The Staircase Procedure Toolkit: Psychophysical Detection Threshold Experiments Made Easy

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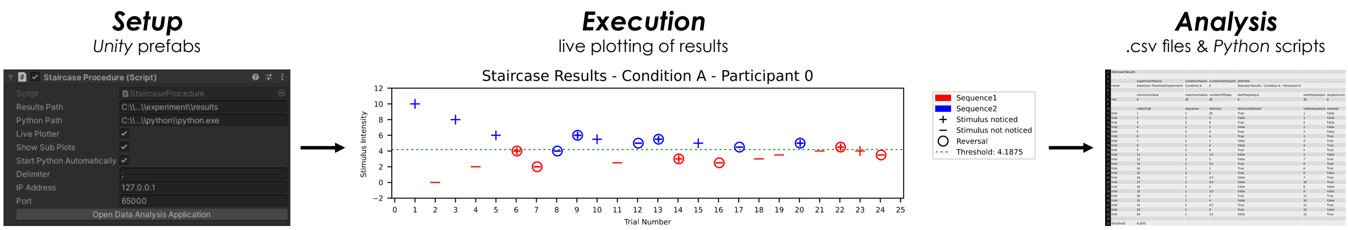

Figure 1: We introduce the open-source *Staircase Procedure Toolkit* that helps researchers conduct psychophysical detection threshold experiments with the Unity engine. Our toolkit covers all stages of an experiment as it provides support during setup, execution, and analysis. Specifically, it implements the weighted up/down method and provides insights in real time by plotting results live during the experiment. In addition, it handles the storage of results and includes basic analysis scripts.

ABSTRACT

We propose a novel open-source software toolkit to support researchers in the domains of human-computer interaction (HCI) and virtual reality (VR) in conducting psychophysical experiments. Our toolkit is designed to work with the widely-used Unity engine and is implemented in C# and Python. With the toolkit, researchers can easily set up, run, and analyze experiments to find perceptual detection thresholds using the adaptive weighted up/down method, also known as the staircase procedure. Besides being straightforward to integrate in Unity projects, the toolkit automatically stores experiment results, features a live plotter that visualizes answers in real time, and offers scripts that help researchers analyze the gathered data using statistical tests.

CCS CONCEPTS

• **Human-centered computing** → **User studies**; **Visualization toolkits**; • **Applied computing** → *Psychology*.

KEYWORDS

psychophysical experiments, detection threshold, up/down method, staircase procedure, Unity, Python

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1 INTRODUCTION

Psychophysical methods have become important tools to investigate scientific questions in human-computer interaction (HCI). In recent years, especially the domain of virtual reality (VR) has made extensive use of psychophysical experiments to study how users perceive novel interaction techniques. Very common in this domain are *detection threshold (DT)* experiments that derive estimates for perceptual boundaries. DTs inform about our ability to detect a specific stimulus, such as, for example, a manipulation of the real-to-virtual registration, or a visual, auditory, or haptic effect. Because of their elegant design and the interesting perceptual data they reveal, DT experiments play a central role, for example, in the development of redirected walking [4], hand redirection [5], haptic feedback [1, 7], and pseudo-haptics [3]. Yet, while many researchers in the VR domain apply the same methods to find DTs, the stimulus presentation logic, result storage, plotting, and analysis is often

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re-implemented from scratch. This leads to a waste of time spent repeatedly coding, testing, and debugging common experiment features. To overcome this, we introduce an open-source toolkit.

2 THE STAIRCASE PROCEDURE TOOLKIT

We present the *Staircase Procedure Toolkit* as an open-source repository on GitHub[1]. Our toolkit offers support throughout the entire experimental process: from implementation, over execution, to data analysis. In contrast to existing tools (e.g., [2]), it is realized with C# and Python to allow users implement DT experiments with Unity[2].

Among the most popular methods for DT estimation are the method of constant stimuli and the adaptive staircase methods. Since staircase methods are usually more efficient in finding DTs [2], i.e., need less trials, our toolkit focuses only on this type of experiment. In addition, staircase procedures profit from a simple threshold computation, which makes the toolkit suitable also for users new to psychophysics and for teaching.

2.1 The Staircase Procedure

Following the terminology of Kingdom and Prins [2], our toolkit supports the weighted 1 up/1 down method. Experiments as supported by the toolkit commonly derive an estimate for the participant's DT (for a specific experimental condition) by repeatedly presenting a stimulus to the participant. After each stimulus presentation, the participant has to indicate their perception of the stimulus by answering a forced-choice question (e.g., 1AFC: *"Did you perceive a manipulation? Yes or No."*). Based on the answer in one trial, the magnitude of the stimulus in the next trial is adjusted: If the participant responds *"perceived"*, the stimulus in the next trial will be decreased in magnitude by Δ^-, otherwise it will be increased by Δ^+. Stimuli at which the participant's response sequence changes from *"not perceived"* to *"perceived"* or vice versa indicate reversal points. Over the course of the experiment, the tested stimuli approach the participant's DT and start to oscillate around it. The stimulus sequence ends after a predefined number of reversal points have occurred. To approximate the DT, the average magnitude of the last reversal points is calculated. To prevent bias, the toolkit implements an interleaved staircase by randomly interleaving trials of an ascending (starting at a minimum/unnoticeable stimulus, red in Figure 1) and a descending sequence (starting at a maximum/noticeable stimulus, blue in Figure 1). The average of both sequences' DTs represents the final threshold result.

Depending on the type of forced-choice question employed, staircase experiments are configured to either approximate the 50%-correct (e.g., for 1AFC yes/no questions) or the 75%-correct threshold ψ_{target} (e.g., for symmetric 1AFC questions). The approximated threshold ψ_{target} can be controlled by varying the ratio between Δ^+ and Δ^-, using the following formula [2]:

$$\frac{\Delta^-}{\Delta^+} = \frac{1 - \psi_{target}}{\psi_{target}} \tag{1}$$

2.2 The Toolkit

To support HCI and VR researchers in applying the staircase procedure, our toolkit is based on a set of Unity scripts and Python tools. The toolkit is available as a `.unitypackage` and ships with prefabs and example scenes. The main features of the toolkit comprise:

- an implementation of the weighted up/down method logic
- a software interface to configure and run staircases
- support for multiple staircases that run in parallel
- live plotting of the staircases and thresholds (see Figure 1)
- automatic result storage (as `.csv` files, see Figure 1)
- plotting of the staircases and thresholds from `.csv`
- support for statistical comparisons of thresholds

A detailed documentation of the toolkit is available online[1] and covers software requirements, setup instructions, a guide on how to use the toolkit and its visualization and analysis features, a detailed explanation of all parameters, and details on the storage of results. The online repository is also used to collect solutions for common issues and a (non-exhaustive) list of publications that have used the toolkit (e.g., [1, 6, 7]).

3 CONCLUSION

With the open-source release of the *Staircase Procedure Toolkit* we aim to speed up the implementation of future DT experiments while maintaining high data quality. Our toolkit is easy to use and supports researchers through a simple interface to set up and run staircase experiments with Unity. It offers live plotting of the staircase results during execution of the experiment and supports researchers also when analyzing their results. With this contribution we intend to bring the HCI, VR, and psychophysics communities closer together, and motivate the development and open-source release of further tools for interdisciplinary research in future work.

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