What Is Artificial Life Today, and Where Should It Go?

Alan Dorin
Monash University
Computational and Collective Intelligence Group
Department of Data Science and AI
Faculty of Information Technology
alan.dorin@monash.edu

Susan Stepney
University of York
Department of Computer Science
susan.stepney@york.ac.uk

1 30 Years of *Artificial Life*

The field called Artificial Life (ALife) coalesced following a workshop organized by Chris Langton in September 1987 (Langton, 1988a). That meeting drew together work that had been largely carried out from the 1950s through to the 1980s. A few years later, Langton became the founding editor of this journal, *Artificial Life*, which started its life with Volume 1, Issue 1_2 in the (northern) winter of 1993/1994.[1] This current issue therefore begins the 30th volume and 30th year of *Artificial Life*. We think this is a milestone worth celebrating!

In the proceedings of that first workshop, Langton famously defined ALife as the study of "life as it *could* be," of "*possible* life," in contrast to biology's study of "life as *we* know it to be" (on Earth). His stated aim was to derive "a truly general theoretical biology capable of making universal statements about life wherever it may be found and whatever it may be made of" (Langton, 1988b, p. xvi).

Central to ALife is a debate that has continued sporadically since the field's formal inception. This explores what should be properly counted as living phenomena and what should not. As a field, ALife has sustained a diverse range of opinions on this topic and has simultaneously investigated even contradictory perspectives. As the field gained attention in the mid-1990s, this was partially responsible for criticism that ALife had a lack of focus, a looseness with metaphor and the use of terminology, and a lack of grounding in fundamental biology (Horgan, 1995; Smoliar, 1995). Such risks were explicitly preempted by Nils Aall Barricelli (1962) as he pioneered digital evolution in the 1950s and 1960s. Similar criticisms, however, have also been leveled at biology for failing to agree on the necessary and sufficient characteristics, hence a definition, of life itself. This is something considered even by Aristotle; countless books, including those by Schrödinger (1944), Monod (1971), Rosen (1991), and Morange (2008), have been written on the subject in the 2,300 years since that time. Hence it is hardly surprising that ALife, a relative newcomer to the debate, has struggled with the same issue, especially because it proposes to broaden biology's definition, whatever that may be.

Possibly as a result of ALife's diversity, the field resembles more a tangled bramble of subdisciplines than some neat "Tree of Life" (Figure 1). Most of its current topics build directly on work

1 Amusingly, at least to Alan, who is interested in such things, a magazine by the name of *Artificial Life* predated the journal. It was first published in the United Kingdom in July 1982 (edited by J. D. Jacob) and covered the emerging goth and postpunk music scene (Mercer, 1991, pp. 26, 73).

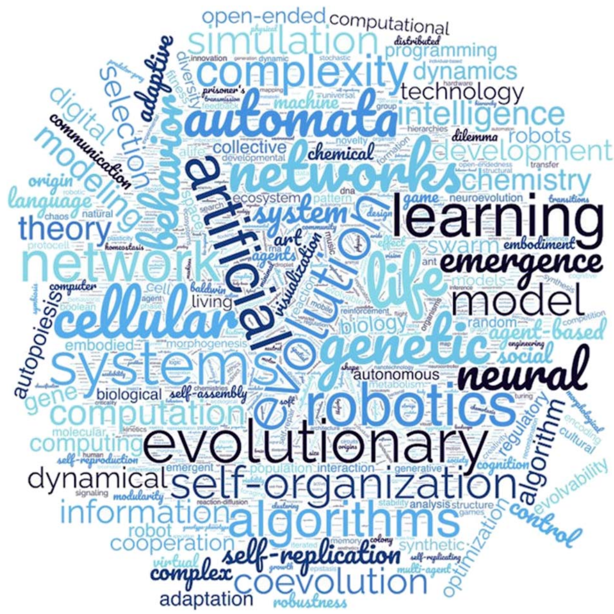

Figure 1. Word cloud of keywords of *Artificial Life* journal articles, 1993–1994, indicating the extent to which the early interests of researchers remain relevant 30 years later.

published in the earliest workshop proceedings (Langton, 1988a; Langton et al., 1992) and the first double issue of this journal. Indeed, we recommend that newcomers to the discipline, and even more established members, (re-)read those early works. They reveal that the relationships between the topics were as tangled then as they are now. Arguably, this is because tight classification seems less interesting to the community as a whole than exploring links between fields; the nodes of this complex network are less important than its edges.

We venture to claim that ALife is an outlet for the parts of ourselves that are "scientific misfits," the parts that do not fit naturally into a single academic discipline. This does not undermine the field's validity, the quality of its practitioners, or the rigor with which ALife research can be conducted; rather, it highlights a strength, namely, that we cherish the opportunity to be creative, to think outside the silos that today's science can inflict regarding "value": departmental foci and territorial stakes, government funding priorities, industry needs, financial reward, initiation of hot topics and trends, promotion paths, employment opportunities, and publication citation metrics. ALife is arguably not a straightforward way to meet such goals.

We have found anecdotally during decades of ALife conferences, meetings, and email exchanges that a diversity of views and explorations is a key feature that maintains individuals' interest in the ALife research community. As a community, we prize novelty, innovation, and open-endedness in approaches to our work as much as we prize them in the outcomes of our research. We have also been historically accepting of a wide range of opinions, have been willing to openly debate them, and have welcomed explorations made by hobbyists or professional academics in their spare time beyond that devoted to "serious" research in traditional and better-supported fields. As a result, ALife remains fresh and fun at 30 plus years, and attendance at an ALife conference can be as exciting as entering a new field, even for those of us who have been involved a long time.

But, if the field is so diverse, does it have a common goal? Yes, and this does not seem to have changed much in the last 30 years, as the word cloud from 1993–1994 (Figure 1) illustrates. We would add, though, that it is not simply to *study* life as it could be using a diversity of approaches; it is also to design it, build it, play with it, and enjoy it from a variety of perspectives. The playful aspect has been criticized repeatedly, especially but not exclusively in the contexts of synthetic biology and cloning, where the manipulated media match those of natural biology. One criticism leveled at practitioners in this subdomain is a perceived need to "play God" (Douglas et al., 2013), usually a male one (throughout Helmreich, 1998), with Frankensteinian connotations of upsetting the natural order (Kember, 2003, p. 56). There may be some elements of this in ALife. But our (one male and one female) editors' sense of the dominant engagement between world builder and worlds here is one of curiosity and wonder, rather than a drive for control or mastery. As pointed out in some accounts of the God-likeness of ALife world builders (Kember, 2003, p. 97), a lack of control is in fact frequently encountered; it may even be desirable (Brooks & Flynn, 1989; Kelly, 1994). Hence the sense of exploration and playfulness not only endures; arguably, it is fundamental.

Playfulness is something we frequently see in submissions to the journal. In fact, we wish that some projects and submissions were less "tinkering" and better structured! We need our journal's submissions to follow at least the main requirements of rigorous science, including well-stated hypotheses; clear context setting; reproducability; careful analysis; and detailed exploration of outcomes, benefits, and their implications. Yet even in the more formal submissions, playfulness and enjoyment need not be diminished; they underpin thoughtful and well-contextualized research in a collective and individual effort to (a) understand the aspects of biological, ecological, and societal systems that facilitate or generate interactions or behaviors typically understood to be characteristics of living systems and (b) replicate the interactions and behaviors of life in media other than those from which natural organisms are constructed.

Ultimately, then, our journal's scope remains more or less constant after 30 years. Studies of life's behaviors and interactions realized through technology are always welcome. The media might change. There may remain long-standing disagreement in the community whether something is "really alive" (Pattee, 1988). There is sometimes a tendency even to ignore or set aside this question and delve recklessly into biological metaphors; we have been warned repeatedly. But all of this has been shown over the years to matter far less to our community than whether our novel study systems behave in ways we deem to be relevant and engaging.

With the design of engaging systems a high priority, it is little wonder that ALife continues to be enthusiastically embraced and broad: compare Figure 2, a title-term plot (1993–2023), and Figure 1, a keyword cloud (1993–1994). Its topics have been surveyed before (Aguilar et al., 2014), even since the early days (Farmer & Belin, 1992), but here we attempt to manage ALife's bramble of subdisciplines with a simple taxonomy and 30 years' hindsight. We then discuss the articles published in this issue of the journal, before concluding with a discussion of some important ethical and practical concerns for future ALife technologies.

2 A Taxonomy of the Discipline of ALife Today: Untangling the Bramble

Today's interdisciplinary study of ALife covers a variety of aspects.[2] Not all researchers in these areas would consider themselves to be studying ALife per se; nevertheless, here we describe a simple taxonomy of research topics in this context. As noted, these topics do not form a neat hierarchical tree but rather form a tangled meshwork of interconnected and interrelated aspects that encompass ALife activities. Our classification is not exhaustive. A complete and detailed scope would be short-lived, because the field shifts with changes in technology, understanding, and culture; its boundaries are ill defined, and as subareas mature, they may calve off, form new (sub-)disciplines; and acquire new names.

2.1 Artificial Organisms

This topic considers *individual artificial entities that represent or behave like artificial organisms*. It can be roughly broken down into three areas: wet, robotic, and virtual ALife (Bedau, 2003; Farmer & Belin, 1992).

2 Langton's definition of ALife was made at the first Artificial Life conference, the proceedings of which are subtitled *Interdisciplinary Workshop on the Synthesis and Simulation of Living Systems* (Langton, 1988a), indicating its then focus.

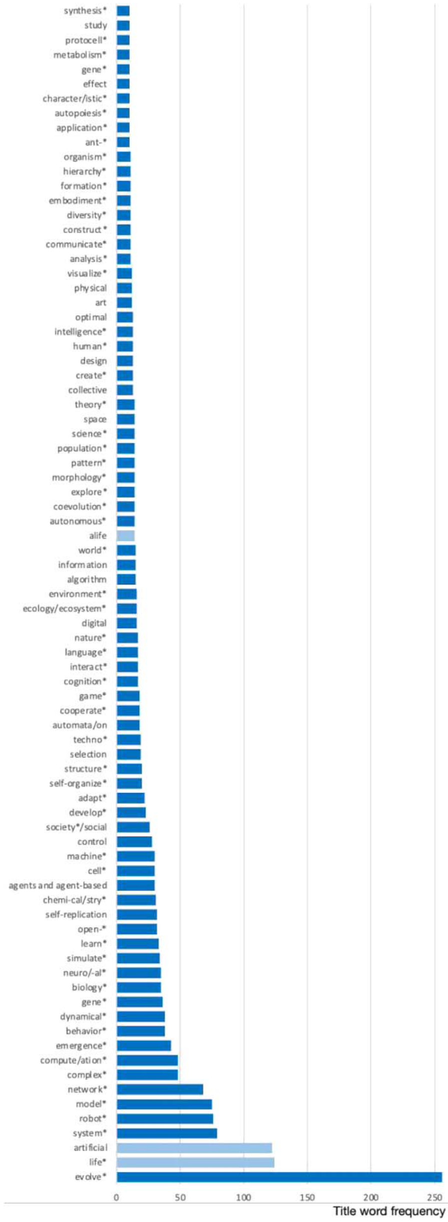

Figure 2. The most frequent title words appearing in the 816 articles published in *Artificial Life* from Volume 1, Issue 1_2 (1993/1994), to Volume 29, Issue 3 (2023). Words are ordered by increasing frequency from 10 occurrences (synthesis*) to 256 occurrences (evolve*). An asterisk indicates that similar terms have been manually, subjectively, and imperfectly selected and amalgamated according to their connotations in the field, for example, synthesis* includes *synthesizes*, *synthesize*, and variant spellings; create* indicates broader topics, including *creation*, *creative*, and *creativity*. The frequencies of *artificial*, *life*, and *alife* (pale blue bars) are hardly surprising. The data reveal also strong interest in evolution, systems, robotics, models, networks, complexity, computation, emergence, behavior, and dynamics, demonstrating the diversity of activity the field encompasses. Some research areas are described by many authors consistently, while others are not; some words are used to describe multiple research areas, while others are not. These differences bias the prominence of terms differently in this plot, which is therefore only broadly reflective of the field's activity. One of the journal's recent efforts is to move toward standardization of keyword selection, something we editors hope will facilitate future analysis of publication topics.

Wet ALife covers artificial entities made from "wet" chemicals and their reactions. Examples include chemical systems like motile droplets (Čejková et al., 2017); minimal protocells constructed either bottom-up, from biochemical components, or top-down, by stripping out nonvital components from natural cells (Rasmussen et al., 2009); and natural organisms modified by synthetic biology techniques, such as gene engineering (Hanczyc, 2020).

Robotic ALife covers artificial entities engineered from "dry" components. The robot bodies may be "hard," mostly rigid, stiff mechanical components with relatively few degrees of freedom, or "soft," mostly pliable, elastic components with very many degrees of freedom (Lee et al., 2017; Yasa et al., 2023). The "brains" of these systems are often some form of neural controller implemented in a standard computer. The area includes *evolutionary robotics*, especially when allowing body and brain to coevolve (Doncieux et al., 2015; Nolfi & Floreano, 2000); *swarm robotics*, a population of homogeneous or heterogeneous robots cooperating to achieve a task, from nano-scale to macro-scale systems (Schranz et al., 2020); and *cognitive robotics*, focusing on the intelligence, learning, and adaptation of robots (Cangelosi & Asada, 2022).

Virtual ALife covers artificial entities that exist in a virtual environment as software running on a computer or over a network of computers. The research goal is for these entities to actually live, not to be mere simulations of life (Pattee, 1988). What this means, and whether it is possible, has been a subject of some philosophical debate, especially in the early days of ALife. Life is a dynamic process; "life is a verb, not a noun" (Gilman, 1904, chap. X). Does that process need to be physically realized in carbon-based chemistry, or can it be realized in different material substrates undergoing different physical processes—or can it even be virtual? Does the matter matter? The computational viewpoint tends to say that it does not (Langton, 1986; Ray, 1992); the biological viewpoint tends to disagree (Maturana & Varela, 1980; Morange, 2008; Rosen, 1991). Pattee (1988) explored criteria for realizations of virtual life.

Some of the issues around virtual ALife are sidestepped by *simulated ALife*, which makes no claims about the simulation being alive, and by *embodied ALife*, which focuses on embodiment and situatedness as necessary components of a living entity (Clark, 1997); a form of embodiment may be possible even in virtual systems (Stepney, 2007). Consideration of embodied ALife includes aspects of growth, morphogenesis, and development (Doursat et al., 2012) and more generally of self-construction, self-assembly, and autopoiesis (McMullin, 2004; Varela et al., 1974).

In addition to these subclassifications of the material (physical or virtual) of organism *bodies*, the *informational and computational* aspects of the various *structures and processes* are also essential facets of the whole living system. From the information content in a genome, through its extraction and translation in developmental processes, to whole-organism and population behaviors and evolution, and on to intelligence, all have an essential computational aspect (Stepney, 2023).

Any and all of the aforementioned subareas can be merged, for example, in evolutionary swarm robotics (Bredeche et al., 2018). Biomolecular nanoswarms (Hauert & Bhatia, 2014) might be classified at the intersection of wet and swarm ALife, given the individuals' wet biomolecular bodies and swarm robotic collective behaviors. Morphogenesis can result from self-organizing swarm behavior (Slavkov et al., 2018). These examples demonstrate the tangled nature of the discipline—something that is true for all parts of our taxonomy, not only for artificial organisms.

2.2 Artificial Ecosystems and Societies

Natural organisms do not, and cannot, live in complete isolation. They exist as populations and live in ecosystems. Several species of organism, including some primates and insects, live in structured societies. This branch of ALife studies *collections of interacting artificial entities*; its themes overlap significantly with artificial organisms (section 2.1).

Populations of organisms undergoing reproduction with inheritance and variation in the context of differential selection experience Darwinian evolution. Evolutionary algorithms (De Jong, 2005) use simple analogies of these concepts to search for optimal values of extrinsic fitness measures; their use can often have unexpected and surprising results (Lehman et al., 2020). However, natural evolution is much more complex, in terms of genome complexity, population sizes, numbers of generations, reproductive strategies from horizontal gene transfer to sexual selection, gene regulation, the role of development and epigenetics, interactions between multiple coevolving populations, and intrinsically defined fitness. These more natural features of evolution are the domain of ALife evolutionary studies, as examples of recent publications in the journal indicate, including the articles by Cussat-Blanc et al. (2018), Liard et al. (2020), Veenstra et al. (2020), and Bull (2021).

Populations also exhibit emergent group behaviors, such as collective movements in schools, flocks, or swarms (Reynolds, 1987) and eusocial insect nest construction (Theraulaz & Bonabeau, 1999). Study of biological processes like these can help drive developments in swarm robotics; simulations can help demonstrate how these group behaviors can emerge from only local interactions, without centralized control.

Organisms live in *ecosystems*, comprising populations of their own species, other species, and an environment of abiotic entities and processes, all of which provide niches, of different ways of making a living, that can themselves appear, disappear, and evolve (Kampis & Gulyás, 2008; Luo et al., 2018). This extra layer of complexity allows different species to interact and affect each other's evolution, through predation and food webs (Lindgren & Nordahl, 1994), cooperative and competitive coevolution, symbiosis (Vostinar & Ofria, 2018), and parasitism (Hickinbotham et al., 2021). Additionally, as complexity increases, the ecosystem can facilitate *social* and cultural interactions (Marriott et al., 2018). Predation, cooperation, and culture all involve *interaction*, which leads to studies of sensing, communication, and language (Yamauchi & Hashimoto, 2010).

Evolution and ecology are also fundamental to biology. Where ALife study systems can differ from natural ones is in their ability to allow researchers to shift parameters far from naturally occurring values (Dorin et al., 2008). Exploration of the possibilities this provides can help us to determine what features are necessary for life and what are merely contingent features and frozen accidents of the single instance of natural life that we have to examine. ALife can not only "replay the tape" (Gould, 1989) of past life; it can design and play tapes very different from those that have been, or could be, run on Earth, helping to clarify and extract life's essential properties. ALife uses two main techniques to do so. *Simulated and virtual worlds* provide a facility to examine the dynamics of complex evolutionary and ecological systems. *Theoretical techniques*, including complex dynamical systems, feedback networks, systems theory, and cybernetics, can provide powerful general models of life, and tools to help us understand them, by providing generalizable results.

2.3 Open-Endedness

One property natural life has is its "*endless forms most beautiful*" (Darwin, 1872, p. 463), the apparently boundless diversity of natural organisms and their ways of making a living. The study of this phenomenon comes under the heading of *open-ended evolution* (Packard et al., 2019a, 2019b; Taylor et al., 2016), or open-endedness in general (Banzhaf et al., 2016). For understanding how open-endedness got started within Earth's evolving populations of organisms, there is the question of the *origin of life* (Cardoso et al., 2020): Is it possible for systems to "evolve" prior to being living? How? Following this, what do transitions from prelife, via protolife, to full life look like? Once living entities exist, how do processes of *speciation* occur? Moreover, how do *major transitions* in evolution (Maynard Smith & Szathmáry, 1995), which involve the emergence of new levels of complexity and organization, occur, and is there a limit to the number of levels that can emerge? Does this involve meta-evolution, the evolvability and evolution of evolvability and evolution (Payne & Wagner, 2019)?

Open-endedness may be considered in the context of social and cultural systems, as well as physical systems. So studies of processes for creativity and novelty generation (Boden, 1990; Saunders & Bown, 2015), of variation, technological innovation (Buchanan et al., 2011), and transformation, also fall into this category of ALife research.

One main activity in this area is the use of a variety of *generative systems* to build demonstrator simulations of purportedly open-ended systems. These include cellular automata (Beer, 2014; Langton, 1986; Wolfram, 1984), generative grammars (Giavitto et al., 2002; Prusinkiewicz & Lindenmayer, 1990), artificial chemistries (Banzhaf & Yamamoto, 2015), and automata chemistries like Tierra (Ray, 1992), Polyworld (Yaeger, 1994), Avida (Adami & Brown, 1994), and Stringmol (Hickinbotham et al., 2011). A parallel strand of activities attempts to define and quantify open-endedness, to detect its presence or absence in such simulations and in physical systems (Dolson et al., 2019; Stepney & Hickinbotham, 2023).

2.4 History, Philosophy, and Inquiry Into the Nature of ALife

There is a rich prehistory to the field now labeled "Artificial Life." Individuals from diverse cultures have mimicked and replicated organisms' appearances and behaviors using many media and technologies (see examples collected by Arnold et al., 2001; Bazopoulou-Kyrkanidou, 2001). Concepts like life, scientific enquiry, and artistic practice remain fluid today and are certainly not universal or constant throughout history. We cannot therefore automatically ascribe to our predecessors from different times or cultures the same goals or motivations as we have. However, the construction of an automaton, an engineered humanoid, has a particularly long-lived and widespread history, including in ancient Greece, ancient Rome, 11th-century China, medieval Persia, Renaissance Italy, and 18th-century France (Al-binkamāt, 1976; Bedini, 1964; Berryman, 2003; Chapuis & Droz, 1958; Gao, 2000; Price, 1964). These capture our attention today as they did the attention of inventors and writers who documented them at the time, in whatever location and conditions they lived and whatever the reasons for the automaton's creation. Hence some authors have created histories of ALife that predate the naming of the field by assembling and studying work that has touched on those themes we now place under its banner. Others have assembled contemporary ALife work conducted since the field's labeling, into surveys and analyses adopting a variety of perspectives (Aguilar et al., 2014; Levy, 1992; Riskin, 2003, 2007; Taylor & Dorin, 2020). These histories help set the context for today's work, and remind us of the fluidity of the concepts to which we may otherwise be tempted to cling.

Some ALife researchers ask what might be termed the "big" questions. Foremost of these is, *What is life*? (Bedau, 2007). Natural life is physical in nature; there is no "vital spark" or nonphysical "life force." However, living systems appear to be qualitatively different from nonliving systems. One goal of ALife is to define life in a way that is not dependent on potentially contingent properties of natural terrestrial life but that would apply to all the endless possible forms of life and to determine necessary and sufficient conditions for it (Bartlett & Wong, 2020; Bedau, 2007).

Other discussion topics within ALife, all touched on in various other sections of this taxonomy, explore relationships between intelligence and life; whether embodiment is essential or just helpful for life; the meaning of autonomy; the concepts of emergence and supervenience; the role of observers in defining boundaries and therefore living systems; how to explain collections of organisms, such as colonies, societies, and organizations; the grounding and generation of language; what it means for an organism to sense or perceive its environment; the relationship between biology, machines, and computation; whether biological evolution is in fact open-ended, as well as what *open-ended* means and how to measure it; and the relationship between open-endedness, novelty, creativity, and evolution. ALife is a highly fertile breeding ground for debate!

The moral and ethical issues of modifying and creating living physical and virtual organisms are also under consideration (Douglas et al., 2013; Witkowski & Schwitzgebel, 2022). Others consider these issues, as well as the environmental and societal impacts of lifelike systems, especially if they interact directly with ecosystems and human societies (Eldridge, 2021; Sayama, 2021). The Artificial Life conference series now includes a recurring track on "ALife and Society" that we hope will continue. We editors welcome submissions to the journal on ALife, society, and the environment. These have not been received nearly as often as we would like.

Although traditional academic articles and software are a common way to voice opinions and debate issues related to ALife, this field in particular has spawned a healthy body of inquiries into the relationships between biology, society, and technology through art. ALife artworks may draw for inspiration on historical artifacts sometimes considered as part of the prehistory of the field, but they also draw on more recent work from the 20th century in cybernetics and computer art (Reichardt, 1968) and specifically from ALife's themes (Dorin, 2015; Ohlenschlöger, 2012; Whitelaw, 2004;

Wu et al., 2024). In addition, ALife's basic techniques, such as interactive evolutionary algorithms, virtual ecosystems, and cellular automata, have found many applications in computer graphics and electronic media art, without the art necessarily focusing explicitly on ALife's themes. Many ALife processes were used for generating patterns and images before their association with ALife was formed. For example, Lindenmeyer's L-Systems for plant modeling and Reynolds's flocking boids are now staples of our field that were first applied as computer graphics techniques. Reaction-diffusion models were, of course, originally conceived by Turing (1952) to explain biological pattern formation.

2.5 Tools, Techniques, and Applications of ALife

As just outlined in the case of computer graphics, ALife research often requires and designs unique tools and repurposes existing tools for new contexts. Many ALife studies develop and use virtual worlds. These may be specific to ALife, but their software might rest on general-purpose, agent-based frameworks or even on computer game worlds. As with any science, analysis tools (statistics, genealogies, metrics, etc.) are needed, and tools for visualizing complex results are helpful in priming relevant intuitions. Some ALife research tool kits have been developed to educate the general public and the next generation of ALife researchers, especially through interactive websites and e-books.

ALife has its own technological and industrial applications; synthetic biology (engineering natural organisms) is a prominent one, but there are also many potential applications of evolutionary algorithms that seek novelty for generative design. In general, our simulation tools can model many complex real-world phenomena and help us tackle societal and environmental problems. They can also be used to manufacture software, hardware, and wetware that mimics the behavior of living organisms. There are many possibilities for ALife systems to interact with biological, ecological, or societal systems. This is potentially valuable but has serious risks and requires careful consideration of ethics.

Tools and techniques are well developed, but applications beyond our field are relatively few and far between compared to (for a current example) the application of large-language models, computer vision, and deep-learning tools. Exceptions include work already noted as falling under the ALife conference "ALife for social / environmental good" activity. But sometimes when things go well, the applications spin off into other domains, such as synthetic biology, land management, epidemiological modeling, urban planning, generative industrial design, or evolutionary algorithms, and we may lose sight of them. ALife is growing tendrils into other fields that help to make our work relevant, even if, as a community, we do not always get the credit.

3 Articles in This Issue

For this anniversary issue, *30*(1), we invited submission of articles related to the history, philosophy, and open questions of ALife and have also selected other submissions that fit our celebratory theme. We anticipate publishing further articles relevant to the anniversary throughout the coming year.

Cartwright et al., in their article "Information, Coding, and Biological Function: The Dynamics of Life," provide a perspective on the need for incorporating information theory in understanding and explaining biological processes, and its place in synthetic biology. This demonstrates the need for interdisciplinarity in ALife: computational and information-theoretic concepts combined with biological processes.

Garbus and Pollack, in "Emergent Resource Exchange and Tolerated Theft Behavior Using Multiagent Reinforcement Learning," present a multiagent model whereby agents playing a bartering game can use reinforcement learning to build cooperation without the need for direct communication. This demonstrates the use of simulation models to investigate the emergence of complex behaviors from apparently simple scenarios.

Harvey, in "Motivations for Artificial Intelligence, for Deep Learning, for ALife: Mortality and Existential Risk," takes us on a historical, philosophical, and personal journey considering artificial intelligence, contrasting the symbolic "GOFAI" approaches and the more biologically inspired "cybernetic" and neural network advances relevant to an Artificial Life perspective. Deep ethical issues are involved, but maybe not the most popularized ones.

Miralavy and Banzhaf, in "A Spatial Artificial Chemistry Implementation of a Gene Regulatory Network Aimed at Generating Protein Concentration Dynamics," present an abstract model of a gene regulatory network and examine the resulting complex dynamics. This provides a model that can potentially contribute to evolving biological protein synthesis and equally to understanding complex dynamics that could be incorporated into an artificial system.

Taylor presents "An Afterword to *Rise of the Self-Replicators*," adding information on further contributors to the history of self-replicating and evolving robots originally presented by Taylor and Dorin (2020). This adds further material from the 19th and early 20th centuries to the deep and long history of the subject.

Wu et al., in "A Survey of Recent Practice of Artificial Life in Visual Art," review and categorize recent artworks about or inspired by ALife. Art is a topic well represented at the ALife conferences, but less so in the journal, and so we welcome its appearance here.

We finish this anniversary issue with two book reviews. The first, by Waldegrave, revisits Levy's popular science book *Artificial Life: The Quest for a New Creation* from 30 years ago. The second, by Caves, reviews Striedter's 2022 book *Model Systems in Biology: History, Philosophy, and Practical Concerns* from an ALife perspective.

4 A Note on the Ethics of Future ALife

How can we ensure that our research makes positive contributions to society broadly, and to our environment, over the next 30 years? This has not been a commonly stated intention of researchers in ALife over the previous 30 years. How do we avoid fiddling while the world burns? Or worse still, how do we avoid building technological systems that directly interact with physical, biological, ecological, and social systems to their detriment?

To begin with, researchers in ALife would do well to avoid the age-old issue of policy failing to keep pace with technology, innovation, and change. As Rick Deckard says,[3] "replicants are like any other machine. They're either a benefit or a hazard. If they're a benefit, it's not my problem." Our technologies have, without a doubt, many benefits, but we also face many hazards. We have long known that the climate is changing due to technological combustion of fossil fuels. We have known that humans are destroying Earth's ecosystems more directly, too, via mining, the increased pace of land clearing for industrial agriculture, and urbanization. We have known since the 1960s that our use of chemical pesticides damages the environment, that agricultural chemical runoff pollutes waterways and oceans, and that trawlers and dragnets are overexploiting fisheries. We have witnessed how technology has forced changes in the job market through the industrial revolutions. And in all of these situations, governments and policymakers have, in general, been slow and ineffective at tackling the complex problems new technologies have generated or facilitated. Even where opportunities existed, often (but not always; McCulloch, 2003) policy and action have failed to keep pace with change. In some cases, change has been perceived to be problematic; for example, vested interests have assisted governments and industries in maintaining the status quo regarding fossil fuel production. In other cases, legislation may appear to be hasty, rather than considered, and inconsistent across countries, for example, the use of genetically modified food.

One fresh issue close to artificial life is what to do about the problems of artificial intelligence, specifically large-language models like ChatGPT and image generators like MidJourney. These systems are widely recognized to be misappropriating the creative work of visual artists and writers; they further undermine the credibility of online media that aim to tell something approximating "truth"; they are powerful weapons for spreading misinformation and customized propaganda and in their consequent influences on public opinion and decision-making. And they aren't done yet.

3 *Blade Runner* (dir. Ridley Scott, 1982). The quoted dialogue is Rick Deckard (Harrison Ford) talking to Rachel (Sean Young). The movie is an adaptation of Philip K. Dick's 1968 novel *Do Androids Dream of Electric Sheep?* and is set in the far future world of 2019.

Artificial Life could follow the reactive policy path of artificial intelligence. We could wait until we have built a physical system capable of self-reproduction, of autonomous goal setting and achievement, and only then scramble to regulate its application and mitigate its impacts. Given past history, in our opinion, this is most likely to cause real problems. The application of swarm robotics, one interest of ALife research, to autonomous armed military drones is an example of a research outcome we feel is ultimately problematic and should have been preemptively regulated. Autonomous military drones in general ought to be regulated, and some countries are calling for this to occur (Australian Human Rights Commission, 2023).

Rather than following the usual reactive approach, ALife should do something that sets us apart as a field. Applications of ALife for societal and environmental good, as noted earlier, are a step in the right direction. Indeed, real-world application of ALife systems to engage with natural ecosystems and societies to better manage and sustain them is a natural yet underexplored aspect of our field.

Working toward positive outcomes, while laudable, is insufficient, however. We should also be establishing policies and frameworks for the proper creation and management of artificial living systems to avoid dangerous or unethical research avenues and applications. It is better to be prepared, because ALife's emerging technology has consequences potentially more profound than anything humans have yet manufactured. An underlying principle at least to "do no harm" is desirable. But in practice, this is not a simple goal to achieve: We must balance harms and benefits between different social, cultural, and political groups and their needs, desires, agendas, and beliefs. And we have to weigh human harms and benefits alongside environmental harms and benefits; we have to weigh the needs of individuals versus those of communities and other groups. This is nothing new: It is the bread and butter of policy development. Perhaps we as researchers accustomed to dealing with complex dynamical and social systems are ideally situated to make inroads here, if we were to extend our field to actively engage policymakers. We are yet to do so.

What are we waiting for? This is a future the ALife community should actively construct, well before the next 30 years elapse. Then, at 60 years, we would really be able to celebrate our achievements!

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