pref R package manual *0.4.0, 29 Jan 2024*

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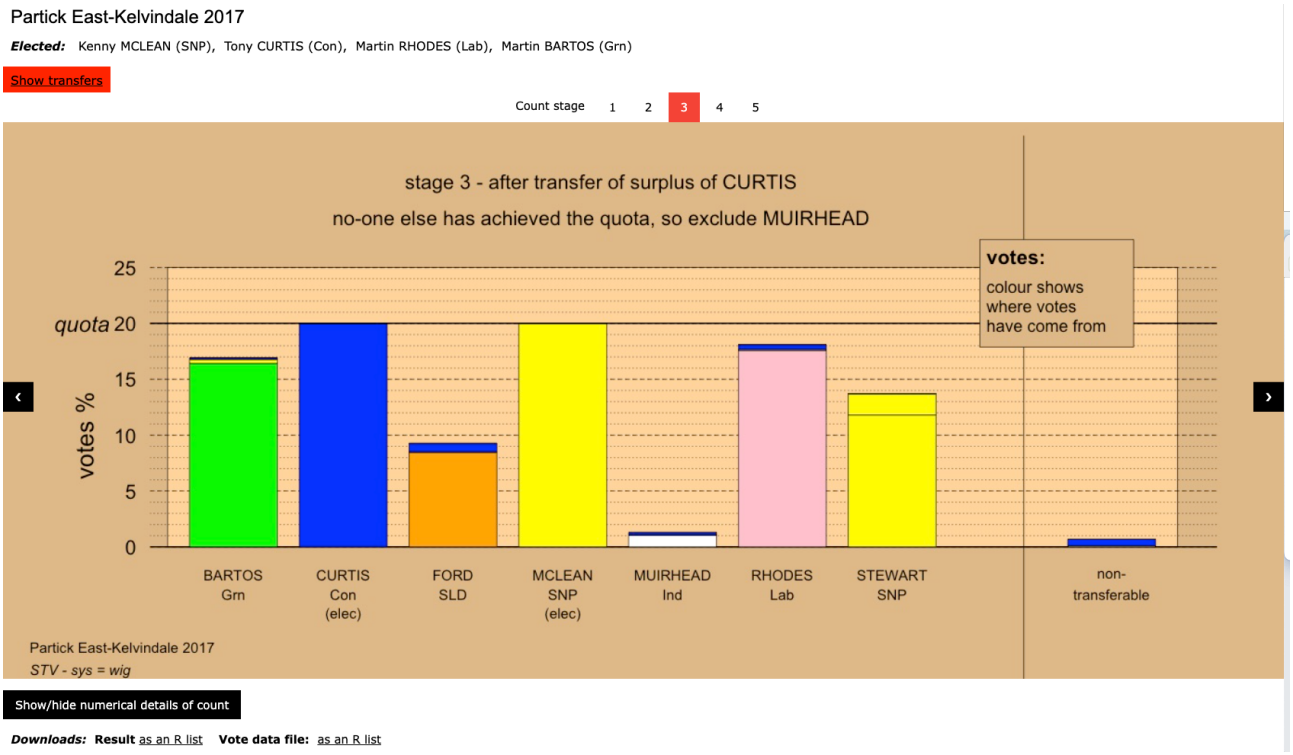
Summary

Implements the Single Transferable Vote (STV) electoral system, with clear explanatory graphics. The core function is Meek's method, the purest expression of the simple principles of STV, but which does require electronic counting. It can handle votes expressing equal preferences for subsets of the candidates. A function stv.wig implementing the Weighted Inclusive Gregory (WIG) method is also provided. The principles of STV and an outline of the steps required to implement it are described in $7.



Example of output for a Scottish Council election

The required vote data format is as an R list (see $ 4 below). A function *pref.data* is provided to transform some commonly used data formats into this format.

1 Package description

The goal of the function ***stv*** (see $3) is to count votes from an STV election, and to provide a clear and full description of the count and the result, using both numbers and graphics. It uses Meek STV, and allows for votes that include equal preferences. Graphical output includes expository web pages; the function ***stv.result*** prints a summary of the election count and result.

The function ***stv.wig*** ($3) implements the Weighted Inclusive Gregory STV method, as used in Scottish council elections since 2007; it has the same options as *stv*.

[A function, *stv.batch*, to run counts for multiple elections, as used to process the complete 2012, 2017 and 2022 Scottish Council elections, is too fragile to include here, but is available from the author.]

Election data for preference voting come in many formats, ranging from a simple vote matrix to the incluson of full candidate names and party affiliations. A function ***pref.data*** is provided to translate various common vote file formats into a flexible R list format, whose only essential element is a matrix of vote data ($4). This flexible R list format provides the input for *stv* and *stv.wig*. A range of examples from actual elections is included ($6).

The most recent stable version of pref can be installed from CRAN (https://cran.r-project.org/) using `install.packages(pref)`.

The development version can be installed from Github:

```
library(devtools)
install_github("denismollison/pref")
```

Either way, the package can then be loaded into an R session using `library(pref)`.

2 Usage

First, if vote data are not in the recommended format they should be converted into an R list, *votedata* say, using the function *pref.data* (see $4 below). Then the election count is run using the function *stv*:

```
res=stv(votedata,outdirec="stv_out")
```

(or similarly for *stv.wig*). This sets an output directory, but otherwise uses the default options for *stv*: a brief summary of the result *res* will be printed, while full details and plots with webpages to display them will be stored in *outdirec*. If you follow the above literally, *outdirec* will be a directory called "stv_out" within your working directory; more likely, you will prefer to replace "stv_out" with the path to a directory of your choice.

Other options (see $3) include pausing the election at each stage with fuller details and a plot of the current state of the count displayed, or omitting graphical output altogether; while the output directory can be left as the default value of tempdir() so that it is ephemeral.

For more on output options see $5.

3 Functions associated with data input

The required input format for the key vote counting functions, *stv* and *stv.wig*, is an R list. This section describes this format, and a function *pref.data* that converts some commonly used vote data formats into it.

In detail, *votedata, vd* for short, should be an R list including some or all of the following elements:

vd$e - election name
vd$s - number of representatives to be elected
vd$c - number of candidates
vd$nv - number of votes
vd$v - matrix of votes (*vd$nv* × *ed$c*)
vd$m - multiplicity for each vote (=1 if just one vote per row)
vdn, edf, ed$n2 - name, first name, and abbreviated name for each candidate
vdp, edcol - party acronyms and party colours of candidates (if appropriate - otherwise the empty character "")

The first thing to say is that the only essential element here is the vote matrix ed$v. If the candidates' names are not given, they will be assumed to be *dimnames(ed$v)[[2]]*, and if this is empty capital letters A,B,... will be used.

An election name and the number of representatives to be elected are also essential, but if these are not given the user will be asked for them (see example *Yale* in $6).

The function ***pref.data*** converts some common preference data formats into this required format. Its defaults –

pref.data(datafile,mult=FALSE,details=TRUE,parties=FALSE,
ballot=FALSE,friendly=FALSE,header=FALSE)

– correspond to the common .blt format, which is for example used for Scottish council elections; except that for the public Scottish Council election datasets one needs mult=TRUE, and should also set parties=TRUE.

In more detail, the options are:

mult - if TRUE, the multiplicity of each row of the vote matrix is given as its first element

parties - either FALSE, or the name of a file with party acronyms nd colours

ballot - if TRUE, ith entry in a row is the preference number for candidate i
- if FALSE, rows are candidate numbers in order of preference, with bracketing indicating equal preference

friendly - if TRUE, file starts with title, then *vd$s* and *vd$c*, then candidate names
- if FALSE, starts with *vd$c* and *vd$s*, with candidate names and election title at end of file (the common '.blt' format)

details - if FALSE, data are simply a vote matrix, with the first column containing multiplicities if mult=TRUE and the first line giving candidate names if *header*=TRUE

Other data formats

Hopefully, users with data in other formats will not find it too hard to convert their data into an R list with components as for *vd* above. Some points to note are:

vd$nv is the number of lines of vote data: this will be the actual vote total if these are all individual votes; otherwise, the vote total is *sum(ed$m)*. The variable *vd$n2* is used to avoid names of excessive length, and to distinguish two candidates with the same surname; if these are not a problem for your data, just set *vd$n2 = ed$n*. If party acronyms and colours are not relevant, just set *vd$p* and *vd$col* to the empty character (*i.e. = rep("",ed$c)*). The program will then use its 'rainbow' default to choose colours for the graphics.

STV allowing equal preferences

It should be noted that *votedata* need not explicitly include information on whether equal preferences are allowed. The numbers in each row of the vote matrix establish that voter's order of preference: if some of the numbers are equal, *stv* treats them as equal preferences. On the other

hand, *stv.wig* expects orders of preference to be strict, and will crash if given data including equal preferences.

4 Functions associated with the count

This section describes the two count functions, *stv* and *stv.wig*. Each has both input and output in the form of an R list; and also, as default, makes plots of the count stages, and webpages to view them.

The required data input format is described in $3.

For *stv*, which implements Meek STV allowing equal preferences, the options and their default values are as follows:

`elecdata = stv(votedata,outdirec=tempdir(),verbose=FALSE,plot=TRUE, webdisplay=FALSE)`

The value returned here is a list *elecdata* of results (*ed* for short), consisting of all the elements of *votedata*, supplemented by the following items:

ed$sys - the STV system used (="meek")
ed$elec - the names of those elected, in order of election
ed$itt - candidates in order of election/exclusion, reported at each stage
ed$narrative - an explanation of each stage of the count, in words
ed$count - a matrix of the votes at each stage and the final keep values
ed$quotatext - the total number of votes, and initial and final values of the quota
ed$va - a 3D array showing how votes have transferred (from first to current preference) for each stage
ed$keep - the keep values (as %s) at each stage
ed$report - a text report on the election (see $5)

This list is stored as a compressed R data file .rda format) in the directory *outdirec*. The default option for *outdirec* is an ephemeral directory *tempdir()*; this choice is to avoid writing to a user's filespace without warning. More usually, users will wish to keep election results, and should make their own choice of *outdirec* accordingly.

Note that the output file name will be *"election name"_"sys".rda*, with any spaces in the election name replaced by underscores ("_"). It is therefore important that the election name should not include any of the special characters that operating systems, especially Windows, do not allow in file names (*e.g.* quotes or brackets).

With the default options, the function *stv* will also make webpages in *outdirec* with plots showing each stage of the count. Note that the plots are saved as jpegs and then displayed using a function *plot_jpeg* that relies on the package *jpeg*. This is to avoid dependence on local R plotting parameters. If *jpeg* is not available, a warning message will be printed and *plot* set = FALSE to disable plotting.

If you set *webdisplay=TRUE* plots should be displayed automatically - but note that this feature is system-dependent and might fail. The safer option is to stay with the default option *webdisplay=FALSE*, and open the web pages from *outdirec* later. Note that these webpages include a numerical display of full details of the count and plots of transfers, each as an option that requires clicking a button to display.

A full expository option is stv(votedata,outdirec="out",verbose=TRUE, webdisplay=TRUE); this displays progress in numbers and a plot at each stage of the count, requiring the user to press 'return' to ask for the next stage when ready, and concludes by displaying the full results as web pages. Alternatively, combining the options verbose=FALSE and plot=FALSE calculates the detailed result with minimal printout and no graphical output.

The other STV count function, *stv.wig*, has the same default options as *stv*:

```
elecdata = stv.wig(votedata,outdirec=tempdir(),verbose=FALSE,
  plot=TRUE,webdisplay=FALSE)
```

This function implements the 'Weighted Inclusive Gregory' (WIG) algorithm, which has been used for Scottish Council elections since 2007. This differs from Meek in not allowing transfers to already elected candidates. While that may seem harmless - or even desirable - it introduces discontinuities, and the quota cannot be adjusted satisfactorally: a significant factor in political elections and those with large numbers of candidates. The sole justification for preferring it to Meek is that it can if necessary be counted by hand (which is probably not relevant if you're reading this). The differences in practice between the WIG and Meek algorithms can be explored at www.macs.hw.ac.uk/~denis/stv_elections, which cross-references each Scottish council count (for 2012 and 2017) with its Meek version.

The value returned by the *stv.wig* function is a list containing the same items (*mutatis mutandis*) as for the *stv* function, except for the last, *keep*, which is not relevant for WIG.

5 Functions associated with output

The list *elecdata* produced by the count functions *stv* or *stv.wig* contains both the original vote data and comprehensive statistics of the count. If either of these functions is run with the option *verbose=TRUE* it prints out as it runs a full report of the count and its result in narrative order; and if run with the default option *plot=TRUE* it makes plots and web pages, which will be shown as it runs if *webdisplay=TRUE*.

The report of the count is stored as an element of the output list *elecdata*, so even if *verbose=FALSE* has been used, it can be printed subsequently; *e.g.*, if the output list is *p17wig*, use *cat(p17wig$report, sep="\n")*.

For output plots, a function *stv.plots* is provided to print the same details as come from running *stv* or *stv.wig* with *verbose=TRUE*:

od = **stv.plots**(*elecdata*,outdirec=tempdir(),webdisplay=FALSE)

The default of a temporary output directory is chosen to avoid writing to the user's permanent file space without consent; and the default of *webdisplay=FALSE* to avoid possible browser problems. Normal users are likely to want either to set a permanent *outdirec* to save their results, or to use *webdisplay=TRUE* to display them (or both). The output value *od* is the value of *outdirec*; it is only needed if you do use the default settings. In that case you can make the output plots permanent in an output directory of your choice; for example:

```
dir.create("p17wig")
file.copy(file.path(od,list.files(od)),"p17wig")
```

6 Examples

This section includes examples for all the input, count and output functions. But first an example that shows how they can be combined to go from raw data to presentation of results.

Jedburgh and District 2012

```
datafile=system.file("extdata","Jedburgh2012.blt",package="pref")
parties12=system.file("extdata","parties_SC2012.txt",package="pref")
```

The first command here loads the full data for a typical Scottish Council election in the common *.blt* format. Scottish Council election data files have two features to note: votes with the same preference order are stored as one, but with their multiplicty noted in the vector *mult*; and the data include each candidate's party affiliation. The second command uses a data file *parties_SC2012.txt* to link each candidate to their party's standard colour. Then the command

jed12=pref.data(datafile,mult=TRUE,parties=parties12)

converts the data into the standard R list format described in $3. Next, running

jed12wig=stv.wig(jed12,outdirec="sc12",plot=FALSE)

reproduces exactly the official result of this election, in the form of an R list (see $4), and also stores that R list in a directory *sc12* (created if necessary) in the current working directory. This `silent' mode may be appropriate when handling a large number of elections at once, such as a countrywide set of local elections like this one. Details can then be extracted subsequently, using *stv.result(jed12wig)* for a text description of the result, and *stv.plots(jed12wig)* for plots.

An alternative is to create both text and plots when running the count function, thus:

jed12wig=stv.wig(jed12,outdirec="sc12",verbose=TRUE)

You may like to add the option *webdisplay=TRUE* to this command; this will show plots at each stage of the count, and display them within web pages once it is complete. Note that you need to press *return* to move on at each stage; this feature is provided particularly to work with live vote counting, so that the result of each stage can be displayed and considered before moving on to the next stage of the count. The option *webdisplay=TRUE* can also be used with *stv.plots*, but since that function is for use after a count has been completed it does not have this interactive requirement.

Other examples where pre-processing input data is required

JMT 2002

An example of a charity trustee election using Meek STV allowing equal preferences; the data are in preference order format, equal preferences being indicated using brackets. Note that this file has been reordered in "friendly" format, *i.e.* with the election title and candidate names at the beginning of the file.

```
datafile=system.file("extdata","jmt2002.blt",package="pref")
j02=pref.data(datafile,friendly=TRUE)
```

Then running *j02result=stv(j02)* should reproduce exactly the official result of this election. As in the first example, you may wish to add options *outdirec=...* or *webdisplay=TRUE*.

Yale

An example with the simplest possible raw input data, simply a vote matrix. There are two options here: you can use *pref.data* as follows:

```
datafile=system.file("extdata","yale.dat",package="pref")
yale=pref.data(datafile,details=FALSE)
```

You will be asked for an election name ("Yale") and the number to elect (4).

Or you can ignore *pref.data* and construct *yale* directly:

```
votematrix=system.file("extdata","yale.dat",package="pref")
votes=read.table(votematrix)
yale=list(e="Yale",s=4,v=as.matrix(votes))
```

You can then use either count function, *stv* or *stv.wig*, to run an election count for these data (see count examples below).

Note that if you use *pref.data* the missing items of the vote data list will be filled, with deduced values where possible (*e.g.* *nv* and *c* are the dimensions of the vote matrix *v*), and otherwise defaults (*e.g.* letters *A, B, C ...* for candidate names). For the construction alternative the vote data list will not be filled in this way; but this does not matter much, as the count functions do a similar job of filling out.

Further examples using the count functions stv, stv.wig

Council 1999

Another example from an election allowing equal preferences, this time with data in ballot format.

```
datafile=system.file("extdata","c99.dat",package="pref")
c99=pref.data(datafile,ballot=TRUE)
```

Then running *c99result=stv(c99)* should reproduce exactly the official result of this election.

`Yale - last 12'

As mentioned above, the count for the Yale faculty election example can be calculated from the vote data list *yale*, using either count function (*). However, this example has a large number of candidates, 44 for 4 places. While the graphics cope, they are difficult to read (easier if you look at plots of individual stages separately). We can prune the data, starting after 32 candidates have been excluded (but none yet elected), to give clearer plots of the later (and decisive) stages of the election. Note that this is relatively easily done for data in ballot format, because it simply requires omitting the 32 columns of the vote matrix corresponding to those candidates. The resulting reduced vote data list is provided as *y12*, so that *y12_stv=stv(y12)* or *y12_wig=stv.wig(y12)* reproduces the later stages of this election count.

(*) Note that the actual election in this case was held under `Cambridge rules', so that neither *stv* nor *stv.wig* reproduces the official outcome. Indeed they both agree in filling the 4th place differently from the official result.

Examples from Scottish Council elections

The following four examples come from Scottish Council elections; using *stv.wig* reproduces the official result exactly. The full results for 2012-22 can be found at www.macs.hw.ac.uk/~denis/stv_elections. For the elections of 2012 and 2017, both the official count and one using Meek STV are given, with links to switch between the two for ease of comparison.

Helensburgh Central 2012 hc12result=stv.wig(hc12)

A very simple example of an election to choose 4 representatives, where 4 candidates had first preference totals of over 20%, and so were elected at the first stage. Note that in this simple case there is no difference between different STV methods.

Partick East - Kelvindale 2017 p17result=stv.wig(p17)

A more typical STV election (see page 1 for a sample of the output web pages).

North West and Central Sutherland 2017
nws17wig=stv.wig(nws17)

An example exposing one of the flaws of WIG STV: none of the elected candidates achieved the quota.

Cumnock and New Cumnock 2017 cnc17wig=stv.wig(cnc17)

An example where WIG and Meek give different results: here one of the two leading parties has fewer first preferences but they are more equally divided between their two candidates; under Meek this matters less because reductions in the quota allow more transfers between a party's candidates.

Other output options

The R list data format described in $3, used as output for *pref.data* and input for the count functions of $4, is intended to make available to users the main statistics of any election using preference voting. Users can extract any part of that, *e.g.* the vote data matrix, for their own use or analysis; and they may wish to add other election statistics such as the size of the electorate, turnout, or number of invalid votes.

The second R list data format, used as output for the count functions, for convenience includes all the input variables, together with those added by the count function; the latter are of course dependent on the STV method employed (Meek or WIG). As already mentioned ($5), one of these is a narrative report of the election that contains the information printed out by the count function when run with *verbose=TRUE*; for example, after running the last of the above examples, try *cat(cnc17wig,sep="\n")*.

Similarly, the function *stv.plots* is used to create plots and webpages of count results when these are not to hand from running the count function with its default option of *plot=TRUE*. Compare:

nws17meek=stv(nws17, plot=FALSE)
stv.plots(nws17meek,webdisplay=TRUE)
  with
nws17meek=stv(nws17,webdisplay=TRUE)

or make the same comparison omitting `*webdisplay=TRUE*' (in which case you should set a permanent *outdirec* for the plots).

7 Background: STV

The Single Transferable Vote is a system designed to elect representatives in such a way that each represents the same number of voters. For its relation to core democratic principles, and comparison with alternative forms of proportional representation, see Mollison (2023).

In STV, each voter provides their order of preference; these preferences are used to transfer unused votes or parts of votes from earlier to later preferences, according to the following algorithm:

(a) Votes are initially assigned to the voter's first choice
(b) The number of votes required to ensure election is calculated; this is called the *quota*. When the total number of votes is v and there are s seats to be filled, the quota is v/(s+1)
(c) Any candidate whose total reaches the quota is elected; if they have more than the quota, the surplus is transferred to their voters' next preferences
(d) If not all seats are filled, the candidate with fewest votes is excluded and all their votes are transferred to their voters' next preferences

Steps (b-d) are repeated, as necessary, until all seats are filled.

In counting the votes the only significant difficulty is in distributing the surplus σ_i of an elected candidates with vote v_i, where fairness suggests that equal fractions σ_i/v_i of each

vote should be transferred, and that, as a slightly less obvious part of that fairness, transfers should go exactly where the voter has requested even if the recipient has sufficient votes already. The latter feature has the knock-on effect of requiring further transfers, which is why (a) the count requires a computer, and (b) why this feature was not implemented until computers were available (Meek published his algorithm in 1969/70).

Meek's method has a number of other advantages, conceptual and practical (Mollison 2022), and is widely regarded as the best form of STV. There is really no good reason why any other method should be used if the vote data can be gathered securely as a computer file. It is therefore surprising that it has not previously been available on CRAN.

History of use

The original idea of STV goes back to Thomas Wright Hill (1819), with various improvements (use of preferential voting (Andrae, Hare), quota $\sim v/(s+1)$ (Droop) rather than $\sim v/s$ (Hare), and fractional transfers (Gregory)) introduced between 1855 and 1881, after which there was little change until Meek's reassessment for the computer age nearly 100 years later. STV has been used for political elections in various countries and regions, including Tasmania (since 1909) and Ireland (since its independence in 1921). In the UK it is currently used for the Northern Ireland Assembly and for Scottish Council elections - the latter provide the best source of STV data currently available.

STV is also increasingly used for electing the governing bodies of non-political organisations. Meek STV allowing voters to express equality of preference has been used by the John Muir Trust and the London Mathematical Society (since 1998 and 1999 respectively). The program used for those elections, the first publicly available for STV allowing equal preferences, was written in Pascal by the late David Hill; it was originally available through ERS Services.

Other STV methods and software

The key motive for this package was to put Meek STV allowing equal preferences into the public, open software, domain together with output, particularly graphics, that help the public to understand how STV works. The hope is that this

should make what is widely regarded as the best form of STV easily available to all for.the long term.

Hill's program remains available, currently through Civica, but not as open software; also, as a Pascal program, its prospects of long term support are limited. A wide range of STV methods are available - commercially - through Opavote; see https://www.opavote.com/methods/single-transferable-vote for descriptions of these. The package *STV* on CRAN makes available Cambridge (Massachusetts) STV, but this is widely regarded as obsolete - its legislation prescribes that only counting methods available in 1941 can be used. The package *Vote* on CRAN presents an elegantly written STV program that does allow equal preferences. However the system used, though it is described as being `developed from' Hill's 1987 Meek STV program is in fact a generalised version of WIG, in which the quota is allowed to reduce during the count; but this revision of the quota is incomplete, being only for those elected later in the count, with the consequence that the method fails to share several key advantages of Meek.

8 Development and extensions

Much of the motivation for developing this software lay in the study of the large sets of data available from Scotland's council elections since 2007, comprising over 1000 individual elections in all. The development therefore included programs to tidy up such data for processing, and a program *stv.batch* to run counts for such large data sets. This software is not currently at a stage suitable for the public domain, but is available from the author on request.

Future planned developments include adapting the web display functions so that they can be used on their own to display already calculated vote results.

The more radical future ambition is to add software for Condorcet's method (`majority rule'), for calculating and analysing results of elections to make a single choice from preference data.

At a more basic level, it would be useful to include implementations of other STV counting methods, and to provide more data handling options. Feedback from users on what would

be useful will be welcome.

Any additions or improvements will in the first instance be available through the development version on github ($2).

References

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Mollison, Denis (2022) `Why Meek?' *(draft under development)* https://www.macs.hw.ac.uk/~denis/stv/why_meek.pdf.

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Feedback

Comments, and expressions of interest in collaboration, will be very welcome.

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