

# Ionotropic receptors as the driving force behind human synapse establishment

## Supplementary Material

Lucas H. Viscardi

Danilo O. Imparato

Maria Cátira Bortolini

Rodrigo J. S. Dalmolin

### Abstract

Model uncertainty and limited data are fundamental challenges to robust management of human intervention in a natural system. These challenges are acutely highlighted by concerns that many ecological systems may contain tipping points, such as Allee population sizes. Before a collapse, we do not know where the tipping points lie, if they exist at all. Hence, we know neither a complete model of the system dynamics nor do we have access to data in some large region of state-space where such a tipping point might exist.

## Contents

<b>Project structure</b>	<b>1</b>
<b>Preprocessing</b>	<b>1</b>
Eukaryota species tree . . . . .	1
NCBI Taxonomy tree . . . . .	1
Duplicated Genera . . . . .	4
Hybrid tree . . . . .	4
Gene selection and annotation . . . . .	8
Neuroexclusivity . . . . .	11
Expression . . . . .	11
Pathways . . . . .	11
COG data . . . . .	11
Network . . . . .	11
<b>Analysis</b>	<b>11</b>

## Project structure

This is the title page

# Preprocessing

This topic refers mainly to data wrangling done before the actual analysis with the intent of making it simpler.

## Eukaryota species tree

We opted to use the TimeTree database in order to obtain an standardized Eukaryota species tree. However, some species were not present in it, so we devised a way to fill them in based on NCBI Taxonomy data.

## NCBI Taxonomy tree

First we preprocess NCBI Taxonomy data to leave only STRING eukaryotes, thus making the task easier.

## Resources

Table 1: Lists all organisms in STRING v11.

string_species					
#	Col. name	Col. type	Used?	Example	Description
1	taxid	character	yes	9606	NCBI Taxonomy identifier
2	string_type	character	no	core	if the genome of this species is core or periphery
3	string_name	character	yes	Homo sapiens	STRING species name
4	ncbi_official_name	character	no	Homo sapiens	NCBI Taxonomy species name
<b>Location:</b> data-raw/download/species.v11.0.txt					
<b>Source:</b> stringdb-static.org/download/species.v11.0.txt					

Table 2: Links outdated taxon IDs to corresponding new ones.

ncbi_merged_ids					
#	Col. name	Col. type	Used?	Example	Description
1	taxid	character	yes	140100	id of node that has been merged
2	new_taxid	character	yes	666	id of node that is the result of merging
<b>Location:</b> data-raw/download/taxdump/merged.dmp					
<b>Source:</b> ftp.ncbi.nlm.nih.gov/pub/taxonomy/taxdump.tar.gz					

Table 3: Represents taxonomy nodes.

ncbi_edgelist					
#	Col. name	Col. type	Used?	Example	Description
1	taxid	character	yes	2	node id in NCBI taxonomy database
2	parent_taxid	character	yes	131567	parent node id in NCBI taxonomy database
3	rank	character	no	superkingdom	rank of this node
4	...	...	no	...	(too many unrelated fields)

**Location:** data-raw/download/taxdump/nodes.dmp  
**Source:** ftp.ncbi.nlm.nih.gov/pub/taxonomy/taxdump.tar.gz

Table 4: Links taxon IDs to actual species names.

ncbi_taxon_names					
#	Col. name	Col. type	Used?	Example	Description
1	taxid	character	yes	2	the id of node associated with this name
2	name	character	yes	Monera	name itself
3	unique_name	character	no	Monera <bacteria>	the unique variant of this name if name not unique
4	name_class	character	yes	scientific name	type of name

**Location:** data-raw/download/taxdump/names.dmp  
**Source:** ftp.ncbi.nlm.nih.gov/pub/taxonomy/taxdump.tar.gz

## Updating STRING taxon IDs

Some organisms taxon IDs are outdated in STRING. We must update them to work with the most recent NCBI Taxonomy data.

```
string_species %<>%
  left_join(ncbi_merged_ids) %>%
  mutate(new_taxid = coalesce(new_taxid, taxid))
```

## Creating tree graph

The first step is to create a directed graph representing the NCBI Taxonomy tree.

```
# leaving only "scientific name" rows
ncbi_taxon_names %<>%
  filter(type == "scientific name") %>%
  select(name, ncbi_name)

# finding Eukaryota taxid
eukaryota_taxon_id <- subset(ncbi_taxon_names, ncbi_name == "Eukaryota", "name", drop = TRUE)

# creating graph
g <- graph_from_data_frame(ncbi_edgelist[,2:1], directed = TRUE, vertices = ncbi_taxon_names)

# easing memory
rm(ncbi_edgelist, ncbi_merged_ids)
```

## Traversing the graph

The second step is to traverse the graph from the Eukaryota root node to STRING species nodes. This

automatically drops all non-eukaryotes and results in a species tree representing only STRING eukaryotes (476).

```
eukaryote_root <- V(g)[eukaryota_taxon_id]
eukaryote_leaves <- V(g)[string_species[["new_taxid"]]]

# not_found <- subset(string_species, !new_taxid %in% ncbi_taxon_names$name)

eukaryote_paths <- shortest_paths(g, from = eukaryote_root, to = eukaryote_leaves, mode = "out")$vpath

eukaryote_vertices <- eukaryote_paths %>% unlist %>% unique

eukaryote_tree <- induced_subgraph(g, eukaryote_vertices, impl = "create_from_scratch")
```

## Saving

Saving `ncbi_tree` and `string_eukaryotes` for package use. These data files are documented by the package. We also create a plain text file `476_ncbi_eukaryotes.txt` containing the updated names of all 476 STRING eukaryotes. This file will be queried against the TimeTree website.

```
ncbi_tree <- treeio::as.phylo(eukaryote_tree)

# plot(ncbi_tree %>% ape::ladderize(), type="cladogram")

string_eukaryotes <- string_species %>%
  filter(new_taxid %in% ncbi_tree$tip.label) %>%
  inner_join(ncbi_taxon_names, by = c("new_taxid" = "name"))

write(string_eukaryotes[["ncbi_name"]], "476_ncbi_eukaryotes.txt")

# usethis::use_data(ncbi_tree, overwrite = TRUE)
write.tree(ncbi_tree, "ncbi_tree.nwk")
usethis::use_data(string_eukaryotes, overwrite = TRUE)
```

```
## <U+2714> Setting active project to 'C:/R/neuro'
## <U+2714> Saving 'string_eukaryotes' to 'data/string_eukaryotes.rda'
```

## Duplicated Genera

Some species from different kingdoms may share the same genus name. These genera must be noted down because one of the ways we fill in missing species is by looking at genera names.

## Loading data

See Table 3 and Table 4.

```
taxid_rank <- read_delim(
  "download/taxdump/nodes.dmp",
  skip = 1,
  delim = "|",
  trim_ws = TRUE,
  col_names = c("taxid", "rank"),
  col_types = "c-c"
)

ncbi_taxon_names <- read_delim(
  "download/taxdump/names.dmp",
  delim = "|",
  trim_ws = TRUE,
  col_names = c("taxid", "ncbi_name", "type"),
  col_types = "cc-c"
)
```

## Finding duplicated genera

```
# keeping genera nodes
taxid_rank %<>% filter(rank == "genus")

# keeping scientific names
ncbi_taxon_names %<>%
  filter(type == "scientific name") %>%
  select(taxid, ncbi_name) %>%
  inner_join(taxid_rank)

# extracting and saving duplicated values
duplicated_genera <- ncbi_taxon_names %>%
  pull(ncbi_name) %>%
  extract(duplicated(.)) %>%
  write("duplicated_genera.txt")
```

## Hybrid tree

Once we have both the NCBI eukaryotes tree and the list of duplicated genera, we can start assembling the complete hybrid tree.

## Downloading data

Besides downloading all TimeTree species data (`Eukaryota_species.nwk`) we also need to manually query the website for the 476 STRING eukaryotes (`476_ncbi_eukaryotes.txt`). The file is called `476_ncbi_eukaryotes.txt` because it contains updated NCBI Taxonomy names rather than STRING outdated names. This ensures better results.

```
download_if_missing(
  paste0("http://timetree.org/ajax/direct_download",
    "?direct-download-format=newick",
    "&direct-download-id=23070",
    "&direct-download-rank=species"),
  "Eukaryota_species.nwk"
)
```

## Loading data

```
# loading species names and taxon ids
data(string_eukaryotes, package = "neurotransmissionevolution")

# loading newick tree manually obtained from timetree
timetree_newick <- read.tree("download/timetree_335_eukaryotes.nwk")

# the following genera names are unreliable and should not be searched for
duplicated_genera <- scan("duplicated_genera.txt", what = "character")

# loading all TimeTree species data we have just download (85000 species)
tree_85k <- read.tree("download/Eukaryota_species.nwk")
```

## Unfound species with matching genera

Some of the 476 STRING eukaryotes are not present in the TimeTree database. However, sometimes TimeTree does contain tree data for closely related species (e.g. *Monosiga brevicollis* is not present, but *Monosiga ovata* is). Therefore, we can use these closely related species as proxies for the actual species. This is done by searching for genera names in the complete database (`Eukaryota_species.nwk`). In the given *Monosiga brevicollis* example, we search for *Monosiga* in the complete database. We see that there is information for at least one other species of the *Monosiga* genus (in this case, *Monosiga ovata*), so we add *Monosiga brevicollis* as a sister branch to the found species.

When you search for a term in TimeTree, it uses a synonym list obtained from NCBI to try to resolve it. Sometimes TimeTree will resolve a searched term to a scientific name different from the one you searched for. The problem with this is that TimeTree does not make it obvious that it is returning a different term. The first step is to find out which species resolved to different names in the `timetree_335_eukaryotes.nwk` file:

```
# plot(timetree_newick %>% ladderize, type = "cladogram", use.edge.length = F)

# replacing timetree species underscores with spaces
timetree_newick[["tip.label"]] %<>% str_replace_all("_", " ")

# which timetree species' names exactly match with ncbi's
taxid_indexes <- timetree_newick[["tip.label"]] %>% match(string_eukaryotes[["ncbi_name"]])

# find out which timetree species names didn't exactly match ncbi's
unmatched_names <- timetree_newick[["tip.label"]] %>% magrittr::extract(taxid_indexes %>% is.na)
print(unmatched_names)
```

```
## [1] "Cercospora fijiensis"      "Arthroderma benhamiae"
## [3] "Macropus eugenii"         "Ostreococcus lucimarinus"
## [5] "Oryza nivara"
```

```
# manually creating lookup table to be joined
ncbi_to_timetree <- tribble(
  ~timetree_name,      ~ncbi_name,
  "Cercospora fijiensis", "Pseudocercospora fijiensis",
  "Arthroderma benhamiae", "Trichophyton benhamiae",
  "Macropus eugenii", "Notamacropus eugenii",
  "Ostreococcus lucimarinus", "Ostreococcus sp. 'lucimarinus'",
  "Oryza nivara", "Oryza sativa f. spontanea"
)

# joining info
species_dictionary <- string_eukaryotes %>% left_join(ncbi_to_timetree)

# coalescing NAs to ncbi_name
species_dictionary %<>%
  mutate(timetree_name = coalesce(timetree_name, ncbi_name)) %>%
  mutate(timetree_name = ifelse(timetree_name %in% timetree_newick[["tip.label"]], timetree_name, NA))
```

Now we can start looking for unfound species genera in the complete tree data.

```
# annotating genera
species_dictionary %<>%
  mutate(genus_search = coalesce(timetree_name, ncbi_name)) %>%
  strsplit(" ") %>%
  sapply("[", 1))

# unique genera
selected_genera <- species_dictionary[["genus_search"]] %>% unique

# these are unreliable selected_genera:
unreliable_genera <- intersect(selected_genera, duplicated_genera)

# ensuring a cleaner newick file with only necessary data
# this is actually really important
tree_85k[["node.label"]] <- NULL
tree_85k[["edge.length"]] <- NULL

# replacing timetree's underscores with spaces
tree_85k[["tip.label"]] %<>% str_replace_all("_", " ")

# storing genus
tree_85k[["tip.genus"]] <- sapply(strsplit(tree_85k[["tip.label"]], " "), "[", 1)
tree_85k_genera <- tree_85k[["tip.genus"]] %>% unique

# subtracting unreliable genera
tree_85k_genera %<>% setdiff(unreliable_genera)

# keeping only selected genera, including unreliable ones
tree_genus <- tree_85k %$% keep.tip(., tip.label[tip.genus %in% selected_genera])
tree_genus[["tip.genus"]] <- sapply(strsplit(tree_genus[["tip.label"]], " "), "[", 1)

# unfound species which genera are present in the 85k tree
unfound_species <- species_dictionary %>%
  filter(is.na(timetree_name) & genus_search %in% tree_85k_genera)
```

Once we figured out which species have proxy genera in the complete data, we can start filling them in as sister branches.

```

# for each unfound species which genus is present in the 85k tree,
for(i in 1:nrow(unfound_species)){
  # we search for all species of this genus ("sister species") in the 85k tree
  # this part is tricky because bind.tip rebuilds the tree from scratch
  # so we need to keep removing underscores. there are better ways to do this.
  tip_genus <- tree_genus[["tip.label"]] %>% strsplit("_") %>% sapply(" ", 1)
  sister_species <- tree_genus[["tip.label"]][tip_genus == unfound_species[[i, "genus_search"]]
  # we obtain the sister_species' most recent common ancestor (MRCA)
  # c(.[1]) is a hack because the MRCA function only works with at least 2 nodes
  where <- getMRCA(tree_genus, sister_species %>% c(.[1]))
  # and then add a leaf node linked to this MRCA
  tree_genus %<>% bind.tip(tip.label = unfound_species[[i, "ncbi_name"]], where = where)
}

# for some reason bind.tip adds underscores to species names
tree_genus[["tip.label"]] %<>% str_replace_all("_", " ")

# keeping track of found species
found_species <- species_dictionary %>% filter(!is.na(timetree_name) | genus_search %in% tree_85k_genera)
# forced_name means it either was found in timetree or we forced it by looking at genera names
found_species %<>% mutate(forced_name = coalesce(timetree_name, ncbi_name))

# so we keep only found species in this tree we are building (timetree + forced by genera)
tree_genus %<>% keep.tip(found_species[["forced_name"]])

# which found_species rows correspond to each tip.label?
match_tiplabel_name <- match(tree_genus[["tip.label"]], found_species[["forced_name"]])

tree_genus %<>% list_modify(
  # converting to ncbi taxids
  tip.label = found_species[["new_taxid"]][match_tiplabel_name]
)

```

## Species of unfound genera

In this part, we try to fill in the remaining missing species (those which genera were not found in TimeTree) by searching for their closest relatives (according to NCBI Taxonomy) that are present in the current tree. Once we find its two closest relatives, we can add the missing species as a branch from their LCA. This is a conservative approach.

```

# converting ncbi phylo to igraph
graph_ncbi <- read.tree("ncbi_tree.nwk") %>% as.igraph.phylo(directed = TRUE)

# converting phylo to igraph
graph_genus <- as.igraph.phylo(tree_genus, directed = TRUE)

# for each species which genus is not in timetree
# we'll look for its two closest species (in the NCBI tree) which are present in the tree_genus we just built
unfound_genera <- species_dictionary %>% filter(is.na(timetree_name) & !genus_search %in% tree_85k_genera)

# this is the igraph equivalent of "phylo_tree$tip.label"
tip_nodes <- V(graph_ncbi)[degree(graph_ncbi, mode = "out") == 0]

# undirected distances between all species nodes
tip_distances <- graph_ncbi %>%
  distances(v = tip_nodes, to = tip_nodes, mode = "all") %>%
  as_tibble(rownames = "from") %>%
  pivot_longer(-from, names_to = "to", values_to = "distance")

# removing self references (zero distances)
tip_distances %<>% filter(distance > 0)

# we only want to search for species of unfound genera
tip_distances %<>% inner_join(unfound_genera %>% select(from = new_taxid))

# we only want to find species already present in the genus_tree
tip_distances %<>% inner_join(found_species %>% select(to = new_taxid))

# we only want the two closest relatives
tip_distances %<>%
  group_by(from) %>%
  top_n(-2, distance) %>% # top 2 smallest distances
  top_n(2, to) # more than 2 species have the same smallest distance, so we get the first ones

# out distance matrix between all nodes in tree, needed to find MRCAs
out_distances <- graph_genus %>% distances(mode = "out")

```

```

# for each species of unfound genera,
# we find the MRCA for its two closest relatives
unfound_genera_mrca <- tip_distances %>% group_by(from) %>% summarise(mrca = {
  # which rows have no infinite distances? the last one represents the MRCA
  mrca_row_index <- max(which(rowSums(is.infinite(out_distances[, to])) == 0))
  rownames(out_distances)[mrca_row_index]
})

# adding unfound genera species nodes
graph_genus %<>% add_vertices(nrow(unfound_genera_mrca), color = "red", attr = list(name = unfound_genera_mrca[["from"]]))

# defining unfound genera species edges
# edges_to_add[1] -> edges_to_add[2], edges_to_add[2] -> edges_to_add[3]...
edges_to_add <- V(graph_genus)[unfound_genera_mrca %>% select(mrca, from) %>% t %>% as.vector]$name

# connecting species leaves to the supposed MRCA
graph_genus %<>% add_edges(V(graph_genus)[edges_to_add])

# plotting
# plot(as.undirected(graph_genus), layout = layout_as_tree(graph_genus), vertex.label = NA, vertex.size=2)

# finally converting to phylo format
phylo_graph_genus <- treeio::as.phylo(graph_genus)

# which species_dictionary rows correspond to each tip.label?
match_tiplabel_taxid <- match(phylo_graph_genus[["tip.label"]], species_dictionary[["new_taxid"]])

phylo_graph_genus %<>% list_modify(
  # adding tip.alias (this is not exported with write.tree)
  tip.alias = species_dictionary[["string_name"]][match_tiplabel_taxid],
  # converting back to string ids
  tip.label = species_dictionary[["taxid"]][match_tiplabel_taxid]
)

# ensuring a cleaner newick file with only necessary data
phylo_graph_genus[["node.label"]] <- NULL
phylo_graph_genus[["edge.length"]] <- NULL

# usethis::use_data(phylo_graph_genus, overwrite = TRUE)
# write.tree(phylo_graph_genus, "../data/hybrid_tree.nwk")

```

## Ctenophora as sister to all animals

According to TimeTree, Ctenophora remains as a sister group to Cnidaria. We believe the most recent consensus in literature is to consider them a sister group to all animals. The following code block moves *Mnemiopsis leidyi*, the only ctenophore in our analysis, to the base of the metazoan lineage.

```

# moving ctenophora before porifera
mnemiopsis_taxid <- species_dictionary %>% filter(ncbi_name == "Mnemiopsis leidyi") %>% pull(taxid)
amphimedon_taxid <- species_dictionary %>% filter(ncbi_name == "Amphimedon queenslandica") %>% pull(taxid)

# reordering tip.labels
from_to <- c(
  "400682" = "27923", # amphimedon to mnemiopsis
  "10228" = "400682", # trichoplax to amphimedon
  "27923" = "10228" # mnemiopsis to trichoplax
)

modified_phylo <- phylo_graph_genus

modified_phylo[["tip.label"]] %<>% recode(!!!from_to)

write.tree(modified_phylo, "../data/hybrid_tree_modified.nwk")

```

## Gene selection and annotation

The anchoring point for this study is basic annotation about genes and the pathways in which they participate. This section describes the process of structuring such data. In the end we will have a table to which all kinds of additional data will be left joined into.



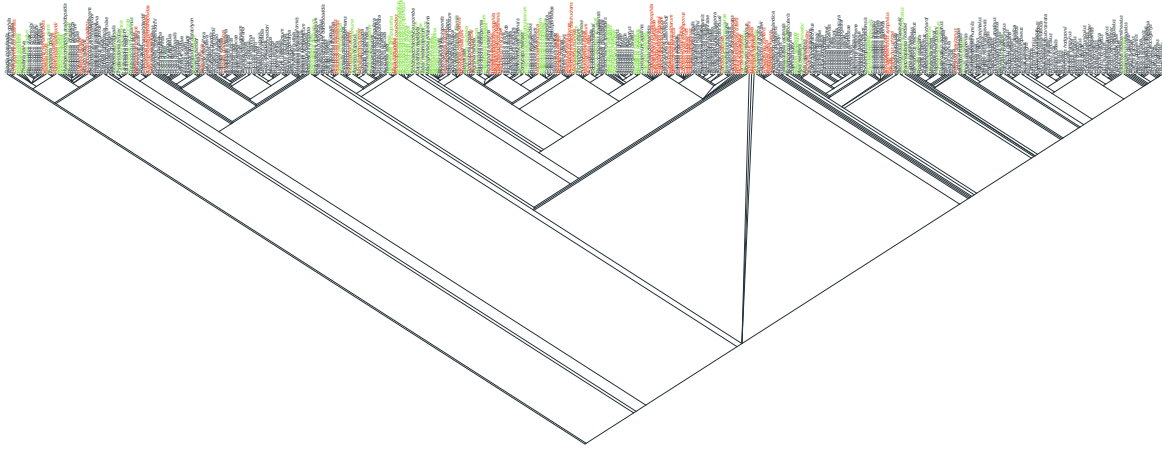


Figure 1: Complete 476 eukaryotes tree. Green species have been filled in by a genus proxy in TimeTree. Red species have been filled in by looking at NCBI Taxonomy.

### Neurotransmitter systems annotation

We start by querying the KEGG api for the pathways of interest. Resulting data is then pivoted to a wider format.

Table 5: All links between genes and pathways in KEGG.

link_pathway_entrez					
#	Col. name	Col. type	Used?	Example	Description
1	entrez_id	character	yes	hsa:10411	NCBI Taxonomy identifier
2	pathway_id	character	yes	path:hsa04726	KEGG pathway ID

**Location:** data-raw/download/link\_pathway\_entrez.tsv

**Source:** <http://rest.kegg.jp/link/pathway/hsa>

```
pathways <- tribble(
  ~pathway_id,      ~pathway_name,
  "path:hsa04724",  "glutamatergic",
  "path:hsa04725",  "cholinergic",
  "path:hsa04726",  "serotonergic",
  "path:hsa04727",  "gabaergic",
  "path:hsa04728",  "dopaminergic",
  "path:hsa04721",  "vesicle"
)

# removing hsa prefix
link_pathway_entrez[["entrez_id"]] %<>% str_split_n(":", 2)

# filtering for pathways of interest and pivoting
gene_pathways <- inner_join(link_pathway_entrez, pathways) %>%
  mutate(n = 1) %>%
  pivot_wider(
    id_cols = entrez_id,
    names_from = pathway_name,
    values_from = n,
    values_fn = list(n = length),
    values_fill = list(n = 0)
  ) %>%
  # filling 1's in all systems for synaptic vesicle genes
  # mutate_at(pathways[["pathway_name"]], ~ ifelse(vesicle == 1, 1L, .)) %>%
  mutate(system_count = rowSums(select(., -entrez_id, -vesicle)))

# exporting for package use
```

```
usethis::use_data(gene_pathways, overwrite = TRUE)
```

```
## <U+2714> Setting active project to 'C:/R/neuro'
## <U+2714> Saving 'gene_pathways' to 'data/gene_pathways.rda'
```

entrez_id	vesicle	glutamatergic	cholinergic	serotonergic	gabaergic	dopaminergic	system_count
10312	1	0	0	0	0	0	0
10497	1	0	0	0	0	0	0
10814	1	0	0	0	0	0	0
10815	1	0	0	0	0	0	0
112755	1	0	0	0	0	0	0
1173	1	0	0	0	0	0	0

### Base ID lookup table

Now we start building a base ID lookup table containing entrez gene IDs, STRING ensembl protein IDs, ensembl gene IDs, STRING protein names and entrez gene names. Every piece of data in subsequent analyses will be progressively joined to it.

Table 6: Conversion dictionary from entrez ID to STRING's ensembl protein ID.

link_entrez_string					
#	Col. name	Col. type	Used?	Example	Description
1	taxid	numeric	no	9606	NCBI Taxonomy ID
2	entrez_id	numeric	yes	7157	entrez gene ID
3	string_id	character	yes	9606.ENSP00000269305	STRING ID

**Location:** data-raw/download/human.entrez\_2\_string.2018.tsv.gz

**Source:** [https://string-db.org/mapping\\_files/entrez/human.entrez\\_2\\_string.2018.tsv.gz](https://string-db.org/mapping_files/entrez/human.entrez_2_string.2018.tsv.gz)

Table 7: Conversion dictionary from STRING ID to protein name.

string_names					
#	Col. name	Col. type	Used?	Example	Description
1	taxid	numeric	no	9606	NCBI Taxonomy ID
2	string_name	character	yes	TP53	protein name
3	string_id	character	yes	9606.ENSP00000269305	STRING ID

**Location:** data-raw/download/human.name\_2\_string.tsv.gz

**Source:** [https://string-db.org/mapping\\_files/STRING\\_display\\_names/human.name\\_2\\_string.tsv.gz](https://string-db.org/mapping_files/STRING_display_names/human.name_2_string.tsv.gz)

Table 8: Conversion dictionary from entrez ID to gene name.

entrez_names					
#	Col. name	Col. type	Used?	Example	Description
1	taxid	numeric	no	9606	taxon ID
2	entrez_id	character	yes	7157	entrez gene ID
3	entrez_name	character	yes	TP53	gene name
4	...	...	no	...	(too many unrelated fields)

**Location:** data-raw/download/Homo\_sapiens.gene\_info.gz  
**Source:** https://ftp.ncbi.nlm.nih.gov/gene/DATA/GENE\_INFO/Mammalia/Homo\_sapiens.gene\_info.gz

Table 9: Conversion dictionary from entrez ID to ensembl gene (ENSG) ID.

link_ensembl_entrez					
#	Col. name	Col. type	Used?	Example	Description
1	entrez_id	character	yes	hsa:7157	entrez gene ID
2	ensembl_id	character	yes	ensembl:ENSG00000141510	ensembl gene ID

**Location:** data-raw/download/link\_ensembl\_entrez.tsv  
**Source:** http://rest.genome.jp/link/ensembl/hsa

```
# removing all kegg prefixes (e.g. "hsa:")
link_ensembl_entrez %<>% mutate_all(~ str_split_n(., ":", 2))

# joining all data
gene_ids <- gene_pathways %>%
  select(entrez_id) %>%
  left_join(link_ensembl_entrez) %>%
  left_join(link_entrez_string) %>%
  left_join(string_names) %>%
  left_join(entrez_names)
```

Some STRING proteins couldn't be automatically resolved, so we perform it manually

```
gene_ids[!complete.cases(gene_ids),]
```

entrez_id	ensembl_id	string_id	string_name	entrez_name
9296	ENSG00000128524	NA	NA	ATP6V1F
100137049	ENSG00000243708	NA	NA	PLA2G4B
85358	ENSG00000251322	NA	NA	SHANK3
8681	ENSG00000168970	NA	NA	JMJD7-PLA2G4B
1139	ENSG00000175344	NA	NA	CHRNA7
107987478	NA	NA	NA	LOC107987478
107987479	NA	NA	NA	LOC107987479
1564	ENSG00000205702	NA	NA	CYP2D7
801	ENSG00000198668	NA	NA	CALM1
805	ENSG00000143933	NA	NA	CALM2
808	ENSG00000160014	NA	NA	CALM3

```
complete_info <- tribble(
  ~entrez_id, ~ensembl_id, ~string_id, ~string_name, ~entrez_name,
  "9296", "ENSG00000128524", "9606.ENSP00000417378", "ATP6V1F", "ATP6V1F",
  "100137049", "ENSG00000243708", "9606.ENSP00000396045", "PLA2G4B", "PLA2G4B",
  "85358", "ENSG00000251322", NA, NA, "SHANK3",
```

```

"8681",      "ENSG00000168970", "9606.ENSP00000371886", "JMJD7-PLA2G4B", "JMJD7-PLA2G4B",
"1139",      "ENSG00000175344", "9606.ENSP00000407546", "CHRNA7",      "CHRNA7",
"107987478", NA,      NA,      NA,      "LOC107987478",
"107987479", NA,      NA,      NA,      "LOC107987479",
"1564",      "ENSG00000205702", NA,      NA,      "CYP2D7",
"801",      "ENSG00000198668", "9606.ENSP00000349467", "CALM1",      "CALM1",
"805",      "ENSG00000143933", "9606.ENSP00000272298", "CALM2",      "CALM2",
"808",      "ENSG00000160014", "9606.ENSP00000291295", "CALM3",      "CALM3"
)

# removing incomplete cases and adding updated ones
gene_ids %<>% na.omit %>% bind_rows(complete_info)

# removing taxid prefix from STRING IDs
gene_ids[["string_id"]] %<>% str_split_n("\\.", 2)

# exporting for package use
usethis::use_data(gene_ids, overwrite = TRUE)

## <U+2714> Saving 'gene_ids' to 'data/gene_ids.rda'

```

## Neuroexclusivity

Explanation

Expression

Pathways

COG data

Network

## Analysis

Analysis

```
#leave this chunk
```