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Special thanks

This document would not have been possible without the help of multiple people. After all, most of my knowledge of layouts is the result of discussing layouts with them. So, I would like to thank Oxey, ClemenPine, StronglyTyped, Brys, Semi, Eve, Lela, Smudge, Heart, Whorf, Flarefin, Tanamr, Kyrime, Colby, Desshaw... among others.

Feedback

If you have feedback or want to contact me you can either DM me on discord (ec0vid) or email me at `Ec0vid`. I had to disable comments because it apparently allowed people to make suggestions in the document itself, and people would trigger those accidentally.

What has changed compared to the first edition

- Many chapters have been added. For example, there are now new chapters for alt fingering, scissors, lateral stretches, trigram stats, consonant and vowel columns... Additionally, each section is now properly numbered for easier navigation and referencing. For each chapter an estimated reading time is given.

- The document should now load a lot faster. The older one took a long time to load because the layout list had hundreds of images. To fix that, layouts are now usually shown in a text format.

- Another benefit of using text (rather than images) for the layouts is that we can now fit multiple layouts plus their stats on a single page, allowing for easier comparisons.

- In the new document the layouts are separated into distinct categories, with each category getting its own chapter. Inside a given category, layouts are further subdivided based on their home row and letter columns.

- For each layout, the document now specifies how each of its stats perform in relation to other layouts. For example, rather than simply saying that a layout has 40% alternation, we will specify if that means "low", "mid" or "high" alternation. The stats are also color coded to make things easier visually.

- Outdated layouts are now up to date. Some layouts were removed, others added.

Introduction

This document is divided into six main parts, with most parts containing multiple chapters.

Part 1 goes over some typing basics and also looks at angle mod in detail. If you are already familiar with those concepts you can probably skip, or quickly scroll by, this part.

Part 2 does a brief analysis of English's letter, bigram and trigram frequency. Naturally, a basic understanding of the English language is required in order to make layouts for it.

Part 3 looks at keyboard layout stats in detail, dedicating a chapter for each. These stats include: same finger bigrams (SFB), same finger skipgrams (SFS), scissors, lateral stretches (LSB), alternation, rolls, redirects, etc...

Part 4 analyzes the building blocks (i.e. letter columns) used to construct layouts. If you want to learn how to make layouts, part 4 will be the most useful one.

Part 5 classifies layouts into a few groups. Afterwards, each category gets its own chapter explaining how to make such layouts and giving many layout examples with their stats.

Part 6 looks at each consonant individually, analyzing which are the best pairs and letter columns for each consonant. This part is basically a much more detailed version of part 4.

Issues with the Qwerty layout

The layout that comes installed by default with most computers is called Qwerty. It is named after the six letters that are placed on the top left corner of the keyboard:

Qwerty is still used nowadays because it became the standard all the way back in the typewriter era. Having said that, **Qwerty is a terrible layout, for many reasons:**

- The most common letters (shown in orange) are scattered around the keyboard.
- Thousands of English words are typed with a single hand, while the other hand sits still (e.g. **afterwards**, **average**, **garbage**, **million**, **monopoly**, **opinion**...).
- There are many words where a single finger types lots of letters (e.g. **December**, **science**, **decided**, **community**, **minimum**, **anonymous**...).
- Similarly, numerous words are typed by alternating only two fingers for the most part (e.g. **return**, **thought**, **monthly**, **bought**, **amendment**, **Sydney**, **burn**...).
- There are instances where one finger has to press two far away keys in a row, forcing that finger to make a big jump (bigrams like **ec**, **br**, **un**, **ny**, **um**, **my**...).
- There are uncomfortable patterns where one finger goes down, but an adjacent finger goes up (e.g. the **cr** bigram, where the index presses R and the middle C).
- Finally, there are bigrams that require a lateral wrist motion (e.g. **eg** or **eb**).

Programs used to install a new layout

- Msklc: Default for windows
- Xkb: Default for linux
- Ukelele: Default for mac
- Kmonad: Runs on all three OS
- Kanata: Runs on all three OS. It is a rewrite of Kmonad with more features.
- Keyd: A Kanata alternative for linux.
- Karabiner-Elements: Has the most features on mac.
- Capsicain: An option for windows that uses the interception driver.
- Autohotkey: A macro creation and automation software for windows. Unlike the previous ones, it is not a program for layouts specifically, but can be used for that.

The first three only require using the program once to install the layout. After that, the layout will always be loaded. For the other ones, the program needs to run each time we start our computer. Regardless, that can generally be setup so it happens automatically.

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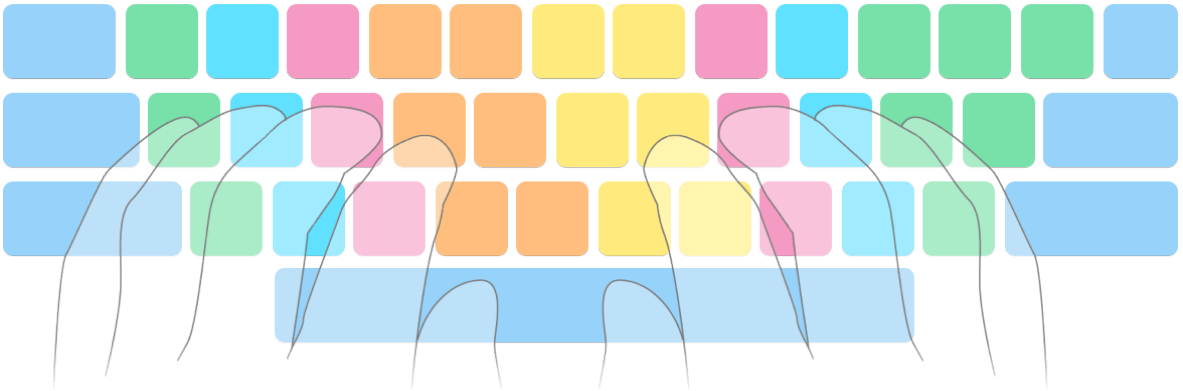
Typing

1. Typing basics (7 min)

1.1. Touch typing

Touch typing refers to developing the necessary muscle memory to be able to type without looking at the keyboard and without consciously thinking about it.

Proper touch typing technique involves using eight fingers (pinky, ring, middle and index of each hand). In the following image, each color highlights the keys assigned to that finger. The color code is as follows: green for pinky, light blue for ring, pink for middle, orange for left index, and yellow for right index. The space bar would be pressed by either thumb.

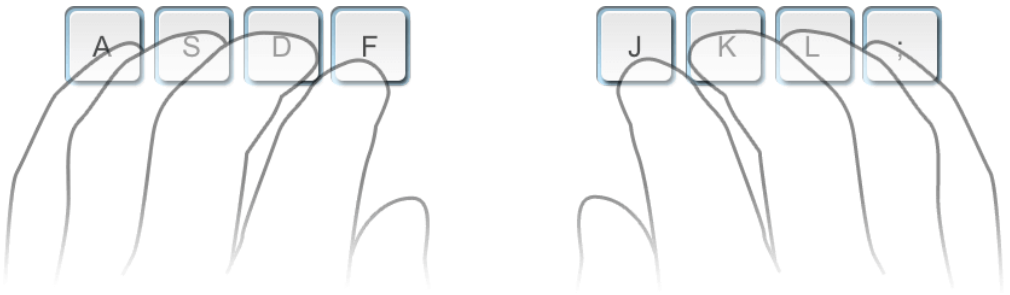


We will refer to the model above as standard fingering. There are many people who do not follow this model, as they learned to type on their own without the use of a typing tutor. However, **if we want to learn an alternative keyboard layout, we will also have to learn the correct typing technique, as layouts are designed with it in mind.** Otherwise, we won't get the benefit of the layout.

If you currently do not use all your fingers when typing, arguably the best reason for learning a new layout is to take it as an opportunity to learn proper touch typing.

1.2. The home row

The usual approach for learning touch typing is to break it in steps. The first step consists of getting used to typing the letters on the home row without looking at the keyboard. The home row refers to **the eight keys that act as the resting position for your fingers**:



The image above shows the home row on a standard Qwerty keyboard. We should be able to place our hands in this position without looking at the keyboard, by feeling with our index fingers the two small bumps in the F and J keys.

Learning the home row before anything else will be very helpful, as we can then develop the muscle memory for the rest of the keyboard in relation to the home row.

Note that, when we say that our fingers will be resting over **ASDF JKL;** , we are simply describing the physical location on the keyboard. The intention is to learn a keyboard layout other than Qwerty. Any modern layout will replace **ASDF JKL;** with more common letters.

1.3. The top and bottom row

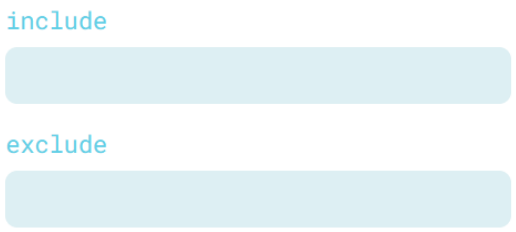
After learning the home row, the next step would be practicing the muscle memory for the row of keys that is directly above it, known as the top row. Lastly, we would do the same with the row of keys directly below the home row, which is referred to as the bottom row.

1.4. How to learn a new layout

A useful tool for this is a word filter. The MonkeyType website already has a word filter built in. To use it, near the top right corner, click on **custom** → **change** → **Words filter**.

By default, MonkeyType only uses the 200 most common English words to generate its tests. Before anything, we should click on **language** and select an expanded word set. English 1k includes the 1000 most common words in English, 5k includes the top 5000, etc...

In the word filter menu, we will see the following two boxes:



By adding a set of letters (separated by space) in **include**, and putting all the remaining letters in **exclude**, we can generate a typing test that uses only the letters we want. This in turn can be used to learn a layout in steps. For example, take the MTGAP layout:

Mtgap

```
y p o u j  k d l c w
i n e a ,  m h t s r
q z ' . :  b f g v x
```

Let's say we wanted to practice the home row. Firstly, we select a word set like English 1k. Secondly, we add all of MTGAP's home row letters to the include box, and put all the remaining letters in exclude. Finally, we click **set**, resulting in the following word list:

```
the a in is it that he are as I his at this there an she their then these
her see has than set three air here near earth state tree start sea ease
eat hear area interest ten rain star rest street test ran heat tire east
heart art sit train sat raise hair either sense ear rise sent hit rather
thin tie enter hat nine shine sister seat sheet share instant teeth
```

All there is left to do is click on **random** (to randomize the order in which the above words will appear in the typing test) and select a duration for the test (either a number of words or of second). We can now practice MTGAP's home row while typing actual words.

Once we are comfortable with the home row, we go back to the word filter screen and progressively move more letters from **exclude** to **include**, until we have learned all of them. How many steps this process should take is entirely up to you.

1.5. Word tests

If we have already learned all the letters in our layout, then we do not need the word filter anymore. Now we can start using either the **time** or **words** settings on MonkeyType.

We can select how long the test will last (either a time in seconds, or how many words it will contain). The default is 50 seconds or 60 words. Regardless, we can change it.

Remember to practice on a bigger word set than the default English option, as that one only includes the 200 most common English words, and should only be used for speed typing.

1.6. Punctuation and shift

By clicking on the **punctuation** option, we add basic punctuation to the test: comma (,), period (.), apostrophe ('), colon (:), semicolon (;), hyphen (-), slash (/), question mark (?), exclamation point (!), quotation marks ("") and parentheses ().

Enabling punctuation also forces us to practice using Shift (the key with an arrow pointing upwards) in order to capitalize letters. **The correct technique is to use the Shift key of the hand opposite to the letter we want to capitalize**. In other words, if we want to capitalize a letter on the left hand, we should use the right Shift key (and vice versa).

The issue with using Shift on the same side as the letter we want to capitalize is that our fingers will be pulled apart (e.g. try holding the right Shift plus the letter Y on Qwerty). Although learning to use Shift correctly is tricky, it will be worth it in the long run.

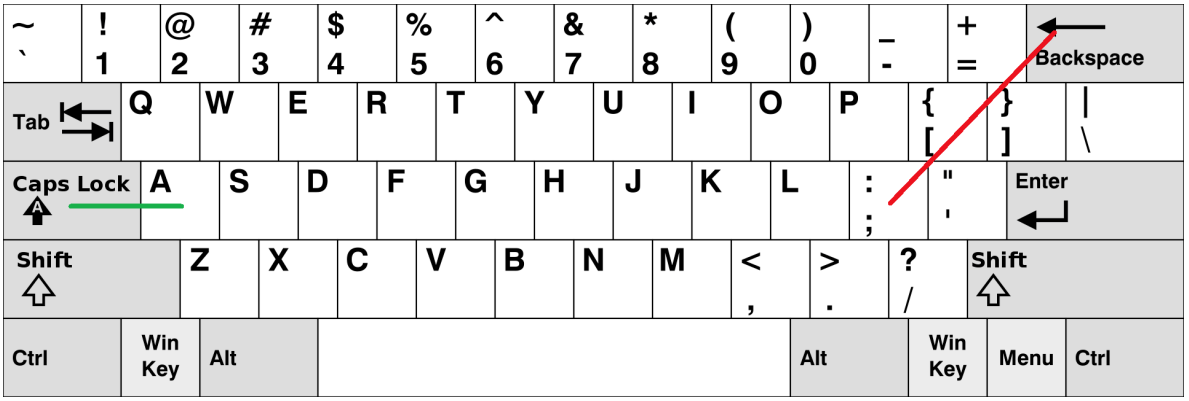
1.7. Quotes

Once we are comfortable with punctuation and Shift we can start using the **quote** setting to practice full sentences, rather than individual words as we had been doing until now.

We can select how long we want the quotes to be. There is even an option to search through all the quotes on MonkeyType to choose specific ones. If we want to practice texts of our own choice, we can click on **custom** → **change**, and paste our desired text.

1.8. Swapping Caps lock and Backspace (on Windows)

Despite the Backspace key being a commonly used key, it is very far from the right pinky's resting position, forcing us to make quite a jump to reach it. A fix some people do is moving Backspace to where Caps lock used to be, making Backspace more comfortable to press:



If you want to try the fix above, download and unzip the following file. Afterward, you can run the .reg file of your choice, and reboot your computer for it to take effect:

- Caps2BS.reg - Rebind Caps to Backspace
- SwapCapsBS.reg - Swap Caps and Backspace
- Caps2Ctrl.reg - Rebind Caps to Control
- SwapCapsCtrl.reg - Swap Caps and Control
- Unbind.reg - Undo All Rebinds

The first .reg file simply makes the Caps lock key act as a second Backspace. In other words, the old Backspace would still work, and we would not have a Caps lock key anymore.

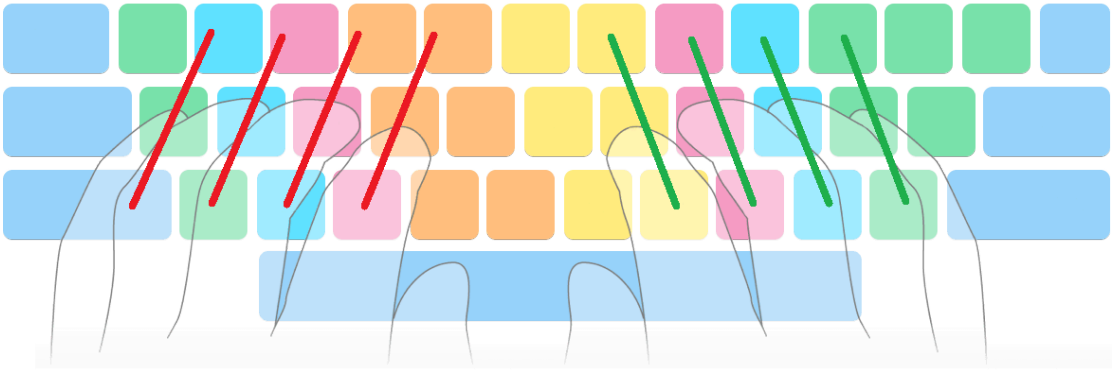
With the second .reg file, Caps lock and Backspace are swapped. So, this option retains a Caps lock key, plus it forces us to get used to utilizing the new Backspace location.

Anyway, Credit goes to Ze_or for making the above file.

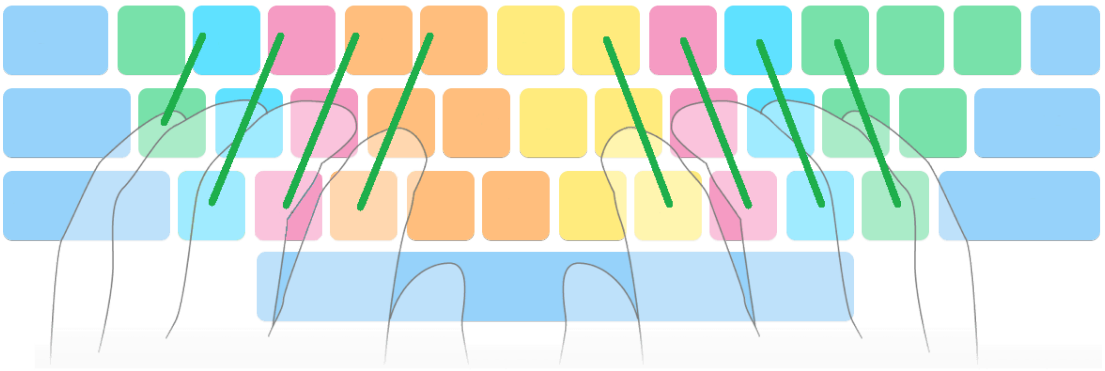
2. Angle mod (10 min)

2.1. Improved typing technique

On standard keyboards, each row is shifted a bit to the side in relation to one another. This is known as the row stagger. **When using the standard finger technique, the row stagger only aligns well with our fingers on the right hand.** To help us visualize this, we will draw lines over the keyboard representing the natural up/down motion of our fingers. We are assuming that our arms approach the keyboard at an angle (70º or so) rather than being perpendicular to it:



On the right hand, the green lines match well with the keys assigned to each finger. However, the same is not true on the left hand, with the bottom row being particularly misaligned. **There is a modified finger technique that aims to fix this, known as Angle mod. It consists of changing the finger assignments for the left bottom row:**



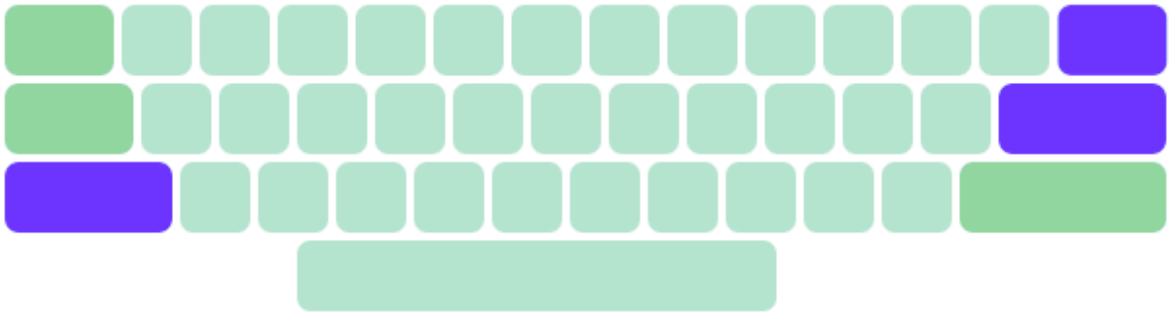
Although angle mod makes the stagger on the bottom row the same on both hands, the stagger on the top row will still align better with our fingers on the right hand vs the left. In any case, the following are the keys that change fingers:

With standard fingering:	**With angle mod fingering:**
Qwerty Z → Pinky	Qwerty Z → Ring
Qwerty X → Ring	Qwerty X → Middle
Qwerty C → Middle	Qwerty C → Index

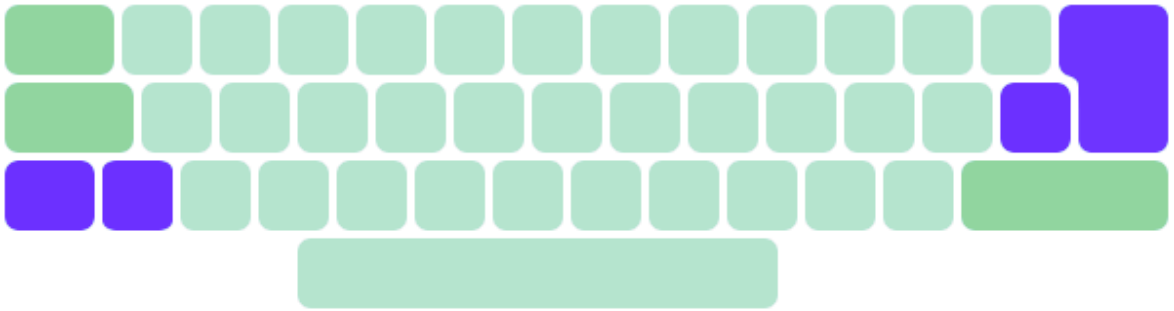
2.2. ANSI and ISO standards

The physical layout of the keyboard varies a bit depending on the country. **In the images below, the differences appear in blue**:

ANSI (American):



ISO (International):



On ISO, the left shift key is split into two, while on ANSI it is not. This affects how angle mod is implemented on each. The key difference is that, on ISO angle mod, the left pinky retains three keys just as with standard fingering. However, on ANSI angle mod the left pinky loses one key (now two total) while the left index finger gains one (now seven total). This will be better understood after seeing some practical angle mod examples.

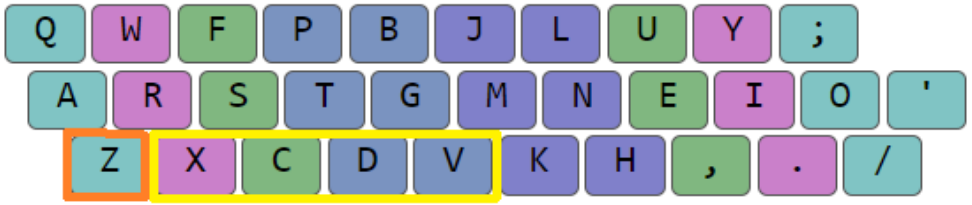
Finally, note that, when angle mod is utilized later throughout this document it will be the ANSI version, as it works on any keyboard. ISO angle mod is exclusive to ISO keyboards.

2.3. Angle modding a layout

Modifying a layout that is arranged for standard fingering into one that uses angle mod fingering instead is known as angle modding the layout. As already mentioned, this process is slightly different depending if we are using an ANSI or ISO keyboard.

2.3.1. ANSI angle mod example

We start with Colemak DH for standard fingering:



Angle modding a layout requires two steps on ANSI keyboards:

1. The letters inside the yellow box (i.e. the bottom row left ring, middle and index finger keys) are all shifted one position to the left.

2. Since the letter inside the orange box (i.e. the bottom row left pinky key) loses its old spot, it is now moved to the new vacant spot on the left index.

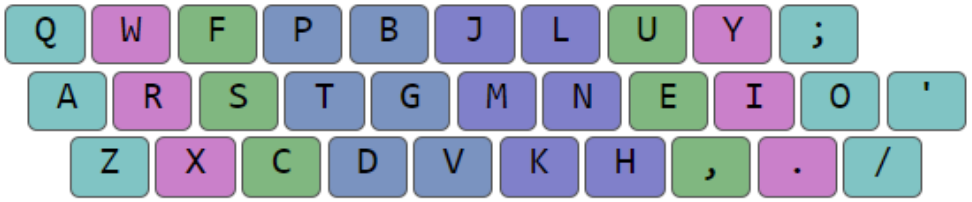
The result is angle modded Colemak DH:

When angle modding a layout, the original columns should remain the same. By "column" we are referring to the letters each finger is supposed to press. Note how, on both the original and the angle modded versions, the **left ring** has a WRX column, the **left middle** a FSC column, and the **left index** a PTD column.

Lastly, for a layout to be easily "angle moddable" on ANSI keyboards, the character inside the orange box (Z in our example) should be a rare letter. The reason for this is that said letter actually changes fingers (it is moved from the left pinky to the left index) meaning that it will create letter interactions that the original layout did not account for. This will not be an issue as long as it is a rare letter, though.

2.3.2. ISO angle mod example

We start with Colemak DH for standard fingering:



To angle mod Colemak DH on a ISO keyboard, we simply have to shift the whole left bottom row one position to the left:

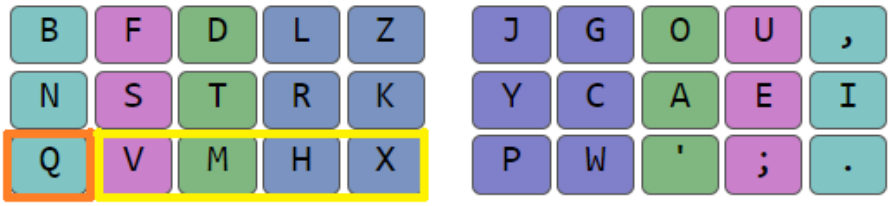
On ISO, thanks to the additional pinky key, we do not need to move the bottom row left pinky letter (Z in our case) to the left index. That was only necessary on ANSI keyboards. Regardless, it is technically possible to use ANSI angle mod on an ISO keyboard, if we want.

2.4. Un-angle modding a layout

When exploring alternative keyboard layouts, we will find lots of angle modded layouts. This is because most layouts were designed with row stagger in mind, and angle mod is the recommended finger technique on such keyboards.

If we want to learn a layout that has already been angle modded, but we plan on using it on a matrix keyboard, then we will have to un-angle mod the layout. After all, angle mod only makes sense on row stagger. For example, take angle modded Noctum:

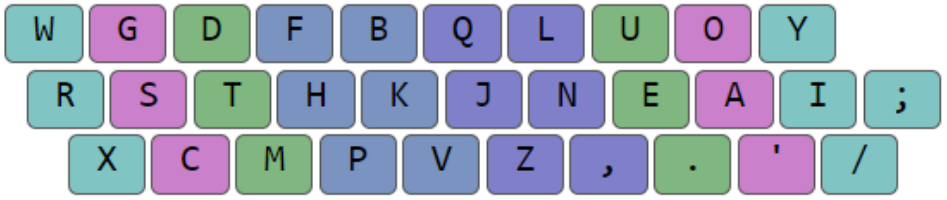
If we were to learn this layout on matrix, we would un-angle mod it first, as follows:



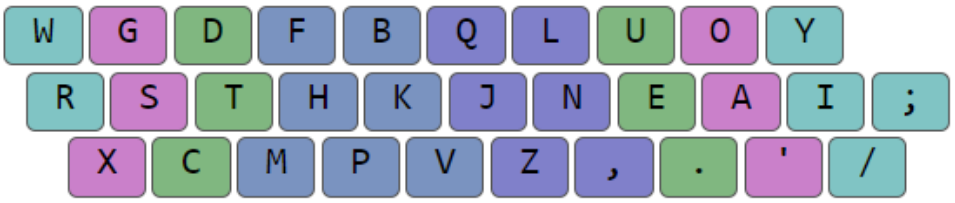
2.5. Errors to avoid with angle mod

2.5.1. Learning a standard layout with angle mod fingering (angle cheat)

Take APT with standard fingering:

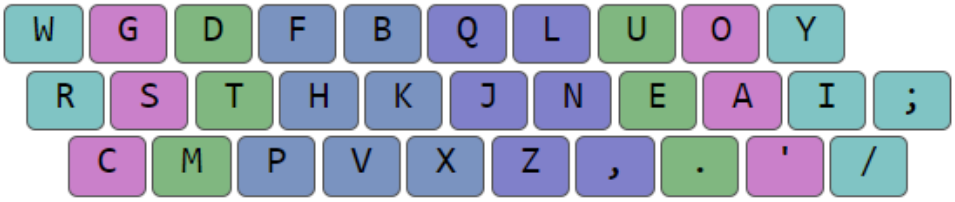


Imagine someone learned the layout above with angle mod fingering, but without actually angle modding the layout first. Doing so is known as “angle cheat”:



Here we are making the layout noticeably worse, as bigrams that used to be typed with two fingers (e.g. **CT**, **MP**, **MB**...) are now typed with the same finger on the second version.

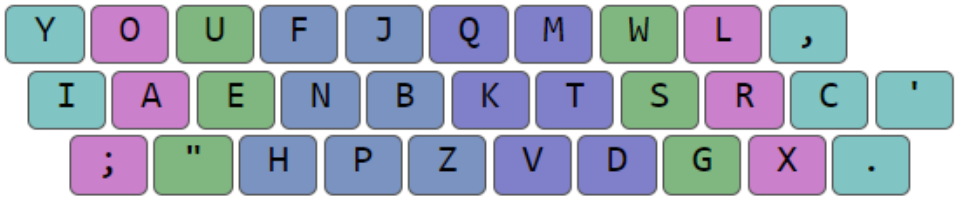
In order to respect the original layout’s columns, we need to actually angle mod it:



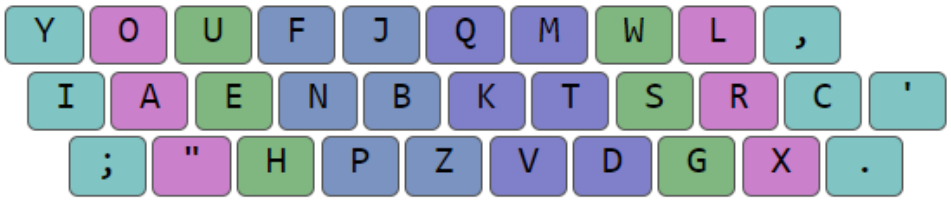
Anyway, both the first and third versions of the layout are correct, they just differ on the finger technique being utilized. The second version however has the columns wrong.

2.5.2. Learning an angled modded layout with standard fingering

Take Rolly, which was designed with angle mod in mind:

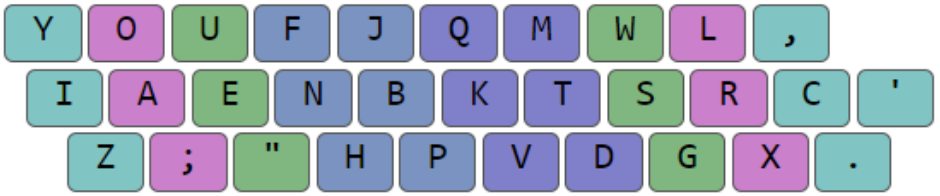


Imagine someone learned the layout above with standard fingering, but without actually un-angle modding the layout first:



Here we have effectively ruined the layout, as H and E are now sharing a finger. Consequently, **HE** becomes a very common same finger bigram (a bigram where one finger presses two keys in a row). Although the original angle modded version only had 0.752% SFBs on the Colemak mods analyzer, the second one goes all the way up to 4.286%!

Let's say we did un-angle mod the layout before applying standard fingering:



This way we are not causing unintended SFBs, as we are respecting the original columns. Having said that, on a row stagger keyboard, this third version would still be a downgrade compared to the first. This is because H and P are now much further apart from E and U, making bigrams like **HE**, **HU**, **PE** and **PU** less comfortable than before.

Anyway, the best version would be the very first one.

2.6. How to tell if a layout is angle modded or not

Later in this document we will list and compare many different layouts. The layouts will often appear as just text. Depending on how that text is formatted, it will indicate one finger technique or the other:

Standard fingering:

Gallium (Bryson)

```
b l d c v   z y o u ,
n r t s g   p h a e i
q x m w j   k f ' ; .
```

For standard fingering, the columns will be strictly vertical. For example, the left hand on Gallium has a **BNQ** pinky, a **LRX** ring, a **DTM** middle and a **CSWVGJ** index.

Angle mod fingering:

Isrt (Whorf)

```
y c l m k   z f u , '
i s r t g   p n e a o ;
 v w d j q   b h / . x
```

For angle mod, the bottom row will be shifted one unit to the right. So, the left hand on Isrt has a **YI** pinky, a **CSV** ring, a **LRW** middle and a **MTDKGJQ** index. Remember that, with ANSI angle mod, the left pinky only has two keys, while the left index now has seven.

Sometimes we will use images (rather than text) to showcase a layout. In those cases, we will specify if the layout is angle modded or not to avoid any confusion. Regardless, as you become more familiar with layouts you will be able to easily tell if a layout is angle modded or not simply by glancing at the layout's columns. For example:

The layout above has obviously been angle modded already. We can tell because its columns would not make sense otherwise. If we assume angle mod, we get a BN pinky, a FSV ring, a DTM middle and a LRHZKXQ index. Those are sensible columns on multiple fronts. For once, they cause negligible same finger bigrams (SFBs). Additionally, the weaker fingers have a low load (a BN pinky and a FSV ring) while the stronger fingers work harder. Instead, if we assumed that the layout above was not angle modded, we would get nonsensical columns (a BNV pinky, a FSM ring, a DTH middle and a LRXZKQ index).

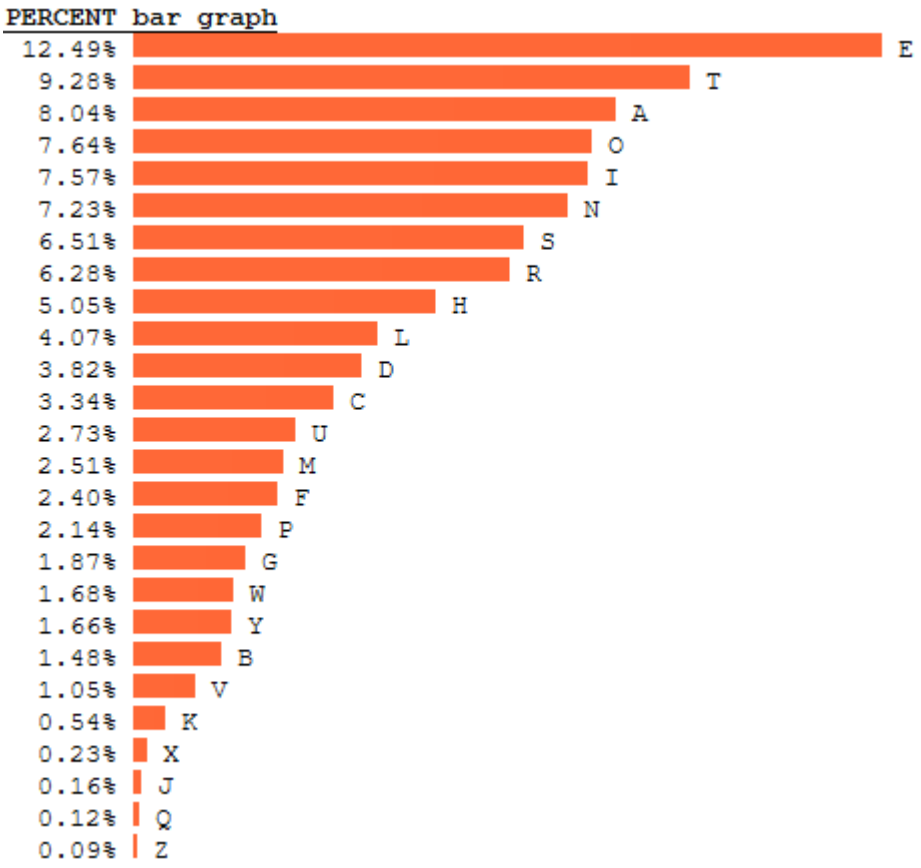
Letter, bigram and trigram data

3. English data (5 min)

To understand where the stats for a layout are coming from, first we need to be familiar with the letter, bigram and trigram frequency of the language the layout is for**.** Most layouts were designed for English, so that is what we will be looking at.

Note: the bigram and trigram tables in the following sections were created using Norvig's English data, which can be found here and here.

3.1. English letter frequency



As one would expect, the vowels **E, A, O, I** are very frequent, while the most common consonants are **T, N, S, R**. These 8 would be the most important letters. Afterwards we would have the letter **H**, followed by **L, D, C**, and then the vowel **U**.

Note that the results will vary to some extent when using a different corpus. For example, on popular typing websites like TypeRacer or MonkeyType the letter H has around the same usage as R, while W and Y are on par with C.

3.2. Top 50 bigrams

Two-letter sequences are known as bigrams. The following is the top 50 (with the top 25 being highlighted):

1-10	11-20	21-30	31-40	41-50
th	**ti**	**st**	ve	ra
he	**es**	**to**	co	ce
in	**or**	**nt**	me	li
er	**te**	**ng**	de	ch
an	**of**	**se**	hi	ll
re	**ed**	ha	ri	be
on	**is**	as	ro	ma
at	**it**	ou	ic	si
en	**al**	io	ne	om
nd	**ar**	le	ea	ur

We can see that **most bigrams involve a consonant + a vowel**. Having said that, there are some consonant-only bigrams that are very common (e.g. **TH**, **ND**, **ST**, **NT**, **NG**, **CH**, **LL**...). Lastly, the most relevant vowel-only bigrams are **OU**, **IO** and **EA**.

3.3. Top 50 trigrams

Three-letter sequences are known as "trigrams". The following is the top 50 (with the top 25 being highlighted):

1-10	11-20	21-30	31-40	41-50
the	**hat**	**nce**	not	sta
and	**tha**	**men**	ive	cti
ing	**ere**	**ith**	was	ica
ion	**ate**	**ted**	ect	ist
tio	**his**	**ers**	rea	ear
ent	**con**	pro	com	ain
ati	**res**	thi	eve	one
for	**ver**	wit	per	our
her	**all**	are	int	iti
ter	**ons**	ess	est	rat

Most trigrams involve both consonants and vowels. In fact, vowel only trigrams are extremely rare. Although not seen on the table, some consonant-only trigrams are decently common, though (e.g. **GHT**, **LLY**, **STR**, **NGS**...).

In case you are wondering, the reason the **YOU** trigram does not appear on the table is probably because the Norving corpus includes lots of books. In a more informal setting, then YOU would become much more common.

3.4. Extended bigram tables

Over the following pages we look at bigram data in more detail. In order to make the information easier to digest, we will subdivide bigrams into different tables:

- Vowel + vowel bigrams
- Consonant + consonant bigrams
- Consonant + vowel bigrams
- Double letters

For a given table, bigrams will be sorted from most to least frequent. The number next to each bigram will indicate its frequency in percent (e.g. **OU** amounts to 0.870% of bigrams).

At the end of this chapter you will also find some additional data:

- Consonant only trigrams
- Consonant only trigrams (excluding Y)
- Top words with apostrophe
- Top trigrams with apostrophe

The data used for the tables will be Norvig, unless specified otherwise.

3.5. Vowel + vowel bigrams

1-10		11-20	
ou	**0.870**	ui	0.101
io	**0.835**	oi	0.088
ea	**0.688**	eo	0.073
ie	**0.385**	oa	0.057
ai	**0.316**	oe	0.039
ia	**0.286**	eu	0.031
ei	0.183	iu	0.017
ue	0.147	ae	0.012
ua	0.136	uo	0.011
au	0.119	ao	0.005

Vowel bigrams amount to 4.4% of bigrams.

3.6. Consonant + consonant bigrams

1-10		11-20		21-30		31-40		41-50	
th	**3.556**	**ly**	**0.425**	mp	0.239	rn	0.160	br	0.112
nd	**1.352**	**nc**	**0.416**	bl	0.233	sc	0.155	pt	0.106
st	**1.053**	**rs**	**0.397**	gh	0.228	cr	0.149	rg	0.100
nt	**1.041**	**wh**	**0.379**	ty	0.227	cl	0.149	tl	0.098
ng	**0.953**	**rt**	**0.362**	fr	0.213	ls	0.142	ny	0.098
ch	**0.598**	**ts**	**0.337**	gr	0.197	ht	0.130	rk	0.097
ns	**0.509**	**sh**	**0.315**	sp	0.191	ds	0.126	ys	0.097
pr	**0.474**	pl	0.263	rd	0.189	lt	0.124	ph	0.094
ct	**0.461**	ld	0.253	by	0.176	rc	0.121	ms	0.093
tr	**0.426**	ry	0.248	rm	0.175	ck	0.118	mb	0.090

Consonant bigrams amount to 21.406% of bigrams.

3.7. Consonant + vowel bigrams

Bigrams under 0.175% frequency are omitted. As expected, less common consonants have fewer bigrams that make the cut. In fact, Q, J and Z have none. The top 50 are highlighted:

T + vowels		N + vowels		S + vowels		R + vowels	
at	**1.487**	**in**	**2.433**	**es**	**1.339**	**er**	**2.048**
ti	**1.343**	**an**	**1.985**	**is**	**1.128**	**re**	**1.854**
te	**1.205**	**on**	**1.758**	**se**	**0.932**	**or**	**1.277**
it	**1.123**	**en**	**1.454**	**as**	**0.871**	**ar**	**1.075**
to	**1.041**	**ne**	**0.692**	**si**	**0.550**	**ri**	**0.728**
ta	**0.530**	**no**	**0.465**	us	0.454	**ro**	**0.727**
ot	0.442	un	0.394	so	0.398	**ra**	**0.686**
et	0.413	na	0.347	su	0.311	**ur**	**0.543**
ut	0.405	ni	0.339	os	0.290	ir	0.315
tu	0.255			sa	0.218		

H + vowels		L + vowels		D + vowels		C + vowels	
he	**3.075**	**al**	**1.087**	**ed**	**1.168**	**co**	**0.794**
ha	**0.926**	**le**	**0.829**	**de**	**0.765**	**ic**	**0.699**
hi	**0.763**	**li**	**0.624**	**di**	**0.493**	**ce**	**0.651**
ho	**0.485**	**el**	**0.530**	ad	0.368	**ca**	**0.538**
		la	**0.528**	id	0.296	**ec**	**0.477**
		il	0.432	od	0.195	ac	0.448
		lo	0.387	do	0.188	ci	0.281
		ol	0.365			uc	0.188
		ul	0.346				

M + vowels		F + vowels		P + vowels		G + vowels	
me	**0.793**	**of**	**1.175**	**pe**	**0.478**	ge	0.385
ma	**0.565**	**fo**	**0.488**	po	0.361	ig	0.255
om	**0.546**	fi	0.285	pa	0.324	ag	0.205
em	0.374	fe	0.237	op	0.224		
mo	0.337	if	0.203	ap	0.203		
im	0.318						
mi	0.318						
am	0.285						

W + vowels		Y + vowels		B + vowels		V + vowels	
wa	0.385	ay	0.217	**be**	**0.576**	**ve**	**0.825**
wi	0.374			ab	0.230	iv	0.288
we	0.361			bo	0.195	vi	0.270
ow	0.330			bu	0.185	ev	0.255
wo	0.222					av	0.205
						ov	0.178

K + vowels		X + vowels	
ke	0.214	ex	0.214

Consonant + vowel bigrams amount to 71.686% of bigrams.

3.8. Double letters

1-10		11-20		21-26	
ll	**0.577**	nn	0.073	jj	0.000
ss	**0.405**	dd	0.043	kk	0.000
ee	**0.378**	gg	0.025	qq	0.000
oo	0.210	ii	0.023	vv	0.000
tt	0.171	bb	0.011	ww	0.000
ff	0.146	aa	0.003	yy	0.000
pp	0.137	xx	0.003		
rr	0.121	zz	0.003		
mm	0.096	hh	0.001		
cc	0.083	uu	0.001		

Double letters amount to 2.508% of bigrams.

3.9. Consonant only trigrams

1-10	11-20	21-30	31-40	41-50
ght	**nst**	**ryt**	rly	scr
lly	**nts**	**why**	ldn	cts
str	**ttl**	**lls**	yst	rch
ngs	**mpl**	**ngl**	hts	mpt
nly	**rth**	**sts**	bly	ppy
rld	**try**	rry	nch	rms
nds	**tly**	mys	rty	dly
thr	**tch**	ntl	sky	ppr
rst	**ntr**	nyt	cks	ply
yth	**rds**	rts	sch	ctl

3.10. Consonant only trigrams (excluding Y)

1-10	11-20	21-30	31-40	41-50
ght	**mpl**	**ldn**	ppr	rns
str	**rth**	**hts**	ctl	nct
ngs	**tch**	**nch**	ndr	ndl
rld	**ntr**	**cks**	nth	ncl
nds	**rds**	**sch**	nsw	ngt
thr	**lls**	scr	xpl	ckl
rst	**ngl**	cts	lth	ths
nst	**sts**	rch	mpr	lds
nts	**ntl**	mpt	stl	ddl
ttl	**rts**	rms	mbl	ldr

The two tables above were made using the TypeRacer corpus.

3.11. Top words with apostrophe

1-10	11-20	21-30	31-40	41-50
it's	**they're**	**what's**	man's	shouldn't
don't	**didn't**	**ain't**	haven't	world's
i'm	**you've**	**we'll**	aren't	hadn't
you're	**he's**	**we've**	who's	they'd
that's	**i'd**	**wouldn't**	they'll	we'd
can't	**you'll**	couldn't	'em	people's
i've	**won't**	wasn't	one's	weren't
there's	**doesn't**	let's	he'd	else's
i'll	**'cause**	you'd	he'll	goin'
we're	**isn't**	she's	they've	it'll

3.12. Top trigrams with apostrophe

1-10	11-20	21-30
n't	**i'd**	o's
t's	**u'l**	y'l
i'm	**n's**	g's
e's	**r's**	y'v
u're	**e'l**	a's
i've	y's	y'd
i'l	e'v	d'v
e're	e'd	t'l
y're	d's	l's
u'v	u'd	h's

The two tables above were made using the TypeRacer corpus.

Layout stats

4. SFBs, SFSs and distance (18 min)

4.1. Same finger bigrams (SFBs)

A SFB consists of pressing two keys in succession with the same finger. For example, take the word **decade** on Qwerty. The green line shows letters pressed by the **left middle**:

So, this word contains three SFBs: **DE**, **EC** and **DE** again. This is an extreme example, as five out of six letters are typed with one finger!

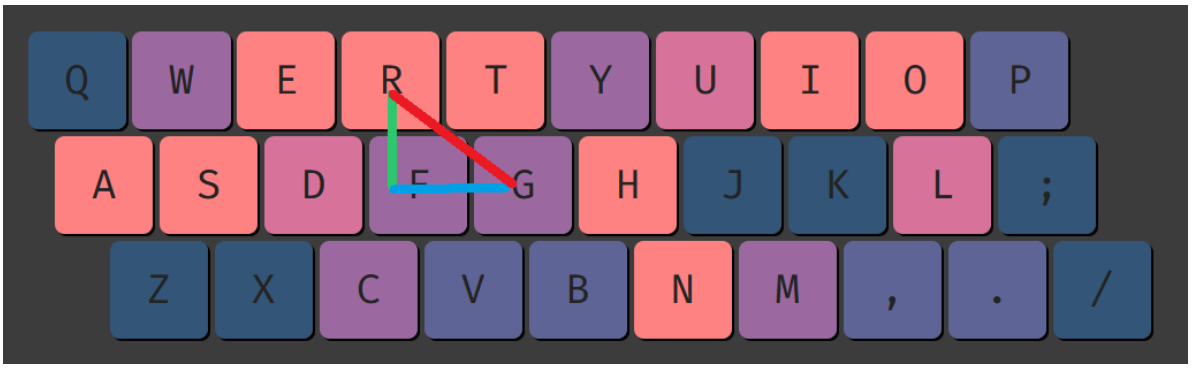
SFBs are dependent on which letters are sharing a column. For example, Qwerty's EDC column is very poor, as it leads to lots of SFBs.

As a reference, Qwerty has around 6% SFBs, Dvorak 2.5% and Colemak 1.5%. Modern layouts can go as low as 0.5%. Moreover, we should also pay attention to how the SFBs are being distributed across the fingers. Generally, **we will favor SFBs being on the index and the middle fingers, and avoid them on weak fingers like the pinkies.**

When we say that a layout has a certain SFB percent, we are assuming that the layout is being utilized with proper touch typing. Advanced Qwerty users often use personalized fingerings (e.g. they press the letter C with the index finger, rather than with the middle) in order to avoid SFBs like CE . This is referred to as "alt fingering" and will be explored later.

4.2. Calculating the distance between two keys

Let's say we want to know the distance for Qwerty **RG** (we are using Qwerty as a method to refer to the different keys on the keyboard):



We can obtain the length of the red line by using **Pythagoras' theorem**. All we need to know is the vertical distance between the two keys (the green line) and the horizontal distance (the blue line).

On a row stagger keyboard, **the top row is horizontally shifted 0.25 units in relation to the home row, and the bottom row is shifted 0.5 units.** This makes the horizontal distance between the top row and bottom row to be 0.75 units. As for vertical distance, the top and the bottom row are each 1 unit away from the home row.

In our Qwerty **RG** example, the vertical distance is 1U and the horizontal distance is 1.25U (1U from **G** to **F**, and 0.25U from **F** to **R**). Knowing this, we can use Pythagoras to determine the distance between the two keys. We have to square both the horizontal and vertical distances, and then square root the sum:

$$c = \sqrt{a^2 + b^2} = \sqrt{1.25^2 + 1^2} = 1.60\,U$$ **RG** is a 1.6U SFB

Another example, Qwerty **MY**. The vertical distance is 2U and the horizontal one 1.75U (1U from **M** to **N**, 0.5U from **N** to **H**, and 0.25U from **H** to **Y**). Thus:

$$c = \sqrt{a^2 + b^2} = \sqrt{1.75^2 + 2^2} = 2.66\,U$$ **MY** is a 2.66U SFB

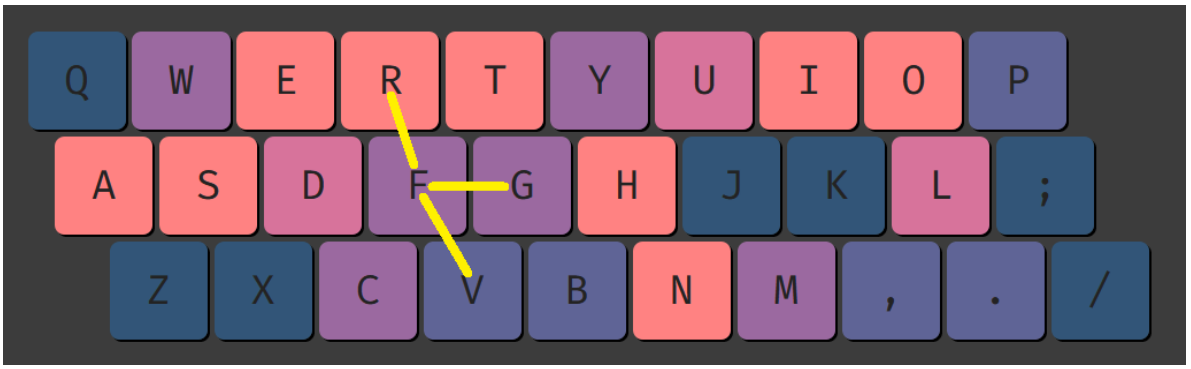
One final example, Qwerty **VT**. The vertical distance is 2U and the horizontal one 0.25U (from **V** to **G** it would be 0.5U, but then we subtract 0.25U going from **G** to **T**). Thus:

$$c = \sqrt{a^2 + b^2} = \sqrt{0.25^2 + 2^2} = 2.02\,U$$ **VT** is a 2.02U SFB

4.3. 1U and 2U SFB

Using the method explained above, we will now list the distance for the different SFBs. In this section we look at either 1U or 2U ones. In the following section we check the rest.

If the two keys that form a SFB are on adjacent keys, then it will be around 1U. In the image below, Qwerty **FG** is exactly 1U, **FR** is 1.03U, and **FV** is 1.12U:

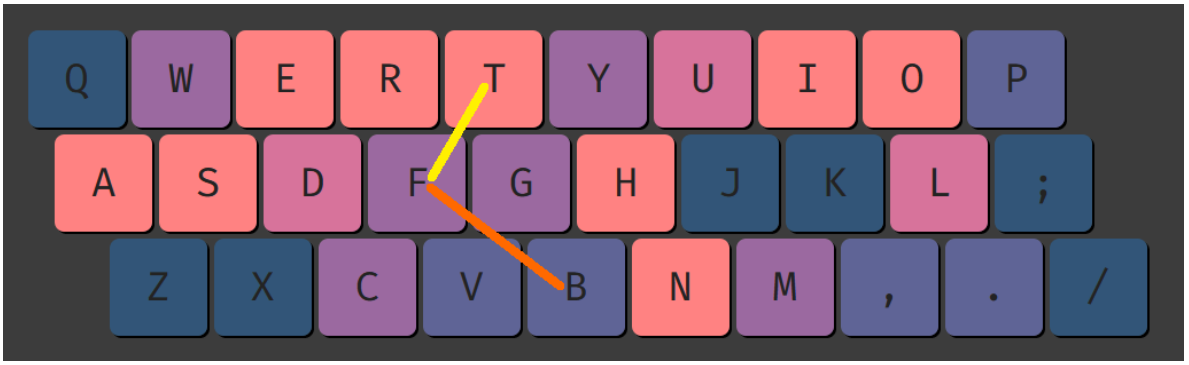


If one of the keys is on the bottom row and the other on the top row, **then the SFB will be around 2U**. In this case, our finger has to jump over the home row to go from one key to the other. Below, Qwerty **VT** & **NU** are 2.02U, while **VR** & **NY** are 2.14U:

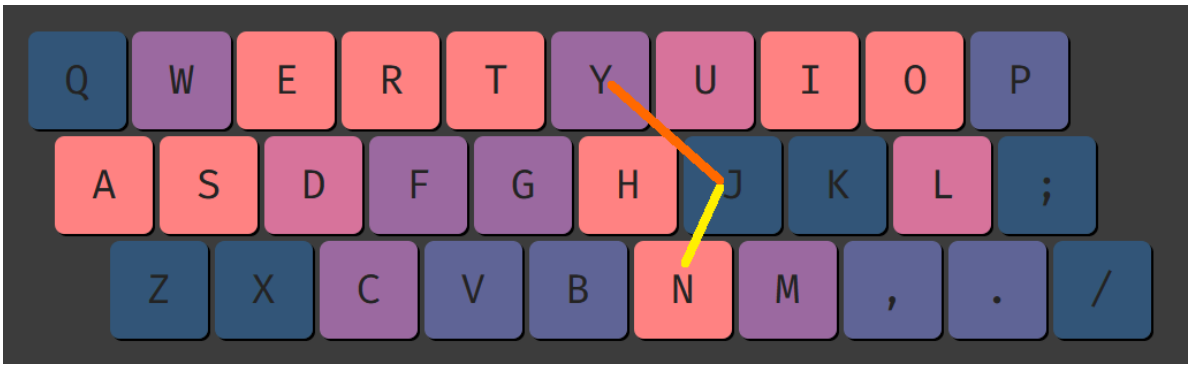
Naturally, **the SFBs we do have in a layout should mostly be 1U.** In other words, 2U SFBs should be reserved for rare bigrams only. The Qwerty layout clearly fails in this regard.

4.4. Diagonals

Traditional keyboards are not symmetrical. For instance, the distance between the left index's resting position (F) and its bottom diagonal (B) is larger than the distance to the top diagonal (T). Below, Qwerty **FT** is 1.25U, while **FB** is 1.8U:



On the right side it is the opposite. Now it is the top diagonal that is further away. Below, Qwerty **JY** is 1.6U, Qwerty **JN** is 1.12U:



So, from best to worst (i.e. from closest to furthest): Qwerty N → T → Y → B.

The absolute longest diagonals are Qwerty **RB** and **MY** which are 2.66U! There is also **MH** which is is 1.8U, and **RG** being is 1.6U:

Finally, when using angle mod fingering (Qwerty C being pressed with the index finger, rather than the middle), we add two other diagonals: Qwerty **CT** (2.36U) and **CG** (1.8U):

Anyway, **the bigger the distance, the higher priority not to have that diagonal as a SFB in a layout.**

4.5. Same finger Skipgrams (SFSs)

A SFS consists of pressing two keys with the same finger, but separated by X letters. An example would be typing **may** on Qwerty (**M** and **Y** are both typed with the right index).

There are two aspects to SFSs: distance, and how many keys there are of separation. For example, the aforementioned **M_Y** SFS is 2.66U, and it is a skip-1-gram (i.e. in between **M** and **Y**, there is only one key, **A**, being pressed by a different finger).

The **M_Y** SFS is the worst of both worlds. Firstly, our right index finger must make a huge jump to go from **M** to **Y**. Secondly, this is done almost consecutively, as there is a single letter, **A**, of separation. Having more keys in between, before a particular finger is needed again, is better, as it gives our finger more time to go back to its resting position (**J** in this case). **An ideal word would be one where each finger is only utilized once.**

Qwerty is unfortunately full of words that are typed with just two fingers. For example, the word **burn** is typed by alternating both index fingers. In the image below, the orange line shows letters pressed by the **left index**. Yellow for **right index**:

So, this word contains two SFSs. Not only that, but the **B_R** SFS on the left index is 2.66U, and **U_N** on the right index is 2.02U. Try typing it.

Another example would be **thought** on Qwerty. Same color/finger pairings as above:

Here, **T_G** is a same finger skip-3-gram (i.e. there are three letters separating **T** and **G**). Therefore, that SFS will be barely noticeable, especially when compared to **H_U, U_H** or **G_T**, all of which are SF skip-1-grams. This time they are only 1U, though. Try typing it.

So, Qwerty performs terribly at SFSs. **The benefit of optimizing SFSs is that each word will be spread across more fingers. Moreover, when we do have to use any particular finger almost consecutively, the distance between the two keys will be minimal.**

4.6. Distance on a layout

For the longest time, distance used to be measured as “distance off the home row”. In other words, it was assumed that pressing keys on the home row required no movement, while pressing keys outside the home row did. However, this is a great oversimplification. Take the word **refer** on Qwerty for example:

If you quickly type this word, you will find that pressing the second **E** requires no movement (despite E being on the top row) as our left middle finger was already over it. Meanwhile, even though **F** is on the home row, pressing it implicates moving our left index downward.

This goes to show that, **to accurately measure the distance it will take to press a key, we need to keep track of which key that finger had pressed beforehand.** This does not only apply within a given word, but also to the connections between words. For example, imagine typing the word **when** followed by **you** on Qwerty:

The yellow line shows letters pressed by the **right index**. The letter **N** in **when** is followed by a space, and right after our right index has to jump over the home row to press **Y**. Therefore, **N_Y** is an inter-word (i.e. in between words) SFS, while **H_N** or **Y_U** are intra-word (i.e. within a word) SFSs.

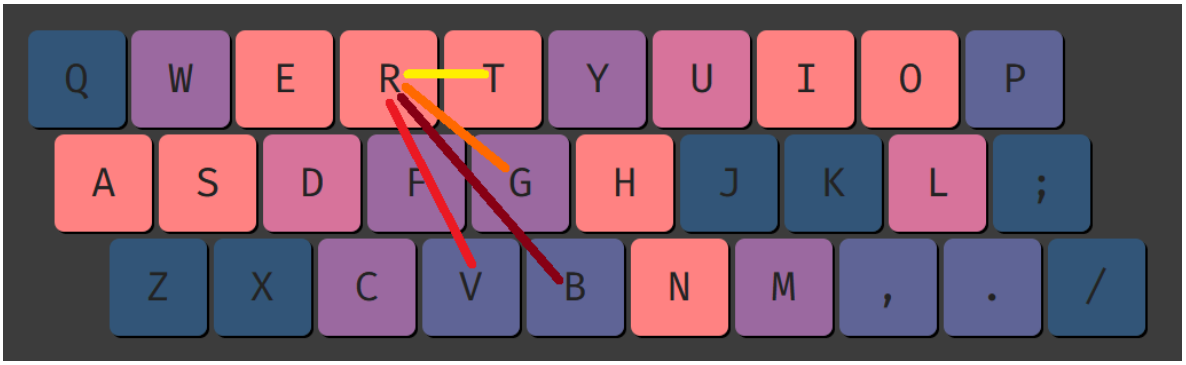
With all this in mind, **the simplest way to measure how a layout performs at SFB distance is to scale each SFB by its distance.** For example, if the frequency of a SFB is 0.4% and the distance is 1.2, we simply multiply 0.4 by 1.2. Then we do the same for all the remaining SFBs in the layout. **Same applies to the SFSs, to get the SFS distance**.

The method above keeps SFB and SFS distances as separate stats. **A more elaborate approach is to combine both stats into one, but penalizing consecutive finger usage more than semi consecutive usage**. For example, we could weight SFB distance by 1, SF skip-1-gram distance by 0.5, and then drop off exponentially (e.g. skip-2-grams by 0.25, skip-3-grams by 0.125). This allows us to account for all skipgrams (not just skip-1-grams).

Moreover, **this later approach can be used to calculate the movement per finger**. With “movement” being SFB + SFS distance. It will sometimes also be referred to as “finger speed”. Regardless, the purpose of finger speed is to, given a group of letters (3 letters on pinky, ring or middle, 6 on index) tell us how to arrange those letters so that SFB + SFS distance is minimized. The Genkey and Oxeylyzer analyzers calculate distance in this way.

4.7. Decentivicing 2U SFBs and SFSs

As explained earlier, to calculate the distance between two keys we simply have to square both the horizontal and vertical distances, and then square root the sum. Doing that, Qwerty **RT** would be 1U, **RG** 1.6U, **RV** 2.02U and **RB** 2.66U:



However, in order to calculate the distance or movement per finger (i.e. "finger speed") analyzers like de Genkey or Oxeylyzer will not square root the sum. Therefore, Qwerty **RT** would still be 1U, but **RG** would now be 2.56U, **RV** 4.56U and **RB** 7.06U!

The point of omitting the square root when measuring distance is to punish longer distances more severely (2U SFBs will now be punished 4 times as hard as a 1U). This results in the analyzer outputting layouts where most of the SFBs and SFSs are only 1U.

4.8. Weights for each finger

On Genkey and Oxeylyzer, distance is weighted based on each finger's strength or dexterity level. The following are the default weights on Genkey (Oxeylyzer uses the same ones, although it does not allow us to customize them, while Genkey does):

```
Index:  5.5
Middle: 4.8
Ring:   3.6
Pinky:  1.5
```

Basically, the purpose of these weights is to establish that weaker fingers (e.g. pinky) can handle much less movement than stronger fingers (e.g. index). Using that information, the analyzer can then spread movement accordingly when making a layout.

4.9. Distributing movement across the fingers

Even if we discard letter columns that perform poorly at SFB and SFS distance, the English language still offers a lot of flexibility regarding how to arrange the alphabet to construct keyboard layouts.

There is a key concept we need to be aware of when designing layouts. To explain it we will use an analogy. Think of a balloon full of air. If we press down on it, air will be displaced to other parts of the balloon. The same is true for movement in keyboard layouts. In other words, **if we place little movement on one finger, another finger will take that load.**

To help us visualize this we will use a few layout examples. All of them will share the exact same right hand (the vowel hand). Then, we will use the remaining consonants to come up with different arrangements for the left hand. The point being that each consonant home row will distribute movement differently across the fingers. For each example, we are only showing the left hand of an angle modded layout:

Rsnt	**Snht**	**Nstr**	**Srht**	**Vowel hand**
x f **h** m z	v **r** l d z	b f d l z	f l **n** d k	' w **o** u j
r s n t v	**s n h t** k	**n s t r** k	**s r h t** v	y **c a e i**
b l d k q	x m b f q	v m **h** x q	x b m z q	p g . - ,

The following table shows the unweighted movement (according to Genkey when using the MonkeyType + TypeRacer corpus) for each of the fingers on the consonant hand:

	Pinky	**Ring**	**Middle**	**Index**	**Top row pinky**
Rsnt	0.10	2.20	10.09	12.19	0.1% (x)
Snht	0.63	4.26	6.29	11.43	1.1% (v)
Nstr	0.66	1.66	6.66	16.85	1.4% (b)
Srht	0.72	2.84	5.71	12.66	2% (f)

In the table above we can see how movement being lower in some parts of the layout means that the opposite will be true in others. For example, on **Rsnt** the ring and especially the pinky are very relaxed, yet center column use is low as well. The drawback is that the middle finger has to make up for it. On **Snht**, ring finger movement almost doubles and top row pinky use increases by 1%, but in return middle finger movement is much lower than before. **Nstr** purposely concentrates movement on the index finger, where the SFBs can be comfortably alt fingered. Lastly, **Srht** has the least overall movement, at the expense of top row pinky use being the highest.

4.10. Distance on Qwerty

```
q w e r t  y u i o p
a s d f g  h j k l ;
z x c v b  n m , . /
```

There are three fingers that have extremely high movement on Qwerty:

- The **left middle**'s high distance is explained by the common **ED** and **DE** SFBs & SFSs, and even more so by **EC** and **CE**, as these last two are 2U.

- On the **left index**, the letter **R** causes lots of SFBs: **TR, RT, FR,** also **GR** (1.6U) and **BR** (2.66U). There are plenty of SFSs as well: **TR, FR, RT, BT** and **VR** (the last two are 2U).

- The **right index** does poorly at distance, as all its SFBs are 2U or more: **UN, NY, UM, MU** and **MY**. As for SFSs, the main ones are **MN, HN** and **YU**, all of which are 1U. However, there are 2U SFSs as well: **UH, UN** and **NY**.

- Finally, although the **right ring** is not anywhere as bad as the prior three, it is poor nonetheless, as it has the common **LO** and **OL** (1U) SFBs and SFSs.

Anyway, the point is that **Qwerty was not optimized with SFB and SFS distance in mind.**

4.11. Examples of bad words on Qwerty

In the following sections we list words that are tricky to type, as they involve Qwerty's problematic fingers: **left middle**, **left index**, **right index** (and to a lesser extent **right ring**).

For each word example, colored lines will indicate the keys pressed by each finger. This aims to accomplish two things. Firstly, it allows us to easily visualize SFBs and SFSs, to ensure the concept is understood well. Secondly, it makes Qwerty's flaws more apparent.

For example, take the word **decided** on Qwerty:

A single colored line points to most of the letters, indicating they are all pressed by the same finger. So, this is a heavy SFB word.

Now take the word **amendment** instead:

Here there are two lines, for two fingers. Furthermore, there is always a one letter gap before a finger is utilized again, indicating SFSs. So, this would be a heavy SFS word.

The color code for the different fingers is as follows:

- **Yellow indicates keys pressed by the right index finger.** So, in this example **NUM** would be a SF trigram (**NU** being 2U and **UM** 2.1U).
- **Orange for the left index finger.** So, **B_R** is a 2.66U SFS.
- **Green for the left middle finger.** **E_E** is a SFS followed by a SFB (**ED**).
- **Blue for the right ring finger** (does not appear in this example).
- **Grey for the remaining fingers**

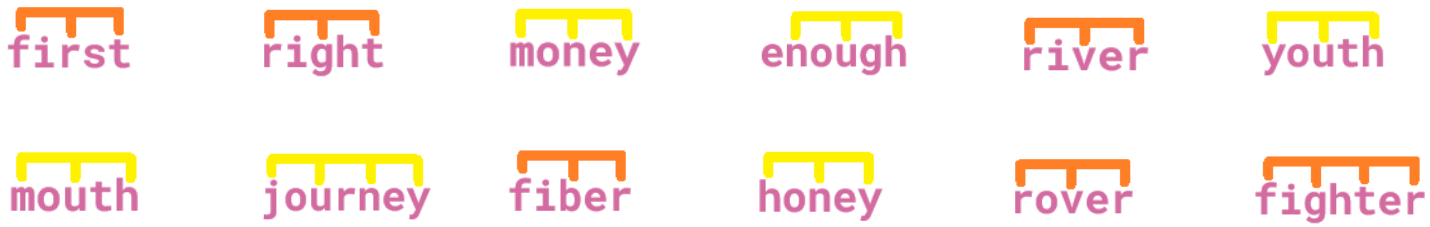
If a finger only presses a single letter in a word, no line will be shown, as SFB and SFS distance for that finger would be zero. Furthermore, there won't be a line either for SFSs deeper than a skip-3-gram (i.e. skip-4-grams, etc...) as they stop being relevant.

4.11.1. Heavy SFS words on Qwerty

Note: SFSs that involve pressing the same key twice require no movement, as our finger is already over said letter after the first press. An example of such a SFS would be `E_E`.

- Words typed mostly by alternating two fingers:

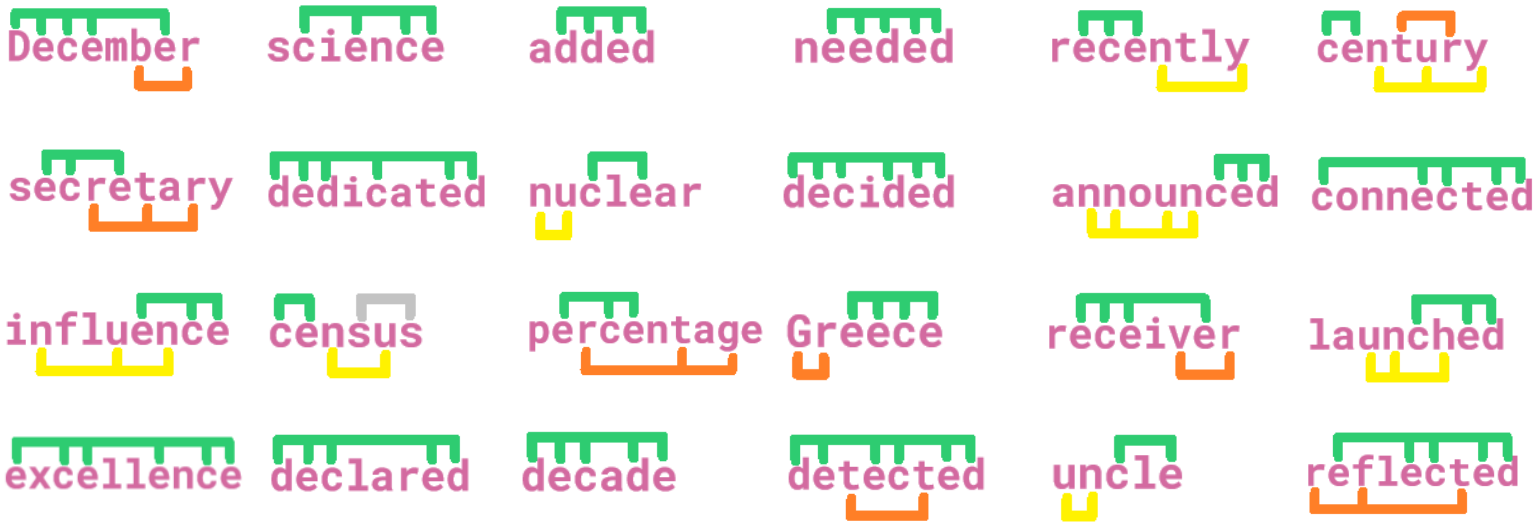
- Words with all their SFSs on one finger:



4.11.2. Heavy SFB words on Qwerty

- Word with high distance (SFBs and SFSs) on the **right index finger**:

- Word with high distance (SFBs and SFSs) on the **left middle finger**:



5. Alt fingering, SFB collisions and sliding (6 min)

5.1. Alt fingering

Using a finger other than the "intended" one to type a certain bigram, with the purpose of avoiding a SFB, is referred to alt fingering. For example, if we use standard fingering on Qwerty, the **CE** and **EC** bigrams are 2U SFBs:

Instead, to remove the aforementioned SFBs we can alt finger CE/EC by pressing C with the index finger (rather than the middle). This is what many advanced Qwerty users do.

5.2. SFB collisions

A collision refers to when alt fingering a SFB creates a new SFB. For instance, with standard fingering, **CT** is not a SFB on Qwerty. However, if we alt finger EC by pressing C with the index, then CT does become a SFB specifically on the **ECT** trigram:

Ideally, **we should aim to minimize SFB collisions**, but they are sometimes unavoidable.

5.3. Designing a layout with alt fingering in mind

Although alt fingering can be used to circumvent some of the issues of bad layouts like Qwerty, we are mainly interested in using it to further improve well optimized layouts.

If we do not ever deviate from either standard fingering or angle mod, we can only minimize SFBs up to a certain point, as we are restricted by English's bigram frequency. **In order to reduce SFBs further, we can purposely place a few SFBs in a location where they are comfortable to alt finger**. A layout that does this is Noctum which has three intended alt fingers: **RK**, **RL** and **LK**. Note that below the layout has been angle modded:

To alt finger **RK** we press R with the middle finger, and K with the index. Since RK is never followed by one of the letters on the index (i.e. trigrams like RKR, RKL or RKH are nonexistent) this alt finger will not cause SFB collisions. The **LK** alt (typed by pressing L with the middle finger and K with the index) is also free of SFB collisions.

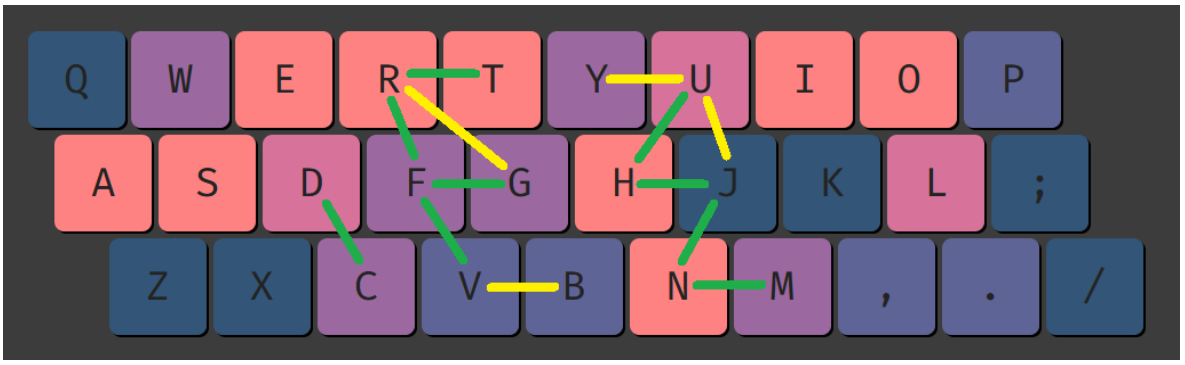
The **RL** alt finger (R with the index, L with the middle) does introduce a SFB collision in the word **WORLD**, as both L and D are pressed with the middle finger in this case. A possible solution would be to introduce yet another alt finger, and press the letter D with the ring finger in this specific case. Some people might argue that if to remove one SFB (RL) we must perform two alt fingers (RL and LD), then it is preferable to just type the SFB normally.

5.4. Most comfortable alt fingers

It is generally agreed that **the best location to place a SFB that we intend to alt finger is the index finger. That way we can comfortably press one of the two index finger keys with the middle finger.** Furthermore, we will often use keys that are adjacent to one another for alt fingers. This is done so that, if the SFB is typed normally, it will only be 1U.

5.4.1. On row stagger

Standard keyboards are not symmetrical. Therefore, a bigram and its mirror (i.e. the same bigram but on the opposite hand) may vary in length. We will compare each alt finger to its mirror. The more comfortable of the two will be shown in **green**, the other in **yellow**.



- Qwerty **FR** (index → middle) is an easy alt. This is because the stagger makes it so R is very close to the middle finger's resting position (D). On the right hand, K is noticeably further away from U, making **JU** a bigger jump for the middle finger.

- Qwerty **UH** (middle → index) is very comfortable on the right hand. Its mirror (**RG**) forces us to splay our fingers a bit more, as the keys are further apart. Having said that, **RG** does require a smaller jump from the middle finger.

- Qwerty **RT** (middle → index) is nicer than its mirror (**UY**) simply because T is closer to the index finger's resting position (F) than Y is to J. Same reasoning applies to Qwerty **MN** being better than **VB**.

- Qwerty **DC** (middle → index) is a possible alt finger if we use standard fingering. If we used angle mod instead, it wouldn't be an alt finger, but CV would become one.

- Qwerty **FG** is identical to **JH**, and so are **FV** and **JN**.

Anyway, if we have a common index finger SFB in our layout of choice, we can turn it into a comfortable alt finger by placing it in one of the lines above.

5.4.2. On matrix

On matrix keyboards there are fewer comfortable alt fingers than on row stagger. This is because the row stagger happens to be useful for alt fingering in particular. For example, compare the “vertical alt fingers” on row stagger vs matrix:

The fact that on row stagger each row is a bit shifted to the side in relation to one another is what made the alt fingers above comfortable. It allowed us to use the middle finger to press one of the index finger keys without our fingers feeling cramped.

Furthermore, some of the center column diagonals (namely Qwerty N & T) are easier to press on row stagger, as they are closer to our index finger’s resting position. Therefore, alt fingers involving those keys work better on row stagger as well.

Anyway, the following alts remain basically the same regardless of the keyboard type:

5.5. Sliding

Similarly to alt fingering, sliding is an alternative method for typing SFBs. **It consists of sliding our finger downwards, going from the first key in the SFB to the second.** An example of a layout were people might use sliding is Dvorak:

On the right hand, all the SFBs happen to go downwards as shown by the arrows. For example, the GH SFB only happens in the direction G → H. To type it, we could press the letter G and then slide our index finger downwards to H. Whether someone prefers doing that or typing the SFB normally is a matter of personal preference.

Note that sliding is intended for flat laptop keyboards. On keyboards with taller keycaps, sliding our finger over the gap between the two keys will not be as comfortable.

6. Scissors (10 min)

6.1. Full scissors bigrams (FSBs)

A FSB is a bigram where:

1. **The vertical separation between the keys is two rows.**
2. **The finger that prefers being higher is not.** This includes bigrams where the middle finger is lower than any other finger, and bigrams where the ring is lower than the pinky or the index.

To understand the suggested scissor definition, we will use the following image. Note that angle mod is assumed, meaning that X is pressed with the middle finger, and Z with ring:

On the left hand, the red lines show bigrams where the longer finger is lower than the shorter one. On the right hand it is the opposite (the longer finger is now higher). If you try both, you will likely find the green lines to be noticeably more comfortable to type.

Although accounting for finger length is important, we also have to consider the fact that our arms approach the keyboard at an angle. That is to say, our wrists are not at a 90º angle in relation to the keyboard, but closer to 70º. This naturally places the index finger a bit closer to the bottom row, and the pinky closer to the top row. Anyway, **the preferred placements for each finger** (in relation to the other finger in the bigram) **will be**:

- The index prefers being lower.
- The middle prefers being higher.
- The ring prefers being higher than index and pinky, but lower than the middle.
- The pinky prefers being lower than middle and ring, but higher than index.

When these preferences are not met (plus the keys are two rows apart) we call the bigram a scissor. The one exception are pinky-index bigrams, which will not be counted as scissors regardless. This is because there are two fingers (ring & middle) of separation.

There are two main factors that affect how a scissor will feel. The first is whether it involves adjacent fingers or not, and the second is the angle between the two keys. **Adjacent finger scissors with a steep angle feel the most "scissory", and are therefore the first to avoid**. A good example is Qwerty **CR** with standard fingering (C with middle, R with index).

6.2. Full scissor skipgrams (FSSs)

The difference between a FSB and a FSS is that on the first the two keys forming the scissor are pressed consecutively, while on the later there is another key in between the two, pressed by a third finger. The fact that there is an in-between key that breaks the scissor means that FSSs are less noticeable than FSBs. Still, some people like optimizing them.

To visualize FSSs better we will use a layout example. Take Compound (angle modded):

The line above is a frequent FSS. This is because **v_r** is a skip-1-gram in words like **never**, **every**, **ever** or **over**. The same line would not be a common FSB, as the **rv** bigram is rare.

6.3. Half scissors bigrams (HSBs)

A HSB is a bigram where:

1. The vertical separation between the keys is **only one row**.
2. The finger that prefers being higher is not. This includes bigrams where the middle finger is lower than any other finger, and bigrams where the ring is lower than the pinky or the index.

In other words, **the only difference between a full scissor and a half scissor is that the vertical separation between the two keys is cut in half**. Naturally, this makes half scissors much less problematic than full scissors, although they are still not ideal.

The red lines indicate half scissors (the longer finger is lower than the shorter one). The green lines are the preferred finger patterns (the longer finger is now higher).

6.4. Half scissor skipgrams (HSSs)

The difference between a HSB and a HSS is that on the first the two keys forming the half scissor are pressed consecutively, while on the later there is another key in between the two, pressed by a third finger.

6.5. Scissor list

Scissors will be represented by colored lines connecting the two keys. For instance, the following are the middle - index finger scissors when using standard fingering (the letter C is pressed by the middle finger):

The idea behind the colors is to highlight that steeper angles usually have a more distinct scissor feel, while shallower angles introduce a lateral stretch component.

From steeper to shallower, the color code is: dark red → light red → orange → yellow → green. If you compare typing Qwerty **CR** vs **,Y** , you should see the difference.

6.5.1. With standard fingering

- Qwerty Z = Pinky
- Qwerty X = Ring
- Qwerty C = Middle

Full scissors

Firstly, **adjacent finger scissors**. They are the first to avoid in a layout, particularly if the have a steep angle:

- Ring is lower than pinky: **.P** → **XQ**
- Middle is lower than ring: **,O** → **CW**
- Middle is lower than index: **CR** → **CT** → **,U** → **,Y**. Technically, Qwerty **,Y** is both a scissor and lateral stretch (two adjacent fingers are pressing far away keys).

Secondly, **non adjacent finger scissors**. Still relevant, but not as important:

- Middle is lower than pinky: **,P** → **CQ**
- Ring is lower than index: **XR** → **XT** → **.U** → **.Y**

The keysolve analyzer uses almost the exact same scissor definition, with the exception that ring - middle bigrams always count as scissors on keysolve, independently of which of the two fingers is higher.

Half scissors

Firstly, **adjacent finger half scissors:**

- Ring is lower than pinky: **.;** → **LP** → **SQ** → **XA**
- Middle is lower than ring: **,L** → **KO** → **DW** → **CS**
- Middle is lower than index: **CF** → **DR** → **KU** → **CG** & **,J** → **DT** → **KY** → **,H**. Technically, Qwerty **KY** & **,H** are both half scissors and lateral stretches

Secondly, **non adjacent finger half scissors:**

- Middle is lower than pinky: **,;** → **KP** → **DQ** → **CA**
- Ring is lower than index: **XF** → **SR** → **LU** → **.J** & **XG** → **ST** → **LY** → **.H**

The keysolve analyzer uses almost the exact same scissor definition, with the exception that ring - middle bigrams always count as scissors on keysolve, independently of which of the two fingers is higher.

6.5.2. With angle mod fingering

- Qwerty Z = Ring
- Qwerty X = Middle
- Qwerty C = Index

Full scissors

Firstly, **adjacent finger scissors**. They are the first to avoid in a layout, particularly if the have a steep angle:

- Ring is lower than pinky: **.P → ZQ**
- Middle is lower than ring: **,O → XW**
- Middle is lower than index: **XR → ,U → XT & ,Y**. Technically, Qwerty **XT** and **,Y** are both scissors and lateral stretches.

Secondly, **non adjacent finger scissors**. Still relevant, but not as important:

- Middle is lower than pinky: **,P → XQ**
- Ring is lower than index: **ZR → .U → ZT → .Y**

The keysolve analyzer uses almost the exact same scissor definition, with the exception that ring - middle bigrams always count as scissors on keysolve, independently of which of the two fingers is higher.

Half scissors

Firstly, **adjacent finger half scissors:**

- Ring is lower than pinky: **ZA** & **.;** → **LP** → **SQ**
- Middle is lower than ring: **XS** & **,L** → **KO** → **DW**
- Middle is lower than index: **DR** → **KU** → **XF** & **,J** → **DT** → **KY** → **XG** & **,H** Technically, Qwerty **KY**, **,H** & **XG** are both half scissors and lateral stretches.

Secondly, **non adjacent finger half scissors:**

- Middle is lower than pinky: **XA** & **,;** → **KP** → **DQ**
- Ring is lower than index: **SR** → **LU** → **ZF** & **.J** → **ST** → **LY** → **ZG** & **.H**

The keysolve analyzer uses almost the exact same scissor definition, with the exception that ring - middle bigrams always count as scissors on keysolve, independently of which of the two fingers is higher.

6.6. Minimizing scissors

6.6.1. Reducing bottom row middle and ring finger use as a whole

A straightforward way of removing full scissors is to place only rare characters on the bottom row middle and ring finger keys. A layout that does this is Canary. Note that below the layout has been angle modded:

We can see that the keys inside the red blocks have very low usage. On the left hand there are no scissors, as J and V rarely combine with the letters on the top row. Same applies for punctuation on the right hand. **With this approach, the only part of the bottom row that is heavily utilized are the index finger keys.** Any layout that arranges the bottom row this way will perform well at scissors.

6.6.2. Strategically avoiding scissors

Imagine we want to make a layout with moderate center column use but without pushing more letters toward the pinkies. The only way of doing that would be to place more common letters on the bottom row ring and middle finger keys. However, doing that will increase the likelihood of scissors. For example, take the following angle modded layout:

There is a lot of up-down motion on the left hand: **WH**, **BL**, **LD** and **LK**. Having said that, this can be easily solved simply by swapping which letters are on the top or bottom row:

Compared to before all the letters remain on the same fingers, yet the scissors have been greatly reduced. Point being, **with smart letter placings it is technically possible to have relatively low scissors despite having common letters on the bottom row middle and ring finger keys.**

6.7. Row skips

A row skip is any bigram where one finger reaches to the top row and another finger on that same hand contracts to hit the bottom row. So, we are expanding the scissor definition to include all the up-down motions, independently of which finger is higher.

To see the difference between scissors and row skips we will use the following two layouts:

Mtgap (Michael Dickens)	Canary (Eve)
y p o u j k d l c w	w l y p k z x o u ;
i n e a , m h t s r	c r s t b f n e i a '
q z ' . : b f g v x	j v d g q m h / , .

Canary aims to minimize the most uncomfortable up-down motions specifically (i.e. scissors). By comparison, Mtgap is not satisfied with just that and instead avoids having any up-down motions at all (i.e. row skips). The difference can be seen by comparing how the **LD** bigram is typed on both layouts. On Mtgap, it is a same row roll. On Canary, it requires an up down motion, but it is a rather comfortable one (if we have to choose between the ring or index being higher than the other, the ring being higher is more comfortable).

Most modern layouts will inevitably have some up-down motions. This is because:

1. The letter O usually goes on the top row, on a OA or OE middle/ring finger.

2. The vowel hand's index finger is frequently used for consonants.

3. The indexes often have more common letters on the bottom row than on the top row (moving the index downwards is generally considered better than upwards).

Consequently, on lots of layouts there are instances where the middle finger presses the letter O on the top row and the adjacent index finger presses a consonant on the bottom row, creating a row skip. A good example are the **HO** and **OM** bigrams on Canary.

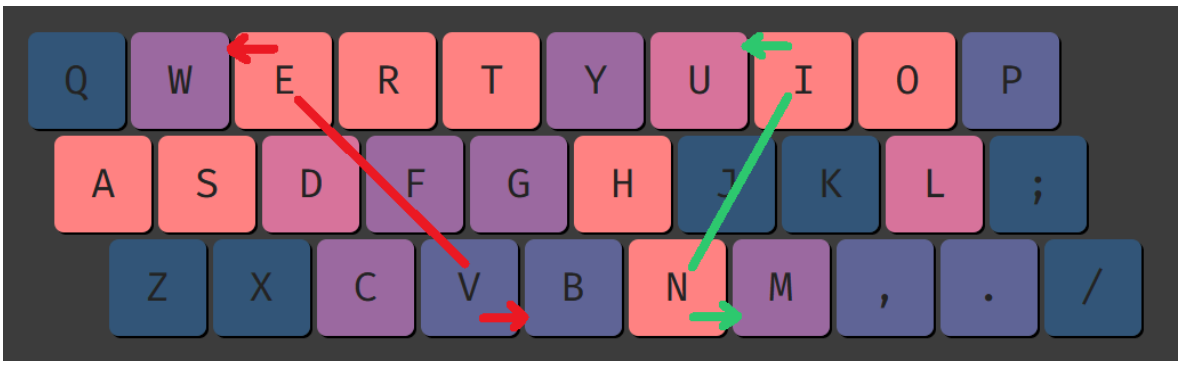
The layouts with the least row skips will break some of the earlier three rules. In fact, Mtgap breaks the latter two. Firstly, the consonants on the vowel side are on the ring finger (not the index). Secondly, the indexes have higher usage on the top row (not the bottom row). Other layouts may reach low row skips by moving the letter O back to the home row.

7. Lateral stretches (10 min)

7.1. The center column

The index finger inner keys are usually referred to as the center column. These keys force us to shift our index finger sideways a bit in order to press them:

Identifying the center column gets trickier on row stagger keyboards. Compared to matrix, the letter I is now shifted a bit to the left, while the letter N is shifted to the right. In other words, N and I are shifted toward each other, making them closer than on matrix. However, the opposite is true for the letters E and V, which are pushed further apart. Therefore, **despite the letter V technically not being on the center column, it effectively feels more like a center column key on row stagger than N does**:



The image above highlights the fact that standard keyboards are not symmetrical. **On row stagger keyboards, a bigram and its mirror** (i.e. the same bigram but on the opposite hand) **usually vary in length.** In fact, this is the case for Qwerty VE vs NI.

7.2. Lateral stretch bigrams (LSBs)

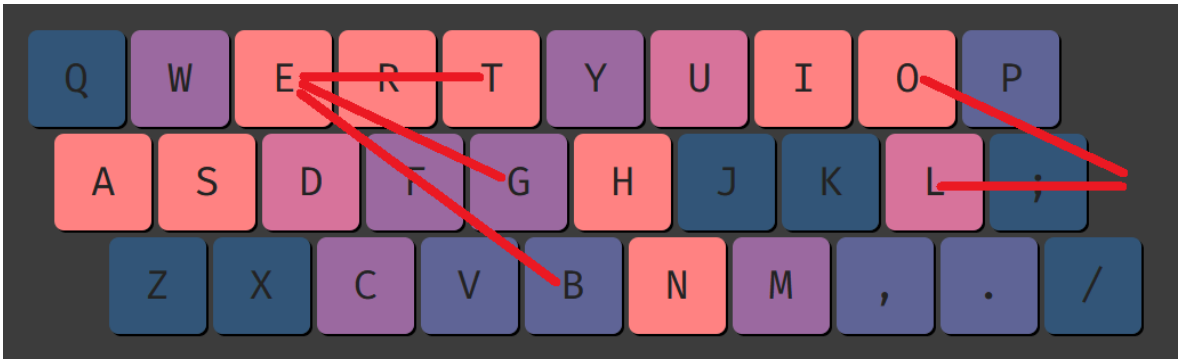
In general terms, a **LSB is a bigram that pulls two of our fingers apart or that forces us to laterally shift our wrist a bit to go from one key to the other**.

The issue with trying to come up with a more specific LSB definition is that **a bigram feeling like a lateral stretch or not depends on personal factors** like:

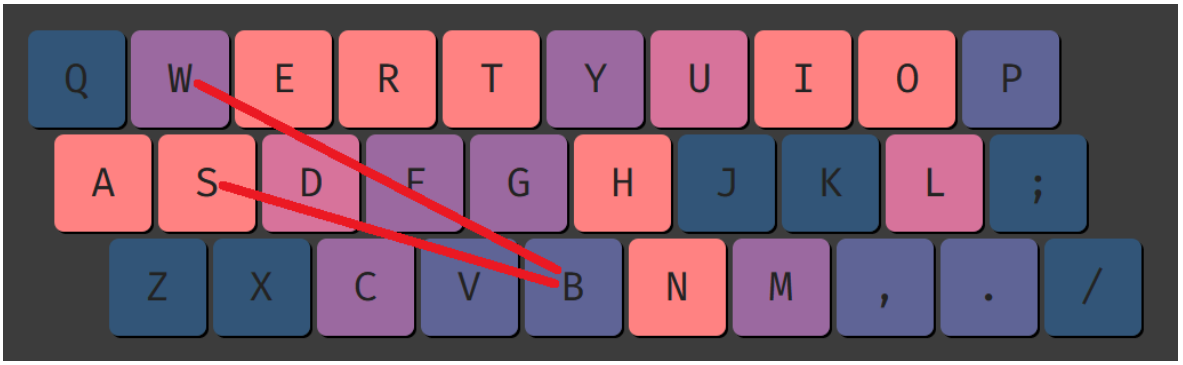
- Our hand size.
- At which angle we place our wrists in relation to the keyboard.
- Whether we rest or float or wrists when typing.
- What type of keyboard we use (i.e. row stagger, matrix, columnar stagger).

In any case, the following is a possible LSB definition:

- **Adjacent finger bigrams where the horizontal distance is 2U or greater.** Usually, this involves pressing one key on the center column with the index finger, followed or preceded by another key with that hand's middle finger (e.g. Qwerty TE, GE, BE...). Same applies to bigrams where we press one of the outer pinky keys followed or preceded by another key with that hand's ring finger (e.g. Qwerty 'O, 'L...).



- **Semi-adjacent finger bigrams where the horizontal distance is 3.5U or greater.** This applies to some ring-index bigrams where the keyboard row stagger pushes the keys rather far apart (e.g. BW, BS...):



7.3. Lateral stretch skipgrams (LSSs)

The difference between a LSB and a LSS is that on the first the two keys forming the stretch are pressed consecutively, while on the later there is another key in between the two, pressed by a third finger. Since there is an in-between key that breaks the lateral stretch, LSSs are less noticeable than LSBs. Anyway, take the following angle modded layout:

The highlighted lines are hardly common LSBs, as the WR & RV bigrams are rare. However, **even if a letter pair does not lead to a LSB it may still lead to a LSS**, and that is the case with our layout example.

Specifically, **w_r** is a common skip-1-gram in words like **were**, **world** or **work**. So, quickly typing **wor** on the layout above forces us to shift our wrist laterally a bit (to go from **w** to **r**). Same thing would apply to **v_r** in words like **never**, **every**, **ever** or **over**.

7.4. Row stagger vs matrix LSBs

On matrix keyboards the rows are perfectly aligned vertically, but on row stagger they are not. Therefore, some lateral stretches vary greatly in length depending on the keyboard:

- The LSBs with the bigger discrepancy between row stagger and matrix are those where one key is on the bottom row and the other key is on the top row. These are 0.75U shorter/longer laterally on row stagger. For example, Qwerty CT:

- The disparity goes down to 0.5U when one key in the LSB is on the bottom row and the other key is on the home row. For instance, Qwerty DB:

- Finally, the difference is only 0.25U when one key in the LSB is on the top row and the other key is on the home row. For example, Qwerty DT:

7.4.1. LSBs on matrix only

If we use a lateral distance of 2U as the threshold for what counts as an adjacent finger LSB, then the following bigrams would qualify as lateral stretches on a matrix keyboard, but not on row stagger (the horizontal distance drops under 2U on the later):

- On the left hand: Qwerty TD TC GC (index - middle)
- On the right hand: Qwerty HI NI NK (index - middle) and L[.[.' (ring - pinky)

On matrix:

On row stagger, using standard fingering (C pressed with the middle finger):

Because of these differences, on programs like Genkey that allow us to analyze a layout assuming either a row stagger or matrix keyboard, the LSB stat will usually be noticeably lower on row stagger than on matrix.

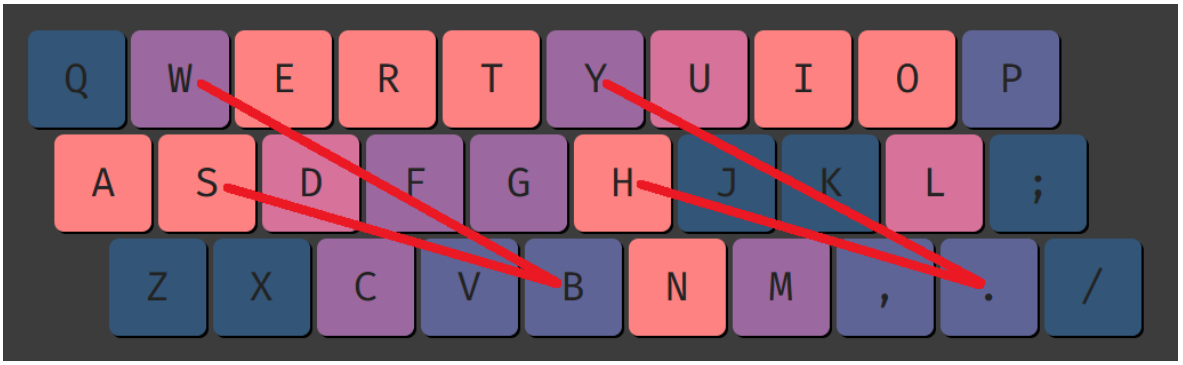
Basically, **placing letters on the center column is generally less problematic on row stagger keyboards**. That is assuming we take advantage of the stretches that are shorter on row stagger, and avoid the ones that become longer (listed in the following pages).

7.4.2. LSBs on row stagger only

If we use a lateral distance of 3.5U as the threshold for what counts as a semi-adjacent finger LSB, then the following bigrams would qualify as lateral stretches on a row stagger keyboard, but not on matrix (the horizontal distance drops to 3U on the later):

- On the left hand: Qwerty BW BS (index - ring)
- On the right hand: Qwerty Y. H. (index - ring)

On row stagger:



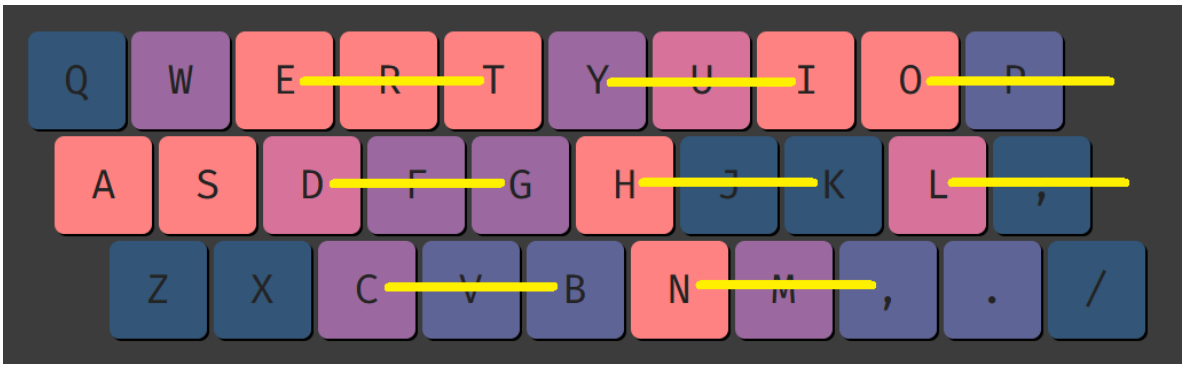
On matrix:

Lastly, although the bigrams below would technically not qualify as adjacent finger LSBs on row stagger (the lateral distance is 1.75U, just short of 2U) they feel noticeably more “stretchy” on row stagger than on matrix:

7.4.3. LSBs on both matrix and row stagger

Same length

Firstly, stretches that do not change in length regardless of the type of keyboard we use:



Longer on row stagger

Bigrams that qualify as LSBs on both row stagger and matrix, but are longer on the former:

- On the left hand: Qwerty GE BE and BD (index - middle)
- On the right hand: Qwerty YK Y, and H, (index - middle) also O' (ring - pinky)

On matrix:

On row stagger:

7.4.4. Angle mod specific LSBs

Although angle mod makes the left bottom row keys more comfortable to use, it also introduces additional stretches that layouts designed for angle mod should avoid.

Firstly, the two images below show the **index-middle LSBs that are added by angle mod**. Note that the green lines would not qualify as LSBs, but the red lines would.

Standard fingering
(the middle finger presses C)

Angle mod fingering
(the middle finger presses X)

Secondly, **angle mod introduces a couple of index-ring LSBs as well**:

Standard fingering
(the ring finger presses X)

Angle mod fingering
(the ring finger presses Z)

We can see that, with angle mod, the bottom row middle and ring finger keys are now further away from the center column. Consequently, the stretches involving those keys will be larger. To solve this, we should place rare bigrams where the big stretches would be. That way we will rarely have to type them.

7.5. Vowel hand and LSBs

A common setup on keyboard layouts is to have a hand with vowels pinky, ring and middle, while the index finger is reserved for consonants. On such layouts, we usually see an OE or OA column on the middle finger:

Canary (Eve)
```
w l y p k   z x o u ;
c r s t b   f n e i a '
 j v d g q   m h / , .
```

Layouts with the above structure usually place the vowels on the right hand, as the letter O will cause smaller stretches on that side. To visualize this, we will compare standard Canary with its mirrored version:

Canary (standard)

Canary (mirrored)

So, when mirroring the layout (not recommended) the FO and MO pairs become larger stretches. This is because, on row stagger, the top row middle finger key is closer to the center column on the right hand than on the left.

Anyway, on matrix keyboards (which are symmetrical) we can mirror layouts more freely.

7.6. Minimizing stretches

7.6.1. Reducing center column use as a whole

If rather than simply reducing lateral stretches our issue is more with center column usage in general, then we could make a layout like Engram:

Minimizing center column use to such an extent has a couple drawbacks, though:

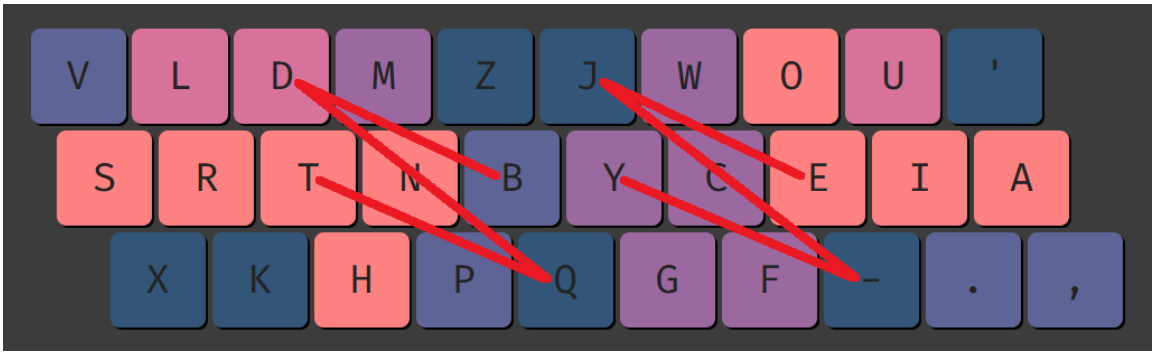
- **Higher pinky movement**, as more letters are pushed to the pinky corners.
- **Higher scissors**. Having said that, uncomfortable up-down motions can be greatly minimized with smart letter placings. For example, Engram does fine in that aspect.

A more middle-ground approach would be something like Mtgap:

Now center column use is a bit higher, but in exchange each pinky has only one common letter off the home row (e.g. Engram had BCG & VNP pinkies, while Mtgap has just YI & WR).

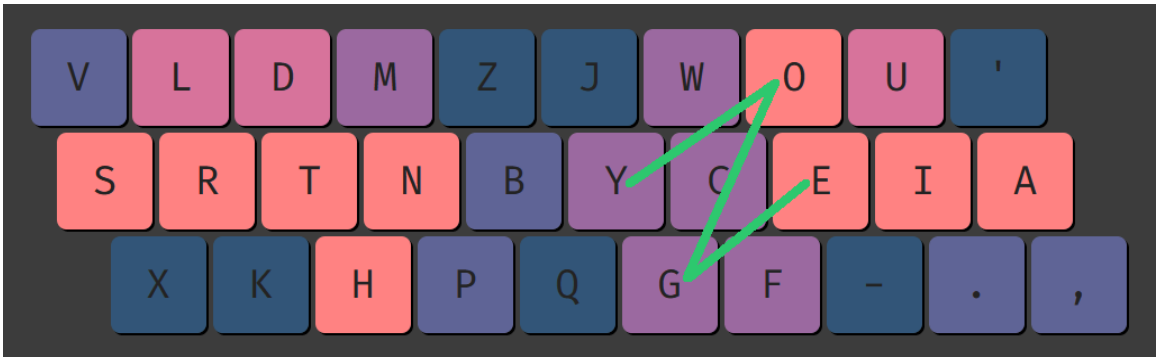
7.6.2. Strategically avoiding stretches

If we do not mind center column use as long as large stretches are avoided, all we have to do is place rare bigrams where the big stretches would be. A layout that does this is Wave eo (angle modded). Note that in this layout the letter M is pressed by the middle finger (there is a DTMK column). In any case, the bigrams connected by the red lines below are very uncommon, meaning we would rarely have to perform those stretches:



The long angle mod specific stretches are also very rare bigrams on Wave:

The layout only places more common bigrams in locations that lead to smaller stretches:



So, having multiple letters on the center column (B, P, Y and G) did not lead to any big stretches in the layout. **The up-sides of having a few letters on the center column are:**

- **Lower pinky movement**, as less letters are pushed to the pinky corners.
- **Lower scissors**, as the bottom row middle and ring finger keys have lower use.

8. Trigram stats (14 min)

8.1. Alts, rolls, 3rolls & redir

There are four stats that highlight what hand motions are most common in a particular layout. These are calculated based on trigrams (three key sequences):

- **ALTERNATE:** pressing one key with one hand, then one with the other, then back to the first (1, 1, 1). In other words, a pure alternating trigram. E.g: Qwerty **AND**.

- **ROLL:** pressing two keys with one hand, and a third key with the other (2, 1 or 1, 2). In other words, a 2 key roll following or preceding a hand change. E.g: Qwerty **OUR**.

- **3ROLL** (also called “onehand”): a one-handed trigram where all keys go in the same direction. In other words, a trigram roll. For example, Qwerty **WER**.

- **REDIRECT:** a one-handed trigram in which the direction changes. For example, Qwerty **SAD** is a redirect, as **SA** is outward while **AD** is inward. Whether redirects should be minimized or not is a matter of personal preference.

The stats above are based on trigrams to avoid redirects being counted as rolls. For example, if we used bigrams to calculate the stats instead, sequences like **DFDFDF** could be labeled as multiple rolls, when it's really just a long one-handed sequence.

8.2. The relation between alts, rolls, 3rolls and redir

Below we list the trigram stats for five layouts. The layouts are sorted from higher to lower alternation. The numbers show percentages, although the % symbol has been omitted:

	Alt	rolls	3rolls	Redir
Poqtea	**Maximal** 46.8	**Minimal** 35.3	**Very low** 1.2	**High** 7.5
Graphite	**Very high** 40.2	**Mid** 45.1	**Mid low** 2.6	**Very low** 3.4
Rolly	**Mid low** 32.1	**High** 49	**Mid** 3.5	**Mid high** 6.9
Inrolly	**Low** 26.7	**Maximal** 52.3	**Mid** 3.8	**High** 8.2
Seht Drai	**Minimal** 22	**High** 48.4	**Maximal** 10.6	**Very high** 10.6

We can identify some patterns from the table:

- **Lower alternation leads to higher rolling, but also higher redirects.** In fact, check the huge difference in total rolling (i.e. rolls + 3rolls) between a max alternation layout like Poqtea (36.5% total rolls) vs Seht Drai (59% total rolls)

- **Conversely, higher alternation leads to lower rolling, and lower redirects**. However, Poqtea (T + vowels setup) is an exception, as it has high redirects despite the high alternation. In all other cases, high alternation will lead to lower redirects.

In any case, the takeaway is that no keyboard layout can fully optimize all the stats, as maximizing one stat will necessarily make other stats worse. So, all layouts will have their pros and cons.

8.3. Balancing alternation & rolling

Which to favor between rolling and alternation is subjective. It can be said that **alternation offers a more consistent typing experience, as it feels rhythmic and minimizes awkward sequences. Meanwhile, rolling has higher highs** (words that feel very smooth) **but lower lows** (long same hand sequences). Regardless, it is not a matter of one or the other. Think of it more as a scale, with max alternation on one end and max rolling on the other. We have to decide where on that scale we want our layout to be.

8.4. Which consonants lead to higher or lower rolling

Most layouts place all the vowels on one hand. Doing so leads to a healthy amount of alternation, which ensures there are fewer long same hand sequences and redirects.

Even if we know where the vowels will be, **we still have to decide what consonants we want to place on the vowel side**. To help us with that we will use the table below, which shows how much each consonant combines with the vowels vs with the consonants. For example, we can see that R + vowels amount to 9.38% of all bigrams, while R + consonants is 4.19%. The table is sorted based on the third column (vowel column minus consonant column). Additionally, the main consonants (i.e. T, N, S, R and H) are highlighted, as their placement will have the most effect on a layout's stats. Anyway, X, J, Q and Z were omitted:

	vowels	cons	v-c				
r	**9.38**	**4.19**	**5.19**	w	1.851	0.717	1.134
n	**9.946**	**5.279**	**4.667**	b	1.75	0.8	0.95
m	3.788	1.114	2.674	p	2.214	1.902	0.312
v	2.237	0.194	2.043	k	0.571	0.464	0.107
f	2.903	0.866	2.037	g	1.704	1.813	-0.109
c	4.405	2.505	1.9	**h**	**5.387**	**5.563**	**-0.176**
l	5.264	3.47	1.794	**t**	**8.243**	**8.62**	**-0.377**
s	**6.492**	**4.802**	**1.69**	y	0.691	1.733	-1.042
d	3.864	2.313	1.551				

** table data: Norvig*

Generally, **consonants with a very large v-c** (e.g. R and N) **will increase rolling the most when placed on the same hand as the vowels. Conversely, letters with a small or even negative v-c** (e.g. H and T) **will favor alternation instead.**

8.5. Common trigrams, rolls & alternation

In order to get a deeper understanding of where a layout's stats are coming from, we can look at the most common trigrams for a given letter, and check how those trigrams would be typed depending if said letter was on the vowel or the consonant hand. Below are some conclusions we can extract after doing this with the main consonants:

Graphite (StronglyTyped)	**Inrolly** (Ec0vid)	**Poqtea** (Ian Douglas)
b l d w z ' f **o** u j ;	y **o** u q x k d l w ,	y w f l m k p **o** q - /
n r t s g y **h a e i** ,	**i a e n** j v **h t s c** '	u **r s n h** d **t e a i** '
q x m **c** v k p . - /	" - **r** b z f p m g .	z x **c** v j b g , . ;

- **H gives decent rolling regardless if we place it on the vowel hand or not.** To understand why this is the case, we will use the following trigrams: **THE**, **THA** & **THI**.

  On the Graphite layout (H on the vowel hand) **T–HE**, **T–HA** and **T–HI** are typed by pressing one key with one hand, and two with the other. Same applies to Inrolly (H on the consonant hand) only that the trigrams are now type as **TH–E**, **TH–A** and **TH–I**. So, they are rolls either way, it is just that the part that is a roll changes.

- **T maximizes alternation on the vowel hand.** This is because the very common **T–H–E**, **T–H–A** and **T–H–I** trigrams are now alternates (i.e. they are typed by pressing only one key at a time, then changing hands). See Poqtea for a layout example. Anyway, **if we want good rolling, T should always stay on the consonant hand.**

- **R and N maximize rolling on the vowel hand**. A good example of this is Inrolly, which has tons of rolls. We have the frequent N + vowels rolls (**IN**, **AN**, **ON**, **EN**...), the R + vowel rolls (**ER**, **RE**, **OR**, **AR**...), some common 3rolls (**YOU**, **OUR**, **ION**, **REA**...) plus all the consonant rolls (**TH**, **ST**, **CH**, **CT**, **WH**, **TS**, **SH**, **LD**...).

If we want, we can check less frequent letters as well. For example, **D** and **G** favor rolling on the consonant side because the common **A–ND** and **I–NG** trigrams are rolls. However, on the vowel side D and G now favor alternation, as **A–N–D** and **I–N–G** become alternates.

8.6. Roll comfort

The following are the main factors affecting how comfortable a roll will be:

- Ideally, we want the two keys in the bigram to share the same row.

- When the keys are either one or two rows apart, it is preferable for the longer fingers to the higher one (e.g. it is more comfortable for the middle finger to be higher than the index, ring or pinky, rather than the other way around).

- Rolls that do not involve any lateral stretch motion (resulting from pressing two keys that are far apart) are more comfortable than those that do.

- Rolls that are typed with strong fingers (index and middle) are generally considered better than rolls that involve weaker fingers (ring and pinky).

- Some people prefer rolls that are on adjacent fingers. The adjacent finger pairings are: pinky - ring, ring - middle and middle - index. Meanwhile, the non adjacent finger pairings are: pinky - middle, ring - index and pinky - index.

- Finally, some people like taking roll direction into account as well. For example a middle - index finger roll can be either inwards (Qwerty DF) or outwards (Qwerty FD). There are layouts designed to favor inward rolls.

So, **not all the rolls in a layout will necessarily be comfortable**. After all, the basic roll definition (a trigram where we press two keys with one hand, and a third key with the other) is rather general, and can include bigrams such as scissors, lateral stretches, etc...

8.7. Which consonants lead to higher or lower redirects

The first rule for minimizing redirects is having all vowels on the same hand. This is because vowels on one side ensures alternation, which reduces redirects.

Next, **we want to identify which consonants roll in a single direction with the vowels,** as that too will minimize redirects. After all, redirects are a change in direction.

The table below shows how much each consonant favors one direction vs the other (i.e. consonant → vowel vs vowel → consonant). Letters that score high in one direction but low on the other appear higher on the table, indicating that they are more unidirectional. Lastly, the fourth column shows the ratio in which each consonant favors its preferred direction:

	c→v	v→c	Favored direction	ratio					
h	**5.322**	**0.064**	**H → vowel**	**83.2**	f	1.269	1.634	Vowel → F	1.29
n	**1.921**	**8.025**	**Vowel → N**	**4.18**	**r**	**4.123**	**5.258**	**Vowel → R**	**1.28**
w	1.343	0.508	W → vowel	2.64	m	2.127	1.661	M → vowel	1.28
b	1.209	0.541	B → vowel	2.23	c	2.428	1.978	C → vowel	1.23
s	**2.409**	**4.083**	**Vowel → S**	**1.69**	d	1.746	2.118	Vowel → D	1.21
p	1.391	0.824	P → vowel	1.69	g	0.903	0.801	G → vowel	1.13
k	0.338	0.233	K → vowel	1.45	**t**	**4.374**	**3.87**	**T → vowel**	**1.13**
v	1.308	0.929	V → vowel	1.41	l	2.503	2.761	Vowel → L	1.10
y	0.288	0.402	Vowel → Y	1.4					

** table data: Norvig*

We can see that **any layout that aims to minimize redirects will place the letter H with the vowels**, as H only combines with them in a single direction (ratio of 83 to 1!). On the other side of the spectrum, **placing R or T with the vowels will noticeably increase redirects**, as they combine with the vowels in both directions about equally.

8.8. Common trigrams & redirects

As a general rule, redirects are the result of increasing rolling in a layout. The following are the main letter patterns that will lead to redirects:

Rolly (Ec0vid)

```
y o u f j   q m w l ,
i a e n b   k t s r c '
 ; " h p z   v d g x .
```

Inrolly (Ec0vid)

```
y o u q x   k d l w ,
i a e n j   v h t s c '
 " - r b z   f p m g .
```

- **Vowel → consonant → vowel trigrams**. These will inevitably be redirects when all three letters are on the same hand. For example, **ERE**, **ONE** & **ARE** on Inrolly.

- **Consonant → vowel → consonant trigrams**. These would also be redirects if the three letters share one side. For example, **HIN**, **HEN** & **HAN** on Rolly.

- **Vowel → vowel, followed or preceded by a consonant**. These are redirects or 3rolls depending on our vowel setup. For instance, on Inrolly, **EAR** & **AIN** are redirects, but **OUR**, **ION** & **REA** are 3rolls.

- **Consonant only trigrams**. These are redirects or 3rolls depending on our consonant setup. For example, **STR** on Rolly is a redirect.

- **Trigrams with punctuation**. For example, **T'S** is a redirect on either Rolly or Inrolly.

Ideally, we want all three keys in a redirect to share the same row (e.g. **AIN** or **STR** or Rolly). However, in practice many redirects will have just two letters on the same row, while a third letter is on a different row (e.g. **ONE**, **HIN**, **HEN** or **HAN** on Rolly).

Another aspect that affects how a redirect will feel is if it has SFS or not. If it does, then the redirect is typed with just two fingers, as one finger is utilized twice (e.g. **HIN**, **HEN** or **HAN** on Rolly). If there is no SFS, then three fingers will be used (e.g. **AIN**, **ONE** or **STR** on Rolly).

8.9. “Weak” redirects

Redirects where the index finger is not utilized are sometimes referred to as “weak” or “bad” redirects, as they are trickier to type. Having said that, people who have developed good finger independence and dexterity with their weaker fingers (from playing a musical instrument for example) will probably not mind “weak” redirects at all.

Seht Drai (Tanamr)

```
f u l v b   q g n o j
s e h t k   ' d r a i .
  ; m p w z   y c x / ,
```

The **SHE** trigram is a weak redirect on Seht Drai, while **STE** is not. Similarly, **AIN** is a weak redirect, but not **DON**.

Most trigrams in the English language (and therefore most redirects) involve both vowels and consonants. Conversely, vowel only trigrams are extremely rare. So, **in order to minimize weak redirects, we must place all the vowels on the same hand and on our last three fingers specifically** (pinky, ring and middle). As such:

Whix (Ec0vid)

```
f l n d k   ' w o u j
s r h t v   y c a e i
  x b m z q   p g . " ,
```

On the right hand, with consonants being on the index finger, and vowels on middle, ring and pinky, we ensure that any trigram with both vowels + consonants will involve the index.

It should be noted that, although vowel only trigrams are rare in English, there are actually some common consonant only trigrams. Regardless, with the right letter arrangement we can avoid weak redirects on the consonant hand as well. For example, none of the redirects on Whix’s left hand (**STR**, **NDS**, **RST**, **NST**, **NTS**, **RTH**...) are weak redirects.

8.10. Common trigrams & 3rolls

Layouts that aim to maximize 3rolls necessarily have to split the vowels, placing three vowels on one hand, and two on the other. This is done so that the most common trigram in the English language (**THE**) can be a 3roll on one hand, while on the other hand we have some of the next most common trigrams as 3rolls too (**ING**, **AND**, **ION**...). An example of such a layout would be Seht Drai (angle modded) which maximizes 3rolls while also doing a great job at optimizing other layout stats like SFBs, SFSs, etc...

Seht Drai (Tanamr)
```
f u l v b   q g n o j
s e h t k   ' d r a i .
  ; m p w z   y c x / ,
```

The following are the 3rolls on Seht Drai. For each hand, they are sorted based on frequency (on the TypeRacer corpus):

- Left hand: **THE**, **WHE**, **PLE**, **BLE**, **SEL**, **LES**, **TLE**...
- Right hand: **ING**, **AND**, **ION**, **IND**, **ANY**, **ON'**, **ONG**, **ARD**, **ANG**, **ANC**, **ORD**...

Ideally, we want all the letters in a 3roll to be on the same row (e.g. **THE**, **ONG** or **ARD**). However, we can only have a few 3rolls like that in a layout. The best we can hope for most 3rolls is having two of the letters sharing a row. See all the remaining 3rolls on Seht Drai other than **PLE**, **ANY** and **ANC** (those three have each letter on a different row).

Anyway, **the disadvantage of utilizing a 3-2 vowel split is that alternation plummets**, meaning redirects and long same hand sequences will be way higher than on other layouts.

How to make a layout

9. Layout structure (8 min)

9.1. Letter stacks

One of the first steps when making a layout is deciding where the high frequency letters will be. These are **E**, **A**, **O**, **I** for the vowels (which we will highlight in green) and **T**, **N**, **S**, **R**, **H** for the consonants (which will be highlighted in red).

The aforementioned letters are the main ones competing for the 8 home row spots in a layout. **Since there are 9 high frequency letters for 8 home row spots, one of them will inevitably be pushed off the home row. The result is that there will always be at least 2 high frequency letters sharing a column/finger. This is referred to as a "stack".** The viable consonant stacks are **NH, RH** & **NR**, while the vowel stacks are **EO** & **AO**:

1 consonant stack:

Isrt (Whorf)

```
y c l m k   z f u , '
i s r t g   p n e a o ;
 v w d j q   b h / . x
```

1 vowel stack:

Graphite (StronglyTyped)

```
b l d w z   ' f o u j ;
n r t s g   y h a e i ,
q x m c v   k p . - /
```

Despite not being that common, **the letter C plays a key role in layouts.** The unique thing about C is that it cannot share a column with T, N, R or H (high SFBs). Therefore, **on 1 stack layouts, C will always be on a SC column** (see the layouts above).

However, there are certain aspects of layout design (SFBs, for example) that can only be fully optimized **if we break the SC pair and give the letter C its own column. And for that, we need 2 stacks** (a consonant stack + a vowel stack):

2 stacks with C on index:

Sturdy (Oxey)

```
v m l c p   x f o u j
s t r d y   . n a e i
 k q g w z   b h ' ; ,
```

2 stacks with C on pinky:

Pine (ClemenPine)

```
y l r m k   q f o u ,
c s n t g   b h a e i
j x z w v   p d ' / .
```

So, there are 4 main categories: 1 consonant stack, 1 vowel stack, and 2 stacks with either a C index or a C pinky. Layouts in the same category will share more similarities. In the next few pages, we go over the properties shared by layouts in each category.

9.2. One consonant stack

Layouts that have two of the top consonants on the same column (e.g. a **NH column**):

[Colemak DH](#) (SteveP)	[Colemak Qi;x](#) (Nyfee)	[Isrt](#) (Whorf)
q w f p b j l u y ;	; l **c** m k j f u y q	y **c** l m k z f u , '
a r s t g m **n e i o** '	**a r s t** g p **n e i o** '	**i s r t** g p **n e a o** ;
x **c** d v z k **h** , . /	x w d v z b **h** / . ,	v w d j q b **h** / . x

These layouts have the highest home row use, as the letter O (the 4th most common English letter) **is on the home row.** To make room for O, H is pushed off the home row.

Since one of the main vowels (usually A or I) is moved to the consonant hand, alternation will noticeably decrease. Consequently, rolls, and especially redirects, will increase.

9.3. One vowel stack

Layouts that have two of the top vowels on the same column (e.g. an **AO or EO column**):

[Gallium](#) (Brys)	[APT](#) (Eve)	[Rollla](#) (Tanamr & Heart)
b l d **c** v z y **o** u ,	w g d f b q l u **o** y	y **o** u b . x k **c** l v
n r t s g p **h a e i**	**r s t h** k j **n e a i** ;	**i a e n** , m **h s r t**
q x m w j k f ' ; .	X **c** m p v z , . ' /	' / p w z f d g j q

The letter O is now relegated to the top row, with H taking the home row spot. Therefore, **home row use will be a bit lower**, as H is less common than O.

A fundamental difference between the previous subgroup and this one is that **here the vowels take just three home row spots, rather than four.** This allows us to have all vowels on one side, while still being able to fit consonants on that same hand. This way we can have good rolling (from consonants + vowels) and low redirects (from one side vowels).

9.4. Two stacks (1 vowel + 1 consonant)

Layouts that have a vowel stack (**EO or AO**) plus a consonant stack (**HN, RN or HR**). **Double stack layouts have the lowest home row use. Despite that, they offer multiple benefits in return.** We can subdivide this group into two based on C's location.

9.4.1. With C on index

C and D cause negligible SFBs & SFSs with plenty of moderately common letters. We can take advantage of this by placing C/D on an index finger with five other letters:

[Sturdy](#) (Oxey)	[Seht Drai](#) (Tanamr)	[Noctum](#) (Oxey)
v m l **c** p x f **o** u j	f u l v b q g **n** **o** j	b f d l z j g **o** u ,
s **t** **r** d y . **n** **a** **e** **i**	**s** **e** **h** **t** k ' d **r** **a** **i** .	**n** **s** **t** **r** k y **c** **a** **e** **i**
k q g w z b **h** ' ; ,	; m p w z y **c** x / ,	v m **h** x q p w ' ; .

Double stack layouts with a C index have the least SFBs and SFSs. The table below lists multiple C index arrangements and gives a layout example for each:

With D:	**Without D:**
DC WGP Semimak	**CYWG F'** Dina
DCYWG Gemini	**C WGPV '** Rainy
DC WGP ' Semimak JQ	**CYWGP '** Whix
DCY G ' Seht Drai	**C WGPV B** Recurva
DC WG MV Trance	**CYWG M** Stronk
DC W PB ' Trendy	**C WG VMB** Snug
DCYWGP Sturdy	**CYWGPV** Whorf

For an easier comparison, letters that appear on multiple rows of the table are kept on the same vertically line.

For example, the indexes on Semimak and Gemini share **D, C, W** & **G**, but differ on **Y** & **P**.

The letters that can be paired with C/D while causing few SFBs are Y, M, W, F, G, P, B & V.

9.4.2. With C on pinky

One drawback with the layouts in the previous section is that C being on the index finger leads to low index usage (11 - 14%). If this is an issue, the letter C can be moved to the pinky instead:

[Canary](#) (Eve)	[Pine](#) (ClemenPine)	[Engram](#) (Arno Klein)
w l y p k z x **o** u ;	y l **r** m k q f **o** u ,	b y **o** u ' " l d w v z
c r s t b f **n e i a** '	**c s n t** g b **h a e i**	**c i e a** , . **h t s n** q
j v d g q m **h** / , .	j x z w v p d ' / .	g x j k - ? **r** m f p

Compared to C index layouts, **moving C to the pinky sacrifices some SFB and SFS optimization, in favor of more traditional indexes with higher usage.**

The table below lists examples of C pinky setups and gives a layout example for each:

WC Canary
YC Pine
WC' Crest
,C.' Rolly
WCG' Saiga
BCG Engram

9.4.3. With a U column

Usually, layouts will place the letter U on an EU, AU or IU column. That was the case in all the layouts we have seen until now. Having said that, it is technically possible to make layouts where the letter U is not sharing a finger with another vowel:

Hands Down (Alan reiser)	**Poqtea** (Ian Douglas)	**Urts** (Ec0vid)
q **c** **h** p v k y **o** j /	y w f l m k p **o** q - /	v l d **c** f q b **o** y '
r **s** **n** **t** g w u **e** **i** **a**	u **r** **s** **n** **h** d **t** **e** **a** **i** '	u **r** **t** **s** w . **n** **e** **i** **a**
x m l d b z f ' , .	z x **c** v j b g , . ;	k x m g z p **h** ; j ,

Note that Y and U being on the same column leads to tons of SFSs. This is because, when typing the word **YOU**, Y and U would be pressed with the same finger, only that with the letter O in between.

9.5. Summary table

This table summarizes the characteristics of the different layout categories. To see the pros and cons of a particular category, go through a row of the table. To compare how the different categories perform on a particular aspect, check a column instead:

	Home row use	SFBs	SFSs	Redirects	Index use	Pinky use	Usual vowel hand split
1 consonant stack (e.g. NH)	High	Mid	Mid	High	High	Mid	4 - 1
1 vowel stack (e.g. AO or EO)	Mid	Mid	Low	Variable	Low	Mid	5 - 0
2 stacks with C on index	Low	Low	Low	Variable	Low	Mid	5 - 0
2 stacks with C on pinky	Low	Mid	Low	Variable	High	Low	5 - 0

* It is possible to get “low SFBs” with any of the categories. The reason only the third appears as **Low**, is simply to highlight that it can optimize SFBs further than the others.

* The word **variable** refers to the redirects being dependent on what consonants are with the vowels. For example, H + vowels has low redirects, but NR + vowels has high redirects.

We can identify some patterns from the table:

- **Low index finger use correlates with lower SFBs.** Reaching the lowest SFBs requires using a C index, and those indexes have low use. Having said that, there are layouts that manage to get quite low SFBs while maintaining high index finger use.

- **Low index finger use also correlates with lower SFSs.** The reason for this is straightforward. Since index fingers have six keys assigned to them, there are many more letter interactions on the indexes, all of which can cause SFSs. The purpose of SFS optimization is for each word to be spread across more fingers. Naturally, this means concentrating less relevant letters on any particular finger.

- **Minimal SFSs requires a vowel stack** (an AO column specifically). This is why 1 consonant stack layouts can not reduce SFSs past a certain point. We will elaborate on this in the next chapter.

10. Vowel blocks and punctuation (14 min)

10.1. Challenging the home row convention

Old keyboard layouts were designed under the assumption that all the common letters should be kept on the home row. This is perfectly exemplified by Colemak:

Colemak (Shai Coleman)
```
q w f p g   j l u y ;
a r s t d   h n e i o '
z x c v b   k m , . /
```

However, **modern layouts will usually place the letter O** (the fourth most frequent letter in the English language) **outside the home row**, on either an OA or OE column:

Graphite (StronglyTyped)
```
b l d w z   ' f o u j ;
n r t s g   y h a e i ,
q x m c v   k p . - /
```

Arranging the vowels in a compact way like this is referred to as a **"vowel block". The point is to reduce the number of fingers that are dedicated to the vowels** (note how the vowels occupy four fingers on Colemak, but only three on Graphite).

Although this approach will lower home row usage, we get multiple benefits in return:

- Consonants can now be spread across more fingers, ideal for SFB & SFS optimization. This is on top of OA and OE causing low SFBs by themselves.

- We can now have all vowels on one side (which minimizes long same hand sequences and redirects) while still being able to fit consonants on the vowel hand (to increase rolling). So, we get the best of both worlds.

10.2. OE stack

An OE column is a good fit if we do not mind high middle finger usage, **in order to lower ring finger use**. **The drawbacks are a few SFBs** (the words **people**, **someone** and **does**) **and multiple SFSs** (words like **one**, **more**, **some**, **over**, **those** or **before**). Having said that, these SFS are only 1U and are typed with the strongest finger.

Below we list the common vowel blocks with an OE column. Each vowel block is named after the vowel pairs it utilizes (i.e. which vowels are sharing a column/finger).

UA OE YI

Mtgap (Michael Dickens)

```
y p o u j   k d l c w
i n e a ,   m h t s r
q z ' . :   b f g v x
```

The point of this vowel block is to maximize inward rolls (i.e. rolls that go from the outside of the keyboard to the inside).

By placing an UA column on the index finger and an OE column on the middle finger, both the **OU** bigram (on the top row) and the **EA** bigram (on the home row) become in-rolls.

Additionally, having an YI column on ring or pinky makes the **IO, IE** and **IA** bigrams inward. Same applies to the word **YOU**.

OE UI A

Canary (Eve)

```
w l y p k   z x o u ;
c r s t b   f n e i a '
 j v d g q   m h / , .
```

With this block we give up inward rotation, as **OU** and **EA** become outward. The upside is that having the vowel hand's consonants on the index finger allows for more comfortable trigrams. For example, compare **ION** on Mtgap vs Canary.

10.3. OA stack

An OA column has lower SFBs and SFSs than EO. **The one drawback is that ring finger usage will noticeably increase**, as we get either an OA or UE ring.

Despite the letters A and O having similar usage, most of the time it will be A that is on the home row when using an OA column. This is because, since U is already on the top row (UE column) we want O next to U in order to make **OU** a same row roll.

OA UE I

Without YI:

Graphite (StronglyTyped)
```
b l d w z  ' f o u j ;
n r t s g  y h a e i ,
q x m c v  k p . - /
```

If the letter Y is on the index finger, the OA column usually goes on the middle finger, and UE on ring. This way **YOU** is a 3roll.

UE OA YI

YI on index:

Mawar (Lela)
```
p l d w v  ; q o u f
n r t s g  j i a e h '
 x m c b z  , y . / k
```

This layout is similar to the previous one, only that the H and I columns swap fingers. So, we get an YI index. Having YI on index is extremely rare, though.

YI on pinky:

Semimak JQ (Semi)
```
f l h v z  ' w u o y
s r n t k  c d e a i
x j b m q  p g , . /
```

Now the YI column is moved to the pinky. Consequently, the OA and UE columns swap fingers, so that **YOU** remains a 3roll. **The most common location for YI is on pinky.**

YI on ring:

Uciea (Ian Douglas)
```
p y u o -  k d h f x q
c i e a '  g t n s r v
z " , . ;  w m l b j
```

Ring finger usage is now lower (YI vs OA/UE). However, **YOU** becomes a redirect. In this setup, the UE column is not on index, because that would put E with all punctuation (SFBs).

Heart (<3)

```
q c d v k   j y o u ;
r s t h l   p n a i e '
w g b m x   z f , . /
```

The earlier UE column is replaced with an UI one. This setup is rarely seen, as the letter E (~12% use) is pushed to the pinky.

Saiga E (RusDoomer)

```
; o u r q   f d l b w
e a i n x   y h t s c '
/ . , j z   k p m v g
```

The OA and UI columns swap fingers. At first glance this is unintuitive, as we are lowering the middle finger usage in favor of higher ring finger use. The point is to make **OU** an in-roll.

10.4. Without OE or OA

On layouts without a vowel stack, **the letter O is moved back to the home row, while one of the main vowels** (usually A or I) **is moved to the consonant hand**. Consequently, alternation will decrease, while redirects will increase. On the bright side, home row usage will now be higher, as O is on the home row.

Depending on the location of the A column and the YI one, we have two main variants:

UE YI O

Colemak Qi;x (Nyfee)
```
; l c m k   j f u y q
a r s t g   p n e i o '
  x w d v z   b h / . ,
```

First we have the colemak approach, where the letter A is the one on the consonant hand. One drawback with this setup is that the common **YOU** and **ION** trigrams become redirects.

UE A O

Isrt (Whorf)
```
y c l m k   z f u , '
i s r t g   p n e a o ;
  v w d j q   b h / . x
```

Alternatively, A and YI can swap places when compared to above. This results in higher rolls and lower redirects (the **YOU** and **ION** trigrams are not redirects anymore). The drawback is that the letter Y is now on top row pinky.

10.5. Letter U on the consonant hand (very rare)

Instead of moving either A or I to the consonant hand as in the previous section, **now we shift the letter U to the consonant side, while maintaining an OE or OA column.**

Naturally, having U on the home row (rather than O) will lower home row use quite a bit. Having said that, alternation and redirects are much less affected by U being on the consonant hand rather than I or A.

In any case, here are a few examples of layouts that separate U from the rest of the vowels:

Urts (Ec0vid)

```
v l d c f  q b o y '
u r t s w  . n e i a
k x m g z  p h ; j ,
```

Tiramisu (ddn)

```
y l ' o ,  k g h c w -
i r e a .  p t n s u /
j z ; x q  b d m f v
```

Ursnf (Eve)

```
k l c m b  q p a j .
u r s n f  g t o i e
w x y h v  z d ' , ;
```

Despite the letter Y not causing SFBs with U, none of the layouts above utilize an YU column. This is because having Y and U on the same finger would introduce a common Y_U skip-1-gram on the word **you**. An WUK column is not ideal either, as words like **know** or **work** would have K_W and W_K 2U skip-2-grams. The best U + consonant columns are WUV and VUK. Regardless, **99 percent of the time the letter U goes in a UE, UA or UI column.**

10.6. Avoiding an UIY column

Take a layout with the YI OA UE vowel block:

Rolly (Ec0vid)

```
y o u f j   q m w l ,
i a e n b   k t s r c '
 ; " h p z   v d g x .
```

Now, say E" and YI swapped fingers:

```
" o u f j   q m w l ,
e a i n b   k t s r c '
 ; y h p z   v d g x .
```

From a SFB perspective, both layouts perform about the same. However, typing the common word **you** is much less comfortable on the second layout. This is because of two reasons. Firstly, the **YO** bigram becomes a scissor (an unpleasant bigram where one finger moves upwards and the other downwards). Secondly, **Y_U** becomes a 2U SFS (our middle finger has to jump over the home row to go from Y to U, with only the letter O in between).

Moving UIY to the ring finger does not fix the problem, as **Y_U** is still 2U:

```
; u o f j   q m w l ,
a i e n b   k t s r c '
 y " h p z   v d g x .
```

Analyzers that are optimized simply for SFBs will often generate layouts with an YIU column. However, as we have seen, the moment we account for SFSs as well then YIU becomes a very poor column.

10.7. Punctuation SFBs

We want to identify which are the letters that cause the least SFBs when sharing a finger with each of the main punctuation symbols (i.e. period, comma and apostrophe).

The corpus utilized to get this data was TypeRacer. The letters are sorted from higher to lower SFBs, and divided by colors into a few groups. The SFBs thresholds are as follows:

Dark red > 0.25% **Red** > 0.09% **Orange** > 0.05% **Yellow** > 0.03% **Green** ~0.02% or lower

- **SFBs with apostrophe**:

  T, **S**, **N**, **I**, **E**, **R**, **U**, **M**, **V**, **L**, **D**, **Y**, **C**, **O**, **A**, **G**, **H**, **W**, **F**, **P**, **B**, **K**

- **SFBs with period**:

  E, **S**, **T**, **D**, **N**, **Y**, **R**, **G**, **L**, **M**, **H**, **U**, **O**, **W**, **K**, **P**, **F**, **A**, **C**, **I**, **B**, **V**

- **SFBs with comma** (almost identical to period):

  E, **S**, **T**, **Y**, **D**, **N**, **R**, **L**, **G**, **H**, **W**, **O**, **M**, **K**, **U**, **P**, **F**, **A**, **C**, **I**, **B**, **V**

Vowels + punctuation

As seen in the SFB data above, **E does poorly with any punctuation. Next, I and U pair well with both period and comma, but not with apostrophe. Lastly, A and O can go with any of the three main punctuation symbols** (although A performs a bit better).

Consonants + punctuation

Most common consonants cause SFBs with punctuation. The most relevant exceptions in regard to layouts are the letter H pairing well with apostrophe and C being able to go with any of the three main punctuation symbols.

Other

Period can cause SFB and SFS with a few other keys:

- The end of a paragraph becomes a SFB if period and enter are on the same finger.
- Capitalizing a letter (period → space → shift) becomes a SFS if period and shift are on the same finger.
- The end of a quote (.”) becomes a SFB if period and apostrophe share a finger.

10.8. Punctuation setup examples

The main factor that determines how punctuation is arranged on a layout is its vowel block. **With UA OE YI, all punctuation can go on the UA column** (e.g. see the Heyyou layout below). Alternatively, apostrophe might be moved elsewhere (e.g. Inrolly2, Mtgap). Note that apostrophe being on the OE column (e.g. Mtgap) leads to E → apostrophe becoming a SFB and O_' being a 2U SFS in contractions like **you've** or **you'll**.

Heyyou (ClemenPine)

```
f y o u z   q k l c b
h i e a ,   m t r s n
j x / . '   g d w v p
```

Inrolly2 (Ec0vid)

```
p l d w v   ; u o y f
n r t s g   . a e i h '
  q m c b z   x , " j k
```

Mtgap (Michael Dickens)

```
y p o u j   k d l c w
i n e a ,   m h t s r
q z ' . :   b f g v x
```

With OE UI A, either period or comma will go on the UI column and we get an apostrophe + A + comma/period pinky (e.g. Canary, Grephati). Some layouts might find another place for apostrophe in order to minimize pinky movement (e.g. Trendei):

Canary (Eve)

```
w l y p k   z x o u ;
c r s t b   f n e i a '
  j v d g q   m h / , .
```

Grephati (StronglyTyped)

```
b l d w z   j f o u ' ;
n r t s g   y h e i a ,
  q x m c v   k p - . /
```

Trendei (Ec0vid)

```
k l h w '   x f o u q
t r n d b   y s e i a
  j m c p z   g v - . ,
```

With OA UE I, the basic option is having a comma + I + period pinky, while apostrophe goes with OA (e.g. Sntm). If we want lower pinky movement, then apostrophe could go with H (e.g. Graphite) or with C (e.g. Whix) allowing us to move period or comma to OA:

Sntm (Oxey)

```
v p d g w   q l o u ,
s n t m y   x r a e i
z b k c f   j h ' ; .
```

Graphite (StronglyTyped)

```
b l d w z   ' f o u j ;
n r t s g   y h a e i ,
  q x m c v   k p . - /
```

Whix (Ec0vid)

```
f l n d k   ' w o u j
s r h t v   y c a e i
  x b m z q   p g . " ,
```

With UE OA YI we have little room for punctuation, so some SFBs are expected. The difference when compared to the previous vowel block is that before we could place comma and/or period on the I pinky without issues, but now that would cause SFBs with Y. The one way to avoid SFBs with this vowel block is a C + all punctuation pinky (e.g. Rolly):

Rolly (Ec0vid)

```
y o u f j   q m w l ,
i a e n b   k t s r c '
  ; " h p z   v d g x .
```

Semimak JQ (Semi)

```
f l h v z   ' w u o y
s r n t k   c d e a i
  x j b m q   p g , . /
```

Recurva (Brys)

```
f r d p v   q j u o y
s n t c b   . h e a i
  z x k g w   m l ; ' ,
```

On Semimak E → comma is a SFB, but it is only 1U. On Recurva Y → comma is 2U. The Rolly approach avoids these issues, but it limits layout structure the most (forces C on pinky).

10.9. On what finger should the consonants on the vowel hand be?

Where the consonants are placed in relation to the vowels will have a significant effect on how a layout feels. We are specifically talking about layouts that have all the vowels on one hand.

10.9.1 Consonant index (+ vowels on middle, ring and pinky)

OE UI A

Canary (Eve)

```
w l y p k   z x o u ;
c r s t b   f n e i a '
 j v d g q   m h / , .
```

OA UE I

Sturdy (Oxey)

```
v m l c p   x f o u j
s t r d y   . n a e i
 k q g w z   b h ' ; ,
```

UE OA YI

Rollla (Tanamr & Heart)

```
y o u b .   x k c l v
i a e n ,   m h s r t
 ' / p w z   f d g j q
```

UI OA E

Saiga E (RusDoomer)

```
; o u r q   f d l b w
e a i n x   y h t s c '
/ . , j z   k p m v g
```

The following are reasons in favor of utilizing a consonant index:

- **If we want to use setups like NH + vowels** (e.g. Canary, Sturdy) **or NR + vowels** (e.g. Saiga), as we would not want to have let's say both N and H on a pinky.

- Index fingers play a key role on keyboard layouts, as they are assigned six keys each (rather than 3). **If we want to minimize SFBs and SFSs, it is ideal to reserve both indexes for consonants**, as there are many useful six-consonant combinations.

- Compare these two redirects: pinky → index → middle vs pinky → middle → ring. Redirects like the second where the index finger is not utilized are referred to as "weak" or "bad" redirects and are considered trickier to type.

  So, **if we want to minimize redirects typed with pinky, ring and middle** (i.e. weak redirects) **all we have to do is place the vowels on those three fingers**. This drastically reduces weak redirects because vowel only trigrams are very rare.

10.9.2 Consonant pinky/ring (+ vowels on ring/pinky, middle and index)

YI OE UA

[Engram](#) (Arno Klein)	[Mtgap](#) (Michael Dickens)
b y **o** u ' " l d w v z	y p **o** u j k d l **c** w
c **i** **e** **a** , . **h** **t** **s** **n** q	**i** **n** **e** **a** , m **h** **t** **s** **r**
g x j k - ? **r** m f p	q z ' . : b f g v x

The following are reasons in favor of utilizing a consonant pinky/ring:

- **If we want the vowel ring to have low use.** The vowel blocks right above lead to ring column like YI or PN (around 9% usage). By comparison, most of the setups in the previous page had either an OA or UE ring (15% use).

- **If we want to utilize the IY OE UA vowel block**. The point of this setup is to turn **OU** and **EA** into in-rolls. In order to do so, a consonant pinky/ring is required, as the middle and index fingers are needed for the OE and UA columns, respectively.

  The IY OE UA vowel block also helps with lowering center column use. Note that lowering the center column use too much has the drawback of more letters being pushed towards the pinky corners (see Engram).

11. Consonant blocks (7 min)

11.1. Consonant patterns

Intuitively, one may think that there is a huge amount of valid consonant arrangements in keyboard layouts. However, **the number of good consonant columns** (i.e. columns with moderate SFB & SFS distance) **is limited**.

Furthermore, **columns usually come in pairs, or even trios.** For instance, if a layout has a **HRL** column, then a **DTM** column becomes very likely. For example, the following three layout all share a **LRH + DTM** setup:

Noctum (Oxey)	**Flow** (Ec0vid)	**Engram** (Arno Klein)
b f d l z j g **o** u ,	v p **h** m z j f **o** u '	b y **o** u ' " l d w v z
n s t r k y **c a e i**	**s n r t** x y **c e i a**	**c i e a** , . **h t s n** q
v m **h** x q p w ' ; .	b l d k q g w " . ,	g x j k - ? **r** m f p

Recurring column patterns like the above can be referred to as a "consonant block". **These are, along with vowel blocks, the foundation around which to build a layout.** We will divide consonant blocks into four main groups: with a HN column, with a HR one, with RN, or with neither one. Each of these will then be split into a few subcategories.

11.2. HN stack (most popular)

Excluding rare letters, **the letters that cause the least SFBs when added to an HN column are, in order: B, M, F, L & P.** Having said that, some of these letters cannot share a column among themselves. For instance, P and B should not share a column with L (**PL** & **BL** SFBs), or with M (**MP** & **MB** SFBs), and F should not be with L (**LF** & **FL** SFBs).

In order to avoid these SFBs, we first have to decide between a **HNB, HNM or HNL column**. The first two would be paired with a **LR column** on another finger, but the third is usually paired with a **WR column** instead. Overall, the most popular option is using **a FNHPB index** finger, while having a LR ring or middle.

LR + HNB

Semimak JQ (Semi)
f l **h** v z ' w u **o** y
s r n t k **c** d **e a i**
x j b m q p g , . /

Sturdy (Oxey)
v m l **c** p x f **o** u j
s t r d y . **n a e i**
k q g w z b **h** ' ; ,

Stronk (Oxey)
f d l b v j g **o** u ,
s t r n k y m **a e i**
q x **h** p z w **c** ' ; .

Wave (Ec0vid)
v l d m z ' w **o** u j
s r t n b y **c a e i**
x k **h** p q g f . " ,

Rolly (Ec0vid)
y **o** u f j q m w l ,
i a e n b k **t s r c** '
; " **h** p z v d g x .

Isrt (Whorf)
y **c** l m k z f u , '
i s r t g p **n e a o** ;
v w d j q b **h** / . x

On Wave, the letter M is pressed with the middle finger, not the index (i.e. a DTMK column).

LR + HNM

Canary (Eve)
w l y p k z x **o** u ;
c r s t b f **n e i a** '
j v d g q m **h** / , .

Dhorf (Oxey)
v l **h** k q j f **o** u ,
s r n t w y **c a e i**
x m d b z p g ' ; .

Trendy (StronglyTyped)
k l **h** w ' x f **o** u q
t r n d b y **s a e i**
j m **c** p z g v **.** - ,

WR + HNL

Colemak DH (SteveP)
q w f p b j l u y ;
a r s t g m **n e i o** '
x **c** d v z k **h** , . /

Uciea pcrw (Philipp Kiefer)
p y u **o** - k m **h** b x q
c i e a , d **t n s r** w
z j ' . ; f g l v /

Norl (ClemenPine)
w **c** d l x k f **o** u ,
r s t h j g y **a e i**
z b m **n** q v p ' / .

11.3. HR stack

The only good option with a HR stack is a **HRL column. In such a setup, the letter R should be on the home row** (otherwise the **RL** SFB in words like **world** becomes 2U)**. The LRH column usually goes on the index finger, although it can go on middle as well:**

Noctum (Oxey)

```
b f d l z   j g o u ,
n s t r k   y c a e i
 v m h x q   p w ' ; .
```

With LRH on the left index, the **LR** SFB becomes a comfortable alt finger on standard keyboards (R with index, L with middle). Same applies to the **RK** and **LK** SFBs (R/L with middle, K with index). Additionally, the very common **TH** bigram becomes an inward roll. Finally, the common **STR** trigram is a 3roll.

Flow (Ec0vid)

```
v p h m z   j f o u '
s n r t x   y c e i a
 b l d k q   g w " . ,
```

With a HRL middle, we remove the **RK** and **LK** SFBs. However, the **LR** SFB is not a comfortable alt finger anymore, **TH** is now an out-roll, and **STR** becomes a redirect. Lastly, the letter L being on bottom row middle will add a few more scissors.

We should also decide which of N or S we want on pinky/ring:

- A BN pinky + a FSV ring (see Noctum). With N on pinky, pinky repeats will be lower (NN is noticeably less frequent than SS).
- A VS pinky + a PNB ring (see Flow). With S on pinky, we will reach a bit less to the top row pinky key (V is less frequent than B) but there are more repeats.

FSV + LRH

Noctum (Oxey)

```
b f d l z   j g o u ,
n s t r k   y c a e i
 v m h x q   p w ' ; .
```

Nstd (Oxey)

```
b f m g p   z l o u ,
n s t d y   j r a e i
q v k c w   x h ' ; .
```

Engram (Arno Klein)

```
b y o u '   " l d w v z
c i e a ,   . h t s n q
g x j k -   ? r m f p
```

PNB + LRH

Santa (Oxey)

```
v p d l j   q w o u ,
s n t r k   y c a e i
 b m h x z   g f ' ; .
```

Sntm (Oxey)

```
v p d g w   q l o u ,
s n t m y   x r a e i
z b k c f   j h ' ; .
```

Flow (Ec0vid)

```
v p h m z   j f o u '
s n r t x   y c e i a
 b l d k q   g w " . ,
```

Most layouts with LRH will have **a DTM column** (and if not that, DTK or MTK).

11.4. RN stack

As seen in the previous section, with a HR pair we would make a HRL column (R on the home row, one of H or L on top row, and the other on bottom row). Since H and L cause few SFBs and SFSs with one another, we can place them two rows apart.

However, **a RNL column will usually be avoided**. The issue with RNL is that, since both R and N actually combine with L a decent amount, we do not want either of them to be two rows apart from L. Technically, this could be solved by placing L on the center column, but that would in turn introduce LSBs. To sum up, RNL either means 2U SFB/SFSs or LSBs.

Instead, the RN column is usually completed with rare letter only (i.e. X, J, Q, Z). One very rare exception is a **NRB column**. This works because the letter B doesn't combine with N, meaning we only need R and B to be right next to each other.

Anyway, RN may appear on any finger other than on pinky.

LH or LHM + RN

Whix2 (Ec0vid)

```
b l n d k   ' f o u j
s h r t w   y c a e i
 q x m v z   p g . " ,
```

Seht Drai (Tanamr)

```
f u l v b   q g n o j
s e h t k   ' d r a i .
 ; m p w z   y c x / ,
```

Recurva (Brys)

```
f r d p v   q j u o y
s n t c b   . h e a i
z x k g w   m l ; ' ,
```

Although we usually see either a LHM middle (Seht Drai) or index (Recurva), it is technically possible to make a LH ring as well (Whix2).

LTM + RN

Saiga (RusDoomer)

```
. o u r q   f d l b w
i a e n x   y h t s c '
, ; / j z   k p m v g
```

Inrolly (Ec0vid)

```
y o u q x   k d l w ,
i a e n j   v h t s c '
 " - r b z   f p m g .
```

LS + RN

Pine (ClemenPine)

```
y l r m k   q f o u ,
c s n t g   b h a e i
j x z w v   p d ' / .
```

Putih (Lela)

```
m l r p k   q y o u ,
h s n t v   f c a e i
 z x d b j   g w ' / .
```

Kuntum (Lela)

```
v l n d k   j w o u ,
t s r h f   g c a e i
 z x p b '   m y q / .
```

11.5. Without HN, HR or RN

Here we look at setups without any of three main consonant stacks. A side effect of this is that **the letter C will necessarily be on the S column**. This is different from most of the layout in the previous pages, as those avoided the SC SFB. Anyway, the **CS column** is usually completed with one or more of: V, W, G or F.

LR + CS

Graphite (StronglyTyped)
```
b l d w z  ' f o u j ;
n r t s g  y h a e i ,
q x m c v  k p . - /
```

Wreathy (Eve)
```
q g d f v  j l u o ,
n s t h y  w r e a i ;
b c m p k  z x / ' .
```

Rollla (Tanamr & Heart)
```
y o u b .  x k c l v
i a e n ,  m h s r t
 ' / p w z  f d g j q
```

Technically, some Colemak-like layouts also use both a LR and CS pair. However, those layouts also used the NH pair, while these layouts do not.

LN or LNM + CS

APT (Eve)
```
w g d f b  z l u o y
r s t h k  j n e a i ;
 c m p v q  x , . ' /
```

Vylet (Acas)
```
w c m p b  x l o u j -
r s t h f  y n a e i ,
q v g d k  z / ' ; .
```

Hands Down Neu (Alan reiser)
```
w f m p v  / . q " ' z
r s n t b  , a e i h j
x c l d g  - u o y k
```

LHM + CS

APT v4 (Eve)
```
w g d l v  j y o u '
r s t h k  p n e i a
x c b m q  z f , . /
```

Snorkle (Untwo)
```
. a y c j  q d l u x
i o n s b  p t h e r
, ' f g v  k w m ; z
```

LTM + CS

Ctgap (Colby)
```
q p l c j  x f o u /
r n t s g  y h e i a
z b m w v  k d ' , .
```

List of layouts plus their stats

12. Layout subgroups (8 min)

12.1. Classifying layouts

Because of the sheer number of layouts, it is very difficult to decide which layout to learn when looking at layouts as a whole. To help us with this issue, **we will separate layouts into five main categories**:

- **Colemak-like**: Self explanatory.
- **In-roll**: Layouts that favor rolls going toward the center of the keyboard.
- **High roll-mid redirect**: Layouts that increase rolling without sacrificing redirects.
- **3 roll**: Layouts that not only want to increase 2rolls, but 3rolls as well.
- **Alternation**: Layouts that favor alternation over rolling.

Inside a given category, layouts will be further subdivided according to which consonants they place on the vowel hand. For example, high roll - mid redirect layouts can be split into two main subgroups: NH + vowels and HML + vowels.

These subcategories can then be split again based on the home row on the consonant side. For instance, the aforementioned NH + vowels subgroup has four main home rows to choose from: CRST, STRD, SRTD and SRTC.

Finally, we can also classify the home rows based on which letter columns they use. For instance, the CRST home row leads to double stack layouts (i.e. OE/OA column + NH column) with a C pinky, while STRD, SRTD and SRTC lead to layouts with a C index instead.

Later in this document, each of the five main categories will get their own chapter. There we will establish how to construct each layout type and highlight its benefits. Additionally, we will also be listing plenty of layout examples for each category, including their stats.

12.2. Layout stat table

When comparing layouts, we will first show each layout in a text format. The top consonants will be highlighted in red and the vowels in green. The letter C will also be highlighted (in black) because of its importance in layout structure. Here is an example:

Noctum (Oxey)	Mtgap (Michael Dickens)	Isrt (Whorf)
b f d l z j g **o** u , **n s t r** k y **c** **a e i** v m **h** x q p w ' ; .	y p **o** u j k d l **c** w **i n e a** , m **h t s r** q z ' . : b f g v x	y **c** l m k z f u , ' **i s r t** g p **n e a o** ; v w d j q b **h** / . x

Afterward, the stats will be compiled on a table, as such:

	SFB	SFS	Scissors	Alt	Roll	Redir	In:out-roll	Pinky off	Hand use
Noctum	Very low 0.550	Very low 5.556	Mid low 0.26	High 41.1	Mid low 43.3	Low 4.1	Low 1.5	Mid 4.5	Even 48 – 52
Mtgap	Mid 1.048	Mid 6.661	Low 0.23	Mid high 37.2	Mid 45	Mid low 5	Mid low 2	Mid 5.1	Even 51 – 49
Isrt	Very low 0.599	Mid low 6.484	Very low 0.12	Mid low 31.4	Very high 49.6	High 8.9	Min 0.8	Low 3.5	Even 48 – 52

You should already be familiar with most of these stats. The "**in:out-roll**" stat is the result of dividing the number of in-rolls and out-rolls in a layout. In other words, it tells how much a layout favors inward rotation. The "**pinky off**" stat tells us how often our pinky has to move off the home row and press a key on the top or bottom row.

If a layout performs great in one stat, then that stat will appear in green. If the layout performs decently, then we will use yellow. If it performs poorly, then red. Most stats are shown in green when they are low (SFB, SFS, Scissors, Redir and Pinky off). However, alternation, rolls and in:out-roll will be shown in green when they are high. Lastly, hand usage gets worse the furthest away it is from even.

Note that a layout having more stats in green does not necessarily make it better than another. That would only be true if all the stats were of the same importance. On the contrary, **how each stat is valued will vary from person to person**. For example, if someone likes high alternation, they will likely discard any layout that fails to optimize said stat. Meanwhile, others might focus on the rolling or pinky off stats instead. Some people prefer layouts with a high in:out-roll ratio, while others disregard that stat entirely. In any case, the minimum requirement for a layout is that it performs decently at SFBs and SFSs.

12.3. How the stats were obtained

The SFB, SFS, alt, roll and redir stats were taken from the Genkey analyzer. Since Genkey does not give the remaining stats, those were obtained elsewhere. **The scissor stat comes from keysolve. The in:out roll** (i.e. in-roll ratio) **and hand use stats are from a200**. For the pinky off stat a simple tool was used to check the frequency of the characters that each layout places on the top and bottom row pinky positions.

The corpus used with all the analyzers was MonkeyRacer (a combination of the quotes on MonkeyType and TypeRacer, but removing the duplicates). The reason for utilizing this corpus is that MonkeyType and TyperRacer are popular typing websites. A peculiarity of the MonkeyRacer corpus is that punctuation (period, comma and apostrophe) play a bigger role than in other corpora. Additionally, since the most frequent English words are also heavily represented in the corpus, letters like W and Y become more common.

12.4. Stats thresholds

For full transparency, in this section we list the ranges that were utilized in order to place each stat in the "**low**", "**mid**" or "**high**" categories.

Stats that one may want to maximize (i.e. alternation, rolling and in:out-roll) **can be referred to as positive. For these, the full range for each stat was used.** This means that we checked what was the lowest and highest point for a given stat, and then evenly split the "**Min**" to "**Max**" categories across that range. It should be noted that the most extreme values require ruining key stats like SFBs, so those values were excluded.

In the table below, each cell indicates the highest value for a given category. For instance, 38.3 alternation qualifies as "**Mid high**", but anything past that counts as "**High**" (until 41.2).

	Min	Very low	Low	Mid low	Mid	Mid high	High	Very high	Max
Alt	23.9	26.8	29.7	32.6	35.4	38.3	41.2	44.1	47
Roll	37.8	39.7	41.5	43.3	45.2	47	48.8	50.6	52.5
In:out-roll	0.8	1.2	1.7	2.1	2.6	3	3.5	3.9	4.4

Stats that we usually want to minimize (i.e. SFB, SFS, Scissors, Redir and Pinky off) **can be referred to as negative. For these, we use a limited range for each stat.** If we did otherwise, the categories below would lose most of their usefulness. For example, although we could potentially make a layout with 20% SFB, there is never a need to make a layout with SFBs anywhere that high. The drawback with not being able to use the full range for these later stats is that the values chosen are intrinsically subjective. Regardless, most people should be satisfied when they see the results from using these ranges:

	Min	Very low	Low	Mid low	Mid	Mid high	High	Very high	Max
SFB	0.525	0.625	0.735	0.875	1.075	1.375	–	–	–
SFS	5.3	5.7	6.1	6.5	6.9	7.3	–	–	–
Scissors	0.1	0.15	0.25	0.35	0.45	0.55	0.7	–	–
Redir	2.8	3.6	4.5	5.4	6.2	7	9	–	–
Pinky off	1.8	2.7	3.5	4.3	5.2	5.9	6.8	–	–

Finally, hand balance is counted as **even** until a 52-48 split. Up to 55-45 it counts as **leans left/right**, and past that it counts as **heavy left/right**.

12.5. Hand balance nuances

As already explained earlier in this document, most layouts nowadays will place all the vowels on one hand. Doing this helps with minimizing long same hand sequences and redirects, in addition to improving rolling. The three main punctuation symbols will often go on the vowel hand as well, as vowels and punctuation usually share a column. Having the vowels plus punctuation together already adds up to around 40% usage on that hand.

A consequence of the above is that, **in layouts that dedicate a hand for the vowels, being strict with hand balance often results in too much finger movement being concentrated on the consonant hand.** For example:

```
w g d f v  j l u o ,
n s t h y  q r e a i ;
b c m p k  z x / ' .
```

The main flaw with this layout is that movement is not evenly distributed. This would be particularly noticeable in contexts where punctuation is often omitted (for example, when chatting). While the fingers on the vowel hand would not move much, the ones on the consonant hand would jump all over the place.

Another potential drawback with hand balance is that it can lead to the vowel side's index finger being underutilized, while weaker fingers take that extra load. For instance, the earlier layout had a LR left index, yet it had WNB pinky and a GSC ring.

As long as we design layouts adequately, it is possible to make layouts that approach a 50-50 hand split yet still avoid the aforementioned issues. The main examples are C + vowel setups like Noctum (see below). Regardless, the most common approach is to be more lenient with hand balance, and have a split of about 45-55. An example would be Pine. There are popular layouts that go even further, like Sturdy, which has a 43-57 split:

Noctum (Oxey)

```
b f d l z  j g o u ,
n s t r k  y c a e i
 v m h x q  p w ' ; .
```

Pine (ClemenPine)

```
y l r m k  q f o u ,
c s n t g  b h a e i
j x z w v  p d ' / .
```

Sturdy (Oxey)

```
v m l c p  x f o u j
s t r d y  . n a e i
 k q g w z  b h ' ; ,
```

Throughout this document we will purposely avoid layouts that achieve hand balance by greatly underutilizing (i.e. having minimal movement on) the vowel side's index finger.

13. Colemak-like layouts (4 min)

13.1. Colemak

Colemak is basically the “mainstream” alt layout. Technically, there is also Dvorak, but Dvorak was designed before the rise of computers, and is therefore quite flawed.

Colemak (Shai Coleman)
```
q w f p g  j l u y ;
a r s t d  h n e i o '
z x c v b  k m , . /
```

Colemak was designed around a few key principles:

- Maximizing home row usage.
- Concentrating effort on the indexes.
- Minimizing pinky movement.
- Favoring rolling.

	SFBs	SFSs	Scissors	Alt	Rolls	Redir	In:out-roll	Pinky off	Hand use
Colemak	Mid high 1.198	High 7.462	Mid 0.37	Low 29.6	Mid high 46	Very high 12.1	Very low 1	Min 1.23	Hard right 44 – 56

The main reason Colemak’s stats do not look very impressive is that Colemak was made in 2006. Since then, keyboard layout analyzers have dramatically improved.

Additionally, the way some stats are defined has changed. For example, the **io** bigram used to always count as a roll on Colemak. However, nowadays there is more nuance to it. On the word **radio**, we indeed count **io** as a roll, but **io** often appears in the **ion** trigram, and that is a redirect on Colemak, not a roll. So, we can see how the redirect concept being introduced has led to Colemak receiving fewer rolls.

Similarly, the SFS concept did not exist back when Colemak was designed, which explains why the layout performs poorly in that aspect. Other concepts like SFBs, even if they did exist, have been optimized much further with the help of modern analyzers. In any case, **Colemak remains a very popular layout, even today.**

13.2. Colemak-like arrangements

13.2.1. HNLM index + 4 vowels

First we look at layouts that maintain Colemak's columns (i.e. the **HNLM index**, the **WR ring**, etc...). In other words, the layouts below are slight Colemak mods.

ARST

Compared to standard Colemak, all these variants move H and D off the center column. Additionally, some remove the **E → comma** SFB, or the **NK/KN** SFBs. Lastly, ColemaQ F removes the **G_T** SFS.

Colemak DH (SteveP)
q w f p b j l u y ;
a r s t g m **n e i o** '
x **c** d v z k **h** , . /

ColemaQ (Nyfee)
; w f p b j l u y q
a r s t g m **n e i o** '
x **c** d k z v **h** / . ,

ColemaQ F (Nyfee)
; w g p b j l u y q
a r s t f m **n e i o** '
x **c** d k z v **h** / . ,

	SFB	SFS	Scissors	Alt	Roll	Redir	In:out-roll	Pinky off	Hand use
Colemak DH	Mid high 1.177	High 7.483	Mid 0.37	Low 29.6	Mid high 46	Very high 12.1	Very low 1	Min 1.2	Hard right 44 – 56
ColemaQ	Low 0.728	High 7.541	Very low 0.14	Low 27.7	Mid high 46.9	Very high 13.6	Very low 1	Very low 2.4	Hard right 44 – 56
ColemaQ F	Mid low 0.832	Mid high 7.033	Very low 0.14	Low 27.7	Mid high 46.7	Very high 13.5	Very low 1	Very low 2.4	Hard right 44 – 56

13.2.2. FNHPB index + 4 vowels

The HNLM index in all the previous Colemak variants has the issue of concentrating a lot of movement (i.e. SFB + SFS distance) on that finger. **Here we use a FNHPB index instead, while the letter L is moved to a LR ring.** These changes have multiple advantages:

- Movement on the right index is greatly reduced.
- The SFSs in the layout decrease by a lot.
- Alternation, redirects and hand balance all improve a bit.

ARST / ARTS

Colemak Qi (Nyfee)
q l w m k j f u y '
a r s t g p **n e i o**
x **c** d v z b **h** , . /

Colemak Qi;x (Nyfee)
; l **c** m k j f u y q
a r s t g p **n e i o** '
x w d v z b **h** / . ,

Arts (ClemenPine)
q l d g v j f u y '
a r t s w p **n e i o**
z x m **c** b k **h** ; , .

	SFB	SFS	Scissors	Alt	Roll	Redir	In:out-roll	Pinky off	Hand use
Colemak Qi	Mid 0.945	Mid low 6.373	Mid high 0.52	Mid low 32.2	Mid high 45.6	Very high 10.4	Very low 1	Min 1.1	Leans right 47 – 53
Colemak Qi;x	Low 0.732	Mid low 6.210	Very low 0.13	Mid low 32.1	Mid high 45.9	Very high 10.5	Very low 1	Very low 2.4	Leans right 47 – 53
Arts	Mid 1.029	Low 5.759	Min 0.08	Mid low 32.5	Mid 45.1	Very high 10.2	Very low 0.9	Very low 2.6	Leans right 47 – 53

The following layouts differ from Colemak further. They aim to improve on Colemak's SFBs, SFSs, rolls and redirects. However, some concessions have to be made in return. Namely, the pinky movement will increase.

CSV ring + LRW middle

Isrt (Whorf)
y **c** l m k z f u , '
i s r t g p **n e a o**
v w d j q b **h** / . x

LR ring + CSG middle

Irst (Ec0vid)
y l **c** m k z f u , '
i r s t w b **n e a o**
j g d v q p **h** " . x

	SFB	SFS	Scissors	Alt	Roll	Redir	In:out-roll	Pinky off	Hand use
Isrt	**Very low** 0.599	**Mid low** 6.484	**Very low** 0.12	**Mid low** 31.4	**Very high** 49.6	**High** 8.9	**Min** 0.8	**Low** 3.5	**Even** 48 – 52
Irst	**Very low** 0.602	**Low** 5.780	**Very low** 0.14	**Mid low** 31.4	**Very high** 49.6	**High** 8.7	**Very low** 0.9	**Low** 3.5	**Even** 48 – 52

Main **changes compared to Colemak**:

- the IY column is moved to the consonant hand, rather than A being there. Consequently, rolls increase while redirects decrease (the **YOU** and **ION** trigrams are not redirects anymore). The drawback is that Y is now on top row pinky.
- Punctuation no longer causes SFBs, as we have a ,A. ring (therefore avoiding Colemak's **Y → period** 2U SFBs, and also the **E → comma** SFB).
- Movement on the right index is drastically reduced, thanks to using FNHPB over HNLM. It is recommended to put P next to H (see Irst) to improve **PH**.
- Different ring + middle setup. Isrt uses **CSV + LRW**. Although **LRW** is a high movement column, it allows us to get the letter L off the ring finger. Alternatively we can use **LR + CSG** (Irst) if we want to optimize SFSs instead.

14. Inward rotation layouts (18 min)

14.1. In-rolls & out-rolls

- **Inward rolls** go towards the index finger. E.g. Qwerty **DF** (middle → index).
- **Outward rolls** go towards the pinky. E.g. Qwerty **FD** (index → middle).

Some people prefer in-rolls over out-rolls, while others do not mind either way. One of the arguments often utilized in favor of in-rolls is that it is easier to smoothly roll our fingers on a table in the direction pinky → ring → middle → index, rather than the other way around.

When optimizing for in-rolls we are restricted on which home rows we can use. For example, a RSTH home row works great for in-rolls, but SHRT does not. **Similarly, we must also avoid using certain letter columns.** For instance, the popular NH column stops being an option. Not having certain columns available results in in-roll layouts having higher SFBs on average.

Additionally, **more letters are pushed toward the pinky corners when favoring in-rolls**. Because of this, it may be preferable to settle for arrangements that give up a bit of inward rotation, in order to avoid the pinkies being too heavy (e.g. a PNB pinky, E being on pinky...).

To sum up, there are multiple concessions that have to be made in order to design an inward rotation layout. Whether the in-rolls are worth those trade-offs or not is subjective.

14.2. How to arrange the vowels for in-rolls

YI OE UA vowel block

Hieamtsrn (Sasha Viminitz)

```
b y o u '   k d c l p q
h i e a ,   m t s r n v
x ( ) . ?   w g f j z
```

The OE and UA columns must be placed on the middle and index fingers respectively, in order to make the **OU** bigram (on the top row) and the **EA** bigram (on the home row) both in-rolls. Furthermore, punctuation being on the index finger makes **E → comma/period** and **I/E → apostrophe** inward.

With this setup, the consonants on the vowel side (e.g. **H**) must go on pinky. Therefore, **this vowel arrangement is ideal for consonants that roll as consonant → vowel** since, by placing them on pinky, their bigrams will be inward (e.g. rolls like **HE**, **HA** or **HI**).

YI OA UE, I OA UE & E OA UI vowel blocks

APT (Eve)

```
w g d f b   q l u o y
r s t h k   j n e a i ;
X c m p v   z , . ' /
```

Wreathy (Eve)

```
q g d f v   j l u o ,
n s t h y   w r e a i ;
b c m p k   z x / ' .
```

Mir (RusDoomer)

```
j o u r q   f d l b g
e a i n x   y h t s c '
/ . , z ;   k p m v w
```

On the vowel side, it is now the index finger that is free for consonants (e.g. **N** and **R**). So, **these vowel arrangements are ideal for consonants that roll as vowel → consonant** since, by placing them on index, their bigrams will be inward (eg. rolls like **IN**, **AN** or **EN**...).

Of the three vowel blocks right above, the third has the highest inward rotation as it is the only one where both the **OU** and **EA** bigrams are inward rolls. However, that vowel block requires placing E (the most frequently used letter in the English language) on a pinky.

14.3. How to arrange the consonants for in-rolls

As a whole, the consonants roll with the vowels in both directions about equally:

- **consonant → vowel** bigrams (e.g. NE) amount to **35.5%** of all bigrams.
- **vowel → consonant** bigrams (e.g. EN) amount to **36.1%** of all bigrams.

However, **there are a few consonants that heavily favor one direction vs the other**. Those are the consonants we will be focusing on in-order to make inward rotation layouts.

14.3.1. Consonants on the vowel hand

The table below shows the direction each consonant favors with the vowels (consonant → vowel vs vowel → consonant). The table is sorted based on the ratio, which is the result of dividing the first two columns (the higher number is divided by the smaller one):

	c→v	v→c	Favored direction	ratio
h	**5.322**	**0.064**	**H → vowel**	**83.2**
n	**1.921**	**8.025**	**Vowel → N**	**4.18**
w	1.343	0.508	W → vowel	2.64
b	1.209	0.541	B → vowel	2.23
s	**2.409**	**4.083**	**Vowel → S**	**1.69**
p	1.391	0.824	P → vowel	1.69
k	0.338	0.233	K → vowel	1.45
v	1.308	0.929	V → vowel	1.41
y	0.288	0.402	Vowel → Y	1.4
f	1.269	1.634	Vowel → F	1.29
r	**4.123**	**5.258**	**Vowel → R**	**1.28**
m	2.127	1.661	M → vowel	1.28
c	2.428	1.978	C → vowel	1.23
d	1.746	2.118	Vowel → D	1.21
g	0.903	0.801	G → vowel	1.13
t	**4.374**	**3.87**	**T → vowel**	**1.13**
l	2.503	2.761	Vowel → L	1.10

** table data: Norvig*

Among the highlighted top consonants, **H & N are by far the most one directional.** The letter H is better at minimizing out-rolls (it has a 83.2 ratio) while N can reach higher overall in-rolls (vowel → N is around 8% of all bigrams, while H → vowel is around 5%). Since H and N roll in opposite directions, their ideal location is different. **On the vowel hand**:

- **H should go on the pinky** (to make **HE, HA, HI** and **HO** inward) **and we should pair it with the YI OE UA block** (as that vowel setup leaves the pinky free for H).

- **N should go on the index** (to make **IN, AN, ON** & **EN** inward) **and we should pair it with the YI OA UE, I OA UE** or **E OA UI blocks** (as they free the index for N).

14.3.2. Consonants on the consonant hand

The table below shows the direction each consonant favors when combining with the rest of the consonants (consonant → rest vs rest → consonant). The table is sorted based on the fourth column (the ratio):

	c→rest	rest→c	Favored direction	ratio
v	0.009	0.185	cons → V	20.6
h	**0.349**	**5.214**	**cons → H**	**14.9**
n	**4.764**	**0.515**	**N → cons**	**9.25**
y	0.232	1.501	cons → Y	6.47
d	0.445	1.868	cons → D	4.2
b	0.634	0.166	B → cons	3.82
w	0.558	0.159	W → cons	3.51
k	0.134	0.33	cons → K	2.46
c	1.639	0.866	C → cons	1.89
g	0.684	1.128	cons → G	1.65
p	1.166	0.736	P → cons	1.58
f	0.525	0.341	F → cons	1.54
t	**4.982**	**3.638**	**T → cons**	**1.37**
m	0.61	0.504	M → cons	1.21
r	**2.257**	**1.933**	**R → cons**	**1.17**
l	1.725	1.745	cons → L	1.01
s	**2.418**	**2.384**	**S → cons**	**1.01**

** table data: Norvig*

Yet again, among the top consonants, **H & N are the most one directional.** Interestingly, the direction each one favors has been flipped when compared to the previous table. So, **on the consonant hand:**

- **H should go on the index**, to make **TH, CH, WH, SH** and **GH** inward.
- **N should go on the pinky** (or ring), to make **ND, NT, NG, NS** and **NC** inward.

Other bigrams we want as inward if possible are: **ST, PR, CT, LY, LD, TR, RS, PL, MP, RY...**

14.3.3. N & H on separate hands

If we want the in-rolls in a layout to be evenly split across both hands, we should place N on one hand and H on the other. Otherwise, the hand with both H and H will do a much better job at maximizing in-roll and minimizing out-rolls than the other hand.

14.4. Avoiding a NH column

As we have established, N and H roll in opposite directions. This means that if we place them on the same finger, it becomes impossible to optimize in-rolls for both. To visualize this, we will use a couple examples of layouts that disregard inward rotation:

Sturdy (Oxey)

```
v m l c p   x f o u j
s t r d y   . n a e i
 k q g w z   b h ' ; ,
```

Although Sturdy has lots of rolling there is not a net in-roll gain. This is because the in-rolls (all the vowel → N bigrams) are offset by the out-rolls (all the H → vowel bigrams).

Stronk (Oxey)

```
f d l b v   j g o u ,
s t r n k   y m a e i
 q x h p z   w c ' ; .
```

On Stronk the letter H leads to some key in-rolls (TH, SH) but the letter N causes some very common out-rolls (ND, NT, NS)

If we want to maximize in-rolls, then H and N should be placed on different fingers, as such:

Hyperroll (Semi)

```
p c l m v   x u o y f
n s r t d   . a e i h
b g ' w z   / , q j k
```

Hyperroll has the H → vowel bigrams as in-rolls, in addition to the N → consonant bigrams as well.

Vylet (Acas)

```
w c m p b   x l o u j -
r s t h f   y n a e i ,
q v g d k   z / ' ; .
```

Vylet has the vowel → N bigrams as in-rolls, plus the consonants → H bigrams.

Wreathy (Eve)

```
q g d f v   j l u o ,
n s t h y   w r e a i ;
b c m p k   z x / ' .
```

Wreathy has the N → consonant bigrams as in-rolls and the consonants → H bigrams too.

As we can see, **inward rotation layouts should not use an NH column**. Note that, in layouts that disregard inward rotation, the NH column will be a very popular option.

14.5. In-roll ratio

The in-roll ratio stat tells us how much a layout favors inward over outward rolls. To calculate it, we simply divide a layout's in-roll percent by its out-roll percent. For example, if a layout has 38.5% in-rolls and 14.1% out-rolls, then the in-roll ratio would be:

> 38.5 / 14.1 = 2.7 in-rolls per out-roll

The **in:out-roll** column shows the in-roll ratio for a given layout:

	SFB	SFS	Scissors	Alt	Roll	Redir	In:out-roll	Pinky off	Hand use
Hyper roll	Mid 0.966	Low 5.783	Mid 0.45	High 39.3	Mid high 45.3	Very low 3	Max 4.2	High 6	Even 49 – 51

The layouts with the most in-rolls are those that have high overall rolls, while also maintaining a good in-roll ratio. For example:

	SFB	SFS	Scissors	Alt	Roll	Redir	In:out-roll	Pinky off	Hand use
Saiga	Low 0.702	Min 5.159	Very low 0.14	Low 29.3	Max 52.4	High 7.5	Mid high 2.8	Very high 8.3	Leans left 53 – 47

14.6. Out-rolls vs alternation

Not all trigrams in a layout can be in-rolls. In fact, a significant part of trigrams will have to be either out-rolls or alternates. Depending on which of those two we favor, we will get a different type of in-roll layout:

- **If we want to minimize out-rolls, we must replace them with alternation**. This results in alternation heavy layouts, which have the highest in-roll ratio (**Hyperoll**).
- **If we want to reach higher rolling, then some of the rolls have to be out-rolls**. Consequently, we get a rolling layout, but with a lower in-roll ratio (e.g. **Saiga**).

14.7. Layout arrangements for in-rolls

For more info on the layouts below, run them through the Keysolve web tool. That way you will get a nice heatmap of the layout, in addition to its lateral stretch and scissor stats. If you need help utilizing Keysolve, you can find it on the Keysolve github page.

14.7.1. H + vowels

These layouts have H on the vowel hand and N on the consonant hand, both on pinky. They are 1 vowel stack layouts (i.e. they have an **OE/OA column**, but not a NH/RH/RN one). Finally, they have high alternation and mid rolls.

NRST / NSRT / NRTS / RSNT...

The NRST & NSRT home rows have the highest in-roll ratio (up to 4.5). However, they result in heavier pinkies (e.g. a PNB or PNV pinky).

Hieamtsrn (Sasha Viminitz)

```
b y o u ' k d c l p q
h i e a , m t s r n v
x ( ) . ? w g f j z
```

Hyperroll (Semi)

```
p c l m v x u o y f
n s r t d . a e i h
b g ' w z / , q j k
```

Heyyou (ClemenPine)

```
f y o u z q k l c b
h i e a , m t r s n
j x / . ' g d w v p
```

	SFB	SFS	Scissors	Alt	Roll	Redir	In:out-roll	Pinky off	Hand use
Hieamtsrn	Mid low 0.872	Mid 6.705	Very low 0.15	Very high 41.4	Mid 44.3	Min 2.5	Max 4.4	Mid 4.4	Even 50 – 50
Hyperroll	Mid 0.966	Low 5.783	Mid 0.45	High 39.3	Mid high 45.3	Very low 3	Max 4.2	High 6	Even 49 – 51
Heyyou	Mid 0.950	Mid 6.694	Min 0.05	High 40.8	Mid 44.9	Min 2.5	Max 4.1	Mid 5.2	Even 51 – 49

If we are willing to sacrifice some in-rolls, then there are other home rows we can use like NRTS or RSNT. With the former, the **ST** and **CT** bigrams become out-rolls (see Inrolly2). With the latter, **NS** and **NC** turn into out-rolls instead (see Hands Down Neu).

Inrolly2 (Ec0vid)

```
p l d w v ; u o y f
n r t s g . a e i h '
q m c b z x , " j k
```

Hands Down Neu (Alan reiser)

```
w f m p v / . q " ' z
r s n t b , a e i h j
x c l d g - u o y k
```

	SFB	SFS	Scissors	Alt	Roll	Redir	In:out-roll	Pinky off	Hand use
Inrolly2	Mid low 0.818	Low 5.792	Mid low 0.31	High 40.7	Mid 45	Mini 2.6	High 3.3	Mid high 5.4	Even 48 – 52
Hands Down Neu	Mid low 0.782	Mid high 6.950	Very high 0.71	Very high 41.9	Mid low 43.8	Very low 2.9	High 3.4	Mid 4.5	Even 50 - 50

14.7.2. NR + vowels

These layouts have N + R with the vowels and H with consonants, all on index. They have 2 stack (i.e. **OA column** + **RN column**) and high rolling (therefore low alternation).

CSTH

The CSTH home row (C on pinky) is the most common in this subgroup. The letter Y might be on either hand. The following variants place Y on the consonant hand:

Mir (RusDoomer)

```
j o u r q   f d l b g
e a i n x   y h t s c '
/ . , z ;   k p m v w
```

Saiga (RusDoomer)

```
. o u r q   f d l b w
i a e n x   y h t s c '
, ; / j z   k p m v g
```

Below we have some variants that move Y with the vowels instead. Doing this turns the **RY** bigram (plus **BY** on Inrolly) into outrolls, though.

Journey (RusDoomer)

```
y o u r q   k v d f g -
i a e n x   l h t s c '
/ . ; , z   j m p b w =
```

Inrolly (Ec0vid)

```
y o u q x   k d l w ,
i a e n j   v h t s c '
  " - r b z   f p m g .
```

Synth (ClemenPine)

```
w l g f k   / q u o y
c s t h b   x r e a i
j v m d p   z n ' , .
```

Mir has the highest in-roll ratio in this family (3.6), but to do so it requires a **E pinky** and a **WCG ' pinky**. By comparison, **Inrolly** sacrifices some in-rolls (2.2 ratio) in order to get lighter pinkies (**YI pinky** and **C + punctuation pinky**). Point being, everything has its trade-offs.

	SFB	SFS	Scissors	Alt	Roll	Redir	In:out-roll	Pinky off	Hand use
Mir	Mid low 0.766	Min 5.175	Mid high 0.46	Low 29.3	Max 52.3	High 7.6	Very high 3.6	Mid high 5.5	Leans left 53 – 47
Saiga	Low 0.702	Min 5.159	Very low 0.14	Low 29.3	Max 52.4	High 7.5	Mid high 2.8	Very high 8.3	Leans left 53 – 47
Journey	Mid low 0.759	Very low 5.385	Mid low 0.33	Low 29	Max 51	High 7.7	Mid 2.6	Very high 8.1	Leans left 55 – 45
Inrolly	Mid low 0.832	Min 5.160	Low 0.23	Very low 26.7	Max 52.3	High 8.2	Mid 2.2	High 6.4	Leans left 54 – 46
Synth	Mid low 0.855	Low 5.934	Mid low 0.26	Low 29.3	Very high 49.7	High 8.2	Mid 2.4	High 6.6	Heavy right 44 – 56

STHC

The STHC home row (C on index) sacrifices some in-rolls in favor of lower SFBs and a more standard pinky (a FS pinky). The loss in inward rotation comes from the **WH**, **CH**, **LD**, **GH** and **CT** bigrams becoming outrolls.

Rain (Ibrahimab)

```
, o u n q   v g l d f
i a e r b   y c h t s
. ' ; j x   w p m k z
```

Rainy (Ibrahimab)

```
y o u n q   ' w l d f
i a e r b   g c h t s
. , ; j z   p v m k x
```

	SFB	SFS	Scissors	Alt	Roll	Redir	In:out-roll	Pinky off	Hand use
Rain	**Min** 0.510	**Min** 5.085	**Mid** 0.45	**Low** 28.7	**Max** 52.1	**High** 8.1	**Mid low** 1.9	**Mid** 5.1	**Leans left** 55 – 45
Rainy	**Low** 0.690	**Min** 4.959	**Mid high** 0.50	**Low** 27.7	**Max** 51.2	**High** 8.4	**Low** 1.7	**High** 6.3	**Heavy left** 57 – 43

Technically, on CSTH or STHC layouts, the letter L could be moved to the left index, in order to make a **RNL column**. However, this is not recommended as it places the letters R and L far apart, creating 2U SFBs and SFSs. Anyway, here is an example of such a layout:

Xenia (RusDoomer)

```
, o u r q   j f d v g
i a e n x   y h t s c
. ' ; l z   k p m b w
```

14.7.3. N or NL + vowels

Compared to the previous subgroup, the letter R is moved back to the consonant hand. So, we do not have a NR stack anymore, only a vowel one (i.e. **OA/OE**).

RSTH

The RSTH home row is the most common in this subgroup. The letter Y is usually on the vowel hand, but it could be on the consonant side as well (see Apt v2.1). Similarly, the letter L also changes hands from one variation to another.

Mtgap (Michael Dickens)

```
y p o u j   k d l c w
i n e a ,   m h t s r
q z ' . :   b f g v x
```

APT (Eve)

```
w g d f b   q l u o y
r s t h k   j n e a i ;
x c m p v   z , . ' /
```

Vylet (Acas)

```
w c m p b   x l o u j -
r s t h f   y n a e i ,
q v g d k   z / ' ; .
```

APT v4 (Eve)

```
w g d l v   j y o u '
r s t h k   p n e i a
x c b m q   z f , . /
```

APT v2.1 (Eve)

```
w g d f v   q l u o ,
r s t h y   j n e a i ;
x c b p k   z m / ' .
```

These layouts are all slight variations of the same idea. All have a **WR** pinky. The ring may be **CSV or CSG**. On the middle finger we can have **DTB, DTM, MTG or LTG**. For the letter Y we might use the **IY, HY or NY** pairs. On the vowel hand, the letter N can go on either the ring (**Mtgap**) or the index (e.g. **Apt**). Having N on the ring leads to lower usage on that finger and better punctuation, but makes trigrams like **ION** and **INI** trickier to type

	SFB	SFS	Scissors	Alt	Roll	Redir	In:out-roll	Pinky off	Hand use
Mtgap	Mid 1.048	Mid 6.661	Low 0.23	Mid high 37.2	Mid 45	Mid low 5	Mid low 2	Mid 5.1	Even 51 – 49
APT	Mid 1.051	Very low 5.404	Mid high 0.54	Mid 34	High 47.4	Mid 6.2	Mid 2.3	Mid 5.2	Leans right 46 – 54
Vylet	Mid 0.890	Low 5.795	Low 0.17	Mid 34	High 47.8	Mid high 6.5	Mid 2.3	Mid high 5.7	Leans right 46 – 54
APT v4	Mid 1.048	Mid 6.656	High 0.68	Mid high 36	Mid high 46.3	Mid low 5.4	Mid low 1.9	Low 3.4	Leans right 46 – 54
APT v2.1	Low 0.643	Very low 5.622	Low 0.18	Mid low 30.8	Very high 50.1	High 8.3	Mid 2.3	Mid high 5.6	Leans right 46 – 55

TRSH

The TRSH home row sacrifices some inward rotation (we lose the **ST** and **WH** in-rolls) in favor of optimizing SFSs further. Additionally, the consonant hand's ring finger now has a LR column (rather than a CSV or CSG one).

Rolll (Semi)

```
y o u w b   x k c l v
i a e n p   d h s r t
j / , . q   f m g ' z
```

Rollla (Tanamr & Heart)

```
y o u b .   x k c l v
i a e n ,   m h s r t
' / p w z   f d g j q
```

	SFB	SFS	Scissors	Alt	Roll	Redir	In:out-roll	Pinky off	Hand use
Rolll	Mid high 1.155	Min 5.061	Mid 0.37	Mid 34.2	Mid high 46.5	Mid high 6.3	Mid low 1.9	Mid low 3.8	Leans left 55 – 45
Rollla	Mid 0.924	Min 5.157	Low 0.2	Mid 34.9	Mid high 46.4	Mid high 6.6	Mid low 1.8	Mid low 3.7	Leans left 55 – 45

14.7.4. LRW + vowels

Unlike all the prior groups, these layouts have both N and H on the same hand. This concentrates more in-rolls on that side. These are 1 vowel stack layouts (i.e. **OA/OE**).

NSTH

The NSTH home row is the most common in this subgroup:

Wreathy (Eve)
```
q g d f v   j l u o ,
n s t h y   w r e a i ;
b c m p k   z x / ' .
```

Wreath (Eve)
```
j g d f b   q l u o y
n s t h k   w r e a i ;
x c m p v   z , . ' /
```

Peppermint (ClemenPine)
```
b c g p k   / x u o y
n s t h f   w r e a i
q z v d j   m l ' . ,
```

The vowel hand can be modified to be IREA, resulting in a lighter ring finger and better punctuation, at the expense of some “weak redirects” (try **WIR** on **Wreathy** vs **Mtgap R**).

Mtgap R (Ec0vid)
```
y w o u '   k d l c p
i r e a .   m h t s n
j x q , ;   b f g v z
```

	SFB	SFS	Scissors	Alt	Roll	Redir	In:out-roll	Pinky off	Hand use
Wreathy	Low 0.679	Very low 5.496	Low 0.19	Mid low 31.4	Very high 50.1	High 7.7	Mid 2.3	Mid 4.7	Leans right 47 – 53
Wreath	Mid high 1.126	Very low 5.629	Mid high 0.54	Mid low 30.8	High 48	High 8	Mid 2.3	Low 3.1	Leans right 45 – 55
Pepper mint	Mid 0.939	Low 5.922	Low 0.24	Low 26.9	Very high 49.4	Very high 10.1	Mid low 2.1	Mid high 5.5	Heavy right 43 – 57
Mtgap R	Mid 0.967	Mid low 6.389	Low 0.17	Mid 34.5	Mid high 46.5	Mid 6	Mid low 2.1	Mid low 4.3	Even 51 – 49

As already explained, higher in-rolls would require having the letter E on pinky.

14.7.5. C + vowels

NSTH

Here we keep the prior NSTH home row, but now use it to make a high alternation layout (rather than a high rolling one). Additionally, while the prior NSTH setups had just one stack, now we need two (i.e. **OE column** + **HR column**) so that C can be on the home row:

Engram (Arno Klein)

```
b y o u '   " l d w v z
c i e a ,   . h t s n q
g x j k -   ? r m f p
```

	SFB	SFS	Scissors	Alt	Roll	Redir	In:out-roll	Pinky off	Hand use
Engram	**Mid high** 1.242	**Mid low** 6.294	**Mid low** 0.30	**High** 41.1	**Low** 41.5	**Low** 4.2	**Mid** 2.3	**High** 6.3	**Even** 49 – 51

Engram has particularly low center column use, but high pinky movement in return.

15. High roll - mid redirect layouts (18 min)

15.1. Rolls & redirects

- **Roll**: pressing 2 keys with one hand, and 1 with the other (e.g. **DFJ** on Qwerty).
- **Redirect**: a one-handed trigram in which the direction changes (e.g. **DFS** on Qwerty).

Generally, rolls are considered a comfortable hand pattern while redirects are seen as worse. So, **a desirable aspect would be having high rolls, yet low redirects.**

The issue is that increasing the former will do the same to the later. Having said that, while a certain amount of redirects is unavoidable, we can greatly reduce them by designing the layout adequately. In this chapter we go over how to do that.

Interestingly, we will find that the home row arrangements needed for high roll/mid redirects are at odds with those necessary for in-rolls. Therefore, none of the layouts in this chapter will favor inward rotation. In fact, their in-roll ratio will usually be below 1.

15.2. Basics

As already explained earlier in this document, any layout that aims to minimize redirects should follow two simple rules:

- **Have all the vowels on the same hand.**
- **Move the letter H to the vowel side as well.**

Other than reducing redirects, we also want to increase rolling. For that we need to **move a few other consonants to the vowel hand, as H alone will not give us enough rolling.**

With all the above in mind, here is an example of a high roll/mid redirect layout. We see a H + vowels setup, with some consonants added on top of H for extra rolling:

Sturdy (Oxey)
v m l **c** p x f **o** u j
s t r d y . **n a e i**
k q g w z b **h** ' ; ,

The letter H being on the vowel hand's index finger will inevitably turn all the H + vowel bigrams (**HE**, **HA**, **HI**, **HO**) into out-rolls. This is why high roll/mid redirect layouts will not favor inward rotation.

The setups that perform best at high roll/mid redirects are **FHNB + vowels, FHMB + vowels and HML + vowels.** Another option is **HRL + vowels**, but this last setups has higher redirects than the previous ones because of the presence of the letter R on the vowel side.

As seen on Sturdy, the consonants on the vowel side will be placed on the index, as that is the only finger that has room for six letters. That leaves the middle, ring and pinky fingers of that same hand for the vowels.

Aside from the vowel hand setup, the other aspect that affects how many redirects there will be on a layout is the home row on the consonant side (e.g. STRD on Sturdy). Having said that, the consonant hand has a much lesser impact on redirects than the vowel hand does. Because of this, we will be able to arrange the consonant hand in multiple ways depending on our preference, without that having too much of an effect on the redirects.

15.3. Layout arrangements for high roll - mid redirects

For more info on the layouts below, run them through the Keysolve web tool. That way you will get a nice heatmap of the layout, in addition to its lateral stretch and scissor stats. If you need help utilizing Keysolve, you can find it on the Keysolve github page.

15.3.1. NH + vowels

This is the most popular high roll/mid redirect setup. Aside from performing solidly at rolls/redirects, these layouts use optimized letter columns and also have low scissors (uncomfortable bigrams that involve pressing a key on the top row followed by the bottom row, or vice versa). **Their one drawback is poor hand balance.**

CRST

These are double stack layouts (i.e. **OA/OE column** + **NH column**) with a C pinky. Having C on pinky allows for more traditional index finger arrangements. However, this is usually at the expense of higher pinky movement.

WC pinky

Canary (Eve)
```
w l y p k   z x o u ;
c r s t b   f n e i a '
  j v d g q   m h / , .
```

YC pinky & **C pinky**

Lela (Lela)
```
y l g m q   j f o u ,
c r s t k   b n a e i
  x w d v z   p h ' / .
```

C + punctuation pinky

Rolly (Ec0vid)
```
y o u f j   q m w l ,
i a e n b   k t s r c '
  ; " h p z   v d g x .
```

Crest (Oxey)
```
w l f d k   z j u o y
c r s t g   p n e a i
' x v m q   b h , . ;
```

Megamak (Smudge)
```
x l y w k   z f o u ;
c r s t g   b n e i a '
  j v d m q   p h / , .
```

	SFB	SFS	Scissors	Alt	Roll	Redir	In:out-roll	Pinky off	Hand use
Canary	**Low** 0.684	**Mid high** 7.038	**Min** 0.08	**Mid low** 31.5	**Very high** 49.7	**High** 7.8	**Min** 0.8	**Mid** 4.9	**Heavy right** 42 – 58
Crest	**Mid low** 0.741	**Low** 6.094	**Mid** 0.42	**Mid** 34.2	**High** 47.2	**Mid high** 6.6	**Very low** 1	**Mid high** 5.8	**Heavy right** 42 – 58
Lela	**Very low** 0.558	**Very low** 5.628	**Low** 0.18	**Mid** 34	**High** 48.8	**Mid high** 6.8	**Min** 0.8	**Mid high** 5.6	**Heavy right** 42 – 58
Megamak	**Mid low** 0.742	**Mid high** 7.233	**Min** 0.09	**Mid** 33.9	**High** 48.7	**Mid high** 6.3	**Min** 0.8	**Very low** 2.7	**Heavy right** 42 – 58
Rolly	**Very low** 0.591	**Min** 5.094	**Very low** 0.14	**Mid low** 32.1	**Very high** 49	**Mid high** 6.9	**Very low** 0.9	**High** 6.4	**Heavy left** 57 – 43

STRD / SRTD / SRTC

These are still double stack variants (i.e. **OA/OE column** + **NH column**). Compared to the previous layouts, the letter C is moved to the index finger. This results in less traditional index finger arrangements. On the bright side, the pinky movement is noticeably lower.

D, C & Y on index

Sturdy (Oxey)

```
v m l c p   x f o u j
s t r d y   . n a e i
 k q g w z   b h ' ; ,
```

Gemini (KayOS)

```
x l m g w   q f o u ,
s r t d y   b n a e i
v j k c z   p h ' ; .
```

C & Y on index

Wave2 (ec0vid)

```
v l d m '   z f o u j
s r t c y   b n a e i
 x k g w q   p h . " ,
```

C & M on index

Snug (Mainstream)

```
q l d m b   j f o u '
s r t c g   p n e i a
 x k w v z   y h / , .
```

On Wave2, the letter M is pressed by middle finger, not the index (i.e. a DTMK column).

	SFB	SFS	Scissors	Alt	Roll	Redir	In:out-roll	Pinky off	Hand use
Sturdy	Low 0.656	Very low 5.566	Mid low 0.34	Mid 34	Very high 49.7	Mid 6	Min 0.8	Very low 2.6	Heavy right 43 – 57
Gemini	Min 0.495	Very low 5.391	Low 0.17	Mid 34	Very high 48.9	Mid high 6.9	Min 0.8	Mid low 4.2	Heavy right 42 – 58
Wave2	Min 0.478	Very low 5.398	Very low 0.13	Mid 32.8	Very high 50.2	Mid high 7	Min 0.8	Very low 2.6	Heavy right 42 – 58
Snug	Mid low 0.762	Low 6.026	Very low 0.12	Mid 34.9	Mid high 46.6	Mid 6.2	Min 0.7	Very low 2.5	Heavy right 41 – 59

Lastly, a more niche option is moving the letter T to the pinky:

D, C & M on index

Trance (Ec0vid)

```
k l y w v   q b o u ,
t r s d g   j n a e i
 x f c m z   p h ' " .
```

15.3.2. HM or HML + vowels

These layouts are less popular than the NH + vowel ones. Despite some drawbacks (explained below) they technically perform the best at high rolls yet low redirects.

NRTS / RNTS

1 vowel stack variants (e.g. an **OA/OE column**).

Fire (Oxey)

```
p l d g v   q f o u ,
n r t s y   j h a e i
  x k c w z   b m ' ; .
```

Blaze (Oxey)

```
w p d f g   q x o u ,
r n t s y   j h a e i
  b k c v z   m l ' ; .
```

Flame (Oxey)

```
x p d w g   q f o u ,
r n t s y   j l a e i
  b k c v z   m h ' ; .
```

	SFB	SFS	Scissors	Alt	Roll	Redir	In:out-roll	Pinky off	Hand use
Fire	Mid low 0.738	Min 5.067	Low 0.2	Mid 35.4	Very high 49.7	Low 4.3	Min 0.8	Mid 4.6	Even 48 – 52
Blaze	Very low 0.584	Very low 5.306	Very low 0.12	Mid 34.8	Very high 49.9	Mid low 5.1	Min 0.8	Mid high 5.3	Leans right 47 – 53
Flame	Low 0.712	Very low 5.415	Very low 0.12	Mid 33.6	Very high 50.2	Mid 5.7	Min 0.7	Low 3.2	Leans right 45 – 55

The drawback of these layouts is that there are a lot of SFBs concentrated on the left index (**SC, YS, WS, GS...**) leading to high movement on that finger. The NH + vowel layouts in the previous section did not have that issue, but their hand balance was more uneven.

Note: Flame's right index might look weird to some, as it places the letter H off the home row, in favor of L. This is done in order to minimize the distance of the **FL** and **LF** SFBs.

SNTC / SNTD / STND

These layouts fix the issue of the SFB heavy left index, but have less standard home rows and a higher load on the ring finger. Additionally, while the layouts in the previous page simply had a vowel stack, these are double stack variants (e.g. **OA column** + **RN column**).

C on index

Recurva (Brys)
f **r** d p v q j u **o** y
s n t c b . **h e a i**
z x k g w m l ; ' ,

C & Y on index

Pycnantha (Brys)
f **r** d p v z q **o** u ,
s n t c y k **h a e i**
x j b g w m l ' ; .

D, C & Y on index

Dvardy (Oxey)
v **r** k **c** p j f **o** u .
s n t d y x l **a e i**
q b g w z m **h** ' ; ,

Flare (Ec0vid)
f b **r c** p q m **o** u ,
s t n d y j **h a e i**
v x g w z k l ' " .

	SFB	SFS	Scissors	Alt	Roll	Redir	In:out-roll	Pinky off	Hand use
Recurva	Very low 0.603	Min 4.905	Mid low 0.27	Mid 34.6	High 48.4	Mid 5.5	Min 0.8	High 6	Hard right 44 – 56
Pycnantha	Min 0.455	Very low 5.309	Low 0.23	Mid 34.8	Very high 49.2	Mid high 6.4	Min 0.7	Mid 5.1	Leans right 46 – 54
Dvardy	Very low 0.593	Very low 5.552	Low 0.23	Mid 33.5	Very high 50.3	Mid 6.2	Min 0.7	Mid low 4.1	Leans right 45 – 55
Flare	Min 0.514	Very low 5.418	Mid low 0.29	Mid 34.8	Very high 49.2	Mid 6	Min 0.6	Mid 5	Leans right 46 – 54

Finally, a more niche option is moving the letter T to the pinky:

D, C & Y on index

Flare2 (Ec0vid)
v f **r c** p q m **o** u ,
t s n d y j **h a e i**
b x g w z k l ' " .

15.3.3. LRH + vowels

These layouts optimize rolling a bit further than the previous ones. However, with the added rolling we also get more redirects. Regardless, they were still included as they show the remaining method in which one can get high rolls when using a H + vowels setup. **The main drawback of LRH + vowels is that it noticeably lowers alternation.**

SNTM / NSTM / NSTD

Double stack variants (e.g. **OA column** + **RH column**) with a C index.

C, M & Y on index

Sntm (Oxey)
v p d g w q l **o** u ,
s n t m y x **r a e i**
b k **c** f z j **h** ' ; .

Fudge (StronglyTyped)
q f d g w z l u **o** ,
n s t m y j **r e a i**
p b k **c** v x **h** ; ' .

D, C & Y on index

Nstd (Oxey)
b f m g p z l o u ,
n s t d y j **r a e i**
v k **c** w q x **h** ' ; .

On Sntm and Fudge, the **MY** SFB would likely be alt fingered (M with middle, Y with index).

	SFBs	SFSs	Scissors	Alt	Roll	Redir	In:out-roll	Pinky off	Hand use
Sntm	**Very low** 0.613	**Min** 5.226	**Low** 0.19	**Mid low** 31.2	**Max** 51.1	**High** 7.6	**Min** 0.8	**Mid low** 4.1	**Heavy right** 44 – 56
Fudge	**Low** 0.626	**Min** 5.194	**Low** 0.18	**Mid low** 31.1	**Max** 51.2	**High** 7.2	**Very low** 1	**Mid** 4.7	**Heavy right** 44 – 56
Nstd	**Min** 0.519	**Very low** 5.527	**Low** 0.18	**Mid low** 31.1	**Max** 51	**High** 7.6	**Very low** 0.9	**Mid** 4.5	**Heavy right** 44 – 56

The Fudge layout has the OA column on the ring because that leads to fewer redirects. By comparison, Sntm prefers sacrificing a bit of redirects in order to get OA off the ring finger.

Anyway, a more niche option is moving the letter T to the pinky:

D, C & M on index

Trance2 (Ec0vid)
k p y w v q l u **o** ,
t n s d g j **r e a i**
b f **c** m z x **h** " ' .

Here is a double stack variant (e.g. **OA column** + **RH column**) with a C pinky:

C + punctuation pinky

Rolly2 (Ec0vid)

```
y o u l q   k m g p ,
i a e r x   w t s n c '
  ; " h j z   v d f b .
```

	SFBs	SFSs	Scissors	Alt	Roll	Redir	In:out-roll	Pinky off	Hand use
Rolly2	**Very low** 0.584	**Very low** 5.428	**Very low** 0.12	**Low** 28.4	**Max** 51.3	**High** 7.9	**Min** 0.8	**High** 6.4	**Leans left** 55 – 45

15.4. Space thumb optimization

Which thumb is used for space can have a significant effect on the alternate, roll, onehand and redirect stats. In the following sections we investigate why this is the case.

15.4.1. Space trigrams

Here we look at trigrams that include space. In other words, **trigrams starting with space (e.g. `[  th]`), with space in the middle (e.g. `[e  t]`), or ending with space (e.g. `[he  ]`).**

The following table shows the top 30 space trigrams on the MonkeyType quotes corpus. The number next to each trigram indicates its frequency in percent (e.g. **`[ th]`** amounts to 1.780% of all trigrams).

1-10		11-20		21-30	
`[ th]`	**1.780**	**`[at ]`**	**0.454**	`[ed ]`	0.363
`[he ]`	**1.028**	**`[e t]`**	**0.430%**	`[ wh]`	0.318
`[nd ]`	**0.690**	**`[o f]`**	**0.429%**	`[e a]`	0.315
`[ to]`	**0.623**	**`[ a ]`**	**0.421%**	`[ll ]`	0.315
`[ an]`	**0.617**	**`[ou ]`**	**0.405%**	`[in ]`	0.314
`[ yo]`	**0.579**	`[ in]`	0.400%	`[t t]`	0.309
`[to ]`	**0.566**	`[is ]`	0.390%	`[ wa]`	0.286
`[ng ]`	**0.542**	`[ I ]`	0.389	`[ it]`	0.284
`[re ]`	**0.464**	`[ be]`	0.378	`[ve ]`	0.283
`[ of]`	**0.455**	`[er ]`	0.377	`[ ha]`	0.282

* You can find the full list here (it was based on MonkeyType, as of October 3rd 2022).

It should not be surprising that space trigrams are very frequent, as space is easily the most common character. In fact, **trigrams including space amount to about half of all trigrams** (55.6% on the MonkeyType quotes corpus to be exact).

For this reason, layout stats will be wildly different depending if we account for space or not. When sharing stats for keyboard layouts, we usually give the stats disregarding space. Otherwise, the stats would have to be given twice (for right vs left thumb space).

15.4.2. How rolls and redirects involving space work

Rolls with or without space are fundamentally different. **A sequence that is a roll when disregarding space may not be a roll anymore one space is included.** Take APT:

APT (Eve)
w g d f b q l u o y
r s t h k j **n e a i** ;
x **c** m p v z , . ' /

Without accounting for space, **TH** is a roll. If we use right thumb space for analysis, **space → TH** would still be a roll (**space** with one hand, **TH** with the other). However, with the left thumb, **space → TH** would now be a redirect (**space → T** is outward, but **T → H** is inward).

The following are APT's stats with each thumb, using the a200 analyzer:

Left thumb space		Right thumb space	
Rolls	**53.51%**	**Rolls**	**44.03%**
Alternates	23.31%	Alternates	30.49%
Onehands	2.94%	Onehands	4.84%
Redirects	**8.39%**	**Redirects**	**8.79%**

Interestingly, on APT we are not able to get the redirects down regardless of the thumb. This is partly because the consonant thumb makes **space → TH** (by far the most common space trigram) a redirect. Meanwhile, the vowel thumb will usually lead to lots of space trigrams being alternates or redirects, regardless of the layout.

The solution is moving the letter H to the vowel hand (as we have done in all the earlier high roll/mid redirect layout examples). **Then we can use the consonant thumb for space, without space → TH being a redirect.**

Technically, by making **TH** into an outward roll it becomes possible to have T, H and space all on the same hand without **space → TH** being a redirect. For example, if T was on the index finger and H on the middle, **space → T→ H** would be a 3roll.

15.4.3. Example of analyzing space trigrams in a layout

The layouts that have the biggest variance on the stats depending on which thumb is being used for space are NH + vowel layouts (we went over them earlier). For example:

Canary (Eve)
w l y p k z x o u ;
c r s t b f **n e i a** '
 j v d g q m **h** / , .

Let's go through the top 30 trigrams that include space, and see how they would be typed on Canary depending if we use the consonant or the vowel thumb for space:

Left thumb space

	1-15		16-30
[th]	roll	[in]	roll
[he]	roll	[is]	roll
[nd]	roll	[I]	alternate
[to]	roll	[be]	roll
[an]	roll	[er]	roll
[yo]	roll	[ed]	roll
[to]	alternate	[wh]	roll
[ng]	roll	[e a]	alternate
[re]	alternate	[ll]	-
[of]	roll	[in]	roll
[at]	roll	[t t]	redirect
[e t]	roll	[wa]	roll
[of]	roll	[it]	alternate
[a]	alternate	[ve]	alternate
[ou]	roll	[ha]	roll

Right thumb space

	1-15		16-30
[th]	alternate	[in]	redirect
[he]	redirect	[is]	alternate
[nd]	alternate	[I]	redirect
[to]	alternate	[be]	alternate
[an]	redirect	[er]	alternate
[yo]	alternate	[ed]	alternate
[to]	roll	[wh]	alternate
[ng]	alternate	[e a]	redirect
[re]	roll	[ll]	-
[of]	redirect	[in]	onehand
[at]	alternate	[t t]	alternate
[e t]	roll	[wa]	alternate
[of]	onehand	[it]	roll
[a]	redirect	[ve]	roll
[ou]	redirect	[ha]	onehand

We can see that the space thumb makes a way bigger difference than we could have imagined. With the consonant thumb we get mostly rolls. Meanwhile, rolls plummet with the vowel thumb. To confirm the results above, the following are Canary's stats on a200 (using all space trigrams for analysis, not just the top 30):

Left thumb space	
Rolls	**58.17%**
Alternates	20.79%
Onehands	2.74%
Redirects	**5.34%**

Right thumb space	
Rolls	**41.51%**
Alternates	29.89%
Onehands	5.71%
Redirects	**9.92%**

15.4.4. a200 analyzer

As a rule of thumb (;p), using space on the consonant side leads to higher rolls. Regardless, if we want to check the thumb stats for a particular layout, we can use the a200 analyzer.

15.4.5. Hand balance and space

Most layouts have higher use on the vowel hand. This is because vowels plus punctuation already adds up to around 40% use, then adding a few consonants on top of that can easily make that hand's use to be 55% or even higher.

If the vowel hand is going to have higher use, it stands to reason that using the consonant thumb for space would be beneficial for balance, while using the vowel thumb would only exacerbate the problem.

The Canary layout perfectly exemplifies this issue. Disregarding space, its hand split is 42-58%. The space key has around 18.5% use. So, to get the hand split with space we just add 9.25% use to the space hand, and subtract 9.25% from the other hand. Doing this, Canary would have a 33-67 split with right thumb space, and 51-49 with left thumb!

15.4.6. Keeping your current space thumb

Most people do not want to change the thumb they have always used for space. Imagine someone that already uses the right thumb for space. If they want to learn a layout and it so happens that the left thumb is the "ideal" for it, they are unlikely to change thumbs.

A workaround is choosing a layout that has the vowels opposite to our current space thumb. This way we would already be using the "ideal" thumb. Alternatively, you could mirror the layout (swap the vowel and consonant hands) to achieve that same effect.

Regardless, choosing a layout based on space is a rather unreasonable proposition. **So, if the thumb you have always used happens to be the "ideal" one for the layout you want to learn, that's great. If not, this aspect of layout design is often ignored.**

16. 3roll layouts (1 min)

16.1. 3rolls

A 3roll consists of pressing 3 keys with the same hand, all in the same direction (e.g. Qwerty SDF). **To maximize 3rolls, we must split the vowels** (usually 3 on one hand, 2 on the other) **in order to make crucial trigrams like THE, ING, AND, HER or ION into 3rolls**.

16.2. Layout arrangements for 3rolls

SEHT / REHT / INTS

Here we have a double stack variant with a C index (Seht Drai), and two 1 vowel stack variants (Ints and Snorkle):

Seht Drai (Tanamr)

```
f u l v b   q g n o j
s e h t k   ' d r a i .
  ; m p w z   y c x / ,
```

Snorkle (Untwo)

```
. a y c j   q d l u x
i o n s b   p t h e r
, ' f g v   k w m ; z
```

Ints (Tanamr)

```
f o u m j   q g d p ,
h a e r x   v s t n i
  ' / l w z   y c k b .
```

Most layouts have between 2 and 4 percent 3rolls, these layouts go all the way up to 10 percent. So, **if we count both 2rolls and 3rolls, this style of layout has the highest overall rolling. Conversely, they have the lowest alternation as well.**

	SFBs	SFSs	Scissors	Alt	Roll	3rolls	Redir	In:out-roll	Pinky off	Hand use
Seht Drai	Very low 0.617	Min 5.227	Mid low 0.30	Min 22	High 48.4	Maxl 10.6	Very high 10.6	Very low 0.9	Mid 5.2	Even 51 – 49
Snorkle	Low 0.641	Low 5.709	Mid high 0.50	Min 23.7	High 48.4	Max 9.8	Very high 9.7	Very low 1.0	Low 3.2	Even 50 – 50
Ints	Mid low 0.779	Low 5.749	Low 0.24	Min 21.2	Max 50.8	Very high 6.8	Very high 12.3	Mid low 1.9	Mid 5	Leans left 53 – 47

Ints performs better at inward rolls than the in-roll ratio stat above would suggest. This is because Ints has lots of inward 3rolls (the in:out roll stat is based on 2rolls alone). Anyway, the following are the main inward 3rolls on Ints:

- Left hand: **HER, FOR, OUR, OUL, HOU**
- Right hand: **ING, IND, INT, INK, ITY, INS**

17. High alternation layouts (15 min)

17.1. Alternation

Alternation consists of pressing a key with one hand, then one with the opposite hand, then back to the first. The advantage of alternation is that it feels rhythmic and minimizes awkward long same hand sequences. The drawback is that rolls will be lower.

To achieve high alternation we place all vowels on the same hand, in addition to pairing the vowels with only certain consonants. The following table shows which vowel hand setups lead to rolls or alternation:

High alternation	High rolling
H + vowels	N + vowels
C/D + vowels	R + vowels
S + vowels	L + vowels
T + vowels	

Note that the above is an oversimplification. It is possible to reach high rolling while having the letter H on the vowel side. We would simply have to add certain letters on top of H (e.g. NH + vowels, HML + vowels, LRH + vowels...).

17.2. Layout arrangements for high alternation

For more info on the layouts below, run them through the Keysolve web tool. That way you will get a nice heatmap of the layout, in addition to its lateral stretch and scissor stats. If you need help utilizing Keysolve, you can find it on the Keysolve github page.

17.2.1. H + vowels

This is the most popular high alternation setup. **H + vowel layouts are best at maximizing alternation while simultaneously minimizing redirects.** Most of them are 1 vowel stack layouts (i.e. **OA/OE column**).

NRTS / NRST

Among modern layouts, NRTS is the most popular high alternation home row. The following layouts are all minor variations of the same idea:

Graphite (StronglyTyped)
```
b l d w z  ' f o u j ;
n r t s g  y h a e i ,
q x m c v  k p . - /
```

Gallium (Brys)
```
b l d c v  z y o u ,
n r t s g  p h a e i
q x m w j  k f ' ; .
```

Maya (Lela)
```
b l d g q  j f o u ,
n r t s v  k h a e i
 x m c w z  p y ' / .
```

	SFB	SFS	Scissors	Alt	Roll	Redir	In:out-roll	Pinky off	Hand use
Graphite	Low 0.707	Min 5.181	Low 0.19	High 40.2	Mid 45.1	Very low 3.4	Min 0.8	Low 3.4	Leans right 47 – 53
Gallium	Low 0.644	Min 5.149	Mid low 0.27	High 40.2	Mid 45.2	Very low 3.4	Min 0.8	Mid 4.6	Leans right 47 – 53
Maya	Low 0.658	Min 5.084	Low 0.21	High 40.2	Mid 45.2	Very low 3.4	Min 0.8	Mid 4.5	Leans right 47 – 53

When compared to the previous layouts, the letters T and S now swap fingers:

Potato (ClemePine)
```
q l c g v  j f o u ,
n r s t d  y h a e i
z x w m b  k p ' / .
```

Pine-v4 (ClemenPine)
```
q l c m k  ' f u o y
n r s t w  p h e a i
j x z g v  b d ; , .
```

Enigmak (StronglyTyped)
```
b l c g v  j f o u '
n r s t d  y h e i a ,
 x q w m z  p k / . ;
```

On Enigmak, the letter G is pressed by the middle finger, not the index (CSGQ column).

	SFB	SFS	Scissors	Alt	Roll	Redir	In:out-roll	Pinky off	Hand use
Potato	Low 0.688	Low 5.964	Low 0.18	High 40.2	Mid 45	Low 3.7	Min 0.8	Low 3.2	Leans right 47 – 53
Pine-v4	Low 0.705	Very low 5.662	Low 0.23	High 39.5	Mid 43.8	Mid low 4.9	Min 0.8	Mid 4.4	Heavy right 43 – 57
Enigmak	Mid low 0.768	Very low 5.660	Min 0.08	High 40	Mid 44.9	Very low 3.4	Min 0.8	Mid low 3.8	Leans right 47 – 54

Here is a double stack variant (i.e. **OA column** + **RN column**) with a C pinky:

Pine (ClemenPine)

```
y l r m k   q f o u ,
c s n t g   b h a e i
j x z w v   p d ' / .
```

	SFBs	SFSs	Scissors	Alt	Roll	Redir	In:out-roll	Pinky off	Hand use
Pine	**Very low** 0.5563	**Low** 5.947	**Very low** 0.12	**High** 39.4	**Mid high** 45.8	**Mid low** 4.9	**Min** 0.6	**Mid high** 5.7	**Leans right** 45 – 55

A more niche option is for T and C to swap places (i.e. T goes to the pinky, C to the index):

Trance3 (Ec0vid)

```
k l r m b   j f o u ,
t s n c v   p h a e i
 q x g w z   y d ' " .
```

17.2.2. C + vowels

Compared to the H + vowel family, C + vowel layouts are not as good as minimizing redirects, but can reach lower SFBs. These layouts will use two stacks (i.e. **OA/OE column** + **HN/RN/HR column**) and a "C index". This refers to an index finger that pairs the letter C with consonants like Y, W, G, P... Such layouts have the absolutely lowest SFBs. This setup gives us a lot of freedom to arrange the home row in many ways.

SRNT / SRHT / SRTN / STRN (NH column)

LR ring + HNB middle

Semimak JQ (Semi)
```
f l h v z   ' w u o y
s r n t k   c d e a i
x j b m q   p g , . /
```

Whix (Ec0vid)
```
f l n d k   ' w o u j
s r h t v   y c a e i
  x b m z q   p g . " ,
```

LR ring + HNM middle

Dhorf (Oxey)
```
v l h k q   j f o u ,
s r n t w   y c a e i
  x m d b z   p g ' ; .
```

LR ring + DTMK middle

Wave (Ec0vid)
```
v l d m z   ' w o u j
s r t n b   y c a e i
  x k h p q   g f . " ,
```

LR ring + DTM middle

Sertain (Smudge)
```
x l d k v   z w o u ;
s r t n f   g y e i a
  j m h b q   p c ' , .
```

DT ring + LR middle

Stronk (Oxey)
```
f d l b v   j g o u ,
s t r n k   y m a e i
  q x h p z   w c ' ; .
```

On Wave, the letter M is pressed by the middle finger, not the index (i.e. a DTMK column).

	SFBs	SFSs	Scissors	Alt	Roll	Redir	In:out-roll	Pinky off	Hand use
Semimak JQ	Low 0.730	Very low 5.366	High 0.66	High 41	Low 41.5	Mid 5.9	Min 0.8	Mid 4.8	Leans right 45 – 55
Whix	Min 0.459	Very low 5.330	Mid low 0.29	High 41.1	Mid 43.6	Mid low 4.6	Very low 1	Mid low 3.6	Even 48 – 52
Dhorf	Min 0.434	Low 6.032	Very low 0.13	Very high 41.7	Mid low 43.1	Mid low 4.6	Very low 0.9	Mid low 4.1	Even 48 – 52
Wave	Min 0.481	Very low 5.430	Very low 0.14	High 40.3	Mid 44.5	Low 4.4	Very low 1.1	Very low 2.6	Even 48 – 52
Sertain	Mid low 0.851	Mid low 6.426	Low 0.21	High 41.1	Mid low 42.7	Low 4.3	Very low 0.9	Very low 1.9	Even 48 – 52
Stronk	Mid low 0.832	Very low 5.406	Very low 0.11	Mid high 37.3	Mid high 45.4	Mid 5.6	Very low 1	Mid 5	Leans right 47 – 53

NSTR / SNTR / NSRT / SNRT (LHR column)

Variants with a LRH column.

FSV ring + DTM middle

Noctum (Oxey)

```
b f d l z   j g o u ,
n s t r k   y c a e i
 v m h x q   p w ' ; .
```

PNB ring + DTM middle

Santa (Oxey)

```
v p d l j   q w o u ,
s n t r k   y c a e i
 b m h x z   g f ' ; .
```

FSV ring + HRL middle

Flow2 (Ec0vid)

```
b f h m z   j w o u '
n s r t x   y c e i a
 v l d k q   p g " . ,
```

PNB ring + HRL middle

Flow (Ec0vid)

```
v p h m z   j f o u '
s n r t x   y c e i a
 b l d k q   g w " . ,
```

	SFBs	SFSs	Scissors	Alt	Roll	Redir	In:out-roll	Pinky off	Hand use
Noctum	Very low 0.550	Very low 5.556	Mid low 0.26	High 41.1	Mid low 43.3	Low 4.1	Low 1.5	Mid 4.5	Even 48 – 52
Santa	Very low 0.527	Very low 5.433	Mid high 0.49	High 40.5	Mid 44.1	Low 4.1	Low 1.4	Mid low 4.1	Even 48 – 52
Flow2	Very low 0.564	Low 6.018	Mid 0.44	High 41.1	Mid 43.5	Low 4.3	Very low 1.1	Mid low 3.7	Even 48 – 52
Flow	Very low 0.539	Low 6.015	Mid 0.45	High 40.3	Mid 44.2	Low 4.4	Min 0.8	Low 3.3	Even 48 – 52

SHRT / SNHT / SNTH / HSNT (RN column)

These variants use the RN stack.

LH ring + RN middle:

Whix2 (Ec0vid)

```
b l n d k   ' f o u j
s h r t w   y c a e i
 q x m v z   p g . " ,
```

RN ring + LHM middle:

Dina (Lela)

```
b r l d j   ' y o u ,
s n h t k   w c a e i
 x m p v z   f g q / .
```

RN ring + DTB middle:

Dvarf (Oxey)

```
' u o w p   q v d r f
a i e y g   l h t n s
, . ; c j   k m b x z
```

RN ring + LTV middle:

Compound (Oxey)

```
' u o g j   q d l r f
a i e c y   k h t n s
, . ; w p   b m v x z
```

LS ring + RN middle

Putih (Lela)

```
m l r p k   q y o u ,
h s n t v   f c a e i
 z x d b j   g w ' / .
```

Kuntum (Lela)

```
v l n d k   j w o u ,
t s r h f   g c a e i
 z x p b '   m y q / .
```

	SFBs	SFSs	Scissors	Alt	Roll	Redir	In:out-roll	Pinky off	Hand use
Whix2	Very low 0.526	Very low 5.555	Min 0.07	Very high 41.8	Mid low 42.9	Mid low 4.8	Very low 1	Low 3	Even 48 – 52
Dina	Min 0.501	Min 4.838	Low 0.25	High 40.5	Mid 44.2	Low 4.5	Very low 1	Mid 4.5	Even 48 – 52
Dvarf	Very low 0.589	Mid low 6.124	Low 0.22	High 41.1	Mid low 43.3	Low 4.4	Very low 1.1	Mid low 4.3	Even 52 – 48
Compound	Low 0.723	Low 5.884	Low 0.18	High 41.1	Mid low 43	Low 4.3	Very low 1.1	Mid low 4.3	Even 52 – 48
Putih	Very low 0.558	Very low 5.550	Low 0.18	High 40.5	Mid 44	Mid low 4.7	Very low 0.9	Mid high 5.6	Even 48 – 52
Kuntum	Mid low 0.751	Min 4.882	Min 0.08	Mid high 36	Mid high 46	Mid high 6.4	Very low 1	Mid low 4.1	Even 48 – 52

RSNT / SNRT

Unlike all the prior C + vowel layouts, these have C on pinky, rather than on index.

With a **HNL middle**:

Uciea (Ian Douglas)

```
p y u o -   k d h f x q
c i e a '   g t n s r v
z " , . ;   w m l b j
```

Uciea pcrw (Philipp Kiefer)

```
p y u o -   k m h b x q
c i e a ,   d t n s r w
z j ' . ;   f g l v /
```

With a **HRL middle**:

Uciea gcsv (Philipp Kiefer)

```
g y u o -   k m h p x q
c i e a ,   d t r n s v
z j ' . ;   f w l b /
```

	SFBs	SFSs	Scissors	Alt	Roll	Redir	In:out-roll	Pinky off	Hand use
Uciea	Mid low 0.800	High 7.344	Very high 0.81	Very high 42.4	Mid low 42.7	Mid low 5.4	Very low 1.1	Low 3.1	Even 48 – 52
Uciea pcrw	Low 0.731	Mid high 7.023	Mid high 0.46	Very high 42.1	Mid low 42.7	Mid low 5.4	Very low 1.2	Mid low 4.3	Even 48 – 52
Uciea gcsv	Mid low 0.799	Mid low 6.446	High 0.60	Very high 43.1	Mid low 42.1	Mid low 4.9	Very low 1	Low 3.5	Even 48 – 52

17.2.3. S + vowels

Most of the high alternation layouts are either H + vowel or C + vowel setups. Regardless, it is possible to reach decent alternation with S + vowels. So, here we list a few examples.

Below we have two double stack variants (i.e. OA column + HN column). One of them has a C index (Trendy) and the other a C pinky (Rolly4).

Trendy (StronglyTyped)

```
k l h w '   z f o u j
t r n d b   y s a e i
 x m c p q   g v . ; ,
```

Rolly4 (Ec0vid)

```
y o u f x   q k h l ,
i a e s g   v t n r c '
  ; " w b z   p d m j .
```

And here we have two 1 vowel stack variants (i.e. they have a OA column, but not a HN):

Pinball (ClemenPine)

```
z k d v q   j f o u ,
n t h r w   y s a e i
p b m l x   g c ' ; .
```

Hrt (ClemenPine)

```
p b l m k   z f o u ,
n h r t w   g s a e i
v q x d j   c y ' ; .
```

	SFBs	SFSs	Scissors	Alt	Roll	Redir	In:out-roll	Pinky off	Hand use
Trendy	Low 0.627	Very low 5.650	Low 0.18	Mid high 37.1	Mid high 45.5	Mid high 6.7	Low 1.3	Very low 2.5	Leans right 46 – 54
Rolly4	Very low 0.583	Min 5.127	Min 0.07	Mid high 37.4	Mid high 45.4	Mid 5.7	Very low 0.9	High 6.4	Leans left 53 – 47
Pinball	Mid low 0.746	Mid low 6.188	Very low 0.11	High 39.5	Mid low 43	Mid 5.5	Low 1.6	Mid 4.7	Heavy right 45 – 56
Hrt	Low 0.703	Low 5.739	Very low 0.14	High 39.4	Mid low 43.4	Mid 5.7	Very low 1.2	Mid high 5.7	Heavy right 45 – 56

17.2.4 T + vowels

T + vowels maximizes alternation. Despite that, it causes high redirects, which is why it is a very niche setup when compared to the other high alternation options.
Regardless, here are a few examples:

Ursnf (Eve)
k l **c** m b q p **a** j .
u **r s n** f g **t o i e**
w x y **h** v z d ' , ;

Poqtea (Ian Douglas)
y w f l m k p **o** q - /
u **r s n h** d **t e a i** '
z x **c** v j b g , . ;

Poutea (Ian Douglas)
k j f l m b p **o** u - /
y **r s n h** d **t e a i** '
z x **c** v q w g , . ;

	SFBs	SFSs	Scissors	Alt	Roll	Redir	In:out-roll	Pinky off	Hand use
Ursnf	Mid low 0.943	Mid low 6.185	Very high 0.8	Max 47	Min 36	Mid high 6.3	Low 1.4	Mid 5	Heavy right 46 – 54
Poqtea	Mid 1.011	Very high 9.309	Mid low 0.28	Max 46.7	Min 35.3	High 7.5	Very low 1	Mid low 3.6	Heavy right 44 – 56
Poutea	Mid high 1.215	Very high 8.744	Mid 0.4	Very high 43.6	Min 37.1	High 7.9	Min 0.6	Very low 2	Heavy right 39 – 61

17.2.5. Other

Another 2 stacks + U column setup.

Hands Down (Alan reiser)
q **c h** p v k y **o** j /
r s n t g w u **e i a**
x m l d b z f ' , .

	SFBs	SFSs	Alt	2roll	3roll	Redir	In:out-roll	Hand use
Hands Down	Mid low 0.790	Very high 8.245	High 41	Mid 43.8	Minimal 0.7	Mid low 5.4	Very low 1.1	Even 51 – 49

Keyboard columns analysis

18. Consonant columns

In this chapter we look at each consonant individually, analyzing which letters can be paired with it and what decent columns one can make that include said letter. Basically, this chapter is a much more detailed version of the consonant block chapter.

18.1 Info given for each consonant

18.1.1. Pairs

If we add the **CR** bigram (0.149%) and the **RC** bigram (0.121%) we get the RC pair (0.27%). **The utility of pairs is that they show the SFB percent resulting from having two letters on the same column** (i.e. on the same finger).

For each consonant, we will be listing its pairs (excluding its X, J, Q, Z and vowel pairs). **Moreover, we will divide pairs into four categories, based on their SFB percent.** For example, the following are the pairs for the letter H:

Minimal sfb				Low sfb		Medium sfb		High sfb	
h + v	0.000	h + d	0.008	h + y	0.051	h + p	0.095	h + g	0.228
h + f	0.002	h + m	0.013			h + r	0.1	h + s	0.33
h + k	0.003	h + l	0.014					h + w	0.384
h + b	0.005	h + n	0.037					h + c	0.599
								h + t	3.686

As a general rule, the **pink** column would be the pairs to avoid. The **yellow** pairs are perfectly viable, but could be better. Finally, the **blue** and **green** column pairs are best. Letters with lots of minimal SFB pairs are particularly useful for making index finger columns. Indexes have six keys assigned to them (rather than three). Therefore, letters that can be paired with many others without causing SFBs (e.g. T, H, D, C) are great on index.

18.1.2. SFB thresholds

The corpus utilized to make the above tables was Norvig. The **green** column includes pairs up to 0.040% SFB. The **blue** column is for pairs up to 0.070%, and the **yellow** column is up to 0.178%. Pairs over 0.178% appear in **pink**. The last threshold was chosen so that the SC pair (0.178%) still makes the cut on Norvig, while pairs like BY (0.181) and YO (0.186) do not.

18.1.3. Columns

The tables below show the movement (SFB + SFS distance) for each letter column according to the genkey analyzer and utilizing the MonkeyType + Typeracer corpus (Norvig only contains bigram data, not actual text, so it cannot be used for this purpose).

Additionally, the numbers are normalized, meaning the movement for each column was divided by its usage. By doing this we can identify which letter columns optimize movement poorly. For example, a HNL column and a RNL one have almost identical usage. Despite that, the former has much lower movement. On HNL, the letters H and L being far apart is not an issue because they interact little with one another (i.e. the HL pair causes few SFBs and SFSs). However, the same is not true for R and L on a RNL column.

Note that a letter column should be adapted to that finger's strength. For example, a high movement column like HNL can go on a middle finger, but not on a ring or pinky. Columns with low movement and no SFBs (e.g. VSX, WCQ) are a good fit for the pinky. Finally, columns for the ring finger would be somewhere in between (e.g. LRJ, PNB).

To indicate how much movement a column has we will use a color code. From lower to higher movement it will go: **green** → **yellow** → **orange** → **red** → **dark red**. The values these colors are applied to will vary depending on the finger. For example, a column with 0.4 movement will appear in green on the middle finger, as a strong finger can easily handle that. However, 0.4 would appear as orange on a ring, and as red on a pinky.

H pinky columns

FHK Hyperroll	0.07
FH' Hrst	0.11
FHB Hands up	0.12
FHK' Inrolly2	0.14
BHK	0.15

H middle columns

HNB Semimak	0.34
DHM Pinball	0.43
LHM Seht Drai	0.53
HNL Uciea	0.67
HNM Dhorf	0.69
HRL Flow	0.69

H index columns (with N)

FNHPB Megamak	0.6
FNH M Canary	0.67
FNH B . Sturdy	0.80
FNHP Y Snug	0.88
NHPB KV Stronk	1.14
NH MLK Colemak DH	1.44

To help with readability, the letters X, J, Q and Z will be omitted from the tables. Also, below each column we will indicate what layout the column was taken from (if any). So, for example, if we are curious about how to arrange the letters on a NHPBKV index, then we can check the Stronk layout:

Stronk (Oxey)
f d l b v j g **o** u ,
s t r n k y m **a e i**
 q x **h** p z w **c** ' ; .

On the tables for the pinky, ring and middle fingers, the first letter on a column will indicate the top row character, then the home row, and lastly the bottom row (e.g. HNB has H on the top row). We will generally use the letter arrangement that leads to the least movement. For instance, for a HRL middle finger the tables will show R on the home row, as placing H on the home row instead (i.e. RHL) would noticeably increase movement.

The tables for the index fingers are structured differently. On these, the letters that appear on multiple rows of the table are kept on the same vertical line. For example, if you look closely, you will see that the letters on the left table are aligned like on the right:

H index columns (with N)

FNHPB	**0.6**
Megamak	
FNH M	**0.67**
Canary	
**FNH B . **	**0.80**
Sturdy	
FNHP Y	**0.88**
Snug	
NHPB KV	**1.14**
Stronk	
NH MLK	**1.44**
Colemak DH	

F	**N**	**H**	**P**	**B**						
F	**N**	**H**			**M**					
F	**N**	**H**		**B**						**.**
F	**N**	**H**	**P**						**Y**	
	N	**H**	**P**	**B**			**K**	**V**		
	N	**H**			**M**	**L**	**K**			

This way we can easily compare which letters are shared (and which are not) between two indexes. For example, the indexes on Canary and Colemak DH share the letters H, N and M. However, they differ in that canary adds F on top of that, while Colemak adds L and K.

18.2. Movement on the index vs the other fingers

The three letters we place on the pinky, ring and middle fingers necessarily have to be one on top of another. However, on the index it becomes possible to move letters to the center column. Because of this, a column can have lower movement just by being on index. For example, take the LRW column in both of the layouts below:

Isrt (Whorf)

```
y c l m k   z f u , '
i s r t g   p n e a o
q v w d j   b h / . x
```

Wreathy (Eve)

```
q g d f v   j l u o ,
n s t h y   w r e a i ;
b c m p k   z x / ' .
```

On Isrt the letters L and W are far apart. By comparison, on Wreathy L and W are now closer to each other, meaning that the overall movement on that finger will be lower.

18.3. High movement columns and alt fingering

When we say that a column has high movement we are assuming that the keys on that column are being pressed only by its intended finger. In other words, potential alt fingerings are not being taken into account.

As already explained in an earlier chapter, alt fingering refers to pressing a key with a finger other than the intended one in order to avoid a SFB. It usually consists of pressing an index finger key with the middle finger, followed by pressing a center column key with the index. For example, take this layout:

Noctum (Oxey)

```
b g d l z   j f o u ,
n s t r k   y c a e i
 v m h x q   p w ' ; .
```

The LRHK left index on Noctum has high movement as it concentrates multiple SFBs. However, this layout was designed so that the **RL, RK** and **LK** SFBs can be comfortably alt fingered. To type **RL**, we would press R with index and L with middle. For **RK** and **LK**, we would press R/L with middle, K with index.

So, as long as we do not mind alt fingering, having a high movement index is not necessarily an issue, as that can be solved by alt fingering some SFBs. On the contrary, If we do not like to alt finger and prefer typing everything normally, then we may want to avoid any high movement indexes. On fingers other than the index alt fingering becomes less viable, as such alt fingers are not very comfortable.

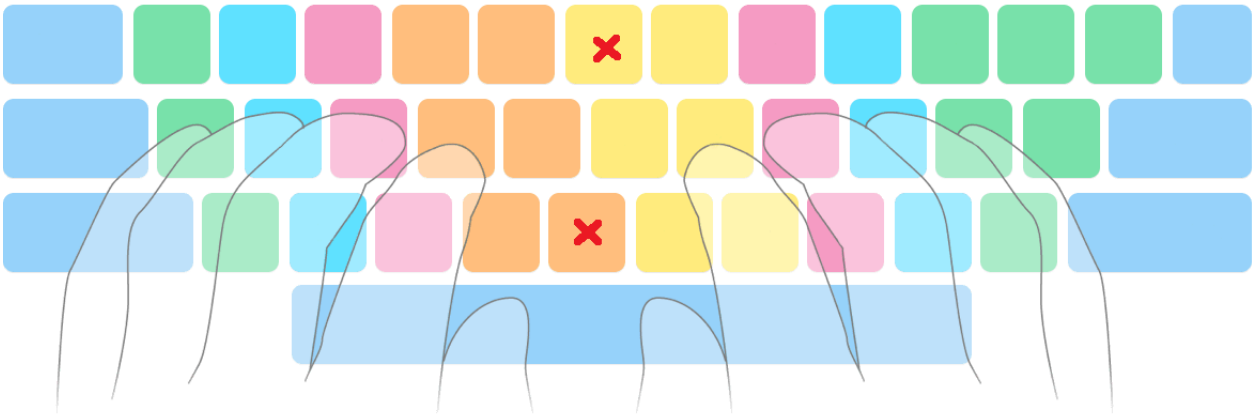
18.4. Index finger columns

18.4.1. Standard fingering

Most of index finger columns will have at least one rare letter (i.e. X, J, Q, Z or if not that, at least K or V). There are two reasons for this.

Firstly, we do not want a single finger to have too much movement (i.e SFB + SFS distance). Naturally, index fingers have the most danger of this, as they have six keys assigned to them. Therefore, **if some of the letters on an index finger already add up to enough movement, the remaining keys on that finger can be left for rare letters.** An example is **LRNXJQ**. With **L, R** and **N** all on the same finger, we complete the column **XJQ.**

Another reason for reserving a rare letter for index fingers is using it for the Qwerty B position (on the left index) **and for Qwerty Y** (on the right index) as pressing those keys is rather uncomfortable. They are marked with an X below:



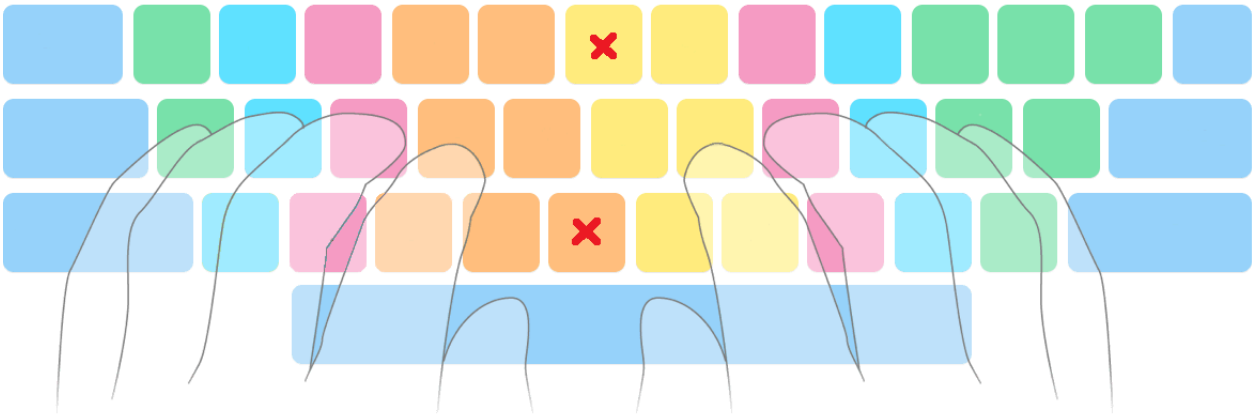
So, for example, if we had a **DTMGKJ** column on one index, and a **FNHPBZ** on the other, Z and J would naturally go on the highlighted red spots:

Isrt

```
y c l m k   z f u , '
i s r t g   p n e a o ;
q v w d j   b h / . x
```

18.4.2. Angle mod fingering

With angle mod we gain one comfortable left index key. We can see that there are now seven orange keys, while there used to be six. Again, Qwerty B/Y are marked with a red X:



This additional index key is especially useful in layouts that use the left index for a D/C column. The unique thing about D and C is that they can be paired with many moderately common consonants (Y, M, W, F, G, P, B & V), while causing minimal SFBs with them.

With standard fingering, we would only place five of those letters on the left index finger, as we need to reserve a rare letter for Qwerty B. However, with angle mod, we can now place one more of the aforementioned letters on the left index, making it six total:

Sturdy (Oxey)	**Snug** (Mainstream)	**Trendy** (StronglyTyped)
v m l **c** **p** **x** f o u j	q l d **m** **b** **j** f o u '	k l h **w** ' **z** f o u j
s t r **d** **y** . n a e i	s r t **c** **g** p n e i a	t r n **d** **b** y s a e i
k q **g** **w** **z** b h ' ; ,	x k **w** **v** **z** y h / , .	x m **c** **p** **q** g v . ; ,

So, **layouts with left indexes like the above are a better fit for angle mod.** If we used standard fingering for such layouts instead, this would be the result:

Sturdy (Oxey)	**Snug** (Mainstream)	**Trendy** (StronglyTyped)
v m l **c** **p** **x** f o u j	q l d **m** **b** **j** f o u '	k l h **w** ' **z** f o u j
s t r **d** **y** . n a e i	s r t **c** **g** p n e i a	t r n **d** **b** y s a e i
z k q **g** **w** b h ' ; ,	z x k **w** **v** y h / , .	q x m **c** **p** g v . ; ,

So, now the letters W, V and P have been relegated to Qwerty B, which is a poor spot for common letters. With angle mod, they used to be on Qwerty V, which was much better.

18.5. Main consonants

All the consonant columns in keyboard layouts are built around one of **T, N, S, H, R** or **C**. So, despite there being twenty one consonants, **by listing the viable columns for the aforementioned letters, we are already covering all the relevant options.**

Letter T

The following are all the T pairs (excluding X, J, Q, Z and the vowels):

Minimal sfb		Low sfb	Medium sfb		High sfb	
t + v	0.001	–	t + f	0.087	t + l	0.222
t + k	0.001		t + w	0.089	t + y	0.244
t + d	0.004		t + p	0.11	t + c	0.487
t + g	0.017				t + r	0.787
t + b	0.02				t + n	1.051
t + m	0.028				t + s	1.391
					t + h	3.686

T is most common on the index or middle finger**.** Still, a few layouts have it on ring (e.g. **BTK, MTK**). Rarely, T appears on pinky (**KT, VT**) as a high usage yet low movement column.

On the middle finger, we usually see DT plus another letter (e.g. **DTK, DTB, DTM, DTG**). Alternatively, we may have MT instead (e.g. **MTK, MTG**, **LTM**).

Indexes with T can be divided into **DTM** or **DTPB** setups (M and PB should not share a finger, because of the **MP** and **MB** SFBs). The rest of the index is completed with letters from the green column (**V, K, G**), maybe orange (**F, W, P**) and rare letters (J, Q, Z). If we want an index finger with high usage yet low SFBs, T is the usual choice.

Note: Despite lowering SFBs, the GT pair noticeably increases SFSs (the verb **get** becomes a SFS, so does the common **ght** trigram, and inter-word skipgrams like **going to**...). To avoid those SFSs we would place G with S or on a C/D index, rather than with T.

T pinky columns

KT Trendy	0.05
VT Rollla	0.05

T ring columns

DT Stronk	0.12
BTK	0.26

T middle columns

DTK Snug	0.25
GTK	0.29
MTK Gemini	0.32
DTB Pycnantha	0.38
DTM Graphite	0.44
DTG	0.47
MTG Nitrix	0.48
LTM Inrolly	0.66
LTG Mtgap	0.78

GTK and DTG are rare.

T index columns

With M

TM KV Semimak JQ	0.38
DTM K Flow	0.63
DTM KV Rolly	0.64
DTM VW Hyperroll	0.64
DTMGK Heyyou	0.80
TMGKVW Pine	0.87
DTM KVW Whix2	0.96
DTMGKV ColemakQi;x	0.99
DTMGK W Megamak	1.05
DTMG V B Potato	1.19

With PB

DT B KV Aqua	0.59
DTP KV Rolly 4	0.59
TPB KVW Seht Drai	0.69
DTP K W Snorkle	0.72
DT B K W Dhorf	0.81
DTPB KV Putih	0.83
DTPBGK Canary	0.92
DTPBG V Colemak DH	1.00
DTPBG F Nrstmak	1.14
DTPBGKV Colemak DHGM	1.16

The T indexes with the least movement avoid the GT SFS.

Letter N

The following are all the N pairs (excluding X, J, Q, Z and the vowels):

Minimal sfb		Low sfb		Medium sfb		High sfb	
n + b	0.006	n + v	0.052	n + w	0.085	n + c	0.417
n + p	0.007	n + f	0.068	n + k	0.103	n + s	0.518
n + m	0.037	n + l	0.07	n + y	0.111	n + g	1.019
n + h	0.037			n + r	0.17	n + t	1.051
						n + d	1.36

On the index finger the letter N usually shares its column with H. In fact, other than using a T index, the best way for accomplishing high index finger usage yet low movement is using the NH pair. Examples of such indexes would be **FNHPB** or **FNHM**.

Without H the letter N becomes a noticeably worse index finger letter, as the resulting columns (e.g. **NYPF**, **RNB**...) have lower use yet higher SFBs than the NH setups. The one upside of splitting H from N is that it becomes possible to optimize inward rotation.

On the middle finger the NH pair is also the most common option (e.g. **HNB**, **HNM**, **HNL**) although some layouts will use a **RN** or **LNM** middle instead.

Finally, on the weaker fingers the NH pair is avoided in favor of columns with lower usage. For example, on the pinky we can use the **BN** or **PN** pairs. On ring we can have both and make a **PNB** column. Overall, the letter N is frequent in all four fingers.

N pinky columns

BN Graphite	0.08
PN Nitrix	0.12

N ring columns

PNB Flow	0.22
LN	0.29

RN may go on ring.
A LN ring is rare.

N middle columns

HNB Semimak	0.34
RN Pine	0.36
HNL Uciea	0.67
HNM Dhorf	0.69
LNM	0.7
RNL	1.06

N index columns

With H

FNH B Sturgeon	0.49
NHPB Wave	0.56
FNHPB Megamak	0.6
FNH M Canary	0.67
FNH B . Sturdy	0.80
FNHP Y Snug	0.88
FNH B KV Sertain	1.01
NH ML Colemak DHGM	1.06
NHPB KV Stronk	1.14
NH ML V ColemaQ	1.36
NH MLK Colemak DH	1.44

The NH pair is very common on both the middle and index.

Without H (in-roll layouts)

RN Saiga	0.47
N P Y F Aptv4	0.53
RN B Inrolly	0.72
NL M Aptv2.1	0.82
N PB W . Rolll	0.85
NL , Apt	0.91
NL Y Vylet	0.94
RN , Journey	1.05
RNL Xenia	1.16
N PB W ., Rollla	1.22

The N indexes with the least movement avoid L, K and punctuation.

Letter S

The following are all the S pairs (excluding X, J, Q, Z and the vowels):

Minimal sfb		Low sfb		Medium sfb		High sfb	
s + v	0.002	s + g	0.054	s + k	0.087	s + l	0.197
s + f	0.023	s + b	0.054	s + d	0.132	s + p	0.246
		s + w	0.059	s + y	0.154	s + h	0.33
				s + m	0.158	s + r	0.403
				s + c	0.178	s + n	0.518
						s + t	1.391

Despite the SC pair causing SFBs in some common words (e.g. **school**, **screen** or **science**) many layouts will use it regardless. The reason is that the letter C can not go on the same finger as T, N, R or H (high SFBs) leaving S as the only option.

The one way of separating C from S is by using two stacks (i.e. a OA/OE column plus a HN/HR/RN column) and dedicating either an index or a pinky to the letter C. In other words, single stack layouts will always have the SC pair, while double stack layouts will not.

If the layout does use the SC pair, then we will see indexes like **CSGVW, CSGVWB**, **CSGVWY**... On the middle or ring fingers we would use **CSV, CSG, CSW** or **CSF**.

If the layout splits C from S, we can now have a **VS** or **FS** pinky. This is where S will often be on minimal SFB layouts, as V and F are its only minimal SFBs pairs. On the ring we can use **FSV, BSV** or **FSB**. For a bit more movement we can include G (e.g. **GSF, GSV, GSW**), Y (e.g. **YSF, YSV**) or even L (**LS**). On an index we would see columns like **SGFYV** or **SGFWB**.

S pinky columns

VS Sturdy	0.09
FS Semimak	0.09
BS Whix2	0.11

A BS pinky is rare.

S ring columns

FSV Noctum	0.19
BSV Uciea pcrw	0.23
FSB Uciea	0.24

S middle/ring columns

Without C

GSF Rolly2	0.31
YSF Trance	0.31
GSV	0.36
YSV Canary	0.39
WSG Rolly	0.39
LS Pine	0.42

With C

CSV Mtgap	0.44
CSG Apt	0.48
CSW ColemakQi;x	0.49
CSF Colemak	0.53
YSC Nrstmak	0.57

A YSC middle is rare.

S index columns

Without C

SG W FB Rolly 4	0.63
SGV YF Trendy	0.72
SGVW M Rolly ST	0.76

M and S being on the same finger is rare.

With C

CS VW B Nitrix	0.78
CSGVW Graphite	0.84
CSGV Y Ints	0.88
CSG YF Hrt	0.9
CSGVW B Inrolly2	0.94
CSGVWY Fire	1.1
CSGV YF Blaze	1.1

The S indexes with the most movement have S, C & Y all on one finger.

Letter H

The following are all the H pairs (excluding X, J, Q, Z and the vowels):

Minimal sfb		Low sfb		Medium sfb		High sfb	
h + v	0.000	h + y	0.051	h + p	0.095	h + g	0.228
h + f	0.002			h + r	0.1	h + s	0.33
h + k	0.003					h + w	0.384
h + b	0.005					h + c	0.599
h + d	0.008					h + t	3.686
h + m	0.013						
h + l	0.014						
h + n	0.037						

H is frequent on all fingers but on ring. It has lots of minimal SFB pairs, and unlike the other top consonants (T, N, S & R) H can actually be paired with apostrophe without causing SFBs.

Some examples of H pinky columns are **FH'** , **FHK** or **FHB**. As already mentioned, H rarely appears on the ring finger. Regardless, a rare example would be a **LH** ring.

On the middle finger, H often shares its column with N (e.g. **HNB, HNM**, **HNL**). Alternatively, H could go with R (**HRL**) or we could make a **LHM** or **DHM** middle.

Lastly, H offers lots of variance on the indexes:

- With N (e.g. **FNHPB**, **FNHM**, **FNHPY**)
- With R (**HRL**)
- With D (**FHDPB, FHDMK, FHDPKV**) or D & Y (**FHDYK, FHDYP, FHDYPK**)
- With ML (**LHM, LHMF, LHMK**)
- Other (**FHPKY, FHPKBV, FHPKYV, FHPKY'**)

H pinky columns

FHK Hyperrol l	0.07
FH' Hrst	0.11
FHB Hands up	0.12
MH Putih	0.15
YH Hillium	0.16

A MH/YH pinky is rare.

H ring columns

LH Whix2	0.12

Other possible rings: YHF, DHK, YHK, MHK.

H middle columns

HNB Semimak	0.34
DHM Pinball	0.43
LHM Seht Drai	0.53
HNL Uciea	0.67
HNM Dhorf	0.69
HRL Flow	0.69

H index columns

With N

FNH B Sturgeon	0.49
NHPB Wave	0.56
FNHPB Megamak	0.6
FNH M Canary	0.67
FNH B . Sturdy	0.80
FNHP Y Snug	0.88
FNH B KV Sertain	1.01
NH ML Colemak DHGM	1.06
NHPB KV Stronk	1.14
NH ML V ColemaQ	1.36
NH MLK Colemak DH	1.44

From higher to lower usage on index: with N > D/R > other.

With D

FHDP K Peppermint	0.5
FHDPB Pine	0.54
FHD KY Nitrix	0.61
FHD K M Rollla	0.63
FHDPBK Vylet	0.68
FHDP K V Inrolly	0.69
FHDP Y Trance 3	0.7
FHD BK M Mtgap	0.78
FHDP KY Saiga	0.8

With R

LHR Nstd	0.81
LRHK Noctum	1.07

Other

LHM Blaze	0.41
F HM B Fire	0.45
F H P YK Maya	0.5
F H PB KV Apt	0.54
F H P YKV Wreathy	0.56
FLHM Flame	0.6
F H P YK ' Graphite	0.63
LHM . Recurva	0.79
LHM K Flare	0.8
LHM KV Nrstmak	0.94

Letter R

The following are all the R pairs (excluding X, J, Q, Z and the vowels):

Minimal sfb	Low sfb	Medium sfb	High sfb
–	r + w 0.044	r + l 0.096	r + f 0.245
	r + v 0.07	r + h 0.1	r + y 0.256
		r + k 0.1	r + c 0.271
		r + b 0.138	r + d 0.275
		r + n 0.17	r + g 0.297
		r + m 0.178	r + s 0.403
			r + p 0.516
			r + t 0.787

R is the letter with the worst pairings. Firstly, it does not have a single minimal SFB pair. Secondly, its low SFB pairs are not great either, as they cause significant SFSs. The **WR** pair causes skip-1-grams on common words like **were, work** or **world**. Meanwhile, **VR** does the same on words like **over, very, never** or **however**.

Consequently, R does not have any low movement pairs that are ideal for the pinky. Despite this, a WR pinky is required on inward rotation layouts that use a RSTH home row. Overall, **the most common place for R is on a LR ring**, as that is ideal for minimizing SFBs.

On the middle finger, other than **RN**, we could use **HRL**. Excluding HRL, none of the remaining combinations of L + R + another letter optimize movement well. Having said that, there are a few layouts that use a **LRW** middle.

The worst location for R is on the index finger. Ideally, on the index we want to have five or six decently common consonants, without that leading to high movement. Doing this with R is impossible, because of how few good pairs it has.

R ring columns

LR Colemak Qi;x	0.27
WR Colemak	0.28

On RSTH layouts WR will appear on pinky.

RN may go on ring.

R middle columns

RN Pine	0.36
HRL Flow	0.69
LRM Dhorf smie	0.78
LRK	0.81
HRM	0.88
LRW Isrt	1.04
RNL	1.06

Other than HRL, adding letters on top of LR leads to high movement.

R index columns

Without N

LR M Superroll	0.7
LRW Wreathy	0.78
LR H Nstd	0.81
LR H K Noctum	1.07
LRW M Ints	1.15
LRW V Pinball	1.22
LRW , Wreath	1.34
LRW MV Straw	1.65

R is a poor index letter, as it lacks low SFB pairs.

R index columns

With N

RN Saiga	0.47
RN B Inrolly	0.72
RN , Journey	1.05
RNL Xenia	1.16

Letter L

The following are all the L pairs (excluding X, J, Q, Z and the vowels):

Minimal sfb		Low sfb		Medium sfb		High sfb	
l + h	0.014	l + g	0.067	l + r	0.096	l + s	0.197
l + m	0.028	l + n	0.07	l + f	0.118	l + t	0.222
l + w	0.028			l + c	0.161	l + b	0.24
l + k	0.03					l + p	0.282
l + v	0.035					l + d	0.285
						l + y	0.44

On the ring finger we can use **LH, LR, LN** or **LS**. From these, LH has the least movement, but **LR is the most common**. The reason is that both L & R are problematic letters. So, by placing them on the same finger we gain a lot of freedom to design the rest of the layout.

On the middle finger, **LHM** has the least movement. However, using that column leads to a heavier ring finger (e.g. a RN or DTK ring). If we want a lighter ring, we simply have to use a heavier middle finger setup like **HNL** or **HRL**. We could also do **LTM** or **LNM**.

On an index finger we usually place 4 or 5 decently common characters. The issue is that most of the L columns already have significant movement with just 3 letters (i.e. columns like LTM, HNL, HRL, LNM). This leaves LHM as the best option for a L index, as we can add K, V or a punctuation symbol on top of LHM without the movement increasing too much.

Finally, L basically never appears on pinky.

L ring columns:

LH Shnt	0.12
LR Whorf	0.27
LN	0.29
LS Pine	0.42

A LR ring is very common.

L middle columns:

LHM Dina	0.53
LTM Ctgap	0.66
HNL Uciea	0.67
HRL Flow	0.69
LNM Nila	0.7
LRM Dhorf smie	0.78
LTG Mtgap	0.78
LRK	0.81
LRW Isrt	1.04
RNL	1.06

L index columns:

With H

LHM Blaze	0.41
LHM F Flame	0.6
LHM . Recurva	0.79
LHM K Flare	0.8
LH R Nstd	0.81
LHM KV Nrstmak	0.94
LHMN Colemak DHGM	1.06
LH RK Noctum	1.07
LHMN V ColemaQ	1.36
LHMN K Colemak DH	1.44

The L columns with the least movement have the letter H.

Without H

LR M Superroll	0.7
LR W Wreathy	0.78
L NM Aptv2.1	0.82
L N , Apt	0.91
L N Y Vylet	0.94
LR MW Ints	1.15
LRN Xenia	1.16
LR W V Pinball	1.22
LR W , Wreath	1.34
LR MW V Straw	1.65

Letter D

The following are all the D pairs (excluding X, J, Q, Z and the vowels):

Minimal sfb		Low sfb		Medium sfb		High sfb	
d + k	0.001	d + y	0.057	d + s	0.132	d + r	0.275
d + p	0.003					d + l	0.285
d + f	0.003					d + n	1.36
d + t	0.004						
d + c	0.005						
d + b	0.005						
d + h	0.008						
d + w	0.012						
d + m	0.019						
d + v	0.019						
d + g	0.034						

D can share a column with most consonants. Just check how long the green column is!

We have already gone over the two basic locations for D:

- **With T**, on a **DTK, DTB, DTM** or **DTG** middle. Alternatively, we could make a **DTM** or **DTPB** index, and then complete the rest of the column with some of K, V, G, J, Q, Z.

- **With H**, on an index finger. This can be with D (e.g. **FHDPB, FHDMK, FHDPKV**) or with both D and Y (**FHDYK, FHDYP, FHDYPK**). A **DHM** middle is possible, but rare.

Having said that, a third option is **placing D on a C index**. This refers to when C is paired with multiple moderately common consonants (e.g. some of **D, M, Y, W, F, G, P, B** or **V**). Such columns can have extraordinarily low SFBs.

Lastly, D basically never appears on pinky.

D ring columns

DT Stronk	0.12

D middle columns

DTK Snug	0.25
DTB Pycnantha	0.38
DHM Pinball	0.43
DTM Graphite	0.44
DTG	0.47

D index columns With T & M

DTM K Flow	0.63
DTM KV Rolly	0.64
DTM VW Hyperroll	0.64
DTMGK Heyyou	0.80
DTM KVW Whix2	0.96
DTMGKV ColemakQi;x	0.99
DTMGK W Megamak	1.05

Without T or H

DC WGP Semimak	0.55
DCYWG Gemini	0.67
DC WGP ' Semimak JQ	0.77
DCY G ' Seht Drai	0.77
DC WG MV Trance	0.8
DC W PB ' Trendy	0.9
DCYWGP Sturdy	0.9

With T & PB

DT B KV Aqua	0.59
DTP KV Rolly 4	0.59
DTP K W Snorkle	0.72
DT B K W Dhorf	0.81
DTPB KV Putih	0.83
DTPBGK Canary	0.92
DTPBG V Colemak DH	1.00

With H

FHDP K Peppermint	0.5
FHDPB Pine	0.54
FHD KY Nitrix	0.61
FHD K M Rollla	0.63
FHDPBK Vylet	0.68
FHDP K V Inrolly	0.69
FHDP Y Trance 3	0.7
FHD BK M Mtgap	0.78
FHDP KY Saiga	0.8

From higher to lower usage on index: with T > H > no T/H.

Letter C

The following are all the C pairs (excluding X, J, Q, Z and the vowels):

Minimal sfb		Low sfb		Medium sfb		High sfb	
c + v	0.000	c + y	0.055	c + k	0.118	c + r	0.271
c + w	0.001			c + l	0.161	c + n	0.417
c + g	0.001			c + s	0.178	c + t	0.487
c + f	0.002					c + h	0.599
c + p	0.002						
c + b	0.003						
c + d	0.005						
c + m	0.007						

The letter C also has lots of minimal SFB pairs, although a few less than D.

To understand where C can go, we must distinguish between single and double stack layouts. The former refers to layouts that have either a vowel stack (i.e. AO / EO) or a consonant stack (i.e. HN / HR / NR). The latter refers to layouts with both.

On single stack layouts C is always paired with S. On the middle or ring finger we can do **CSV, CSG, CSW** or **CSF**. On index, it would be something like **CSGVW, CSGVWB**, **CSGVWY**...

On double stack layouts C gets its own column (away from S) on either pinky or index:

- On pinky we can do columns like **WC, YC** or **WCG**. We could even take advantage of the fact that C rarely causes punctuation SFBs, and make a **C + punctuation** pinky.

- On index C can be paired with four or five of the following letters: **D, M, Y, W, F, G, P, B** or **V**. The apostrophe key might also be added to that index.

C pinky columns

WC Canary	0.04
YC Lela	0.08
WCG	0.15
,C. Octa8	0.18
WCG' Saiga	0.29
WC' Crest	0.3
,C.' Rolly	0.3
BCG Engram	0.37

Past ,C. we get into high movement.

C middle/ring columns

CSV Mtgap	0.44
CSG Apt	0.48
CSW ColemakQi;x	0.49
CSF Colemak	0.53
YSC Nrstmak	0.57

C index columns

With D

DC WGP Semimak	0.55
DCYWG Gemini	0.67
DC WGP ' Semimak JQ	0.77
DCY G ' Seht Drai	0.77
DC WG MV Trance	0.8
DC W PB ' Trendy	0.9
DCYWGP Sturdy	0.9

With S

CS VW B Nitrix	0.78
CSGVW Graphite	0.84
CSGV Y Ints	0.88
CSG YF Hrt	0.9
CSGVW B Inrolly2	0.94
CSGVWY Fire	1.1

Without D or S

CYWG F Santa	0.46
CYWGP Sertain	0.57
CY GPF Dhorf	0.58
CYWG F ' Wave	0.59
C WGP VB Recurva	0.67
CY GPF ' Whix2	0.68
CYWGP ' Whix	0.72
C WG MVB Snug	0.73
CYWGP V Whorf	0.77
CYWG M Stronk	0.82
CYWG FM Sntm	0.94

The one drawback with C indexes that do not have D or S is that they have low use.

18.6. Remaining consonants

Letter Y

The following are all the Y pairs (excluding X, J, Q, Z). Note that the vowel pairs are included, as Y is a semivowel:

Minimal sfb		Low sfb		Medium sfb		High sfb	
y + v	0.005	y + h	0.051	y + m	0.086	y + b	0.181
y + w	0.006	y + c	0.055	y + n	0.111	y + o	0.186
y + u	0.006	y + d	0.057	y + s	0.154	y + a	0.233
y + k	0.006					y + e	0.236
y + f	0.01					y + t	0.244
y + g	0.029					y + r	0.256
y + i	0.029					y + l	0.44
y + p	0.037						

Y usually goes on either a YI pinky, a C index or a H index. A few layouts pair Y with N, or even S, but that leads to noticeably higher SFBs. Despite the YU pair causing no SFBs, it is basically never used because it creates a very common Y_U SFS in the word **you**.

Letter W

The following are all the W pairs (excluding X, J, Q and Z). Note that the vowel pairs are included, as W is a semivowel:

Minimal sfb				Low sfb		Medium sfb		High sfb	
w + v	0.000	w + f	0.002	w + r	0.044	w + n	0.085	w + h	0.384
w + g	0.001	w + p	0.002	w + s	0.059	w + t	0.089	w + i	0.375
w + c	0.001	w + k	0.003					w + a	0.445
w + u	0.001	w + y	0.006					w + e	0.478
w + b	0.001	w + d	0.012					w + o	0.552
w + m	0.002	w + l	0.028						

The one way for W not to cause SFBs is to place it on either a C index or a C pinky. If the layout does not dedicate a finger to the letter C (because the SC pair is used instead) then W would go with R, S, N or T.

Letter M

The following are all the M pairs (excluding X, J, Q, Z and the vowels):

Minimal sfb				Low sfb		Medium sfb		High sfb	
m + v	0.000	m + h	0.013	–		m + y	0.086	m + p	0.255
m + w	0.002	m + d	0.019			m + b	0.093		
m + k	0.002	m + l	0.028			m + s	0.158		
m + f	0.005	m + t	0.028			m + r	0.178		
m + c	0.007	m + n	0.037						
m + g	0.011								

M is usually paired with T, N or H. It can also go on a C index, but that is more rare.

Letter F

The following are all the **F** pairs (excluding X, J, Q, Z and the vowels):

Minimal sfb				Low sfb		Medium sfb		High sfb	
f + v	0.000	f + w	0.002	f + n	0.068	f + t	0.087	f + r	0.245
f + b	0.000	f + c	0.002			f + l	0.118		
f + y	0.001	f + h	0.002						
f + p	0.002	f + d	0.003						
f + k	0.002	f + m	0.005						
f + g	0.002	f + s	0.023						

F usually goes with either H or S. It could also go on a C index or a N index (i.e. FNHPB).

Letter P

The following are all the P pairs (excluding X, J, Q, Z and the vowels):

Minimal sfb				Low sfb	Medium sfb	High sfb
p + v	0.000	p + w	0.002	–	p + h 0.095	p + s 0.246
p + g	0.001	p + c	0.002		p + t 0.11	p + m 0.255
p + k	0.002	p + d	0.003			p + l 0.282
p + f	0.002	p + n	0.007			p + r 0.516
p + b	0.002	p + y	0.037			

P causes the least SFBs either with N, or on a C index. Still, it may also appear with H or T.

Letter G

The following are all the G pairs (excluding X, J, Q, Z and the vowels):

Minimal sfb				Low sfb	Medium sfb	High sfb
g + v	0.000	g + k	0.003	g + s 0.054	–	g + h 0.228
g + w	0.001	g + m	0.011	g + l 0.067		g + r 0.297
g + b	0.001	g + t	0.017			g + n 1.019
g + p	0.001	g + y	0.029			
g + c	0.001	g + d	0.034			
g + f	0.002					

G can with T, S or on a C index. The latter two options cause fewer SFSs.

Letter B

The following are all the B pairs (excluding X, J, Q, Z and the vowels):

Minimal sfb				Low sfb		Medium sfb		High sfb	
b + f	0.000	b + v	0.004	b + s	0.054	b + m	0.093	b + y	0.181
b + g	0.001	b + d	0.005			b + r	0.138	b + l	0.24
b + k	0.001	b + h	0.005						
b + w	0.001	b + n	0.006						
b + p	0.002	b + t	0.02						
b + c	0.003								

B can go with H, N, T or on a C index.

Letter V

The following are all the V pairs (excluding X, J, Q, Z and the vowels):

Minimal sfb				Low sfb		Medium sfb	High sfb
v + w	0.000	v + c	0.000	v + n	0.052	–	–
v + f	0.000	v + t	0.001	v + r	0.07		
v + g	0.000	v + s	0.002				
v + k	0.000	v + b	0.004				
v + h	0.000	v + y	0.005				
v + m	0.000	v + d	0.019				
v + p	0.000	v + l	0.035				

V goes best with H, T, S or on a C index.

Letter K

The following are all the K pairs (excluding X, J, Q, Z and the vowels):

Minimal sfb				Low sfb	Medium sfb		High sfb
k + v	0.000	k + m	0.002	–	k + s	0.087	–
k + b	0.001	k + g	0.003		k + r	0.1	
k + d	0.001	k + w	0.003		k + n	0.103	
k + t	0.001	k + h	0.003		k + c	0.118	
k + p	0.002	k + y	0.006				
k + f	0.002	k + l	0.03				

K always goes with either T or H.