Artificial life and embodied robotics: current issues and future challenges.

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Abstract

In this paper we explore some of the issues currently facing researchers in the interface between the twin fields of Artificial Life and Robotics, and the challenges and potential synergy of these two areas in the creation of future robotic life forms. There are three strands of research we feel will be of key importance in the possible development of future embodied artificial life forms. These are the areas of evolutionary robotics, and evolutionary humanoid robotics in particular, probabilistic robotics for deliberation, and robot benchmarking with associated metrics and standards. We explore each of these areas in turn focusing on our current research in each field and what we see as the potential issues and challenges for the future.

1. Introduction

Evolutionary robotics and evolutionary humanoid robotics in particular, should be a key area for future research, because as we seek to create artificial life (Alife) forms demonstrating complex behaviour patterns, it will become more difficult to explicitly program these behaviours. This is particularly the case for humanoid robots which will be expected to perform in increasingly unpredictable environments and where safety issues will take higher precedence (e.g. when operating in environments where small children are present and interacting with the robot).

So-called 'hard' Alife involves real robots [1]. We can identify two major subcategories in hard Alife. Creature-oriented Alife (after Rodney Brooks' *creatures*) focuses on the creation of embodied artificial life forms with no particular attention to their form or specific function, Function-oriented Alife concentrates on the creation of artefacts engineered with a specific function or set of functions in mind.

Some researchers may contend that the twin areas of Artificial Life and Robotics are becoming increasingly separate with researchers in one field paying little attention to results in the other. We contend there is a potentially high overlap between the two fields and advocate a more synergistic approach to research in this general area, with researchers in both fields benefiting. This paper attempts to present a unified approach the development of robotic platforms that comply with the principles of the hard Alife paradigm. Our unified approach for embodied Alife is based on the three-layered robot control architecture.

This consists of a deliberative tier, sequencer, and reactive module based on subsumption principles. This tiered approach has created barriers to the evolution of a cohesive development methodology. For example, while Evolutionary Algorithms (EAs) have been applied to the synthesis or specification of a subsumption architecture, it is difficult to envisage how EAs can be used to generate higher-level goal-oriented behaviours such as mapping and localisation. Therefore, research efforts have frequently been focused on the development of competencies for a single tier, assuming the existence of other tiers a priori. This approach has resonance with criticisms of the Toy Blocks World program, one of the motivators that drove the emergence of Behaviour-Based Robotics. This picture has been further exacerbated by the emergence of the Probabilistic Robots paradigm for control and mapping, with heavy emphasis on mathematical formalisms based on Bayes filters and Hidden Markov Models. Which approach to use?

For further interesting discussions on possible reasons for (and avenues toward) creating robots that imitate living entities see the papers by Holland [2] and Brooks [3].

The next section introduces our work in evolutionary humanoid robotics, a key element of our overall approach.

2. Evolutionary humanoid robotics

Evolutionary humanoid robotics is a branch of evolutionary robotics dealing with the application of the laws of genetics and the principle of natural selection to the design of humanoid robots. By humanoid we mean that we are concerned specifically with autonomous robots that are human-like in that they mimic the body or aspects of the sensory, processing and/or motor functions of humans to a greater or lesser degree. A major advantage of humanoid robots is that they may be able to operate with ease in environments and situations where humans live and work. This will allow the robot to be useful in a whole host of situations in which a non-humanoid robot could well be powerless. The human-like form of these robots may also facilitate human-robot interaction. However because of the complex nature of the robots' morphology and potential desired behaviours, traditional design methodologies may not be adequate to the task. Our approach is that by using artificial evolution robots may be evolved which are stable and robust, and which would be difficult to design by conventional techniques alone.

Our current work in this area focuses on the difficult problem of bipedal locomotion in humanoid robots. Our initial work in this area involved the evolution of walking purely on a simulated humanoid robot. Our latest research continues to evolve the behaviours in simulation; once bipedal locomotion has evolved we then move the evolved control algorithms to the real (embodied) robot. Our current robot platform is the Robotis Bioloid humanoid robot. This robot has 18 degrees of freedom and is particularly suited to evolutionary robotics research because of the easily extensible and modifiable nature of the platform. A modified version of this humanoid robot was used for Humanoid Team Humboldt in the RoboCup competitions in Bremen 2006. [4]. To gain initial experience with this platform we first constructed a "puppy-bot" (Fig. 1) which can walk on four legs, avoid obstacles and perform several cute tricks.

The humanoid robot is simulated using the Webots mobile robot simulation package, which allows for the creation and modification of a large variety of robot types and robot worlds and it also allows for the creation of controllers for these robots. Webots uses an accurate physics simulator allowing for the potential transfer of evolved robots from simulated to real robots with little or no modification. [5]

We have built an accurate model of the Bioloid humanoid in Webots and it is now possible to evolve walking, and other behaviours, in Webots using our model and then transfer the evolved behaviour directly to the Bioloid humanoid robot. The translation of the motion data is currently done partly by hand but we are working on fully automating this process.

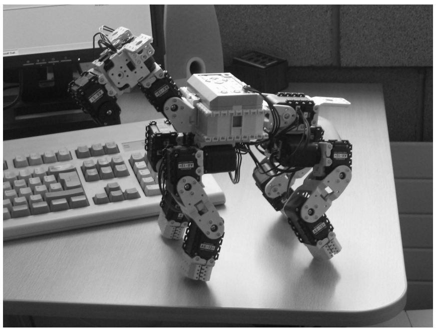


Figure 1. The "puppy-bot"

We use a genetic algorithm to evolve the positions of the joints of the robot at four points in the walk cycle, called keyframes. An existing interpolation function fills in the joint values between these keyframes and the cycle repeats until the robot falls over or until a set time limit is reached. The fitness function used is a simple function based mainly on the distance total travelled by the robot with a bias added for motion in the forward direction.

Our previous work involved evolving a subset of the Bioloid robots' joints [6], however a recent upgrade of the Webots software allowing for the detection of internal collisions has allowed us to extend the evolution to the full 18 joints of the Bioloid humanoid. Fig.2 shows a walk evolved in the Webots simulator and Fig. 3 demonstrates this walk as transferred to the Bioloid humanoid. This walk evolved in generation 482 of a run (population size 100) and corresponds to a rapid but slightly unstable walk in the forward direction. The transfer to the real robot is not perfect due to some small inconsistencies between the Webots model and the actual robot indicating work remains to be done to fully "cross the reality gap" but our current results are very promising. The evolved robots have developed different varieties of walking behaviours and many observers commented of the lifelike nature of some of the walks developed. We are also exploring the evolution of humanoid robots that can cope with different environmental conditions. These include reduced ground friction (ice) and modified gravitation (moon walking).

Nolfi and Floreano provide a good introduction to the general topic of evolutionary robotics [7]. See references [8-10] for other work in this general area.

The next section introduces our approach to the areas of model building and planning.

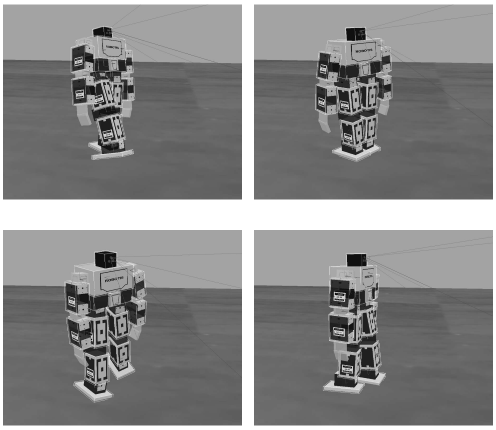


Figure 2. Webots simulation of Bioloid humanoid

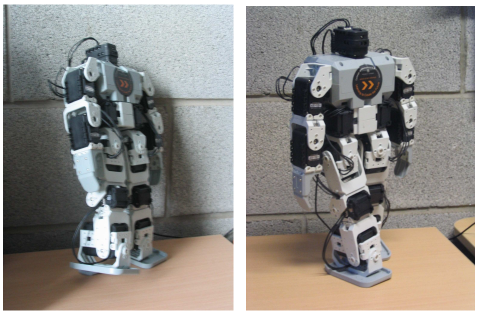


Figure 3. Bioloid humanoid walking

3. Probabilistic Robotics

The term *Artificial* has particular resonance within the unified framework previously introduced. Not only does it refer to mechanisms that can generate artificial life, but also to paradigms that endow such artificial forms with higher-level intelligent behaviour. These behaviours are built upon behaviours of perception, mobility, and survivability in dynamic real world environments.

The behaviour-based approach to robot engineering has become synonymous with the subsumption architecture [11]. This architecture has itself been equated with reactive or stimulus-response implementations. Reactive paradigms in general fail to support the emergence of platforms with higher-level intelligent competencies which rely on deliberation and planning, or model building and strategy formulation. While model building has been correctly criticised in the past for the barrier posed by this endeavour to real-time control, this does not imply that it serves no useful purpose in the field. One could argue that much of the recent success in the field of artificial intelligence, machine learning, and embodied robotics, has been the result of probabilistic paradigms that build models appropriate to the task at hand.

The field of probabilistic robotics has emerged as the dominant paradigm in the field of robot mapping and localisation [12]. The approach is based on the principle that a robot that fails to embrace uncertainty has no basis for rational decision making. The process of map building can be viewed as a learning task, in which the robot searches for either an optimal mapping from sensors to occupancy, or navigates through the universe of maps to find that which best matches the input on the sensory channels. Maps can then serve as a basis for higher-level functionality such as path planning in a variety of tasks from robotic Hoovers and lawnmowers, to care assistants.

Map-building in static environments is difficult due to the following:

1. Noisy perceptual channels
2. Localisation requirements
3. Specification of a sensor model
4. Simplifications introduced to ensure tractability

These difficulties are depicted in Figure 5, illustrating the difference in quality of the maps generated by alternative paradigms when a robot is deployed in an environment that corresponds to that shown in Figure 4.

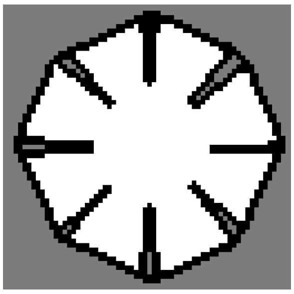
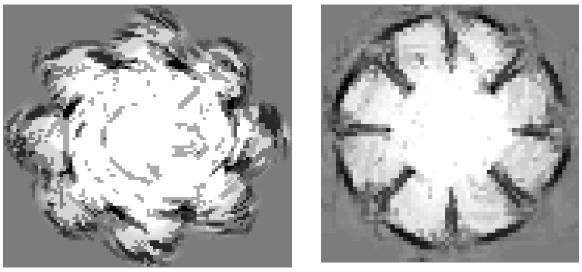


Figure 4. The ideal map of a star environment.



(a) (b)

Figure 5. Occupancy grid maps generated for figure 4.

A considerable range of map building paradigms have been documented in the literature, ranging from probabilistic and Bayesian frameworks, to artificial neural networks, to the Cartesian symbolic-oriented approach. At the University of Limerick, the focus on probabilistic robotics is in the field of map building using the Expectation Maximisation algorithm in an online manner [13]. Further challenges include partially observable state, another topic of research at this University, with a focus on the specification of reinforcement learning paradigms with respect to robot pursuit and evasion [14]. Our current work in this area is based on the Pioneer 2 platform with a sonar array and laser range finder (see below).

Figure 6. Pursuit-evasion using Pioneer 2 robots

4. Benchmarking

One of the more important tasks currently facing researchers in the fields of artificial life and embodied intelligence is the provision of common benchmarks for performance evaluation. Current benchmarks, while useful, have their problems. We advocate a bottom-up approach to the generation of a common set of experimental frameworks for performance evaluation and benchmarking of bio-inspired robots [15][16]. A current *de facto* standard in this field is RoboCup annual challenge. RoboCup operates in four categories: simulated teams, a small size league, a middle size league, and legged robots. An example small size robot is Khephera; a typical middle sized robot is the Pioneer platform, and the Sony artificial dog fits in the third category. There is also a humanoid league.

Individual skills to be mastered include navigation and localisation on the field of play, and the selection of optimal paths. Inter-individual skills include the coordination of movements with playing partners in order to pass accurately. At the top level the tasks of strategy generation and recognition of opponents' strategies are crucial.

Criticisms of RoboCup stem from the controlled environment in which the robots operate, and the fact that soccer-playing skills are quite specific and may lead to the development of highly focused robots of little use for any other task. Also, the self-localisation problem is somewhat constrained by the used of highly artificial landmarks that completely reduce dependence on dense sensor matching-oriented paradigms.

So while RoboCup may currently be a useful testing bed for approaches to Artificial Intelligence and Artificial Life, problems exist. One potential approach, which we espouse, involves the provision of a set of specifically designed experimental frameworks, and involving tasks of increasing complexity, rigorously defined to facilitate experimental reproducibility and verification.

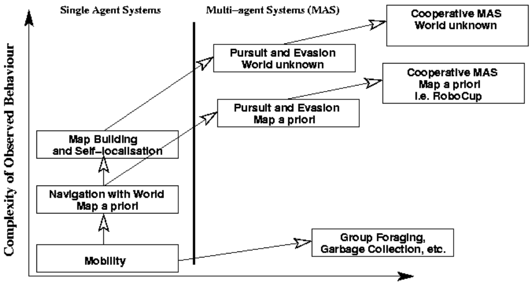


Figure 7. Benchmarking framework.

The authors advocate that issues of map-building and self-localisation are fundamental to progressing robotic-based research as shown in Figure 7. It is also argued that that pursuit and evasion should be undertaken prior to RoboCup type applications, primarily because the modelling of behaviour and interaction can be constrained to just two players. Secondly, pursuit and evasion have strong biological and game theoretic foundations, and thus provide a framework in which scientific modelling of the system can be performed, and later validated through experimentation. Figure 7 strongly hints that current robot competitions should be focused on map building and, pursuit and evasion with a map a priori. Our current approach is focused on the specification of a set of robust benchmarks for (a) map building [18], and (b) robot pursuit and evasion [14].

5. The road forward

In this paper we have addressed what we see as some of the major issues for the future of function-oriented hard Alife. We advocate developing a multi-faceted approach aimed at the specification of a robot architecture that exhibits a range of competencies. In answer to the question posed in the introduction "what approach to take" we see evolutionary robotics as an indispensable tool for the development of complex individual behaviour patterns. For higher-level tasks, such as robot mapping and localization, probabilistic robotics is emerging as the dominant paradigm for the future. Finally we advocate the development of a set of specially designed experiments, freely accessible by researchers, involving graded tasks of increasing complexity, to facilitate future work in this important and exciting field.

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