Hunting behaviour: One (Intelligent) System versus Another

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Abstract

In nature, animals routinely engage in predator-prey competitions called hunts. Every hunt is unique and dynamic; to increase the possibility of success, agents in a hunt gain advantage if they can predict the future actions of their competitor by creating a model of the other agent [7]. Animals have been shown to build cognitive maps of their environment and use them to make decisions [25] and plan future actions [19, 8]. But how flexible and sophisticated of a model can they create? How is this accomplished by the brain, and how can we study this in the laboratory? For this PhD project we propose to create a novel hunting behaviour assay to test whether and how a predator creates a predictive model of its prey. After shaping the experimental animal to associate the artificial prey with reward, we will test the animal's predictive model-making ability and strategies by presenting it with unique hunting scenarios. Simultaneously, we will collect sensor data from the artificial prey and the environment, as well as video tracking and psychophysical data from the experimental subject. By creating a more quantitative hunting behavior assay, we hope to also provide insight into the nature and definition of intelligence.

1 Motivation and State of the Art

Hunting is a complex and ethologically important interaction that pressures predator and prey to develop improved motor and cognitive skills [9, 14, 1]. Hunters benefit from developing behaviors that are often considered "intelligent" behaviors, such as the ability to plan, adapt quickly to the environment, learn from experience, and predict the actions of independent agents [13, 26]. Thus, hunting behaviour makes an excellent candidate for a new assay to study the origins and neural implementation of intelligent behavior.

Current studies of hunting behaviour can be divided into two categories: in the wild, and in the lab.

1.1 Challenges of studying hunting in the wild

Most existing studies of hunting behaviour in the wild are detailed collections of qualitative data describing the movement patterns, sensory inputs, and/or development of the hunter. This characterization of the hunter is often accompanied by descriptions of the prey and various environmental features. But wild environments are incredibly complex and measuring everything relevant to a hunt is incredibly challenging. For instance, a 1992 study of African lions in Serengeti National Park, Tanzania, characterized the lions hunting behaviour according to observations of encounter rates with prey types and preferred prey types [22]. Predatory behaviour was predicted based on optimal foraging models, thus excluding from the analysis any anti-predator decision-making by the prey. Such limitations are understandable, as quantifying behaviour and controlling stimuli are difficult in the wild. In the face of this overwhelming complexity, studies must make many simplifying assumptions and end up treating either predator or prey as behaviorally inert.

1.2 Limitations of current laboratory studies of hunting behaviour

Based on the challenges of studying hunting behavior in the wild, it makes sense to study hunting behavior in the lab to gain more control over the interaction. However, existing experiments that probe hunting behaviour in the lab must also simplify the complexities of hunting in the wild in order to isolate specific aspects of the hunting interaction. This often leads to experimental procedures that test the hunting interaction in tightly constrained environments which cannot fully probe the predator-prey relationship [11, 20]. However, some studies have used live prey to provide more realistic hunting scenarios, such as cockroaches to induce predatory behaviour in rats [15, 21]. But even with live prey, the experimenters do not have control over or access to the behavior and predictive abilities of the prey, and thus only limited tests of the predator-prey relationship can be performed. The use of artificial prey, one which experimenters could control within the closed-loop interaction of hunting, could provide a significant advance in the study of hunting behavior.

1.3 Development of behaviorally complex artificial agents

In the last thirty years, the fields of robotics and artificial intelligence have taken more and more inspiration from biological systems to build complex synthetic agents [4, 5, 24]. From virtual simulations to autonomous mobile robots, behaviour-based or reactive control systems have led to artificial agents that are more competent in real or simulated physical worlds, and less predictable in their specific behaviours [3, 23, 27, 10]. Meaningful understanding of complex, higher-level cognitive processes could be achieved by building synthetic agents with very simple behavioral rules, such as "move toward light", then combining these rules to achieve more complex tasks, such as collecting fuel from within a dynamic environment [2, 16]. Based on these advances in robotics and artificial intelligence, we are motivated to engage in a more detailed investigation of the highly adaptive, natural behavior of hunting by building behaviorally complex artificial prey.

2 Goals

We propose to create a novel behavioral assay that quantitatively explores the predictive model-making ability of animals during simulated hunting of artificial prey. By directly and precisely controlling the abilities of the prey, we can develop a more quantitative intelligence test for animals that measures "the maximum intelligence of a successfully caught prey"; in other words, the maximum behavioral complexity with which this animal can compete. Using rats as our first experimental hunter, we will do this by:

- creating artificial prey encoded with behavior-based control algorithms that implement a variety of different behaviors, from stationary availability, to simple physics, to reacting to and predicting the hunter.
- building a "hunting box" embedded with sensors and actuators, such as nose pokes, video cameras, pressure sensors, and stepper motors that can give feedback and present manipulations; we can thus collect quantitative data on the interactions of the rat with a dynamic environment while hunting.
- presenting the artificial prey to the rat inside of the hunting box in both repeated and

novel conditions, and while parametrically increasing the complexity of rules governing the prey's behaviour.

- systematically assaying the predictive model-making abilities of different animals by using these basic elements - artificial prey, hunting box, and increasingly challenging hunting simulations. Potential other experimental subjects include rats under different starting conditions based on age, fatigue, or water- or food-deprivation, or animals of other species.

We believe that developing a new kind of "intelligence assay", based on hunting of experimentally controlled prey, will be fundamentally useful for a number of further experiments, such as probing anticipatory behavior, understanding the role of practice and training in the improvement of predictive models, and examining the power of play, especially role-play, in the development of adaptive behaviour.

3 Implementation and Methodology

The assay will consist of a hunting task in which the rat must catch artificial prey to earn a reward. The artificial prey will be implemented as a projected image made of light or a moving reward vessel. The rat will first be shaped to associate the artificial prey with a reward; then it will be tested on its ability to understand two kinds of causal relationship: reactive and agentive. Data will be collected and analyzed using Bonsai, a dynamic data stream processing tool [18].

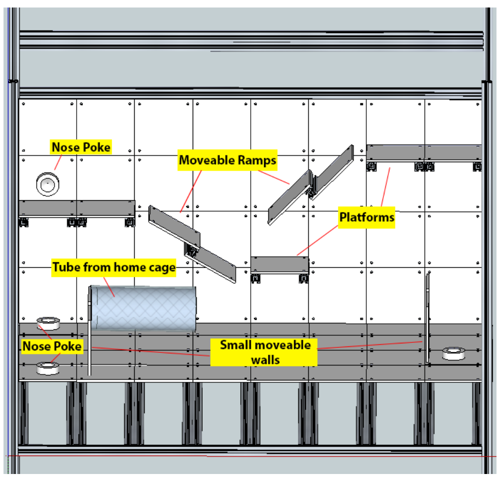
3.1 Environment: the hunting box

The assay will be conducted inside of a "hunting box" environment (See Fig. 1.) which will be embedded with data-collecting sensors and interactive features such as:

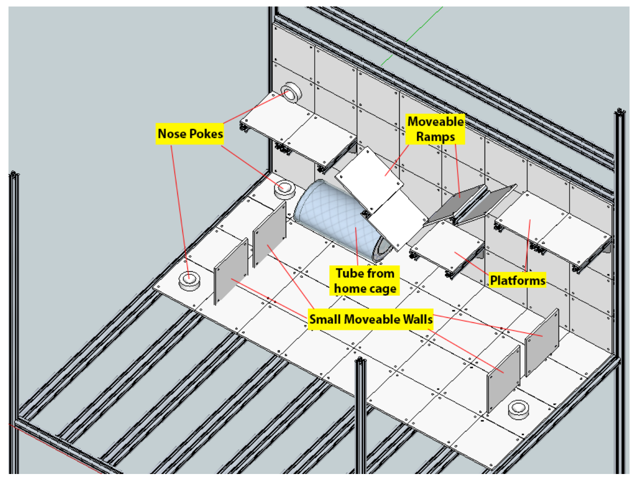
- cameras placed at various views relative to the hunting box, to record video data of the hunt and provide visual tracking of the rat and the target prey (See Fig. 2.)

- projectors for simulating target prey or other environmental features, which can be installed next to the cameras to minimize interference with the visual tracking (infrared filters on the cameras can also minimize this interference)

- small moveable walls on the floor that are connected to stepper motors in order to track their rotational position, which can be changed by the rat during the hunting trial
- moveable ramps on the back vertical wall of the hunting box, also connected to stepper motors to precisely measure their displacement over the course of a hunting trial
- pressure sensors on platform edges to quantitatively characterize jumping, landing, and climbing activity of the rats over the course of the trial



(a) Front (camera) view



(b) View from above

Figure 1: Preliminary hunting box, designed by João Frazão, Danbee Kim, Gonçalo Lopes, Murat Ozdemir, and Malte Zopfs; rendered by Malte Zopfs in SketchUp. Cameras, projectors, and enclosing walls of box not shown.

3.2 Trial structure

Each trial will begin when the rat enters the hunting box and will last for 30 minutes. During those 30 minutes, target prey will appear and be available for predation at random intervals.

3.3 Stages of shaping

1. *Target is motionless and has varying availability.* In this stage, the rat is first shaped to know that reward is available at a fixed port, such as a nose poke with a water delivery

Figure 2: A frame from a video recording of a rat foraging in the preliminary hunting box, taken using a Point Grey Flea3 digital camera with an infrared filter.

spout inside. The reward port will then become available for limited periods of time and will indicate its availability with a tone, thus pairing the tone with the reward. Next, the rat will be conditioned to induce availability of the reward port by collecting the target prey, such as an image made of light which can appear anywhere in the hunting box. Touching the target prey, which can be measured using video tracking or pressure sensors, will elicit the tone and indicate that the reward port is now available. The duration of target availablility will then be incrementally shortened (See Fig. 3.).

2. *Target moves with simple newtonian physics.* Now the target prey can emulate the physical properties of an object such as a rubber ball, and the rat must chase and "catch" the prey by touching it. Similar to the previous stage, when a catch is made the reward tone will sound and the reward port will become available. If the target prey is a moving reward vessel, the reward will be available at the location of the catch to better simulate a real hunt.

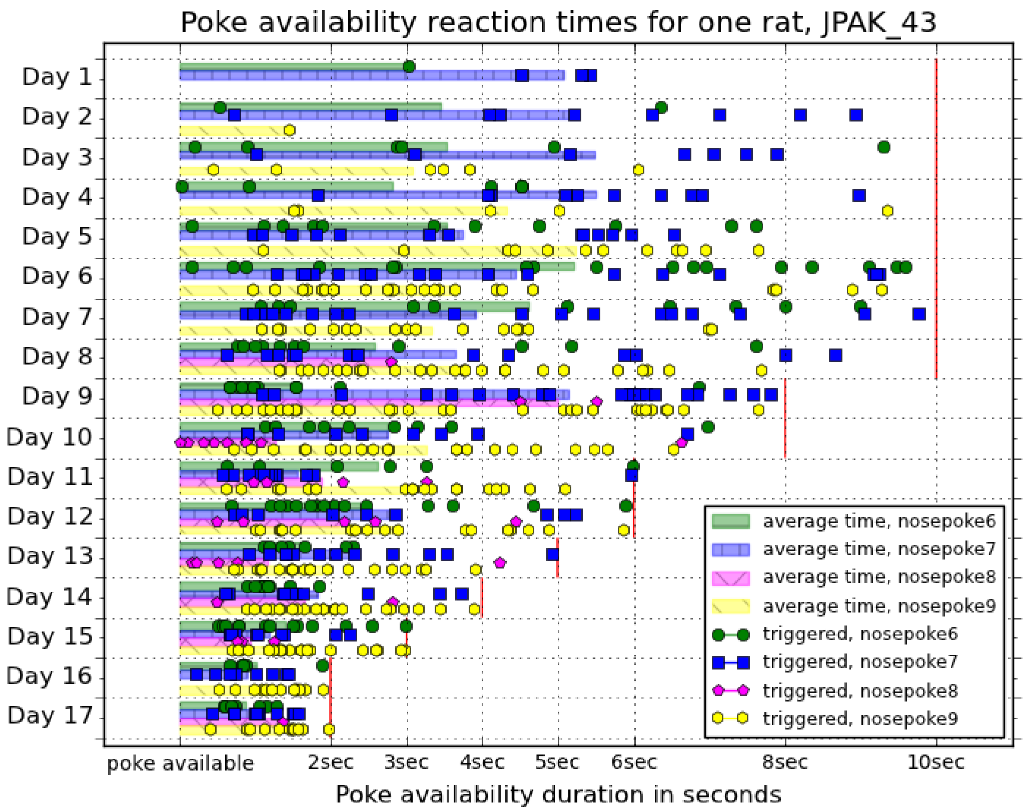


Figure 3: Reaction times to poke availability for one animal (JPAK_43) during the foraging (stationary prey) phase. Four reward ports that delivered water (nosepoke6, etc.) became available at random intervals and were initially available for 10 seconds. On Day 9, port availability was shortened to 8 seconds; on Day 11, it was shortened to 6 seconds; and so on, until on Day 16 and 17 the reward ports were only available for 2 seconds. Each marker (colored circle, square, or hexagon) indicates a nose poke event, which triggers the reward port. As ports became available for less and less time, experimental subjects adjusted their behaviour in order to continue receiving reward.

3.4 Understanding causal relationships: reactive and agentive

Once the rat has been shaped to exhibit predatory behavior towards the target prey, we will test its ability to understand reactive and agentive relationships.

Reactive

The target prey will move according to rules based on the movements of the rat and changes the rat may make to the environment, such as the following:

- Given a certain threshold on hunter velocity, if the rat moves faster than that threshold the target prey will move to maintain a distance of half a rats body length between itself and the rat. If the rat moves slower than the threshold, the target prey will stay still.

- If a variable in the environment, such as one of the moveable walls, is set at a certain value, such as rotated up to 90 degrees clockwise from its nearest neighbor, then the target prey is most likely to appear from the top of the left wall of the hunting box.

These rules can be implemented for both a projected image or a moving reward vessel. Video data from the cameras recording the hunting box can be used to control a live simulation of a ball in Bonsai, which can then be projected into the hunting box. The moving reward vessels from the second stage of shaping can be equipped with visual sensors and an internal gyro (for balance), servo (for steering), and drive motor to propel themselves according to reactive rules.

Agentive

The target prey's movements are now influenced not just by the behavior of the rat in a given instant, but also by the history of the rat's behavior and an active aversion to capture; the prey now behaves as an agent. This can be achieved by adding parameters such as the following to the target prey:

- *directional gaze*: the visual information available to the target prey is now dependent on the prey's physical location and orientation, allowing the rat to "stalk" or "sneak up" on the prey.

- *motor initiative*: before, the target prey used its sensors and the contingencies of its movement rules to find a "free" space, and was content to stay still until triggered by a movement rule. Now, if the target prey has been still for longer than a certain amount of time, it will move in a random direction.

- *vigilance*: if the rat attacks the target prey in quick succession or multiple times in the same location, the prey will grow wary and will spend more time moving in areas of the hunting box where the frequency of attacks from the rat are lower, or it is harder for the rat to sneak up on the prey.

These parameters can be implemented for both a projected image or a moving reward vessel. For instance, the projected image can use a visual representation of an "eye" to indicate the orientation of the prey; mobile reward vessels can have embedded visual sensors and a "face" that indicate orientation and determine what visual information is available to the "prey".

3.5 Guidance from behavioral theories of predator-prey interactions

By creating an empirical method that treats both predator and prey as participants in a behavioral interaction instead of behaviorally inert sources of risk or energy, this assay could provide much needed information on how predator and prey respond to the behavior of the other across different time scales. Some existing theoretical phenomena that can guide the development and analysis of this assay include:

- *predator-prey "shell games"*: shell games occur when predators search for prey that stay on the move to remain elusive; however, these games seem to emerge only at relatively large spatial scales where both predator and prey have multiple options for feeding sites. [17]

- *pursuit-deterrence signaling*: this is a kind of signaling from prey to predator thought to indicate that the predator has been spotted ("perception advertisement") and/or that the prey is able to escape predation ("quality advertisement"). But in studies these signals are usually inferred instead of tested directly, in part because of the difficulty in observing these signals in natural predation attempts, and as a result the nature of information passed from prey to predator can be easily misinterpreted [6].

- *predator management of prey*: predators may try to influence the anti-predator behavior of their prey by making predation attempts more or less frequently in certain locations, and in a way that makes prey easier to capture. Prey management requires the spatial and cognitive abilities to remember what events happened in a given location and create a long-term energy intake strategy. Though the idea of resource-related risk management has been around since the 70s [12], it has not yet been empirically or theoretically explored.

4 Research and Writing Timetable

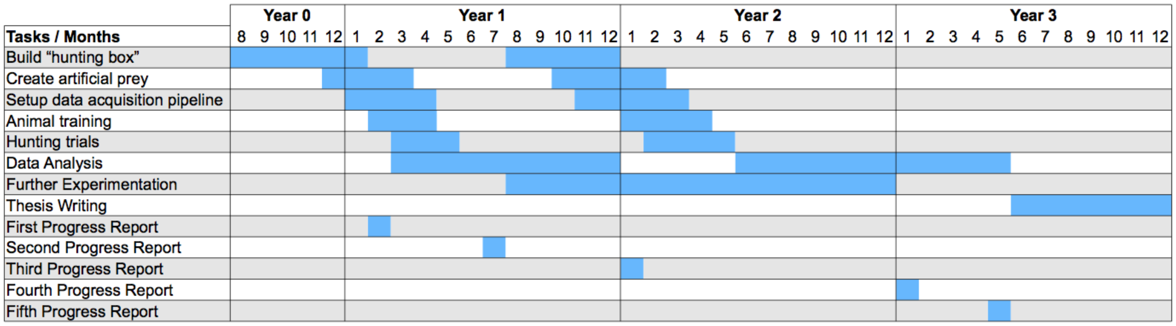


Figure 4: Estimated timeline for project activities.

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