# Understanding Language Evolution Using an Event-Based Model

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#### Introduction

Modern languages are related to one another through a complicated history of divergence and word borrowing. The divergence of languages is caused by the slow change in spoken language as it is passed from parents to offspring. Over time, divergence causes languages to become increasingly different from one another, ultimately to the point where they are mutually unintelligible. Languages that were spoken by the same human group more recently in time are considered to be more closely related to each other than they are to groups that spoke the language more distantly in time; this relatedness information can be depicted by a tree-like diagram called a 'phylogeny.' Linguistic borrowing, by contrast, causes languages to become more similar to one another.

| Language | IPA      | Coding |
|----------|----------|--------|
| English  | /hænd/   | 0      |
| German   | /hant/   | 0      |
| French   | /mẽ/     | 1      |
| Spanish  | /mano-/  | 1      |
| Italian  | /ma:no-/ | 1      |
| Russian  | /rʊka/   | 2      |
| Polish   | /rɛŋka/  | 2      |

**Table 1.** Coding of lexical cognates for the word *hand*.

### Languages



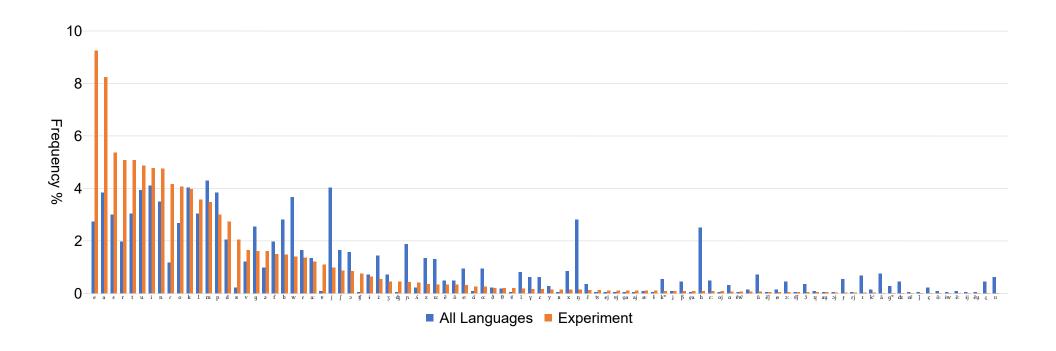
## Concept Examples

|                  | I  | We   | YouPlural   | YouSingular   | YouSingular-<br>VostramMercedem  | Woman   |
|------------------|--|--|---|---------------|--|---|
| Latin            | - e g o:   | n or - s                                   | wo: - s   | t u:          |  | f e: - m i - n - a                                  |
| French           | 3 ə  | n u  | v u   | t y           |  | f a - m   |
| Spanish          | j o  | n o - s                                    | b o - s   | t u           | - u s t e d  | -   e   -   m   -   b   r   -   a                   |
| Italian          | - i - o  | n o: i -                                   | v   o:   i   -  | t u           |  | f e m m i - n - a                                   |
| PortugueseBrazil | -   e   -   w  | n oj - s                                   | v oj s -  | t u           | v o s - e -  | f e - m e e   |
| Portuguese       | - e - w  | $ \mathbf{n}   \mathbf{n}  -  \mathbf{j} $ | $ \mathbf{v}  \mathbf{o}  $ – $ \int$   | t u           | v   o   s   -   e   -  | f e - m j e   |
| Catalan          | 3 3  |  | $ \mathbf{b}  \mathbf{u}   -  \mathbf{s} $  | t u           | v o s t e -  | f e - m - b r - a                                   |
| Walloon          | dg 1   | n o  | v o - s   | t y           |  | f œ - m   |
| Friulian         | j o  | n or                                       | v   o:   -   -  | t u           |  | $  f   \epsilon   -   m   i   -   n   -   \epsilon$ |
| Romanian         | j   e   -   w  | n oj                                       | v  oj   -   -   | t u           |  | f e - m e j e                                       |
|                  | Woman-Mulier   | Woman-Domina                               | Child   | Child-Ninnus  | Wife   | Husband   |
|                  | m u l i e r e m  | d o m i n a                                | $i \mid n \mid f \mid a \mid n \mid t \mid e \mid m$  |               | - s p o n s a  | m a r i: t u s                                      |
| French           |  | d a m                                      | $\left  oldsymbol{	ilde{lpha}}  ight  - \left  oldsymbol{f}  ight  \left  oldsymbol{	ilde{lpha}}  ight  - \left  -  ight  - \left  -  ight $                    |               | e - p u - z -  | m а в і   |
|                  | m u x - e r  | d   o   -   -   n   a                      | $ \mathbf{i}   \mathbf{n}   \mathbf{f}   \mathbf{a}   \mathbf{n}   \mathbf{t}   \mathbf{e}  -$  | n i n o       | e s p o - s a  | mariðo-   |
|                  | m o h h e  | d o n - n a                                | - - f a n t e -   | n i n o       | -   s   p   o   -   z   a  | m a r i t o -                                       |
|                  | m u V - 6 R  | d o n v                                    | $ 	ilde{i}  -  f   	ilde{v}  -  f   i  -$   | n e n ẽj̃     | i s p o - z a  | m a r i d u -                                       |
|                  | $m \mid u \mid \Lambda \mid - \mid e \mid \Gamma \mid - \mid - \mid$ | d o n v                                    | $\left  \widetilde{\mathbf{i}} \right  - \left  \mathbf{f} \right  \widetilde{\mathbf{g}} \left  - \left  \mathbf{t} \right  \widetilde{\mathbf{i}} \right  - $ | n e n ẽj̃     | i   f   p   o   -   z   e  | m e r i ð u -                                       |
|                  | m u   \lambda   -   e   -   -   -                                    | d   o   -   -   n   ə                      |   | n   e   n   - | $ \mathfrak{d}  s  \mathfrak{p}  \mathfrak{d} -  \mathfrak{z}  \mathfrak{d}$ | m   a   r   i   t   -   -                           |
| Walloon          |  | d œ m -   -   -                            | $ \epsilon $ - $ f $ $ \tilde{\alpha} $ - $ - - $ -   |               |  |   |
|                  | m u i: r   | d   o   -   -   n   e                      |   |               |  | m a r i: t  |
| Romanian         | m u - j e r e -  | d oam - n ə                                |   |               |  | m ə r i t   |
|                  | Husband-Sponsus  | Husband-Socius                             | Mother  | Father        | Father-Tata  | Animal  |
| Latin            | - s p o n s u s  | s o k i u s                                | m a: t r e m  | p a t r e     | t a t a  | a n i m a l i a                                     |
| French           | e - p u  |  | m e -   | ре-в-         |  | o   -   m   a   -   j   -                           |
| Spanish          | e s p o - s o -  |  | maðre-  | рабге         | t a t a  | a 1 i m a n - a                                     |
| Italian          | - s p o - z o -  | s o tf - o -                               | m a: d r e -  | p a: d r e    | t a t a  |   |
| PortugueseBrazil | i s p o - z u -  |  | m ej  | p aj          | t a t a  |   |
| Portuguese       | $\mathbf{i} \int \mathbf{p} \mathbf{o} - \mathbf{z} \mathbf{u} -$    |  | m ej  | p aj          | t a t a  |   |
| Catalan          | ə s p ə - s  |  | ma-rə-  | pa-rə         |  |   |
| Walloon          |  |  | m e - R   | p e: - r -    |  |   |
| Friulian         | -   s   p   o:   -   s   -   -                                       |  | m a - r i -   | p a - r i     |  | - n e m a: 1  |
| Romanian         |  | s o ts                                     |   |               | t a t ə  | -   n   ə   m   a   -   j   e                       |

#### Character Assignments

#### Each segment gets a different number

## Prior Segment Frequencies



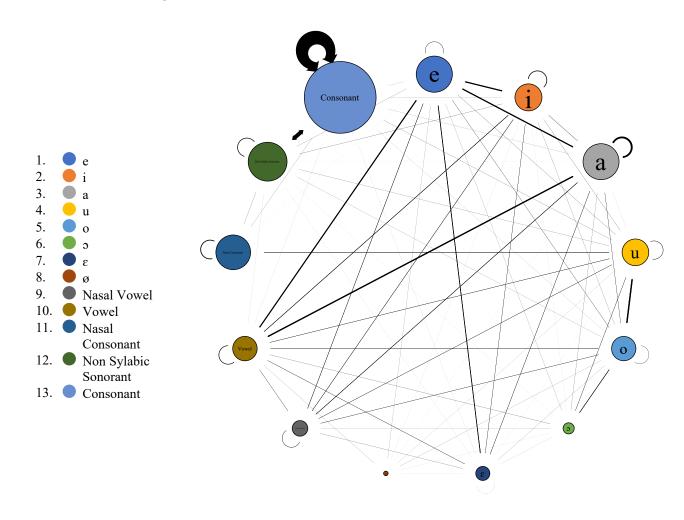
#### Partition Assignments

#### Model: "Linguistically Informed"

```
1) e
                                                                                e e:
                                                                               i i:
                                                                                a a:
       u
                                                                                u u:
        0
                                                                                o: o
                                                                                o o:
                                                                                13 3
         Ø
                                                                                ø: ø
        Nasal Vowel
                                                                               \tilde{\alpha} \tilde{i} \tilde{e} \tilde{e} \tilde{j} \tilde{e} \tilde{j} \tilde{o} \tilde{e} \tilde{e} \tilde{w} \tilde{e} \tilde{o}: \tilde{a} \tilde{e}: \tilde{o} \tilde{e} \tilde{u} \tilde{u} \tilde{o}
10) Vowel
                                                                                ə ı oj oj y e œ oa i aj ej ej ij iw au ea α εj σ
11) Nasal Consonant
                                                                               nmnŋĵ
12) Non Sylabic Sonorant
                                                                               wjlr
                                                                               g \, \exists \, j \, d\! j \, s \, \int v \, b \, t \, d \, f \, r \, x \, \land \, \kappa \, t\! f \, p \, z \, \check{o} \, k \, t\! s \, R \, \theta \, h \, c \, \beta \, \mathring{f} \, \psi \, d\! z \, g^w \, \varsigma \, k^j \, \mathring{f} \, \gamma \, k^w \, \, \mathcal{I}
13) Consonant
```

#### **Prior Transition Rates**

For the 'Linguistically Informed' model, states were grouped into 13 sets. Here, the area of the circles is proportional to the occurance frequencies for each group. The width of the lines is proportional to the rates of transition between the each partition.

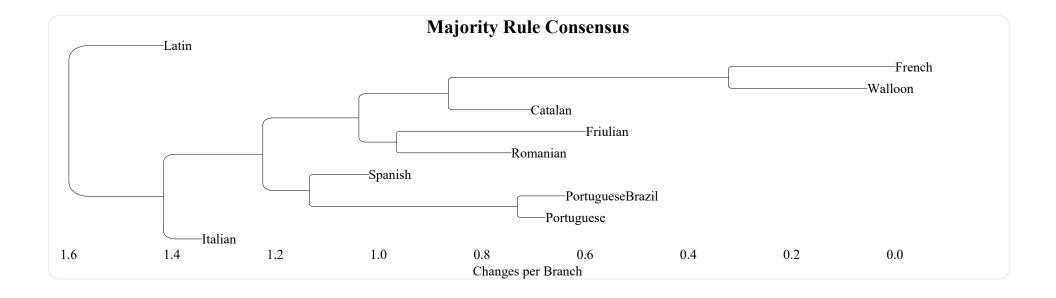


#### Segment Transition Rates

This chart shows the number of times that each segment (on the left vertical bar) differs from any other other segment in the same cognate set at the same aligned segment position. The rates of transitions to gaps and from gaps are ignored. The segments are grouped into partitions, represented by the sections divided by lines. Within each partition, the segments are ordered from highest to lowest frequency of occurrance. Transition counts are shown with the number in a red box, where the darker reds are larger numbers. The chart has diagonal symmetry.

| e e i i a a  | n n: 0 0:                         | 2 2: 8 8: 0:              | occurrance.         | Transition counts      | ire snown v                      | in the num            | per in a red     | DOX, Wh  | ere the dai                    |                            |                               | er numbers                      |                            | i nas diagonal     | symmetry.         | n + k) o* dr c |
|--|-----------------------------------|---------------------------|---------------------|------------------------|----------------------------------|-----------------------|------------------|----------|--------------------------------|----------------------------|-------------------------------|---------------------------------|----------------------------|--------------------|-------------------|----------------|
| 112 690 64 628 14<br>112 26 4 18 1   | 46 41 8 82 3<br>1 1 2             | 33 2 430 19 19<br>21 1 5  | 9 11 8 99 40        | 17 17 7 11<br>2 1 1    | 1 324 68 181<br>10 2 3           | 33 35 2 13 4<br>4 4   | 6 2 1            |          | 5                              | 3 36                       | 7 2                           | 1 9 7                           | D J 9 3 45                 | A Z O O Y C R      | хогк ј ј н        | ч тку ос с     |
| 690 26 248 48 1<br>64 4 248 38 1   | 1 1 2<br>1 53 1 43<br>3 2         | 8 1 99 4 7 23 2 1         | . 3                 | 63 26 2 8 8<br>5 2     | 7 5                              | 16 13 12 2 1 5<br>1 2 | 5 7 3 5<br>1 1   | 4 1      | 1                              | 8 6 40 5                   | 2 5                           | 1 4                             | 2                          | 5 7<br>1 2         | 1                 |                |
| 628 18 48 38 621<br>146 1 1 13 621   | 21 12 1 94 12<br>4                | 9 34 128 19 4<br>3 2 10 1 | 15 16 73 112<br>2 3 |                        | 5 296 429 42<br>8 15 1<br>19 2 1 | 3 7 9 3 26<br>1 1 2   | 5 22 2<br>1      | 4 5<br>1 | 1                              | 2 2                        | 2 6                           | 6 8                             | 2                          |                    |                   | 2              |
| 41 1 53 12<br>8 2 1 1  | 138 842 35<br>138 45 2            | 116 1 4 8<br>17 1 1       | 8 68 3 3<br>2 1 1   | 2 7 32 2 14 8<br>1 2 1 | 2 2                              | 12 1                  | 3 9 4<br>5       | 3        |                                | 3 34 7                     |                               | 2 7 6                           | 3                          |                    |                   | 18 2           |
| 82 43 2 94 4<br>3 12   | 4 842 45 80 3<br>35 2 80          | 304 2 25 2 13<br>29 2 5   | 3 11 82 2           | 4 6 8 4 18<br>2 4      | 22 7 6                           | 3 30 3 17<br>7 2 10   | 25 15 9<br>4 1 6 | 2        |                                | 1 28 1                     | 6 4 4                         |                                 |                            | 2                  |                   | 2              |
| 33 8 9 3<br>2 1 34 2   | 3 116 17 304 29<br>2 1 2          | 2 14 4                    | 6 23 4              | 3                      | 1 1<br>2 1                       | 3 21 7                | 4 1 6<br>12 8 2  |          |                                | 6                          |                               | 1                               |                            |                    |                   |                |
| 430 21 99 23 128 10<br>19 1 4 2 19 1   | 0 4 1 25 2<br>1 2 2<br>8 1 13 5   | 14 2 12 8<br>12           | 2 20 10             | 8 7 2<br>1             | 1 23 21 21<br>1 2 1              | 2 3                   | 12 3 1           | 1 1      |                                | 4 4                        | 6                             | 4 2                             |                            |                    |                   |                |
| 19 5 7 1 4   | 8 1 13 5<br>8 2 11 2<br>68 1 82 3 | 4 8<br>6 2 2              | 2 1                 |                        | 1                                | 2 3 2 4<br>1 1 1 1 4  | 1 2 2            |          |                                | 1 1                        |                               |                                 |                            |                    |                   |                |
| 8 2 15<br>99 3 51 3 16 2<br>40 1 22 73   | 68 1 82 3<br>2 3                  | 20 1                      | 1 25                | 7 9 6 1 1              | 5 2<br>9 9                       | 3 1                   | 3                | 1        |                                | 1                          |                               |                                 |                            |                    |                   |                |
| 112 2  | 3                                 | 10                        | 25 24<br>24         | 7 5 2                  | 2 6 3 10                         |                       |                  |          |                                |                            |                               |                                 |                            |                    |                   |                |
| 17 63 5  | 7 1 4                             | 8<br>7 1                  | 7 7                 | 5 2 2                  | 2 3 4 6 2                        | 2                     |                  | 1        |                                |                            |                               |                                 |                            |                    |                   |                |
| 2 24 4   | 4 2 6 8 2                         | 2                         | 2 6                 | 2 4                    | 2                                |                       |                  | 2 2      |                                |                            |                               |                                 |                            |                    |                   |                |
| 7 1 8<br>11 1 8 6 4  | 4                                 |                           | 1                   | 5                      | 1 1                              |                       |                  |          |                                |                            |                               |                                 |                            |                    |                   |                |
| 11   | 14 18 4                           | 3                         | 6 2 2               | 4                      | 1                                |                       |                  |          |                                |                            |                               |                                 |                            |                    |                   |                |
| 1 1  | 8 1                               | 1                         | 1 1                 | 4                      |                                  |                       |                  |          |                                |                            |                               |                                 |                            |                    |                   |                |
| 1 3 5  |                                   | 1                         | 1 2                 | 2                      | 1                                |                       |                  |          |                                |                            |                               |                                 |                            |                    |                   |                |
| 1 3 3 3 3 3 3 3 3 4 10 131 7 296 8 8 2 6 429 11 8 1 3 7 2 5 42 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 | 8 19 2 22<br>5 2 2 7              | 1 2 23 1 1 21 2           | 5 9 8 6 4 3         | 3 6 1 1                | 114 37<br>114                    | 1 2 4 2 1<br>2 1      | 5<br>4           | 1        |                                | 4 1                        |                               | 2 2                             | 2                          |                    |                   |                |
| 181 3 72 5 42 1<br>16 1 3  | 1 1 6 1 70 12 3                   | 1 21 1 1                  | 2 9 8 10            |                        | 1 37<br>1 2 1                    | 1 2                   | 1 1              |          | 1                              | 2                          |                               |                                 |                            |                    |                   | 1              |
| 33 4 13 7 1<br>35 4 12 9 1   | 1                                 | 15 2 2<br>13 3            | 1 3                 | 2                      | 2 1<br>4 1                       | 10 1                  | 1                | 1        |                                | 1                          |                               |                                 |                            |                    |                   |                |
| 2 2 3<br>13 1 2 26 2   | 2 15 1 30 7 3 2                   | 21 2 2                    | 1                   |                        | 2 1                              | 1 2                   | 3 3 1            |          |                                |                            |                               |                                 |                            |                    |                   | 1              |
| 4<br>21 6 5 1 5  | 9 17 10                           | 7 12 4                    | 4                   |                        | 1                                | 2 2                   | 1                | 1        |                                | 1                          |                               | 3                               |                            |                    |                   |                |
| 10 2 7 1 22 1<br>8 1 2   | 1 3 5 25 4                        | 1 3 2<br>12 1 2           |                     |                        | 5 4 1                            | 1 3                   | 1                |          |                                |                            |                               |                                 |                            |                    |                   |                |
| 5 3  | 3 5 25 4<br>9 15 1<br>4 9 6       | 8 2                       | 4 3                 |                        |                                  | 3<br>1 2              | 1                |          |                                | 2                          |                               |                                 |                            |                    |                   |                |
| 4 5<br>7 4   |                                   | 1                         |                     |                        | 1 1                              | 1 1                   |                  |          |                                | 3                          |                               |                                 | 1                          |                    |                   |                |
| 1 4 1  | 1                                 | 1                         | 1                   | 1 2                    |                                  |                       |                  |          |                                |                            |                               |                                 |                            |                    |                   |                |
| 5 1 1  | 3 2                               |                           |                     |                        | 1                                |                       |                  |          | 36 174 56<br>36 1 7<br>174 1 7 | 9 12 3<br>12               | 7 4                           | 4                               | 1                          | 6                  |                   |                |
|  |                                   |                           |                     |                        |                                  |                       |                  |          | 174 1 7<br>56 7 7              | 2                          | 1                             | 2 3                             |                            |                    |                   |                |
| 3 8 2 2  | 2 1                               | 4                         |                     |                        |                                  |                       |                  |          | 9 12<br>12 2 10                | 45 4 1                     | 5 12 1140<br>4 4 50 4<br>8 10 | 4 725 2<br>20 11<br>17 3 184 20 | 3 11                       |                    | 1 1<br>4 49 35    |                |
| 36 40 5 2  | 34 1 28 3<br>7 1<br>4 6           | 6 4 1                     | 1                   |                        | 4                                | 2                     | 1 2 3            |          | 3                              | 4 99 6<br>1 74 6<br>5 4    | 8 10<br>3 6<br>33 1 45        |                                 | 50 1 2                     | 2                  | 6 5 1             | 2              |
| 2 5  | 2 4                               |                           |                     |                        |                                  |                       |                  |          |                                | 12 4                       | 33 3 37                       | 5 1 7<br>5 152 3 4              | 321 114 1 3<br>2 12 141 14 | 2 1 69 6 1 11      | 20 20 8 6<br>1 45 | 2 2            |
| 7 2 2 6  | 2 4                               | 6                         |                     |                        |                                  |                       |                  |          | 7 4 1                          | 1140 50 8 3<br>4 10 6      | 1 3<br>45 37 1                | 31/                             | 00 140 7 4                 | 13 11 11 37 87     | 13 6 58 1         | 10 5 1         |
| 1 6  | 2                                 | 1                         |                     |                        | 2                                |                       | 3                |          |                                | 4 20 17                    | 5 152 11                      | 30 3 3<br>6 5                   | 31 36 4<br>4 2 17 51       | 3 22 43 1          | 2 7 10            | 2 2            |
| 9 1 8  | 7                                 | 4                         |                     |                        | 2                                |                       |                  |          | 9 2 3                          | 2 184                      | 1 3 517                       | 0 6 2 30                        | 1 1 5<br>339 6 6           | 2                  | 28                |                |
| 7 4  | 6                                 | 1 2                       |                     |                        |                                  |                       |                  |          | 9 2 3                          | 20                         | 7 4 121                       | 3 30                            | 6 45 49<br>8 22 7          | 57 4               | 1 3 1 3           | 4 11           |
| 2 2  | 3                                 |                           |                     |                        | 2                                |                       |                  |          | 1                              |                            | 2<br>321 12 90 3              | 11 4 1 339 6 8<br>16 22         | 6 9 9<br>16                | 5 15 9<br>24 30 10 | 7 1 2 3           | 1 3            |
|  |                                   |                           |                     |                        |                                  |                       | 1                |          |                                | 1 25                       | 321 12 90 3<br>114 141 140 7  | 4 2 7<br>17 1 6 45              | 6 16 4 1<br>9 4 97         | 7 1 5              | 12 10 2<br>13 8   | 5 1            |
| 5  | 2                                 |                           |                     |                        |                                  |                       |                  |          |                                | 11 2 12<br>144 18<br>2 2 2 |                               | 3 5 6 49                        | 9 1 97                     |                    | 8 5 1<br>16 1 4   |                |
|  |                                   |                           |                     |                        |                                  |                       |                  |          |                                | 2 2 2                      | 69                            | 43                              | 5 24 7 5                   |                    | 1 3               | 1              |
| 1  |                                   |                           |                     |                        |                                  |                       |                  |          |                                | 2                          | 64 6 11<br>1 37               | 2 57                            | 15 30 1<br>5 4             | 11 1               | 3 2 1             |                |
| 7 2  |                                   |                           |                     |                        |                                  |                       |                  |          | 6                              | 46                         | 12 11 87                      | 25                              | 9 10 1                     | 1                  |                   | 3 1            |
| 1  |                                   |                           |                     |                        |                                  |                       |                  |          |                                |                            | 20 1 13<br>20 45 6            | 1 1                             | 7 13 8<br>1 12             | 3                  |                   | 3 1            |
|  |                                   |                           |                     |                        |                                  |                       |                  |          |                                | 1 49 6 2<br>35 7           | 8 58                          | 2 1 3                           | 10                         | 2 2                |                   |                |
|  |                                   |                           |                     |                        |                                  |                       |                  |          |                                | 5                          | 6 1                           | 0 28 3                          | 2 8 5                      |                    |                   |                |
| 2  | 18 2 2                            |                           |                     |                        |                                  | 1 1                   |                  |          |                                | 3                          | 0 1                           | 2 4                             | 3 2 1<br>1 5 2             |                    |                   |                |
|  |                                   |                           |                     |                        |                                  |                       |                  |          |                                | 2                          | 1 5                           | 2 4                             | 1 3 2                      |                    | 3                 |                |
|  |                                   |                           |                     |                        |                                  |                       |                  |          |                                |                            | 2                             | 2                               | 1 1 1                      | 1                  | 1                 |                |
|  |                                   |                           |                     |                        |                                  |                       |                  |          |                                |                            | 1                             |                                 | 3                          |                    |                   |                |

#### Results



# Questions

