



ICE - Periodic Functions

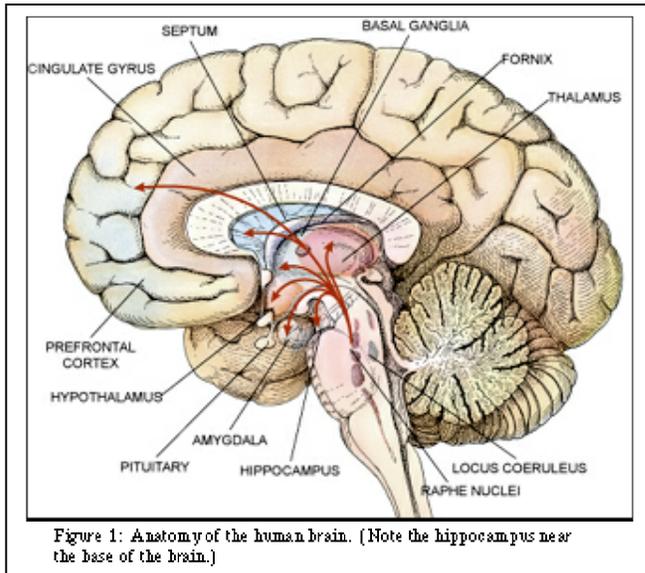


Figure 1: Anatomy of the human brain. (Note the hippocampus near the base of the brain.)

In Math X we have studied the seasonal variation of the number of neurons in the hippocampal formation of food-storing birds (such as the black-capped chickadee, *Poecile atricapillus*).

One reason for studying this phenomenon is to better understand what functions different parts of the brain perform.

Some neurobiologists have suggested that the hippocampus may be important to spatial tasks such as navigating and remembering where hidden objects are located¹. In humans, the hippocampus is located near the base of the brain (see Figure 1²).



Figure 2: Examples of animals that exhibit food-caching behavior. (a) Townsend's Chipmunk (*Tamias townsendii*). (b) Clark's nutcracker (*Nucifraga columbiana*). (c) Columbian ground squirrel (*Spermophilus columbianus*). (d) Common beaver (*Castor canadensis*).

¹ For example, see: J. O'Keefe and L. Nadel. *The Hippocampus as a Cognitive Map*. Oxford, England: The Clarendon Press, 1978. or more recently: L. Nadel. "The psychobiology of spatial behavior: The hippocampal formation and spatial mapping." in E. Alleva, H.-P. Lipp, L. Nadel, A. Fasolo and L. Ricceri (eds.) *Behavioral Brain Research in Naturalistic and Semi-naturalistic Settings: Possibilities and Perspectives*. Dordrecht, The Netherlands: Kluwer Academic Press, 1995. or even more recently: R. Hampton, D. Sherry, S. Sheetleworth, M. Khurgel and G. Ivy. (1995) "Hippocampal volume and food-storing behavior are related in *Parids*." *Brain, Behavior and Evolution*, **45**: 54-61.

² Image source: Scientific American.

Over the last few years years, several studies have appeared that try to establish a clear link between the hippocampus and navigational skills or spatial memory. Figure 2³ shows a number of animals that create hidden food “hordes” or “caches” in times when food is plentiful, and retrieve the stored food (sometimes months later) when food is scarce. Neurological theorists have speculated that animals who show this “food caching” behavior may also exhibit seasonal fluctuations in either the size or level of activity in the hippocampus to reflect the greater use that the animals might make of spatial memory when establishing food caches or when locating food caches in hard times.



Figure 3: The black-capped chickadee (*Poecile atricapillus*).

In this ICE, you will review the two methods that we have used to model the seasonal variations in the hippocampal formation of the black-capped chickadee⁴ (*Poecile atricapillus*). In particular, you will determine what features of those models give unrealistic predictions, and describe the features that a more realistic model would need to exhibit.

The black-capped chickadee is a small bird (see Figure 3⁵) that establishes caches of seeds during the spring and later retrieves food from these caches during the winter.

One interesting note is that the instinct to store food is does not appear to be associated with the hippocampus – only the ability to

remember where the food was stored. Experiments on chickadees with damaged hippocampuses⁶ showed that the birds stored food as enthusiastically as always, but searched in the wrong locations when attempting to find the stored food at a later time.

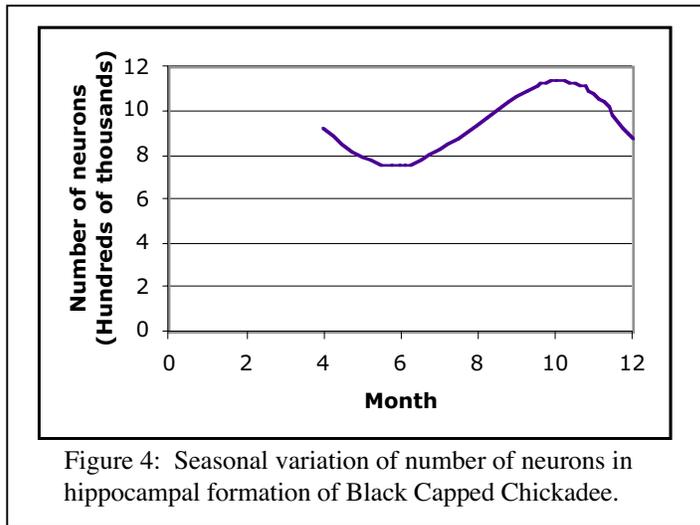
³ Image sources: (a) <http://www.washington.edu/burkemuseum/> (b) <http://www.scsc.k12.ar.us/> (c) <http://www.washington.edu/burkemuseum/> (d) <http://www.pnl.gov/ecology/>

⁴ Source: T.V. Smulders, M.W. Shiflett, A.J. Sperling and T.J. DeVoogd. (2000) “Seasonal changes in neuron numbers in the hippocampal formation of a food-hoarding bird: The black-capped chickadee.” *Journal of Neurobiology*, **44**(4): 414-422.

⁵ Image source: <http://www.cevl.msu.edu/>

⁶ Source: D.F. Sherry, L.F. Jacobs and S.J.C. Gaulin. (1992) “spatial memory and adaptive specialization of the hippocampus.” *Trends in Neuroscience*, **15**: 298-303.

Model 1: Math Xa Midterm, Fall 2001.



The first time that you attempted to model the hippocampal formation of the black-capped chickadee was on the first Math Xa midterm. You were given a table of values (see Table 1 below) and asked to plot a graph showing the number of neurons as a function of time (see Figure 4).

Month	4	5	6	7	8	9	10	11	12
Number of neurons (hundreds of thousands)	9.2	7.9	7.5	8.2	9.4	10.7	11.4	10.8	8.7

Table 1: Number of neurons in hippocampal formation of Black Capped Chickadee (*Poecile atricapillus*).

You were then asked to select the equation for the function (see Figure 5 below) that you thought would do the best job of representing the patterns in the data.

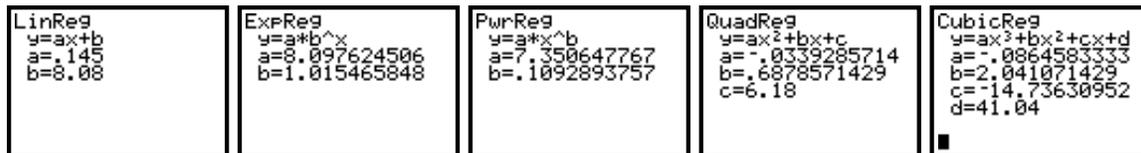


Figure 5: Regression equations obtained from data in Table 1.

- Of the functions shown in Figure 5, which would do the best job of representing the patterns in the data from Table 1?**
- During which months will the function you have selected do the best job of matching the data from Table 1?**
- Do you expect the function you have selected to always provide accurate predictions of the number of neurons in the hippocampal formation of a black-capped chickadee? Indicate why or why not.**

Model 2: Math Xb ICE, Spring 2002.

On an ICE from earlier in the semester, you were given information⁷ on the rate at which the number of cells in a chickadee's hippocampus changed throughout the year. (See Figure 6 below. Note that in Figure 6, January is month 1 and December is month 12.)

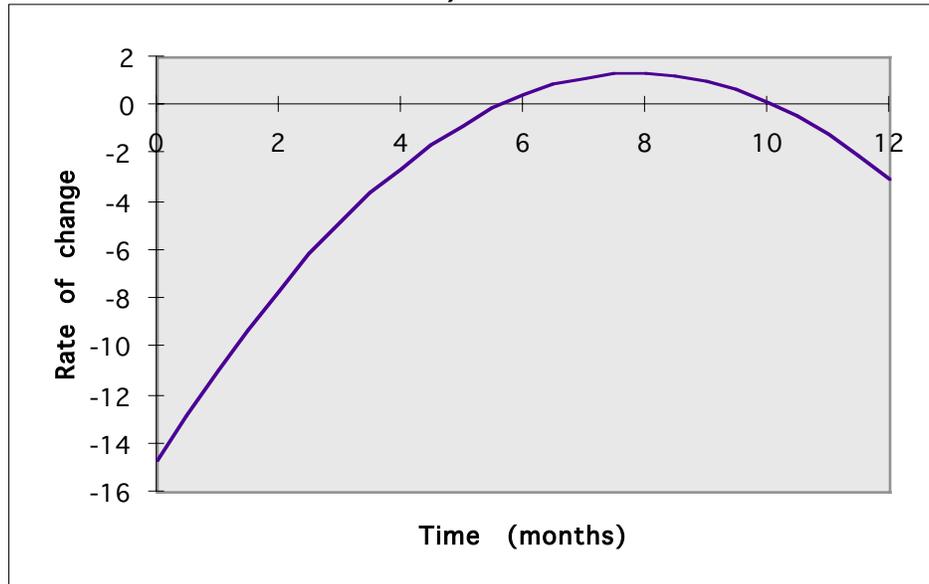


Figure 6: Rate of change of number of neurons in chickadee hippocampus.

- **Over the course of one year, what net change would you expect in the number of neurons in the hippocampal formation?**

- **Based on the appearance of Figure 6, will there be a net increase or a net decrease in the number of neurons in the hippocampal formation over the course of one year? How can you tell?**

⁷ Source: T.V. Smulders, M.W. Shiflett, A.J. Sperling and T.J. DeVoogd. (2000) "Seasonal changes in neuron numbers in the hippocampal formation of a food-hoarding bird: The black-capped chickadee." *Journal of Neurobiology*, **44**(4): 414-422.

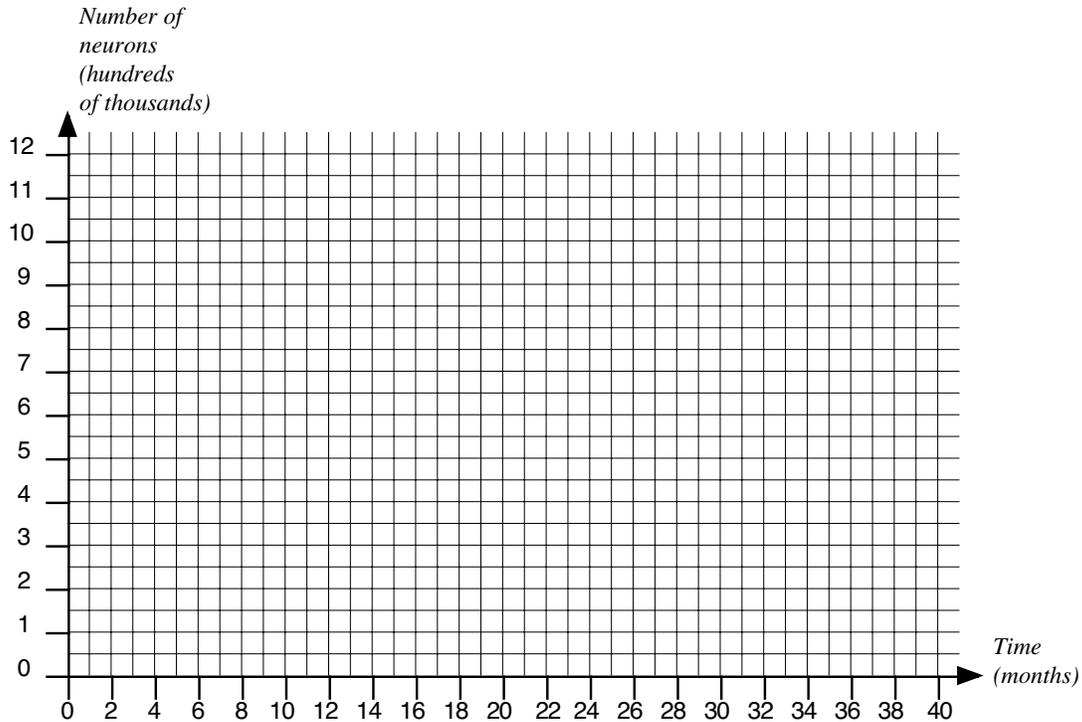
- **Suppose that the pattern shown in Figure 6 was applied to a chickadee hippocampus over the course of several years. According to this model, what would happen to the hippocampus of a black-capped chickadee over the course of a few years? (Note that there is some scientific evidence⁸ to suggest that spatial memory and navigational skills decrease as an animal gets older.) What additional information would help you to decide whether this really happens or not?**

⁸ For example, see: B. Contant-Astrom. *Aging and Spatial Memory. Assessment of Age-Related Alterations of Spatial Memory in Rats*. Philadelphia, PA: Coronet Books, 1994. and H. Tanila, M. Shapiro, M. Gallagher and H. Eichenbaum (1997) "Brain aging: Changes in the nature of information coding by the hippocampus." *Journal of Neuroscience*, **17**: 5155-5166.

Model 3: Today.

The average lifespan of a black-capped chickadee is two and a half years (30 months)⁹, and chickadees are usually born between April (month 4) and July (month 7)¹⁰.

- **Use the axes provided below to sketch what you think the graph of neurons versus time should be over the lifetime of a chickadee.**



- **Take a good look at the graph you have drawn and note any features of this model that are not shown by the two previous models that we have tried. In today's class we will attempt to devise methods for finding equations for functions that have some (or all) of the features that you have identified.**

⁹ Source: G. Loery and J.D. Nichols. (1985) "Dynamics of a black-capped chickadee population, 1958-1983." *Ecology* **66**(4): 1195-1203.

¹⁰ Source: S.M. Smith. *The Black-Capped Chickadee: Behavioral Ecology and Nautral History*. Ithaca, New York: Cornell University Press, 1991.

Calculator Exercises

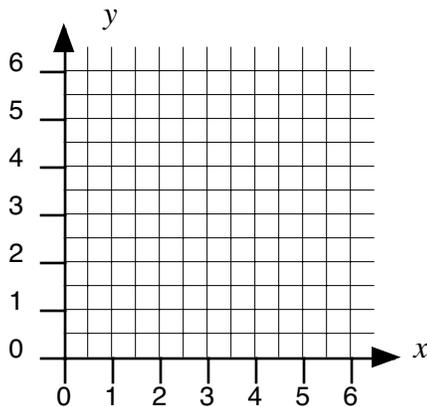
- **Set the viewing window of your calculator to the following size:**

$$X_{\min} = 0 \quad X_{\max} = 6.3 \quad X_{\text{scl}} = 1$$

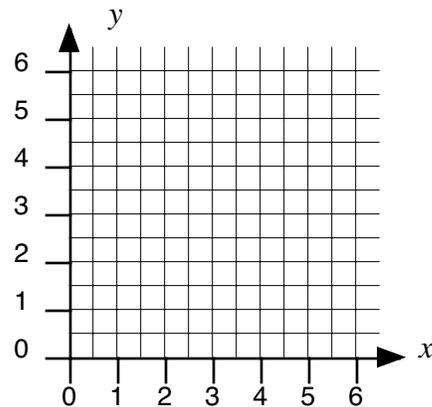
$$Y_{\min} = 0 \quad Y_{\max} = 6 \quad Y_{\text{scl}} = 1$$

- **Graph each of the following equations on your calculator and use the axes provided to sketch the graph that appears on the screen of your calculator.**

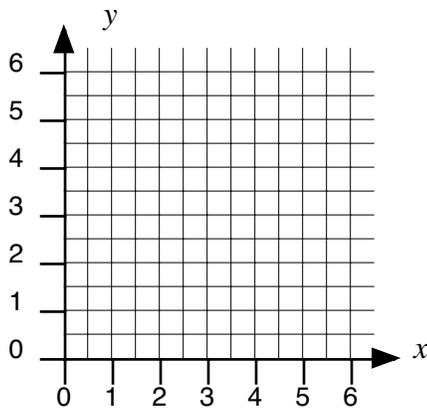
$$y = f(x) = 2 \cdot \sin\left(\frac{x}{2}\right) + 3$$



$$y = f(x) = -2 \cdot \sin\left(\frac{x}{2}\right) + 3$$



$$y = f(x) = 2 \cdot \cos\left(\frac{x}{2}\right) + 3$$



$$y = f(x) = -2 \cdot \cos\left(\frac{x}{2}\right) + 3$$

