

Alex: Associative Learning EXperiments

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Introduction

Alex is a program for running associative learning experiments described in configuration files. This manual explains how to configure the experiments. Please refer to the README file that comes with alex for installation instructions. The README also describes in brief what alex can and cannot do.

Workflow

To build a new experiment you create a dedicated folder, and within it the following subfolders:

- **Design:** This folder contains the files that specify experimental design, such as which stimuli to use, the structure of trials, and different treatments for subjects. See [Configuration files](#).
- **Materials:** Here you have any image, sound, or text files you need for your experiment, including an Instructions.txt file for the initial instructions (see the [section on text files](#)).
- **Data:** This folder holds the data collected during experiment runs.

The program `alex-init` generates a bare-bones experiment so that you know what files you need. It is run like this:

```
alex-init -v <experiment name>
```

This creates folder `<experiment name>` with the above mentioned subfolders (except Data, which is created on first run) and skeleton configuration files.

Acknowledgments

Alex is written using Shane Mueller's [Psychology Experiment Building Language](#) (PEBL). Many thanks to Shane for sharing PEBL!

Starting and stopping alex

From the folder where the Design and Materials folders are, you can just type `alex` in the command line. You can also run experiments in a different folder using:

```
alex -v <path to folder>
```

The folder is expected to have Design and Materials subfolders with appropriate files. A Data subfolder will be created if not present.

Alex has been designed so that multiple instances of an experiment can be run simultaneously. This feature is useful when the experiment folder is shared among multiple computers, as it may occur in a lab. All instances of alex will read the same design files, and in particular the same `Groups.csv` file which describes how to run subjects. Different instances, however, will run different subjects and will not overwrite each other's data files.

The fact that a subject has been run is signaled by the existence of the corresponding data file (see [Data format](#)). If the experiment is interrupted before it completes, alex will still consider that subject as having been run. It is up to you to check that data files are complete (that they have the appropriate number of lines, for example).

Although this may be inconvenient at times, it is hard to improve upon this situation because there is no way for alex to decide whether important data would be overwritten by re-running a subject. If you decide a data file is worthless, either remove it or rename it with something like an ‘incomplete-’ prefix, and alex will automatically re-run that subject.

To interrupt a running experiment, you can use the interrupt key combination for PEBL: `Ctrl+Alt+Shift+\\`.

Configuration files

All configuration files are in the Design folder:

- `Phases.csv` describes the experimental design proper. It defines experimental phases in terms of the stimuli, desired responses, possible outcomes, and number of trials in each.
- `Stimuli.csv` specifies the presentation details of the stimuli mentioned by name in `Phases.csv`.
- `Groups.csv` specifies the number and size of experimental groups, as well as the treatments to which subjects in each group are allocated.
- `Parameters.csv` defines some global parameters such as screen background color, text color, font, and size, the duration of inter-trial intervals, and so on. It can also be used to define parameters that are the same for all stimuli, such as which key is used for responses.

The `Phases.csv` file

Suppose we want to teach subjects to discriminate a red square from a white square. We then want to know how subjects respond to, say, a pink square. Table 1 shows how a suitable `Phases.csv` file might look.¹ The file describes an experiment with two phases, with each line defining one type of trial that occurs in a phase. Here, there are two kinds of trials in phase 1, specifying 20 presentations of each of two stimuli, called Red and White. Red will be rewarded 90% of the time, White only 10%. On these trials, stimulus Smiley will be displayed as the reward (US). In phase 2, stimulus Pink is presented five times and never rewarded.

When the experiment is run, Red and White trials will be intermixed randomly because they all pertain to phase 1. Pink trials, on the other hand, will be performed in phase 2 after all phase 1 trials have been run.

Table 1: A simple `Phases.csv` to teach a discrimination between stimuli Red and White, and then test responding to Pink. Note that the US field can be left empty if the Reward probability is 0.

Phase	Stimulus	Trials	Reward	US
1	Red	20	0.9	Smiley
1	White	20	0.1	Smiley
2	Pink	5	0	

¹In this manual, we use tables to display design files in a readable form. These files, however, are actually comma-separated-values (CSV) files. You can edit CSV files in any spreadsheet using the CSV format for saving. Alex wants double quotes (if needed) in CSV files. Single quotes will result in errors. (This comes from the PEBL function that reads CSV files.) Most spreadsheet software uses double quotes by default, but do check in case alex cannot read your CSV files.

Note: Phases are run in the order they are defined, not in their numerical or alphabetical order (thus you can use descriptive names like Training, Testing, etc). To be more precise, phases are run in the order in which their *first* stimuli are defined. For example, the `Phases.csv` file in Tables 1 and 2 are equivalent, but the file in Table 3 runs phase 2 before phase 1.

Table 2: With this `Phases.csv` file, alex will run phase 1 before phase 2 (cf. Table 3).

Phase	Stimulus	Trials	Reward	US
1	Red	20	0.9	Smiley
2	Pink	5	0	
1	White	20	0.1	Smiley

Table 3: With this `Phases.csv` file, alex will run phase 2 before phase 1 (cf. Table 2).

Phase	Stimulus	Trials	Reward	US
2	Pink	5	0	
1	Red	20	0.9	Smiley
1	White	20	0.1	Smiley

The `Stimuli.csv` file

How does alex know that Red, White, and Pink mentioned in the `Phases.csv` files in Tables 1–3 represent red, white, and pink squares, and that Smiley is a smiley face? This information is contained in the `Stimuli.csv` file, see Table 4.

Table 4: A `Stimuli.csv` file instructing alex that stimuli Red, White, and Pink are differently colored 50x50 pixel squares, and that Smiley is an image contained in the file `smile-o-white.png`.

Name	Type	Parameters	Color	XOffset	YOffset
Red	square	50	red	0	0
White	square	50	white	0	0
Pink	square	50	255,128,128	0	0
Smiley	image	smile-o-white.png		0	-150

The fields in Table 4 should be fairly intuitive, but here is a detailed explanation:

- **Name:** A label for the stimulus, so that it can be referenced in `Phases.csv`. This can be anything that does not contain the characters " (double quote), + (plus), * (asterisk), : (colon), or , (comma). These characters are reserved for special operations described below.
- **Type:** This can be `square`, `circle`, `text`, `textfile`, `image`, or `sound`.

- **Parameters:** The meaning of parameters varies according to the stimulus type:
 - square: side length in pixels.
 - circle: radius in pixels.
 - text: the text to be displayed.
 - textfile: name of a file in the Materials folder where the desired text is stored.
 - image or sound: name of a file in the Materials folder that contains the image or sound. An optional zoom factor can be provided to scale the image to a desired size. It should be separated from the filename by a + sign. The following stylized faces (smileys) come with alex and you can use them without having them in the Materials folder:
 - * smile-o-white.png: a happy face, as used above
 - * meh-o-white.png: a neutral face
 - * frown-o-white.png: a sad face

These images are drawn in white over a transparent background; equivalent black images are available as smile-o.png, etc. All images have been taken from [Font Awesome](#), via [this project](#). They are 256x256 pixels in size to look OK even on high resolution monitors. If that is too big for you, you can zoom them as indicated above.
- **Color:** The color of squares, circles, or text. This field is ignored for images and sounds. Colors can either be named or given as an RGB triplet. As the latter are themselves comma-separated lists, they need to be double-quoted in the CSV file (spreadsheet software will do this for you). In the case of text, you can specify the background as well as the foreground color by writing the color in the form Color1+Color2, where Color1 will be foreground and Color2 the background. If no foreground or background color is given, the defaults set in Parameters.csv are used.

The PEBL reference manual lists valid color names, which are many hundreds. If you stick to simple stuff like red, blue, cyan, purple, and so on, you can get by without consulting this file. RGB, of course, enables you to define color shades more precisely.
- **XOffset** and **YOffset:** Offset from the center of the screen, in pixels. In Table 4, all stimuli are centered except for the reward stimulus Smiley, which is displayed 150 pixels above center (negative Y values place stimuli above center, negative X values place them left of center).

The Groups.csv file

The Groups.csv file contains information about the experimental groups you want to run. If all subjects undergo the same treatment, you only to specify one group and its size. The file in Table 5, for example, instructs alex to run a single groups of 10 subjects (groups can be numbered or named, as is most convenient to you). Often, however, subjects need to be divided in different treatment groups. Any of the fields in the Stimuli.csv file can be specified on a per-subject bases. If you want to test two shades of pink, for example, you would extend the Stimuli.csv file in Table 6. The special value * in the table indicates that the color of stimulus Pink will be looked up, for each subject, in the column PinkColor of the Groups.csv file (Table 7). This syntax is available for all stimulus properties. For example, to change the size of Red square across subjects you would use the Groups.csv and Stimuli.csv files in Tables 9 and 8.

Table 5: A `Groups.csv` file instructing alex to run 6 subjects.

Group	Size
1	10

Table 6: A `Stimuli.csv` file instructing alex to look up the Color of the Pink stimulus in the `Groups.csv` file.

Name	Type	Parameters	Color	XOffset	YOffset
Red	square	50	red	0	0
White	square	50	white	0	0
Pink	square	50	*	0	0
Smiley	image	smile-o-white.png		0	-150

Table 7: A `Groups.csv` file instructing alex to run 6 subjects split in two treatment groups with different Color attributes for the Pink stimulus (see Table 6).

Group	Size	PinkColor
1	10	255,128,128
2	10	255,190,190

Table 8: A `Stimuli.csv` file instructing alex to run look up in the `Groups.csv` file both the Color of stimulus Pink and the Parameters of stimulus Red (see Table 9).

Name	Type	Parameters	Color	XOffset	YOffset
Red	square	*Red	red	0	0
White	square	50	white	0	0
Pink	square	50	*Pink	0	0
Smiley	image	smile-o-white.png		0	-150

Table 9: A `Groups.csv` file instructing alex to run 4 experimental groups. Each group receives a unique combination of PinkColor and RedParameters (see Table 8).

Group	Size	PinkColor	RedParameters
1	10	255,128,128	25
2	10	255,128,128	50
3	10	255,190,190	50
4	10	255,190,190	75

The Parameters.csv file

The Parameters.csv file contains some parameters that affect the whole experiment. Here is a sample file (as above, the file is in CSV format, displayed here as a table for legibility):

Table 10: Sample Parameters.csv file with default values.

Parameter	Value
CSDuration	4000
CSUSInterval	0
USDuration	400
ResponseTimeMin	0
ResponseTimeMax	4000
MinITI	1000
MaxITI	3000
Response	<space>
MaxResponses	100
BackgroundColor	gray95
ForegroundColor	black
FontName	Vera
FontSize	36
Test	0

CSDuration is the default duration of all the non-US stimuli, while **USDuration** is the default duration of all US stimuli. All durations are in milliseconds. Note that you can set different durations for different stimuli by including a Duration column in the Stimuli.csv file. When using compound stimuli, all components must have the same duration.

CSUSInterval is the interval between CS offset and US onset.

ResponseTimeMin and **ResponseTimeMax** define at what times within a trial subjects can respond. Responses outside this time window are registered with a special code (see [Data format](#)) and no USs are delivered. If not specified, ResponseTimeMin is set to 0 and ResponseTimeMax to CSDuration, thus allowing responses at any time during the trial.

MinITI and **MaxITI** are the minimum and maximum values of the inter-trial interval. Each inter-trial interval will be drawn between these values with uniform distribution.

Response is the key subjects are instructed to press if they want to respond. Note that this can also be set on a per-stimulus basis, see [here](#).

MaxResponses is the maximum number of response a subject is allowed to make in one trial. There are essentially two useful settings. If you set this to 1 the trial ends with the first response (the US is delivered if appropriate, of course). If you set it to an unrealistically large value, say 1000, you can record any number of responses per trial. Each of these may result in the US being delivered, as described above. Note that you can set MaxResponses to a different value for different trial types, by including a MaxResponses column in Phases.csv (see the [section on text files](#) for an example). If a MaxResponses column exists, but the value is empty for some stimuli, the MaxResponses value in Parameters.csv will be looked up. If MaxResponses is not set there, it is given a default value of 1.

The next few parameters control the screen background color while the experiment is running and the color, font, and size of text used for instructions and other messages.

The **Test** parameter, if set to 1, skips instructions and acquisition of demographic information. It is meant to quickly start the experiment during development.

More about stimuli

We mentioned above one bit of special notation in the definition of stimuli, namely the construction * (star) + stimulus name (see the end of the previous section). There are two more bits of special notation, explained next.

Sometimes we want some stimuli to share characteristics. For example, they should be of the same color. We can express the fact that we want a stimulus characteristic to equal that of another stimulus using a colon (:) followed by the stimulus name (we would have liked to use = rather than :, but unfortunately spreadsheet software stubbornly interprets = as introducing a formula). Consider the example above, with three squares of the same size as stimuli. The file in Table 11 is equivalent but uses colon notation for the Parameters field. This has two advantages: it makes explicit our intention of having three squares of equal size, and it reduces the possibility of typing errors.

Table 11: A Stimuli.csv file demonstrating the * and : special notations for stimuli.

Name	Type	Parameters	Color	XOffset	YOffset
Red	square	50	red	0	0
White	square	:Red	white	0	0
Pink	square	:Red	Pink	0	0
Smiley	image	smile-o-white.png		0	150

Another bit of special notation is + (plus), which is used to present stimuli together (compound stimuli). Suppose that, after training a discrimination between red and white squares, we want to test the red and white squares together. We would then use the files in Tables 12 and 13.

Table 12: A Phases.csv file with a compound stimulus in phase 2.

Phase	Stimulus	Trials	Reward	US
1	Red	20	0.9	Smiley
1	White	20	0.1	Smiley
2	Red+White	5	0	

Table 13: A `Stimuli.csv` file to go with the `Phases.csv` file in Table 12. Note that we need to offset the white square, otherwise it would overlap with the red one when the two are presented together.

Name	Type	Parameters	Color	XOffset	YOffset
Red	square	50	red	0	0
White	:Red	:Red	white	60	:Red
Smiley	image	smile-o-white.png		0	150

Note: The + notation is also valid for USs. This can be used to implement USs of different “magnitude.” For example, one can instruct subjects that each smiley face represents a point earned, and have multiple smileys appear for more valuable stimuli (this requires defining several smiley stimuli offset from each other, so that they do not overlap when displayed simultaneously). Compounding of USs may also be used to present a combination of a visual and auditory US.

Superposition of stimuli

Visual stimuli are added to the screen in the order they appear in the `Stimuli.csv` file. This means that, should some stimuli overlap on the screen, those defined *later* will be displayed *on top* of those defined earlier, obscuring them partly or wholly.

Stimuli that are always present during a phase

It is sometimes desirable to have a stimulus or combination of stimuli present at all times, including inter-stimulus intervals, for example as a background on which others are superimposed. A stimulus whose name starts with “Background” followed by the name of a phase will be displayed for the entire duration of that phase. You can define many such stimuli, e.g, `BackgroundPhase1-1` and `BackgroundPhase1-2`.

Note: The rules for stimulus superposition for always-present stimuli are the same as for other stimuli, see [Superposition of stimuli](#). This means that if you want to use a stimulus as a backdrop for other stimuli, you have to define the stimulus before all those that are intended to appear on top of it. If the order is incorrect, the intended backdrop will instead obscure the other stimuli.

More about phases

Similarly to what we have just seen about stimuli, phase parameters can be set to differ by group using the * and : notation. For example, imagine we want to investigate how discrimination learning proceeds as a function of reward probability. We could use the `Phases.csv` file in Table 14, which employs * notation for the Reward variable, and the `Groups.csv` file in Table 15, which provides the information that is “starred” in `Stimuli.csv`.

Table 14: A `Phases.csv` using * notation indicating that the value of the Reward variable given as *Training has to be looked up in the `Groups.csv` file (see Table 15).

Phase	Stimulus	Trials	Reward	US
Training	A	50	*	Smiley

Phase	Stimulus	Trials	Reward	US
Training	B	50	0	

Table 15: A `Groups.csv` file serving as a companion to the `Phases.csv` file in Table 14.

Group	Size	TrainingAReward
Rich	20	1
Poor	20	0.5

Note that the name of the column in `Groups.csv` is `TrainingAReward`, or, more generally, `(phase name)(stimulus name)(parameter)`. Thus the column name specifies two things: the phase and the stimulus to which the column value refers to (in doing the same things for stimuli, we had to worry only about the stimulus name). This works also to set phase parameters for a compound stimulus. For example, if you want to set the Reward value for stimulus A+B, you would use the column `TrainingA+BReward`.

Responses and classical vs. instrumental trials

The default Response key for all stimuli can be specified in `Parameters.csv`. We can also, however, specify different responses for different stimuli by adding a Response column to the `Phases.csv` file. For example, to specify that the left arrow key is the correct response for stimulus Red, but the right arrow is correct for White, you would write as in Table 16.

Table 16: A `Phases.csv` specifying different responses for stimuli Red and White.

Phase	Stimulus	Trials	Reward	US	Response
1	Red	20	1	Smiley	<left>
1	White	20	1	Smiley	<right>

Here `<left>` and `<right>` are special codes that denote the left and right arrow keys. The following is a comprehensive list of valid key codes that can be used to specify correct responses:

- Characters: a–z, 0–9, all standard punctuation (except braces, pipes, tildes, and percent signs)
- Editing keys: `<space>`, `<backspace>`, `<tab>`, `<clear>`, `<kp_enter>`, `<return>`, `<insert>`, `<delete>`
- Modkeys: `<lshift>`, `<rshift>`, `<lctrl>`, `<rctrl>`, `<lalt>`, `<ralt>`, `<lmeta>`, `<rmeta>`, `<numlock>`, `<capslock>`, `<scrolllock>`
- Navigation, function keys: `<up>`, `<down>`, `<left>`, `<right>`, `<home>`, `<end>`, `<pageup>`, `<pagedown>`, `<esc>`, `<f1>`–`<f15>`

Responses can also employ `*` notation. Prefixing a specified response with an asterisk means that the US will be displayed *only* at the end of the trial (with the appropriate Reward probability) *regardless* of what the

subject does during the trial, as in classical conditioning or causal rating studies. Thus the `Phases.csv` file in Table 17 specifies that Red is to be rewarded 90% of the time at the end of a trial, *regardless* of whether the subject responds or not. Note that subject responses are still recorded, and if they exceed the allowed maximum the trial terminates without reward. This last feature makes it possible to implement omission training, i.e., reward subjects only when they abstain from responding. This is controlled by the `MaxResponses` parameter. The default value is 1, which corresponds precisely to omission training. If you don't want the trial to ever terminate before the allotted time, you can use a value of `MaxResponses` so high that it cannot be possibly reached, such as 1000.

Table 17: A `Phases.csv` file using the Response notation `*<space>` to indicate a classical conditioning trial in which the US is delivered at the end of the trial regardless of subject behavior.

Phase	Stimulus	Trials	Reward	US	Response
1	Red	20	.9	Smiley	*<space>

Note also that on `*` trials, the `ResponseTimeMin` and `ResponseTimeMax` features are disabled (see `Global parameters`). Because the US (if any) is delivered only once at the end of the trial, it is irrelevant when a subject responds.

Instructions and other text displays

Instructions or other longish text can be displayed with the `textfile` stimulus type. For example, to include both a start and an end message (say a 'thank you' or similar) you can use `Phases.csv` and `Stimuli.csv` file like those in Tables 18 and 19 to include the presentation of text files that are displayed until the subject responds once. As you see in these Tables, the display of instructions is construed simply as a stimulus that stays on for a long time (here 10 minutes), unless the subject performs the required response (which, by default, is the space bar). The `Start.txt` and `End.txt` files will be looked for in the `Materials` folder of the experiment. Note the column `MaxResponses` in `Phases.csv`, which makes sure the user has to press the space bar (the default response) only once to move on, even if a larger number of responses is allowed for actual experimental trials.

Table 18: A `Phases.csv` file for displaying to subjects instructions and a final message (see also Table 19).

Phase	Stimulus	Trials	MaxResponses
Start	StartText	1	1
End	EndText	1	1

Table 19: A `Stimuli.csv` file for displaying to subjects instructions and a final message (see also Table 18).

Name	Type	Parameters	Color	XOffset	YOffset	Duration
StartText	textfile	Start.txt				600000
EndText	textfile	End.txt				600000

Data Format

When you run an experiment with alex, data are saved in the Data folder (which alex creates if it is not found) in CSV files named with group names and subject numbers, e.g., `Data/Training-1.dat` for the first subject of group Training. These files have a header followed by one data line per response. This is so that each line identifies all variables it pertains to (so called “long format” in statistical software) and can be loaded easily into statistical software without having to manually add data.

The first few columns of each data line consist of the hostname, followed by the group, subject number, and pertinent treatments as specified in the `Groups.csv` line for the particular subject. The remaining columns are as follows:

- **Sex:** Subject’s sex (collected by alex at the start of experiments, otherwise NA).
- **Age:** Subject’s age (ditto).
- **Phase:** Experimental phase the trial belongs to.
- **Trial:** Trial number within the phase.
- **Stimulus:** Stimulus presented in the trial (one of those defined in `Stimuli.csv`), or ITI for responses registered between trials.
- **Duration:** Duration of this stimulus (or inter-trial interval).
- **Response:** Key designated as the correct response. Recall that this may be prepended by * (asterisk) if the trial was a “classical conditioning” one (see [here](#)).
- **RewardPr:** Reward probability assigned to the stimulus, in case of a correct response (from the `Phases.csv` design file).
- **Key:** Subject’s actual response. This can be the correct key, any other key the subject may have pressed, or `<timeout>` in the case of no responses within a trial (the goal is to have a faithful record of everything the subject does).
- **RT:** Reaction time for this response.
- **Reward:** The reward received for the response, using the following code:
 - 1: The response was rewarded (the US was presented)
 - 0: The response was not rewarded (no US presented)
 - -1: The response was invalid, i.e., it fell outside of the window delimited by `ReactionTimeMin` and `ReactionTimeMax`, see above. No US is presented on such responses.

For inter-trial intervals and trials that time out, **Reward** is set to NA. **Response** and **RewardPr** are also set to NA for responses registered during ITIs.

We believe this information characterizes subject behavior competely, but please do let us know if you think details could be added.

Troubleshooting

Errors may arise if Design files have incorrect or incomplete information. Presently, alex performs some checks at startup, but some errors are caught only as they occur while running the experiment. We advise to always run the experiment a few times before putting it into production. If you think errors are due to bugs in alex, please write us at the address in [Contacts](#). Also do contact us if you think that your design files are correct but the experiment does not run as you expect.

With a few exceptions, all errors print a hopefully informative message both on the standard console output (terminal) and on screen. A few errors that may occur before the screen is set up, such as not finding necessary files, are reported only on the standard output. On Windows, these messages will appear in files `stdout.txt` and `stderr.txt`, which PEBL creates in the folder where alex is run.

There is one error that appears mysterious to the uninitiated: the screen remains black and alex hangs forever. The reason is that alex uses a lock system on the `Groups.csv` file to prevent concurrent instances of alex from running the same subject. The lock is held for as little as possible, but if you interrupt alex at a critical time, or if alex crashes for any reason before the lock is released, subsequent instances of alex will wait forever for the lock to be released. In these cases, you can simply delete the lock file, which is `Groups.csv.lock` in the Design folder.

Contacts

Please send suggestions to improve alex or this manual to Stefano Ghirlanda, drghirlanda@gmail.com.