

Human Simulation of Adaptive Behavior: Interactive studies of pursuit, evasion, courtship, fighting, and play

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Abstract

To understand more about how animate motion is generated and perceived, we need quantitative analyses of motion trajectories from organisms interacting in various important adaptive tasks. Such data is difficult to obtain for most animals, but one species provides a ready source. We have developed software that allows human subjects to generate such motion data by interacting across a computer network in on-screen pursuit and evasion, fighting, courtship, and play. Each subject uses a mouse to control a “bug” that moves in a 2-D environment with another bug controlled by a second remote subject. We have visualized and analyzed the resulting motion data for each task in several ways: 3-D space-time plots of the trajectories themselves, scatterplots of one bug’s positions relative to the other, and statistical measures of trajectory parameters including velocity, vorticity, and energy. All of these methods distinguish between the different motion categories. Having human subjects perform these kinds of scenarios can lead to better techniques for analyzing, comparing, and designing the motion capacities of simulated agents.

1 Introduction

Behavior is motion. Consequently, simulation of adaptive behavior (SAB) research typically implies the simulation of motion. But research in this field too often relies on the creator’s subjective impressions of whether a certain behavioral trajectory generated by a simulated agent looks sufficiently “lifelike” or “animate” in a particular task. We suggest a simple, novel method for overcoming this problem: have people simulate the desired motion trajectories themselves, and use this data as the basis for judging a system’s performance.

This method requires human subjects interacting over a computer network to perform the same behavioral tasks that SAB researchers impose on their simulated animals. Such experiments can yield rich motion-trajectory data, as well as subject comments and reactions that can be used in several ways. First, we can check that the imposed tasks make sense to a 100-billion-neuron human; if not, they may not make sense to a 10-neuron

simulated bug. After this simple reality-check, we can compare the human-generated motion trajectories to those generated by our simulated agents, using a whole arsenal of quantitative measures, to assess how appropriate the simulation’s behavior is. We can also use the human-generated data as training exemplars for simulated evolution or learning to shape our agents’ behavior in the first place. Finally, we can study human responses to motion generated by other humans and by simulated agents, and to investigate the cues our species uses to perceive and interpret animate motion – and, by extension, the cues that simulated agents should both generate and perceive themselves.

We are particularly interested in this last use of the tool we have developed: understanding how humans and other animals categorize the different functional types of animate motions we observe in the world. We all can tell the intentions of predators or prey, courtiers or desired mates, by the patterns of positions in space that they occupy over time. What cues do we use to make these judgments? How can we tell when one organism is fleeing, stalking, or playing with us or with another organism? To find out, we need a set of motion patterns that we can have people categorize, and then analyze to find their distinguishing characteristics. But such data is somewhat hard to come by. The literature in both biology and psychology is full of studies of both long-range animal navigation, migration, and commuting, on the one hand, and small-scale limb movements, on the other. However, rather little recorded data on behavioral trajectories exists at the scales of interest inbetween these two extremes. So instead we decided to generate our own, using the animals at hand: the other people in our own lab.

But rather than attach beacons to the tops of their heads and film them from above as they go about their daily activities, we put pairs of people into a simple, highly constrained computer world setting in which they can only interact through movement. Specifically, each person controls their own two-dimensional “bug” in an on-screen environment in which both bugs appear. These human subjects are instructed to engage in various tasks via their bugs – in other words, to “simulate” through their behaviors the very motion types

we are interested in. We collect the data our subjects generate in this way, and analyze it to find the cues that distinguish one category of motion from another.

Part of the application of this work will be in the design of simulated or robotic autonomous agents that move in natural ways that we can identify and attribute specific goals and functions to. One way to test whether our newly-minted motion algorithms truly capture the relevant aspects of animate behavior is to see if people find them convincing. To do this, we have devised a kind of behavioral Turing test, in which one human subject controls a bug interacting with a second bug as usual. But in this case, the subject must decide if the other bug is also controlled by a person, or by an artificial algorithm, based solely on their intertwined motions. If the human subjects cannot tell when they are interacting with a program or another person, then our algorithms will be deemed successful, by being able to produce the appropriate cues of animate motion for this particular task.

This paper reports the results of our human-simulated-behavior approach. Section 2 reviews the biological and psychological foundations of animate motion research. Section 3 describes our methods, including the computer task environment and our experimental procedure. Section 4 presents our results, including motion trajectories from six different tasks and various measures for distinguishing each trajectory type. Finally, section 5 describes possible applications of this method, both for SAB research directly, and for investigating the psychology of animate motion perception. We offer this approach as a useful adjunct to existing SAB research methods – a way of keeping ourselves from being deluded by our human tendency to attribute animacy and intelligence to almost anything that moves.

2 Theoretical Foundations

There has been a great deal of work on animate motion from a variety of theoretical angles. Perceptual psychologists following Johansson [Johansson, 1975] have run hundreds of studies showing that humans are rather good at perceiving and classifying animate motion from point-light displays – videos that show only the traces of tiny lights attached to various parts of a moving human or animal [Cutting and Kozlowski, 1977, Dittrich, 1993, Mather and West, 1993]. Neurophysiologists have identified various temporal lobe areas specialized for perceiving these animate motion displays [Oram and Perrett, 1994]. Developmental psychologists have stressed the high degree of innate preparedness that infants show for recognizing animate motion [Gelman, 1990, Premack, 1990]. Neuroethologists have studied the neural circuits for attack and escape behaviors of invertebrates in great detail, sometimes recording motion trajectories but seldom doing quantitative analysis on them [May, 1991]. Behavioral biologists have studied animal navigation and foraging trajectories, spanning large distances and extended time periods. Some psychologists have attempted to

apply dynamical systems theory to model the dynamics of high-level cognition [Port and van Gelder, 1995], but only a few researchers have applied this theory to the lower-level dynamics of animate motion itself [Beer, 1995, Cliff et al., 1993].

We have found little work, however, to guide us in analyzing the perceptual cues that distinguish one functional category of motion from another. The first step in finding these cues is to establish the basic set of motion categories that concern animate species, with which the cues will be associated. Animate motion is used for a rather small number of functions that can be largely deduced from the implications of natural selection and sexual selection. Basically, animals evolve to interact adaptively with various “fitness affordances” in their environments – things that are likely to affect the replication of their genes [Miller and Freyd, 1993, Todd and Wilson, 1993]. Positive fitness affordances, like food and sexual mates, promote survival or reproduction; negative fitness affordances, like predators, pathogens, parasites, and sexual competitors, interfere with survival or reproduction. Animals evolve sensory-motor systems to approach the positives and avoid the negatives. If two animals offer mutually positive yields, mutual approach results; if they threaten mutually negative yields, then mutual avoidance results. Finally, if instead, two animals have a conflict of interest, more complex interactions can result, transforming simple approach into persistent pursuit, and simple avoidance into desperate evasion [Miller and Cliff, 1994].

From the above arguments, it follows that the fundamental categories of animate interaction are mutual approach (boring), mutual avoidance (also boring), and pursuit and evasion (interesting and unpredictable). In the survival domain, pursuit and evasion usually occur between predators and prey, or between fighting dominant and submissive conspecifics; in the reproductive domain, pursuit and evasion usually occur between male and female in the roles of courter and courtess (or sexual harasser and harassee). Thus, any particular animal will need to master some subset of five basic categories of animate motion: pursuing, evading, fighting, courting, and being courted. To these categories we also add a sixth, play, which is widely used as a way of learning the skills to master the other five movement types. Between species, these motion categories can vary dramatically in the degree of cognitive complexity that they require, but they remain functionally similar over the entire animal kingdom. We now briefly consider the characteristics of each of these classes in turn.

Pursuit: Animals move towards objects they desire. If the desired object is inanimate, we have a degenerate case of goal-directed behavior. But if the object is animate and does not want to be exploited as a fitness affordance (e.g. as food or as a mate), then it will move away (evade). Pursuing often benefits from a predictive strategy, as opposed to reactive approach: more successful pursuers try to anticipate where their opponent

will go, based on that opponent’s current heading and intentions and the environmental constraints they face (obstacles and boundaries), and then try to cut them off [Reynolds, 1994].

Evasion: Animals move away from things that threaten them. Again, if the threatening object is inanimate, we have a degenerate case of obstacle avoidance, or one-step “evasion”. If the threat is animate, however, and does not wish to be evaded, then it will pursue, and sustained evasion becomes necessary. Evasion often favors strategies of deceptive feints and lunges, and/or unpredictable, “protean” zig-zagging [Driver and Humphries, 1988]. Also, evaders must avoid being boxed in by environmental features that limit their trajectory options.

Fighting: Animals of the same species often fight over fitness affordances such as territories, resources, sexual mates, and social status. Fights are tricky because both animals must combine pursuit and evasion, attack and defense, in a way that intimidates or overcomes the opponent, without risking injury or death to themselves. Because animal bodies are heterogeneous, with some parts specialized for attack and other parts vulnerable to injury, fighting includes a great deal of precise body-positioning.

Courting: Animals – usually males – move towards members of the opposite sex – usually females – that they want to mate with. But because selective mate choice is almost always imposed by the opposite sex, simple approach is almost never enough. Instead, mate-seeking animals often evolve extremely complex courtship behaviors with special features designed to display their health, strength, size, status, intelligence, or creativity [Andersson, 1994, Miller, 1996]. These displays are usually produced close enough for the desired mate to perceive them, but not too close, lest they flee. After some display time, ranging from seconds (for some insects) to years (for some humans), if the desired mate signals their interest somehow, the final approach and copulation can occur.

Being courted: Animals sought after as mates – usually females – have strong incentives to select among their suitors quite carefully, because the genetic quality of the suitors they choose to mate with will determine half the genetic quality of their offspring. Random mating is stupid mating. The task when being courted, then, is to express enough interest to elicit informative courtship behavior from various suitors, but not to express so much that they skip courtship altogether and try to move straight to copulation. Thus, being courted requires a delicate balance between interactive encouragement and coy reticence. Courted animals usually maintain enough proximity to their suitors that they can see what’s going on, but do not get close enough to risk real sexual harassment or rape.

Playing: Play is basically a catch-all category in which young animals might practice all of the above movement types, using various play signs to indicate that they

are pursuing, evading, courting, or fighting without real lethal or sexual intent [Fagen, 1981]. In basic play, animals repeatedly switch roles between pursuer and evader, or attacker and defender. In more complex play characteristic of large-brained primates, animals may interact in more abstract ways with imaginary partners or mutual mimicry.

3 Methods for Motion

3.1 Motivation for our design

Real animate motion in natural environments filled with other agents and obstacles is too complex to analyze very clearly. Our experimental methods were designed to collapse this complexity down to manageable but still informative dimensions – specifically, two spatial dimensions plus time. We decided to squeeze the camel of animate motion through the needle’s eye of a two-person computer-based interaction occurring in a featureless, two-dimensional on-screen environment. Based on our theoretical analysis in the previous section, we picked just six tasks for subjects to do in this environment, solely by generating movement patterns through the horizontal and vertical positions of a computer mouse. Although these simplifications might seem extreme, we found that subjects had no trouble identifying with the expressionless one-inch bug they controlled on-screen, becoming highly motivated to guide its motion as best they could to cope with the varied challenges posed by the other subject-controlled bug.



Figure 1: Example bug environment

3.2 Experimental setting

In a series of six pilot studies, twelve subjects participated in our interactive games. Subjects were all researchers, and had various degrees of knowledge about our project’s aims, ranging from complete ignorance (in the case of a researcher’s nine-year-old daughter)

to mild confusion (in the case of two of the authors, Miller and Todd). During each experiment, two subjects (hereafter called A and B) were run at the same time in different rooms. Each subject was seated at a unix workstation, and told that they would be engaging in a series of interactions between their own bug and another bug that appeared on the screen.

Throughout the trials, the chief experimenter seated at a third workstation started and stopped each trial and watched a display of both bugs interacting. During an initial two minute practice period, subjects learned how to control their bug using their mouse, getting used to the physics we instantiated (see section 3.4). Then, subjects (who were anonymous to each other) completed six experimental trials of ninety seconds each. Before each trial, an assistant in each lab room explained the trial task using standardized instructions, and then left the room to minimize biases due to social factors. The trials were ordered as follows:

- (1) A pursues B, B evades A: Subject A was instructed to try to pursue and hit the other bug as quickly and as often as possible, and was told that the other bug would try to avoid being hit. Subject B was instructed to try to avoid being hit, and was told that the other bug would try to pursue it.
- (2) B pursues A, A evades B: As in (1), with roles reversed.
- (3) Fighting (same for A and B): Subjects A and B were instructed to attack the other bug from behind, while at the same time avoiding being attacked in return.
- (4) A courts B, B is courted by A: Subject A was instructed to court the other bug, by interacting with it in any way that it might find interesting, exciting, or enticing. Subject B was instructed to play the role of being courted, and to show interest or disinterest, or to elicit further displays in any way desired, in response to what the other bug is doing.
- (5) B courts A, A is courted by B: As in (4), with roles reversed.
- (6) Playing (same for A and B): Subjects A and B were instructed to play with the other bug in whatever manner they wanted.

3.3 The Appearance of the Environment

For each trial, a new environment window fills each subject’s 21” computer screen. The window is a featureless light-tan rectangular space, representing a top-down view of a simple environment. In that space are two bugs, identical except for color (one red and one green). From the subjects’ top-view perspective, each bug is about an inch long on-screen (see figure 1).

The environments used in all trials had constraining walls around the perimeter, which strongly affects the resulting motion trajectories. The bugs also had a different

preprogrammed reflexive behavior for each task, which fired whenever contact was made: for pursuit/evasion and fighting, a low-frequency temporary grappling ensued; for courtship, a higher-frequency temporary interaction was used; and for play, a simple bouncing repulsion occurred. All of these simulations of localized behavior were developed to encourage more realistic impression of the assigned tasks, as well as forming a type of natural payoff for good performance.

3.4 Bug Physics

Subjects move their bugs using their mouse. Rather than direct “screen cursor” control that instantly tracks mouse movement the mouse moves a “target cursor,” invisible to subjects, that specifies where the bug should head at each moment. The greater the distance between bug and target, the faster the bug moves towards the target, according to the following simple first order differential equation, integrated by Euler approximation¹:

$$\{\dot{x}\} = \{x_p\} - \{x\} \quad (1)$$

where $\{x_p\}$ is the position of the mouse-controlled target and $\{x\}$ denotes the bug’s current position vector. The bug also has limited linear and rotational speeds. In practice, subjects moved their mice around quite quickly in pursuit, evasion, and fighting, usually sacrificing fine positional control for raw speed. In courtship and play, subjects moved their bugs more slowly and deliberately.

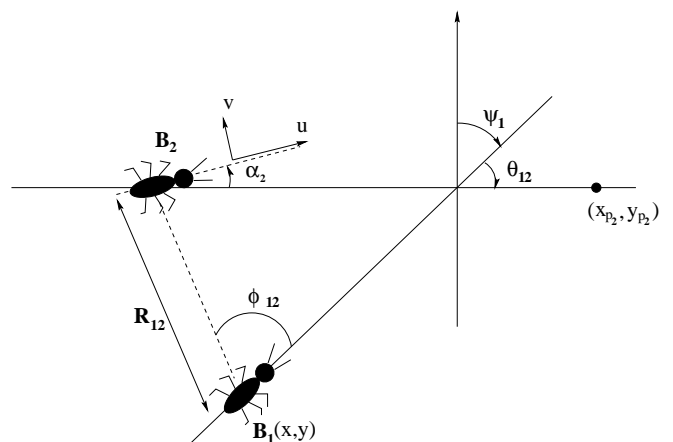


Figure 2: Parameters of the bug environment

Figure 2 illustrates the relevant parameters in the simulation, which fall into two major groups. The first are the dynamic parameters used for simulating the motion of the bugs:

$\{x, y\}$: bug position in the environment

$\{x_p, y_p\}$: mouse-controlled target position

¹A high refresh time of 100-200Hz is required in the simulation dynamics, even though display rates need not be as high, to prevent accumulation of round-off errors in the integrations and ensuing spurious motion effects.

ψ : bug heading relative to the environment

$\{u, v\}$: bug velocities relative to the bug's heading

The second group of parameters capture the relationships between the two bugs that can strongly influence the subjects' controlling behavior. As such, these parameters are probably more important for distinguishing and producing different types of animate motion than the first group:

R_{ij} : current distance between the two bugs (i.e. their centers)

ϕ_{ij} : the perceptual angle between one bug's current heading and the other bug's location

θ_{ij} : the relative angle between the targeted headings of the two bugs

4 Results

4.1 Space-time plots

To visualize the motion trajectories generated in the interactive tasks, 3-D plots of position over time were constructed for each subject pair and each task (see figures 3-6). In each plot, the horizontal coordinates directly correspond to the position of each bug on-screen, and the vertical coordinate is time, running from the start of the 90-second trial (bottom) to the end (top). Thus, the flatter the slope of a plotted line, the faster a bug's position is changing over time – that is, the higher its velocity. Relative distance and relative heading between the bugs are also implicit in this representation. Each plot contains the two trajectories (one for each subject) simultaneously generated in a single trial. Because pursuit and evasion are reciprocal tasks, as are courtship and being courted, we have only shown one plot for each, capturing both roles.

By comparing plots for sample runs from the different tasks, several distinctive features are immediately apparent. In pursuit and evasion (figure 3), one can see very flat (very high speed) movements extending over a greater area of the environment than during courtship (figure 4) or play (figure 6). Pursuit/evasion (figure 3) and fighting (figure 5) show similarly high speeds and large amounts of turning and looping, but in fighting the average distance between bugs is smaller, and the looping is tightly intertwined. In courtship (figure 4), the courter moves much more than the often stationary courtier, sometimes circling, and occasionally engaging the courtier in little bursts of pursuit and evasion. Only a few body contacts (where the trajectories meet) are apparent in courtship. Play (figure 6) looks like a combination of pursuit, evasion, fighting, and courtship; in the trial shown, one of the subjects was much more active than the other.

4.2 Scatterplots of relative position

Of all the on-screen information that is perceptually available to subjects, only a few parameters might

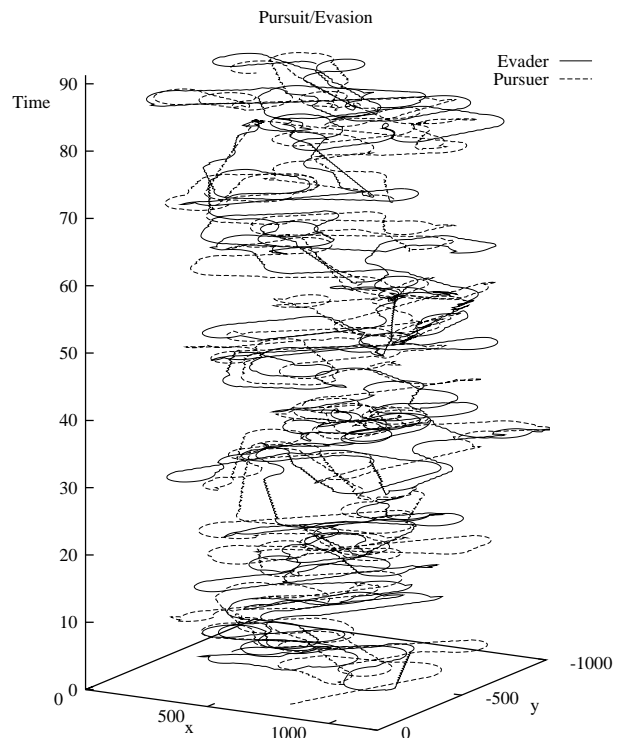


Figure 3: Sample chasing trajectories

actually be used to control the bugs. We hypothesized that subjects use the position of the other bug relative to their own bug's current position and heading as input to simple motion-control heuristics. We also expected that, even if relative position is not the only information used in bug control, scatterplots of this information should show up differences between the motions generated in different tasks.

To represent this information, polar-coordinate scatterplots were constructed for each task, including all data from all subject pairs. For each subject's bug at each point in time, the relative position of the other bug is represented as a single dot at a certain relative angle and distance. One's own bug is positioned at the origin, facing rightward. If the other bug were close and straight ahead, for example, it would be plotted as a point just to the right of the origin on the horizontal axis. Thus, the scatterplots portray the statistical distribution of where the other bug stands in relation to one's own bug, as a result of the strategic interactions between subjects in each task.

When pursuing (figure 7), subjects were usually able to keep the other bug in front of their own bug, and not very far away. However, the pursuers rarely achieved a "kill":

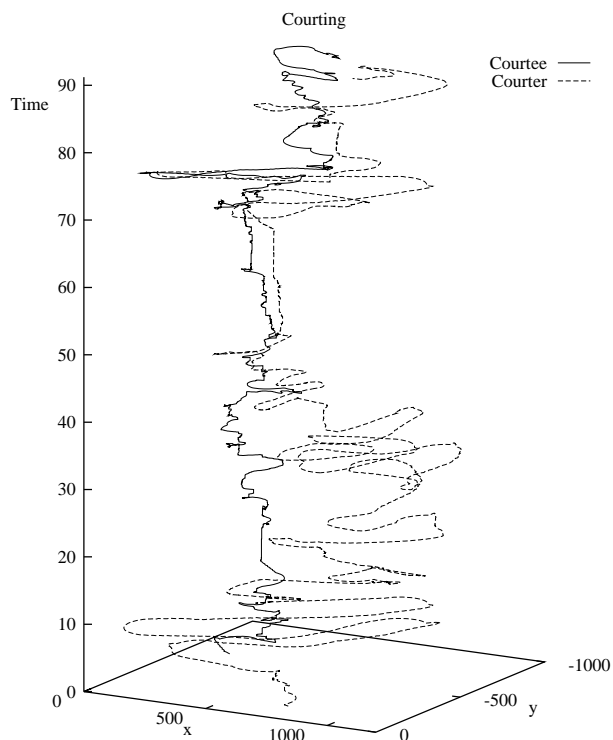


Figure 4: Sample courting trajectories

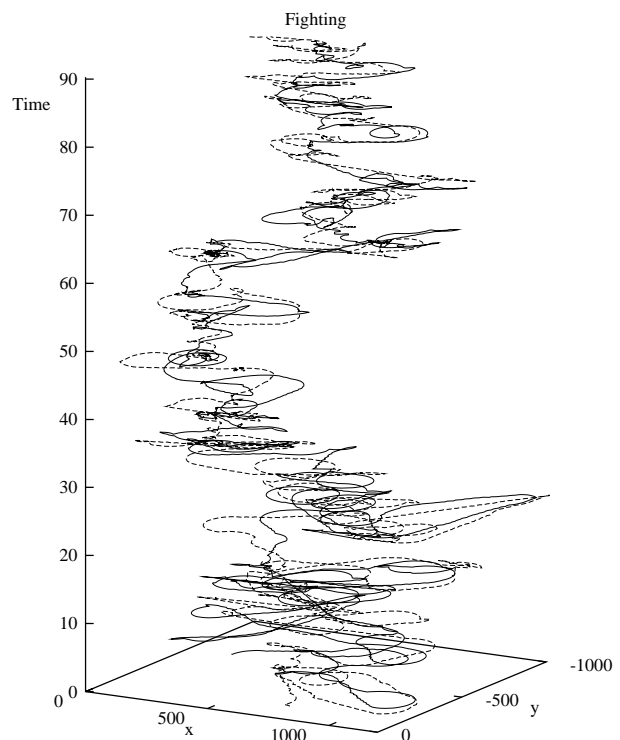


Figure 5: Sample fighting trajectories

the heart-shaped (cardioid) distribution of relative positions grows sparse around the origin, where actual contact points would appear. The distinctive cardioid shape of this distribution is mirrored in evasion (figure 8), where subjects were able to keep their pursuers behind them. The results for fighting (figure 9) are strikingly different: although both subjects were trying to pursue the other bug's tail with their own head, we do not see the same cardioid distribution as for pursuit. Rather, we see a scatterplot almost indistinguishable from a 2-D normal distribution, with complete radial symmetry and the highest density of points right around the origin, corresponding to close-body contact. Play (figure 10) looks completely different again, with a ring of other-bug positions centered around the origin, slightly biased towards forward rather than rearward positions, indicating that individuals oriented themselves toward the other bug more often than not. Also, courtship (not shown) and play both included many distinctive long looping structures, unlike anything apparent in pursuit, evasion, or fighting. These loops sometimes look rather aimless, but nevertheless we intend to analyze them with more sophisticated measures to see whether they might represent a sort of adaptively unpredictable (protean) strategy designed to interest or amuse the other bug.

4.3 Quantitative measures of trajectory parameters

In addition to the rather qualitatively interpreted 3-D space-time plots and the relative position scatterplots, we also applied a set of quantitative measures to the trajectory data. Our hope was that one or a combination of these measures could be used to distinguish motion generated in the different tasks. The measures applied so far are:

- Average Velocity (computed for each bug over an entire 90-second trial)
- Kinetic Energy (the integrated expended kinetic energy of a bug over an entire trial)
- Vorticity (the summed total of the absolute changes in heading of a bug over an entire trial, indicating the amount of twisting and turning it did)
- Radial Distance (computed between the two bugs at each instant and time-averaged over an entire trial)

Table 1 compares these measures, averaged across all subjects, for each different task. Velocities were very high in pursuit, evasion, and fighting, whilst only slightly slower in play, moderate in courting, and lowest when

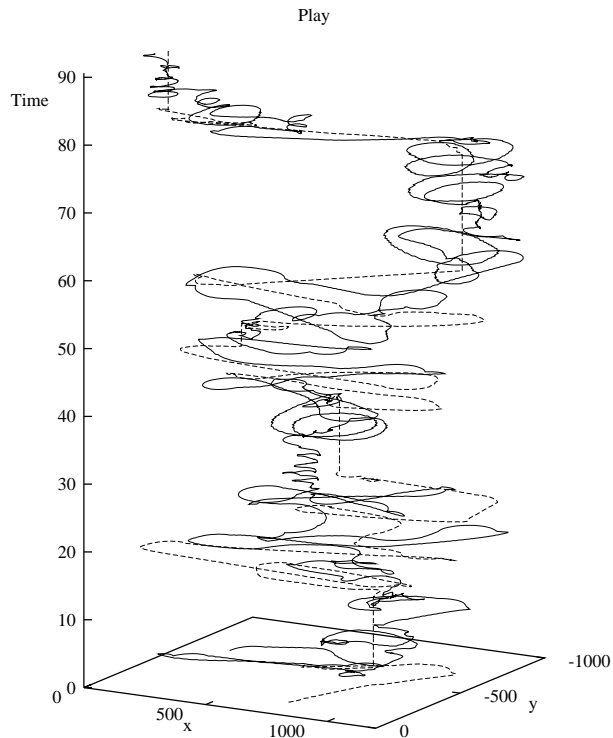


Figure 6: Sample playing trajectories

being courted. However, expended kinetic energy highlights an interesting difference: although playing showed much higher velocities than courtship, they used equal amounts of energy, suggesting that courtship included a large amount of rapid acceleration and deceleration (as it does in animal mating dances). Also, the vorticity patterns are distinctive, with fighting involving the largest amount of turning and looping, followed by courting, with pursuit, evasion, play, and being courted all showing significantly less turning. Finally, the average distance measure shows little difference between pursuit, evasion, courtship, and fighting, but reveals that the bugs were rather far apart during play. This could reflect the subjects’ somewhat relaxed attitude towards interaction in this more cooperative task. In future studies, we plan to develop further measures based on more sophisticated dynamical analysis, and to identify which measures correspond to perceptual cues used by people and animals to categorize animate motion types.

4.4 Subject reports and experimenter observations

After the six trials, subjects were interviewed and asked to comment on all aspects of the experiment: the software, the bugs, the tasks, the environment, their reac-

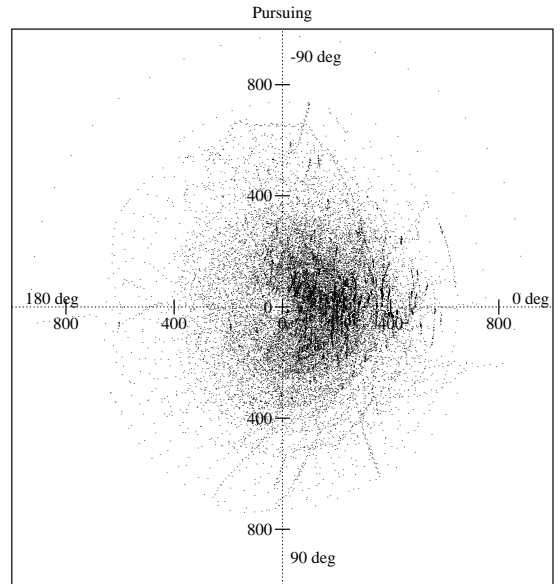


Figure 7: Relative heading / distance plot for chasing

	Pursuing	Evading	Courting	Courted	Fighting	Playing
Velocity	849 \pm 97	853 \pm 75	592 \pm 297	291 \pm 310	837 \pm 127	714 \pm 277
Kinetic Energy	726	714	540	222	719	552
Vorticity	5.07	4.14	6.46	3.88	7.60	4.21
Radial Distance	261 \pm 124	261 \pm 124	208 \pm 147	208 \pm 147	234 \pm 117	395 \pm 237

Table 1: Quantitative parameters of trajectories

tions and feelings. In the pursuit/evasion and fighting games, subjects quickly became absorbed in the task, using quite energetic, sometimes desperate mouse movements, and reporting substantial excitement and stress afterwards. In courtship, subjects adopted a wide variety of distinctive motion styles and sexual ploys, and those being courted acted at times coy and aloof. In play, subjects spontaneously combined various slower, more ritualized play-versions of the other tasks, sometimes taking turns and alternating pursuit with evasion, courting with being courted, and fighting with reconciling. In general, subjects found the tasks highly engaging, despite the cartoonish appearance of the bugs, the emptiness and flatness of the environment, and the indirect way that their mouses controlled the bugs via the target positioning. The interactiveness of animate motion alone was enough to give the experiment a sense of realism.

4.5 Pilot studies of a motion Turing test

As a direct contrast to the human “bugjects,” we have developed a series of simple robot bugs to perform certain interactive behavioral tasks, such as pursuit, evasion and courtship. A primary motivation for this is to generate “un-animate” behavioral data that can be used as a comparative baseline for determining exactly what constitutes convincing animate motion. Typically, the driving algorithms for these robot bugs use the

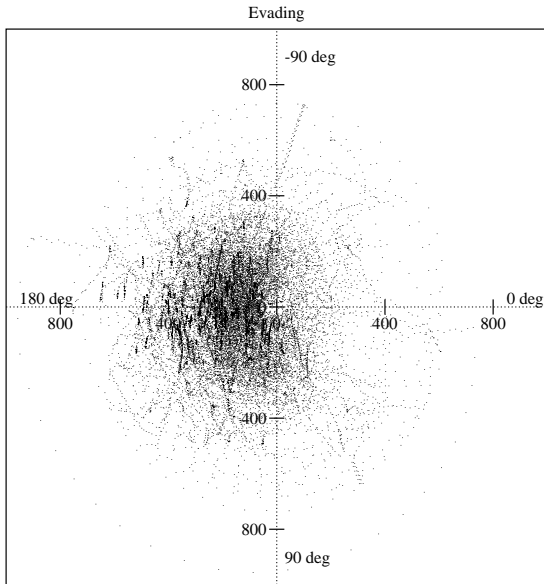


Figure 8: Relative heading / distance plot for evading

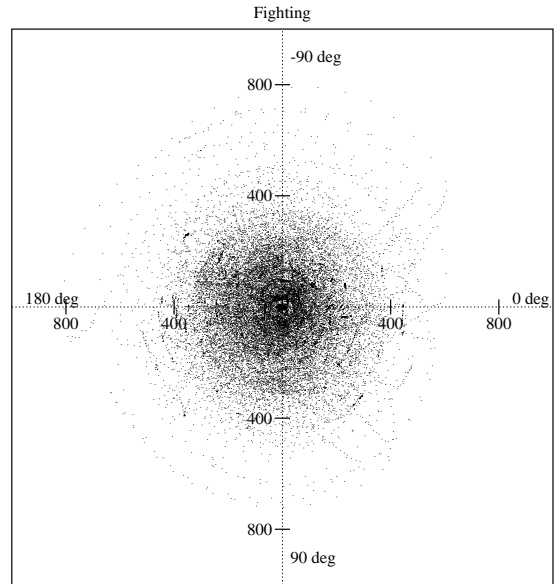


Figure 9: Relative heading / distance plot for fighting

position and relative distance of the other bug to determine its new trajectory. Though we have only created extremely simple algorithms at this point (including “narky,” who evades by heading toward the opposite quadrant of a pursuing bug, and “peter,” who courts by heading to positions at small random offsets from the courted bug), they are nevertheless convincingly animate when run against a real human-controlled bug.

To test just how convincing some of these simple strategies might be, we have devised a purely motion-based Turing test, in which a robot bug replaces one of the human subjects in a trial. After the trial, we ask the human subject whether they thought they were interacting with another human-controlled bug, or a computer-controlled robot bug². In one instance of this test, the robot bug algorithms were judged “human” by a subject in both the pursuit and evasion tasks. In another case, a subject spontaneously concluded that she had run all six trials – including courtship – against an automaton, when in fact they were all against a slightly embarrassed human subject. Clearly these two cases are purely illustrative, but even at this stage we have seen that this kind of a motion-based Turing test can be a powerful tool for gathering human judgments.

We have also created a further Turing test-like scenario for investigating the cues that are crucial to animate motion. For this scenario, we place subjects in front of a display on which they see the interactions of two bugs, played in real time. Subjects are purely passive observers in this case, watching the actions of others without controlling a bug of their own. We can show

²We will also try a variant of this test in which we tell subjects at the start of a trial that they might be interacting with another human or a computer, and they are to figure out which is the case within the 90-second trial.

these subjects runs that are generated by two humans, by one human and one computer algorithm, or by two algorithms interacting with each other. We then ask the subjects to tell us what kind of entity was controlling each bug. In such runs, it quickly becomes clear that two simple algorithms playing against each other look very mechanical and stereotyped, but a robot bug interacting with a human-controlled bug can look very animate. Essentially, by basing its trajectory on the motions of a human-controlled bug, the robot bug superimposes the animacy of the human onto its own movement patterns. This effect points up the need for very careful control in studying the generation of interactive animate motion, to know when we are seeing the result of the algorithm, and when the influence of the environment (including other agents).

5 Further applications

The software that we have developed to elicit human simulation of adaptive behavior can be put to many uses. After further enhancements, we plan to release this system for use and development by other SAB researchers in a variety of domains. Here, we outline four possible applications.

5.1 Qualitative human pre-testing of simulated environments and tasks

Researchers can run themselves as subjects to better understand the tasks they are actually setting for their simulated animals. In our experience, much of the wasted effort and false starts in doing SAB research (especially simulated evolution of animal nervous systems) come from misunderstanding how one’s simulated creatures actually experience their environment and their intended

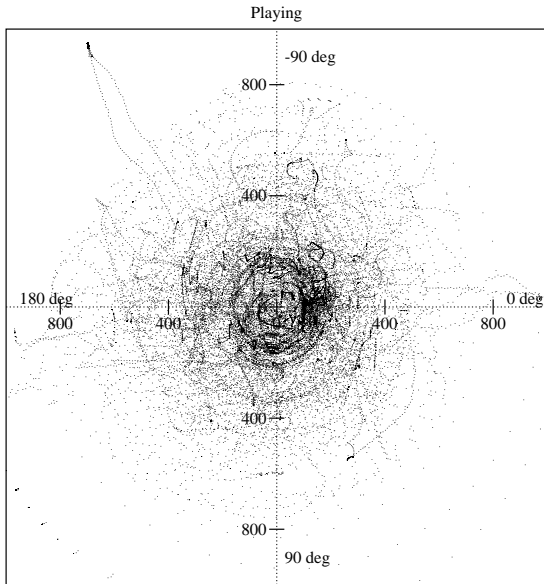


Figure 10: Relative heading / distance plot for play

tasks. Simulated evolution has a maddening tendency to find all of the trivial, degenerate “cheats” that allow animats to fulfill the letter but not the spirit of some adaptive task. We suggest that researchers might often save weeks of computer time by running themselves first, as “pilot animats,” to see what strategies they learn to solve the relevant task. Since many animat tasks are becoming more interactive, either based on predator-prey interactions, communication during courtship, or cooperative social behavior, network-based human experiments can be particularly useful. The basic theme is to discover how people can solve the task first, before seeing how one’s animats solve it. One can then better understand how the environment is perceived by the animat, and how it differs from the environment as imagined by the researcher.

5.2 Quantitative comparison of human- and animat-generated trajectories

SAB research has always paid at least lip service to the necessity of comparing simulated behavior to real animal behavior. But it is usually prohibitively difficult to get real animals to run a perfect analog of one’s simulated task. By contrast, it is easy to get human subjects to run perfect analogs, by having them play a computer-game version of the behavioral task, often using much of the same simulation code. If the resulting motion trajectories (or other behaviors) generated by human subjects are represented in the same data format as the motion trajectories generated by animats, comparisons become easy, using a variety of quantitative measures. We have outlined a few such methods in this paper. Many more are possible. If the human and animat trajectories are indistinguishable according to such measures, they may also be indistinguishable qualitatively to human judges. That is, the animats could be considered to have passed

a weak version of the Turing Test, using motion trajectories rather than the teletext as the arena of comparison.

5.3 Human-generated motion trajectories as training exemplars for evolution/learning

Many simulated evolution and learning systems must provide animats with some form of feedback about their performance, either in the form of a fitness value used by a genetic algorithm, or a reinforcement value used by a learning algorithm. These values are usually calculated by an evaluation function designed by the SAB researcher to favor behaviors that achieve a particular goal or task. Here, we propose a radically different approach to evaluations, based on imitating successful behaviors, rather than evolving or inventing them from scratch. One can simply use human-generated trajectories as training exemplars for teaching animats what to do in particular situations. This is more efficient than other methods of direct human reinforcement [Nehmzow and McGonigle, 1994], in which robot designers must hover over their creations, giving them positive and negative reinforcements every time they do something. Instead, one can develop error measures based on instantaneous deviations between the animat’s behavior and the trajectory generated by a human subject.

5.4 Extracting cues for animate motion perception through iterative experiments

Cartoonists show a profound intuitive understanding of how to make something inanimate look animate. Consider the dancing brooms from Disney’s film, “The Sorcerer’s Apprentice.” Psychologists lag far behind, unable to capture such intuitions in formal specifications of the cues used by our perceptual system to distinguish different types of animate motions, or even animate from inanimate motions. We propose a simple method to help identify the basic cues of animacy by having human subjects play the fundamental motion games that all animal species play, in a much simplified computer form. This yields more manageable data. The multi-step research method that lies at the heart of our research program proceeds as follows: (1) collect human-generated motion data for representative tasks; (2) develop useful measures that bring out the important category-distinguishing parameters in that data; (3) vary those parameters in animats to generate new kinds of motion trajectories; and (4) have human subjects judge those new trajectories as inanimate, nicely animate, weirdly animate, or super-animate in controlled experiments. These steps will be iterated as necessary until we know how to generate animacy “super-stimuli,” indicating that we have identified some important animacy cues.

6 Conclusions

Our extraordinary human perceptual capacities for recognizing and classifying animate motion have been a mixed blessing for the behavioral sciences and for SAB research. On the one hand, they make animal

field studies and observational psychology easy: we just watch what the chimp does and can usually decide whether she is chasing, escaping, courting, or playing. On the other hand, we not only anthropomorphize animals, we also attribute animacy and intentionality to almost anything to moves, and yet rarely bother to ask how we achieve such fast, effortless, accurate feats of perception.

Our intuitive assessments of animacy are not sufficient. We need to be able to compare motion patterns generated by our animats to motions generated by real organisms. Because other animals don't follow directions very well or interact with computer games very skillfully, we have explored using human subjects to generate benchmark motion data that is directly comparable to animat-generated data. Even the simple measures and analyses reported here can distinguish among different classes of behaviors, and allow informative comparisons against the behavior of simple simulated control systems. In addition, we have demonstrated the use of a motion-based Turing test as a method for evaluating animate robot algorithms. We have also reported four applications of this human-simulation approach in SAB research, suggesting that whenever we set our animats some task in some environment, we should try out the task ourselves first, to see how we fare. In the great tradition of psychopharmacologists who always try their own drugs before selling them to others, we should never force a virtual environment on our animats that we haven't first tasted ourselves.

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