Investigating Lemurs Sensory Modality in Technologies: How do Lemurs Engage with Single and Multimodal Stimuli in Zoos?

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Figure 1: Left: Exterior view of the multi-modal device, with the camera on top, the speakers at the side of the screen, and the olfactory boxes at the bottom. Centre: Two lemurs are triggering the device that is presenting olfactory and visual stimuli. Right: The device and the CCTV camera in the lemurs enclosure.

ABSTRACT

Current computer-based enrichment in zoos is often limited to providing a single-sensory experience, disregarding that animals perceive the world through multiple senses. To address this, we developed and deployed a multi-sensory device for six red ruffed lemurs in a zoo, incorporating visual, auditory, and olfactory stimuli in varying combinations to determine whether multi-sensory or single-sensory engage lemurs more in using the device. The device was deployed in the lemur's enclosure over 63 days, where when a lemur approached the device it would trigger a stimuli combination and record their engagement with the device. Framing our findings with zookeeper interviews, our initial results suggest that lemurs used the device more when it was presenting multi-modal stimuli, rather than a single stimulus. Future research will look further at individual, lemur numbers and specific sense types factors on lemur engagements with multi-sensory systems to investigate how technology can better meet their needs.

CCS CONCEPTS

• **Human-centred computing → User interface design**.

KEYWORDS

animal-computer interaction, red ruffed lemurs, multi-sensory, single-sensory, zoo technology

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1 INTRODUCTION

Red ruffed lemurs (*Varecia rubra*) are critically endangered non-human primates. With only 10,000 red ruffed lemurs left in the world [2, 3, 27] after approximately 80% population decline over the past two decades [2, 3, 27], red ruffed lemurs are increasingly held in zoo habitats for conservation agendas. How to provide enriching experiences for lemurs has been an ongoing challenge in zoo habitats due to limited space and keeper time [22, 39, 44, 45]. Introducing technologies for enrichment has been posed as a way to aid in conservation objectives by jointly increasing lemurs' welfare and our knowledge of how to support lemurs inside and outside of zoo settings [12].

Technologies have become widely implemented in zoos for animals and visitors alike and recognised as effective strategies for enhancing animal enrichment[34, 35]. Technologies used by zoo-housed animals typically focus on providing sensory stimuli to animals such as audio, video, and a combination of both [20]. The stimuli made available to animals aim to enhance their enclosure experiences in a manner that aligns with their biological nature by

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catering to their olfactory, visual, and auditory needs [8, 48, 50, 51]. These systems have been shown to have positive effects on non-human primates, from music devices for gorillas reducing stereotypical behaviours [43], to video screens for white-faced sakis reduced scratching behaviours [19, 21], and olfactory games increasing orangutans movements in their enclosure [52]. Yet zoo enrichment devices currently only employ single-sensory stimuli, which does not align with findings that non-human primates predominantly engage with their environments through multiple senses [36]. Multi-sensory devices have been suggested to provoke quicker behavioural responses in non-human primates [28], though research has been limited in this area.

To assess how multi-sensory stimuli impact red ruffed lemurs' usage of computer-based enrichment devices, we developed and implemented a multi-sensory device at Blair Drummond Safari & Adventure Park specially built for the lemurs and zoos' needs and requirements. The multi-sensory device presented single stimuli (olfactory, audio, and video) or a combination of stimuli (multi-modal) when a lemur was detected in front of the device. Deploying this device in a lemur enclosure over 63 days with six red ruffed lemurs, we analysed how the lemurs engaged with the system. We ask the following research questions:

RQ1: Will red ruffed lemurs use a multi-sensory stimuli device?

RQ2: When presented, are single-sensory or multi-sensory stimuli more engaged with by red ruffed lemurs?

We found the lemurs triggered the device a total of 4021 times for a total duration of 10,732 minutes. From our initial analyses, we found that lemurs significantly use the enclosure space more when the device is present than before the device was introduced, implying the device impacted the lemurs' movements (RQ1). We also found that red ruffed lemurs engaged with multi-sensory stimuli for longer and more frequently than single-sensory stimuli (RQ2).

This study demonstrates that multi-sensory devices have the potential to be more engaging than single-stimuli devices for red ruffed lemurs, and potentially other zoo-housed species. As there is limited work on olfactory technologies for zoo-housed animals, this paper also begins to unpick the complexities of how to build and implement technologies in challenging environments. From this, we contribute a method for deploying olfactory technologies in zoo-housed animal enclosures.

2 LITERATURE REVIEW

In response to the modern zoo's objectives of animal conservation, zoos are increasingly introducing technologies to enhance captive animals' experience in the enclosures [7]. Recent work has demonstrated that augmenting non-human primates' enclosures with technologies has significantly improved the cognitive abilities of various non-human primates [33, 49]. Many of these technology devices focus on presenting information to non-human primates (the computer output) in one modal output, often visual [49] or auditory [30, 41, 50]. Multi-sensory outputs have been shown to activate different areas of primates' brains with many researchers suspecting that the integration of visual, auditory, olfactory, and tactile inputs to the brain serves as a key part of primates' communication and expression [36]. Drawing on the importance of external stimuli for a non-human primate life, some of these technologies' outputs are designed to mimic the animals' wild environments [38]. However, while scientists have increasingly recognised that non-human primates perceive the world through multi-modality ways [11], also referred to as animals unique umwelt [14, 32], many technologies designed for non-human primates in zoos do not offer these versatile experiences.

Visual stimulation is a frequent modality when augmenting non-human primates' enclosures designed to attract their spatial attention[24, 30]. As a visual method, video interaction has been shown to enhance non-human primates' experiences in enclosures [13, 21] by reducing stereotypical behaviours and affecting endocrine aspects as an enrichment tool for example with video games [16, 42]. Colours, shapes, and movement speeds are key elements in video-based visual interaction [26]. Audio stimuli have also long been recognised as a way to augment non-human primates' enclosures [50]. Acoustic research indicates that certain sound features are attention-grabbing for all primates, including humans [5]. Appropriate audio for non-human primates in general aids in focus [6] and has been indicated to have calming effects [23]. For example, Piitulainen and Hirskyj-Douglas employed rain, Zen, traffic, and electronic music in audio equipment for white-faced sakis, suggesting a reduction in white-faced sakis‘ scratching with audio compared to silence [41].

Regarding smell, non-human primates' olfactory organs are more sensitive than humans [52]. While limited research has been conducted for olfactory technologies, zoos use non-technology-based olfactory enrichment to enhance animals' exploration within enclosures and reduce their inactivity [9] such as foraging food puzzles. Of note, Livneh et al. [29] designed an olfactory device for non-human primates capable of releasing various scents finding that olfactory stimulation can increase their food intake. When put together, these studies on non-human primates indicate that visual, auditory, and olfactory single-sensory technologies provide non-human primates in enclosures with varied enrichment experiences [50]. However, non-human primates communicate using multiple signals across various senses, including vision, hearing, touch, and smell[28]. Investigations into the behaviour of non-human primates in response to stimuli in psychological tasks show that their reaction time (RT) is quicker and more effective for multi-sensory stimuli than for single-sensory stimuli [28]. Noting this, Guntuka's [17] developed technology systems that involved multi-sensory stimuli of a box with leaves attached which when moved blinked LED lights and played frog sounds. Employing the device with capuchins' monkeys, Guntuka [17] noted that the monkeys' foraging behaviour increased arguing that the multi-sensory nature of the device improves the quality of their indoor enclosures [17]. However, it remains unknown if a multi-sensory device would enhance a non-human primate's quality of life vs a single-sensory device. With a growing population of lemurs in captivity and increasing decline in the wild, it is imperative to investigate how to support these species.

3 PARTICIPANTS

The participants were six red ruffed lemurs housed together in Blair Drummond Safari & Adventure Park. The lemurs consisted of P1 M, 20 years old; P2 F, 20 years old; P3 F, 6 years old; P4 F, three years old; P5 F, two years old; and P6 M, a one-year-old. To maintain high welfare standards, the zoo keepers, as well as the researchers using the study data, monitored the lemurs' behaviours throughout the study. The lemurs were given a choice to interact or not with the device to maintain their autonomy [31]. We also involved three zoo keepers. Keeper 1, a male, has been responsible for the dietary management and care of red ruffed lemurs for over three years. Keeper 2, a female with 17 years of experience looking after these lemurs, is the supervisor of the red ruffed lemurs' zookeeper team. Keeper 3, also a female, has eight years of experience with lemurs and specialises in their dietary management. Ethical approval was given by the Blair Drummond Safari & Adventure Park Board and the University of Glasgow Veterinary Ethics Board (EA1523).

4 DESIGNING A LEMUR ENRICHMENT SYSTEM

As no prior multi-modal system exists for red ruffed lemurs to develop the device we first surveyed the literature, interviewed the zoo keepers who took care of the lemurs, and measured the lemur's size to determine the size of the device. From this discussion, we uncovered that the keepers wanted the device in the lemurs' outside enclosure and to be relatively autonomous, requiring little maintenance.

The device exterior was built from wood particleboard in the shape of a small box. This material and shape were chosen on the advice of zookeepers for their robustness and ability to withstand the lemurs' gnawing, jumping, and defecation. To enhance durability, a waterproof cover was developed to protect the device from lemur urine and excrement and the weather. The screen and speakers were positioned higher up on the box towards the lemur's eye and ear level (the largest lemur size of 50-55cm), while the olfactory stimuli were positioned on the bottom due to the larger size of the olfactory stimuli boxes to hold the smells.

To detect the lemurs, three infrared sensors (Sharp GP2Y0A02YK0F) were chosen and positioned 10 cm apart in width and 30 cm from the bottom of the device in height to capture a lemur at their thickest body point to increase detection accuracy. As lemurs can not see infrared, this detection was deemed a suitable method for real-time detection without the need for prior training to use the interface. When a lemur was detected, the device's camera (Raspberry Pi Camera Module 3) was activated, recording the interaction, and a random stimulus (either a single sensory stimulus or a combination of the three sensory stimuli) was triggered for as long as a lemur(s) was detected in front of the device. The camera (Tapo C420) is positioned at the top of the device and aligned with the height of the red ruffed lemurs. The screen is a 7-inch screen (Waveshare capacitive touch screen featuring an LCD display and HDMI interface), appropriately sized for lemurs and protected by a polycarbonate plastic smash-proof front. The three odour boxes at the bottom were each controlled to release odour by lifting a panel, and then a fan blew air over the smell to release these from the box through holes made in the front of the device. These holes and their sizes were chosen rather than a fully sliding door to prevent trapped lemur fingers, tongues or noses within the system. Likewise, holes were made in the system in front of the speaker to prevent the lemurs from accessing the technology. The top is equipped with a safety lock.

The device is powered by a Raspberry Pi 3 Model B Board, which was built to be held inside the device, and remotely accessed to reduce the need for the researchers to enter the enclosure while being able to monitor the system's output, status, and other relevant data. The device would loop each stimulus for as long as the lemur was detected. After each trigger, the device sent the interaction time, length, pictures, and videos of the interaction and the stimuli triggered to an online data sheet and stored videos on an online drive. We also recorded the lemur's interactions in context by installing a CCTV camera that we positioned near the device to get an overall view throughout the study. This design ensures an efficient, non-intrusive approach to studying red ruffed lemurs' engagements with the developed technology.

4.1 Visual, Auditory and Olfaction Stimuli Choice

To choose the stimuli, we selected three videos, audio, and olfactory smells. Three stimuli were chosen to enable a balanced experiment design. For red ruffed lemurs, vision plays a significant role in their everyday social behaviours, foraging, and predator avoidance, making their vision a crucial aspect of their sensory experience [46]. Research on lemurs suggests that colours, movement, and content are key elements in attracting their visual attention [1]. To engage red ruffed lemurs, three videos featuring green, blue, yellow, and orange colours were selected based on their dichromatic vision that distinguishes blue and green but is less effective with red [37], and their sensitivity to warm colours like yellow [46]. While little is known about lemur's ability to perceive rapid movements, it is generally thought to be better than humans [4]. With this being unknown, we implemented a 60hz refresh rate as the flicker fusion rate was unknown. Each video was chosen to be 20 seconds long given that prior work on visual interfaces for non-human primates indicates short interaction times [19]. The videos used were; (1) abstract colour videos [1], (2) rose garden videos [2], and (3) fruit videos[3] (Figure 2).

Figure 2: Screenshots of the three videos: On the left abstract videos, middle rose video, and on the right fruit.

Red ruffed lemurs frequently use auditory signals to interact within their groups and warn against predators, making sound a potent medium for capturing their attention [40]. Research on non-human primates' auditory preferences highlights that rhythm and frequency significantly influence their attention [15]. Lemurs in general are particularly attracted to sounds at frequencies ranging from 2000 to 8000 Hz [47]. Given their origin in Madagascar,

[1] Abstract colours https://www.youtube.com/watch?v=cvDrUHCjOVM
[2] Colourful rose garden https://www.youtube.com/watch?v=1jw20R9cVu8
[3] Colourful fruit https://www.youtube.com/watch?v=2FVnHioq4A8

it is hypothesised that they may find natural and African music more appealing [25]. For stimuli, we used the spectral and signal characteristics of three varying audios in terms of frequencies and rhythms: (1) Madagascar waterfall sound accompanied by bird song, within a frequency range of 50Hz to 15000Hz [4], (2) African music within a frequency range of 50Hz to 15000Hz [5], and (3) traffic noise, which spans frequencies from 47Hz to 20000Hz [6]. Each sound was chosen to be 2 minutes long to make the stimulus the same length between modalities and drawing from prior work that suggests typically short (4-second) long interactions when audio is triggered by non-human primates [20].

As no prior research has been conducted on red ruffed lemurs' olfactory preferences or interactions to identify smells to use, we first conducted informal interviews with zookeepers and literature on lemurs' smell preferences. Based on this, odours aligned with the lemurs' dietary habits (flowers and fruit) and those that reside in the natural environment of Madagascar were chosen for testing [53]. Ideally, we would have used synthetic smells, as these last longer than the smell produced by perishable items in a zoo context. To see if the red ruffed lemurs preferred synthetic vs real smells, we presented real and synthetic versions of these to the lemurs in a mesh-covered box with the synthetic smell on cotton pads. For this test, we used fruits (mango, banana, fig, and blueberry) plants (osmanthus, roses, lavender, palm leaves) honey, and vanilla. We presented each box to the whole group of lemurs by placing them on the ground in their enclosure for five minutes and recording their interactions with the boxes to monitor the number of lemurs that smelled each scent and the frequency and duration of their smelling behaviours (Figure 3). To avoid cross-contamination of scents, a minimum of a two-minute interval was taken between tests.

Figure 3: Red ruffed lemurs during the smell testing

The results revealed a stronger attraction of the lemurs to non-artifical smells. Lemurs engage with boxes with real food items inside for an average of 200 seconds at a frequency of 5 times, in contrast to 127 seconds and 2-3 times for synthetic scents. Zookeepers also recommended real smells over simulated ones to minimise potential harm to the lemurs. However, they warned that the real fruits and plants would need to be changed daily to prevent mould. As we wanted to minimise disturbances to the lemurs' habitat through our presence, we tested food-grade dried versions of the above of mango, banana, fig, blueberry, osmanthus, roses, lavender, palm leaves, honey (non-dried), and vanilla. We used the same method as above for comparison. The scents that achieved the highest level of engagement, consistently engaging all six lemurs for over 250 seconds and more than five times, were blueberries, roses, and figs. This was followed by mango, osmanthus, and lavender, which were engaging but only maintained the lemurs' interest for 3-4 minutes. Bananas, honey, palm, and vanilla achieved only one criterion each and were less engaging (Table 1).

	Frequency	Duration	Number
Rose	12 times	255 seconds	6 lemurs
Blueberry	8 times	261 seconds	6 lemurs
Fig	7 time	300 seconds	6 lemurs
Mango	11 time	195 seconds	6 lemurs
Osmanthus	21 times	203 seconds	6 lemurs
banana	6 times	162 seconds	4 lemurs
palm leaf	2 times	66 seconds	3 lemurs
Honey	6 times	193 seconds	4 lemurs
Vanilla	4 time	275 seconds	2 lemurs
Lavender	9 times	202 seconds	6 lemurs

Table 1: Olfactory results of the red ruffed lemur smell test with dried fruits and flowers

5 METHOD

To measure whether red ruffed lemurs would use a sensory stimuli device (RQ1) and whether multi-sensory can engage red ruffed lemurs more than single-sensory (RQ2), we employed the device inside the enclosure using the baseline research method [18]. This method first measures the red ruffed lemurs' interactions with the space where the device was present for seven days, followed by 49 days with the device (28 days multi-sensory and 21 days single-sensory), and then seven days post-study analysis of the lemur's space usage with the device removed. This method allows the effect of the device itself to be measured on the lemurs' space usage. The baseline also helped determine the optimal length for presenting each stimulus to the lemurs depending on how frequently they used the device. During the baseline data collection, the lemurs used the space on average of 69.43 times per day, with an average total interaction duration of 4251.14 seconds per day. Typically, one or two lemurs (average 1.31) were present in the space at any time. Consequently, we changed the stimulus daily, each stimulus mode being active for 24 hours.

There are seven stimuli conditions in the study: (1) video,(2) audio, (3) smell (4) video and audio, (5) video and smell, (6) audio and smell, and (7) video, audio, and smell. To counteract ordering effects and novelty interactions in animal technology studies [21], stimuli are presented in a random order every seven days resulting in 49 days. Overall, this counterbalanced and allows for a long-term study approach that minimises the confounding variables present

[4]Madagascar waterfall sound accompanied by bird song: https://tinyurl.com/muduazvb
[5]African music: https://tinyurl.com/yezcnv69
[6]Traffic noise: https://tinyurl.com/4vwkheus

in zoo environments [49]. After the study was run and the findings analysed, we then interviewed three zoo keepers who cared for the lemurs during the study.

6 DATA ANALYSIS

The 63-day study ran without any system failures. Data comprised of videos and logs of the interactions, CCTV data, and zookeeper interviews. The quantitative analysis involved data cleaning and coding, descriptive statistics, comparison, and analysis. Zookeeper interviews are analysed qualitatively.

For the first stage, the data was cleaned and encoded. In this phase, 4049 data points were collected, each representing a device trigger or lemur present in the zone across the baseline, stimuli, and post-stimuli phases. To clean the data, each of these data points was confirmed to be initiated by a lemur by triangulating the output from the system with the videos from the camera and CCTV recordings. From this process, 28 triggers were removed as they were triggered by the zookeepers doing their everyday duties, such as cleaning the enclosure or putting out food.

In the second stage, SPSS 16.0 was used to conduct descriptive statistics and statistical tests. The analysis of lemur trigger frequency revealed a slight left skew (-0.715) with skewness and kurtosis z-scores of -2.37 and -0.32, respectively but within the normal distribution range. The trigger duration exhibited a right skew with a skewness of 1.272 and a z-score of 4.21, exceeding the normality threshold suggesting non-normal distribution. As a result, the red ruffed lemurs' triggering behaviours across baseline, stimuli, and post-stimuli phases were conducted using ANOVA for the frequency of triggers. Mauchly's Test of Sphericity was not required for either baseline, stimuli, and post-stimuli comparison ($p= 0.753$, $p > 0.05$) or multi-modal vs single stimuli ($\eta^2 = 0.959$, $p=1.000$, $p > 0.05$). When ANOVA detected significant differences, Tukey's HSD (Honestly Significant Difference) test was applied for post-hoc comparisons to identify specific group differences. For the duration of triggers, the Wilcoxon Signed-Rank Test was used. In cases where comparisons involved more than two groups, Holm's correction was applied as needed to adjust for multiple comparisons. The null hypothesis posits no significant variance in trigger frequency and trigger duration in the specific space across these phases (H0).

7 RESULTS

Red ruffed lemurs triggered the sensory device a total of 4021 times; 485 during the baseline, 3264 during the stimuli phase, and 272 during the post-stimuli, averaging 63.83 triggers of the device per day day. The zookeepers observed this device could increase red ruffed lemurs' engagement "The device was quite stimulating for them," (Keeper 1). Keeper 3 also observed behaviour changes "Initially, they were scared of audio stimuli, but other stimuli could attract them. Then they got more used to it and really liked using it.".

7.1 Baseline, Stimuli and Post-stimuli Comparison (RQ1)

Across baseline, stimuli, and post-stimuli phases, there was a variance of triggering behaviours by the lemurs in all three stages ($p= 0.032$, $p < 0.05$) with significant group differences ($F = 4.370$, $p = 0.017$, $p < 0.05$). There were no significant differences in trigger frequency between baseline and stimuli phases ($\eta^2 = 0.851$, $p = 0.956$, $p > 0.05$) and baseline and post-stimuli phases ($\eta^2 = 0.405$, $p = 0.051$, $p > 0.05$). However, a significant difference was noted between stimuli and post-stimuli phases ($\eta^2 = 0.213$, $p = 0.015$, $p < 0.05$). Significant differences were also found between the trigger duration between baseline and stimuli phases ($r = 0.870$, Adj. $p = 0.002$, Adj. $p < 0.05$), baseline and post-stimuli phases ($r = -0.881$, Adj. $p = 0.001$, Adj. $p < 0.05$), and stimuli and post-stimuli phases ($r = -0.875$, Adj. $p = 0.000$, Adj. $p < 0.05$). Thus, the lemurs significantly used the space where the device was less and for shorter periods once the device was removed and used the space more when the device was present stimuli.

7.2 Single Vs. Multi-modal Stimuli (RQ2)

Comparing single-sensory stimuli and multi-sensory stimuli on triggering behaviour, lemurs spent a significantly longer amount of time triggering the system when a multi-sensory stimulus was presented over a single stimulus ($r=0.842$, $p=0.001$, $p < 0.05$). However, the multi-modality did not significantly result in lemurs triggering the device more than a single stimulus ($F=0.146$, $p=0.704$, $p > 0.05$). Reflecting on this, Keeper 2 mentioned that " Lemurs are supposed to use visual and smell in the world to search for food ... so they are really attractive for lemurs rather than one sense."

8 DISCUSSION

This paper focuses on designing a device for red ruffed lemurs to use in zoos, enabling them to trigger audio, visual, smell, or a combination of stimuli. Our results demonstrate that the device increased the red ruffed lemurs' usage of the space where the device was kept in the zoo enclosure (RQ1). Furthermore, lemurs triggered the multi-sensory stimuli for longer periods than single-sensory stimuli, but not more frequently (RQ2).

While the device was used more by lemurs, it remains unclear whether this engagement positively or negatively affects lemurs beyond usage alone. Interviews with the lemurs' zookeepers suggest that their observations of the lemurs' behaviour when using the device may be positive. However, it remains an open question when developing computers for animals how to assess an animal user experience of technology beyond quantitative metrics of usage alone. Part of assessing a non-human animal user experience is to evaluate whether the increased engagement by the sensory device is effective for the lemurs' long term and what lifetime usage would look like for zoo-housed animals.

Looking at our interaction method during the design phase we considered the physical characteristics of lemurs to trigger a device. Given that lemurs have limited fine motor skills with their hands and feet [10], we used infrared sensors rather than physical triggering devices such as buttons. This approach allowed an element of choice by facilitating lemurs not to use the device by moving away or avoiding the area. Yet it remains unknown how much this interaction mechanism fits in with a lemurs perception of the world. Future work could investigate the unique experience of lemurs by looking into further interaction modalities and individual lemurs' device usage. When reflecting on individuality, during the interviews with zookeepers, they mentioned that younger lemurs were more inclined to engage with the device than older lemurs. Factors such as age, personality, and other demographics could provide further clues to deepen findings. Our findings that multi-modality systems engage lemurs more than a single modality are not surprising on reflection as lemurs experience the world through multi-sensory lenses. It would be interesting in the future to explore the importance of crossmodal correspondences, that is the matching between the different stimulus attributes e.g., flower and fruit visual and olfactory, within zoo enrichment devices.

9 CONCLUSION

Lemurs are increasingly becoming endangered, resulting in more lemurs being housed in zoos for conservation and the ongoing challenge of how to meet the lemur's welfare needs and engage them in ongoing tasks in zoos. Toward this aim, we investigated whether a device that presents single and multi-modal stimuli would be triggered more by six red ruffed lemurs housed in a zoo. We built a multi-sensory device that presented audio, visual, and olfactory stimuli and deployed this device for 63 days measuring the lemurs' trigger frequency and trigger duration. We discovered that lemurs engage longer with the device when exposed to multi-sensory stimuli than single-sensory stimuli and use the space in the zoo longer when the device is present. This research begins to look at the effect of multi-modal technologies on non-human primates to align technologies further with their everyday sensory experiences.

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