The Dynamics of Escape Attempts from Quick, Intelligent Pursuers

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***Abstract*—We present a theoretical analysis on the interaction of a human versus one or many velociraptors on an open plain under the assumption that the velociraptor has perfect predictive power. Our numerical simulations are based on the assumptions given in a foretelling webcomic. We adjust the human's running capacity by varying its acceleration and terminal velocity as well as the initial separation between both parties to compare each instance and generate survival profiles. We conclude that below an initial separation of 30m, a focus on improving the human's acceleration results in a faster rate of survival time improvement. Above this threshold, the focus should be turned to a higher terminal velocity by training for sustained power output. We also examine a scenario provided by the aforementioned webcomic where the human is trapped between three velociraptors, one being injured, and discuss the survival profile in this case.**

I. Introduction

A. *"What a Dastardly Situation!"*

After *Jurassic Park* came to theaters in 1993, a portion of the previously carefree, happy-go-lucky population came to fear velociraptors like little else. And what's not to fear? They are fast, they work well in groups, they have nasty teeth, they can open doors…the list goes on. Curiously, a sizeable proportion of people found this fear preposterous and refused to entertain the thought of a velociraptor uprising decimating the human and livestock populations. Others took preparation for this inevitable* occurrence into their wise and capable hands.

This train of collective thought has a surprisingly weak base of literature supporting it, but evidence of its ongoing consideration nonetheless exists. We hope to address and expand upon these explorations into this metaphorical – and potentially, eventually, literal – land of primal terror.

We were inspired by a serious address to this possibility from Randall Munroe, author of xkcd, a popular webcomic. In his famous and fateful comic panel titled *Substitute*, he satirizes the unease of those who consider this threat viable. [1] The main character, a substitute teacher named Mr. Munroe, is concerned about this looming hazard enough to justify hijacking a presumably elementary school classroom so that he may bring attention to this threat in the hopes of preparing the younger generation† to face the velociraptor onslaught. Hidden in this not-so-subtle satire, however, is a faint plea for people to finally grant the repeated warnings the audience they deserve. One can also find hope in the delivery of this comic, almost hearing a long-lost child within who says, "Finally! a test that challenges me as the real world might!" The students who wandered into this classroom just might emerge with the wherewithal to defend themselves against those unforgiving beasts and earn their place as saviors of Humanity As We Know It.

When the velocirevolution comes, the world will be composed of two people: those who used their wits to prepare for this most dastardly of situations, and those who scoffed at their own fragile nature and brought upon their demise.

B. *Velociraptors Are Not Dumb Lizards*

Let us at once dispel the notion that velociraptors do not know what they are doing. They know exactly what they are doing.

It is no accident that these predators came to be some of the most feared during the Late Cretaceous Period. They were known as efficient hunters, working in packs much as modern-day wolves to overwhelm and swiftly down their prey. Due to their size‡, feathers, and talons, they were lightweight, agile, and capable of unspeakable mayhem. They were ruthless in a cute-until-you-suddenly-sprung-a-leak sort of manner. Faced with a large enough pack, your best choice would be to accept your unenviable fate and end it as quickly as possible.

We must remain conscious of their honed skills in the arts of pursuit and murder. They are intelligent and capable of prediction. They know exactly their capabilities and they know exactly a human's flaws. After all, it is only safe to assume that they have killed enough bumbling super-apes to understand the facilities and limitations of the human body. They know how fast we can run, how quickly we can stop and turn, and how much power we are capable of producing at peak adrenaline production.§

C. *How We Can Help*

We are interested in exploring human-velociraptor contests, and how the human may best act to extend his life one more day before the gnashing maws are finally indulged. Certain

Thanks to Randall Munroe for bringing to light the problems associated with this terrible situation. May no one ever find themselves in such a predicament. Thanks also to the IEEE for providing the `IEEEtran.cls` class file with which to write good-looking papers in LaTeX.

*Cosmically speaking, of course.

†Though hapless pioneers they may be, they're all we've got!

‡Admittedly this was somewhat exaggerated in the most famous cinematic rendition of this menace; those were more likely Utahraptors.

§Having dined on many humans before, they have a very good sense of how one might run whilst soiling one's pants: that is, with a rather wide gait.

simplifications will be adopted, but we attempt to use realistic approximations to keep the calculations as relevant as possible.

In this model, we assume that human evasion behavior is predictable. The human runs in a straight line and justifies this decision by pointing out that this method results in maximal displacement from the origin.

Velociraptors would likely be very aware of this common behavior among humans as well as a typical human's running capabilities. Thus it follows from the human's predictability that velociraptors have perfect predictive power. This means that they correctly choose their running path so that they will meet the human along its path in minimal time.

We are interested in studying the particulars of the survival profile for all directions in the case where there may be some environmental advantage (high wall, herd of people, weapon laying on the ground) to give a better sense of what's possible in this context.

We can also perform some analysis on the sensitivity of the profile to changing parameters, to determine what parameters are most beneficial for the human to optimize. We will do this and later superimpose profiles dependent on multiple velociraptors in a 2D configuration to the extent of what is possible in such a scenario, using the classic xkcd scenario as a demonstration.

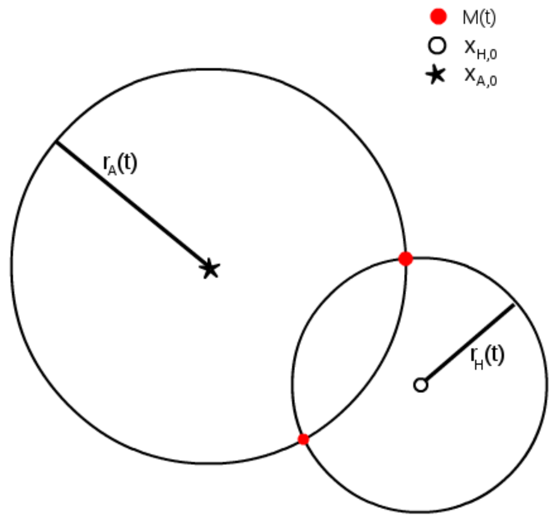


Fig. 1: A visual aid to understand the calculation. For any given time t, the human and velociraptor may occupy any point along the perimeters of their respective circles. The set $M(t)$ is represented by the points of intersection of these two circles, shown here as two red points.

II. Setup

A. Conceptualization of Environment and Problem

For the purposes of this analysis, we will set up the environment as minimally advantageous for the human. By providing an analysis of the simplest worst-case scenario, there will be no disillusionment about one's chances head-to-head with a velociraptor. It is hoped that, when faced with this contest in reality, one will then be able to make use of various environmental features, *i.e.*, obstacles or weapons, to improve one's odds of survival.

The human and velociraptor are each given two quantities that define their running characteristics: a, their respective accelerations; and v_{max}, their respective maximum running velocities. They also have an initial position, $\vec{x}_0$.

Let us define the set of valid positions for a given party at time t to be

$$P\left(t; a, v_{max}, \vec{x}_0\right) = \{\vec{x}(t) \text{ s.t. } \|\vec{x}(t) - \vec{x}_0\| = r\left(t; a, v_{max}\right)\} \in \mathbb{R}^2 \quad (1)$$

and the set of valid positions at which the two parties will meet at time t as

$$M(t) = P_H(t) \cap P_A(t), \quad (2)$$

where the subscripts denote each involved party: H for human and A for adversary.

In words, we will model the positions of the human or velociraptor as "spheres of influence," *i.e.*, expanding circles centered on their respective initial positions. The radius of each circle will be determined by the function defining distance vs. time for each party as parametrized by a and v_{max}. The perimeter of this circle represents the set of possible positions the individual would occupy if they were to run in a straight line at maximal effort.

We will consider the set of meeting points $M(t)$ as the set of positions at a given time at which the perimeters of these two circles intersect. Under the assumption that each party is running with maximum effort in a straight line, this represents an intersection of the possible positions of human and velociraptor given that the velociraptor has perfect predictive power¶. We can then define the meeting points of human and velociraptor as

$$M = \bigcup_{t>0} M(t). \quad (3)$$

Eq. (3) describes the set of all meeting points that are possible for given initial parameters for both human and velociraptor.

The initial position of the human will be defined as $\vec{x}_{H,0} = (0, 0)$, and the velociraptor is located at $\vec{x}_{A,0} = (x_A, y_A)$.

A visual aid for the math is provided in Fig. 1.

For now, the goal is to examine the relation between a and v_{max} for each party as well as their initial displacement $d := \|\vec{x}_{A,0} - \vec{x}_{H,0}\|$ to their meeting point space M.

B. The Radius Function

For each party, the radius function will have a similar structure: a simple Newtonian equation of motion with a quadratic drag term. The drag term represents the aerodynamic drag force on the runner's body, and it is this force that limits runners' speeds in the presence of atmosphere. It is

¶...and the human is scared shitless.

parametrized holistically, combining the air density as well as the cross-sectional area and drag coefficient of the body into a single variable that can be later defined to impose an explicit terminal velocity. This differs from the xkcd formulation so as to provide a more realistic and programmatically simple representation of what would happen, for discontinuities are seldom found in reality as we know it and equations containing continuous functions are comparatively easy to numerically solve.

The simple equation of motion for a Newtonian particle under ordinary forces (including quadratic drag) may be defined as

$$\ddot{r} = a - bv^2. \tag{4}$$

Next, we can determine the value of b in terms of the other parameters. The equation of motion then becomes

$$\ddot{r} = a - bv^2|_{\ddot{r}=0, v=v_{max}} \to b = a/v_{max}^2 \tag{5}$$

$$\Rightarrow \ddot{r} = a\left(1 - (v/v_{max})^2\right). \tag{6}$$

Since the drag is only a function dependent on velocity and not on position, we can rewrite Eq. (6) as

$$\dot{v} = a\left(1 - (v/v_{max})^2\right) \tag{7}$$

and solve for the velocity function, giving

$$v(t) = v_{max} \tanh\left(at/v_{max}\right). \tag{8}$$

From here we simply integrate once and solve with the initial condition $r(0) = 0$ to get the radius function as a function of time,

$$r(t) = \left(v_{max}^2/a\right) \log\left(\cosh\left(at/v_{max}\right)\right). \tag{9}$$

Thus, we can define the formal radius functions for each party as

$$\begin{aligned} r_H(t) &= \sqrt{x^2 + y^2} \\ &= \left(v_{H,max}^2/a_H\right) \log\left(\cosh\left(a_H t/v_{H,max}\right)\right) \end{aligned} \tag{10}$$

and

$$\begin{aligned} r_A(t) &= \sqrt{(x - x_A)^2 + (y - y_A)^2} \\ &= \left(v_{A,max}^2/a_A\right) \log\left(\cosh\left(a_A t/v_{A,max}\right)\right). \end{aligned} \tag{11}$$

C. The Meeting Point

Our task now is to determine the structure of M, following Eqs. (2) and (3) and determining the set of points by utilizing Eqs. (10) and (11).

We will not be able to do this analytically. Or rather, we would prefer not to go through the trouble, and have no guarantee that it is even possible. If someone would like to pay us, we would be more than happy to pursue this further as the one- or two-line formula can be distributed much more easily than a paper such as this one. As it stands now, we can instead compute the results numerically to generate a useful image. In this way we hope to understand the function qualitatively and pass on the interpretations.

First, it is straightforward to calculate the maximum distance attained by the human before being devoured, effectively solving the general form of Question 1 on Mr. Munroe's pop quiz. [1] It is trivial to see that running directly away from the velociraptor affords the human the highest survival time.

We will define a characteristic length L that represents the average distance that a person or velociraptor can run in a straight path before encountering an obstacle. Lower L may represent more rugged terrain, close-quarters conditions in a metropolis, or other similarly impeded environments. A higher L will correspond to more open, flat terrain that has the advantage of longer sight lines but the disadvantage of less things to hide in or behind. In our simulations, the initial displacement d will be set equal to L to generate a useful analogue. We will examine how the human's terminal velocity and acceleration parameters affect survival time at given characteristic lengths, and which parameter is more important to improve in such scenarios.

Finally we will revisit Question 2 of the pop quiz issued by Mr. Munroe and examine the survival profile of an average person against the velociraptors defined in the quiz question where all parties are subject to the assumptions stated in this paper.

For our analyses we will consider the range of running skills according to three classes of person: a hopelessly obese bon-bon of a person ($a = 1\,\mathrm{m\,s^{-2}}, v_{max} = 2\,\mathrm{m\,s^{-1}}$), your average Joe ($a = 2\,\mathrm{m\,s^{-2}}, v_{max} = 7\,\mathrm{m\,s^{-1}}$), and Usain Bolt ($a = 3\,\mathrm{m\,s^{-2}}, v_{max} = 12\,\mathrm{m\,s^{-1}}$). Their running capabilities serve to define a range of acceptable parameter values for subsequent analysis.

III. Results

A. The One-on-One Contest

To call it a "contest" is indeed a bit of a misnomer. Perhaps "confrontation" or, from the velociraptor's perspective, "lunchtime ceremony" are more appropriate.

As previously mentioned, we will consider a worst-case scenario from the perspective of the human – a perfectly flat, open arena.

We can now generate some visual aids to determine how to best prepare for the worst case.

We will now consider purely the maximum survival time, *i.e.*, when the person runs directly away from the velociraptor. In Fig. 2, we see a comparison in benefits seen when improving acceleration versus maximum velocity at various values of L for the average Joe. The benefit is calculated as

$$B_x = R_x \frac{\partial D}{\partial x} \tag{12}$$

where x is the skill being improved (either a or v_{max}), R_x is the width of the range of acceptable values for that skill, and D is the distance achieved against a velociraptor with $a = 4\,\mathrm{m\,s^{-2}}$ and $v_{max} = 25\,\mathrm{m\,s^{-1}}$. The scaling factor R_x is included to normalize the results against the theoretical difficulty in improving each skill, *i.e.*, assuming that the effort

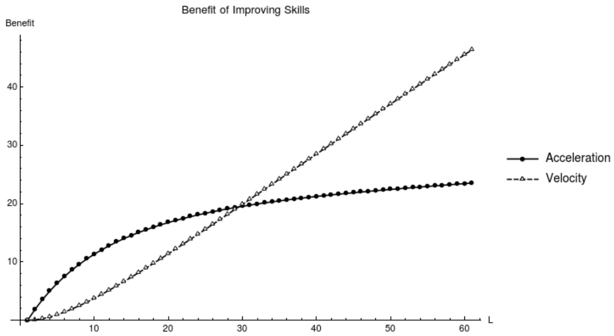


Fig. 2: A plot indicating the benefit an average Joe would gain from improving either their acceleration or maximum velocity. A higher value of "benefit" is better. One can see that below $L = 30\,\mathrm{m}$, it is more beneficial to improve acceleration, but that above this threshold one should focus instead on maximum velocity.

required to improve from worst to best ability with each skill is equivalent.

From the results, we can say that below $L = 30\,\mathrm{m}$, the person should focus on improving their acceleration, and above that threshold they should instead improve their maximum velocity.

Of course, in reality, improvements of this sort tend to correlate with each other. However, we must make a distinction between the improvement we seek and the effort and specific methods used to attain said improvement. We can reword our conclusions slightly by saying that below $L = 30\,\mathrm{m}$ focus should be on *speed and agility*, while above this threshold focus should be on *sustained power output*. The former is correlated with explosive power while the latter is strongly correlated with cardiovascular health. [2] [3] The explosive power will also be beneficial in the case where the terrain is uneven or there are significant advantages to be earned through jumping or climbing.

Regardless of training focus, an emphasis on improving acceleration will improve the area of influence of the human in cases where they may need to run tangential to the velociraptor rather than away from it. While both parameters will likely grow together, focusing too much on one or the other may have detrimental effects in the long term, such as spontaneous blood loss from a row of sharp teeth. We will leave the determination of specifics of how this might occur as an exercise for the reader.

B. The Triangle of Execution

You will not get out of this one alive.

The problem is set up exactly like Question 2 in the pop quiz. A person is standing in the center of an equilateral triangle whose side length is $\sqrt{3}L$, corresponding to initial displacement L between the human and each velociraptor. At each corner is a velociraptor with the same running capabilities as in Question 1, with the exception of one of them, whose top speed is limited to $10\,\mathrm{m\,s^{-1}}$, a scaling of 40% compared to baseline.

For our simulation we will assume that the crippled velociraptor has a similarly limited acceleration: $40\% \times 4.0\,\mathrm{m\,s^{-2}} = 1.6\,\mathrm{m\,s^{-2}}$.

Due to the apparent mismatch between human and velociraptor capabilities, the question is not if the human can avoid being intercepted, but how to maximize the time before it is intercepted. An understanding of the profile would be valuable to know in the cases where there are environmental features that could give advantage to the human.

Fig. 3 displays the survival for very low and very high values of L. One can see that the shape of the profile does not change very much, and scales with L with only minor variation. The crippled velociraptor, positioned at the top of the triangle as in the original question, poses a significant vulnerability to the team. This will turn out to be key for the human. Indeed the human's longest survival time results from running to the point where the crippled velociraptor and one other raptor meet him at the same time. Might as well go out with style, right? And by style we mean being torn in half.

In cases where there are multiple opportunities for the human to delay its extinction, it is in general more advantageous to choose the one closer to the crippled raptor.

Also interesting for the intrepid survivalist is the maximum survival distance as a function of L, shown in Fig. 4.

While the profile does change somewhat over a large change in L, as shown in Figs. 3a and 3b, the general shape is easily gleaned from the images. And though the shape of this profile may change slightly as the human's running capabilities increase, the angle of maximum survival will not change in a major way. This is obvious due to the fact that the profile for each velociraptor will extend outward and away much faster than they will extend toward the respective dinosaur.

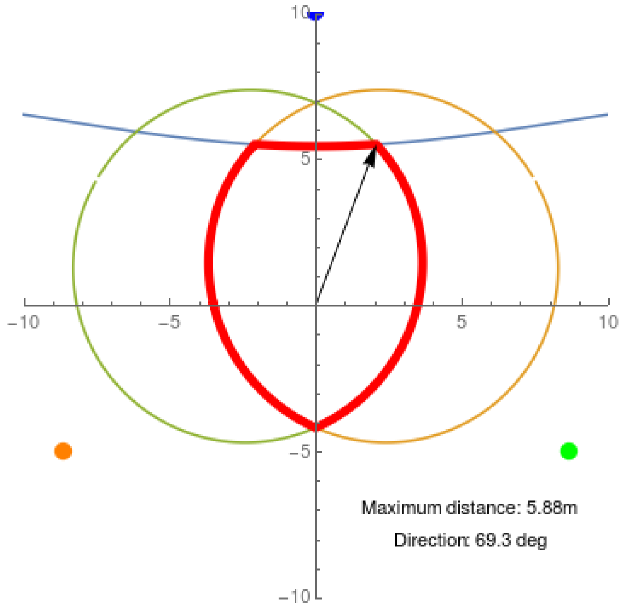
IV. Conclusion

In a future where velociraptors become the dominant lifeform on Earth, all hope is not yet lost. Though humans may be at a serious disadvantage physically, we have the advantage of foresight and the concept of delayed gratification. We can prepare for a given situation by optimizing our bodies and minds to most effectively modify them, and thus our futures, in our favor.

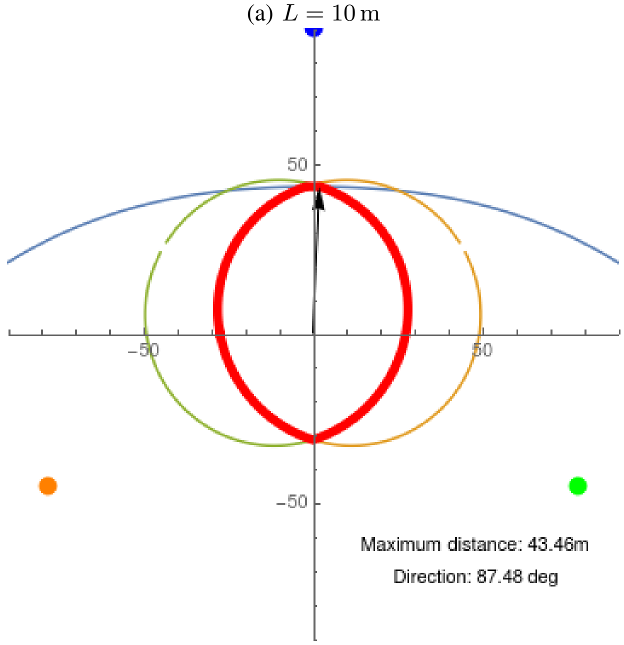
In the realm of physical agility, we can train our bodies to attempt to neutralize the playing field between man and protoreptile, though we may never achieve our goal completely. Any improvement will become of vital importance.

When considering the terrain of a particular encounter, there will be trade-offs between endurance and agility. The best way to minimize the hazards of a relatively flat terrain with long sight lines is to focus on training for sustained power output, *i.e*, running swiftly for relatively long distances. For shorter sight lines and more obstructed terrain, a focus on agility and acceleration will be more advantageous. The turning point between these two regimes is found to be when the sight lines are on average approximately $30\,\mathrm{m}$ in length.

For a more acceleration-based regimen, one may consider high-intensity interval training, such as sprints, as well as



(a) $L = 10\,\mathrm{m}$



(b) $L = 90\,\mathrm{m}$

Fig. 3: The survival profile of an average Joe against the velociraptors as described in Question 2. The initial position of the human is at the origin of each plot and the initial positions of the velociraptors are marked with colored dots. Also depicted as colored curves are the sets M respective for each velociraptor. The red, thicker curve indicates the edge of the survival region of the human. The arrow indicates the path of longest survival for the human.

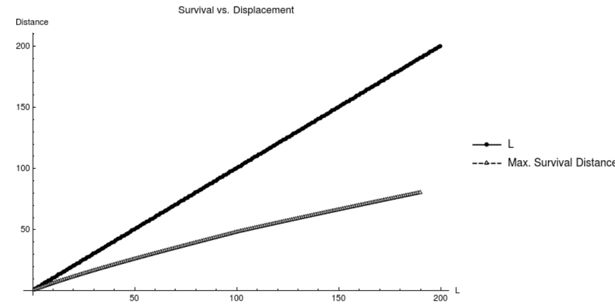


Fig. 4: The maximum distance travelled by the human against a single velociraptor as a function of initial separation L.

traditional plyometrics. If one is more sport-inclined, baseball is a good candidate for training because it focuses heavily on speed and quick starts and stops. As an added bonus, you may become more proficient at wielding two-handed blunt objects and could find yourself sending a velociraptor's head to the fences when the need arises. Similarly beneficial sports include squash, racquetball, and tennis due to their need for quick reaction times and high acceleration and deceleration. In this case, one's proficiency with one-handed blunt or edged objects may be improved upon drastically, much to the dismay of the reptilian horde.

For more sustained power regimens, running cannot be beat as long as the person training themselves is focusing on continually improving their speed. For useful sports, basketball and football (a.k.a. soccer) both have heavy emphases on speed and cardiovascular health. For practice with blunt objects, we recommend lacrosse and hockey.

For those in more uneven, three-dimensional environments, we strongly recommend adding climbing or parkour to the training regimen. We hope the reason for this is obvious.

We must also disclaim that this is not a comprehensive preparation manual for the post-velocirevolution period. There are many more subjects to be studied, from ideal barricades through effective weapons to functional social structures. We hope the braver souls among us will take it upon themselves to seriously consider these questions and contribute to public knowledge so that our history, our culture, and our fellow humans may not be wiped from the face of this earth by those fearsome, leathery demon-turkeys.

Appendix A
Supplementary Materials

All supplementary materials can be found online in a GitHub repository [4], in particular the Mathematica notebook used to perform the analysis and generate the plots. In case the source code and accompanying images cannot be found, for instance if the velociraptors figured out what the Internet is and why it's such a good idea to disable it for human use, we hope that the information provided within this document will serve enough to reconstruct your own analysis. To those who comprehend the necessity to preserve this knowledge, we encourage you to keep copies of this document and the accompanying material on your own storage media for later distribution.

References

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