

# Replicating experiments in "detour behavior" with artificially evolved robots: an A-life approach to Comparative Psychology

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**Abstract.** To be useful in psychology "artificial organisms" have to perform tasks comparable to those performed by animals. One way to achieve this is to replicate actual animal experiments. Here we reproduce an experiment showing "detour behavior" in chicks - a behavior usually explained in terms of "cognitive maps" or other forms of internal representation. We artificially evolve software-simulated robots with a "generic" ability to detour. Sensor-motor physics are carefully calibrated with data from a physical robot. Robot architecture is constrained to exclude internal representation. The evolutionary process rewards exploratory skills as well as detour behavior. Robot performance matches the results achieved in the original experiment. This proves that internal representations are not a necessary condition for primitive detour behavior and suggests that "detouring" evolves naturally from simpler behaviors. Future research will show whether it is possible to evolve more complex detour abilities using a similar bottom-up strategy.

## 1 Introduction

Experimental animal psychology is based on the study of animals performing well-defined tasks in closely controlled conditions. Psychologists use descriptions of behavior to infer animals' cognitive abilities, inputs and outputs, algorithms and internal representations [1]. Comparative studies provide insight into general mechanisms of perception and cognition. This mature tradition has produced a vast volume of reliable data and well-tried methodologies which pose a severe challenge for A-life researchers. An artificial organism, to be useful, has to perform tasks comparable to those that animals perform in the laboratory or the wild [2]: it has to acquire input from a noisy environment using imperfect sensors; motor mechanisms have to be based on realistic physics. Last but not least, the behavior of the organism has to be

measured and recorded with the precision animal psychologists have come to demand. One way to achieve these goals is to replicate experiments from the past, no longer with animals but with robots produced by artificial evolution. In this paper we apply this approach to so-called "detour behavior" – the ability of an animal to negotiate an obstacle to reach a target.

## **2 Related work**

### **2.1 A-life and Evolutionary robotics as a tool in psychological research**

In 1984 V. Braitenberg suggested that it was possible to gain insight into problems of sensory-motor coordination by designing robots exhibiting specific forms of behavior [3]. In recent years a number of researchers began to build robots deliberately designed to test hypotheses in cognitive science. Robots have been built with the ability to simulate insect locomotion [4], to orient towards mating calls from female crickets [5] and to model theoretical models of animal navigation [6].

The challenge of designing "embodied" robots capable of operating in complex environments has been a source of important insights. Psychologists and computer scientists have come to recognize the difficulty of the tasks faced by autonomous agents and the unimagined simplicity of some of the possible solutions [7] [8].

While one school of researchers was developing "adaptive robotics" a second school has worked on the "artificial evolution" of software-based "animats". This approach avoids the limitations associated with manual design. Animats have been "evolved" with a broad range of "interesting" behaviors, such as pursuit and evasion [9]. There have however been charges that animats fail to address the complex problems inherent in the design of physical motor-sensory systems [10].

One way of combining the strengths of adaptive robots and "artificial evolution" is to build simulations which effectively reproduce the behavior of a physical robot. In our group [11] [12], we have developed a methodology for calibrating simulations with data from physical robots. In recent work we have "bred" robots which exhibit efficient exploratory behavior [13] Another theme of recurrent interest has been so-called "detour behavior" [14].

### **2.2 Detour behavior and its interpretations**

When an animal seeks to reach a target it often meets an obstacle. The only way to reach the target is to take an indirect route during which it loses visual contact with the target. This is known as "detour behavior". Detour behavior has been demonstrated in many animals including chimpanzees [15], rats [16] and two day old chicks [17].

For Tolman and Honzik [18] detour behavior is incompatible with behaviorist theory. If there is no stimulus the animal's behavior cannot be a response. Detour behavior, they argue, requires "cognitive maps" of spatial relationships. As Bennett has pointed out, however [19], every experiment which has been explained in terms of "cognitive maps" can also be interpreted in different, often simpler, ways. The neurological evidence is inconclusive. Recording of single neuron activity in the hippocampus appears to indicate the existence of "place cells" which fire when an experimental animal is in a given location [20]. This finding is supported by evidence that hippocampal lesions disrupt landmark-based navigation [21]. Recently however it has been shown that neurons thought to be "place cells" may also respond to non-locational data [22].

### 2.3 Detour behavior in 2 day old chicks

The work reported in this paper replicates experiments by Regolin et al. [19] which have demonstrated the existence of detour behavior in two day old chicks. In these experiments the chicks are placed in a white cage divided in two by a barrier (see Figure 1). The part of the cage on the other side of the barrier contains a corridor. On the end of the corridor facing the target there is a grill through which the chicks can see the target. On each side of the corridor there are apertures leading into two compartments, one facing the target, and one facing in the opposite direction. The two compartments facing the target are labeled C and D.; the two compartments facing in the other direction are labeled A and B.

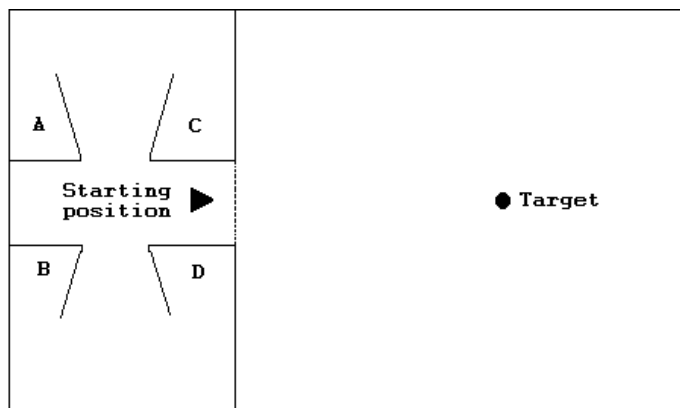


Figure 1: Diagram of apparatus for chick experiment

At the beginning of each session a chick is placed in the corridor close to the barrier and allowed to wander freely. The experimenter records the first compartment the chick enters and the time it takes to reach it. After 10 minutes the experiment is halted.

The results of the experiment show that of 25 chicks tested 5 failed to leave the corridor within the allotted time. Of the remaining 20 animals 18 chose compartments C or D; two choose compartments A and B. The excess of birds choosing the correct compartment was statistically significant ( $\chi^2=12.80$ ,  $df=1$ ,  $p<0.001$ ). There was no significant difference between the number of chicks entering compartment C and the number entering compartment D. These results demonstrate that the chicks were able to turn towards the goal in the absence of locally orienting clues. This, it is argued, shows the ability to maintain a representation of the goal after the loss of perceptual contact. Additional experiments (not replicated in this paper) showed that on repeated trials successful chicks would sometimes choose compartment C and sometimes compartment D. This seems to show that the birds "did not learn a fixed response, (i.e. turn left or right) but a position in space in egocentric coordinates" (i.e. turn left or right depending on the previous direction of turn).

### 3 Objectives and methods

The goal of the work reported in this paper was to "evolve" robots with the ability to replicate the behavior of the chicks yet whose architecture categorically excluded the presence of "cognitive maps" or other forms of internal representation. An analysis of the strategies, sensors and architectures used by successful robots, would lead, we hoped, to interesting explanatory hypotheses for detour behavior.

The experiments used a genetic algorithm operating on a population of 100 robots, simulated in software. The simulation software was designed to precisely emulate the well-known Khepera robot [23]. Input to the robot came from 8 infrared proximity sensors, 4 sensors linked to a linear video-camera and 3 "time sensors". The use of time sensors was motivated by previous work in which we showed that such sensors improve the efficiency of exploratory behavior [13]. Proximity sensors have a sensory field of  $20^\circ$  and are sensitive to obstacles within 3 cm of the sensor. Output (between 0 and 1) is a continuous, decreasing function of distance to the obstacle. The video-camera has a field of vision of  $36^\circ$ . Each sensor produces an output of 1 if the center of the target lies within its own  $9^\circ$  field of vision. The output values of the three time sensors were initially set to zero, increasing respectively by 0.01, 0.02 and 0.03 on each cycle of computation. When a sensor value reached 1 it was reset to zero.

The motor apparatus consisted of a left and a right wheel driven by stepping motors which can move both forwards and backwards. The motor apparatus was controlled by an Artificial Neural Network (ANN) with input neurons representing the state of the sensors and output neurons controlling the stepping motors. A number of different architectures were tested. The architecture finally chosen was based on a simple Perceptron [24] in which all sensors have a direct connection to the two output units. Evolution involved "mutations" in connection strengths. The genome of the organism consisted of a sequence of binary coded numbers (8 bits per number) representing the strengths of individual connections.

We evolved "detour behavior" by applying "artificial selection" to the population of ANNs. In the initial population connection strengths for individual networks were set to random real values uniformly distributed between -1 and 1.

In preliminary work it became clear that it would never be possible to evolve detour-capable robots without rewarding intermediate steps in the evolutionary process as well as the ultimate goal. We hypothesized that detour behavior might be derived from other, more primitive forms of exploration and food-seeking e.g. the ability to move towards a visible target, to negotiate an obstacle and to efficiently search an open space. We therefore designed fitness formulae and evaluation protocols so as to reward these abilities individually even when they did not lead to successful detours. Fitness was recalculated on each cycle of computation, using the following algorithm:

```
IF ( "some infrared sensor" > 0 && old_position ><
new_position) fitness ++

IF ( "some infrared sensor" > 0 && old_position =
new_posion) fitness --

IF (distanceToTarget< 15 cm.) fitness += 10
```

The first two components in the fitness formula were designed to encourage obstacle avoidance; the last component rewarded the robot when it approached the target.

The authors wished to simulate natural evolution and to avoid the emergence of adaptations specific to a particular experimental setting. To achieve this goal robots were evaluated in four different environments (see Figure 3). Each environment consisted of an open field with no external fence. In the first environment there was no obstacle between the robot and the target. The fitness formula rewarded robots which successfully searched for the target and moved towards it. The second, third and fourth environments selected for actual detour behavior. In the second environment the target was placed behind a linear obstacle 80 cm long. In the third environment Khepera was placed inside an 10\*80 cm corridor. The fourth environment used a 40\*70 cm U-shaped obstacle. Obstacles were 3 cm high and of negligible thickness; the target was 12 cm high. It follows that in the "evaluation sessions" the robot was always able to "see" the target even when the path to the target was obstructed by an obstacle. The evaluation test was repeated five times for each environment. At the beginning of each cycle the robot was placed in a randomly chosen position 90 cm from the target. The heading was chosen randomly from a uniform distribution. Each test consisted of 600 cycles of computation.

When all robots had been tested individual robot fitness scores were summed over each of the five tests in each of the four test environments. The 20 robots with the highest overall score were selected for "reproduction". Each of the selected robots produced 5 offspring. Reproduction was asexual. During the cloning process "mutations" were introduced by flipping bits in the genome with a probability of 0.02 per bit per generation. This process was iterated for 350 generations. Each simulation was repeated six times using a different random number seed on each occasion.

Finally, the 4 best robots produced in the last generation of each of the simulations were tested in a replica of Regolin et al.'s experimental apparatus. It is important to note that in this setting the obstacle completely obstructed the robot's view of the target. As in Regolin's work, the results of the experiment were given by the number of robots choosing the correct compartments within a pre-determined duration (600 cycles of computation)

## 4 Results

### 4.1 Evolution of generic detour behavior

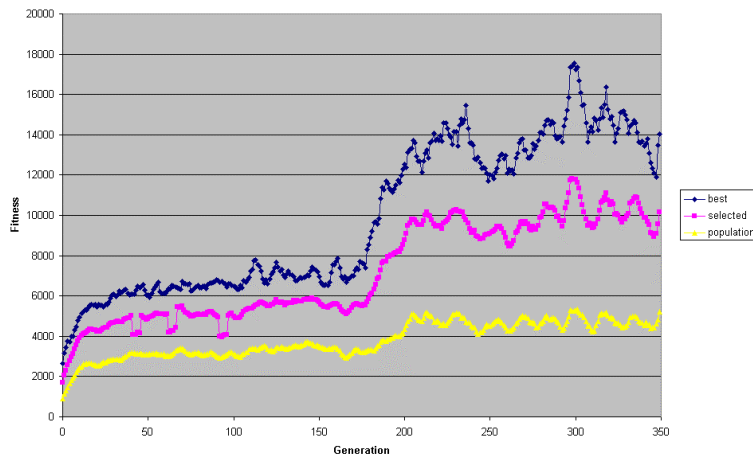


Figure 2: Fitness scores averaged over the 6 simulations.

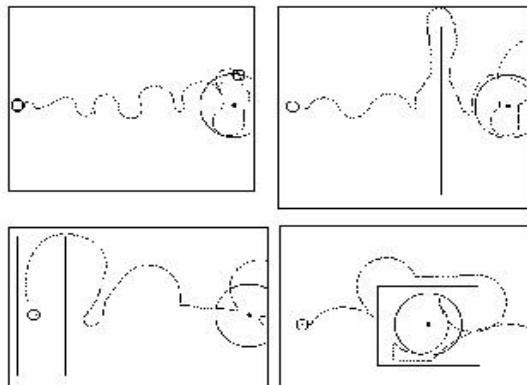


Figure 3: Typical trajectories followed by robots in the four training environments

Legend: Small circles: terminal points for trajectories (if within field box). Large circle: target area rewarded by fitness function

Figure 2 shows the score achieved by the fittest robot in the population, the mean score achieved by robots selected for reproduction and the mean score for the whole population. As can be seen the fitness score for the best organism in the population initially increased rapidly, rising from 2640 in generation 0 to 6500 in generation 50. Between generation 50 and generation 180 fitness levels oscillated around a stationary level of approximately 7000. From generation 180 to the end of the simulation fitness scores again rose, reaching a level of 14,000 in generation 350. A qualitative examination of the trajectories followed by individual robots show that by the end of the evolutionary process all robots selected for reproduction were exhibiting satisfactory detour behavior in all four environments (see Figure 3)

#### 4.2 Performance in the experimental setting

Table 1 compares the performance of the 24 robots with the chicks in Regolin et al.'s experiment.. As can be seen from the table 1/24 of our robots failed to enter one of the compartments within the allotted time (5/25 in the original experiment). Of the remaining robots 22 entered the correct compartment (20 in the original work) and 3 chose the wrong compartment. As is the original experiment there was no significant difference between the number of robots entering compartment C and the number entering compartment D.

**Table 1.** Robots and chicks performances in the experimental setting

	Do not leave the corridor	Sector A	Sector B	Sector C	Sector D	Total
Chicks	5	2	3	9	11	25
Robots	1	0	2	11	11	24

There is no statistically significant difference between the results achieved in our experiment and those reported in Regolin et al. We therefore conclude that our simulation successfully replicates the results of the original experiment.

An examination of individual trajectories shows few differences among individuals; the trajectories followed by robots choosing Sector C are a rough mirror-image of those used to reach Sector D. A typical trajectory is shown in Figure 4.



Figure 4: A typical robot trajectory in the experimental apparatus

## 5 Discussion

In our work every neuron in the ANN directly represented either an input or an output; there were no hidden neurons. In brief the robots we evolved had no access either to maps or to any other internal representation of location.

In different simulations robots evolved different strategies. We have not as yet performed a detailed analysis either of the strategies themselves or of the underlying computational mechanisms. In general however they appear to be based on simple rules, for example (see Figure 3.):

- 1) Main: Move forward turning first clockwise (slowly) and then anti-clockwise (more rapidly).
- 2) Taxis: On visual contact with target turn sharply towards the target. Return to Main
- 3) Wall following: If left proximity sensors active turn right. If right sensors active turn left. Move forwards until obstacle out of view. Return to Main

Input from the time sensors allows the robot to generate differentiated responses to identical external stimuli. It is the time sensors which make it possible for the robot to change its direction of motion in the absence of any external stimulus. The combination of exploration and taxis, which these sensors make possible, represents an efficient strategy for moving towards the target even when it is often outside the camera's field of vision. It is this strategy (rather than an explicit representation of target position) which enables the robots to perform successfully in the experimental setting.

The observation that artificially evolved robots can generate a particular behavior using simple behavioral rules does not demonstrate that chicks use the same rules or that that cognitive maps or target representations do not exist. There is, in fact, at least some evidence that chicks and robots use different rules. Individual chicks are reported to have no particular preference for left over right turns; individual simulation runs on the other hand produce asymmetrical strategies (though the asymmetry may be reversed from one simulation to the next).

While our work does show is that it is possible to generate, at least the simplest forms of detour behavior, without resort to internal representations. It should be added that feed-forward control networks like those used in our experiments have no internal representation of past states. They cannot, in other words, follow the rule Regolin et al. suggest for their chicks, turning left or right depending on their previous direction of turn.

Our work suggests alternative models for detour behavior and the behavioral primitives on which this behavior is likely to depend. The ability to efficiently explore an environment, to locate food, to move towards the food and to negotiate obstacles, are of fundamental importance for a broad range of animal species. The results of our experiment suggest that primitive detour behavior may, in fact, be a relatively simple extension of these basic exploratory capabilities. What they seem to show is that it is possible to generate primitive detour behavior on the basis of nothing more than: (a) a robot's ability to move towards a target, (b) a strategy guaranteeing that it will never permanently lose visual contact and (c) a simple "wall following" routine.

None of this implies, of course, that all forms of detour behavior can be explained so simply. The evidence in favor of cognitive maps is still, at this stage of the game, relatively convincing. And yet a doubt remains. If elementary detour behavior can evolve, step by step, from simple behavioral primitives, might it not be possible to evolve more complex detour abilities using a similar bottom-up approach? This is an issue which we will address in future experimental work.

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