Introduction to Bioinformatics Summer Series

Center for Cancer Research

BTEP

Bioinformatics Training & Education Program

Alexandra L Emmons Ph.D., Joe Wu Ph.D. & Amy Stonelake Ph.D.
BTEP/GAU/CCR/NCI/NIH - email ncibtep@mail.nih.gov
Bioinformatics Training and Education Program

Table of Contents

Course Overview

Bioinformatics Resources at NIH

Introduction to Unix and Biowulf

R and Python

Document Analysis using Jupyter Lab

BTEP Bioinformatics Introduction Bioinformatics software Bioinformatics education Unix Biowulf R Python Reproducible analysis Jupyter Lab

Course Overview

The BTEP Bioinformatics Summer Series is five classes that introduce novices and new NIH scientists the essentials for getting started with bioinformatics analysis of next generation sequencing (NGS) data. Topics include a broad survey of bioinformatics resources available to all scientists at NIH, an overview of the NIH High Performance Computing System (Biowulf), a discussion and comparison between programming languages R and Python, and tips for making data FAIR and data analyses reproducible. These classes are open to NIH audience only.

- August 7, 2025 (Thursday, 1 PM – 2 PM):
    - Introduction to Bioinformatics Resources will inform participants of software (commercial and open-source), self-learning tools, and resources for bioinformatics and data science.
- August 14, 2025 (Thursday, 1 PM – 2 PM):
    - Introduction to Unix and Biowulf will serve as a crash course for using the NIH Unix-based High Performance Computing system (Biowulf). Participants will learn to navigate through directories, work with files, and use bioinformatics applications that are installed on the system.
- August 21, 2025 (Thursday, 1 PM – 2 PM):
    - Overview of R and Python will discuss the benefits that these two popular programming languages can bring to a bioinformatics project. After this session, participants should be able to decide which language to use for a given data analysis.
- September 4, 2025 (Thursday, 1 PM – 2 PM):
    - Managing Data Analysis Projects using Jupyter Lab. This class will introduce participants to Jupyter Lab, a tool for maintaining data, code, output, and description of analyses all in one place, which facilitates transparency and reproducibility of data analysis.

Course Expectations / Learning Objectives

This course will make participants aware of available bioinformatics training resources and software at NIH. Participants will walk away from these classes with the knowledge and confidence needed to pursue bioinformatics and continual self learning. In sum, after this course series, participants will:

- Be able to describe available training resources and software available for bioinformatics at NIH.

- Know the rationale and basics of getting started with working on Unix-based high performance computing platforms.
- Be informed of when to use Python or R in a bioinformatics project.
- Understand best practices for managing and organizing data.
- Become familiar with rationale and tools used to make data analysis reproducible.

Required Course Materials

Participants will not need to have bioinformatics experience to attend and there are no required course material. However, the following may help with following along.

- Biowulf account *(https://hpc.nih.gov/docs/accounts.html)*. This would be helpful for participants to follow along in the Unix and Biowulf class. Biowulf will also provide a limited number (40) of student/temporary accounts for those who would like to follow along. Student/temporary accounts are meant for use during teaching activities and must be approved and supplied by Biowulf.
- Have R, Python, and/or Jupyter Lab installed on participant's government furnished computer. Reach out to institutional computing help desk to request installation of software. NCI CCR affiliates can submit a ticket with service.cancer.gov for software installation.
- To install R, see https://cran.r-project.org/ *(https://cran.r-project.org/)*
- To install Python, see https://www.python.org/downloads/ *(https://www.python.org/downloads/)*
- To install Jupyter Lab, see https://jupyter.org/install *(https://jupyter.org/install)*

Bioinformatics Resources at NIH

Introduction to Bioinformatics Resources

Introduction to Unix and Biowulf

Unix for Bioinformatics Beginners Slides

Unix for Bioinformatics Beginners

Joe Wu, PhD (BTEP)
August 14, 2025

- `ssh` (connect to remote computer such as a high performance computing cluster)
- `pwd` (print working directory)
- `cd` (change directory)
- `ls` (list directory content)
- `mkdir` (make a directory)
- `touch` (creates an empty file)
- `nano` (basic editor for editing text files)
- `cp` (make a copy of files or folders)
- `mv` (rename files/folder or move files or folders to different location)
- `rm` (to remove files or folders)
- `cat` (print file content to screen)
- `less` (page through file content)
- `column` (display tabular data nicely aligned on screen)
- `wc` (word count, line count and character count)
- `grep` (pattern search)
- `sinteractive` (request compute and time resources on Biowulf's compute node to perform interactive data analysis and file transfers)
- `sbatch` (used to submit analysis Biowulf rather than working interactively, step-by-step)
- `module` (find, load, and unload applications installed on high performance computing clusters)
- `man` (view manual for a command)

Tip

All Unix commands follow the syntax of `command option(s) input`. Think of the `command` as a verb in natural language. The `input` is what users would like the command to act on and `option(s)` changes the default way in which a command runs.

Connecting to Remote Computer

As bioinformatics often deal with dataset that are too large to be analyzed using compute resources on a personal computer, a motive for learning Unix command line is to enable scientists to perform bioinformatics analyses on high performance computing systems such as

Biowulf at NIH. To connect to a remote computer, the `ssh` command construct below can be used and the breakdown is as follows.

- `ssh`: The command for connecting to a remote computer.
- `username`: The user name that is used to sign onto a remote computer such as high performance computing system. For Biowulf, `username` will be replaced by the user's NIH user name. Username is followed by `@` (ie. the "at" symbol).
- `remote`: This is the name of the remote computer. For Biowulf this would be `biowulf.nih.gov`.

```
ssh username@remote.computer
```

The command above could be annunciated as `ssh username at remote.computer`.

To sign onto Biowulf, the NIH high performance computing system, use the following. Again, replace username with the user's NIH user name.

```
ssh username@biowulf.nih.gov
```

Next, enter the user specific password for the remote computer. Note that nothing shows up when the password is being type, but keep typing and hit enter when ready to sign on.

The Command Prompt

In Unix, the command prompt is where users issue commands to interact with the computer. For example, upon connecting to Biowulf, users will see the prompt shown below. Replace username with the user's NIH user name. The prompt below tells users that they are connected to Biowulf and are currently in the `home` directory (denoted by ~).

```
[username@biowulf ~]$
```

Warning

The prompt will look different depending on the computer system. It can also be customized, so do not panic if a prompt does not look exactly like that above.

Knowledge Check 1

Enter passcode `woclgu` to answer the multiple choice question in the Slido poll.

Print the Working Directory

Terminology

The working directory is the folder in a computer system in which a user is currently in.

It is a good idea to know which directory a user is currently in as data analysis progresses. To check, use the following.

```
pwd
```

For instance, upon signing on to Biowulf users will land in the `home` directory (also denoted by ~). The `pwd` command will give the directory path below (replace username with the user's specific user name).

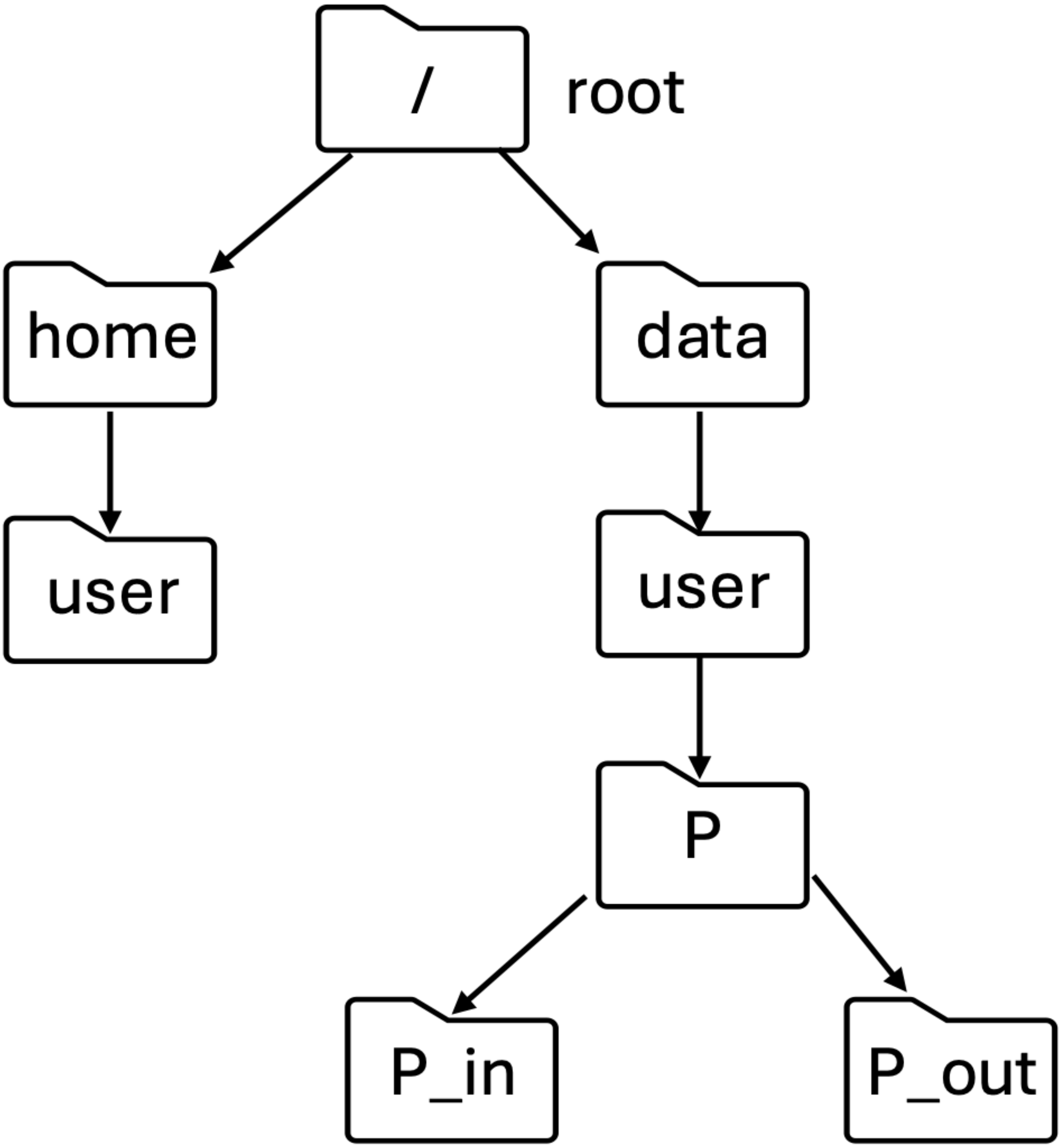
```
/home/username
```

Note

In Unix, a directory path indicates where in the file system hierarchy a user is. Directory paths that start with `/` are known as absolute. Each part of the directory path is separated by `/` and followed by the name of the folder in the file system hierarchy.

The figure below shows a basic and typical hierarchy of the Unix and Unix-based high performance computing systems. At the upper most level there is the root directory, which is denoted by `/`. Branching of from `/` there are a `home` and `data` folders. The `home` directory has limited space so users use the `data` folder for analysis. In the example below, the `data` folder contains hypothetical project directory `P`, which in turn has folders that store input (`P_in`) and output (`P_out`). Directory paths that do not start from `/` are known as relative (ie. `P/P_in`).

Example File Hierarchy



Change Directory

Note

The user's `home` directory on Biowulf is not the place to store analysis input and output as it only has 16gb of storage space and quota cannot be increased. The user's `data` directory can be used for this as storage quota can be increased at the request of the user.

To change directory use the `cd` command follow by the directory to change into. Upon signing onto Biowulf, users should change into their `data` directory to performing analyses. To do this use the following. Replace username with the user's specific user name.

```
cd /data/username
```

The prompt will contain the user's NIH user name rather than ~ if the directory change to `/data/username` is successful.

```
[username@biowulf username]$
```

Knowledge Check 2

Use the passcode g1apic to answer the following question on Slido.

The `pwd` command can be used to check whether the directory change is successful.

```
pwd
```

If the directory change is successful, the following path will be shown, again replace username with the user's NIH user name.

```
/data/username
```

To go back to the user's `home` directory use `cd`, `cd ~`, or `cd /home/username`. Use `cd ..` to go back one directory. To go back two directories, use `cd ../../`. To go back three directories use `cd ../../../` and so on.

Grab Some Examples Data

If the participants choose to follow along using either a personal Biowulf or one of the student accounts, please stay in the `/data/username` folder (remember to replace `username` with the participants own Biowulf log-in ID).

> **Spoiler**
>
> Copying of files and folders will be covered later in this tutorial but because the instructor wants the audience to copy over example data to their Biowulf `/data/username` directory, a glimpse of it will be shown here.

There is a folder called `unix_demonstration` in `/data/classes/BTEP`. Use the `cp` command construct below to copy into the user's Biowulf `/data` directory. In command construct below, `cp` is used copy content in Unix. The option `-r` tells it copy a folder and all of its contents. The arguments are the file or folder to be copied and the name of the copy or destination in which to place the copy. In the example below, a copy of the `unix_demonstration` in `/data/classes/BTEP` needs to be made, so the first argument would be `/data/classes/BTEP/unix_demonstration`. The second argument for the `cp` construct below is the destination to place the copy, which is here or `.` in the user's Biowulf `/data` directory.

```
cp -r /data/classes/BTEP/unix_demonstration .
```

After the `cp` command finishes, users will be automatically returned to the prompt. Make sure that the `unix_demonstration` is actually there by doing the following.

```
ls
```

Knowledge Check 3

Use the passcode ulsgtd to answer the question in the Slido poll.

Listing Directory Content

Stay in the `/data/username/unix_demonstration` folder for these exercises.

To view the files and subfolder within a directory, the `ls` command can be used. For instance, `ls` will retrieve the following items in the `unix_demonstration` directory when issued.

```
file.txt example_fastq.fq example_rna_sequencing_counts.csv
```

Unix commands come with options that alter its default behavior. The `-l` option of `ls` gives a detailed view of each item in a directory, line-by-line. For instance, on the left hand column of the table below, lines that start with `-` are files while those starting with `d` are folders. The fifth column list the file or folder size. Note file.txt has a file size of 0 bytes since it is empty. Also, `ls -l` by default displays the files size in bytes.

```
-rw-r-----. 1 owner group       0  Jun 15 16:20 file.txt
-rw-r-----. 1 owner group 29108029 Jul  3 13:35 example_fastq.fq
-rw-r-----. 1 owner group 29108029 Jul  3 13:35 example_rna_sequenci
```

Creating a New Directory

Stay in the `/data/username/unix_demonstration` folder for these exercises.

To make a new folder, use the `mkdir` command followed by the name of the folder.

```
mkdir folder
```

Recall

As mentioned previously, if the first column in the `ls -l` results starts with `d` then this indicates a directory, which is what `folder` should be.

```
ls -l
```

```
-rw-r-----. 1 owner group        0 Jun 16 10:09 file.txt
drwxr-x---. 2 owner group     4096 Jun 16 10:18 folder
-rw-r-----. 1 owner group 29108029 Jul  3 13:35 example_fastq.fq
-rw-r-----. 1 owner group 29108029 Jul  3 13:35 example_rna_sequenci
```

Knowledge Check 4

Use the passcode myu18x to answer the following question.

Editing Files

Stay in the `/data/username/unix_demonstration` folder for these exercises.

Nano is a basic file editor that is built into Unix and enables editing of plain text files including txt, csv, fasta, genbank, gtf, and fastq. To edit a file using Nano, just use `nano` followed by the file name.

```
Unix is an operating system, just like Windows or MacOS.
Linux is a variety of Unix, and sometimes the names are used interch
```

For instance, to add the text above to file.txt, use:

```
nano file.txt
```

Then copy and paste the text into the editor. Hit control-x and then save to go back to the command prompt.

> **Note**
>
> If a file does not exist, then the `nano` command will create it as well as open the editor to enable editing. To create a blank file without opening the Nano editor, use the `touch` command instead.

```
touch bioinformatics.txt
```

```
ls -l
```

```
-rw-r-----. 1 owner group        0 Jun 16 18:13 bioinformatics.txt
-rw-r-----. 1 owner group      135 Jun 16 18:13 file.txt
drwxr-x---. 2 owner group     4096 Jun 16 10:18 folder
-rw-r-----. 1 owner group 29108029 Jul  3 13:35 example_fastq.fq
-rw-r-----. 1 owner group 29108029 Jul  3 13:35 example_rna_sequenci
```

Copying Files and Folders

Stay in the `/data/username/unix_demonstration` folder for these exercises.

To copy a file use `cp` followed by the file name and the name of the duplicate.

For instance, to make a copy of bioinformatics.txt called btep_bioinformatics.txt, do:

```
cp bioinformatics.txt btep_bioinformatics.txt
```

```
ls
```

```
bioinformatics.txt  btep_bioinformatics.txt  example_fastq.fq exampl
```

The `cp` command can be used to copy a file into a folder. Just provide the file and the path to the folder in which to copy it. If a new name is desired for the duplicate, then append it to the destination folder path separated by a `/`. For instance, the command below will make a duplicate of bioinformatics.txt in `folder` called `bioinformatics_for_beginners.txt`.

```
cp bioinformatics.txt folder/bioinformatics_for_beginners.txt
```

Tip

To see contents of a folder other than those in the working directory, supply the path to the folder to the `ls` command.

```
ls folder
```

```
bioinformatics_for_beginners.txt
```

To copy a folder include the `-r` option in `cp`. The `-r` option recursively copies everything in a folder. The arguments are the folder to copy and the name of the duplicate folder.

```
cp -r folder bioinformatics_folder
```

The `-1` option of `ls` prints directory content one item per line.

```
ls -1
```

```
bioinformatics_folder
bioinformatics.txt
btep_bioinformatics.txt
example_fastq.fq
example_rna_sequencing_counts.csv
file.txt
folder
```

```
ls bioinformatics_folder
```

```
bioinformatics_for_beginners.txt
```

Renaming Files and Folders

Stay in the `/data/username/unix_demonstration` folder for these exercises.

The `mv` command can be used to rename files and folders.

To rename a file, use the `mv` command then provide the name of the file to rename and the new name of the file.

```
mv btep_bioinformatics.txt bioinformatics_for_noobies.txt
```

```
ls -1
```

```
bioinformatics_folder
bioinformatics_for_noobies.txt
bioinformatics.txt
example_fastq.fq
example_rna_sequencing_counts.csv
file.txt
folder
```

To rename a folder, use the `mv` command and then provide the name of the folder to rename and the new name of the folder.

```
mv folder project_folder
```

```
ls -1
```

```
bioinformatics_folder
bioinformatics_for_noobies.txt
bioinformatics.txt
example_fastq.fq
example_rna_sequencing_counts.csv
file.txt
project_folder
```

Moving Files and Folders

Stay in the `/data/username/unix_demonstration` folder for these exercises.

To move a file from one folder to another, the `mv` command can be used. The arguments in this application of the `mv` command is the file to be moved and the name of the folder in which the file will be moved to.

```
mv bioinformatics.txt bioinformatics_folder
```

```
ls bioinformatics_folder
```

```
bioinformatics_for_beginners.txt  bioinformatics.txt
```

Tip

`mv` can also move folders. Just supply the name of the folder to be moved as the first argument and the path of the destination folder.

Deleting Files and Folders

Stay in the `/data/username/unix_demonstration` folder for these exercises.

To delete a file use the `rm` command followed by the file name.

For instance, to delete bioinformatics_for_noobies.txt do:

```
rm bioinformatics_for_noobies.txt
```

Warning

There is no trash can or recycling bin in Unix. Once a file is deleted, it cannot be recovered. Use the `-i` option with `rm` to confirm deletion.

```
rm -i bioinformatics_for_noobies.txt
```

Type `n` for no and `y` for yes (to delete).

```
rm: remove regular empty file 'bioinformatics_for_noobies.txt'? n
```

Empty folders can be deleted using `rmdir`. On the other hand, folders with content can be removed using `rm -r`, where the `-r` option tells `rm` to delete the folder and recursively delete everything inside that folder.

```
rm -r -i project_folder
```

The command above will ask if the user wants to delete the project_folder and everything in it. Type `y` to confirm deletion. Users will be asked to confirm the deletion of each item in the folder.

```
rm: descend into directory 'project_folder'? y
rm: remove regular empty file 'project_folder/bioinformatics_for_beg
rm: remove directory 'project_folder'? y
```

```
ls -1
```

```
bioinformatics_folder
bioinformatics_for_noobies.txt
example_fastq.fq
example_rna_sequencing_counts.csv
file.txt
```

Snapshots

If users were to delete something that was not meant to be removed, there is a chance that the item could be recovered from snapshots, which are just static backups of the user's `home` or `data` directories at a certain point in time. See Biowulf's guide on snapshots *(https://hpc.nih.gov/storage/backups.html)* to learn more.

The absolute path for the `home` directory snapshot is `/home/username/.snapshot` while that for the `data` directory is `/data/username/.snapshot`.

Knowledge Check 5

Use the passcode tgrgvt to answer the question in the Slido poll.

Viewing File Content

Stay in the `/data/username/unix_demonstration` folder for these exercises.

The `cat` command will print the entire content of a file to the terminal screen.

For instance, to view the content of file.txt in the terminal screen do:

```
cat file.txt
```

```
Unix is an operating system, just like Windows or MacOS.
Linux is a variety of Unix, and sometimes the names are used interch
```

The `cat` command can also be used to view fastq or fq files, which contain sequences from high throughput sequencers. For long files that take a while to completely print, hit control-c to exit the `cat` command and return to the prompt.

```
cat example_fastq.fq
```

Tabular data in the form of csv files can be displayed by `cat` as well.

```
cat example_rna_sequencing_counts.csv
```

Paging through Files

Rather than printing file content in its entirety to the terminal, users can page through files using `less`.

```
less example_rna_sequencing_counts.csv
```

Users can use the up and down arrow on the keyboard to scroll up/down the file to view content. The up/down arrows enable scrolling line by line. Hit `q` to exit `less` and return to the command prompt.

Printing Tabular Data to Terminal Nicely Aligned

For tabular data in the form of csv files, which could contain multiple columns, the columns do not print to the terminal nicely aligned. The `column` command can fix this. Hit `q` to exit `less` and return to the command prompt.

The options and arguments in the column command include:

- Option `-t`: Creates a table.
- Option `-s`: Prompts users to provide the column separator (ie. comma for csv files)
- Argument: Name of the file which users would like to view (ie. example_rna_sequencing_counts.csv)
- `|` is the pipe operator, which sends output from one command as input for another (ie.`less` to enable paging through the data table)

```
column -t -s ',' example_rna_sequencing_counts.csv | less
```

{{Sdet}}{{Ssum}}`column` command output{{Esum}}

```
Geneid              HBR_1.bam  HBR_2.bam  HBR_3.bam  UHR_1.bam  UHR_
U2                  0          0          0          0          0
CU459211.1          0          0          0          0          0
CU104787.1          0          0          0          0          0
BAGE5               0          0          0          0          0
ACTR3BP6            0          0          0          0          0
5_8S_rRNA           0          0          0          0          0
AC137488.1          0          0          0          0          0
AC137488.2          0          0          0          0          0
CU013544.1          0          0          0          0          0
CT867976.1          0          0          0          0          0
CT867977.1          0          0          0          0          0
CT978678.1          0          0          0          0          0
CU459202.1          0          0          0          0          0
AC116618.1          0          0          0          0          0
CU463998.1          0          0          0          0          0
CU463998.3          0          0          0          0          0
CU463998.2          0          0          0          0          0
U6                  0          0          0          0          0
LA16c-60D12.1       0          0          0          3          2
LA16c-13E4.3        0          0          0          0          0
LA16c-60D12.2       0          0          0          0          4
ZNF72P              0          0          0          0          1
BNIP3P2             0          0          0          0          2
YME1L1P1            0          0          0          0          0
OR11H1              0          0          0          0          0
LA16c-60G3.6        0          0          0          0          3
ARHGAP42P3          0          0          0          0          2
LA16c-23H5.4        0          0          0          0          1
LA16c-60G3.8        0          0          0          0          2
LA16c-60G3.7        0          0          0          0          0
LA16c-60G3.5        0          0          0          0          0
```

```
LA16c-2F2.8         0          0          0          0          3
NEK2P2              0          0          0          0          1
LA16c-2F2.5         0          0          0          0          0
NF1P6               0          0          0          1          4
MED15P7             0          0          0          0          2
POTEH               0          0          1          7          7
POTEH-AS1           0          0          0          0          2
RNU6-816P           0          0          0          0          0
LA16c-3G11.7        0          0          0          2          1
LA16c-83F12.6       0          0          0          3          1
GRAMD4P2            0          0          0          0          1
DUXAP8              10         4          9          250        199
LL22NC03-N64E9.1    0          1          0          16         9
BMS1P22             0          1          3          25         24
LL22NC03-N14H11.1   4          2          0          98         38
NBEAP3              0          0          0          5          3
LA16c-60H5.7        0          0          0          11         6
LA16c-4G1.4         0          0          0          0          0
LA16c-4G1.3         0          0          0          0          3
AC092854.1          0          0          0          0          0
ABCD1P4             0          0          0          0          2
LA16c-17H1.3        0          0          0          0          0
PABPC1P9            0          0          0          0          1
SLC9B1P4            0          0          0          0          1
ACTR3BP2            0          0          0          0          0
CHEK2P4             0          0          0          0          0
KB-67B5.17          0          0          0          0          0
KB-67B5.12          0          0          0          0          0
KCNMB3P1            0          0          0          2          1
CCT8L2              0          0          0          1          2
FABP5P11            0          0          0          0          0
AP000547.1          0          0          0          0          1
TPTEP1              19         23         20         141        94
KB-7G2.9            0          0          1          3          4
SLC25A15P5          0          0          0          2          2
PARP4P3             0          0          0          1          1
ANKRD62P1-PARP4P3   0          1          0          3          3
ANKRD62P1           0          0          0          2          0
KB-7G2.8            0          0          0          0          0
VWFP1               2          2          4          1          2
AC005301.8          0          0          0          1          0
XKR3                0          0          0          3          4
HSFY1P1             0          0          0          0          0
GPM6BP3             0          0          0          0          0
AC007064.22         0          0          0          0          0
ZNF402P             0          0          0          1          1
AC007064.24         1          3          2          3          0
```

```
MTND1P17            0          0          0          0          0
AC007064.25         0          0          0          0          0
AC006548.19         0          0          0          0          0
IGKV1OR22-5         0          0          0          0          0
IGKV2OR22-4         0          0          0          0          0
IGKV2OR22-3         0          0          0          0          0
IGKV3OR22-2         0          0          0          0          1
IGKV1OR22-1         0          0          0          0          0
AC006548.28         1          1          1          4          40
GAB4                0          0          0          0          0
AC006548.26         0          0          0          0          0
VN1R9P              0          0          0          0          0
CECR7               22         27         32         31         27
AC006946.16         7          6          4          3          3
AC006946.17         0          2          2          0          3
IL17RA              58         65         58         95         71
AC006946.12         0          1          1          1          1
CECR6               26         45         32         9          6
AC006946.15         3          3          1          0          2
CECR5               30         44         33         127        82
CECR5-AS1           0          2          2          1          2
CECR1               30         28         32         39         35
AC005300.5          0          0          0          1          0
FAM32B              0          1          0          0          0
CECR3               1          0          1          0          1
CECR9               0          0          0          0          0
RN7SL843P           0          0          0          0          0
CECR2               115        88         119        119        81
AC004019.10         1          5          1          0          1
CLCP1               1          2          0          0          0
DNAJA1P6            0          0          0          0          0
SLC25A18            100        111        74         6          8
AC004019.13         1          2          1          1          2
ATP6V1E1            392        454        391        244        181
BCL2L13             212        284        264        244        166
BID                 70         85         84         112        76
MIR3198-1           0          0          0          0          0
LINC00528           1          0          0          1          2
MICAL3              339        429        425        211        145
XXbac-B461K10.4     6          6          9          1          2
MIR648              0          0          6          0          0
XXbac-B476C20.14    2          7          2          2          1
XXbac-B476C20.13    2          9          4          1          2
RHEBP3              1          2          3          0          0
FLJ41941            0          0          0          0          2
XXbac-B476C20.9     3          5          4          2          3
PEX26               135        174        137        205        135
```

```
XXbac-B476C20.11    0          0          1          3          0
XXbac-B476C20.10    0          0          0          0          0
ARL2BPP10           0          0          0          0          0
TUBA8               13         13         15         2          2
AC008079.10         55         68         53         14         14
USP18               3          6          2          28         14
AC008079.9          0          0          0          0          0
GGTLC5P             0          0          0          0          0
AC011718.2          1          0          0          0          0
AC011718.3          0          0          0          0          0
PPP1R26P3           0          0          0          0          0
XXbac-B33L19.6      0          0          0          0          0
FAM230A             0          0          0          2          4
XXbac-B33L19.12     0          0          0          0          0
GGTLC3              0          0          0          0          0
Metazoa_SRP         0          0          1          0          2
XXbac-B33L19.15     0          0          0          0          0
TMEM191B            6          1          3          0          2
PI4KAP1             18         11         36         65         33
SCARNA17            0          0          0          0          0
RN7SKP131           0          0          0          0          0
RIMBP3              1          2          0          2          3
XXbac-B33L19.10     0          0          0          0          0
CA15P2              0          0          0          0          0
PPP1R26P2           0          0          0          0          0
PPP1R26P4           0          0          0          0          0
AC008132.15         0          0          0          0          1
GGT3P               0          0          0          0          0
AC008132.14         0          0          0          0          0
E2F6P1              0          0          0          3          0
AC008132.13         0          0          1          1          3
BCRP7               0          0          0          0          0
AC008103.3          0          0          0          0          0
AC008103.4          0          0          0          0          0
DGCR6               73         91         76         24         13
PRODH               102        127        123        44         34
AC007326.1          0          0          0          3          1
AC007326.10         0          1          0          0          3
DGCR5               196        239        201        8          9
AC007326.9          11         9          12         1          0
DGCR9               30         30         27         5          2
AC000095.9          0          0          0          0          0
AC000095.11         9          5          9          0          0
CA15P1              4          3          5          1          2
DGCR2               304        354        314        308        178
Y_RNA               4          2          2          5          2
DGCR11              4          10         13         19         6
```

```
AC004461.4          1          1          0          0          2
DGCR12              2          1          7          2          2
AC004471.9          5          4          5          4          3
AC004471.10         1          1          0          0          2
TSSK1A              0          0          0          0          2
DGCR14              46         50         37         77         39
TSSK2               0          0          0          0          0
GSC2                0          0          0          0          0
LINC01311           3          1          3          11         8
SLC25A1             32         50         41         226        138
CLTCL1              33         40         36         102        71
AC000081.2          0          0          1          0          1
SNORA15             0          0          0          0          1
KRT18P62            1          1          0          1          0
HIRA                20         15         10         59         27
C22orf39            64         74         76         100        88
RN7SL168P           0          1          0          4          2
MRPL40              29         36         31         113        70
AC000068.5          5          4          1          6          8
UFD1L               38         58         53         228        148
AC000068.9          0          0          0          0          0
AC000068.10         0          0          0          0          2
CDC45               2          1          0          224        154
CLDN5               60         86         57         2          2
LINC00895           0          0          0          0          0
AC000077.2          0          0          0          0          1
AC000067.1          0          0          0          0          0
SEPT5               481        635        547        145        97
GP1BB               0          0          0          0          0
TBX1                1          0          2          7          9
GNB1L               14         17         8          39         36
AC000089.3          1          0          0          2          1
C22orf29            83         123        95         211        149
TXNRD2              55         52         41         84         68
AC000078.5          2          9          2          8          4
COMT                96         113        87         205        111
MIR4761             0          0          1          1          0
ARVCF               143        157        135        86         35
TANGO2              36         47         38         68         48
MIR185              0          0          0          0          0
AC006547.13         7          17         15         13         9
AC006547.15         0          0          0          0          0
DGCR8               80         96         67         238        162
MIR3618             0          0          0          0          0
MIR1306             0          0          0          0          0
AC006547.8          0          0          0          0          0
TRMT2A              42         62         49         164        82
```

```
MIR6816             0          0          0          0          0
RANBP1              52         74         70         593        399
SNORA77             0          0          0          0          0
ZDHHC8              95         97         91         114        84
AC006547.14         6          5          4          3          3
XXbac-B444P24.8     0          1          3          0          0
LINC00896           0          3          0          7          4
RTN4R               74         93         84         19         11
MIR1286             1          3          0          0          0
XXbac-B444P24.10    1          1          0          1          4
DGCR6L              47         42         38         96         46
XXbac-B444P24.13    1          2          3          2          1
XXbac-B444P24.14    3          3          3          3          0
XXbac-B33L19.4      0          0          0          1          0
USP41               0          0          0          3          2
ZNF74               38         40         41         110        79
RNU6-225P           0          0          0          0          0
SCARF2              11         7          2          34         23
XXbac-B562F10.12    0          0          0          0          0
KLHL22              63         80         83         81         52
XXbac-B562F10.11    4          8          13         10         5
RNY1P9              0          0          0          0          0
RN7SL812P           0          0          3          1          0
KRT18P5             4          3          1          4          2
AC007731.1          0          0          0          0          0
MED15               94         110        87         258        156
AC007050.17         0          0          0          3          2
AC007050.18         0          0          1          0          0
SMPD4P1             2          4          2          1          3
IGLL4P              0          0          0          0          1
SLC9A3P2            0          0          0          0          0
AC007050.1          0          0          0          0          0
ABHD17AP4           0          1          3          0          2
POM121L4P           0          0          0          0          1
BCRP5               0          0          0          0          0
TMEM191A            5          7          5          0          4
PI4KA               1102       1211       1079       433        343
SERPIND1            13         11         8          158        109
SNAP29              33         48         44         114        82
AC007308.7          0          0          0          0          0
CRKL                343        423        367        758        482
XXbac-B135H6.15     5          3          4          1          6
AIFM3               85         82         100        7          13
LZTR1               140        179        126        297        188
XXbac-B135H6.18     4          5          1          1          2
THAP7               36         56         39         95         77
THAP7-AS1           4          7          6          9          2
```

```
TUBA3FP             2          1          2          6          6
P2RX6               35         33         31         23         19
SLC7A4              19         25         14         9          4
AC002472.11         0          0          1          0          0
MIR649              0          0          0          0          0
P2RX6P              5          2          2          0          1
LRRC74B             0          2          2          1          1
TUBA3GP             0          0          0          0          0
BCRP2               1          0          0          0          1
KB-1592A4.15        0          0          0          0          0
POM121L7            1          0          1          0          0
E2F6P2              0          1          0          0          0
FAM230B             0          0          0          0          1
KB-1592A4.14        0          0          0          0          0
GGT2                0          0          1          3          2
E2F6P3              0          0          0          0          0
POM121L8P           0          0          0          0          0
BCRP6               0          0          0          0          0
KB-1183D5.13        0          0          0          0          0
KB-1183D5.14        0          0          0          0          0
PPP1R26P5           0          0          0          0          1
KB-1183D5.18        0          0          0          0          0
KB-1183D5.16        0          0          0          0          0
RIMBP3B             0          1          0          0          2
RN7SKP63            0          0          0          0          0
HIC2                29         25         28         209        106
TMEM191C            1          1          6          1          5
PI4KAP2             28         26         20         96         60
RN7SKP221           0          0          0          0          0
RIMBP3C             0          0          0          0          1
UBE2L3              207        241        198        470        310
YDJC                18         28         24         155        83
CCDC116             2          0          1          5          3
KB-1440D3.14        0          0          0          2          1
SDF2L1              5          14         3          51         34
PPIL2               60         65         60         243        146
MIR301B             0          0          0          0          0
MIR130B             0          0          0          0          0
KB-1440D3.13        0          0          0          4          5
YPEL1               25         45         31         17         9
RN7SL280P           1          0          1          1          1
MAPK1               741        955        901        840        502
RNA5SP493           0          0          1          3          4
KB-1027C11.4        0          1          1          1          0
PPM1F               80         106        108        217        140
LL22NC03-86G7.1     26         50         28         69         74
TOP3B               2          0          1          12         10
```

```
PRAMENP             0          0          0          0          0
IGLVI-70            0          0          0          0          1
IGLV4-69            0          0          0          0          0
IGLVI-68            0          0          0          0          0
LL22NC03-23C6.13    0          0          0          0          1
LL22NC03-23C6.12    0          0          0          0          1
IGLV10-67           0          0          0          0          0
LL22NC03-23C6.15    0          0          0          0          0
IGLVIV-66-1         0          0          0          0          0
IGLVV-66            0          0          0          0          0
IGLVIV-65           0          0          0          0          0
IGLVIV-64           0          0          0          0          0
IGLVI-63            0          0          0          0          1
IGLV1-62            0          0          0          0          2
LL22NC03-88E1.18    0          0          0          0          0
IGLV8-61            0          0          0          0          0
LL22NC03-88E1.17    0          0          0          0          0
ABHD17AP5           0          0          0          0          0
LL22NC03-30E12.10   0          0          0          0          0
LL22NC03-30E12.11   0          0          0          0          0
IGLV4-60            0          0          0          0          0
LL22NC03-30E12.13   0          0          0          0          0
SOCS2P2             0          0          0          0          1
IGLVIV-59           0          0          0          0          0
IGLVV-58            0          0          0          0          0
BMP6P1              0          0          0          0          0
IGLV6-57            0          0          0          1          0
IGLVI-56            0          0          0          0          0
IGLV11-55           0          0          0          0          0
IGLV10-54           0          0          0          0          0
IGLVIV-53           0          0          0          0          1
TOP3BP1             0          0          0          1          0
LL22NC03-123E1.5    0          0          0          0          1
VPREB1              0          0          0          1          0
CH17-264L24.1       12         12         18         16         15
LL22NC03-2H8.5      2          0          1          2          6
LL22NC03-2H8.4      0          0          0          0          0
LL22NC03-80A10.6    9          11         3          10         3
BMS1P20             3          1          7          6          1
IGLV5-52            1          2          3          0          0
IGLV1-51            1          4          1          0          1
IGLV1-50            1          3          0          0          0
LL22NC03-80A10.11   0          0          0          0          1
IGLV9-49            0          0          0          0          1
LL22NC03-75A1.9     0          0          0          0          0
IGLV5-48            0          0          0          0          0
IGLV1-47            0          0          0          0          0
```

```
LL22NC03-22A12.9    0          0          0          0          1
IGLV7-46            0          0          0          0          0
LL22NC03-22A12.12   0          0          0          0          0
IGLV5-45            0          0          0          0          0
IGLV1-44            0          0          0          0          0
IGLV7-43            0          0          0          0          0
IGLVI-42            0          0          0          0          0
IGLVVII-41-1        0          0          0          0          0
IGLV1-41            0          0          0          0          0
IGLV1-40            0          0          0          0          1
ASH2LP1             0          0          0          0          0
IGLVI-38            0          0          0          0          1
IGLV5-37            0          0          0          0          0
IGLV1-36            0          0          0          0          1
KB-288A10.17        0          1          0          0          1
IGLV7-35            0          0          0          0          0
KB-288A10.19        0          0          1          0          1
ZNF280B             28         37         39         65         55
ZNF280A             0          0          0          11         11
PRAME               0          0          0          822        472
LL22NC03-63E9.3     0          0          0          1          1
IGLV2-34            0          0          0          0          0
IGLV2-33            0          0          0          0          0
IGLV3-32            0          0          0          0          0
IGLV3-31            0          0          0          0          1
IGLV3-30            0          0          0          0          0
BCRP4               0          0          0          0          0
POM121L1P           0          0          0          0          1
GGTLC2              0          0          0          0          1
IGLV3-29            0          0          0          0          1
AC244250.2          0          0          0          0          0
IGLV2-28            0          0          0          0          0
IGLV3-27            0          0          0          2          0
IGLV3-26            0          0          0          0          0
IGLVVI-25-1         0          0          0          0          0
IGLV3-25            0          0          0          0          2
LL22NC03-102D1.16   0          0          0          0          0
LL22NC03-102D1.18   0          0          0          0          0
IGLV3-24            0          0          0          0          0
IGLV2-23            0          0          0          0          0
AC244250.1          0          0          0          0          0
IGLVVI-22-1         0          0          0          0          0
IGLV3-22            0          0          0          0          0
IGLV3-21            0          0          0          0          0
IGLVI-20            0          0          0          0          0
IGLV3-19            0          0          0          0          1
LL22NC03-48A11.14   0          0          0          0          0
```

```
AC244250.4          0          0          0          0          0
IGLV2-18            0          0          0          0          0
IGLL5               0          0          0          1          0
IGLV3-17            0          0          0          0          0
IGLV3-16            0          0          0          0          0
IGLV3-15            0          0          0          0          0
AC244250.3          0          0          0          0          0
IGLV2-14            0          0          0          26         12
IGLV3-13            0          0          0          0          0
IGLV3-12            0          0          0          0          0
LL22NC03-24A12.8    0          0          0          0          0
LL22NC03-24A12.9    0          0          0          0          0
AC244157.1          0          0          0          0          0
IGLV2-11            0          0          0          0          0
LL22NC03-84E4.13    0          0          0          0          0
IGLV3-10            0          0          0          0          0
LL22NC03-84E4.11    0          0          0          0          0
IGLV3-9             0          0          0          0          1
IGLV2-8             0          0          0          0          1
MIR650              0          0          0          0          0
LL22NC03-84E4.8     0          0          0          0          1
IGLV3-7             0          0          0          0          0
IGLV3-6             0          0          0          0          0
AC245028.1          0          0          0          0          0
IGLV2-5             0          0          0          0          0
IGLV3-4             0          0          0          0          0
IGLV4-3             0          0          0          0          0
IGLV3-2             0          0          0          0          0
IGLV3-1             0          0          0          0          0
MIR5571             0          0          0          0          0
IGLJ1               0          0          0          0          0
IGLC1               0          0          0          0          0
IGLJ2               0          0          0          0          0
IGLC2               0          0          0          706        503
IGLJ3               0          0          0          0          1
IGLC3               0          0          0          1170       317
IGLJ4               0          0          0          0          0
IGLC4               0          0          0          0          0
IGLJ5               0          0          0          0          1
IGLC5               0          0          0          0          0
IGLJ6               0          0          0          0          0
IGLC6               0          0          0          2          1
IGLJ7               0          0          0          0          0
IGLC7               0          0          0          8          5
AP000361.2          0          0          0          0          0
AP000362.1          0          0          0          1          0
RSPH14              4          8          5          1          0
```

```
GNAZ                223        247        214        32         17
AC000029.1          0          1          0          0          0
U7                  0          0          0          0          0
RAB36               29         30         33         20         15
BCR                 228        357        302        332        204
BCRP8               0          1          0          0          0
RN7SL263P           1          1          0          1          0
FBXW4P1             2          4          5          8          6
AP000343.1          0          2          0          0          0
AP000343.2          0          0          1          0          0
CES5AP1             2          2          0          0          1
ZDHHC8P1            21         16         14         1          2
KB-1269D1.8         1          1          0          0          0
AP000344.3          0          0          0          0          1
AP000344.4          0          1          0          1          3
AP000345.1          0          0          1          0          1
AP000345.4          0          0          0          4          4
PCAT14              0          0          1          202        156
AP000345.2          0          0          0          0          2
IGLL1               0          0          0          0          0
KB-208E9.1          1          3          1          0          1
KB-1572G7.5         0          1          0          1          1
DRICH1              2          2          1          0          4
KB-1572G7.4         0          0          1          0          0
KB-1572G7.3         0          3          0          0          0
GUSBP11             1          0          1          1          0
AP000347.4          0          0          0          1          5
ASLP1               1          1          2          5          3
KB-1572G7.2         0          0          1          0          0
AP000347.2          4          4          8          12         8
RGL4                16         27         18         17         15
ZNF70               26         46         32         80         48
VPREB3              0          0          0          0          0
C22orf15            2          7          7          4          3
CHCHD10             44         53         39         46         36
MMP11               3          1          1          15         17
AP000349.2          0          0          0          0          0
SMARCB1             70         78         62         169        131
DERL3               4          8          7          81         43
KB-1125A3.11        0          3          0          1          0
SLC2A11             54         63         46         28         34
AP000350.10         0          0          0          0          0
KB-1125A3.12        4          4          1          8          5
RN7SL268P           1          1          1          4          1
MIF                 3          3          3          3          1
MIF-AS1             5          1          5          8          11
AP000350.5          11         14         12         30         24
```

```
AP000350.1          0          0          0          0          0
AP000350.6          2          2          1          3          1
AP000350.7          0          0          0          0          0
AP000350.8          0          0          0          0          0
GSTT2B              3          4          3          10         4
KB-1125A3.10        0          0          0          0          0
DDTL                3          3          3          2          17
KB-226F1.2          1          2          1          1          4
DDT                 4          5          4          18         8
AP000351.3          0          0          0          0          0
GSTT2               0          0          0          0          0
AP000351.4          0          0          0          1          0
GSTTP1              0          0          0          0          1
AP000351.13         0          0          0          0          1
CABIN1              280        320        309        509        296
KB-318B8.7          13         11         7          14         10
SUSD2               8          8          7          11         17
GGT5                22         31         23         10         4
AP000354.4          0          0          1          0          0
POM121L9P           1          1          2          0          1
BCRP1               0          0          0          0          0
AP000354.2          0          0          0          0          1
SPECC1L             64         80         70         156        82
SPECC1L-ADORA2A     0          1          0          0          1
ADORA2A             2          4          2          4          0
ADORA2A-AS1         2          5          5          6          12
UPB1                0          1          2          1          10
AP000355.2          0          0          0          0          1
GUCD1               62         62         62         384        214
SNRPD3              71         87         98         293        211
GGT1                9          14         13         86         42
LRRC75B             20         30         26         21         24
AP000356.2          0          0          0          0          0
BCRP3               2          1          2          5          5
POM121L10P          0          0          0          0          0
ARL5AP4             0          0          0          0          0
AP000357.4          0          0          0          0          1
LL22NC03-N95F10.1   0          0          0          0          0
AP000358.5          0          0          0          0          0
CRIP1P4             0          0          0          0          1
PIWIL3              0          0          0          1          3
SGSM1               151        187        161        5          8
SNORD56             0          0          1          0          0
TMEM211             0          0          1          0          1
KIAA1671            126        148        131        158        97
CTA-243E7.4         3          3          0          1          3
CTA-243E7.3         0          1          1          1          1
```

```
CTA-243E7.2         0          2          1          4          4
CTA-243E7.1         5          6          3          12         19
CTA-221G9.12        7          7          6          4          1
CTA-221G9.10        0          0          0          0          0
CRYBB3              0          1          1          1          0
CTA-221G9.7         0          1          0          0          0
CRYBB2              0          1          0          0          4
Z99916.1            0          0          0          0          0
CTA-221G9.11        0          0          0          0          0
RP3-462D8.2         0          0          0          0          1
IGLL3P              0          0          0          0          0
CTA-246H3.8         0          1          0          2          2
CTA-246H3.11        0          2          2          4          2
LRP5L               7          5          5          41         24
CTA-246H3.12        0          0          0          1          2
CTA-390C10.9        0          1          0          0          0
IGLVIVOR22-1        0          0          0          0          0
CRYBB2P1            24         27         23         54         37
MIR6817             0          0          0          0          0
CTA-390C10.10       10         18         11         12         8
AL008721.1          0          0          0          0          0
CTA-407F11.8        1          1          0          1          2
ADRBK2              206        283        260        170        134
CTA-407F11.7        0          0          1          2          3
YES1P1              3          5          4          9          4
RNA5SP494           0          0          0          0          0
MYO18B              0          0          0          86         85
CTA-407F11.9        0          0          0          2          1
CTA-125H2.2         0          0          0          1          6
Z98949.1            0          0          0          1          1
CTA-125H2.1         0          0          0          0          0
RN7SKP169           0          0          0          0          1
CTA-125H2.3         0          0          0          0          0
CTA-796E4.3         0          0          0          0          1
CTA-796E4.4         1          0          0          0          1
SEZ6L               399        508        463        16         17
RP11-259P1.1        3          5          2          0          0
RNA5SP495           0          0          0          0          0
CTB-1048E9.7        0          0          0          0          1
ASPHD2              44         56         80         18         13
HPS4                114        176        183        318        202
SRRD                35         37         43         62         47
TFIP11              60         93         52         141        77
CTA-445C9.14        14         23         13         27         13
TPST2               38         39         38         85         46
MIR548J             0          0          0          2          0
HMGB1P10            2          3          2          9          10
```

```
CRYBB1              2          0          1          3          3
CRYBA4              1          0          0          0          1
ISCA2P1             0          0          0          0          1
MIAT                429        453        443        43         34
MIAT_exon1          0          0          0          0          0
CTA-373H7.7         0          4          0          0          0
MIAT_exon5_1        0          0          0          0          0
MIAT_exon5_2        0          0          0          0          0
MIATNB              4          6          8          11         14
MIAT_exon5_3        0          0          0          0          0
LINC01422           2          4          6          3          9
RP1-40G4P.1         0          0          0          0          0
CTA-992D9.11        0          0          0          0          8
RNU6-1066P          0          0          0          0          0
CTA-992D9.10        0          0          0          0          0
CTA-992D9.9         0          0          0          0          0
CTA-992D9.6         1          0          0          0          2
CTA-992D9.8         0          0          0          1          4
CTA-992D9.7         0          0          0          0          1
CTA-503F6.2         0          0          0          0          1
RP5-1172A22.1       1          0          0          2          1
CTA-929C8.5         0          0          0          0          0
CTA-929C8.7         0          0          0          0          0
CTA-929C8.6         0          0          0          0          3
CTA-929C8.8         1          3          1          0          0
RP1-205F14P.1       0          0          0          1          0
RP11-46E17.6        0          0          0          0          0
RP1-231P7P.1        0          0          0          0          2
RP1-213J1P__B.1     0          0          0          2          1
RP1-213J1P__B.2     0          0          0          0          0
RP11-375H17.1       0          0          0          0          1
MN1                 44         34         31         123        93
PITPNB              80         92         64         111        87
TTC28-AS1           42         51         66         48         46
TTC28-AS1_1         0          0          0          0          0
MIR3199-2           1          0          0          1          0
TTC28-AS1_2         0          0          0          0          0
TTC28               87         123        79         191        108
TTC28-AS1_3         0          0          0          0          0
TTC28-AS1_4         0          0          0          0          0
RN7SL757P           1          0          0          0          0
SNORD42             0          0          0          0          0
MIR5739             0          0          1          3          2
RN7SL162P           0          0          0          0          0
CHEK2               1          5          3          98         82
HSCB                7          9          11         35         20
CCDC117             68         75         58         259        176
```

```
XBP1                67         102        79         1082       636
Z93930.1            0          0          0          1          0
CTA-292E10.6        4          7          2          10         12
CTA-292E10.8        1          0          0          4          3
CTA-292E10.7        0          0          0          0          0
ZNRF3               97         103        102        99         89
ZNRF3-IT1           1          6          3          4          3
ZNRF3-AS1           6          3          3          8          2
C22orf31            0          2          0          0          1
KREMEN1             50         62         36         75         59
CTA-747E2.10        1          0          2          0          0
Z95116.1            0          0          0          0          0
RNU6-810P           1          0          0          0          0
RNU6-1219P          0          0          0          0          0
EMID1               11         19         29         12         6
RHBDD3              23         40         33         79         57
CTA-984G1.5         2          1          3          9          3
EWSR1               346        356        357        920        675
GAS2L1              73         77         66         32         23
RASL10A             9          27         17         0          2
AC002059.10         0          0          1          1          1
AP1B1               230        272        256        358        244
MIR3653             0          0          0          0          0
SNORD125            0          0          0          0          0
AC000041.8          0          0          0          0          0
RFPL4AP6            0          0          0          0          1
RFPL1S              116        107        115        6          2
AC000041.10         0          0          0          0          0
RFPL1               0          0          0          0          0
AC000035.3          0          0          0          0          0
NEFH                194        265        253        27         24
THOC5               73         123        65         218        137
CTA-256D12.11       0          0          1          1          2
NIPSNAP1            105        131        119        291        188
NF2                 206        270        235        445        307
RPEP4               2          4          1          2          0
RP1-76B20.11        0          1          0          0          1
RP1-76B20.12        0          0          0          0          0
CABP7               18         21         25         2          1
ZMAT5               16         12         6          20         20
UQCR10              83         94         104        185        98
ASCC2               35         42         39         144        91
MTMR3               36         46         35         29         15
AC004819.1          1          0          1          0          1
RNU6-331P           0          0          0          0          0
AC003681.1          0          0          1          0          0
RP3-394A18.1        81         94         75         86         63
```

```
MIR6818             0          0          0          0          0
HORMAD2-AS1         2          0          0          1          1
CNN2P1              0          1          0          0          1
HORMAD2             0          0          0          1          5
CTA-85E5.7          0          0          0          0          0
CTA-85E5.6          0          0          0          0          0
RP3-438O4.4         0          0          0          0          2
RP1-102K2.6         0          0          0          2          0
LIF                 2          3          3          154        97
RP1-102K2.8         0          0          0          3          1
OSM                 0          0          1          0          0
RP1-102K2.9         2          3          0          0          1
GATSL3              5          6          3          2          0
RP1-130H16.18       0          0          0          0          0
TBC1D10A            13         15         14         39         30
SF3A1               184        232        179        388        259
CCDC157             3          15         9          9          8
RNF215              54         65         42         57         40
SEC14L2             53         81         68         42         33
RP4-539M6.19        0          0          0          0          0
AC004832.1          0          0          1          0          0
RP4-539M6.20        3          6          4          4          6
RNU6-564P           1          1          0          0          0
RP4-539M6.21        0          2          1          4          4
MTFP1               0          0          0          3          5
RP4-539M6.22        0          0          0          1          1
RP4-539M6.18        0          0          0          1          0
SEC14L3             1          0          0          0          2
RP4-539M6.14        0          0          0          0          0
SDC4P               0          0          0          0          0
SEC14L4             0          0          0          3          2
SEC14L6             4          12         3          3          7
SIRPAP1             0          0          0          0          0
GAL3ST1             19         18         21         4          6
PES1                65         80         70         271        202
RP1-56J10.8         0          0          0          0          1
TCN2                19         26         23         56         49
SLC35E4             18         32         26         21         12
DUSP18              8          13         9          12         10
CTA-963H5.5         1          2          0          3          0
OSBP2               119        137        98         113        57
AL022336.1          2          0          0          0          0
EIF4HP2             1          4          9          3          6
MORC2-AS1           1          2          3          5          2
MORC2               75         82         50         146        100
TUG1                188        227        207        545        349
TUG1_1              0          0          0          0          0
```

```
TUG1_2              0          0          0          0          0
TUG1_3              0          0          0          0          0
TUG1_4              0          0          0          0          0
RP3-430N8.11        0          0          0          0          0
RP3-430N8.10        0          0          0          0          0
RP3-412A9.17        0          0          0          2          5
RN7SL633P           0          0          0          0          0
SMTN                42         51         47         142        91
RP3-412A9.16        1          2          2          11         6
SELM                83         86         77         25         18
RP3-412A9.12        0          0          0          0          0
INPP5J              59         77         58         7          8
PLA2G3              1          5          2          13         12
RP3-412A9.15        0          0          0          0          0
MIR3928             0          0          0          0          0
RNF185              57         105        74         106        82
RNF185-AS1          0          0          0          0          0
LIMK2               96         119        103        113        70
RNU6-1128P          0          0          0          0          1
PIK3IP1             112        165        128        52         32
PIK3IP1-AS1         1          1          3          2          0
RNA5SP496           0          0          0          0          0
PATZ1               72         74         61         191        116
LINC01521           12         14         13         8          9
RNU6-338P           0          0          0          0          0
DRG1                83         105        96         191        143
EIF4ENIF1           95         107        96         94         77
RP11-247I13.11      0          0          2          1          1
RNU6-28P            1          0          0          0          1
SFI1                112        125        107        142        102
H2AFZP6             1          0          1          0          0
RP11-247I13.6       0          0          0          0          0
RP11-247I13.3       0          1          1          4          1
PISD                195        250        233        156        95
MIR7109             0          0          0          0          0
PRR14L              219        269        234        418        294
DEPDC5              51         79         76         77         50
RN7SL20P            0          0          0          1          2
CTA-440B3.1         0          0          1          1          2
RNU6-201P           0          0          0          0          0
RP1-180M12.1        0          1          2          0          0
C22orf24            0          6          6          4          2
YWHAH               1029       1363       1146       336        220
CTA-342B11.1        0          0          0          1          0
CTA-342B11.2        0          0          0          0          2
RN7SL305P           0          0          0          0          0
SC22CB-1E7.1        0          0          0          0          0
```

```
SLC5A1              0          0          0          0          6
AP1B1P1             0          0          0          0          1
RP1-127L4.10        0          0          0          0          0
AP1B1P2             0          0          0          0          0
RP1-127L4.7         0          0          0          1          0
C22orf42            0          2          0          0          1
RP1-90G24.8         0          0          0          0          0
RFPL3-AS1_1         0          0          0          0          0
RFPL2               5          3          10         1          1
AL008723.1          0          0          0          1          0
IGLCOR22-1          0          0          0          0          0
RP1-90G24.10        4          7          3          2          3
SLC5A4              7          12         5          13         9
CPSF1P1             41         43         42         6          12
RP1-90G24.6         1          1          3          0          0
RP1-90G24.11        0          3          0          1          0
RP1-149A16.12       0          1          1          1          0
RFPL3               0          0          0          0          0
IGLCOR22-2          0          0          0          0          0
RFPL3S              1          1          1          0          0
RFPL3-AS1_2         0          0          0          0          0
RP1-149A16.3        1          3          2          1          1
IGLVIVOR22-2        0          0          0          0          0
RP1-149A16.17       0          1          0          4          2
RP1-149A16.16       2          0          0          2          0
RTCB                109        150        124        339        182
BPIFC               0          0          0          0          2
FBXO7               163        181        194        426        375
SYN3                74         110        78         11         12
LL22NC03-104C7.1    1          4          5          1          1
RNA5SP497           0          0          0          0          0
LL22NC01-116C6.1    0          0          1          0          1
TIMP3               214        271        243        805        491
CTA-415G2.2         0          0          0          0          0
RP1-302D9.1         0          0          0          0          0
RP1-302D9.2         0          0          0          0          0
RP1-302D9.5         0          0          0          0          1
LARGE               173        213        199        83         58
RP1-302D9.3         0          0          0          0          0
SC22CB-1D7.1        1          1          2          3          1
MIR4764             1          0          0          0          0
SNORA76             0          0          0          0          0
SNORA50             0          0          0          0          0
LARGE-IT1           0          0          0          0          0
LARGE-AS1           7          6          5          5          7
LL22NC03-32F9.1     0          0          0          1          0
LL22NC03-86D4.1     0          0          0          0          1
```

```
LL22NC03-13G6.2     0          1          2          0          0
RP1-101G11.2        0          0          0          0          0
RP1-101G11.3        0          0          0          3          4
RP1-288L1.5         2          3          0          0          1
RP1-288L1.4         0          0          1          0          0
ISX-AS1             1          0          0          2          1
ISX                 0          0          0          6          4
LINC01399           0          0          0          1          0
CTA-714B7.7         0          0          0          0          0
RP3-323A16.1        0          0          1          75         77
CTA-714B7.4         0          0          0          0          0
COX7BP1             0          0          0          0          0
RNU7-167P           0          0          0          0          0
HMGXB4              32         45         49         124        103
RP3-510H16.3        2          0          1          0          0
TOM1                99         119        103        84         56
MIR3909             1          0          0          1          1
MIR6069             0          0          0          0          0
CTA-286B10.7        0          0          0          1          0
CTA-286B10.8        0          0          0          0          0
HMOX1               13         19         13         83         51
MCM5                29         32         34         544        294
RP4-569D19.5        0          0          0          4          1
RP4-569D19.8        0          0          0          0          0
RASD2               55         81         60         15         15
MB                  0          1          0          9          8
CITF22-62D4.1       0          0          0          0          1
APOL6               64         54         56         331        197
RP1-41P2.7          0          0          0          0          0
MRPS16P3            0          0          0          0          0
APOL5               0          0          1          0          0
RBFOX2              621        738        711        515        367
NDUFA9P1            3          3          2          4          4
RP1-78B3.1          10         8          4          21         23
CTA-212A2.4         0          0          0          0          0
CTA-212A2.3         0          0          0          0          9
CTA-212A2.2         0          0          0          0          0
CTA-212A2.1         1          0          1          0          1
APOL3               8          6          12         39         33
Z95114.4            0          0          0          0          1
Z95114.3            0          0          0          0          0
Z95114.5            0          0          0          0          1
Z95114.6            0          0          0          0          1
Z95114.7            0          0          0          0          0
MTND1P10            0          0          0          0          1
APOL4               10         6          8          9          5
APOL2               113        151        135        148        112
```

```
APOL1               4          9          6          87         65
MYH9                449        512        485        2685       1608
MIR6819             0          0          0          1          1
RP4-633O19__A.1     1          2          1          2          0
RPS15AP38           0          0          0          0          1
BX470187.1          0          0          0          0          0
RP5-1119A7.14       0          1          3          0          0
TXN2                27         41         39         82         49
FOXRED2             74         108        107        218        104
EIF3D               103        119        131        745        494
RP5-1119A7.11       0          0          0          0          0
RP5-1119A7.10       0          0          0          0          0
RP5-1119A7.17       41         56         44         0          0
CACNG2              33         34         48         0          1
RP1-293L6.1         3          2          4          0          0
IFT27               53         58         56         77         57
PVALB               100        129        102        25         17
CITF22-24E5.1       2          0          0          0          0
CTA-833B7.2         0          0          1          1          4
NCF4                3          7          1          24         17
CSF2RB              2          4          4          50         42
CSF2RBP1            0          0          0          0          1
LL22NC01-81G9.3     0          0          0          0          1
TEX33               0          0          0          0          0
TST                 18         21         18         88         61
MPST                34         29         33         131        76
KCTD17              47         74         73         32         21
RN7SKP214           0          0          0          1          0
TMPRSS6             1          3          0          5          5
RP5-1170K4.7        0          0          0          0          1
IL2RB               1          0          0          6          6
AL022314.1          0          0          0          0          1
RP1-151B14.6        0          0          0          1          0
C1QTNF6             11         8          10         85         65
SSTR3               30         36         48         14         12
RP1-151B14.9        0          0          0          0          0
RAC2                8          8          5          111        79
CYTH4               13         18         16         22         19
ELFN2               106        137        114        19         17
RP1-63G5.7          1          2          1          1          3
RP1-63G5.8          0          0          0          0          0
MFNG                4          5          6          75         30
CARD10              2          5          5          97         76
RP5-1177I5.3        1          1          0          0          0
CDC42EP1            68         100        65         144        81
LGALS2              0          0          0          7          5
GGA1                119        155        128        307        193
```

```
SH3BP1              20         13         16         55         34
Z83844.1            1          3          1          7          2
PDXP                5          6          5          2          1
RN7SL385P           0          1          0          0          0
LGALS1              75         93         78         729        447
NOL12               9          10         15         28         17
RP1-37E16.12        0          0          0          0          0
TRIOBP              36         28         25         164        103
H1F0                106        146        112        252        167
GCAT                34         27         33         76         56
GALR3               1          0          2          1          1
ANKRD54             33         48         55         91         50
MIR658              0          0          0          0          0
MIR659              0          0          0          1          0
EIF3L               191        222        206        704        454
RP5-1014D13.2       12         23         15         48         32
RNU6-900P           0          0          0          0          0
MICALL1             52         64         62         149        96
RP5-1039K5.12       1          8          1          4          2
C22orf23            2          1          5          9          6
AL031587.1          0          2          0          0          0
RP5-1039K5.19       167        192        150        105        83
RP5-1039K5.17       0          0          0          0          0
POLR2F              15         28         17         12         8
MIR6820             0          0          0          0          0
SOX10               0          0          0          0          0
MIR4534             0          0          0          0          0
RP5-1039K5.16       6          3          10         4          7
RP5-1039K5.18       0          0          1          0          1
PICK1               79         81         85         46         33
RP5-1039K5.13       0          0          0          0          0
SLC16A8             9          13         11         11         5
BAIAP2L2            5          17         8          18         8
CTA-228A9.3         10         3          3          4          2
PLA2G6              61         57         62         86         48
CTA-228A9.4         2          3          4          13         7
MAFF                31         27         20         97         63
TMEM184B            207        235        215        191        140
RP1-5O6.5           0          0          0          1          0
RN7SL704P           0          0          0          0          1
AL020993.1          0          0          0          0          0
CSNK1E              232        229        222        592        338
RP3-449O17.1        10         15         10         30         28
RP1-5O6.4           2          0          1          6          4
RP3-434P1.6         0          0          0          0          0
KCNJ4               49         70         50         2          1
KDELR3              6          7          7          106        92
```

```
DDX17               1532       1797       1637       2814       1818
DMC1                2          4          0          15         11
RP1-199H16.6        1          0          0          0          0
FAM227A             16         12         17         40         48
CBY1                17         19         13         25         22
RP3-508I15.10       3          1          0          0          4
RP3-508I15.9        12         7          15         7          9
TOMM22              52         67         51         178        112
JOSD1               149        161        133        261        204
GTPBP1              146        187        152        335        182
PRDX3P1             3          5          2          11         3
RP3-508I15.18       0          0          0          0          2
SUN2                289        369        314        266        151
RP3-508I15.19       0          2          0          4          1
RP3-508I15.20       1          1          1          2          3
RP3-508I15.14       1          0          2          3          0
RP3-508I15.21       1          5          2          4          9
RP3-508I15.22       0          1          1          4          0
DNAL4               19         42         34         46         18
NPTXR               390        446        394        69         59
CBX6                738        873        830        362        240
CTA-150C2.13        0          0          0          0          0
APOBEC3A            0          0          0          0          1
APOBEC3B            1          0          0          19         22
APOBEC3B-AS1        0          0          0          0          0
APOBEC3C            4          3          3          80         48
APOBEC3D            1          1          2          16         8
APOBEC3F            1          1          0          11         6
APOBEC3G            4          9          3          41         25
CTA-150C2.20        0          0          0          0          0
RP4-742C19.12       0          2          1          0          0
APOBEC3H            4          3          0          0          0
CBX7                185        257        208        25         21
COX5BP7             0          0          0          0          0
RP4-742C19.13       6          19         10         8          6
FUNDC2P4            0          0          0          0          0
PDGFB               34         45         32         40         28
RP3-333H23.8        0          0          0          0          0
RPL3                659        761        721        4027       2406
SNORD83B            0          0          0          0          0
SNORD83A            2          0          0          7          5
AL022326.1          0          0          0          1          1
SNORD43             0          0          0          0          0
SYNGR1              763        997        870        54         51
RP3-333H23.9        1          2          2          0          0
TAB1                99         91         70         82         75
MGAT3               257        328        274        35         15
```

```
MGAT3-AS1           5          9          8          1          2
MIEF1               95         122        114        312        164
ATF4                291        358        307        1354       819
RPS19BP1            72         88         72         129        95
CACNA1I             106        139        136        2          7
ENTHD1              0          0          0          2          3
RP1-172B20.6        0          0          0          0          1
RN7SKP210           0          0          0          0          0
UQCRFS1P1           1          5          6          4          8
GRAP2               1          0          1          64         45
RP3-370M22.8        0          0          0          8          1
FAM83F              0          1          6          28         20
RP3-496C20.1        0          2          0          1          0
TNRC6B              582        686        592        528        327
RPL7P52             2          4          2          3          2
ADSL                40         41         48         302        176
RP5-1042K10.14      0          0          1          1          0
SGSM3               109        136        114        147        104
RP5-1042K10.10      1          2          1          4          4
MKL1                139        132        104        137        81
RP5-1042K10.13      0          0          1          1          1
RP5-1042K10.12      2          0          2          0          4
RP4-591N18.2        4          10         8          11         7
AL031594.1          1          1          1          2          2
COX6B1P3            1          0          0          1          0
RPL4P6              1          2          1          8          5
GAPDHP37            0          1          0          0          1
MCHR1               12         21         17         2          3
SLC25A17            39         39         40         119        96
RP3-408N23.4        1          1          3          5          1
JTBP1               1          1          0          6          1
MIR4766             0          0          0          2          0
ST13                389        470        463        880        640
XPNPEP3             31         43         39         149        105
DNAJB7              2          2          0          2          1
RNU6-379P           0          0          0          0          0
RBX1                50         68         60         122        77
AL080243.1          0          0          0          0          0
RP11-12M9.3         0          0          0          0          0
RP11-12M9.4         0          0          0          0          0
EP300               302        403        405        569        328
MIR1281             0          0          0          0          0
RNU6-375P           0          0          0          0          1
RP1-85F18.6         0          3          0          3          3
EP300-AS1           1          2          0          1          1
LRRC37A14P          0          1          0          0          0
L3MBTL2             91         96         83         108        82
```

```
RP4-756G23.5        6          8          9          2          5
CHADL               32         40         39         2          3
RANGAP1             256        316        267        464        296
MIR6889             0          0          0          0          0
ZC3H7B              417        531        475        453        288
TEF                 335        384        341        43         34
RNU6-495P           0          2          0          0          0
CTA-223H9.9         0          0          2          4          1
TOB2                203        279        197        173        116
PHF5A               34         36         17         134        79
ACO2                301        366        347        254        168
POLR3H              106        93         91         131        77
CSDC2               72         94         65         6          5
PMM1                34         40         55         51         31
DESI1               129        188        159        190        134
XRCC6               365        415        378        1431       973
NHP2L1              168        201        178        366        219
RNU6-476P           0          1          0          3          1
C22orf46            34         36         32         56         46
MEI1                1          5          1          8          6
HMGN2P10            0          1          0          0          0
RNU6ATAC22P         0          0          0          0          0
CCDC134             9          24         19         39         24
RP5-821D11.7        12         14         13         34         18
SREBF2              497        669        575        627        384
MIR33A              0          1          2          0          0
SHISA8              33         31         18         0          0
TNFRSF13C           4          2          2          11         9
MIR378I             0          0          0          0          0
CENPM               0          3          1          65         35
LINC00634           28         16         21         0          1
SEPT3               721        907        863        54         38
CTA-250D10.19       4          3          4          0          1
WBP2NL              14         11         8          5          9
SLC25A5P1           0          0          1          0          1
NAGA                30         43         53         144        107
FAM109B             9          3          4          6          5
SNORD13P1           0          0          0          0          1
SMDT1               25         42         34         28         15
NDUFA6              67         101        81         167        109
RP1-257I20.14       2          1          2          8          4
NDUFA6-AS1          10         18         21         15         6
OLA1P1              1          0          3          3          0
CYP2D6              15         23         16         17         9
RP4-669P10.19       2          1          0          4          1
RP4-669P10.16       1          3          0          2          0
RP4-669P10.20       4          6          5          2          2
```

```
CYP2D7              6          9          8          2          3
CYP2D8P             2          3          4          6          7
TCF20               205        259        209        455        281
OGFRP1              0          3          1          13         6
Z83851.4            1          2          1          8          5
CTA-989H11.1        1          3          1          8          1
LINC01315           1          3          5          2          4
NFAM1               5          5          11         8          9
CTA-126B4.7         0          0          0          1          1
SERHL               4          3          5          2          2
RRP7A               59         89         80         157        86
Z93241.1            0          0          0          0          0
SERHL2              6          11         7          18         14
RRP7BP              20         30         18         52         42
RN7SKP80            284        319        228        250        413
RNU6-513P           0          0          0          0          0
POLDIP3             139        155        150        263        169
RNU12               6          10         7          17         4
CYB5R3              126        169        136        372        250
ATP5L2              0          3          1          2          0
A4GALT              8          5          2          36         23
RPL5P34             0          0          0          0          0
GOLGA2P4            0          1          0          0          1
RP1-47A17.1         0          0          1          1          2
ARFGAP3             53         65         44         187        145
PACSIN2             114        127        111        261        174
AL049758.2          0          1          0          1          0
AL022476.2          5          3          1          0          4
TTLL1               16         29         26         10         12
AL022237.3          0          1          0          0          0
BIK                 1          3          6          4          5
MCAT                19         27         25         43         27
TSPO                12         10         13         136        88
TTLL12              57         94         59         278        212
SCUBE1              1          5          3          11         15
Z82214.3            0          0          0          0          0
Z82214.2            0          0          0          0          0
Z99756.1            0          0          0          1          0
RP4-754E20__A.5     1          0          0          1          3
MPPED1              122        154        138        1          3
EFCAB6-AS1          2          3          0          0          2
EFCAB6              36         43         35         6          4
RP3-388M5.8         1          0          1          0          0
HMGN2P9             0          0          0          0          0
RP3-388M5.9         3          3          6          2          4
SULT4A1             290        334        288        5          7
PNPLA5              3          2          2          0          3
```

```
Z97055.1            0          0          0          0          0
PNPLA3              6          5          5          45         37
SAMM50              45         46         50         132        118
RP4-796I17.5        0          1          0          0          0
PARVB               69         89         68         162        134
CTA-414D7.1         3          6          4          10         10
RP4-671O14.6        3          7          5          18         15
PARVG               7          10         8          18         19
RP4-671O14.5        0          0          1          3          1
RP4-671O14.7        0          3          0          3          7
KIAA1644            149        205        176        162        111
RP1-32I10.10        0          0          0          0          0
RP1-32I10.11        0          0          0          0          0
CTA-397C4.2         0          0          0          0          0
MRPS18CP6           0          0          0          0          0
RP5-1033E15.3       0          0          0          0          0
LDOC1L              174        261        176        237        149
KRT18P23            0          0          0          0          2
LINC00207           0          0          0          0          4
LINC00229           0          0          0          0          0
ANP32BP2            0          0          0          0          0
PRR5                10         5          6          26         23
PRR5-ARHGAP8        0          1          0          1          1
ARHGAP8             2          1          2          6          6
PHF21B              15         14         9          16         16
RP1-127B20.4        1          1          0          1          1
RP4-753M9.1         1          5          0          5          4
NUP50-AS1           27         24         31         32         29
CTA-217C2.2         1          3          0          6          2
NUP50               131        172        154        413        289
CTA-268H5.12        0          0          0          0          1
KIAA0930            312        364        315        260        166
MIR1249             1          2          4          0          1
CTA-268H5.14        1          3          1          0          0
CTA-268H5.9         0          0          0          0          0
UPK3A               0          0          0          2          1
FAM118A             53         50         50         113        66
SMC1B               3          0          4          6          11
RIBC2               0          4          1          12         11
RP1-102D24.5        0          0          0          0          1
FBLN1               43         47         33         122        96
LINC01589           0          0          0          3          1
RNU6-1161P          0          0          0          1          0
CTA-941F9.10        16         22         15         31         17
ATXN10              193        253        246        199        154
MIR4762             1          0          0          0          1
RP1-37M3.8          0          3          2          5          1
```

```
WI2-85898F10.2      0          4          3          0          1
WI2-85898F10.1      1          0          0          0          0
WNT7B               7          11         6          9          9
CR536603.1          0          0          0          0          0
CITF22-92A6.2       3          2          2          4          5
CITF22-92A6.1       0          0          1          1          6
LINC00899           7          14         9          7          5
PRR34               7          12         15         7          2
RP6-109B7.5         4          8          3          0          0
PRR34-AS1           6          13         5          15         5
MIRLET7BHG          82         137        87         61         56
RP6-109B7.2         10         14         11         2          1
RP6-109B7.4         17         15         12         6          6
MIR3619             2          2          1          5          1
MIRLET7A3           0          0          0          0          0
MIR4763             0          0          0          0          0
MIRLET7B            0          0          0          0          0
PPARA               72         101        84         193        147
RP4-695O20.1        0          1          1          3          5
CDPF1               15         13         11         28         11
PKDREJ              6          6          7          8          12
TTC38               29         28         20         90         71
GTSE1-AS1           2          2          3          2          2
GTSE1               2          2          1          145        111
TRMU                64         78         75         191        111
CELSR1              0          6          4          250        136
RP5-996D20.3        0          0          0          0          0
RP3-439F8.1         0          0          0          0          9
GRAMD4              97         106        75         156        96
CERK                209        249        268        298        188
CTA-29F11.1         2          6          12         14         13
TBC1D22A            39         52         47         78         50
U51561.1            1          1          2          1          4
FP325331.1          2          4          3          2          1
RP1-111J24.1        1          1          0          1          3
CITF22-49D8.1       0          1          0          0          2
LL22NC03-75H12.2    0          0          0          0          1
LINC00898           7          6          1          5          3
RP11-191L9.4        8          8          8          32         28
RP11-191L9.5        1          0          2          0          2
RP13-455A7.1        1          0          0          2          3
CTA-280A3.2         4          3          3          7          12
CTA-280A3__B.2      0          0          0          0          0
LL22NC03-27C5.1     0          0          0          0          2
LL22NC03-121E8.4    0          0          0          0          1
LL22NC03-121E8.3    0          0          0          0          0
MIR3201             0          0          0          0          0
```

```
RP11-536P6.3        0          0          0          0          0
FAM19A5             140        163        151        18         16
CTA-299D3.8         17         16         18         0          1
MIR4535             0          0          0          0          1
AL954742.1          0          0          0          0          0
LINC01310           8          7          6          0          9
RPL35P8             0          0          0          0          1
RP1-34P24.3         0          0          0          0          3
C22orf34            2          4          2          36         25
CTA-722E9.1         0          0          0          0          3
RP4-566L20.1        0          0          0          0          1
MIR3667             0          0          0          0          0
RP1-29C18.10        0          0          1          13         19
RP1-29C18.9         0          0          0          7          1
RP1-29C18.8         1          0          1          17         14
RP5-983L19.2        0          0          0          0          4
RN7SKP252           0          0          0          0          0
RPL5P35             0          0          0          0          1
BRD1                92         116        103        186        121
RP3-522J7.7         3          2          8          5          8
RP3-522J7.5         2          3          2          3          3
RP3-522J7.6         1          2          1          1          2
RP11-494O16.3       0          1          0          0          0
RP11-494O16.4       0          0          0          2          0
ZBED4               51         68         77         196        153
ALG12               21         30         40         53         27
CITF22-1A6.3        0          0          0          1          0
CRELD2              30         40         43         74         64
CITF22-49E9.3       0          0          0          1          4
PIM3                47         59         55         159        103
MIR6821             0          0          0          0          0
IL17REL             0          1          2          0          5
TTLL8               0          0          0          0          0
MLC1                297        324        307        13         12
MOV10L1             10         8          8          0          7
RP5-898I4.1         1          0          0          0          1
PANX2               59         71         74         9          7
TRABD               33         40         37         103        79
RP3-402G11.25       2          7          3          4          5
RP3-402G11.26       9          17         7          2          0
SELO                52         72         33         77         37
RP3-402G11.27       7          2          0          5          1
RP3-402G11.28       2          2          3          4          2
TUBGCP6             248        289        237        279        174
HDAC10              4          9          12         9          9
MAPK12              60         57         56         116        73
MAPK11              64         98         82         25         23
```

```
PLXNB2              241        301        248        475        285
DENND6B             61         101        67         36         20
XX-C283C717.1       0          1          0          0          0
XX-C00717C00720L.1  0          0          0          0          0
PPP6R2              170        249        259        227        150
RN7SL500P           0          0          1          0          0
SBF1                682        840        696        530        339
ADM2                0          2          1          27         21
MIOX                0          0          0          1          1
LMF2                57         73         69         174        113
NCAPH2              86         93         78         219        131
SCO2                4          24         10         19         14
CTA-384D8.36        8          12         8          7          1
TYMP                23         24         30         58         22
ODF3B               9          11         9          11         12
CTA-384D8.35        0          1          0          0          1
CTA-384D8.34        0          0          0          0          0
CTA-384D8.31        0          0          0          6          2
KLHDC7B             0          0          1          3          8
SYCE3               0          0          1          0          0
CPT1B               5          3          5          9          8
CHKB-CPT1B          2          4          2          6          5
CHKB                6          8          4          11         8
CHKB-AS1            5          1          3          1          2
CTA-384D8.33        0          2          4          1          2
MAPK8IP2            410        545        482        13         17
ARSA                53         55         65         63         47
SHANK3              363        456        375        43         25
RNU6-409P           0          0          0          0          0
AC000036.4          0          2          1          0          1
ACR                 0          0          0          0          2
AC002056.5          0          0          0          0          0
AC002056.3          0          0          0          0          0
RPL23AP82           41         59         54         32         23
RABL2B              74         62         54         68         50
```

{{Edet}}

Word, Character, and Line Count in a File

The `wc` command is used to obtain word, character, and line count in a file.

```
wc file.txt
```

The output (from left to right) for `wc` can be interpreted as follows.

- 2 indicates that the file has two lines.
- 23 indicates that the file has 23 words.
- 135 indicates that the file has 135 characters.
- The file in which statistics were generated (ie. file.txt).

```
  2  23 135 file.txt
```

The `wc` results above can be obtained separately. For instance, to just get the number of lines in a file include the `-l` option.

```
wc -l file.txt
```

```
2 file.txt
```

Word count can be obtained using the `-w` option.

```
wc -w file.txt
```

```
23 file.txt
```

Character count can be obtained uisng the `-m` option.

```
wc -m file.txt
```

```
135 file.txt
```

Pattern Searching

Sometimes users may want to search for a keyword in a file. The `grep` command can be used to do this. The `grep` command prints every line in a file that contains the search pattern. The arguments in `grep` are as follows.

- Search pattern (ie. Linux)
- File to search (ie. file.txt)

```
grep Linux file.txt
```

```
Linux is a variety of Unix, and sometimes the names are used interch
```

To search for lines that do not contain a pattern include the `-v` option.

```
grep -v Linux file.txt
```

```
Unix is an operating system, just like Windows or MacOS.
```

What would happen if "linux" with a lower case "l" is used as the search pattern instead of an upper case "L" as shown in the file.txt? Nothing is returned because `grep` is case sensitive. To ignore case, include the `-i` option.

```
grep linux file.txt
```

```
grep -i linux file.txt
```

```
Linux is a variety of Unix, and sometimes the names are used interch
```

Working with Software Installed on Biowulf

The `module` command is important for anyone who wishe to work with software that are installed on Biowulf. This `avail` option enables users to browse the software that are available on the cluster.

```
module avail
```

Glimpse of `module avail` results. Users can scroll up/down using the arrow keys to learn what software are available. Hit Q to exit the `module avail` results and return to the prompt.

```
----------------------------------------------------- Global Aliases
   bowtie1        -> bowtie/1.3.1                  deeptrio/1.6.0 ->
   bowtie2        -> bowtie/2-2.5.3                deeptrio/1.6.1 ->
   deeptrio/1.5.0 -> deepvariant/1.5.0-deeptrio
```

```
------------------------------------------- /data/classes/BTEP/apps
   biostars/1.0

--------------------------------------------- /usr/local/lmod/modul
   3DSlicer/4.8.1                                            hwloc/2.
   3DSlicer/5.2.2                               (D)          hwloc/2.
```

To find if a particular software is available include the software name with the `avail` option.

```
module avail fastqc
```

```
----------------------------------------------------- Global Aliases



--------------------------------------------- /usr/local/lmod/modul
   fastqc/0.11.8    fastqc/0.11.9    fastqc/0.12.1 (D)

  Where:
   D:  Default Module

Module defaults are chosen based on Find First Rules due to Name/Ver
See https://lmod.readthedocs.io/en/latest/060_locating.html for deta

If the avail list is too long consider trying:

"module --default avail" or "ml -d av" to just list the default modu
"module overview" or "ml ov" to display the number of modules for ea

Use "module spider" to find all possible modules and extensions.
Use "module keyword key1 key2 ..." to search for all possible module
```

To get a description of a software use `module whatis`.

```
module whatis fastqc
```

```
fastqc/0.12.1       : fastqc: It provide quality control functions t
fastqc/0.12.1       : Version: 0.12.1
```

Warning

Upon signing onto Biowulf, users will land in the "log-in" node, which is not meant for analyzing data or transferring files. To perform these task, request time and resources on a compute node using the `sinteractive` command.

> To learn more about the `sinteractive` command, see https://bioinformatics.ccr.cancer.gov/docs/unix-on-biowulf-2024/Lesson4/#requesting-an-interactive-session *(https://bioinformatics.ccr.cancer.gov/docs/unix-on-biowulf-2024/Lesson4/#requesting-an-interactive-session)*

To load a software use `module load` followed by the name of the package.

```
sinteractive
```

Users will see the following when the interactive session has been granted.

```
salloc: Pending job allocation 61831125
salloc: job 61831125 queued and waiting for resources
salloc: job 61831125 has been allocated resources
salloc: Granted job allocation 61831125
salloc: Waiting for resource configuration
salloc: Nodes cn0003 are ready for job
```

```
module load samtools
```

```
[+] Loading samtools 1.19  ...
```

Getting Help

To get help, use the `man` command which pulls up the manual for a command. Use the up and down arrow keys to scroll through the manual and learn about the different options. Hit q to return to exit `man` and return to the prompt.

For instance, to pull up the manual for `grep`, do the following.

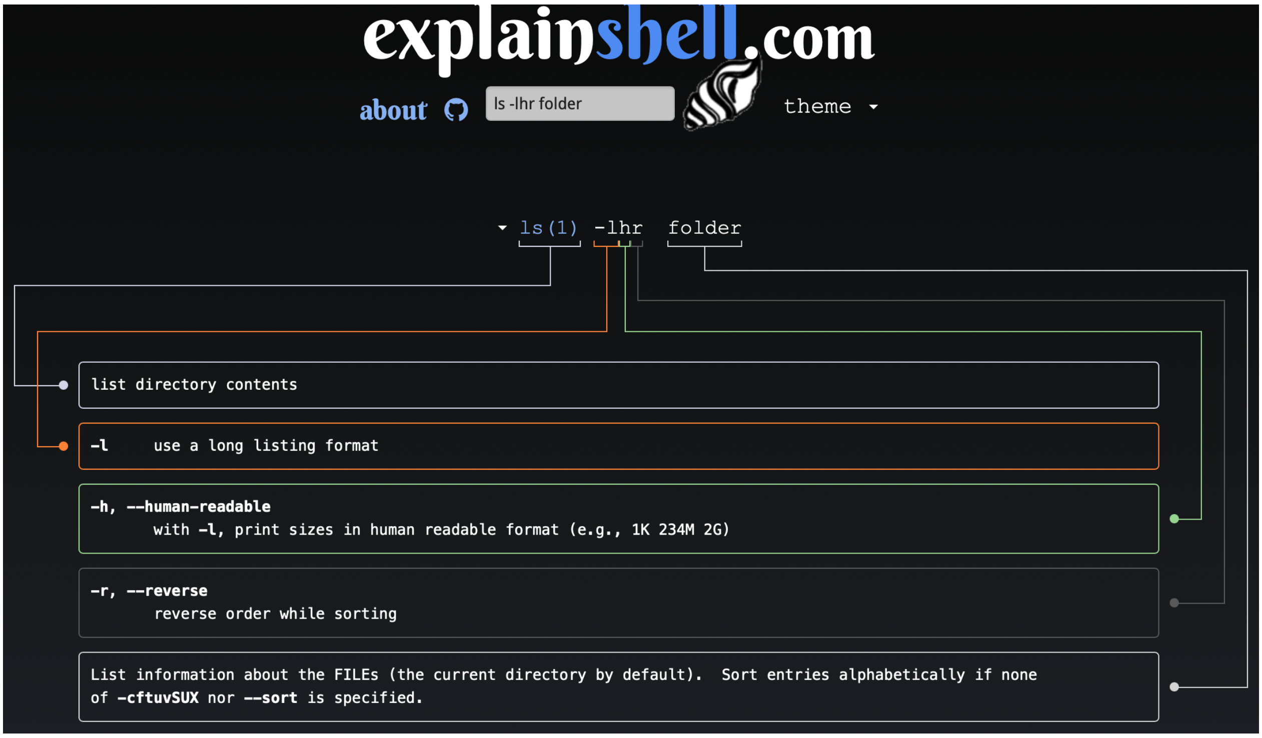
```
man grep
```

Glimpse of `man` command output for `grep`.

```
GREP(1)                                General Commands Manual

NAME
       grep, egrep, fgrep - print lines matching a pattern

SYNOPSIS
       grep [OPTIONS] PATTERN [FILE...]
```

```
       grep [OPTIONS] -e PATTERN ... [FILE...]
       grep [OPTIONS] -f FILE ... [FILE...]

DESCRIPTION
       grep searches for PATTERN in each FILE.  A FILE of “-” stands
       FILE is given, recursive  searches  examine  the  working  di
       searches read standard input.  By default, grep prints the ma

       In  addition,  the variant programs egrep and fgrep are the s
       respectively.   These  variants  are  deprecated,  but   are
       compatibility.

OPTIONS
   Generic Program Information
       --help Output a usage message and exit.

       -V, --version
              Output the version number of grep and exit.
```

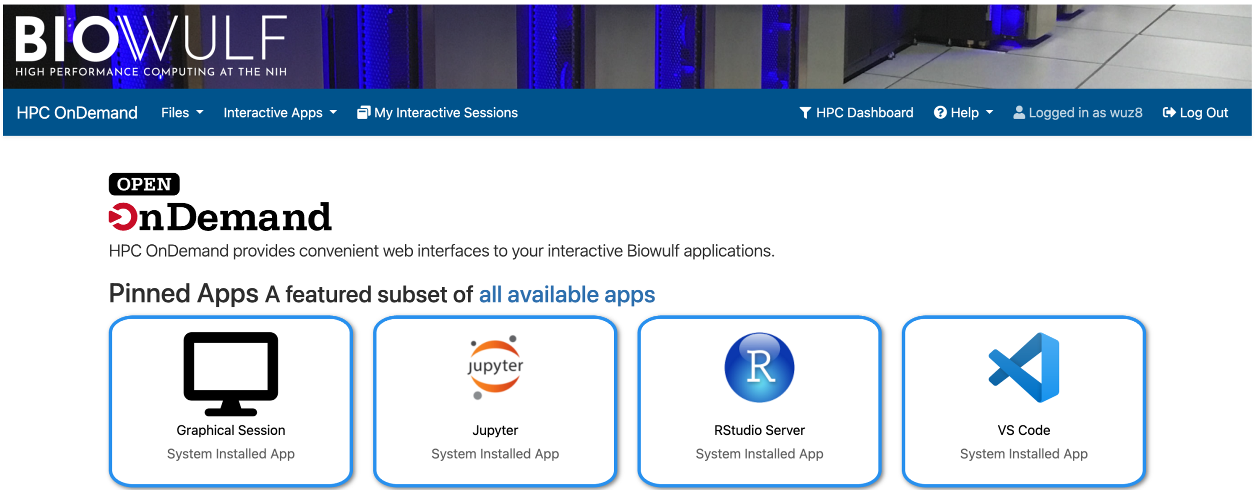
Want clear explanation of a command? Try https://explainshell.com/# *(https://explainshell.com/#)*. It will explain each component in a command construct, just type it into the search box. For instance, below `ls -lhr folder` is used.



```
list directory contents

-l     use a long listing format

-h, --human-readable
       with -l, print sizes in human readable format (e.g., 1K 234M 2G)

-r, --reverse
       reverse order while sorting

List information about the FILEs (the current directory by default).  Sort entries alphabetically if none
of -cftuvSUX nor --sort is specified.
```

HPC OnDemand

HPC OnDemand enables researchers to access Biowulf resources such as graphical applications (R Studio, Jupyter Lab, IGV, Globus) and files from a web browser. To connect to Biowulf HPC OnDemand use https://hpcondemand.nih.gov/ *(https://hpcondemand.nih.gov/)*. See https://bioinformatics.ccr.cancer.gov/btep/classes/getting-started-with-hpc-ondemand-a-new-interface-for-nih-hpc-users *(https://bioinformatics.ccr.cancer.gov/btep/classes/getting-started-with-hpc-ondemand-a-new-interface-for-nih-hpc-users)* to access the training for HPC OnDemand.



HPC OnDemand provides convenient web interfaces to your interactive Biowulf applications.

Pinned Apps A featured subset of all available apps

Continual Learning

- See https://bioinformatics.ccr.cancer.gov/docs/unix-on-biowulf-2024/ *(https://bioinformatics.ccr.cancer.gov/docs/unix-on-biowulf-2024/)* for a more detailed Unix and Biowulf class. Check the BTEP Calendar *(https://bioinformatics.ccr.cancer.gov/btep/)* for upcoming advanced Unix classes. Email ncibtep@nih.gov with questions.
- Coursera offers self learning classes for Unix and other data science related topics such as R and Python programming. See https://bioinformatics.ccr.cancer.gov/btep/self-learning/ *(https://bioinformatics.ccr.cancer.gov/btep/self-learning/)* to learn how to request a Coursera license.
  - Example Coursera classes:
    - Hands-on Introduction to Linux Commands and Shell Scripting *(https://www.coursera.org/learn/hands-on-introduction-to-linux-commands-and-shell-scripting#modules)*
    - Command Line Tools for Genomic Data Science *(https://www.coursera.org/learn/genomic-tools#modules)*
    - Unix and Bash for Beginners Specialization *(https://www.coursera.org/specializations/unix-and-bash-for-beginners)*

R and Python

Overview of R and Python

Learning Objectives

In this presentation, we will:

- Learn about popular programming languages in bioinformatics
- Compare advantages and disadvantages of Python and R
- Discuss what you will need to learn to use these languages
- Discuss learning resources

Presentation Slides

Document Analysis using Jupyter Lab

Documenting Data Analysis with Jupyter Lab Slides

Documenting Data Analysis with Jupyter Lab

Joe Wu, PhD
Bioinformatics Training and Education Program
ncibtep@nih.gov
September 4, 2025

Start Jupyter Lab

To start Jupyter Lab, type the following into the command prompt.

```
jupyter lab
```

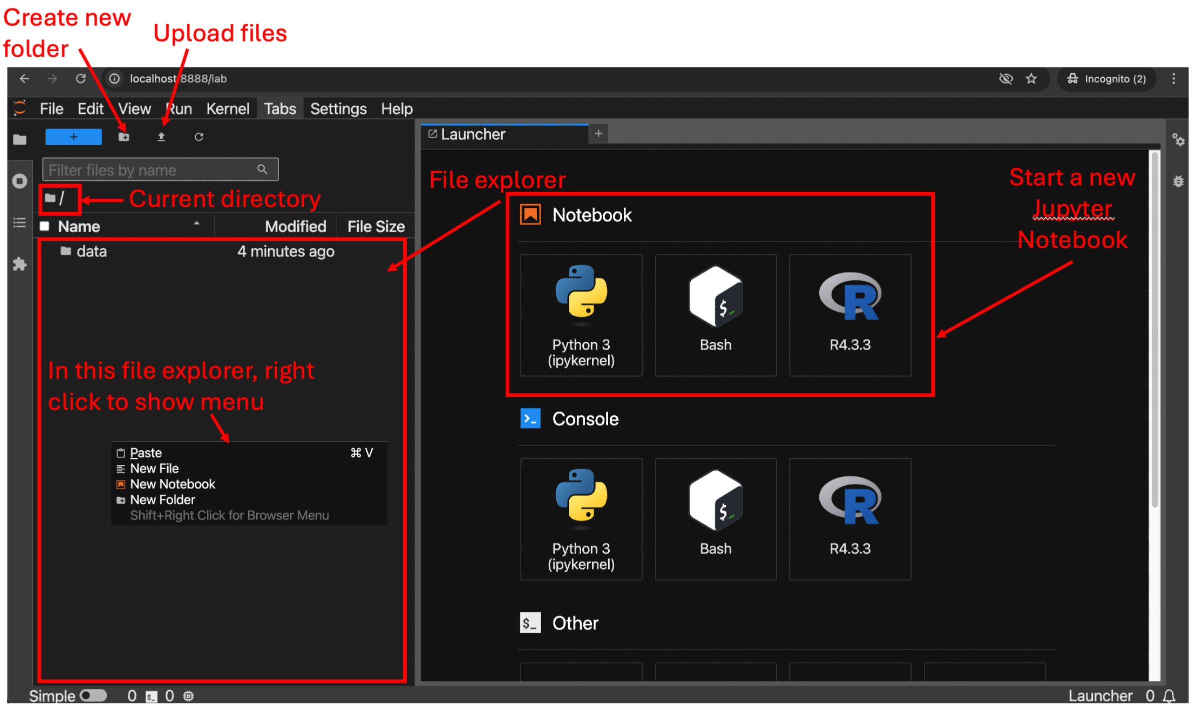
Jupyter Lab Interface

Upon starting Jupyter Lab, users will see an interface with the following.

- To the left, there is a file explorer where users can access files and subfolders available in the directory in which the Jupyter Lab session was started (also referred to as the project directory in these documents). In the example below, there is a subfolder called "data".
- A folder icon with a "+" enclosed can be used to create new folders within the project directory. These will be available in the file explorer.
- In case there are files or folders that are not in the project directory, users can use the upload button to transfer these so that they will appear in the file explorer. An alternative is to click and drag content into the file explorer.
- The Launcher contains options for starting a Jupyter Notebook in various languages. Users will have to install the specific language and add it into their Jupyter Lab environment to be able to use it. The link addressing Jupyter Lab language compatibility is included in the section titled "Jupyter Lab is Compatible with Many Languages". By default, the Python notebook option is available upon installing Jupyter Lab so no need to add it unless there is another version of Python that the user would like to utilize.
- Right clicking on the file explorer will bring up a menu where users can create new files, folders, and Jupyter Notebooks.

Warning

The file explorer will only display files and subfolders in the directory in which the Jupyter Lab session was created. To transfer files that reside in a different directory, either click and drag into the file explorer or use the upload button. Alternatively, users may create a symbolic link, which will appear in the file explorer to access content outside of the Jupyter Lab session directory.



Create new folder

Upload files

Current directory

File explorer

Start a new Jupyter Notebook

In this file explorer, right click to show menu

Jupyter Lab is Compatible with Many Languages

- Bash, Python, and R
- See https://docs.jupyter.org/en/latest/projects/kernels.html *(https://docs.jupyter.org/en/latest/projects/kernels.html)* for a list of Jupyter compatible languages.

Start a New Jupyter Notebook

To start a new Jupyter Notebook, click on any of the available panels under the "Notebook" section in the Launcher. Each of the panels represent a notebook that will work with a specific language that was added to the Jupyter environment by the user.

This class will use a Python notebook as an example. Click on the "Python 3 (ipykernel)" panel to start a Python Jupyter Noteook. The instructor has Python 3.12.2 installed and this will be differ depeneding on what each user has installed. Remember to keep track of language and package versions to ensure analysis reproducibility.

The Jupyter Notebook is a part of Jupyter Lab.

The note book is where users

- Write code
- View and maintain output
- Document analysis steps using formatted text written in markdown

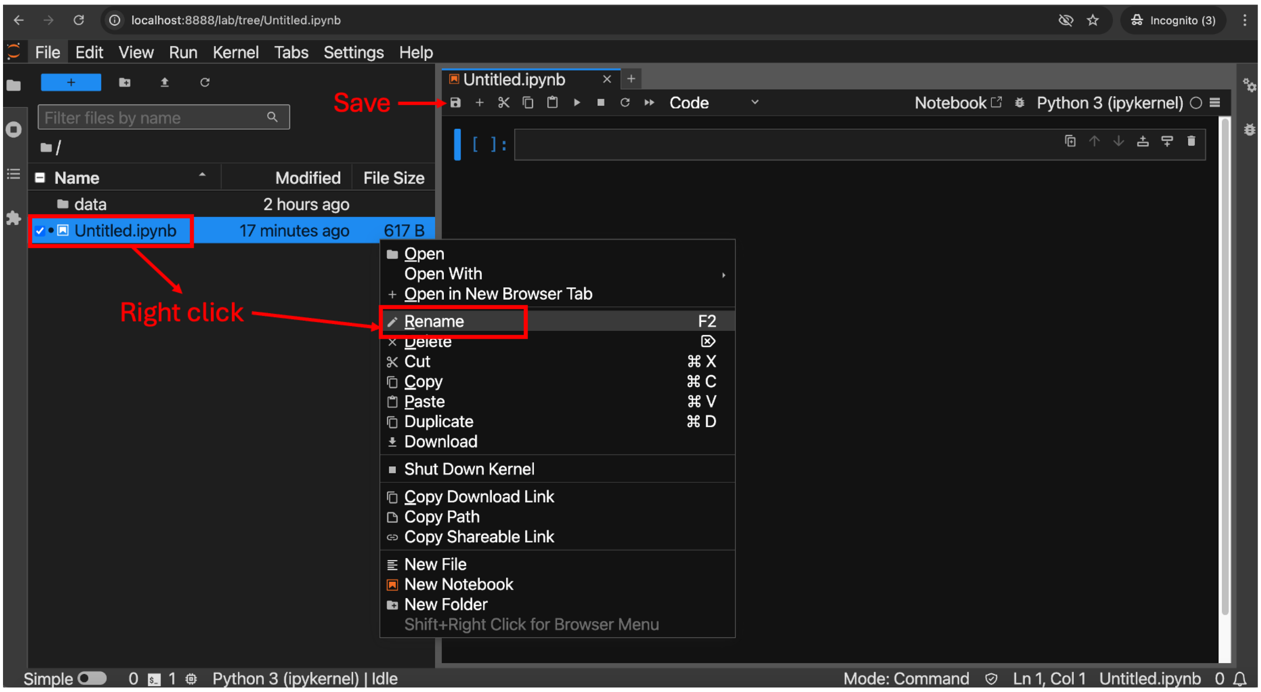
Note:

"Markdown is a lightweight markup language for creating formatted text using a plain-text editor." -- https://en.wikipedia.org/wiki/Markdown *(https://en.wikipedia.org/wiki/Markdown)*

Rename Untitled Jupyter Notebook

A new Jupyter Notebook is given the name "Untitled". Change this to something meaningful either using the save icon on the notebook menu bar or right-clicking on the "Untitled.ipynb" notebook in the file explorer and choose "Rename".

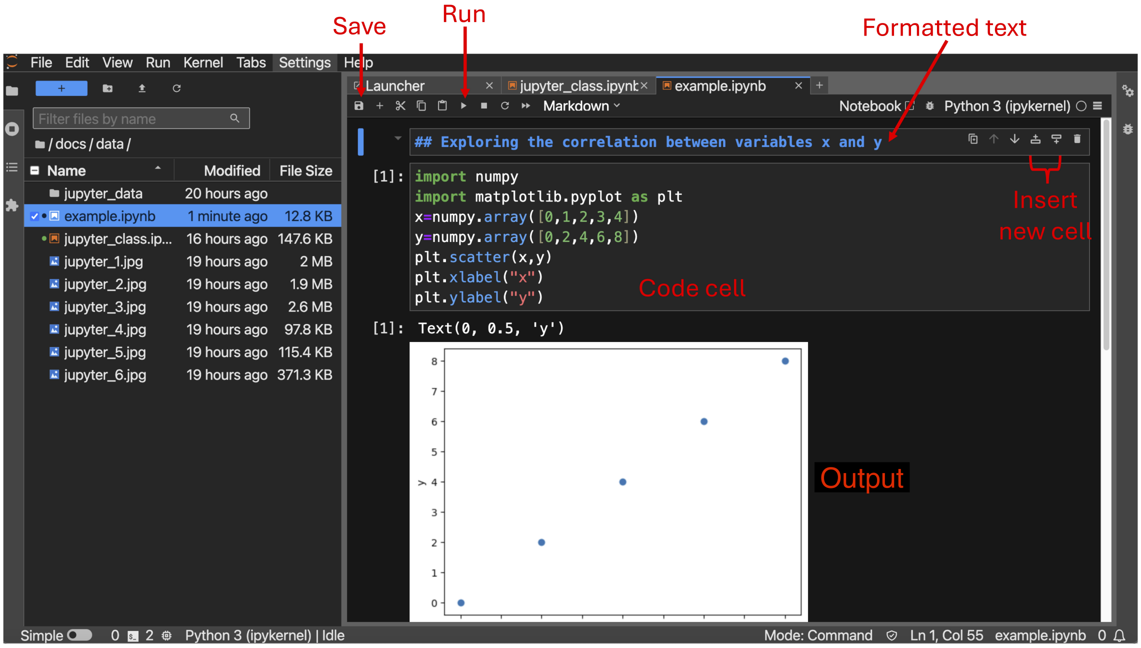
Jupyter Notebooks have extension ipynb, which stands for interactive Python notebook.



Save

Right click

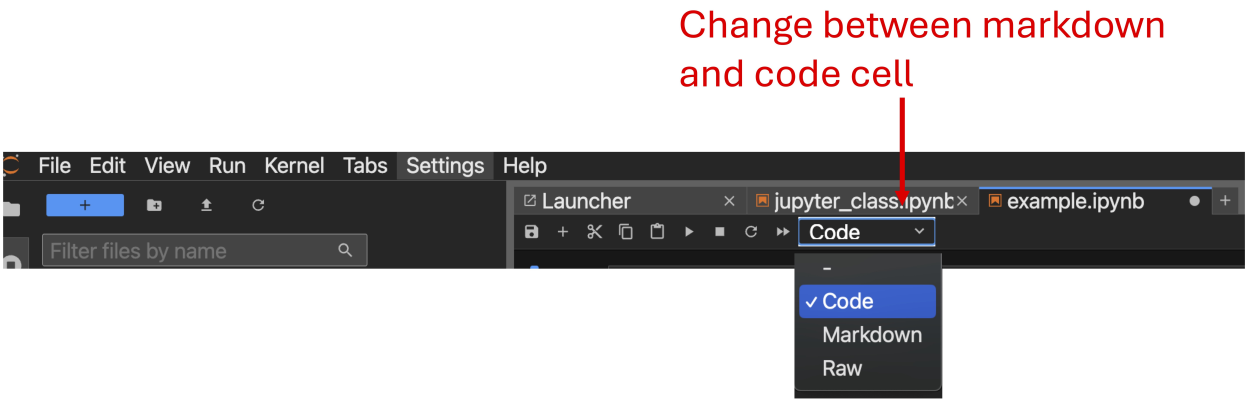
Keeping Code, Output, and Analysis Steps in One Place



Name	Modified	File Size
jupyter_data	20 hours ago	
example.ipynb	1 minute ago	12.8 KB
jupyter_class.ip...	16 hours ago	147.6 KB
jupyter_1.jpg	19 hours ago	2 MB
jupyter_2.jpg	19 hours ago	1.9 MB
jupyter_3.jpg	19 hours ago	2.6 MB
jupyter_4.jpg	19 hours ago	97.8 KB
jupyter_5.jpg	19 hours ago	115.4 KB
jupyter_6.jpg	19 hours ago	371.3 KB

```
## Exploring the correlation between variables x and y

[1]: import numpy
     import matplotlib.pyplot as plt
     x=numpy.array([0,1,2,3,4])
     y=numpy.array([0,2,4,6,8])
     plt.scatter(x,y)
     plt.xlabel("x")
     plt.ylabel("y")

[1]: Text(0, 0.5, 'y')
```

Changing Between Markdown and Code



Ways to Access and Use Jupyter Lab

- Biowulf (https://hpc.nih.gov/apps/jupyter.html *(https://hpc.nih.gov/apps/jupyter.html)*). Biowulf is the NIH Unix-based high performance computing system.
- Requires getting a Biowulf account *(https://hpc.nih.gov/docs/accounts.html)*
- Jupyter is available through Biowulf's Open On Demand *(https://hpcondemand.nih.gov/)*. Open On Demand enables users to run interactive applications such as Jupyter Lab through a web browser.
- NIH Anaconda Professional *(https://nih.sharepoint.com/sites/CIT-ApplicationRepository/SitePages/Anaconda.aspx)*. This the way to go if users want to use Jupyter locally on

government issued computer. Click here *(https://forms.office.com/g/CArrnuE4cD)* to request access.

Installing Jupyter Lab on Personal Computer

To run Jupyter Lab on a personal computer, users will need to have

1. Python
   - Comes with Anaconda *(https://nih.sharepoint.com/sites/CIT-ApplicationRepository/SitePages/Anaconda.aspx)* OR
   - Install as stand alone (https://www.python.org/downloads/ *(https://www.python.org/downloads/)*)
2. Jupyter Lab
   - Included full Anaconda.
   - Requires separate install if using Miniconda (https://jupyter.org/install *(https://jupyter.org/install)*)
3. Install languages and language specific packages. For instance:
   - R
   - Julia
   - C++
4. Add the languages to Jupyter Environment (Python is automatically added)

> **Tip**
>
> Jupyter Lab is compatible with many languages. For more information about Jupyter compatible languages see https://docs.jupyter.org/en/latest/projects/kernels.html *(https://docs.jupyter.org/en/latest/projects/kernels.html)*.

Code and Visualization

Jupyter Notebook enables organization of code, analysis steps, and output all in one place.

The example below will use Python code to demonstrate the utility of Jupyter Notebook for keeping code, output, and analysis steps all in one place.

- First, the `import` command of Python will be used to load packages `numpy` which is used for numeric computation and `matplotlib` which is a popular Python data visualization tool.
- Next, two numeric arrays (x and y) will be generated using `numpy` and its `array` sub-command. To call a Python sub-command just type the package name (ie. numpy), followed by a ".", and then the sub-command. So to create an array, use `numpy.array`. The elements in the array are enclosed in "([])".

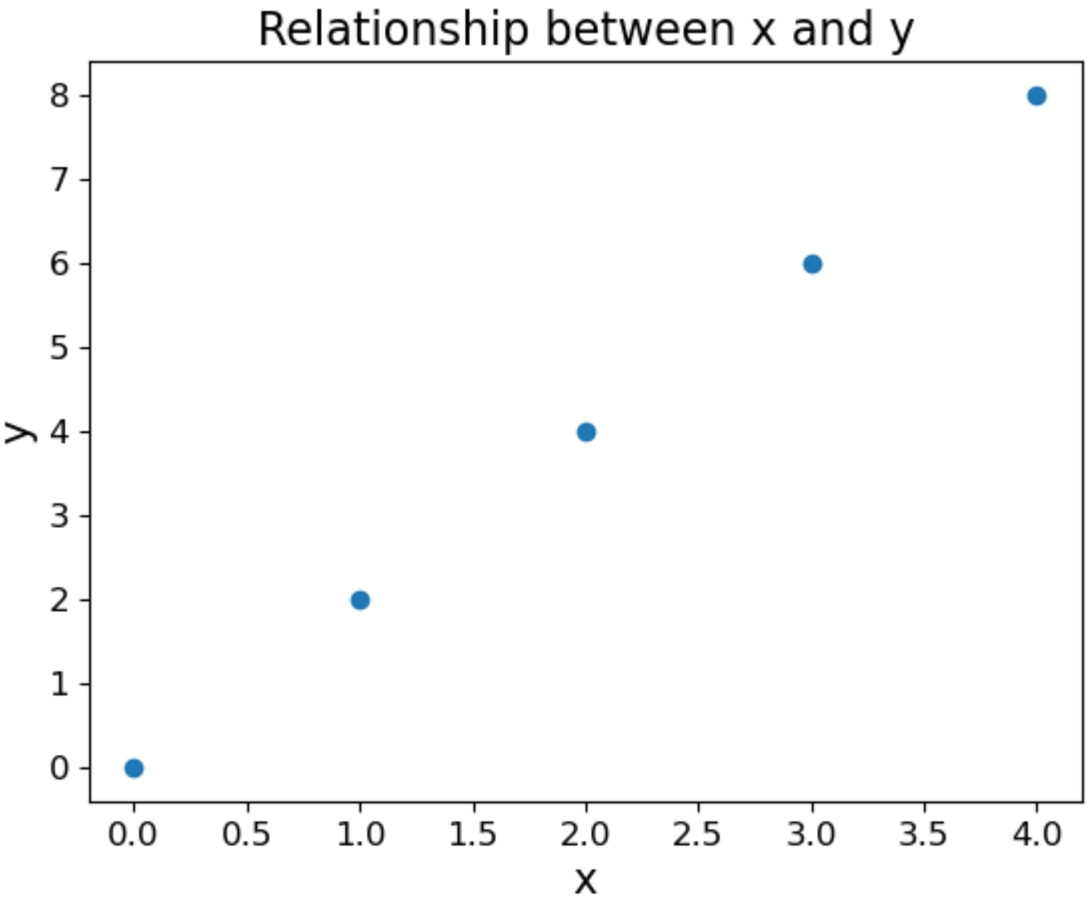
- Finally, a scatter plot will be generated using `matplotlib's pyplot` module, which will be loaded under the alias `plt` for easy referencing in the code. The `scatter` sub-command will be used to generate the scatter plot showing the relationship between the values in array x versus those in array y. The arguments enclosed in "()" are name of the two arrays separated by a comma (ie. (x,y)).
- After scatter plot has been generated, the following sub-commands from `matplotlib's pyplot` or `plt` will be used to customize the graph:
    - `xlabel`: assign label to the x axis, the option `size=` allows font size adjustment.
    - `ylabel`: assign label to the y axis, the option `size=` allows font size adjustment.
    - `plt.tick_params`: adjust axis tick mark label font size by setting the `labelsize` option.
    - `plt.title`: assigns a plot title and `size` is used to adjust the fontsize of the title.

```
# Import some Python packages
import numpy
import matplotlib.pyplot as plt
```

```
# Generate numeric arrays x and y using numpy
x=numpy.array([0,1,2,3,4])
y=numpy.array([0,2,4,6,8])
print("The array x contains: ", x)
print("The array y contains: ", y)
```

```
The array x contains:  [0 1 2 3 4]
The array y contains:  [0 2 4 6 8]
```

```
# Generate scatter plot using matplotlib
plt.scatter(x,y)
plt.xlabel("x", size=15)
plt.ylabel("y", size=15)
plt.tick_params(labelsize=12)
plt.title("Relationship between x and y", size=16)
plt.show()
```



Importing data tables into Jupyter Notebook

Users will be working with data tables during analyses. These can be imported into the a Jupyter Notebook although the approach for doing so will be language dependent.

The example below will use a Python package called Pandas *(https://pandas.pydata.org)* to import a data table. The data table contains the differential gene expression analysis results from the HBR and UHR study *(https://rnabio.org/module-01-inputs/0001/05/01/RNAseq_Data/)* and is in the comma separated value or CSV format where each column in the table is separated by a comma.

The file used is hbr_uhr_deg_chr22_with_significance.csv.

Step 1 in the process is to load `pandas` into the work environment using the `import` command of Python (ie. `import pandas`). The data will be stored in a data table called hbr_uhr_deg_chr22. Use `pandas.read_csv` to call the `read_csv` sub-command. Enclosed in parentheses is the path to the file hbr_uhr_deg_chr22_with_significance.csv. Once the data has been loaded, append the `.head()` attribute to the hbr_uhr_deg_chr22 to preview the first five lines.

The hbr_uhr_deg_chr22 data table contains five columns and these are:

- name: contains gene names

- log2FoldChange: gene expression change between two experimental conditions on the log2 scale
- PAdj: adjusted p-value indicating statistical confidence of the calculated gene expression change
- -log10PAj: negative of the values in the PAdj column on a log10 scale
- significance: whether the gene expression is up regulated, down regulated, or has no change

```
# Load the Pandas package
import pandas
```

```
# Import the data

hbr_uhr_deg_chr22=pandas.read_csv("./hbr_uhr_deg_chr22_with_significa

# View the first several lines of hbr_uhr_deg_chr22 using the head a
## of the imported data table (hbr_uhr_deg_chr22)
hbr_uhr_deg_chr22.head()
```

	name	log2FoldChange	PAdj	-log10PAdj	significance
0	SYNGR1	-4.6	5.200000e-217	216.283997	down
1	SEPT3	-4.6	4.500000e-204	203.346787	down
2	YWHAH	-2.5	4.700000e-191	190.327902	down
3	RPL3	1.7	5.400000e-134	133.267606	ns
4	PI4KA	-2.0	2.900000e-118	117.537602	down

Data visualization in Jupyter Notebook: scatter plot

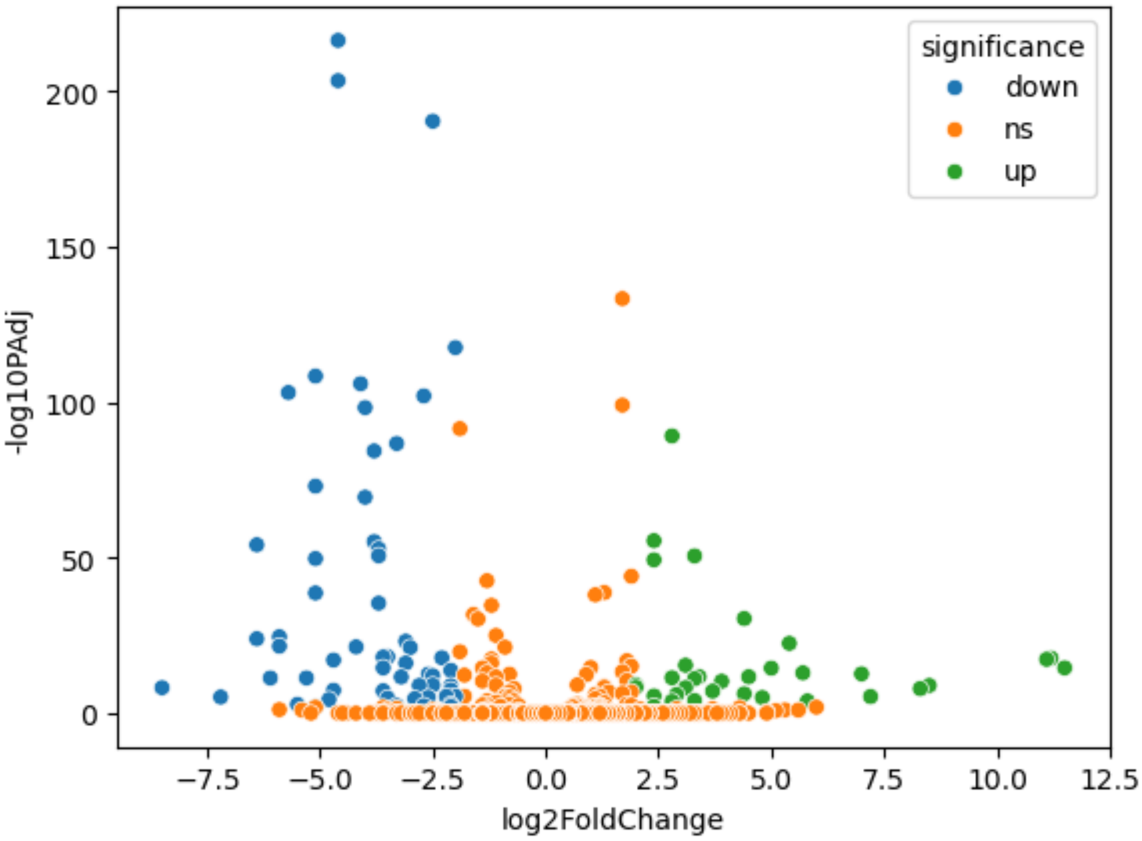
The exercise below will use the Python package Seaborn *(https://seaborn.pydata.org)* to create a volcano plot for the HBR and UHR differential analysis results table that was previously imported. A volcano plot is essentially a scatter plot that shows magnitude of change on one axis and statistical confidence of the change on another axis. In the case of RNA sequencing differential expression, this will be log2 of fold change and -log10 of adjusted p-values.

The `scatterplot` function in seaborn will be used to generate volcano plots. This function takes on arguments below:

- Data: hbr_uhr_deg_chr22 (differential gene expression analysis results table imported using `pandas.read_csv`)
- x: x-axis values (ie. gene expression log2FoldChange)
- y: y-axis values (ie. -log10 of adjusted p-value)

- `hue`: color dots by whether gene expression change is up, down, or has no change (see signifcance column of the data)

```
## Load the seaborn plotting package
import seaborn

seaborn.scatterplot(hbr_uhr_deg_chr22,x="log2FoldChange", y="-log10P
plt.show()
```



Data visualization in Jupyter Notebook: heatmap

This exercise will use Seaborn's `clustermap` function to construct a gene expression heatmap of top differentially expressed genes in the HBR and UHR study. Heatmaps are another common visualization in RNA sequencing and allow scientists to identify clusters of samples with similar gene expression patterns.

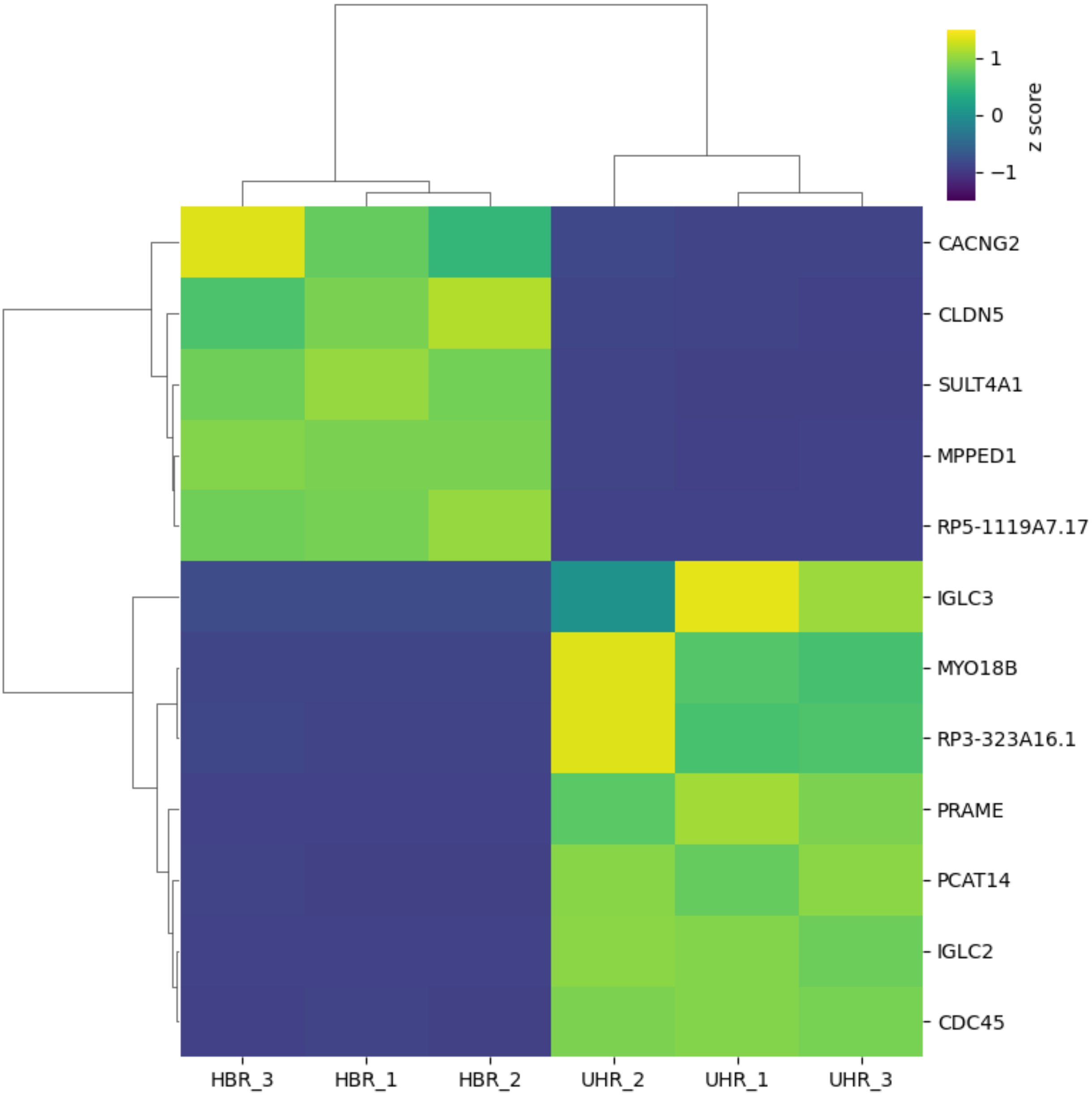
First, import the dataset (hbr_uhr_top_deg_normalized_counts.csv) using `pandas.read_csv` and assign it to the variable hbr_uhr_top_deg_normalized_counts. The `clustermap` function of seaborn takes the following arguments and options.

- Data: hbr_uhr_top_deg_normalized_counts (the expression counts table imported using `pandas.read_csv`).
- `z_score`: set this to 0 to scale the expression counts for each gene by the z_score.

- `cmap`: specify a coloring scheme (ie. viridis)
- `figsize`: specify figure size
- `cbar_kws`: specify title for the heatmap color bar using a key-value pair
- `cbar_pos`: specify coordinate to place the heatmap color bar

```
# Import the data

hbr_uhr_top_deg_normalized_counts=pandas.read_csv("./hbr_uhr_top_deg_
```

```
seaborn.clustermap(hbr_uhr_top_deg_normalized_counts,z_score=0,cmap='
                   figsize=(8,8),vmin=-1.5, vmax=1.5,cbar_kws=({"labe
                   cbar_pos=(0.855,0.8,0.025,0.15))
plt.show()
```



R Code in a Python Jupyter Notebook

Using the `[rpy2.ipython](https://rpy2.github.io)` package, users can run R code inside a Python Jupyter Notebook. This package requires user installation (see https://pypi.org/project/rpy2/ *(https://pypi.org/project/rpy2/)*). To load `rpy2.ipython`, use `%load_ext`

```
# Load rpy2.ipython
%load_ext rpy2.ipython
```

Using R to generate a volcano plot

Here, R will be used to generate a volcano plot for the HBR and UHR study differential expression analysis results as was done using Python. To run R code in a Python Jupyter Notebook, place at the top of the code cell `%%R` then proceed to write the R code.

R's `read.csv` function takes on a file path enlosed in "()" as an argument. There are many options for this command that could alter the default ways in which it imports data. Here, the file hbr_uhr_deg_chr22_with_significance.csv will be imported using `read.csv` with default settings and stored as hbr_uhr_chr22_deg. The `head` command will be used to preview the first six lines of the data table. Because the "-" sign in the column name `-log10PAdj` violates R's column heading naming convention, `read.csv` by default changes the "-" with "X.". This column will be renamed `neg.log10PAdj`.

```
%%R
# Import gene expression data using read.csv and store is as variabl
hbr_uhr_chr22_deg <- read.csv("./hbr_uhr_deg_chr22_with_significance
```

```
%%R
# Look at the first few lines of counts using the head command
head(hbr_uhr_chr22_deg)
```

```
    name log2FoldChange      PAdj X.log10PAdj significance
1 SYNGR1           -4.6 5.2e-217    216.2840         down
2  SEPT3           -4.6 4.5e-204    203.3468         down
3  YWHAH           -2.5 4.7e-191    190.3279         down
4   RPL3            1.7 5.4e-134    133.2676           ns
5  PI4KA           -2.0 2.9e-118    117.5376         down
6  SEZ6L           -5.1 4.2e-109    108.3768         down
```

```
%%R

# Rename the X.log10PAdj column header to neg.log10PAdj

colnames(hbr_uhr_chr22_deg)[4] <- "neg.log10PAdj"
```

```
%%R
# Load the ggplot2 package using R's library command
library(ggplot2)
```

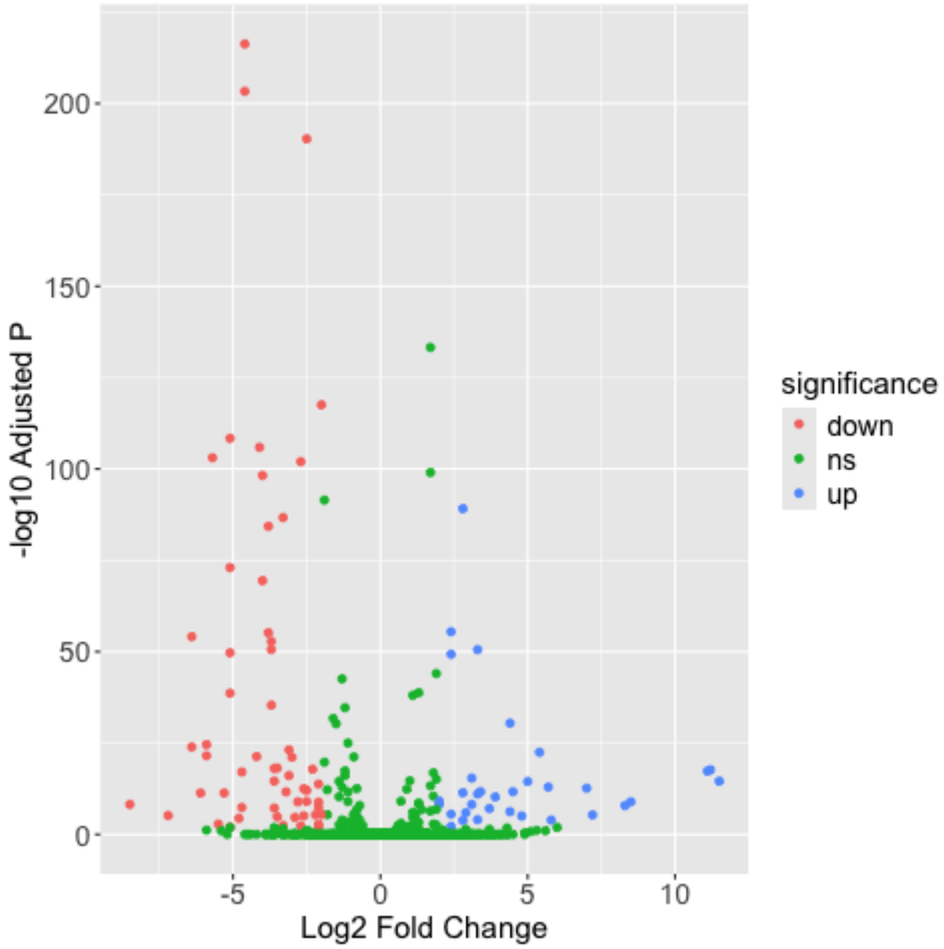
Using ggplot2 to construct a volcano plot

To create the volcano plot initiate it with the `ggplot` command, which creates a blank plotting canvas. Enclosed in the `ggplot` command are the arguments and these are as follows.

- Data table to generate a plot from: hbr_uhr_chr22_deg
- aes: specifies aesthetics of the plot include:
- Values to plot on the x axis (ie. log2FoldChange)
- Values to plot on the y axis (ie. neg.log10PAdj)
- What to color the points by (set by `color` and in this example values in the significance column in the data table showing whether gene expression change was statistically significant)

Next, specify the plot type. For a volcano plot (or scatter plot), `geom_point` will be used. The labels for the x and y axes are set by `xlab` and `ylab`, respectively. Finally, inside axis label, tick mark, and legend text fontsizes are specified in `theme`.

```
%%R

# Construct volcano plot.

ggplot(hbr_uhr_chr22_deg, aes(x=log2FoldChange, y=neg.log10PAdj, col
geom_point()+xlab("Log2 Fold Change")+ylab("-log10 Adjusted P")+
theme(axis.title.x=element_text(size=15),axis.title.y=element_text(s
axis.text.x=element_text(size=14),axis.text.y=element_text(size=14),
legend.title=element_text(size=15),legend.text=element_text(size=14)
```



Running Unix commands

Users can run Unix commands within a Python Jupyter Notebook. To do this start a code block with "!" followed by the unix command. For instance, using the `pwd` command in the code block below to list the present working directory.

```
!pwd
```

```
/Users/wuz8/Library/CloudStorage/OneDrive-NationalInstitutesofHealth/tutorials/
document_analysis_with_jupyter/docs/data
```

Writing Formatted Text

See https://www.markdownguide.org/basic-syntax/ *(https://www.markdownguide.org/basic-syntax/)* for a markdown guide.

Custom heading sizes

Use # to specify heading levels

```
# Heading level 1 (largest)
## Heading level 2 (second largest)
### Heading level 3 (third largest)
...
```

Lists

Un-ordered lists: use * or -

```
- DNA
- RNA
- protein
- metabolite
```

Ordered list: use numbers

```
1. Obtain sequencing data
2. Perform pre-alignment QC
3. Adapter and/or quality trim
3. Align sequencing data to reference genome
4. Obtain gene expression count matrix
5. Run differential expression analysis
6. Pathway analysis
```

Insert images

- Via HTML: `<img src="image_path" />`
- Via markdown: `![](image_path)`

Insert links

`[Description of website](insert url)`

Build a Table of Contents

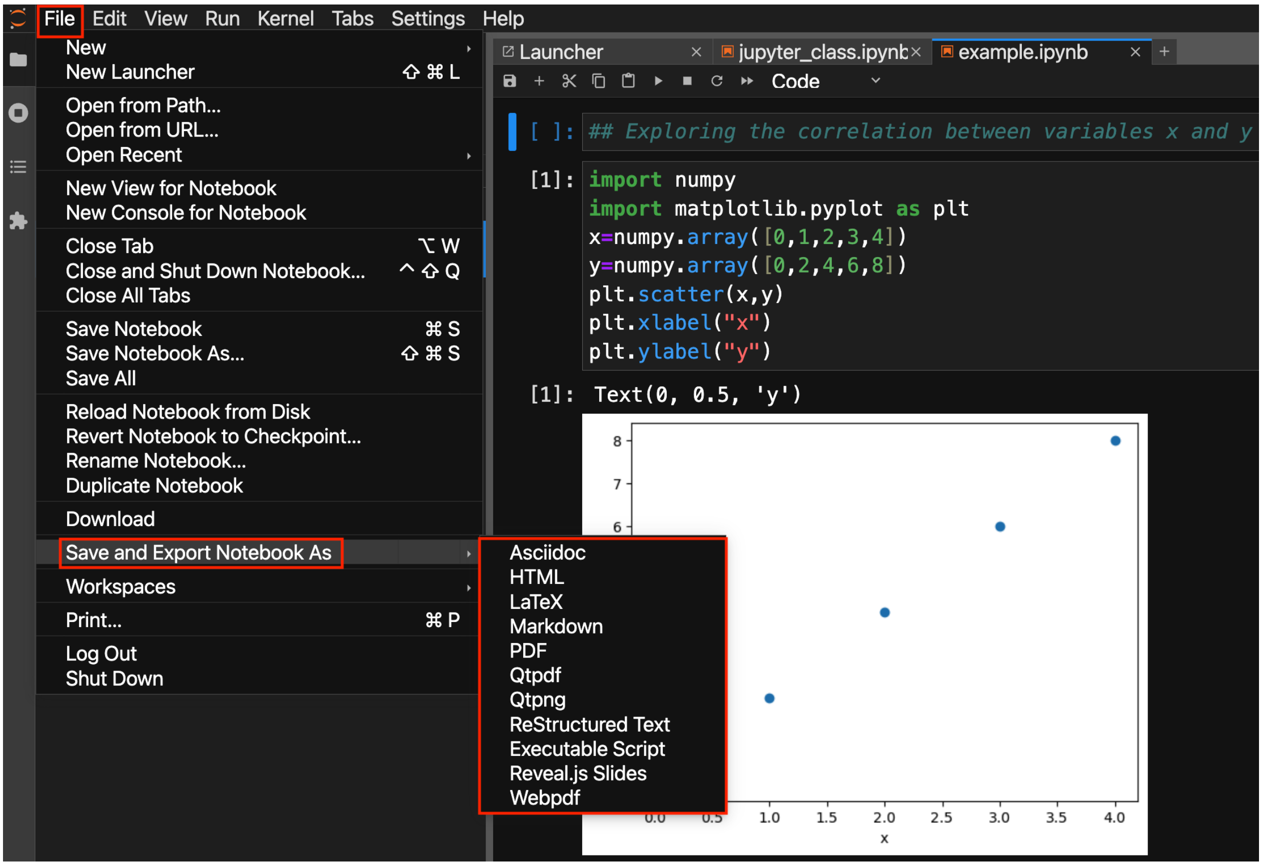
To build a table of contents that links from one section of a Jupyter notebook to another do the following, where

```
```

```
[Display name](#Section-header)
```

- Enclosed in `[]` is the display name for the link. The display name cannot have punctuations such as commas.
- Enclosed in `()` is the Markdown header for that section (ie. section header)
    - This is prepended by #
    - Each part the header is connected by `-`.

Exporting Jupyter Notebook using GUI



```
[ ]: ## Exploring the correlation between variables x and y
```

```
[1]: import numpy
     import matplotlib.pyplot as plt
     x=numpy.array([0,1,2,3,4])
     y=numpy.array([0,2,4,6,8])
     plt.scatter(x,y)
     plt.xlabel("x")
     plt.ylabel("y")
```

```
[1]: Text(0, 0.5, 'y')
```

Exporting Jupyter Notebook using Command Line

Use the `jupyter nbconvert` command at the command prompt to convert Jupyter Notebook to various available format, including html, pdf, and slides. The format is specified after the `--to` option.

```
jupyter nbconvert --to format
```

Obtain Example Data and Jupyter Notebook

Option 1 for obtaining the class data and example Jupyter Notebook is to download the jupyter_class_data.zip. Users may need to uncompress the zip file if local computer does not automatically do this.

Option 2 is to visit https://github.com/JWrows2014/document_analysis_with_jupyter *(https://github.com/JWrows2014/document_analysis_with_jupyter)*, click on the green button labeled "<> Code" and select "Download as ZIP". The example Jupyter Notebook, data, and images will download as a zip file and unzipping, change into the project folder and start Jupyter Lab to try out the example notebook.

Sharing Jupyter Notebook

- Github *(https://github.com)*
    - Static notebook (ie. users will not be able to run)
- Binder *(https://mybinder.org)*
    - Provide data
    - Provide list of packages
    - Users can run the notebook
    - Example *(https://mybinder.org/v2/gh/ncbi/workshop-ncbi-data-with-python/main?filepath=notebooks%2Fworkshop.py)*