TEAMS Monthly High School Math Challenge

February 2019

The computational power of the human brain compared to a computer is a common topic of discussion both in popular media and within some research and scientific fields. Unfortunately, in many ways, comparing these systems is a lot like comparing apples and oranges. While a computer CPU is a neat, well-defined system, with the ability to follow a specific set of instructions very quickly, the human brain does not appear to be as clearly structured and is heavily networked. This means that individual neurons may be slower than a CPU, but that the overall process of finding a solution or simulating advanced cognition may be far more efficient. One comment often made is that the human brain is extremely energy hungry, requiring around 20% of the total energy usage of a human body at any given time, unlike computer processing hardware, which requires a relatively small percentage of the total system's energy to function. However, this is also due to having a significantly less efficient/compact brain/body assembly. This being said, fundamental biological rules appear to be at work for all organisms, governing both available metabolic needs and brain mass and even different within types of organisms, those rules appear to have similar values. Two examples that relate directly to organism energy consumption and brain mass are the governing equations for mammalian Resting Metabolic Rate (RMR) (the total metabolic usage of an organism in one day in kiloCalories) and an accompanying equation for the limits of brain mass (in kg) for an organism.

$$RMR\ (Resting\ Metabolic\ Rate) = k1 * M^{0.75} \qquad (1)$$
$$BM(Brain\ Mass) = k2 * M^{0.667} \qquad (2)$$

where k1 and k2 are dimensionless constants and M is the mass of the entire organism (in kg). The precise values of the coefficients in each of these questions is still a matter of debate (as they are empirically derived and may or may not vary across species and family boundaries), and the k component varies not only across family boundaries but across species as well. However, all organisms appear to obey these rules, or close to them. Human values are generally approximated as k1=50, and k2=0.0855, when using resting metabolic rates.

While there is significant disagreement regarding correlating observed intelligence and brain structure, one proposed method for mammals is called the Encephalization Quotient (all masses are in grams):

$$EQ = (Brain\ Mass) \div (0.12 * (Body\ Mass)^{0.67})$$

The EQ of an organism is defined as the ratio between actual brain mass, and predicted brain mass based on biological expectations for mammalian brain size, with a larger value representing a larger brain proportional to body size than expected based purely on increase in

Assumptions:

- Sufficient circulatory penetration to cool the brain
- 1 kiloCalorie is equivalent to 4184 joules
- Average human brain temperature (37.3 degrees Celsius)
- The laptop assembly consumes the same percentage of supplied power that the human brain does relative to the body.

size.

Question:

Consider a laptop/webcam assembly being used to record and process an image that requires 60 watts to function. Assuming this power consumption and an EQ equivalent to that of an average human (6.653), determine the following physical parameters for a brain with equivalent energy costs to this laptop:

- Brain mass
- Body mass

Solution

The brain mass is 617.68 kg (answers between 617 – 618 kg are acceptable)

The equivalent body mass is 680,531.89 kg (answers between 680000 – 681000 kg are acceptable).

The biological assembly requires 60 watts of power--that means that the brain of a person requires 60 watts (not the person as a whole). Since the accompanying prompt established that the brain uses approximately 20% of the total power of the human body, and we know the conversion between Joules and kCalories is 1:4184, we can say that the total metabolic rate of the body in question (brain + supporting organs) is:

$$Total\ metabolic\ rate\ in\ kCal = (Brain\ metabolic\ rate) * (1/20\%) * 60s/min * 60min/hour * 24hours/day$$

or

$$Total\ metabolic\ rate\ in\ kCal = (60) * \left(\frac{1}{20}\%\right) * \frac{60s}{min} * \frac{60min}{hour} * \frac{24hours}{day} = \ 6195\ kCal$$

This gives us the metabolic rate, in kCal/day of the entire body, from watts (j/s) and the given ratios.

Now that we have the total metabolic rate of the body and brain, we can plug it into equation (1), and find the brain mass,

$$RMR\ (Resting\ Metabolic\ Rate) = k1 * M^{0.75} \quad \gg \quad \frac{RMR}{k1} = \frac{6195}{50} = 123.9 = \ M^{0.75}$$

$M = brain\ mass\ =$ 617.7 kg

then solve equation (3) for body mass (converting brain mass to g first), and solve.

$$EQ = (Brain\ Mass) \div (0.12 * (Body\ Mass)^{0.67})\ (3)$$

$$or\ \ BodyMass = \frac{\left(\frac{BrainMass}{0.12*EQ}\right)^{1.5}}{1000} = \text{ 680,562 kg}$$

Be sure to convert the masses into kg or g where appropriate (units used are specified in each equation).

Programming the solution into MATLAB:

```
clc; clear;
RMRWatts=60;
Eff=(0.2);
JouleTokCal=1/4184;
% Note; next step is to get TOTAL RMR--not JUST the 'brain'
RMRkCal=RMRWatts*JouleTokCal*(60*60*24)/Eff;


BrainMass=(RMRkCal/50)^(4/3); %NOTE: THIS IS IN KG
BrainMassG=BrainMass*1000;   %THIS CONVERTS TO GRAMS
EQ=6.653;
BodyMass=((BrainMassG/(0.12*EQ))^(3/2))/1000;
x=['The brain mass would be ' num2str(BrainMass), ' kg and the equivalent body mass would be
', num2str(BodyMass), ' kg.'];
disp(x)
```