

# How to use bimap from the ".db" annotation packages

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## 1 Introduction

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### 1.0.1 Purpose

AnnotationDbi is used primarily to create mapping objects that allow easy access from R to underlying annotation databases. As such, it acts as the R interface for all the standard annotation packages. Underlying each AnnotationDbi supported annotation package is at least one (and often two) annotation databases. AnnotationDbi also provides schemas for these databases. For each supported model organism, a standard gene centric database is maintained from public sources and is packaged up as an appropriate organism or "org" package.

### 1.0.2 Database Schemas

For developers, a lot of the benefits of having the information loaded into a real database will require some knowledge about the database schema. For this reason the schemas that were used in the creation of each database type are included in AnnotationDbi. The currently supported schemas are listed in the DBSchemas directory of AnnotationDbi. But it is also possible to simply print out the schema that a package is currently using by using its "\_dbschema" method.

There is one schema/database in each kind of package. These schemas specify which tables and indices will be present for each package of that type. The schema that a particular package is using is also listed when you type the name of the package as a function to obtain quality control information.

The code to make most kinds of the new database packages is also included in AnnotationDbi. Please see the vignette on SQLForge for more details on how to make additional database packages.

### 1.0.3 Internal schema Design of org packages

The current design of the organism packages is deliberately simple and gene centric. Each table in the database contains a unique kind of information and also an internal identifier called \_id. The internal \_id has no meaning outside of the context of a single database. But \_id does connect all the data within a single database.

As an example if we wanted to connect the values in the genes table with the values in the kegg table, we could simply join the two tables using the internal \_id column. It is very important to note however that \_id does not have any absolute significance. That is, it has no meaning outside of the context of the database where it is used. It is tempting to think that an \_id could have such significance because within a single database,

it looks and behaves similarly to an entrez gene ID. But `_id` is definitely NOT an entrez gene ID. The entrez gene IDs are in another table entirely, and can be connected to using the internal `_id` just like all the other meaningful information inside these databases. Each organism package is centered around one type of gene identifier. This identifier is found as the `gene_id` field in the `genes` table and is both the central ID for the database as well as the foreign key that chip packages should join to.

The chip packages are 'lightweight', and only contain information about the basic probe to gene mapping. You might wonder how such packages can provide access to all the other information that they do. This is possible because all the other data provided by chip packages comes from joins that are performed by `AnnotationDbi` behind the scenes at run time. All chip packages have a dependency on at least one organism package. The name of the organism package being depended on can be found by looking at its "ORGPKG" value. To learn about the schema from the appropriate organism package, you will need to look at the "`_dbschema`" method for that package. In the case of the chip packages, the `gene_id` that in these packages is mapped to the `probe_ids`, is used as a foreign key to the appropriate organism package.

Specialized packages like the packages for GO and KEGG, will have their own schemas but will also adhere to the use of an internal `_id` for joins between their tables. As with the organism packages, this `_id` is not suitable for use as a foreign key.

For a complete listing of the different schemas used by various packages, users can use the `available.dbschemas` function. This list will also tell you which model organisms are supported.

```
require(org.Hs.eg.db)

## Loading required package: org.Hs.eg.db
## Loading required package: AnnotationDbi
## Loading required package: stats4
## Loading required package: BiocGenerics
## Loading required package: parallel
##
## Attaching package: 'BiocGenerics'
##
## The following objects are masked from 'package:parallel':
##
##   clusterApply, clusterApplyLB, clusterCall, clusterEvalQ, clusterExport,
##   clusterMap, parApply, parCapply, parLapply, parLapplyLB, parRapply,
##   parSapply, parSapplyLB
##
## The following object is masked from 'package:stats':
##
##   xtabs
##
## The following objects are masked from 'package:base':
##
##   Filter, Find, Map, Position, Reduce, anyDuplicated, append, as.data.frame,
##   as.vector, cbind, colnames, do.call, duplicated, eval, evalq, get,
##   intersect, is.unsorted, lapply, mapply, match, mget, order, paste, pmax,
##   pmax.int, pmin, pmin.int, rank, rbind, rep.int, rownames, sapply, setdiff,
##   sort, table, tapply, union, unique, unlist, unsplit
##
```

```
## Loading required package: Biobase
## Welcome to Bioconductor
##
## Vignettes contain introductory material; view with 'browseVignettes()'. To
## cite Bioconductor, see 'citation("Biobase")', and for packages
## 'citation("pkgname)".
##
## Loading required package: GenomeInfoDb
## Loading required package: S4Vectors
## Loading required package: IRanges
##
## Attaching package: 'AnnotationDbi'
##
## The following object is masked from 'package:GenomeInfoDb':
##
## species
##
## Loading required package: DBI
require(AnnotationForge)
## Loading required package: AnnotationForge
available.dbschemas()
```

## 2 Examples

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### 2.0.4 Basic information

The *AnnotationDbi* package provides an interface to SQLite-based annotation packages. Each SQLite-based annotation package (identified by a ".db" suffix in the package name) contains a number of *AnnDbBimap* objects in place of the *environment* objects found in the old-style environment-based annotation packages. The API provided by *AnnotationDbi* allows you to treat the *AnnDbBimap* objects like *environment* instances. For example, the functions `[`, `get`, `mget`, and `ls` all behave the same as they did with the older environment based annotation packages. In addition, new methods like `[`, `toTable`, `subset` and others provide some additional flexibility in accessing the annotation data.

```
library("hgu95av2.db")
##
```

The same basic set of objects is provided with the db packages:

```
ls("package:hgu95av2.db")
## [1] "hgu95av2" "hgu95av2.db"
## [3] "hgu95av2ACCNUM" "hgu95av2ALIAS2PROBE"
## [5] "hgu95av2CHR" "hgu95av2CHRLNGTHS"
## [7] "hgu95av2CHRLOC" "hgu95av2CHRLOCEND"
```

```
## [9] "hgu95av2ENSEMBL"      "hgu95av2ENSEMBL2PROBE"
## [11] "hgu95av2ENTREZID"     "hgu95av2ENZYME"
## [13] "hgu95av2ENZYME2PROBE" "hgu95av2GENENAME"
## [15] "hgu95av2GO"           "hgu95av2GO2ALLPROBES"
## [17] "hgu95av2GO2PROBE"     "hgu95av2MAP"
## [19] "hgu95av2MAPCOUNTS"   "hgu95av2OMIM"
## [21] "hgu95av2ORGANISM"     "hgu95av2ORGPKG"
## [23] "hgu95av2PATH"         "hgu95av2PATH2PROBE"
## [25] "hgu95av2PFAM"         "hgu95av2PMID"
## [27] "hgu95av2PMID2PROBE"   "hgu95av2PROSITE"
## [29] "hgu95av2REFSEQ"       "hgu95av2SYMBOL"
## [31] "hgu95av2UNIGENE"      "hgu95av2UNIPROT"
## [33] "hgu95av2_dbInfo"      "hgu95av2_dbconn"
## [35] "hgu95av2_dbfile"      "hgu95av2_dbschema"
```

### Exercise 1

Start an R session and use the `library` function to load the `hgu95av2.db` software package. Use `search()` to see that an organism package was also loaded and then use the appropriate `"_dbschema"` methods to the schema for the `hgu95av2.db` and `org.Hs.eg.db` packages.

It is possible to call the package name as a function to get some QC information about it.

```
qcdata = capture.output(hgu95av2())
head(qcdata, 20)

## [1] "Quality control information for hgu95av2:"
## [2] ""
## [3] ""
## [4] "This package has the following mappings:"
## [5] ""
## [6] "hgu95av2ACCNUM has 12625 mapped keys (of 12625 keys)"
## [7] "hgu95av2ALIAS2PROBE has 33755 mapped keys (of 103735 keys)"
## [8] "hgu95av2CHR has 11540 mapped keys (of 12625 keys)"
## [9] "hgu95av2CHRLNGTHS has 93 mapped keys (of 93 keys)"
## [10] "hgu95av2CHRLOC has 11474 mapped keys (of 12625 keys)"
## [11] "hgu95av2CHRLOCEND has 11474 mapped keys (of 12625 keys)"
## [12] "hgu95av2ENSEMBL has 11460 mapped keys (of 12625 keys)"
## [13] "hgu95av2ENSEMBL2PROBE has 9814 mapped keys (of 28553 keys)"
## [14] "hgu95av2ENTREZID has 11543 mapped keys (of 12625 keys)"
## [15] "hgu95av2ENZYME has 2125 mapped keys (of 12625 keys)"
## [16] "hgu95av2ENZYME2PROBE has 786 mapped keys (of 975 keys)"
## [17] "hgu95av2GENENAME has 11543 mapped keys (of 12625 keys)"
## [18] "hgu95av2GO has 11245 mapped keys (of 12625 keys)"
## [19] "hgu95av2GO2ALLPROBES has 17214 mapped keys (of 18826 keys)"
## [20] "hgu95av2GO2PROBE has 12920 mapped keys (of 14714 keys)"
```

Alternatively, you can get similar information on how many items are in each of the provided maps by looking at the `MAPCOUNTS`:

```
hgu95av2MAPCOUNTS
```

To demonstrate the *environment* API, we'll start with a random sample of probe set IDs.

```
all_probes <- ls(hgu95av2ENTREZID)
length(all_probes)

## [1] 12625

set.seed(0xa1beef)
probes <- sample(all_probes, 5)
probes

## [1] "31882_at" "38780_at" "37033_s_at" "1702_at" "31610_at"
```

The usual ways of accessing annotation data are also available.

```
hgu95av2ENTREZID[[probes[1]]]

## [1] "9136"

hgu95av2ENTREZID$"31882_at"

## [1] "9136"

syms <- unlist(mget(probes, hgu95av2SYMBOL))
syms

##   31882_at   38780_at 37033_s_at   1702_at   31610_at
##   "RRP9"    "AKR1A1"  "GPX1"    "IL2RA"  "PDZK1IP1"
```

The annotation packages provide a huge variety of information in each package. Some common types of information include gene symbols (SYMBOL), GO terms (GO), KEGG pathway IDs (KEGG), ENSEMBL IDs (ENSEMBL) and chromosome start and stop locations (CHRLOC and CHRLOCEND). Each mapping will have a manual page that you can read to describe the data in the mapping and where it came from.

```
?hgu95av2CHRLOC
```

## Exercise 2

For the probes in 'probes' above, use the annotation mappings to find the chromosome start locations.

### 2.0.5 Manipulating Bimap Objects

Many filtering operations on the annotation *Bimap* objects require conversion of the *AnnDbBimap* into a *list*. In general, converting to lists will not be the most efficient way to filter the annotation data when using a SQLite-based package. Compare the following two examples for how you could get the 1st ten elements of the hgu95av2SYMBOL mapping. In the 1st case we have to get the entire mapping into list form, but in the second case we first subset the mapping object itself and this allows us to only convert the ten elements that we care about.

```
system.time(as.list(hgu95av2SYMBOL)[1:10])

## vs:
```

```
system.time(as.list(hgu95av2SYMBOL[1:10]))
```

There are many different kinds of *Bimap* objects in AnnotationDbi, but most of them are of class *AnnDbBimap*. All *RclassBimap* objects represent data as a set of left and right keys. The typical usage of these mappings is to search for right keys that match a set of left keys that have been supplied by the user. But sometimes it is also convenient to go in the opposite direction.

The annotation packages provide many reverse maps as objects in the package name space for backwards compatibility, but the reverse mappings of almost any map is also available using `revmap`. Since the data are stored as tables, no extra disk space is needed to provide reverse mappings.

```
unlist(mget(syms, revmap(hgu95av2SYMBOL)))
```

##	RRP9	AKR1A1	GPX1	IL2RA	PDZK1IP1
##	"31882_at"	"38780_at"	"37033_s_at"	"1702_at"	"31610_at"

So now that you know about the `revmap` function you might try something like this:

```
as.list(revmap(hgu95av2PATH) ["00300"])
```

```
## $`00300`
```

```
## [1] "35870_at" "36132_at"
```

Note that in the case of the `PATH` map, we don't need to use `revmap(x)` because `hgu95av2.db` already provides the `PATH2PROBE` map:

```
x <- hgu95av2PATH
## except for the name, this is exactly revmap(x)
revx <- hgu95av2PATH2PROBE
revx2 <- revmap(x, objName="PATH2PROBE")
revx2
```

```
## PATH2PROBE map for chip hgu95av2 (object of class "ProbeAnnDbBimap")
```

```
identical(revx, revx2)
```

```
## [1] TRUE
```

```
as.list(revx["00300"])
```

```
## $`00300`
```

```
## [1] "35870_at" "36132_at"
```

Note that most maps are reversible with `revmap`, but some (such as the more complex GO mappings), are not. Why is this? Because to reverse a mapping means that there has to be a "value" that will always become the "key" on the newly reversed map. And GO mappings have several distinct possibilities to choose from (GO ID, Evidence code or Ontology). In non-reversible cases like this, AnnotationDbi will usually provide a pre-defined reverse map. That way, you will always know what you are getting when you call `revmap`.

While we are on the subject of GO and GO mappings, there are a series of special methods for GO mappings that can be called to find out details about these IDs. `Term`, `GOID`, `Ontology`, `Definition`, `Synonym`, and `Secondary` are all useful ways of getting additional information about a particular GO ID. For example:

```
Term("GO:0000018")
```

```
## Loading required package: GO.db
```

```
##                                GO:0000018
## "regulation of DNA recombination"
Definition("GO:0000018")
##
## "Any process that modulates the frequency, rate or extent of DNA recombination, a DNA metaboli
```

### Exercise 3

Given the following set of RefSeq IDs: `c("NG_005114","NG_007432","NG_008063")`, Find the Entrez Gene IDs that would correspond to those. Then find the GO terms that are associated with those entrez gene IDs.

*org.Hs.eg.db* packages.

## 2.0.6 The Contents and Structure of Bimap Objects

Sometimes you may want to display or subset elements from an individual map. A *Bimap* interface is available to access the data in table (*data.frame*) format using `[` and `toTable`.

```
head(toTable(hgu95av2G0[probes]))
##   probe_id      go_id Evidence Ontology
## 1  1702_at GO:0006915      TAS      BP
## 2  1702_at GO:0006955      TAS      BP
## 3  1702_at GO:0007166      TAS      BP
## 4  1702_at GO:0008283      TAS      BP
## 5  1702_at GO:0038110      TAS      BP
## 6  1702_at GO:0002437      IEA      BP
```

The `toTable` function will display all of the information in a *Bimap*. This includes both the left and right values along with any other attributes that might be attached to those values. The left and right keys of the *Bimap* can be extracted using `Lkeys` and `Rkeys`. If it is necessary to only display information that is directly associated with the left to right links in a *Bimap*, then the `links` function can be used. The `links` returns a data frame with one row for each link in the bimap that it is applied to. It only reports the left and right keys along with any attributes that are attached to the edge between these two values.

Note that the order of the cols returned by `toTable` does not depend on the direction of the map. We refer to it as an 'undirected method':

```
toTable(x)[1:6, ]
##   probe_id path_id
## 1  1000_at   04010
## 2  1000_at   04012
## 3  1000_at   04062
## 4  1000_at   04114
## 5  1000_at   04150
## 6  1000_at   04270

toTable(revx)[1:6, ]
##   probe_id path_id
```

```
## 1 1000_at 04010
## 2 1000_at 04012
## 3 1000_at 04062
## 4 1000_at 04114
## 5 1000_at 04150
## 6 1000_at 04270
```

Notice however that the Lkeys are always on the left (1st col), the Rkeys always in the 2nd col

For `length()` and `keys()`, the result does depend on the direction, hence we refer to these as 'directed methods':

```
length(x)
## [1] 12625

length(revx)
## [1] 229

allProbeSetIds <- keys(x)
allKEGGIds <- keys(revx)
```

There are more 'undirected' methods listed below:

```
junk <- Lkeys(x)           # same for all maps in hgu95av2.db (except pseudo-map
                           # MAPCOUNTS)
Llength(x)                 # nb of Lkeys
## [1] 12625

junk <- Rkeys(x)           # KEGG ids for PATH/PATH2PROBE maps, GO ids for
                           # GO/GO2PROBE/GO2ALLPROBES maps, etc...
Rlength(x)                 # nb of Rkeys
## [1] 229
```

Notice how they give the same result for `x` and `revmap(x)`

You might be tempted to think that `Lkeys` and `Llength` will tell you all that you want to know about the left keys. But things are more complex than this, because not all keys are mapped. Often, you will only want to know about the keys that are mapped (ie. the ones that have a corresponding Rkey). To learn this you want to use the `mappedkeys` or the undirected variants `mappedLkeys` and `mappedRkeys`. Similarly, the `count.mappedkeys`, `count.mappedLkeys` and `count.mappedRkeys` methods are very fast ways to determine how many keys are mapped. Accessing keys like this is usually very fast and so it can be a decent strategy to subset the mapping by 1st using the mapped keys that you want to find.

```
x = hgu95av2ENTREZID[1:10]
## Directed methods
mappedkeys(x)              # mapped keys
## [1] "1000_at" "1001_at" "1002_f_at" "1003_s_at" "1004_at"
## [6] "1005_at" "1006_at" "1008_f_at" "1009_at"

count.mappedkeys(x)        # nb of mapped keys
## [1] 9
```



```
## Undirected methods
mappedLkeys(x)          # mapped left keys

## [1] "1000_at"  "1001_at"  "1002_f_at" "1003_s_at" "1004_at"
## [6] "1005_at"  "1006_at"  "1008_f_at" "1009_at"

count.mappedLkeys(x)    # nb of mapped Lkeys

## [1] 9
```

If you want to find keys that are not mapped to anything, you might want to use `isNA`.

```
y = hgu95av2ENTREZID[isNA(hgu95av2ENTREZID)] # usage like is.na()
Lkeys(y)[1:4]

## [1] "1007_s_at" "1047_s_at" "1089_i_at" "108_g_at"
```

#### Exercise 4

How many probesets do not have a GO mapping for the `hgu95av2.db` package? How many have no mapping? Find a probeset that has a GO mapping. Now look at the GO mappings for this probeset in table form.

### 2.0.7 Some specific examples

Lets use what we have learned to get information about the probes that are not assigned to a chromosome:

```
x <- hgu95av2CHR
Rkeys(x)

## [1] "19" "12" "8" "14" "3" "2" "17" "16" "9" "X" "6" "1" "7"
## [14] "10" "11" "22" "5" "18" "15" "Y" "20" "21" "4" "13" "MT" "Un"

chroms <- Rkeys(x)[23:24]
chroms

## [1] "4" "13"

Rkeys(x) <- chroms
toTable(x)

##      probe_id chromosome
## 1    1029_s_at          4
## 2    1036_at          4
## 3    1058_at         13
## 4    1065_at         13
## 5    1115_at          4
## 6    1189_at         13
## 7    1198_at         13
## 8    1219_at          4
## 9    1220_g_at          4
## 10   1249_at          4
## 11   1285_at          4
## 12   1303_at          4
```

## 13	1325_at	4
## 14	1348_s_at	13
## 15	1369_s_at	4
## 16	1377_at	4
## 17	1378_g_at	4
## 18	1451_s_at	13
## 19	1503_at	13
## 20	1507_s_at	4
## 21	1527_s_at	13
## 22	1528_at	13
## 23	1529_at	13
## 24	1530_g_at	13
## 25	1531_at	13
## 26	1532_g_at	13
## 27	1538_s_at	4
## 28	1542_at	4
## 29	1545_g_at	13
## 30	1567_at	13
## 31	1570_f_at	13
## 32	1571_f_at	13
## 33	1593_at	4
## 34	1597_at	13
## 35	1598_g_at	13
## 36	159_at	4
## 37	1600_at	4
## 38	1604_at	4
## 39	1605_g_at	4
## 40	1616_at	13
## 41	1624_at	4
## 42	1629_s_at	4
## 43	1670_at	13
## 44	1672_f_at	13
## 45	1679_at	4
## 46	1708_at	4
## 47	1709_g_at	4
## 48	170_at	13
## 49	1720_at	4
## 50	1721_g_at	4
## 51	1731_at	4
## 52	1732_at	4
## 53	1819_at	13
## 54	1828_s_at	4
## 55	1836_at	4
## 56	1883_s_at	4
## 57	1888_s_at	4
## 58	1900_at	13
## 59	1905_s_at	13

## 60	1913_at	4
## 61	1914_at	13
## 62	1931_at	13
## 63	1934_s_at	4
## 64	1943_at	4
## 65	1954_at	4
## 66	1963_at	13
## 67	1964_g_at	13
## 68	1987_at	4
## 69	1988_at	4
## 70	1989_at	13
## 71	1990_g_at	13
## 72	2044_s_at	13
## 73	2062_at	4
## 74	2092_s_at	4
## 75	214_at	4
## 76	215_g_at	4
## 77	252_at	13
## 78	253_g_at	13
## 79	260_at	4
## 80	281_s_at	4
## 81	31314_at	4
## 82	31320_at	13
## 83	31333_at	4
## 84	31345_at	4
## 85	31349_at	4
## 86	31356_at	4
## 87	31382_f_at	4
## 88	31404_at	13
## 89	31408_at	4
## 90	31464_at	13
## 91	31465_g_at	13
## 92	31516_f_at	13
## 93	31543_at	4
## 94	31562_at	13
## 95	31584_at	13
## 96	31628_at	13
## 97	31631_f_at	4
## 98	31639_f_at	13
## 99	31640_r_at	13
## 100	31670_s_at	4
## 101	31684_at	4
## 102	31686_at	4
## 103	31706_at	4
## 104	31744_at	4
## 105	31753_at	13
## 106	31790_at	13

```
## 107 31792_at 4
## 108 31805_at 4
## 109 31811_r_at 4
## 110 31847_at 13
## 111 31849_at 13
## 112 31851_at 13
## 113 31876_r_at 4
## 114 31894_at 4
## 115 31969_i_at 4
## 116 31970_r_at 4
## 117 32006_r_at 4
## 118 32026_s_at 4
## 119 32080_at 4
## 120 32102_at 13
## 121 32145_at 4
## 122 32146_s_at 4
## 123 32147_at 13
## 124 32148_at 13
## 125 32163_f_at 4
## 126 32180_s_at 4
## 127 32220_at 13
## 128 32299_at 4
## 129 32349_at 4
## 130 32353_at 4
## 131 32357_at 4
## 132 32368_at 13
## 133 32393_s_at 4
## 134 32439_at 13
## 135 32446_at 4
## 136 32449_at 4
## 137 32465_at 4
## 138 32482_at 13
## 139 32506_at 4
## 140 32507_at 4
## 141 32570_at 4
## 142 32580_at 4
## 143 32595_at 4
## 144 32602_at 4
## 145 32641_at 13
## 146 32675_at 4
## 147 32703_at 4
## 148 32768_at 13
## 149 32769_at 4
## 150 32770_at 4
## 151 32771_at 4
## 152 32812_at 4
## 153 32822_at 4
```

```
## 154 32832_at 4
## 155 32862_at 13
## 156 32906_at 13
## 157 32979_at 4
## 158 32986_s_at 13
## 159 32998_at 4
## 160 33013_at 4
## 161 33050_at 4
## 162 33068_f_at 4
## 163 33069_f_at 4
## 164 33100_at 4
## 165 33150_at 4
## 166 33151_s_at 4
## 167 33155_at 4
## 168 33156_at 4
## 169 33168_at 13
## 170 33171_s_at 4
## 171 33172_at 4
## 172 33173_g_at 4
## 173 33199_at 13
## 174 33208_at 13
## 175 33241_at 4
## 176 33249_at 4
## 177 33267_at 4
## 178 33276_at 13
## 179 33299_at 4
## 180 33318_at 13
## 181 33356_at 4
## 182 33359_at 4
## 183 33369_at 4
## 184 33370_r_at 4
## 185 33382_at 4
## 186 33483_at 4
## 187 33488_at 4
## 188 33490_at 4
## 189 33494_at 4
## 190 33519_at 4
## 191 33520_at 13
## 192 33525_at 4
## 193 33526_at 4
## 194 33529_at 4
## 195 33536_at 4
## 196 33544_at 4
## 197 33564_at 4
## 198 33576_at 13
## 199 33584_at 4
## 200 33596_at 4
```

```
## 201 33657_at 4
## 202 33672_f_at 4
## 203 33673_r_at 4
## 204 33687_at 13
## 205 33700_at 13
## 206 33733_at 4
## 207 33791_at 13
## 208 33823_at 4
## 209 33827_at 13
## 210 33837_at 4
## 211 33859_at 13
## 212 33975_at 4
## 213 33990_at 4
## 214 33991_g_at 4
## 215 33992_at 4
## 216 33997_at 4
## 217 34021_at 4
## 218 34022_at 4
## 219 34026_at 13
## 220 34029_at 4
## 221 34048_at 4
## 222 34051_at 13
## 223 34058_at 4
## 224 34075_at 4
## 225 34122_at 4
## 226 34131_at 4
## 227 34144_at 4
## 228 34145_at 4
## 229 34149_at 4
## 230 34170_s_at 4
## 231 34181_at 4
## 232 34198_at 4
## 233 34211_at 13
## 234 34239_at 13
## 235 34240_s_at 13
## 236 34247_at 4
## 237 34248_at 4
## 238 34275_s_at 4
## 239 34284_at 13
## 240 34307_at 13
## 241 34319_at 4
## 242 34324_at 13
## 243 34334_at 13
## 244 34335_at 13
## 245 34341_at 4
## 246 34342_s_at 4
## 247 34353_at 4
```

```
## 248 34398_at 13
## 249 34411_at 4
## 250 34423_at 4
## 251 34459_at 13
## 252 34476_r_at 4
## 253 34482_at 4
## 254 34512_at 4
## 255 34551_at 4
## 256 34564_at 4
## 257 34565_at 4
## 258 34578_at 13
## 259 34583_at 13
## 260 34596_at 4
## 261 34637_f_at 4
## 262 34638_r_at 4
## 263 34657_at 13
## 264 34672_at 13
## 265 34745_at 4
## 266 34803_at 13
## 267 34898_at 4
## 268 34953_i_at 4
## 269 34954_r_at 4
## 270 34955_at 13
## 271 34973_at 4
## 272 34984_at 4
## 273 34988_at 4
## 274 35020_at 4
## 275 35021_at 4
## 276 35025_at 4
## 277 35028_at 4
## 278 35039_at 4
## 279 35053_at 4
## 280 35061_at 4
## 281 35063_at 4
## 282 35081_at 13
## 283 35105_at 13
## 284 35107_at 13
## 285 35110_at 13
## 286 35131_at 4
## 287 35134_at 4
## 288 35140_at 13
## 289 35147_at 13
## 290 35164_at 4
## 291 35181_at 4
## 292 35182_f_at 4
## 293 35193_at 13
## 294 35213_at 13
```

```
## 295 35214_at 4
## 296 35215_at 4
## 297 35220_at 4
## 298 35285_at 4
## 299 35306_at 4
## 300 35344_at 13
## 301 35356_at 4
## 302 35357_at 4
## 303 35371_at 4
## 304 35372_r_at 4
## 305 35400_at 13
## 306 35410_at 4
## 307 35435_s_at 4
## 308 35437_at 4
## 309 35469_at 13
## 310 35470_at 13
## 311 35471_g_at 13
## 312 35481_at 13
## 313 35507_at 4
## 314 35523_at 4
## 315 35554_f_at 13
## 316 35555_r_at 13
## 317 35591_at 4
## 318 35656_at 13
## 319 35662_at 4
## 320 35664_at 4
## 321 35678_at 4
## 322 35689_at 4
## 323 35698_at 4
## 324 35725_at 13
## 325 35730_at 4
## 326 35777_at 4
## 327 35793_at 4
## 328 35827_at 4
## 329 35837_at 4
## 330 35845_at 4
## 331 35871_s_at 4
## 332 35877_at 13
## 333 35904_at 13
## 334 35939_s_at 13
## 335 35940_at 13
## 336 35949_at 13
## 337 35972_at 13
## 338 35989_at 4
## 339 35991_at 4
## 340 36012_at 13
## 341 36013_at 4
```



```
## 342 36017_at 13
## 343 36021_at 4
## 344 36031_at 13
## 345 36046_at 4
## 346 36047_at 4
## 347 36065_at 4
## 348 36080_at 4
## 349 36143_at 4
## 350 36157_at 4
## 351 36188_at 13
## 352 36194_at 4
## 353 36212_at 13
## 354 36243_at 4
## 355 36247_f_at 4
## 356 36269_at 4
## 357 36274_at 13
## 358 36358_at 4
## 359 36363_at 4
## 360 36433_at 4
## 361 36434_r_at 4
## 362 36510_at 13
## 363 36521_at 13
## 364 36606_at 4
## 365 36622_at 4
## 366 36627_at 4
## 367 36659_at 13
## 368 36717_at 4
## 369 36788_at 13
## 370 367_at 13
## 371 36814_at 4
## 372 36830_at 13
## 373 36913_at 4
## 374 36914_at 4
## 375 36915_at 4
## 376 36918_at 4
## 377 36939_at 4
## 378 36968_s_at 13
## 379 36990_at 4
## 380 37006_at 4
## 381 37019_at 4
## 382 37023_at 13
## 383 37056_at 4
## 384 37058_at 4
## 385 37062_at 4
## 386 37067_at 13
## 387 37079_at 13
## 388 37099_at 13
```

## 389	37109_at	13
## 390	37154_at	13
## 391	37170_at	4
## 392	37172_at	13
## 393	37173_at	4
## 394	37187_at	4
## 395	37206_at	4
## 396	37219_at	4
## 397	37223_at	4
## 398	37243_at	4
## 399	37244_at	13
## 400	37280_at	4
## 401	37282_at	4
## 402	37291_r_at	4
## 403	37303_at	13
## 404	37322_s_at	4
## 405	37323_r_at	4
## 406	37356_r_at	4
## 407	37366_at	4
## 408	37404_at	4
## 409	37416_at	4
## 410	37472_at	4
## 411	37518_at	13
## 412	37520_at	4
## 413	37521_s_at	4
## 414	37522_r_at	4
## 415	37571_at	13
## 416	37578_at	4
## 417	37593_at	13
## 418	37619_at	4
## 419	37658_at	13
## 420	37707_i_at	4
## 421	37708_r_at	4
## 422	37723_at	4
## 423	37747_at	4
## 424	37748_at	4
## 425	37752_at	4
## 426	37757_at	13
## 427	37767_at	4
## 428	37840_at	4
## 429	37852_at	4
## 430	37926_at	13
## 431	37930_at	13
## 432	37964_at	4
## 433	38008_at	4
## 434	38016_at	4
## 435	38024_at	4

```
## 436 38025_r_at      4
## 437 38035_at      13
## 438 38065_at      4
## 439 38102_at      13
## 440 38120_at      4
## 441 38168_at      4
## 442 38254_at      4
## 443 38304_r_at      13
## 444 38353_at      13
## 445 38375_at      13
## 446 38438_at      4
## 447 38485_at      4
## 448 38488_s_at      4
## 449 38489_at      4
## 450 38587_at      4
## 451 38606_at      4
## 452 38615_at      13
## 453 38643_at      4
## 454 38649_at      13
## 455 38714_at      4
## 456 38715_at      4
## 457 38736_at      4
## 458 38751_i_at      4
## 459 38752_r_at      4
## 460 38767_at      4
## 461 38768_at      4
## 462 38778_at      4
## 463 38821_at      4
## 464 38825_at      4
## 465 38838_at      4
## 466 38854_at      4
## 467 38891_at      4
## 468 38957_at      13
## 469 38972_at      13
## 470 38988_at      4
## 471 39028_at      13
## 472 39032_at      13
## 473 39037_at      4
## 474 39056_at      4
## 475 39083_at      4
## 476 39131_at      13
## 477 39132_at      4
## 478 39208_i_at      4
## 479 39209_r_at      4
## 480 39224_at      4
## 481 39256_at      13
## 482 39257_at      13
```

```
## 483 39269_at 13
## 484 39295_s_at 4
## 485 39297_at 13
## 486 39333_at 13
## 487 39337_at 4
## 488 39355_at 4
## 489 39369_at 4
## 490 39380_at 4
## 491 39382_at 4
## 492 39405_at 13
## 493 39469_s_at 13
## 494 39475_at 4
## 495 39481_at 4
## 496 39488_at 13
## 497 39489_g_at 13
## 498 39535_at 4
## 499 39536_at 4
## 500 39554_at 4
## 501 39555_at 4
## 502 39576_at 4
## 503 39579_at 13
## 504 39600_at 4
## 505 39634_at 4
## 506 39662_s_at 4
## 507 39665_at 4
## 508 39680_at 4
## 509 39690_at 4
## 510 39698_at 4
## 511 39734_at 4
## 512 39746_at 4
## 513 39748_at 13
## 514 39758_f_at 13
## 515 39777_at 13
## 516 39786_at 4
## 517 39847_at 4
## 518 39850_at 4
## 519 39851_at 4
## 520 39852_at 13
## 521 39878_at 13
## 522 39897_at 4
## 523 39924_at 13
## 524 39929_at 4
## 525 39955_at 13
## 526 39960_at 4
## 527 39979_at 13
## 528 40018_at 13
## 529 40058_s_at 4
```

```
## 530 40059_r_at      4
## 531 40060_r_at      4
## 532  40067_at      13
## 533  40072_at      13
## 534  40082_at      4
## 535    400_at      13
## 536  40114_at      4
## 537  40121_at      4
## 538  40148_at      4
## 539  40180_at      13
## 540 40181_f_at      13
## 541  40199_at      4
## 542 40217_s_at      4
## 543  40218_at      4
## 544  40225_at      4
## 545  40226_at      4
## 546  40272_at      4
## 547  40310_at      4
## 548  40312_at      13
## 549  40323_at      4
## 550  40349_at      4
## 551  40354_at      4
## 552  40392_at      13
## 553 40404_s_at      13
## 554  40449_at      4
## 555  40454_at      4
## 556  40456_at      4
## 557  40473_at      13
## 558  40492_at      4
## 559  40530_at      4
## 560  40570_at      13
## 561 40576_f_at      4
## 562  40633_at      13
## 563  40681_at      13
## 564  40697_at      4
## 565  40710_at      4
## 566  40711_at      4
## 567  40727_at      4
## 568  40746_at      4
## 569 40770_f_at      4
## 570  40772_at      4
## 571  40773_at      4
## 572  40818_at      4
## 573  40828_at      13
## 574  40839_at      13
## 575  40853_at      4
## 576 40880_r_at      4
```

```
## 577 40893_at 13
## 578 408_at 4
## 579 40908_r_at 13
## 580 40943_at 4
## 581 40970_at 13
## 582 40989_at 4
## 583 40990_at 4
## 584 40991_at 4
## 585 40992_s_at 4
## 586 40993_r_at 4
## 587 41014_s_at 4
## 588 41024_f_at 4
## 589 41025_r_at 4
## 590 41026_f_at 4
## 591 41069_at 13
## 592 41071_at 4
## 593 41104_at 4
## 594 41118_at 13
## 595 41119_f_at 13
## 596 41145_at 4
## 597 41148_at 4
## 598 41182_at 13
## 599 41191_at 4
## 600 41276_at 13
## 601 41277_at 13
## 602 41300_s_at 13
## 603 41301_at 13
## 604 41308_at 4
## 605 41309_g_at 4
## 606 41317_at 13
## 607 41318_g_at 13
## 608 41319_at 13
## 609 41376_i_at 4
## 610 41377_f_at 4
## 611 41391_at 4
## 612 41392_at 4
## 613 41402_at 4
## 614 41434_at 4
## 615 41436_at 13
## 616 41456_at 4
## 617 41459_at 13
## 618 41470_at 4
## 619 41491_s_at 13
## 620 41492_r_at 13
## 621 41493_at 13
## 622 41534_at 4
## 623 41555_at 4
```

```
## 624 41556_s_at      4
## 625  41585_at      4
## 626 41667_s_at     13
## 627 41668_r_at     13
## 628  41697_at      4
## 629  41801_at      4
## 630  41806_at      4
## 631  41860_at     13
## 632   431_at       4
## 633   504_at       4
## 634  507_s_at      4
## 635   579_at      4
## 636   618_at      4
## 637   630_at      4
## 638  631_g_at      4
## 639   655_at      4
## 640  690_s_at      4
## 641  692_s_at      4
## 642  764_s_at      4
## 643   820_at      4
## 644   886_at      4
## 645   931_at     13
## 646  936_s_at      4
## 647  948_s_at      4
## 648   963_at     13
## 649   975_at      4
## 650   990_at     13
## 651  991_g_at     13
```

To get this in the classic named-list format:

```
z <- as.list(revmap(x)[chroms])
names(z)

## [1] "4"  "13"

z[["Y"]]

## NULL
```

Many of the common methods for accessing *Bimap* objects return things in list format. This can be convenient. But you have to be careful about this if you want to use `unlist()`. For example the following will return multiple probes for each chromosome:

```
chrs = c("12", "6")
mget(chrs, revmap(hgu95av2CHR[1:30]), ifnotfound=NA)

## $`12`
## [1] "1018_at"  "1019_g_at" "101_at"    "1021_at"
##
## $`6`
```

```
## [1] "1026_s_at" "1027_at"
```

But look what happens here if we try to unlist that:

```
unlist(mget(chrs, revmap(hgu95av2CHR[1:30]), ifnotfound=NA))
##          121          122          123          124          61          62
## "1018_at" "1019_g_at"  "101_at"  "1021_at" "1026_s_at"  "1027_at"
```

Yuck! One trick that will sometimes help is to use `Rfunctionunlist2`. But be careful here too. Depending on what step comes next, `Rfunctionunlist2` may not really help you...

```
unlist2(mget(chrs, revmap(hgu95av2CHR[1:30]), ifnotfound=NA))
##          12          12          12          12          6          6
## "1018_at" "1019_g_at"  "101_at"  "1021_at" "1026_s_at"  "1027_at"
```

Lets ask if the probes in 'pbids' mapped to cytogenetic location "18q11.2"?

```
x <- hgu95av2MAP
pbids <- c("38912_at", "41654_at", "907_at", "2053_at", "2054_g_at",
          "40781_at")
x <- subset(x, Lkeys=pbids, Rkeys="18q11.2")
toTable(x)
##   probe_id cytogenetic_location
## 1  2053_at                18q11.2
## 2 2054_g_at                18q11.2
```

To coerce this map to a named vector:

```
pb2cyto <- as.character(x)
pb2cyto[pbids]
##      <NA>      <NA>      <NA>  2053_at 2054_g_at      <NA>
##      NA      NA      NA "18q11.2" "18q11.2"      NA
```

The coercion of the reverse map works too but issues a warning because of the duplicated names for the reasons stated above:

```
cyto2pb <- as.character(revmap(x))
## Warning in .local(x, ...): returned vector has duplicated names
```

## 2.0.8 Accessing probes that map to multiple targets

In many probe packages, some probes are known to map to multiple genes. The reasons for this can be biological as happens in the arabidopsis packages, but usually it is due to the fact that the genome builds that chip platforms were based on were less stable than desired. Thus what may have originally been a probe designed to measure one thing can end up measuring many things. Usually you don't want to use probes like this, because if they manufacturer doesn't know what they map to then their usefulness is definitely suspect. For this reason, by default all chip packages will normally hide such probes in the standard mappings. But sometimes you may want access to the answers that the manufacturer says such a probe will map to. In such



cases, you will want to use the `toggleProbes` method. To use this method, just call it on a standard mapping and copy the result into a new mapping (you cannot alter the original mapping). Then treat the new mapping as you would any other mapping.

```
## How many probes?  
dim(hgu95av2ENTREZID)  
## [1] 11543      2  
  
## Make a mapping with multiple probes exposed  
multi <- toggleProbes(hgu95av2ENTREZID, "all")  
## How many probes?  
dim(multi)  
## [1] 13372      2
```

If you then decide that you want to make a mapping that has only multiple mappings or you wish to revert one of your maps back to the default state of only showing the single mappings then you can use `toggleProbes` to switch back and forth.

```
## Make a mapping with ONLY multiple probes exposed  
multiOnly <- toggleProbes(multi, "multiple")  
## How many probes?  
dim(multiOnly)  
## [1] 1829      2  
  
## Then make a mapping with ONLY single mapping probes  
singleOnly <- toggleProbes(multiOnly, "single")  
## How many probes?  
dim(singleOnly)  
## [1] 11543      2
```

Finally, there are also a pair of test methods `hasMultiProbes` and `hasSingleProbes` that can be used to see what methods a mapping presently has exposed.

```
## Test the multiOnly mapping  
hasMultiProbes(multiOnly)  
## [1] TRUE  
  
hasSingleProbes(multiOnly)  
## [1] FALSE  
  
## Test the singleOnly mapping  
hasMultiProbes(singleOnly)  
## [1] FALSE  
  
hasSingleProbes(singleOnly)  
## [1] TRUE
```

### 2.0.9 Using SQL to access things directly

While the mapping objects provide a lot of convenience, sometimes there are definite benefits to writing a simple SQL query. But in order to do this, it is necessary to know a few things. The 1st thing you will need to know is some SQL. Fortunately, it is quite easy to learn enough basic SQL to get stuff out of a database. Here are 4 basic SQL things that you may find handy:

First, you need to know about SELECT statements. A simple example would look something like this:

```
SELECT * FROM genes;
```

Which would select everything from the genes table.

```
SELECT gene_id FROM genes;
```

Will select only the gene\_id field from the genes table.

Second you need to know about WHERE clauses:

```
SELECT gene_id, _id FROM genes WHERE gene_id=1;
```

Will only get records from the genes table where the gene\_id is = 1.

Thirdly, you will want to know about an inner join:

```
SELECT * FROM genes,chromosomes WHERE genes._id=chromosomes._id;
```

This is only slightly more complicated to understand. Here we want to get all the records that are in both the 'genes' and 'chromosomes' tables, but we only want ones where the '\_id' field is identical. This is known as an inner join because we only want the elements that are in both of these tables with respect to '\_id'. There are other kinds of joins that are worth learning about, but most of the time, this is all you will need to do.

Finally, it is worthwhile to learn about the AS keyword which is useful for making long queries easier to read. For the previous example, we could have written it this way to save space:

```
SELECT * FROM genes AS g,chromosomes AS c WHERE g._id=c._id;
```

In a simple example like this you might not see a lot of savings from using AS, so lets consider what happens when we want to also specify which fields we want:

```
SELECT g.gene_id,c.chromosome FROM genes AS g,chromosomes AS c WHERE g._id=c._id;
```

Now you are most of the way there to being able to query the databases directly. The only other thing you need to know is a little bit about how to access these databases from R. With each package, you will also get a method that will print the schema for its database, you can view this to see what sorts of tables are present etc.

```
org.Hs.eg_dbschema()
```

To access the data in a database, you will need to connect to it. Fortunately, each package will automatically give you a connection object to that database when it loads.

```
org.Hs.eg_dbconn()
```

You can use this connection object like this:

```
query <- "SELECT gene_id FROM genes LIMIT 10;"
result = dbGetQuery(org.Hs.eg_dbconn(), query)
result
```

### Exercise 5

Retrieve the entrez gene ID and chromosome by using a database query. Show how you could do the same thing by using `toTable`

## 2.0.10 Combining data from multiple annotation packages at the SQL level

For a more complex example, consider the task of obtaining all gene symbols which are probed on a chip that have at least one GO BP ID annotation with evidence code IMP, IGI, IPI, or IDA. Here is one way to extract this using the environment-based packages:

```
## Obtain SYMBOLS with at least one GO BP
## annotation with evidence IMP, IGI, IPI, or IDA.
system.time({
bpids <- eapply(hgu95av2GO, function(x) {
  if (length(x) == 1 && is.na(x))
    NA
  else {
    sapply(x, function(z) {
      if (z$Ontology == "BP")
        z$GOID
      else
        NA
    })
  }
})
bpids <- unlist(bpids)
bpids <- unique(bpids[!is.na(bpids)])
g2p <- mget(bpids, hgu95av2GO2PROBE)
wantedp <- lapply(g2p, function(x) {
  x[names(x) %in% c("IMP", "IGI", "IPI", "IDA")]
})
wantedp <- wantedp[sapply(wantedp, length) > 0]
wantedp <- unique(unlist(wantedp))
ans <- unlist(mget(wantedp, hgu95av2SYMBOL))
})
length(ans)
ans[1:10]
```

All of the above code could have been reduced to a single SQL query with the SQLite-based packages. But to put together this query, you would need to look 1st at the schema to know what tables are present:

```
hgu95av2_dbschema()
```

This function will give you an output of all the create table statements that were used to generate the hgu95av2 database. In this case, this is a chip package, so you will also need to see the schema for the organism package

that it depends on. To learn what package it depends on, look at the ORGPKG value:

```
hgu95av2ORGPKG
```

Then you can see that schema by looking at its schema method:

```
org.Hs.eg_dbschema()
```

So now we can see that we want to connect the data in the go\_bp, and symbol tables from the org.Hs.eg.sqlite database along with the probes data in the hgu95av2.sqlite database. How can we do that?

It turns out that one of the great conveniences of SQLite is that it allows other databases to be 'ATTACHed'. Thus, we can keep our data in many different databases, and then 'ATTACH' them to each other in a modular fashion. The databases for a given build have been built together and frozen into a single version specifically to allow this sort of behavior. To use this feature, the SQLite ATTACH command requires the filename for the database file on your filesystem. Fortunately, R provides a nice system independent way of getting that information. Note that the name of the database is always the same as the name of the package, with the suffix '.sqlite':

```
orgDBLoc = system.file("extdata", "org.Hs.eg.sqlite", package="org.Hs.eg.db")
attachSQL = paste("ATTACH '", orgDBLoc, "' AS orgDB;", sep = "")
dbGetQuery(hgu95av2_dbconn(), attachSQL)
```

Finally, you can assemble a cross-db sql query and use the helper function as follows. Note that when we want to refer to tables in the attached database, we have to use the 'orgDB' prefix that we specified in the 'ATTACH' query above.:

```
system.time({
SQL <- "SELECT DISTINCT probe_id,symbol FROM probes, orgDB.gene_info AS gi, orgDB.genes AS g, org
zz <- dbGetQuery(hgu95av2_dbconn(), SQL)
})

##      user  system elapsed
##  0.257    0.017    0.295

#its a good idea to always DETACH your database when you are finished...
dbGetQuery(hgu95av2_dbconn(), "DETACH orgDB" )
```

## Exercise 6

Retrieve the entrez gene ID, chromosome location information and cytoband information by using a single database query.

## Exercise 7

Expand on the example in the text above to combine data from the hgu95av2.db and org.Hs.eg.db with the GO.db package so as to include the GO ID, and term definition in the output.

The version number of R and packages loaded for generating the vignette were:

```
## R version 3.1.3 (2015-03-09)
## Platform: x86_64-apple-darwin13.4.0 (64-bit)
## Running under: OS X 10.9.5 (Mavericks)
##
## locale:
```

```
## [1] C/en_US.UTF-8/en_US.UTF-8/C/en_US.UTF-8/en_US.UTF-8
##
## attached base packages:
## [1] parallel stats4 stats graphics grDevices utils
## [7] datasets methods base
##
## other attached packages:
## [1] GO.db_3.0.0 hgu95av2.db_3.0.0 AnnotationForge_1.8.2
## [4] org.Hs.eg.db_3.0.0 RSQLite_1.0.0 DBI_0.3.1
## [7] AnnotationDbi_1.28.2 GenomeInfoDb_1.2.4 IRanges_2.0.1
## [10] S4Vectors_0.4.0 Biobase_2.26.0 BiocGenerics_0.12.1
## [13] knitr_1.9
##
## loaded via a namespace (and not attached):
## [1] BiocStyle_1.4.1 evaluate_0.5.5 formatR_1.0 highr_0.4
## [5] stringr_0.6.2 tools_3.1.3
```