

# Muybridge's Cat -- Key

(*Animals in Motion*, Eadweard Muybridge, Dover Publications.)

Details: The distance between gridlines is 5 cm. The time between successive frames is 0.031 sec.

1. Just from casually looking at the pictures, what observations can you make about the motion of the cat?
2. How big is the cat? **About 50 cm from base of tail to tip of nose. There will be some student discussion about how to measure the size.**
3. How far did the cat go? How long did it take him? What was his average speed? **There will be student discussion about the need for reference points (on the cat and on the grid) and where to establish them. In making out this key, I used the dark line behind the cat's head in the first frame as the reference point for measuring distance. I used the tip of the nose to establish the position of the cat. Other good points on the cat are the tip of the ear and where the tail joins the body.**  
**The cat traveled about 135 cm in .713 sec, for an average speed of about 189 cm/sec. (Note, this is roughly 4.4 ft/sec.)**
4. Is this average speed the same as the cat's speed in frame 2? Why or why not? **No, the speed in frame 2 is an "instantaneous speed," like the reading on a speedometer.**
5. In which frames do you think that the cat is probably going faster than his average speed? **From about frame 10 on.**
6. We now ask you to gather some data and plot some points in order to draw a graph of the cat's distance from his starting point as a function of time. In other words, we want you to construct a graph with time on the horizontal axis and distance on the vertical axis. You should answer the following questions before you begin your graph.

*What exactly will we use as our reference point for measuring distance?  
Exactly how will we describe the cat's position at a given time?*

Frame Number	Time (sec) since first photo was taken	Position of Cat
1	0	5
2	0.031	6
3	0.062	7
4	0.093	10
5	0.124	11
6	0.155	11
7	0.186	11
8	0.217	12
9	0.248	14
10	0.279	16
11	0.31	23
12	0.341	30
13	0.372	38
14	0.403	45
15	0.434	52

16	0.465	60
17	0.496	68
18	0.527	75
19	0.558	85
20	0.589	95
21	0.62	110
22	0.651	116
23	0.682	130
24	0.713	135

Use a whole sheet of graph paper to draw your graph!

- On your graph, draw a line whose slope represents the cat's average speed. (Hint: Your line will connect two points on your graph. Which two? Why does the slope of this line represent the cat's average speed?) **This line will be the secant line connecting the first and last points on the graph. It is important that students realize that when they computed the average speed, they were doing an identical calculation to "rise over run" for this secant line.**
- What was the average speed of the cat between frame 10 and frame 20? On your graph draw a line whose slope represents the average speed of the cat between frame 10 and frame 20.  **$(95-16)/(0.589-0.279)$  or 255 cm/sec. The line is the secant line which connects the point ( 0.279, 16) with the point (0.589, 16).**
- Estimate the speed of the cat in frame 10. **One way to estimate the speed of the cat in frame 10 s would be to look at the position of the cat in frames 9 and 11 and do an average speed calculation.  $\rightarrow (23-14)/(0.31-0.248)$ , about 145 cm/sec.**
- Estimate the speed of the cat in frame 20.  **$(110-85)/(0.62-0.558)$ , about 403 cm/sec**
- On your graph draw a line whose slope represents the speed of the cat in frame 10. **The line is the line which is tangent to the graph at the point which represents frame 10.**
- Use your graphing calculator to fit a function formula to your data. **Students might try a quadratic model, an exponential model, and/or a general power model. A quadratic model is  $\text{distance} = 313.2 t^2 - 35.77 t + 7.068$**
- Take a derivative to estimate the speed of the cat in frame 10. How does this estimate compare with your earlier estimate? **Using the quadratic model, the derivative (velocity function) is  $626.4 t - 35.77$ . This function gives a velocity estimate of  $626.4 \cdot 0.279 - 35.77$  or about 139 cm/sec.**
- Your friend has a brother in the fifth grade. He wants to know the difference between average speed and instantaneous speed. In fifty words or less write an explanation for him. (He is a bright young man, but he does not yet know calculus.) **Average speed takes into account the entire journey from point A to point B – how far you went divided by the time it took. Instantaneous speed is the speedometer reading at a given instant.**
- Sketch a graph of the cat's speed as a function of time. **Students may estimate instantaneous speed for each frame directly from the data or they may use their model and graph the derivative.**