Genome project tables in the genomes package

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The `genomes` package collects genome project metadata and provides tools to track, sort, group, summarize and plot the data. The genome project tables from the National Center for Biotechnology Information (NCBI) and the Genomes On Line Database (GOLD) are the primary sources of data and include a rapidly growing collection of organisms from all domains of life (viruses, archaea, bacteria, protists, fungi, plants, and animals) plus metagenomic sequences.

Genome tables are a defined class (*genomes*) in the package and each table is a data frame where rows are genome projects and columns are the fields describing the associated metadata. At a minimum, the table should have a column listing the project name, status, and release date. A number of methods are available that operate on genome tables including `print`, `summary`, `plot` and `update`.

There are a number of ways to install this package. If you are running R version 2.11, you can use the `biocLite` command.

```
R> source("http://bioconductor.org/biocLite.R")
R> biocLite("genomes")
```

You can also install the package on earlier versions of R using `install.packages`, but this has not been tested completely.

```
R> install.packages("genomes",
    repos="http://www.bioconductor.org/packages/release/bioC")
```

Finally, since the format of online genome tables may change (and then `update` commands may fail), I would recommend downloading the development version for fixes in between the six month release cycle. On some systems (Mac 10.4), you may need to add the `type='source'` option to install the package source. In addition, the `genomes` package depends on some functions in the `lattice` and `XML` packages, so these two should be installed first (`lattice` is usually installed by default, but not `XML`).

```
R> install.packages("genomes",
    repos="http://www.bioconductor.org/packages/devel/bioC")
```

NCBI tables

Genome tables at NCBI are downloaded from the Genome Project database. The primary tables include a list of prokaryotic projects (`lproks`), eukaryotic projects (`leuks`), and metagenomic projects (`lenvs`). The `print` methods displays the first few rows and columns of the table (either select less than seven rows or convert the object to a `data.frame` to print all columns). The `summary` function displays the download date, a count of projects by status, and a list of recent submissions. The `plot` method displays a cumulative plot of genomes by release date in Figure 1 (use `lines` to add additional tables). The `update` method is not illustrated below, but can be used to download the latest version of the table from NCBI.

```
R> data(lproks)
R> lproks

  A genomes data.frame with 4951 rows and 32 columns

      pid                                          name      status
1   30807                       'Nostoc azollae' 0708    Complete
2   33011            Abiotrophia defectiva ATCC 49176    Assembly
3   12997              Acaryochloris marina MBIC11017    Complete
4   16707                Acaryochloris sp. CCMEE 5410 In Progress
5   45843              Acetivibrio cellulolyticus CD2    Assembly
...   ...                                          ...         ...
4951 34927 Zymomonas mobilis subsp. pomaceae ATCC 29192 In Progress
      released ...
1   2009-03-06 ...
2   2009-03-17 ...
3   2007-10-16 ...
4         <NA> ...
5   2010-08-11 ...
...        ... ...
4951      <NA> ...

R> summary(lproks)

$`Total genomes`
[1] 4951 genome projects on Oct 06, 2010

$`By status`
            Total
In Progress  2198
Assembly     1509
Complete     1244
```

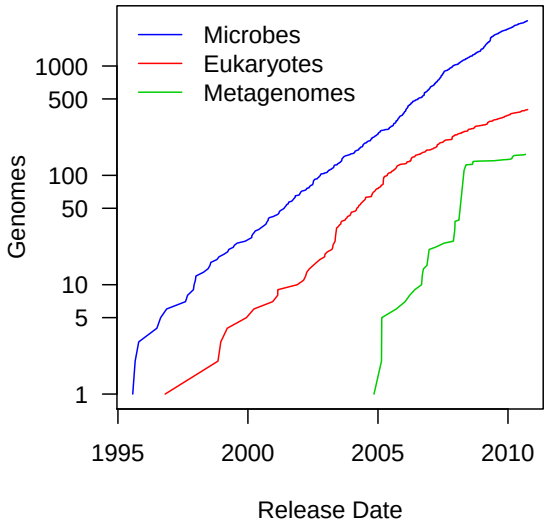

Figure 1: Cumulative plot of genome projects by release date at NCBI.

```
$`Recent submissions`
  RELEASED   NAME                                                STATUS
1 2010-10-01 Helicobacter pylori Cuz20                           Complete
2 2010-10-01 Helicobacter pylori PeCan4                          Complete
3 2010-10-01 Helicobacter pylori Sat464                          Complete
4 2010-10-01 Helicobacter pylori SJM180                          Complete
5 2010-10-01 Lactobacillus plantarum subsp. plantarum ST-III Complete
```

```
R> plot(lproks, log = "y", las = 1)
R> data(leuks)
R> data(lenvs)
R> lines(leuks, col = "red")
R> lines(lenvs, col = "green3")
R> legend("topleft", c("Microbes", "Eukaryotes", "Metagenomes"),
     lty = 1, bty = "n", col = c("blue", "red", "green3"))
```

For microbial genome projects, the number of complete genomes doubles every 22 months and a new microbial genome is released about every other day. At least in 2008, fewer complete genomes were released than the previous year (Figure 2).

```
R> complete <- subset(lproks, status == "Complete")
R> doublingTime(complete)
```

```
days
 683
```

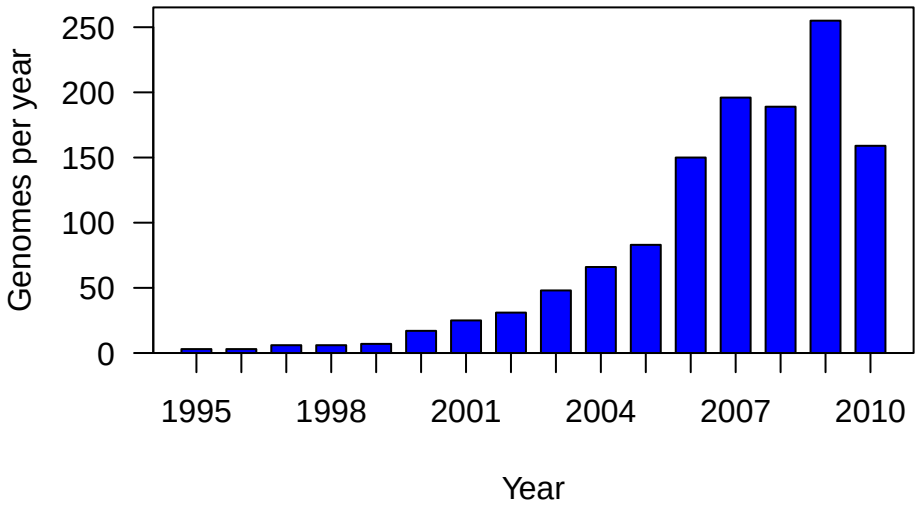

Figure 2: Number of complete microbial genomes released each year at NCBI

```
R> x <- table(format(complete$released, "%Y"))
R> barplot(x, col = "blue", ylim = c(0, max(x) * 1.04), space = 0.5,
     las = 1, axis.lty = 1, xlab = "Year", ylab = "Genomes per year")
R> box()
```

A number of functions are available to assist in sorting and grouping genomes. For example, the `species` and `genus` function can be used to extract the genus or species name. The `table2` function formats and sorts a contingency table by counts.

```
R> table2(species(lproks$name))
```

	Total
Escherichia coli	392
Streptococcus pneumoniae	212
Staphylococcus aureus	91
Mycobacterium tuberculosis	81
Salmonella enterica	79
Acinetobacter baumannii	74
Propionibacterium acnes	74
Enterococcus faecalis	72
Streptococcus mutans	60
Bacillus cereus	53

Because subsets of tables are often needed, the binary operator `like` allows pattern matching using wildcards. The `plotby` function below expands on the default plot method

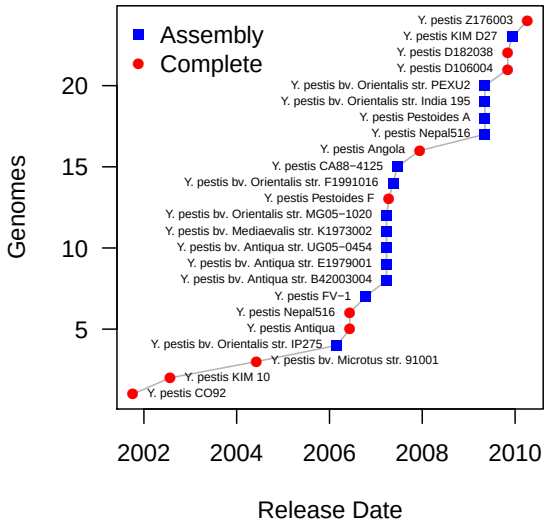

Figure 3: Cumulative plot of *Yersinia pestis* genomes by release date.

and adds the ability to plot by groups (default is status) using either labeled points or multiple lines like Figure 1. For example, the release dates of complete and draft sequences of *Yersinia pestis* are displayed in Figure 3.

```
R> yp <- subset(lproks, name %like% "Yersinia pestis*")
R> plotby(yp, labels = TRUE, cex = 0.5, lbty = "n")
```

GOLD and other tables

The Genomes Online Database (GOLD) is a comprehensive resource that collects detailed project metadata from over 7,000 genomes. There are currenlty over 100 columns in this large table with specific fields relating to the organism, host, environment, and sequencing methods. Just two of the hundreds of possible queries are illustated below. In first example, a list of endosymbiotic intracellular organisms is divided into pathogens and commensal bacteria. In the second example, the comma-separated list of phenotypes is split and a new table is created listing the GOLD identifier, name, and a single phenotype. Then genomes matching "Arsenic metabolizer" are displayed.

```
R> data(gold)
R> obligate <- subset(gold, symbiotic.interaction == "Endosymbiotic intracellular",
     c(goldstamp, name, phenotype))
R> obligate$pathogen <- "Pathogen"
R> obligate$pathogen[obligate$phenotype %like% "Non-*|Symb*|Carb"] <- "Commensal"
R> obligate$pathogen[obligate$phenotype == ""] <- "Commensal"
R> table2(genus(obligate$name), obligate$pathogen)
```

```
               Commensal Pathogen Total
  Chlamydia            0       50    50
  Rickettsia           2       19    21
  Rhizobium           18        0    18
  Wolbachia           18        0    18
  Chlamydophila        0       12    12
  Buchnera            11        0    11
  Coxiella             0        7     7
  Ehrlichia            0        7     7
  Anaplasma            0        6     6
  Mesorhizobium        5        0     5
```

```
R> x <- subset(gold, phenotype != "")
R> x2 <- strsplit(x$phenotype, ", ")
R> gold2 <- as.data.frame(cbind(goldstamp = rep(x$goldstamp,
     sapply(x2, length)), name = rep(x$name, sapply(x2, length)),
     phenotype = unlist(x2)))
R> table2(gold2$phenotype)
```

```
                      Total
Pathogen               2391
Non-Pathogen            414
Intracellular pathogen  115
Parasite                 92
Acidophile               72
Probiotic                60
Meticillin resistant     48
Radiation resistant      39
Catalase positive        34
Symbiont                 33
```

```
R> subset(gold2, phenotype %like% "Arsenic metabol*")
```

```
     goldstamp                                name           phenotype
153    Gc00422    Alkalilimnicola ehrlichei MLHE-1 Arsenic metabolizer
156    Gc00666      Alkaliphilus oremlandii OhILAs Arsenic metabolizer
336    Gi00970    Bacillus selenitireducens MLMS-1 Arsenic metabolizer
338    Gc01337    Bacillus selenitireducens MLS-10 Arsenic metabolizer
2008   Gc00526 Herminiimonas arsenicoxydans ULPAs1 Arsenic metabolizer
3711   Gi00788                  Thiomonas sp. 3As Arsenic metabolizer
```

Finally, genome data from the Human Microbiome Project is stored in the `hmp` dataset and includes additional information such as the primary body site occupied by a sequenced organism.