MakerLens: What Sign-In, Reservation and Training Data Can (and Cannot) Tell You About Your Makerspace

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INTRODUCTION

Data can help makerspace staff and leadership understand the "pulse" of their space and inform strategic planning and decision making. Data can also be useful in crafting compelling narratives to stakeholders and funders. Multiple prior papers at ISAM have stressed the importance of collecting and analyzing data about makerspace usage. Prior work tends to follow one of two primary methodological approaches. First, descriptive statistics of automatically collected usage or sign-in data may reveal a fine-grained view of activity patterns. Second, surveys completed by makerspace users can unravel the motivations and reasons for makerspace use. In this paper, we describe how to gain additional insights from automatically collected makerspace data by applying aggregated time-series analytics over multiple semesters.

We focus on some of the most pervasive and accessible data in makerspaces: (1) sign-in data when users enter a space or start using a particular machine; (2) reservation data (e.g., calendar sign-ups) for popular machines; and (3) training records for individual machine types. Many makerspaces already collect such data for access control and scheduling purposes. We show how aggregated time-series analyses of such data over days, weeks, months, and semesters can yield a richer picture than instantaneous statistics.

Our dataset for these analyses is data collected over three semesters at the Jacobs Institute for Design Innovation and the Citris Invention Lab at UC Berkeley. The makerspace in Jacobs Hall is classified as S-3, A-4, U-3, F-4, M-3 [1], serving roughly 1,000 unique students per semester. A comprehensive introduction to this makerspace can be found in [2]. The Citris Invention Lab is a satellite makerspace which shares training and access control with Jacobs Hall, serving approximately 350 unique students per semester (S-3, A-4, U-2, F-1, M-3). While we analyze the data from these particular makerspaces, our goal is to show that our analyses may be replicated at other similar makerspaces.

RELATED WORK

Cooke and Charnas argue for the importance of data in makerspaces to "craft and promote one's makerspace story; support strategic decisions; measure and validate metrics; and gauge impact" [3]. They describe different technical approaches to measure usage at ThinkBox and suggest one combine usage counts with demographic data; and combine automatic techniques with surveys. Linsey et al. outline three different types of data collected about the Georgia Tech Invention Studio: surveys on design self-efficacy, automatic people counting, and ethnographic results [5]. Imam et al. describe implementation of the "Shared User Management System" (SUMS) at Georgia Tech that provides the back-end infrastructure for access control and data collection [6]. Cooke also describes how quantitative data can be combined into a dashboard of Key Performance Indicators (KPIs) to guide makerspace staff [4].

Culpepper demonstrates that surveys can be used to capture student demographics and makerspace preferences to influence equipment selection and availability for new makerspaces [7]. Filippi shows that using a survey to measure student usage patterns and satisfaction can confirm the benefit a makerspace has on its community [8]. Hunt contributes an interesting just-in-time survey technique in which users are prompted for the reason for their visit to a makerspace when they badge in [9], bridging the approaches of collecting sign-in data with survey information.

This paper follows prior work's approach of analyzing quantitative data from student sign-ins and equipment usage. One of our key contributions beyond prior work is that we show how data analytics and visualization techniques can be used to extract additional insight, resulting in actionable metrics for makerspace staff.

CONTEXT: THE MAKERPASS PROGRAM

The Jacobs Institute uses a custom-built software infrastructure, the MakerPass system, for access control and training. Holding a MakerPass grants access to Jacobs Hall makerspaces and equipment; and the CITRIS Invention Lab.

MakerPass holders fall into four primary categories: (1) faculty and shop staff (professional staff and student workers), (2) students taking classes through the Jacobs Institute, (3) members of the campus community who independently purchase their MakerPass, and (4) researchers who have PI or department sponsored access. Demographics and user classifications are collected once per semester, when users sign up or renew their MakerPass account.

Each MakerPass holder must first complete general workshop safety (GWS) training, which grants access to Jacobs Hall work areas with handheld tools. Afterwards, students can complete additional training modules for different equipment types, such as laser cutters, 3D printers, or CNC mills. Training is a combination of online learning modules and quizzes administered through Canvas[1], our institution's courseware system; and in-person training. Staff record successful completion of training in the courseware system.

[1] https://www.canvaslms.com

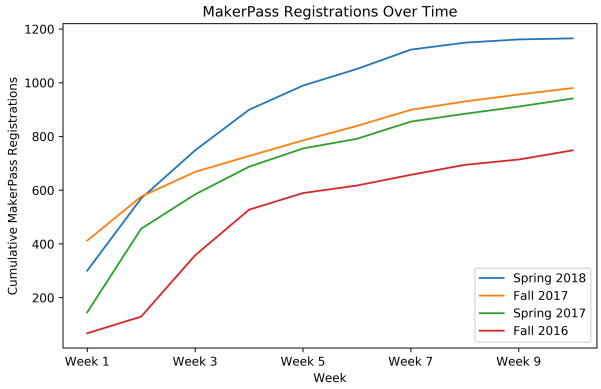

Fig.1: Weekly cumulative MakerPass registrations

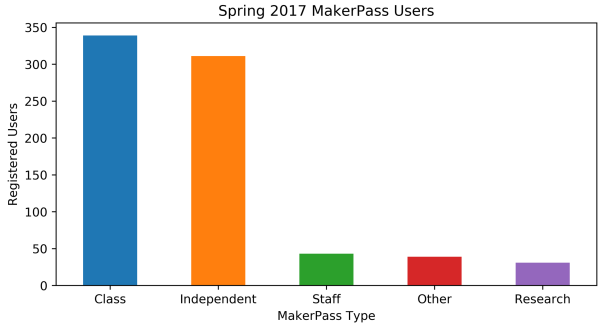

Fig.2: Types of MakerPass user registrations

The MakerPass system comprises card readers which use RFID technology to log university-issued ID cards; software to import training records from Canvas; and software which checks logins to computers running specific machines and equipment. Card readers are positioned at the main entrances to our makerspaces, where users must badge in before entering. Readers output light and sound patterns to indicate access granted, access denied, and "see staff member" messages. Training records are used to grant or deny login access to the computers driving each piece of equipment, i.e., only users with laser cutter privileges can log in to laser cutter computers. The login software runs on all computers attached to equipment and is invisible to users unless their access is denied, in which case their use of the PC is blocked. This modularized training and permission scheme enables an implementation of Control Banding [9] where tools with different hazard levels require different amounts of training.

Another source of data is a calendar reservation system[2] permitting students to book time for exclusive use of a machine or tool, such as a laser or waterjet cutter. For most equipment types, reservations are capped at 60-90 minutes per week.

EXTRACTING USEFUL INSIGHTS FROM AUTOMATICALLY COLLECTED DATA

Our analysis consists of complete data for three semesters: Fall 2016, Spring 2017, and Fall 2017; and partial data for Spring 2018. We report major statistics for each semester and provide analysis over time, identifying trends in usage of MakerPass spaces within and across semesters.

[2] http://reserve.jacobshall.org using the http://supersaas.com cloud hosted platform

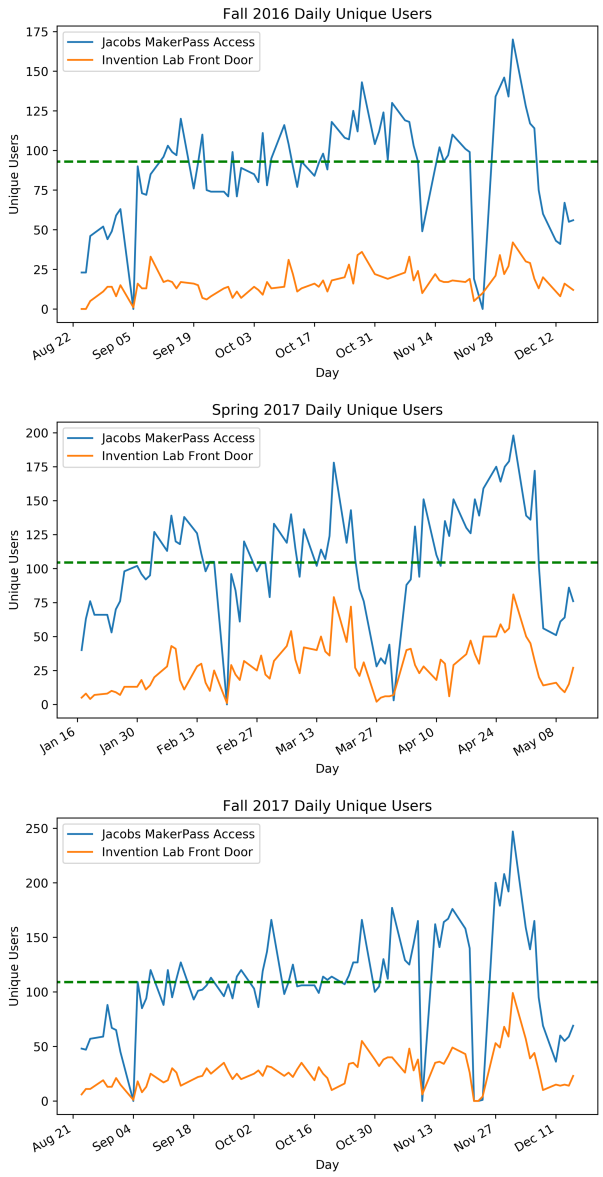

Fig.3: Unique users per day in Jacobs Hall over 3 semesters. Horizontal lines represent medians of Jacobs MakerPass Access.

A. TRACKING REGISTRATIONS EARLY HELPS FORECAST AND MANAGE DEMAND LATER

A key concern of many academic makerspaces is managing demand, especially at crucial high-use times such as the end-of-semester crunch. Tracking the number of students who activated their MakerPass in early weeks of the semester has proven valuable in forecasting and managing the eventual usage later on. Fig. 1 shows cumulative activation rates by week for the first 10 weeks during Fall 2016, Spring 2017, and Spring 2018. In Spring 2017, we approached a total of 1,000 users for the semester, which according to staff, meant the space was almost at capacity. In Spring 2018, we saw that we would reach this activation count much earlier in the semester. This led staff to stop accepting sign-ups from students not

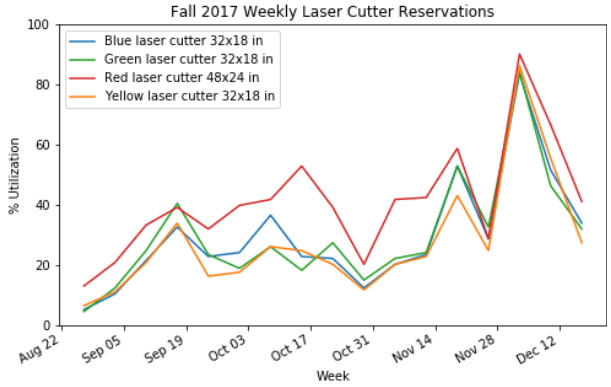

Fig.4: % utilization of individual laser cutter reservations

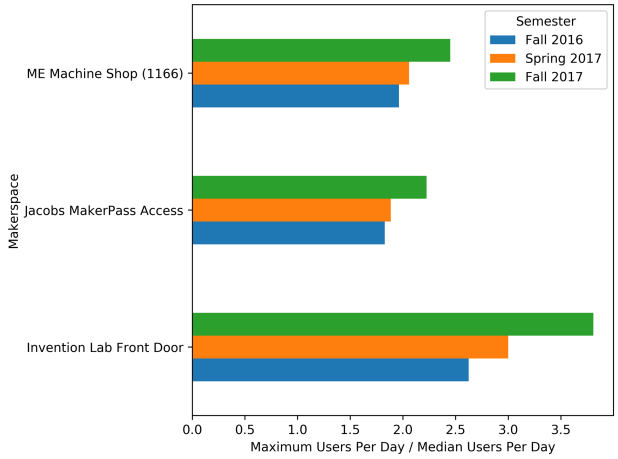

Fig.5: Ratio of maximum to median daily makerspace use

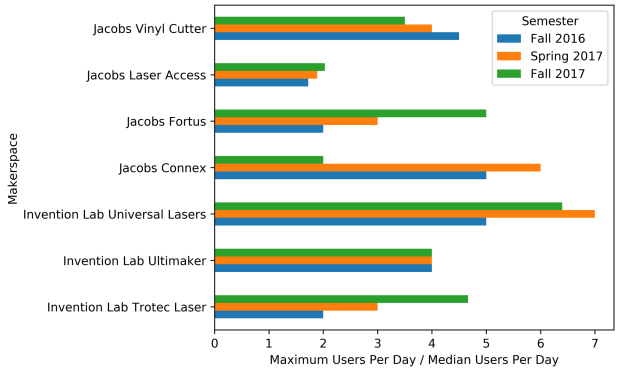

Fig.6: Ratio of maximum to median daily equipment use

enrolled in courses requiring use of the makerspace (category #3 in "Context") by week 6 to slow overall enrollments (blue curve in Fig. 1).

Analyzing the primary reason that members sign up for the makerspace also helps inform staff of the usage pattern of the makerspace. Fig. 2 shows that in Spring 2017, roughly half (44.4%) of users signed up because of a class. These students will be especially heavy users at the end of the semester, while other categories of users may be more flexible or less predictable in their use of space. We note that researchers only make up a small fraction of total users (3.6%), but they account for a significant fraction (23.8%) of sessions on high-end equipment such as industrial 3D printers.

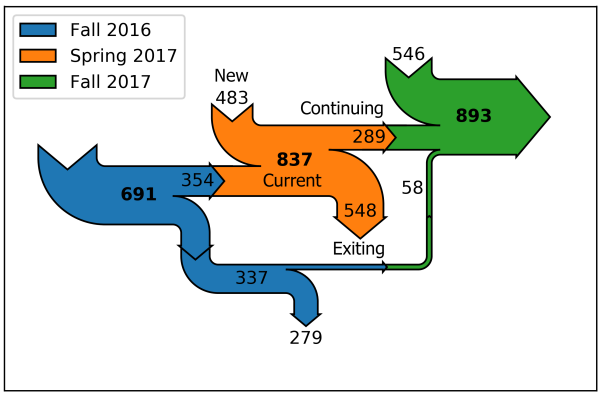

Fig.7: MakerPass retention across semesters

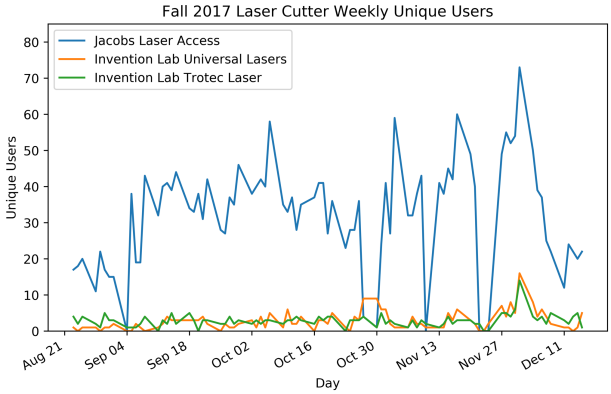

Fig.8: Unique daily laser cutter uses across makerspaces

B. THE SIZE OF THE END-OF-SEMESTER SPIKE IS PREDICTABLE

Fig. 3 shows the number of unique users per weekday in Jacobs Hall and the Invention Lab over time for the 3 semesters analyzed. A horizontal line through each plot represents the median usage (Fall 2016: 92, Spring 2017: 104, Fall 2017: 112.5). Fig. 4 shows the percentage individual laser cutters in Jacobs Hall are reserved per week in Fall 2017. Dips in the plots each represent holidays and spring breaks when Jacobs Hall is closed. Each plot shows an upward trend in usage throughout the semester, with a significant spike during final projects season.

The size of this spike can be predicted from median usage, which itself can be approximated: median usage per day is roughly 10% of registered users. The characteristic ratio of maximum active users per day (during the spike) to median users per day is about 2:1 – meaning the end-of-semester crunch will bring twice as many daily users into the space as a mid-semester day. For both Jacobs Hall and the Mechanical Engineering Department Machine Shop (for comparison), this ratio is remarkably stable across semesters (Fig. 5). The Invention Lab, a smaller makerspace, has a less-stable ratio that keeps growing over time as well. The question how this ratio relates to ultimate capacity or the mix of users in a particular space is worth investigating in future work. Individual machines tend to have larger ratios of peak-to-median use, which likely reflects that they operate near capacity during the spike but significantly below capacity at other times (Fig. 6).

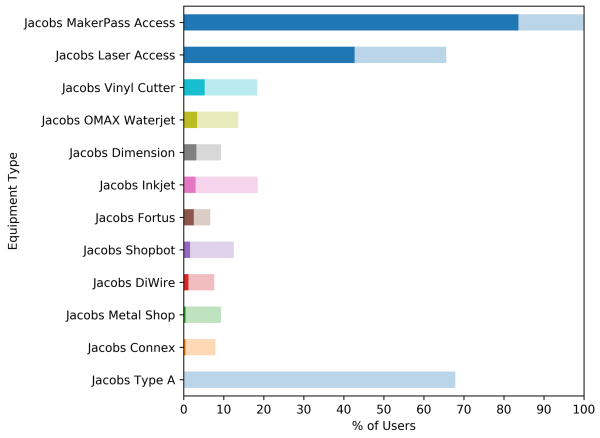

Fig.9: (Transparent): % of registered users who have completed safety trainings in Fall 2017. (Opaque): % of registered users who have accessed equipment. Type A 3D printer activity is not tracked.

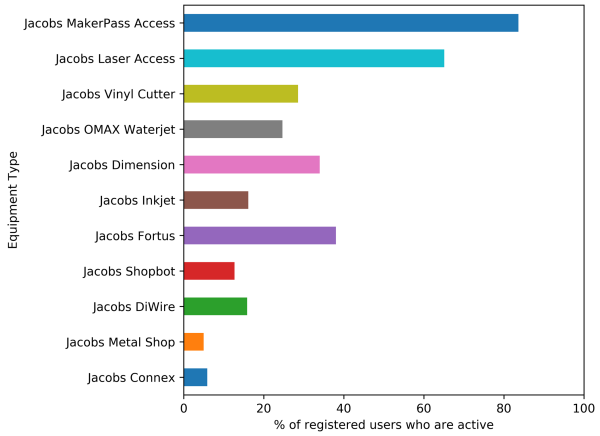

Fig.10: % of trained users who have used equipment in Fall 2017

C. MORE THAN HALF OF THE USER COMMUNITY IS NEW EACH SEMESTER

Since our community is predominantly undergraduate students, regular turnover as students enter college and graduate is to be expected. However, tracking which students re-registered for a MakerPass yields a more nuanced and surprising picture that suggests that many students only join our makerspace temporarily. A Sankey diagram (Fig. 7) visualizes flows (of students) between different process steps (semesters in our case). Arrows from one semester into a subsequent semester show students who re-enrolled. Arrows exiting to the bottom indicate students who did not enroll again. It is especially notable that more than 50% of users each semester are completely new to the space. This level of understanding of the user base has implications for planning initial safety trainings as well as the number and mix of introductory versus advanced workshops.

D. EQUIPMENT USAGE IS NOT EVENLY DISTRIBUTED ACROSS MAKERSPACES

Users who complete Jacobs Hall laser cutter safety training are also granted access to Universal laser cutters in the Invention Lab, but these machines are not utilized equally.

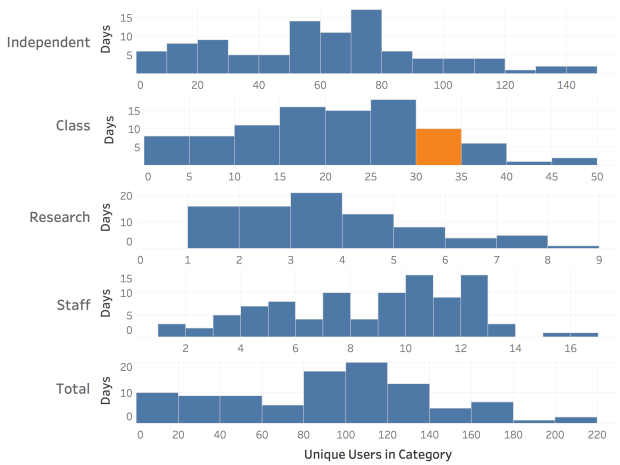

Fig.11: Days in Fall 2017 in which ranges of unique users were present. For example, there were 10 days in the Fall 2017 semester where 30-34 Class MakerPass Holders were present (orange bar).

Although Jacobs Hall has four times the capacity, usage is over *eleven times* that of the Invention Lab, suggesting use is not evenly distributed across Berkeley's making ecosystem (Fig. 8). Possible reasons for this include a gravitation to larger design hubs or an increased familiarity with the environment training had taken place in. Surveys or ethnographic study could identify the reasons for this divide and help increase awareness and utilization of other makerspaces.

E. CASUAL AND FREQUENT USERS EMERGE AS TWO DISTINCT COMMUNITIES

While the majority of MakerPass holders (83.6%) use the design lounges, CAD workstations, and hand tool workshops in Jacobs Hall, equipment usage is more variable. Most MakerPass users also receive training for entry-level 3D printers (67.9%) and laser cutters (65.6%), but fewer than 20% of users train on other types of equipment (Fig. 9). Furthermore, of those who complete training, only a fraction uses the equipment (Fig. 10). Laser cutters are still the most popular, where 65.1% of trained users continue to use them, resulting in an overall 42.7% activity rate. Few users train on more advanced tools, such as the OMAX water jet cutter and Fortus 3D printer, but even fewer continue to use them. This suggests users who complete training on advanced tools do not necessarily self-select to use the equipment more frequently. Generally, the most in-demand equipment is entry-level, such as 3D printers and laser cutters, which do not require prerequisite training, and often integrate into course curricula[3].

These results suggest the emergence of two major communities of users: many choose to use the space and facilities of Jacobs Hall occasionally, while a smaller group is especially active. For instance, the 42.7% of MakerPass holders who used laser cutters drove utilization to over 90% at the end of Fall 2017. The most active MakerPass users were students who had independently registered, outside the context of classes or research (Fig. 11). This, on the other hand, *could be* described by self-selection, where independent registration potentially reflects an existing intent to use the space for a

[3] http://jacobsinstitute.berkeley.edu/learn/courses/

particular purpose. Confirming this hypothesis and quantifying the goals of regular MakerPass holders is a promising direction for future analysis through surveys or ethnography.

LIMITATIONS

The type of data we analyzed above has several important intrinsic limitations that determine what it *cannot* tell us about a makerspace and its users. Data is seldom clean and complete; it is often noisy, incomplete, and may in fact be misleading. To judge the reliability and explanatory power of the collected data requires careful thinking and observation of data collection in use: do students actually use badge-in systems as intended? Do students show up for the reservations they make? Is there "borrowing" of credentials? Below we list several concrete limitations we are aware of in our own data:

Calendar data is a lower bound: calendar reservations for equipment, such as laser cutters, represents a lower bound of actual use. Many students use equipment without advance reservations. Furthermore, some students prefer to share their reservation time with friends, fitting multiple users into one time slot.

Infrequent card swipes or logins does not guarantee infrequent use: students only badge into equipment, not out, which means *duration* of equipment use is only upper bounded by the next scan. Consequently, swipes cannot measure equipment availability.

Data is only as good as is collected: multiple students can complete work on the same login session on a PC, leading the data to be an underestimate. Users who circumvent the MakerPass system are not reflected in analysis; we have anecdotal evidence that circumvention has taken place, albeit rarely.

One user's activity may represent the interests of many: an individual may use a machine in proxy of a group, e.g., in class projects or extracurricular teams. Since the MakerPass system does not have knowledge of specific individual contexts, the interests of broader stakeholders cannot be measured with card-swipe data alone.

FUTURE WORK AND CONCLUSION

One clear area of future work arises directly from the limitations discussed above: data about people entering a space of starting a session only tells half of the story about actual usage. More precision would be desirable. However, the desire for more accurate usage data has to be balanced with the need to not encumber users with inconvenient or tedious procedures for tracking. One promising approach is to embed data collection directly into machines or spaces, instead of exclusively collecting it through user accounts or student cards. For better estimation of equipment usage, we have started to experiment with wireless sensor networks that record different characteristics such as current flow [11], or vibration and heat [12]. These measurements can be used to infer accurate equipment operating times and duty cycles. They also build bridges to research groups in IoT systems - and we have argued before that makerspaces in research universities should build such connections [13]. To measure room occupancy, we have experimented with a system that tracks Bluetooth MAC addresses of smartphones, which can give a rough estimate[4]. These technologies also come with their own limitations and inaccuracies, which are important to consider within the higher-level goals of collecting data.

In this paper, we have described a series of longitudinal analyses of automatically collected makerspace data. The type of data we analyzed is a by-product of core functions of makerspace administration: training records, access control, and scheduling. We hope other makerspaces will find value in replicating similar analyses. Towards this goal, we conduct our analyses in the popular Jupyter Notebook environment and have open-sourced our code[5].

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