseminated among the entire collectivities. There is thus greater robots *diffusion* (expansion) and the application of AIs to an increasing number of users (*dissemination*).

CONTROL = STRENGTHENING AND WEAKENING ACTIONS: if the improvement of AI produces benefits for individuals who use it in their processes, then the system is *reinforced* by the creation of tools to spread its use and dissemination, allowing users to improve productivity, quality, and well-being: educational use in schools, use in the professions, industrial, social, and individual applications, and free use for groups of users are all examples of *reinforcing factors*. If the pursuit of individual improvement actions or processes causes accidents, damage, or social envy, then collective improvement tends to weaken and, in the worst cases, terminate.

As a result, powered by strong necessitating and recombining forces, the combinatory system of AI dissemination and improvement is expanding the number and variety of AI applications ever more rapidly and extensively. At the same time, this system increasingly interacts with another parallel process: the dissemination and evolution of robotics in all its forms and uses. Robotics and AI are converging to create intelligent machines capable not only of carrying out physical tasks, but also of analyzing their own behavior, learning autonomously from environmental conditions and adapting to unfamiliar situations.

Through AI, robots become intelligent entities. They can interpret verbal and nonverbal communication, develop models of understanding that support decision-making and efficient action, conduct self-diagnosis and self-repair, reproduce certain functions, and even enhance themselves by reconfiguring their systems or integrating new components. Many robots are equipped with advanced vision systems, motion detection and analysis, and sound-processing capabilities, including the interpretation of human speech and music. As a result, they may acquire forms of increasingly autonomous operation that become progressively harder to supervise or control externally.

Robots may eventually manage not only themselves but also other robots, exchanging information and learning collectively through communication networks they autonomously establish and refine (Holland, 1975). This continuous sharing of data allows robotic systems to improve together, accelerating both their evolution and the expansion of their autonomy. Some robots already employ evolutionary algorithms to enhance their performance. These algorithms imitate processes similar to natural evolution, optimizing robotic structures and behavior through repeated cycles in which the most effective configurations are selected and refined. In addition, robots can carry out self-repair, maintenance, and reprogramming, while modular architectures enable reconfiguration and potentially even forms of replication or reproduction.

Even before AI arrived, John von Neumann presented in his *Theory of Self-Reproducing Automata* (1966) the theory that operational programs for robots could include instructions for reproducing themselves and carrying out these instructions autonomously. This is similar to DNA replication in biological systems. Von Neumann conceived of a "Universal Constructor" that could program a machine (and thus an automaton) to build an object— including a copy of itself— by reading a description (or a "tape") of it. We can argue that autonomous robots equipped with AI will not only be capable of enhancing their performance through continuous perception, learning, and adaptation, but will also acquire the ability to modify, optimize, and replicate their own physical structures. In this way, they could evolve into an autonomous, though non-biological, "species".

Several studies already exist on "evolutionary robotics" (Holland, 1975; Koza, 1992, Floreano and Keller, 2010), which highlight how the population of robots evolves according to Darwin's principle of natural selection applied to the robot population.

> The general idea of evolutionary robotics […] is to create a population with different genomes, each defining parameters of the control system of a robot or of its morphology. The genome is a sequence of characters whose translation into a phenotype can assume various degrees of biological realism. For example, an artificial genome can describe the strength of synaptic connections of an artificial neural network that determines the behaviour of the robot. […] At the beginning, robots have random values for their genes, leading to completely random behaviours. The process of Darwinian selection is then imitated by selectively choosing the genomes of robots with the highest fitness to produce a new generation of robots (Floreano and Keller, 2010, online).

The combinatory system of AI dissemination and evolution and the parallel system of the dissemination and evolution of robots — and intelligent machines in general — are increasingly interconnected in ways that are ever more complex. Their interaction is expected to transform numerous sectors by significantly improving the efficiency, safety, and operational capabilities of autonomous systems. As these technologies continue to evolve, they are likely to reshape not only industrial processes and social organization, but also the fabric of everyday human life.

One of the most rapidly advancing areas within robotics and AI is the development of "androids", robots specifically designed to possess human-like characteristics. These include facial features, realistic simulations of skin and hair, articulated upper and lower limbs, and expressive behavior that resemble those of human beings in both appearance and conduct. Androids are highly sophisticated machines that integrate AI systems in order to improve their capacity for interaction, adaptation, and the management of complex, realistic social exchanges.

Although still at an early stage of development, android technology is progressing quickly. Modern androids are increasingly capable of learning from experience, understanding complex instructions, and responding appropriately to environmental stimuli, thus allowing them to gradually achieve more effective performance.

More generally, robots in their many forms are already widely employed across numerous sectors to perform tasks with precision, speed, and autonomy. Androids, however, are primarily intended for contexts that involve direct social interaction with humans, including elderly care, education, hospitality, entertainment, domestic assistance, customer and visitor services, and security or protection activities. As AI-driven robots evolve into increasingly autonomous machines, their use is expected to expand broadly throughout production systems and within family and community environments. Androids differ from other robots in that they are specifically designed with human features to facilitate interaction and communication with people.

In science fiction literature, particularly in the works of Isaac Asimov, androids and intelligent robots occupied a central role and were often portrayed as omnipresent entities operating in the service of humanity. This vision is especially evident in Asimov's most famous works, including the *Foundation* series, the *Galactic Empire* series, and the *Robot series* (Wikipedia, online, entry: Isaac Asimov).

Alan Turing, one of the most influential figures in the history of computer science and artificial intelligence, argued that intelligence is fundamentally connected to interaction and communication among human beings. From this perspective, if attention is limited exclusively to linguistic interaction, intelligence may be defined as the ability to communicate in a manner indistinguishable from human conversation.

More specifically, intelligence exists when, through dialogue alone, it becomes impossible to determine whether the entity interacting with a human is itself human or a non-human agent — such as an animal, a machine, an artificial intelligence system, or even an extraterrestrial being.

To explore this idea, Turing proposed a simulation experiment — the famous "Turing Test" or "imitation game" — which he specifically described in a 1950 essay titled *Computing Machinery and Intelligence*:

> I propose to consider the question, "Can machines think?" [···] The new form of the problem can be described in terms of a game which we call the "imitation game". It is played with three people, a man (A), a woman (B), and an interrogator (C) who may be of either sex. The interrogator stays in a room apart from the other two. The object of the game for the interrogator is to determine which of the other two is the man and which is the woman. He knows them by labels X and Y, and at the end of the game he says either "X is A and Y is B" or "X is B and Y is A" (Turing, 1950, p. 433).

Put simply and in a non-technical way, we can describe the test as follows: if we disregard the physical characteristics of the entities involved — for example, by imagining that the entity being evaluated is located in a separate room and communicates only through a computer interface — an entity may be considered intelligent when, after conversing with it at length on any subject, we are unable to distinguish it from a human being.

This test is both simple and persuasive because it is based on the assumption that the only form of intelligence we can clearly recognize and verify is one that resembles human intelligence. In his influential work *The Oxford Companion to the Mind*, (1987), neuropsychologist Richard Gregory called Turing's "imitation game" *"the best test available for confirming the presence of intelligence in a machine [and thus in men and animals]"* (Gregory, 1987).

In contrast to the "Imitation Game" and the Turing Test (Turing, 1950), the philosopher John Searle presented a different hypothesis to detect cognition: the well-known "Chinese Room" thought experiment (Searle, 1980). Searle argues that the pure syntactic manipulation of symbols (computational, logic) does not equate to semantic understanding (true intentionality or consciousness). He draws the line between "Weak AI" (which simulates the mind) and "Strong AI" (which is a mind), challenging the very nature of computational logic as a source of true intelligence.

10 –Automatic reinforcement in the five Combinatory Systems of Improvement and Progress. The role of AI and its contributions to other four systems

This paper examined four fundamental systems of Improvement and Progress which, acting uninterruptedly from the dawn of civilization, have led to the current level of well-being of humanity. These four systems, presented in Figure 11 (as **X1 … X4**), although producing autonomous and observable dynamics, act interrelatedly since the dynamics of each depend, more or less profoundly, on those of the others, as evidenced by the double-headed blue arrows. In very recent years, with the progress of studies and applications of Artificial Intelligence and Robotics, a fifth autonomous system of Progress Improvement has emerged, in which the pervasive action of Artificial Intelligence influences the destiny of all of humanity itself: the *System of the Expansion and Dissemination of Ais and Robots* (indicated by **Y**), new "populations" of entities that connect pervasively to the other four systems, until now operated by Human Intelligence with the help of computers that provided sophisticated tools.

Figure 11 offers a simplified representation of the interactions among the five systems considered in this study. The sign "**s**" along each arc indicates in Systems Thinking terminology "*the same direction of variation*", that is:

- in the *upper* arcs, oriented from left to right, the sign "**s**" indicates that if a positive variation occurs in the levels of improvement and progress for the variables at the end of the arrow, then a "request" is sent to increase the pervasiveness of AI and Robotics.
- in the *lower* arcs, oriented from right to left, the sign "**s**" indicates that a positive variation in the levels of improvement and progress of AIs and Robots produces a correlated increase in the performance levels of the other four systems.

The joint action of the five systems produces an overall *reinforcing* effect (loop **(R)**), with a continuous reciprocal increase between the X and Y variables.

In a single paper it is not possible to indicate in what forms (the *how*) and in what contexts (the *where*) artificial intelligence (AI) (variable Y in Figure 11) offers significant contributions to the other four systems of Improvement and Progress and how it is 'redesigning' knowledge, know-how, and overall efficiency.

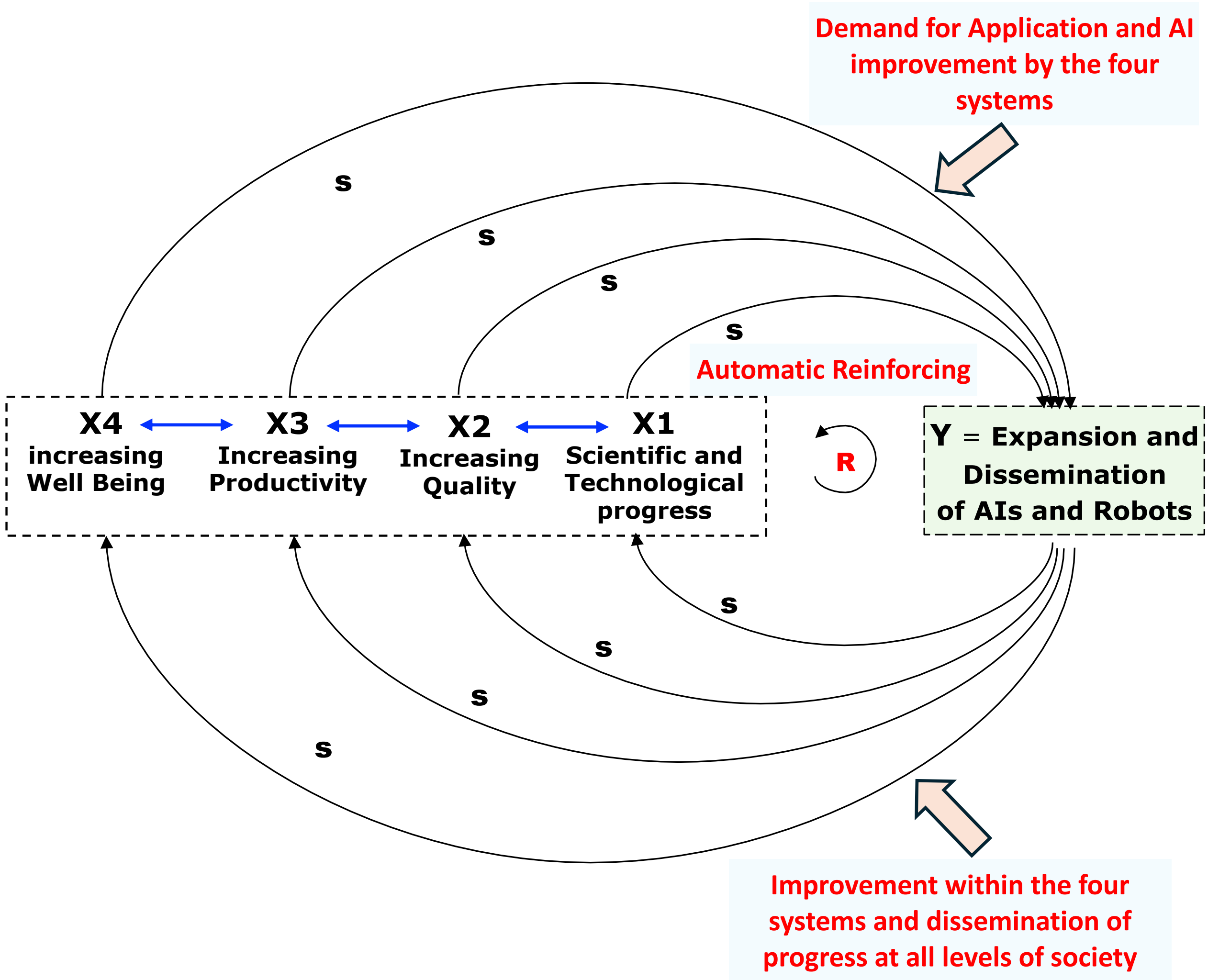

Fig. 11 – Automatic reinforcement in the five Combinatory Systems of Improvement and Progress. The role of AI

In support of the considerations presented in this paper, it is useful to mention some relevant contributions that AI offers to the other four systems in Figure 11.

(A) **CONTRIBUTION OF AI TO THE SYSTEM OF *INCREASING PRODUCTIVITY*** (variable **X3**). AI applications are radically transforming productivity, not only by accelerating existing tasks, but by redefining the very way we conceive work. This revolution manifests itself through significant contributions, including:

A1 – *Task Automation*, reducing routine and low-value activities to a minimum, freeing labor for higher-level roles, and reorganizing work flows and staff self-training;

A2 – *Augmented Intelligence*, increasing efficiency in many activities by taking on the role of "co-pilot", drastically reducing the labor time of humans (Bousdekis,et al., 2025);

A3 – the control of processes through *predictive analysis* and *decision-making*, implementing advanced algorithms to reduce human decision-making errors, thereby contributing to production and logistics;

A4 – increasing the efficiency and effectiveness of marketing campaigns and creating customized learning paths;

A5 – the development, increasingly rapid and profound, of programming for the operating rhythms of machinery, thereby assisting operators and reducing production times.

(B) **CONTRIBUTION OF AI TO THE SYSTEM OF *INCREASING QUALITY*** (variable **X2**). Among the many positive effects of AI on quality are:

B1 – the *control of quality* through sophisticated systems that operate at an increasingly microscopic level, such as vision systems with high-speed monitoring of the characteristics of flows of objects or characters. *Automated visual inspection* (AVI) using cameras on production lines connected to AI has become increasingly widespread;

B2 – reduction of the error rate through the implementation of an effective Zero-Defect Strategy. By analyzing historical data flows, AI learns to recognize the conditions which, in the past, led to a defect in a product, proactively intervening to prevent the anomaly from occurring again. AI is especially effective in analyzing texts and software codes to find spelling mistakes or bugs, resolve errors, and suggest improvements.

B3 – reduction of human error in customer relations and in information provided to the public and to capital providers.

(C) **CONTRIBUTION OF AI TO THE *SCIENTIFIC AND TECHNOLOGICAL SYSTEM*** (variable **X1**). The contributions to scientific and technological progress are so vast that I am forced to limit myself to some specific topics.

C1 – progress in *medicine* and *biology*: AI is able to map the contents of every human cell and the functioning of every organ, producing simulations and targeted drugs;

C2 – contribution to the *exploration of space* and *astrophysics*: super-modern telescopes (such as the James Webb and, when completed, the Extremely Large Telescope) detect an enormous quantity of data and images of the universe impossible to analyze without AI. Based on the data examined and developed, AI can analyze, with unprecedented clarity, the images of objects far distant in space and time.

(D) **CONTRIBUTIONS OF AI TO THE SYSTEM OF INCREASING WELL-BEING** (variable **X4**); at the level of society and the community in general, AI offers tools to address some of the major challenges of humanity.

D1 – "Driven" by the other four systems of Improvement and Progress, AI systems have become powerful contributors to the study and control of *Environmental Sustainability* and *Climate Change* and to the enhancement of many processes that impact our well-being, among which:

– *Energy efficiency*: AI can optimize electricity grids (*smart grids*) to reduce waste and integrate renewable sources more efficiently;

– *Precision agriculture*: AI can help optimize the volumes of water and fertilizer needed even for each individual plant, ensuring food security and minimizing the use of pesticides (Panotra, et al. 2025);

– Predicting *natural disasters* (floods, fires, hurricanes): AI-based predictive meteorological models make it possible to predict the dynamics of natural catastrophic events, suggesting, well in advance, evacuation and safety plans for areas at risk (Venkadesh, et al., 2024).

D2 – The "democratization" of knowledge and education: by reducing linguistic, educational and socio-economic barriers in different places on the planet, AI promotes the spread of distance learning, producing a noticeable impact on social mobility and equality of opportunity;

D3 – Increasing public safety and encouraging the creation of *Smart Cities*; in increasingly large and congested cities, AI can make traffic management efficient so as to reduce travel times and noise and air pollution. AI makes cities more livable and safer, optimizing public transport, allowing "predictive maintenance" of infrastructures (railways, metro, bridges, roads), thereby increasing safety at the social level;

D4 – Significant contributions to both medicine and surgery (Ghebrehiwet et al., 2024):

– *Medicine*: facilitating Medical Diagnosis and Treatment. AI systems can analyze medical images and patient data to detect diseases earlier and more accurately. In particular, detecting cancers from X-rays, CT scans, MRIs, and mammograms; Drug Discovery and Development accelerating the process of finding new medicines.

– *Surgery:* enhancing robotic surgical systems, remote operations between continents, helping surgeons perform complex procedures with greater precision (smaller incisions, reduced blood loss, less postoperative pain, faster recovery times, less postoperative pain, etc.).

D5 – However, despite the advantages produced in society and the environment, AI can also have negative effects, among which social isolation, techno-stress (Rahmi et al. (2025), inequalities, and data selection discrimination and bias, which can give rise to and spread many prejudices and stereotypes. Fortunately, there are also AI applications that monitor and try to control such negative effects.

The extreme power and versatility of AI, in its various configurations, are made evident by the previous examples. Even without addressing it, however, we cannot fail to mention the relevant problem of the “Explainablility” of Artificial Intelligence systems, vital for the assessment of the algorithms and to determine the completeness of the data used (Saarela & Podgorelec, 2024).

> Artificial intelligence (AI) and machine learning (ML) have demonstrated their potential to revolutionize industries, public services, and society, achieving or even surpassing human levels of performance in terms of accuracy for a range of problems, such as image and speech recognition … and language translation (…). However, their most successful offering in terms of accuracy—deep learning (DL) (… 5)—is often characterized as being “black box” and opaque (…). Indeed, such models have a huge number (many millions or even a billion) of weights (parameters) which are supposed to contain the information learned from training data. Not only is the number of these weights very large, but their link to the physical environment of the problem is extremely hard to isolate. This makes explaining such forms of AI to users highly roblematic. Using opaque “black box” models is especially problematic in highly sensitive areas such as healthcare and other applications related to human life, rights, finances, and privacy (Angelov et al., 2021, p. 1)

In Figure 11, only *reinforcement loops* appear, which means that the system might generate a continuous increase in the values of all the Combinatory Systems indicated in the model. Consequently, the system of AIs produces, and will increasingly produce, the *Expansion* and

Dissemination of AIs and Robots, and thus improvement and progress in Well-Being and in the other three very important connected systems. This generates in people many concerns for the fate of Humanity because the danger is perceived that technological development, driven by AI (loop **X1 – Y**) will lead to the *decrease of human work* and the *increase od competition* between humans and AIs and Robots, – non-human entities much more powerful, efficient and faster than humans – which could generate unthinkable scenarios similar to those proposed in many science fiction films.

With great Authority, His Holiness POPE LEO XIV, in his:

ENCYCLICAL LETTER ***MAGNIFICA HUMANITAS*** ON SAFEGUARDING THE HUMAN PERSON IN THE TIME OF ARTIFICIAL INTELLIGENCE,

In several places, it has clearly highlighted the dangers of AIs (and Robots) on people's lives, for example by stating, as stated in paragraph 102.

> 102. The use of AI is never a purely technical matter: when it enters processes that affect people's lives, it touches on rights, opportunities, status and freedom. Important and sensitive decisions — concerning employment, credit, access to public services or even a person's reputation — risk being fully delegated to automated systems that do not know "compassion, mercy, forgiveness, and above all, the hope that people are able to change," [125] and can therefore give rise to new forms of exclusion. There are clearly harmful uses, such as the manipulation of information or violations of privacy. Yet there is also a subtler danger, for when AI systems present themselves as neutral and objective, they end up reflecting and reinforcing the stereotypes or ideological bias of their designers and developers (POPE LEO XIV, 2026, Par. 102).

11 – Conclusion. Repetitive system does not endlessly produce its own reinforcing or balancing processes

There is also the possibility (risk) that AIs and robots, interacting with scientific and technological progress, evolve to such a degree as to escape human control, transforming themselves from useful tools for man into autonomous "entities" capable of "improving and "reproducing", like the self-replicating automata von Neuman has demonstrated were possible (von Neuman, 1966). With the use of advanced 3D laser printers — which are rapidly improving as a result of scientific and technological progress systems — autonomous robots guided by advanced AIs could be equipped with a human appearance, generating a worrying level of *social danger*. An automaton that reaches a sufficiently advanced level could even camouflage itself among humans to manipulate them. This would be even more terrifying because the self-reproduction and improvement of the automata and the integrated AIs could follow an exponential curve. If a machine could self-replicate and connect autonomously to other devices to improve itself, the speed and intensity of artificial evolution could soon surpass natural biological evolution, which has taken millions of years.

I conclude with a crucial question that many are asking: will the dynamics of the systems in Figure 11, which act in a necessary, continuous, and tireless way — in particular, the system of *Expansion and Dissemination of AI and Robotics* — lead to continuous advancement in society? The answer would seem to be positive, based on the logic of the *Combinatory Systems of Improvement* connected only by a single reinforcing *loop*.

I hope that a cardinal principle of Systems Thinking can be applied, a true general law:

> LAW OF DYNAMIC INSTABILITY: *expansion and equilibrium are processes that do not last forever; they are not propagated ad infinitum. Sooner or later stability is disturbed. Sooner or later the dynamics are stabilized.*
> Every expansion is attenuated and reversed by *brake* variables and by connected *balancing* processes which, in turn, can be disturbed by external *disturbances* or even by linked *reinforcing* processes. …
> Systems Thinking could instead state: «*Every repetitive system does not endlessly produce its own reinforcing or balancing processes because other processes intervene to reverse the dynamics*» (Mella, 2012, Sect. 2.7, CLD 2.16)

In fact, the uninterrupted growth of a variable produced by a Combinatory System of Improvement and Progress, sooner or later, generates negative effects in the related systems, which slow down growth and can even reverse it. Referring to AIs and Robots, it is not unrealistic to think that their improvement and diffusion, accompanied by increasing productivity and quality, can reduce the level of human work, and therefore of saleable or deliverable goods, negatively affecting the levels of well-being.

> 104. From this follows a simple but compelling consequence: we cannot consider AI to be morally neutral. In reality, every technical tool embodies choices and priorities through what it measures, ignores and optimizes, and how it classifies people and situations. If a system is designed or used in a way that treats some lives as less worthy, or excludes them without the possibility of appeal, then it is not merely a tool "to be used well," since it has already introduced criteria that contradict the inalienable dignity of the human person. For this reason, ethical discernment cannot be limited to asking whether we are using a system for good or bad purposes; it must also examine how that system is designed and what vision of the human person and society is embedded in the data and models that guide it (POPE LEO XIV, 2026, Par. 104).

All that remains is to hope in the capacity for human control and in the wisdom in the use of AI, waiting… with apprehension, but also with curiosity.

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