

A tutorial on how to use the Brain Observatory Toolbox

This tutorial will show you how to access the Brain Observatory data using MATLAB. In particular, this tutorial will show you how to:

1) Download meta information from brain observatory api and save it as MATLAB datatype

2) Build a *brain_observatory_cache* object to:

A) Get general information on the brain observatory data

B) Filter sessions by specified criteria such as brain areas, imaging depth and stimuli type

C) Download Neurodata Without Borders (NWB) files of filtered sessions

3) Extract imaging data from NWB files to:

a) Get and plot fluorescence traces

b) Convert fluorescence trace into data that is in "raster format" for further analysis

Organization of the Brain Observatory Data

Before we start, we first want to describe the organization of the Brain Observatory Data.

An *experiment container* contains three *sessions* (also called *experiments* or *ophys_experiments*) where recordings were made on a single mouse, in a single brain region and at a particular imaging depth. Each of these three sessions consists of a series of "subexperiments" where a particular stimulus set was shown. Neurodata Without Borders (NWB) files downloaded from the Allen Institute API each consist of data from a single session. As described below, all data that we extract into "raster format" consists of data from a single "subexperiment" where a particular stimulus set was shown.

Note: within an experiment container the same stimuli might be repeated in different sessions (i.e., different sessions can have the same "subexperiment type"). For example, Natural Movie 1 is shown in all three sessions in an experiment container. For more information see: http://alleninstitute.github.io/AllenSDK/brain_observatory.html

1) Download meta information from brain observatory api and save it as MATLAB datatype

To begin, add the path to Brain Observatory Toolbox:

```
bot_dir_name = '/om/user/xf15/Brain-Observatory-Toolbox/';  
addpath(bot_dir_name)
```

Next we will download the meta information which is stored in manifest files on the Allen API. We can do this using the function `get_manifests_info_from_api(bot_dir_name)`. This function creates a MATLAB structure array with three tables and saves this structure array in a file called `manifests.mat`; `manifests.mat` will be used as an argument to the `brain_observatory_cache` as shown in the next section.

```
get_manifests_info_from_api(bot_dir_name) % this should take around a minute to run in order
```

```
Elapsed time is 0.001425 seconds.
```

```
load([bot_dir_name 'manifests'])
```

```
manifests % view the tables in the manifests structure
```

```
manifests = struct with fields:
    container_manifest: [216×13 table]
    session_manifest: [648×14 table]
    cell_id_mapping: [27124×4 table]
```

There are three tables in `manifest.mat`:

- *container_manifest* a [num_containers x num_fields of meta data] size table contains metadata of all experiment containers
- *session_manifest* contains metadata of all sessions a [m sessions x n aspects of meta data], and
- *cell_id_mapping* contains mapping between new cell ids and the old cell id of all cells (m cells by number of ids).

Note: The reason there is a mapping between new cell id and old cell id is: "The cross-session alignment algorithm has been updated and re-run, so all cell specimen IDs have changed", as quoted from AllenSDK's release note (0.13.2).

2) Build a `brain_observatory_cache` object

`brain_observatory_cache` is a class that resembles `BrainObservatoryCache` in `allensdk` (see Python code at: https://github.com/AllenInstitute/AllenSDK/blob/master/allensdk/core/brain_observatory_cache.py).

The MATLAB `brain_observatory_cache` takes manifest files and enables you to get information and access data using three types of methods:

- A) Get general information on the brain observatory data using methods that start with "get_"
- B) Filter sessions by different criteria using methods that start with "filter_"
- C) Download NWB file(s) of filtered session(s) using the method named "download_nwb"

To begin, build a `brain_observatory_cache` object

```
boc = brain_observatory_cache(manifests)
```

```
boc =  
    brain_observatory_cache with properties:  
        session_table: [597×14 table]  
        container_table: [199×13 table]  
        filtered_session_table: [597×14 table]  
        stimuli: {9×1 cell}  
        targeted_structure: {6×1 cell}  
        imaging_depth: [11×1 double]  
        container_id: [199×1 double]  
        session_id: [597×1 double]  
        session_type: {4×1 cell}
```

As you can see here, the data in manifests.mat is stored in the brain_observatory_cache properties *manifests.session_table*, and *manifests.container_table*. The other properties in the *brain_observatory_cache* will be explained below.

2A) Get general information on the brain observatory data

There are several methods start with "get_" which summarize in the brain observatory data based on particular criteria.

To get the total number of experiment containers we can use:

```
boc.get_total_num_of_containers()
```

```
ans = 199
```

Note: Total number of sessions is the number of containers times 3 since there are three sessions per container.

To get all the cortical depths that were ever recorded in any experiment container we can use:

```
boc.get_all_imaging_depths()
```

```
ans =  
    175  
    265  
    275  
    300  
    320  
    325  
    335  
    350  
    365  
    375
```

⋮

Note: Recordings didn't take place equally among these depths, only the most common depths are shown on homepage of Brain Observatory: <http://observatory.brain-map.org/visualcoding>

To get all the get all type of cre driver lines from all mice we can use:

```
boc.get_all_cre_lines()
```

```
ans = 6x1 cell array
      'Cux2-CreERT2'
      'Emx1-IRES-Cre'
      'Nr5a1-Cre'
      'Rbp4-Cre_KL100'
      'Rorb-IRES2-Cre'
      'Scnn1a-Tg3-Cre'
```

Note: All mice had the same reporter line: Ai93 and tTA driver line: Camk2a-tTA

For more information about transgenic lines: <http://observatory.brain-map.org/visualcoding/transgenic>

To get all the all brain regions that were recorded in any experiment container we can use:

```
boc.get_all_targeted_structures()
```

```
ans = 6x1 cell array
      'VISal'
      'VISam'
      'VISl'
      'VISp'
      'VISpm'
      'VISrl'
```

For more information on these locations, see homepage of Brain Observatory: <http://observatory.brain-map.org/visualcoding>

To get all the all types of sessions that appear in any experiment container we can use:

```
boc.get_all_session_types()
```

```
ans = 4x1 cell array
      'three_session_A'
      'three_session_B'
      'three_session_C'
      'three_session_C2'
```

Note: There are always three sessions in each container: session A, session B, and session C or session C2

To get all the all type of stimuli that were used in any of the four types of sessions we can use:

```
boc.get_all_stimuli()
```

```
ans = 9x1 cell array
      'drifting_gratings'
      'locally_sparse_noise_eight_degree'
      'locally_sparse_noise_four_degree'
      'natural_movie_one'
      'natural_movie_three'
      'natural_movie_two'
      'natural_scene'
      'spontaneous_activity'
      'static_gratings'
```

Note: For mapping between session type and stimulus type see http://alleninstitute.github.io/AllenSDK/brain_observatory.html

To get the numer of experiment containers recorded in each brain region we can use:

```
boc.get_summary_of_containers_along_targeted_structures()
```

VISal	33
VISam	25
VISl	36
VISp	54
VISpm	35
VISrl	16

To get the numer of experiment containers recorded at each cortical depth we can use:

```
boc.get_summary_of_containers_along_imaging_depths()
```

175	50
265	1
275	72
300	4
320	1
325	3
335	3
350	33
365	1
375	30
435	1

To get the number of experiment containers recorded at each cortical depth in each brain region we can use:

```
boc.get_summary_of_containers_along_depths_and_structures()
```

```
ans = 12x7 table
      VISal  VISam  VISl  VISp  VISpm  VISrl  total
```

	-----	-----	-----	-----	-----	-----	-----
175	8	5	10	11	11	5	50
265	1	0	0	0	0	0	1
275	12	9	15	20	11	5	72
300	1	0	1	1	1	0	4
320	0	1	0	0	0	0	1
325	0	1	1	0	1	0	3
335	0	0	0	2	1	0	3
350	4	4	4	13	4	4	33
365	1	0	0	0	0	0	1
375	6	4	5	7	6	2	30
435	0	1	0	0	0	0	1
total	33	25	36	54	35	16	199

2B) Filter sessions by specified criteria such as brain areas, imaging depth and stimuli type

"Filter methods" reduce the meta data in the *brain_observatory_cache*'s *filter_session_table* based on particular criteria. To illustrate this, let's start by creating a new clean *brain_observatory_cache* object:

```
boc = brain_observatory_cache(manifests)
```

```
boc =
  brain_observatory_cache with properties:
    session_table: [597x14 table]
    container_table: [199x13 table]
    filtered_session_table: [597x14 table]
    stimuli: {9x1 cell}
    targeted_structure: {6x1 cell}
    imaging_depth: [11x1 double]
    container_id: [199x1 double]
    session_id: [597x1 double]
    session_type: {4x1 cell}
```

Note that this *brain_observatory_cache* object has a property named *session_table* and a property named *filtered_session_table*. When the *brain_observatory_cache* object is first created, both of these properties are initialized to the same [597x14] dimensional table *manifest.session_manifest*, where the number 597 refers to the total number of sessions that have currently been made available by the Allen Institute. As different filter methods get called on the *brain_observatory_cache* object, rows in *filtered_session_table* are eliminated to meet specified criteria, and other properties (e.g., *stimuli*, *targeted_structure*, etc) in the *brain_observatory_cache* object that summarize the meta data in *filtered_session_table* are also updated.

Here we show an example of searching for sessions that primary visual cortex was recorded at 275 mm deep and during where drifting gratings were shown.

Eliminate information to only sessions where drifting gratings were shown:

```
boc.filter_sessions_by_stimuli('drifting_gratings')
```

```
ans =  
brain_observatory_cache with properties:  
    session_table: [597×14 table]  
    container_table: [199×13 table]  
    filtered_session_table: [199×14 table]  
        stimuli: {4×1 cell}  
    targeted_structure: {6×1 cell}  
    imaging_depth: [11×1 double]  
    container_id: [199×1 double]  
    session_id: [199×1 double]  
    session_type: {'three_session_A'}
```

Note that all properties of the *brain_observatory_cache* object have changed except the first top three properties.

Eliminate information to only sessions that have posterior Primary Visual Cortex recordings:

```
boc.filter_sessions_by_targeted_structure('VISp')
```

```
ans =  
brain_observatory_cache with properties:  
    session_table: [597×14 table]  
    container_table: [199×13 table]  
    filtered_session_table: [54×14 table]  
        stimuli: {4×1 cell}  
    targeted_structure: {'VISp'}  
    imaging_depth: [6×1 double]  
    container_id: [54×1 double]  
    session_id: [54×1 double]  
    session_type: {'three_session_A'}
```

Eliminate information to only sessions that were recorded at 275 mm deep

```
boc.filter_sessions_by_imaging_depth(275)
```

```
ans =  
brain_observatory_cache with properties:  
    session_table: [597×14 table]  
    container_table: [199×13 table]  
    filtered_session_table: [20×14 table]  
        stimuli: {4×1 cell}  
    targeted_structure: {'VISp'}  
    imaging_depth: 275  
    container_id: [20×1 double]  
    session_id: [20×1 double]  
    session_type: {'three_session_A'}
```

As we can see now, there are 20 sessions that met all of the criteria given.

Every experiment container in the Brain Observatory has an unique experiment container ID that was created by the Allen Institute. These container IDs are stored in the *experiment_container_id* field in *session_table* or *filtered_session_table*. For example, to see the 20 experiment container IDs that met our filtering criteria we can run:

```
boc.filtered_session_table.experiment_container_id
```

```
ans =
  527550471
  511510675
  528959519
  527676429
  511506664
  530243910
  511510779
  511510927
  524691282
  511510667
  :
```

Let's now filter sessions to the session from the first experiment session container (experiment container ID 527550471), which will make the code run much faster when we download the two-photon imaging data in the next stage.

```
boc.filter_sessions_by_container_id(527550471)
```

```
ans =
  brain_observatory_cache with properties:
    session_table: [597x14 table]
    container_table: [199x13 table]
    filtered_session_table: [1x14 table]
    stimuli: {4x1 cell}
    targeted_structure: 'VISp'
    imaging_depth: 275
    container_id: 527550471
    session_id: 527745328
    session_type: {'three_session_A'}
```

Take a look at metadata of the final filtered session we can see all the properties that are associated with this session:

```
boc.filtered_session_table
```

```
ans = 1x14 table
    date_of_acquisition    experiment_container_id    fail_eye_tracking    id    imaging_depth
    -----
    '2016-07-08T15:59:05Z'    5.2755e+08    true    5.2775e+08    275
```


Note there is only one row in this table because only one of the sessions in the experimental container 527550471 met our previous filter criteria. If we create a new *brain_observatory_cache* object called *boc2* and only use the *boc2.filter_sessions_by_container_id(527550471)* method, then there will be three rows corresponding to the three sessions in this experiment container.

```
boc2 = brain_observatory_cache(manifests);
boc2.filter_sessions_by_container_id(527550471);
boc2.filtered_session_table
```

```
ans = 3x14 table
    date_of_acquisition    experiment_container_id    fail_eye_tracking    id    imaging_dept
    -----
    '2016-07-06T15:22:01Z'    5.2755e+08    false    5.2755e+08    275
    '2016-07-08T15:59:05Z'    5.2755e+08    true    5.2775e+08    275
    '2016-07-07T15:22:43Z'    5.2755e+08    true    5.2768e+08    275
```

Note, *brain_observatory_cache* object is not merely useful for helping to get NWB files to download, but it can also be used to retrieve information about files you have already downloaded in case you need to find more information about these files.

2C) Download NWB files of filtered session(s)

Finally real data stored in Neurodata Without Borders (NWB) files. More information about NWB files can be found at:

- Their github page: <http://neurodatawithoutborders.github.io/>
- A publication about the data format: <http://www.sciencedirect.com/science/article/pii/S0896627315009198>

Let's begin by creating a variable that has the directory name where the NWB files will be saved.

```
nwb_dir_name = [bot_dir_name, 'nwb_files/'];
```

We can then call the *brain_observatory_cache* method *download_nwb()* to download all NWB file(s) corresponding to filtered session(s) stored in *brain_observatory_cache* and save then in the specified directory:

```
boc.download_nwb(nwb_dir_name);
```

```
desired /om/user/xf15/Brain-Observatory-Toolbox/nwb_files/three_session_A/527745328.nwb already exists
```

Note: The size of a NWB files are around 600MB, and take 25 minutes to download on our system, so you might want to take a break and get some coffee. Once the file has been downloaded, *brain_observatory_cache* will return a message the the file has been downloaded.

3) Import imaging data from NWB files

Now we have downloaded an NWB file, we can extract the fluorescence traces from the file and convert them to data in "raster format" which makes the data easier to analyze. For more info about raster format, see <http://www.readout.info/toolbox-design/data-formats/raster-format/>

3a) Get and plot fluorescence traces

Before we start converting data to raster format, let us plot some fluorescence traces to make sure the data looks reasonable. The Brain Observatory NWB files contain fluorescent traces in 4 different stages of processing from raw to fully processed, which are called: raw, demixed, neuropil corrected, and Df over F. We can plot these traces in two different ways by either:

- i) Extracting the fluorescence traces of all cells in one session and then plotting them using general MATLAB plotting functions
- ii) Using the Brain Observatory Toolbox's `plot_fluorescence_traces()` function.

Here we show an example of i):

Extract and compute all four types fluorescence traces available in the NWB file of session 517745328 and save them to the workspace.

```
session_id = 527745328;  
[raw, demixed, neuropil_corrected, DfOverF] = extract_fluorescence_traces_from_NWB_file(nwb_di
```

Elapsed time is 4.172420 seconds.

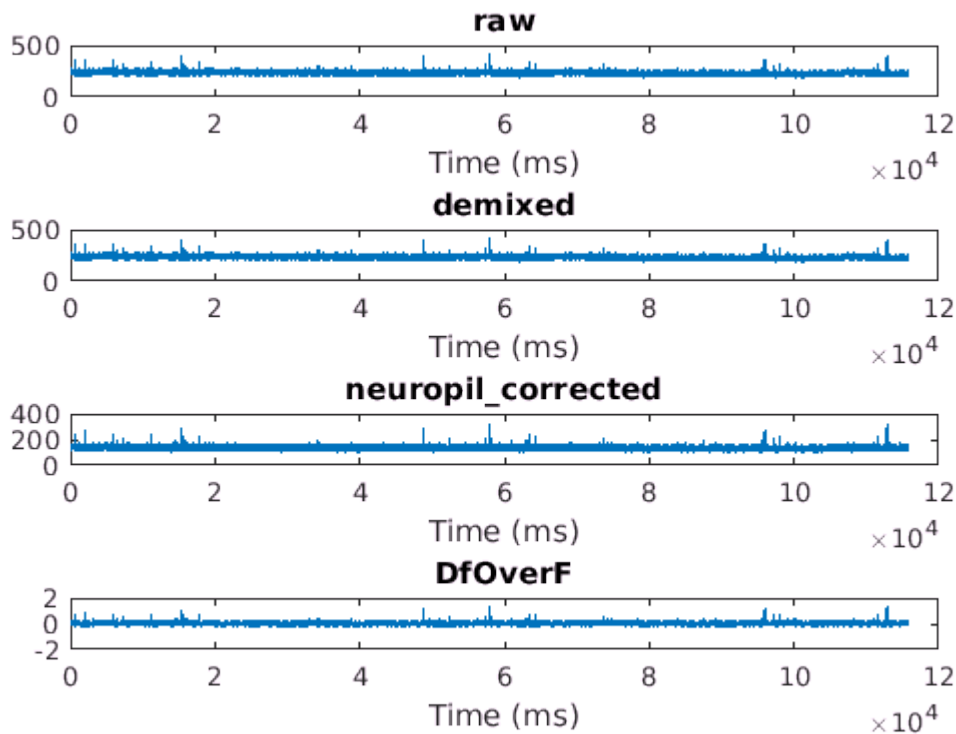
This function returns a [num_time x num_cells] sized matrix for each of the types of fluorescence trace extracted. We can plot the first cell's fluorescence trace of the raw signal using:

```
plot(raw(:, 1))  
xlabel('Time (ms)')  
ylabel('Flourescence intensity')
```

Alternatively, as an example of method ii, we can use the `plot_fluorecence_traces()` function to plot the traces of a cell with id 529022196 in session 527745328 directly using:

```
session_id = 527745328;  
cell_id = 529022196;
```

```
plot_fluorecence_traces(nwb_dir_name, session_id, cell_id);
```



3b) Convert fluorescence trace into data in "raster format"

We will now save the fluorescence traces to raster format. To start, let us specify the path where directories containing raster files will be saved:

```
raster_dir_name = [bot_dir_name, 'raster/'];
```

We can then use the `convert_fluorescence_trace_into_raster_format()` function to create the raster data by specifying the session ID, the type of stimuli you are interested in, and the type of fluorescence trace you want to use, along with the directory names for the `nwb_files` and `raster_data`:

```
session_id = 527745328;
stimuli = 'drifting_gratings';
fluorescence_trace_type = 'DfOverF';

convert_fluorescence_trace_into_raster_format(fluorescence_trace_type, session_id, ...,
stimuli, raster_dir_name, nwb_dir_name)
```

Elapsed time is 28.813435 seconds.

254 cells converted into raster formats.

There are 254 raster files in folder /om/user/xf15/Brain-Observatory-Toolbox/raster/drifting_gratings/

Elapsed time is 52.328782 seconds.

current_raster_dir_name =

'drifting_gratings_527745328/'

4) Get Masks...