# (R) GloVe Compartment (1/3) [Solution]

**R1.** *Answers:*

| | | | | | |
|---|---|---|---|---|---|
| 1. G | 2. K | 3. D | 4. F | 5. H | 6. C |
| 7. B | 8. I | 9. A | 10. J | 11. E | |

*Explanation:*

The words *man* and *woman* are given as examples. Those 2 words mean the same thing except that they have different genders. If we look at the vectors that are provided for them (which are [0.5, 0.9, 0.3, 0.3] for *man* and [0.5, 0.9, 0.1, 0.5] for *woman*), we see that they have the same first 2 elements, then the last 2 elements differ slightly: the $3^{rd}$ element is 0.3 for *man* and 0.1 for *woman*, while the $4^{th}$ element is 0.3 for *man* and 0.5 for *woman*.

We've also been given *daughter* as an example. Based on what we've seen about *man* and *woman*, it seems like a good place to start would be to try to figure out which vector goes with *son*, because we have *daughter* and it seems reasonable to expect that *son* and *daughter* are related in the same way that *man* and *woman* are. We observed that *man* and *woman* have the same first 2 elements as each other, so let's start by assuming that *son* has the same first 2 elements as *daughter*: 0.5 and 0.7. Thus, *son* would be one of the following options:

[0.5, 0.7, 0.4, 0.1]
[0.5, 0.7, 0.2, 1.1]
[0.5, 0.7, 0.4, 0.9]

But which one? We also saw that the $3^{rd}$ element for *man* was 0.2 plus the $3^{rd}$ element for *woman.* Thus, perhaps we can expect that the $3^{rd}$ element of *son* should be 0.2 plus the $3^{rd}$ element of *daughter*, giving 0.4 – narrowing it down to the first and third of our options. Finally, we saw that the $4^{th}$ element of *man* was the $4^{th}$ element of *woman* minus 0.2; so, the $4^{th}$ element of *son* is probably the $4^{th}$ element of *daughter* minus 0.2, or 0.3 – 0.2 = 0.1. Thus, we conclude that *son* = [0.5, 0.7, 0.4, 0.1] (2 = K). More generally, we've also figured out that, for a pair of words that differ only in gender, their vectors will differ by [0, 0, 0.2, -0.2].

What other vector pairs do we have that have this difference of [0, 0, 0.2, -0.2]? We have:

3 = [0.5, 0.9, 0.3, -0.5] and 9 = [0.5, 0.9, 0.1, -0.3]
11 = [0.5, 0.7, 0.4, 0.9] and 4 = [0.5, 0.7, 0.2, 1.1]
5 = [0.5, 0.8, 0.9, 1.3] and 7 = [0.5, 0.8, 0.7, 1.5]
6 = [0.5, 0.8, 0.9, 0.5] and 10 = [0.5, 0.8, 0.7, 0.7]

We also have 4 pairs of male/female words to account for: *boy/girl, king/queen, prince/princess, father/mother*. As leftovers, we also have the words *person* and *ruler,* and the vectors 1 = [0.5, 0.9, 0.2, 0.4] and 8 = [0.5, 0.8, 0.8, 1.4]. Let's try to match these leftovers up. If you look closely, you'll notice that the vector 1 = [0.5, 0.9, 0.2, 0.4] is exactly halfway between the vector for *man* and the vector for *woman*. Thus, perhaps this vector goes with a word that is in between *man* and *woman* in meaning, which is most likely *person* (rather than *ruler*). This leaves our last leftover, [0.5, 0.8, 0.8, 1.4], to mean *ruler*. Thus, we can match up 1 = *person* = G, and 8 = *ruler* = I.

# (R) GloVe Compartment (2/3) [Solution]

Since *person* was halfway between *woman* and *man,* we can expect *ruler* to be halfway between *king* and *queen.* Looking at the pairs of vectors listed above, this would be true if *king* = 5 and *queen* = 7.

If we look at the pairs we have left, we might notice that there is another type of relationship here: not just male/female pairs, but also adult/children pairs. That is, we might expect analogies of the form *queen* is to *princess* as *mother* is to *daughter*. How could our remaining vectors be assigned to make such analogies work systematically with the vectors? Let's take a look again at the pairs we've figured out and the pairs that are left:

Pairs figured out:

*son* = [0.5, 0.7, 0.4, 0.1], *daughter* = [0.5, 0.7, 0.2, 0.3]
*man* = [0.5, 0.9, 0.3, 0.3], *woman* = [0.5, 0.9, 0.1, 0.5]
*king* = [0.5, 0.8, 0.9, 1.3], *queen* = [0.5, 0.8, 0.8, 1.4]

Pairs still left:

3 = [0.5, 0.9, 0.3, -0.5] and 9 = [0.5, 0.9, 0.1, -0.3]
11 = [0.5, 0.7, 0.4, 0.9] and 4 = [0.5, 0.7, 0.2, 1.1]
6 = [0.5, 0.8, 0.9, 0.5] and 10 = [0.5, 0.8, 0.7, 0.7]

Note in particular that, of the pairs still left, we have one pair with 0.9 in the second spot, one with 0.7 in the second spot, and one with 0.8 in the second spot. This could make these pairs match up nicely with the pairs that are already figured out, where the child and adult versions of a word have the same second element. Thus, we can match up that 3/9 = *boy/girl*; 11/4 = *father/mother*; and 6/10 = *prince/princess.* Overall, this gives us that and adult version of a word minus a child version of a word will be [0, 0, 0, 0.8].

**R2.** *Answers:*

| | | | | |
|---|---|---|---|---|
| 12. N | 13. Q | 14. L or U | 15. O | 16. R |
| 17. M | 18. U or L | 19. T | 20. P | 21. S |

*Explanation:*

For R1, we figured out 2 things that will be important here:

(a) When words form an analogy "*A* is to *B* as *C* is to *D*", their vectors will have a relationship of the form *A* – *B* = *C* – *D*.

(b) If a word *Y* is in between words *X* and *Z* in meaning, then the vector for *Y* will be halfway between the vectors for *X* and *Z.*

Here, there is one more complicating factor: 2 of our words (*second* and *third*) have 2 different relevant definitions. Let's pretend that these relevant definitions were 2 different words: $second_{time}$ meaning "one sixtieth of a minute" vs. $second_{list}$ meaning "after first"; and $third_{fraction}$ meaning "one third" vs. $third_{list}$ meaning "after second." Then fact (a) gives us:

*$second_{time}$ – clock = millibar – barometer*
*$second_{list}$ – two = first – one*
*$third_{fraction}$ – three = half – two*
*$third_{list}$ – three = first – one*

# (R) GloVe Compartment (3/3) [Solution]

Solving for each *second* or *third* word gives:

$second_{time} = millibar - barometer + clock$

$second_{list} = first - one + two$

$third_{fraction} = half - two + three$

$third_{list} = first - one + three$

Based on fact (b) (and also on the hint given in R3), let's now assume that the vector for *second* will be halfway between the vectors for $second_{time}$ and $second_{list}$, and similarly for *third*. That is:

$second = 0.5(second_{time} + second_{list})$

$third = 0.5(third_{fraction} + third_{list})$

Plugging in from above gives:

$second = 0.5(millibar - barometer + clock + first - one + two)$

$third = 0.5(half - two + three + first - one + three)$

Now, with some guess and check, we can find that there are only two ways to match the vectors up to the words that will satisfy both of these equations; either of these ways counts as a correct solution.

**R3.** *Answer:*

Third in a list:

[0.4, -0.2, -0.8, 0]

One third, the fraction:

[0, -0.2, 0.2, -0.4]

*Explanation:*

Once we've solved R2, we can use the equations given for $third_{fraction}$ and $third_{list}$ to figure out what these two vectors would be.

**R4.** *Answer:*

(a) is nurse, (b) is doctor.

*Explanation:*

Words encode gender-related properties as follows: For a pair of words that are identical except for gender (e.g., *woman* and *man*), the vector for the female word minus the vector for the male word will equal [0, 0, -0.2, 0.2]. (Equivalently, the male word minus the female word will be [0, 0, 0.2, -0.2]). That is, gender is encoded via the difference between 2 vectors having that specific value. As the *doctor/nurse* example shows, these differences do not always reflect true gender differences, but instead sometimes reflect statistical or societal biases in terms of which roles tend to be held by members of particular genders.