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Technology-Based Cognitive Enrichment for Animals in Zoos: A Case Study and Lessons Learned

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Abstract

Cognitive enrichment for captive animals is the idea that cognitive stimulation can improve animal welfare. In zoos, cognitive enrichment not only helps the animals themselves but also contributes to zoo missions of educating the public, supporting research, and more. Technology-based cognitive enrichment tools are increasingly popular for a variety of reasons, though they also present unique challenges for design and deployment. In this paper, we present a short review of technology-based cognitive enrichment programs in zoo settings, and then describe the design and development process we used to create a new, touchscreen-based enrichment app for a group of orangutans at Zoo Atlanta. We discuss initial observations about the orangutans' use of this app, as well as lessons learned by our research team.

Keywords: animal-computer interaction (ACI); comparative cognition; interactive technology; user-centered design.

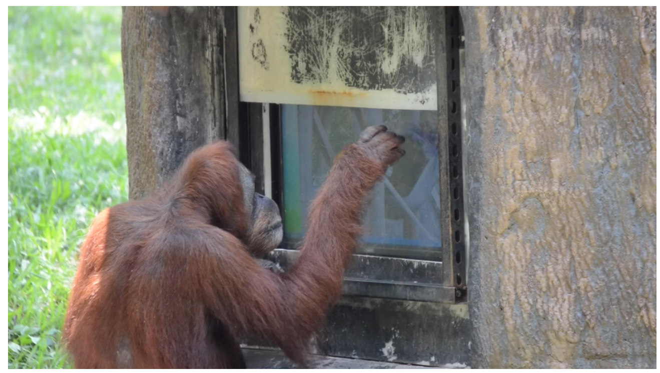

Figure 1: An orangutan uses the video activity in our app on a touchscreen at Zoo Atlanta.

Introduction

Zoos worldwide, which welcome nearly 200 million visitors annually, provide important scientific, economic, and educational benefits to the public through their captive animal care and management programs (*Zoo & Aquarium Statistics*, 2018). These programs are increasingly paying attention to the cognitive health of captive animals, in addition to their physical health, as a critical dimension of animal well-being.

In nature, animals experience many cognitive challenges requiring attention, search, memory, etc., often in situations directly related to their survival. Examples include foraging, reasoning about social dominance relationships, detecting predators/prey, and so on. Many animals in captivity do not experience the same kinds of challenges, since they are guaranteed food, water, territory, safety, and a social group.

Cognitive enrichment for captive animals is the idea that cognitive stimulation can improve animal welfare (Meehan & Mench, 2007), not just in zoos but in other settings as well, such as farm/livestock facilities (Manteuffel, Langbein, & Puppe, 2009). In zoos, cognitive enrichment programs can provide additional benefits beyond those for the animals themselves. Zoos generally have a mission of educating the public about animals, and cognitive enrichment can be both a point of connection with visitors as well as a topic for informal science education, for instance to engage the public around issues of cognitive health, the role of play and challenge in mental development, and more. In addition, zoos are often sites for important research in comparative psychology and anthropology, and cognitive enrichment both helps to maintain a healthy animal population for researchers and also provides platforms for conducting cognitive research.

Cognitive enrichment approaches that use technology are becoming increasingly popular in zoos, and have both advantages and disadvantages. Technology-based enrichment programs often require significant up-front investments in hardware acquisition and software development, especially when compared to non-technology-based enrichment tools like physical toys. However, if designed properly, these technologies can be reusable and extensible for continued enrichment activities, and furthermore, hardware costs for consumer-grade devices are continually decreasing. On the other hand, hardware can often be damaged by animals, technology-based activities may not be "realistic" to animals, and, just as with people, there may be harmful effects from animals spending too much time using screens.

Parallels can be drawn between studying technology usability for animals and for humans. The emerging field of animal-computer interaction (ACI), like human-computer interaction (HCI), emphasizes the development of systematic, user-centered design and evaluation practices for interactive technology applications (Mancini, 2011).

In this paper, we briefly review technology-based cognitive enrichment in zoos, and then describe the design process we used to create a new, touchscreen-based enrichment app for a group of orangutans at Zoo Atlanta. We discuss initial observations about the orangutans' use of this app, as well as lessons learned by our research team.

Cognitive Enrichment Using Touchscreens

In this section, we review and discuss a sampling of previous studies that used technology-based approaches for cognitive enrichment for captive zoo animals, with a focus on touchscreen-based applications.

Cognitive Enrichment Versus Cognitive Research

Many interactive technologies used with captive animals involve applications designed for research purposes. For example, many of the orangutans in our case study in Zoo Atlanta already have experience using touchscreens through cognitive psychology experiments that have studied capabilities like conspecific face recognition, working memory, etc. Often, the goal of a research application is to answer a specific cognitive science question, but the goal of cognitive enrichment is to provide enrichment. Secondarily, enrichment applications may, of course, also provide data that are interesting for cognitive research, but that is not the primary goal.

Thus, while the design of cognitive enrichment applications may be motivated by cognitive observations about a species, the applications themselves may be more open-ended or complex than those developed for research. Training animals to perform a task may also be less important in enrichment, as tasks are often designed to draw upon an animal's intrinsic curiosity and motivation. In this vein, cognitive enrichment applications do not always require the use of food rewards to motivate animals (though some do). Instead, enrichment can provide animals with entertainment, challenges, and a sense of control over their environment.

Research on the effectiveness of cognitive enrichment applications is critical (Weed & ONeill-Wagner, 2015), which brings up questions about how to measure the degree to which an animal is "enriched" by engaging in a set of activities. Usage or participation in the activity is one measure, but generally, the goal for enrichment is to provide benefits of a more holistic kind. Studies have used both qualitative and quantitative measures of observed animal behaviors to estimate different aspects of the overall "well-being" of an animal, such as, for example, reducing stereotypies or aggression, or increasing play behaviors, exploration, or social interaction (Alligood & Leighty, 2015).

Enrichment and Animal Welfare

Negative effects of typical zoo animal environments can stem from limitations in physical space, diversity of activities, lack of problem solving challenges, and even the withdrawal of rewards from previously entrenched reward-based activities. Minor mental challenges like puzzle-solving can therefore be positive for animal welfare, especially if the challenges are at an appropriate difficulty level. Benefits can include reduced anxiety, increased learning abilities, improved physical condition, more resistant immune systems, faster recovery from illness, and less fearfulness in new scenarios.

Although enrichment benefits animals the most when they are provided it from birth, it appears to have measurable benefits even if introduced later (Millar, 2013). Given the limited flexibility of many enrichment strategies, their utility is often limited by a lack of challenge or the inability to provide a lasting sense of control for animals, making them prone to habituation or frustration. Thus, what is needed is not just the introduction of one-off, ad hoc enrichment activities, but rather the development of flexible tools that support continually evolving, diverse enrichment programs.

Touchscreens and other technology-based applications have often been examined with respect to their effects on animal welfare outcomes. In some studies, technology-based enrichment approaches were found to have some aversive effects on animals (Ritvo & MacDonald, 2016; Tarou, Kuhar, Adcock, Bloomsmith, & Maple, 2004; Elder & Menzel, 2001). However, many other studies have found beneficial effects such as reduced negative behaviors like frustration, and more (see examples in Table 1).

Touchscreen applications have several practical advantages. Because digital enrichment can be dynamic and flexible, it can provide a breadth of activities and be customized to the needs of individual animals or groups of animals (Kim-McCormack, Smith, & Behie, 2016; Boostrom, 2013). This makes this technology more resistant to habituation when compared to traditional enrichment. This form of enrichment may also require little-to-no training for the animals. Touchscreen applications can also be useful in situations when animals are unable to be on exhibit because of inclement weather, injury, or group management.

Designing Applications for Non-Human Animals

When considering the design of an application for a different species, the consensus has been to begin with a user-centered approach (Wirman, 2013; Kim-McCormack et al., 2016; Wirman, 2014; Boostrom, 2013; Péron et al., 2012; Dolins, Schweller, & Milne, 2017). In the case of animal users who cannot directly provide input or feedback, zookeepers and other domain experts are critical resources for informing the design of new applications.

Studies have shown that applications with auditory and visual components along with frequent opportunities for touch interaction have been seen to have the highest interaction times overall, and in terms of content in the application, content displaying photorealistic images has been preferred over 2D graphics (Boostrom, 2013; Wirman, 2014). Having an application that provides immediate response to physical action can be rewarding because of the sense of control (Kim-McCormack et al., 2016). When creating graphics that encourage interaction from primates, designers of applications for primates have heavily focused on small details, such as thickness of borders around content, decisions about colors that will stand out against a background, the sizes of graphics, and more (Péron et al., 2012; Dolins et al., 2017; Wirman, 2013, 2014). One such program that focused on graphics presented to four chimpanzees a simple training regimen with thick, wide green borders along the four sides of a square against a black background (Dolins et al., 2017).

Designers have also considered the touchscreen itself, in-

Table 1: A sampling of the literature on technology-based cognitive enrichment for captive animals.

Reference	Species	# Individuals	Technology	Frequency/Duration	General Findings
Boostrom, 2013	Orangutans	16	iPad	5 min sessions at least twice per month per individual, over a span of 6 months.	There was varying interest in the iPad among the groups, with all groups showing a preference for brightly colored applications that also provided auditory stimulation.
Elder & Menzel, 2001	Orangutans	1	Computer with joystick	33 test days over a total study period of 90 days.	Extended periods of delay between trials induced signs of frustration, but stress was not induced by task performance.
Gray et al., 2018	Gorillas	7	Objects with IoT	Two 60-minute sessions.	Technology can help us learn about and tailor playful experiences for gorillas.
Martin & Shumaker, 2018	Orangutans	12	Touchscreen	Single 20 min session.	The versatility and programmability of computers tasks makes them an ideal platform for achieving functionally naturalistic outcomes for great apes.
Millar, 2013	Pigeons, dogs	16, 58	iPad	10-min sessions for 10 days (pigeons). Various number of 10-min sessions (dogs).	Both cognitive and physical enrichment were found to reduce agonistic behaviour and increase alertness.
Mueller-Paul et al., 2014	Tortoises	4	Touchscreen	Tested five days a week from 9 am to 5 pm.	Red-footed tortoises could operate a touchscreen and solve a spatial task.
Perdue et al., 2012	Orangutans	4	Touchscreen	Random 30-minute observation periods.	Touchscreen technology had no negative effects on the animals.
Péron et al., 2012	Parrots	3	Touchscreen	Always available; each piece of music lasted 90 seconds when played.	Music can be used as an environmental enrichment for captive parrots, and musical preferences seemed to be influenced by personality.
Ritvo & MacDonald, 2016	Orangutans	3	Touchscreen	30-60 min sessions, once per day for 3-4 days per week.	Musical stimuli were not reinforcing; use of music as enrichment may be more aversive than enriching for some species.
Scheel, 2018	Orangutans	11	Touchscreen	There were 10 random observations sessions.	Overall, the orangutans appeared to have enjoyed the touchscreen.
Schmitt, 2018	Gorillas, chimps, orangutans	5, 4, 4	Touchscreen	Available about 45 minutes per day, 3 to 5 times per week.	The ZACI system proved to be highly applicable for work with zoo-housed primates.
Tarou et al., 2004, Mallavarapu et al., 2013	Orangutans	8	Computer with joystick	1 hour sessions, for a total of 240 hours.	Behavioral changes associated with the computer included increases in aggressive behavior and more. The lack of habituation by frequent users indicates that computer-assisted tasks may be useful environmental enrichment for orangutans.
Wirman, 2012, 2013, 2014	Orangutans	2	Tablet-based touchscreen	Random, short durations of play with the touchscreen.	Digital play allows a form of communication that eliminates some obstacles and creates new ways for togetherness in play.

cluding viewing angle, software and hardware specs, and input mechanisms (Wirman, 2014), as well as expected physical usage. For example, orangutans often sit in an upright position to use a touchscreen, similar to human behavior.

Just as with the design of technologies for people, design for non-human animals requires significant creativity and imagination on the designers' part. Furthermore, non-human animals may interact with applications in unexpected ways, despite a designer's best-laid plans. Thus, early prototyping and "user testing" is key.

Our Case Study

We developed an enrichment application intended for use by the eleven orangutans (age 3-48 years) at Zoo Atlanta in Atlanta, GA, USA.

The zoo that our team worked with has an existing, somewhat unique technology installation in one of their open-air orangutan enclosures: an artificial "tree" (fiberglass, etc.) that has a touch-screen monitor built into one face, and houses a desktop computer inside (see Figure 2). The intent of this installation was to provide a platform for cognitive enrichment for the orangutans that could be used in a relatively unstructured way. The tree had previously been loaded with applications designed for comparative psychology research.

In conversations with our team, zookeepers stated their desire for a new "app" for the tree that would: 1) be easy enough for the orangutans to use without oversight from staff members; and 2) be engaging enough for the orangutans that they might choose to use it without extrinsic rewards (e.g., food).

In addition to these criteria, we added two more from the software development side: 3) be easily extensible by zookeepers to add/modify content to individual app activities; and 4) be modular and thus easily extensible by future developers to add/modify individual activities within the app.

Figure 2: "Learning Tree" touchscreen installation.

App Design and Development

Through many discussions with four zookeepers over a period of two and a half years, we designed a cognitive enrichment application that consisted of an "activity chooser" home screen, from which the orangutans would be able to select individual activities to engage in. Initially, we designed three modular activities to populate the system: 1) a video player activity, 2) a visual puzzle activity, and 3) a musical instruments activity.

A primary concern throughout the design process was aiming to ensure that the interface and individual activities would be simple enough for use by the orangutans. Often, such enrichment app designs overestimate the level of complexity that animals can understand in terms of interface and task design. In conversations with other zoos that attempted similar technology-based enrichment efforts with non-human primates, we learned that **simplicity** of the interface and **familiarity** of the elements presented to animals were both important design factors to keep in mind (McAuliffe, 2017).

Home screen. As illustrated in Figure 3 (left), the application's home screen holds an array of orangutan images, and a vertical green home button. Contrary to many common formats of reward-based applications, where the orangutans have to figure out where to press or what to do in order to get food, this design seeks to draw the animal's attention by showing them images they will recognize: familiar orangutans from their own social group. Research has shown that orangutans, while not among the most social of non-human primates, still do show fairly robust conspecific (e.g. within-species) visual recognition of familiar faces (Hanazuka et al., 2013; Talbot et al., 2015). Each cell with an orangutan image leads to one of three different activities.

The home button appears on all screens of the app and will always return the orangutan to the original home screen. The button appearance was not designed arbitrarily; the green gradient was featured in the home buttons of other reward-based applications that the orangutans had already been using. As a result, the familiar pattern attempts to give the orangutans visual clues about the button's function.

Video player activity. The first of the activities is illustrated in Figure 3 (right side, top row). Pressing any of four brightly colored boxes triggers a short video clip (15-30 seconds) of one of the zoo's orangutans, taken from the zoo's existing store of videos. The layout was designed to be simple and visually distinguishable from the other screens. Again, zookeepers thought that showing videos of individuals familiar to the orangutans would be engaging.

Visual puzzle activity. The second activity is the simple visual puzzle illustrated in Figure 3 (right side, middle row). We wanted to create an activity a bit more challenging than the passive-viewing video player activity, but also simple enough to be solvable by most of the orangutans fairly quickly, especially in their initial exposure to the app.

Thus, we created a design in which puzzle "pieces" of an image are shown around the perimeter of the screen, with a target grid in the middle. Pressing any of the puzzle pieces prompts the piece to move on its own to the correct grid location, greatly reducing the difficulty of the task while also providing some visual interest. Once all four pieces have been pressed and are in position, the completed image then plays as a video (puzzle images are taken from the first frames of video clips), providing a type of "visual reward" for completing the puzzle. As with the previous screens, images were chosen from the zoo's stock of photographs of their own orangutans, to facilitate interest through familiarity.

Musical instruments activity. Finally, as illustrated in Figure 3 (right side, bottom row), we created an activity that displays an array of eight different musical instruments which play an audio clip (1-30 sec) of their corresponding sound when pressed. While the recording is playing, the selected instrument icon also oscillates in place to emphasize the connection between the button and the sound.

Previously cited research suggests that musical stimuli is not reinforcing as orangutan enrichment, but we believed that research on musical enrichment is minimal enough to explore further. Additional cited research proposes that orangutans tend to be more interested in photorealistic images than graphics, but through conversations with zoo researchers, we concluded that this information is not as essential for images of instruments as it is for images and videos of orangutans contained in the other activities.

Modularity of design. Though our design choices primarily strive to achieve simplicity of use, it is also important to keep activities somewhat novel when designing for orangutans in order to prevent boredom and frustration (Wirman, 2013). Therefore, one important aspect of modular design in our app relates to the video content used for the video player activity and for the visual puzzle activity. Videos are drawn from a specific folder, and zookeepers can easily change the available videos by adding or removing video files from the library. In addition, the image/video used for

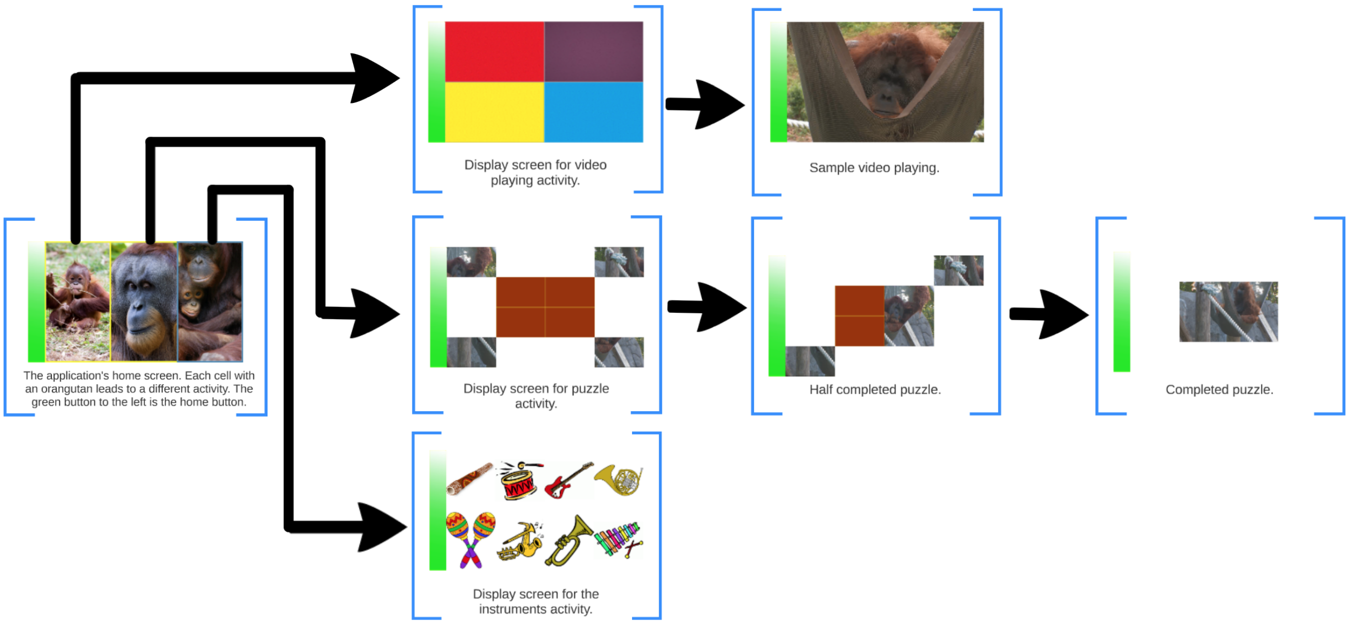

Figure 3: Flow diagram of the touchscreen-based application we designed to provide cognitive enrichment for orangutans.

the puzzle activity is randomly chosen from this store, to add some novelty to that activity over repeated sessions.

Because some orangutans become familiar with touch-screen activities faster than others, the goal was to design activities that were, on average, challenging, but not frustrating. Thus, an expectation was that some orangutans would learn activities more quickly than others, and that many orangutans would continue to perceive activities as novel for a substantial amount of time.

One other modular design choice is that each individual activity resides in its own "container." Thus, activities can be added or swapped in a relatively straightforward fashion. In conversations with zookeepers, one common issue with enrichment apps seems to be the lack of ease of extensibility, especially given that it is often difficult to access software developers to work on extensions or modifications.

Finally, log files are saved from each session and hold a timestamped record of every activity performed in the app. The information in these logs is valuable for understanding orangutan usage patterns, and perhaps inferring measures of orangutan amusement and satisfaction, as potentially important components of overall cognitive enrichment.

Ideally, additional data would be collected to establish a durable record of which individual orangutans were using the app at various times. For example, we discussed with zookeepers the potential value of having a webcam-like setup that would record video of the orangutan user every time the app was activated. Such a video would provide not only identifying information about users but potentially also information on the user's affect and engagement levels. However, due to logistical constraints, we were not able to deploy such a setup. As a result, our log files record usage but not which individual or individuals were using the app.

Observations and Lessons Learned

Initial deployment of the app with the group of orangutans at the zoo seems to show many positive signs. Based on our team's qualitative observations of the orangutans, they seemed curious and interested in what was happening on the touch screen, often rushing over in a group to see what was happening when zookeepers opened the app on the learning tree computer. Several individual orangutans were also observed at various times interacting with the app for moderately lengthy durations.

Figure 4 shows ten examples of orangutan interactions with the app, as recorded in the system logs. These ten sessions, shown on the y-axis in no particular order, were chosen from the full set of log data to show a sampling of interaction patterns that were observed. The x-axis shows time across a duration of about 24 minutes, measured from the first touch screen press that was recorded by the app during a given session.

Clearly, there is a lot of variability in usage. Sometimes (e.g., logs 2, 8, and 9), there is some initial activity that quickly tails off within a minute or two. Other sessions show much more sustained activity. The orangutans seem to have accessed each of the app's activities more than once, though the extent to which they are purposefully navigating through the app, versus just pushing various buttons, is an open question. More detailed analyses of such log files will be an important part of our future work.

In addition to the log data, we also discuss, in qualitative terms, two episodes of interaction that were particularly noteworthy. First, one of the most interesting moments occurred when Madu, a female orangutan in her 30s, was viewing videos through the video player activity. (The image in Fig-

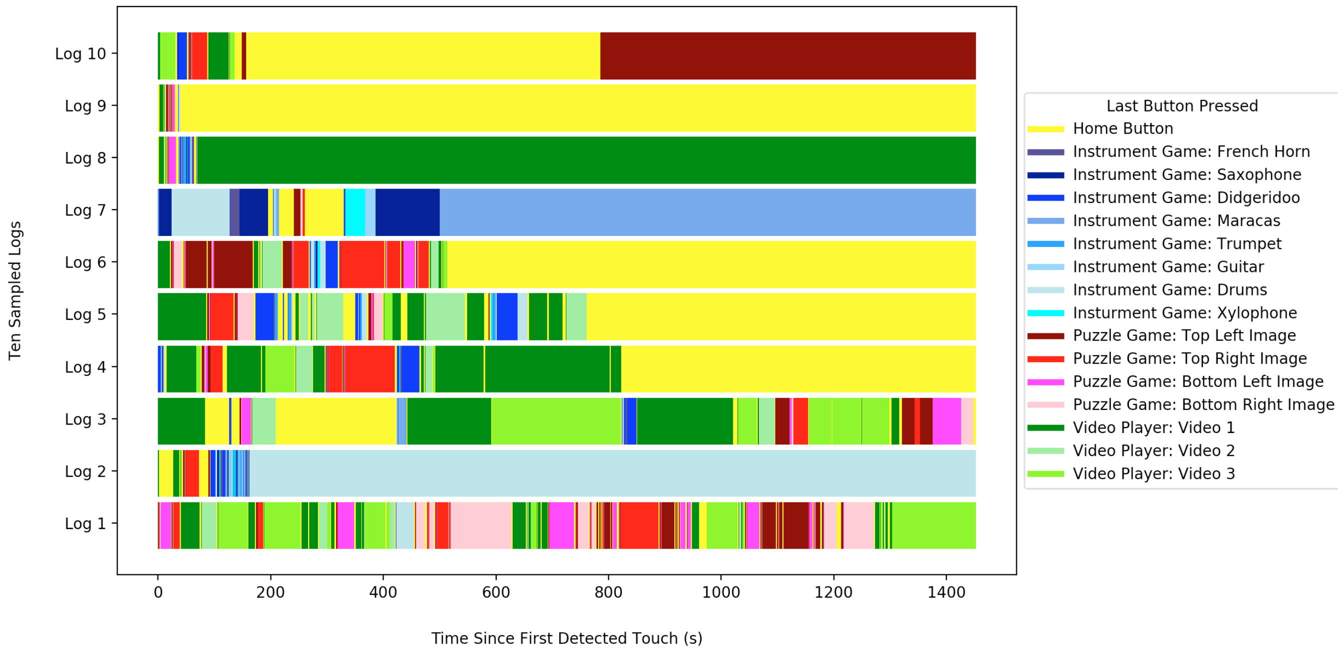

Figure 4: Sampling of app log data from 10 different interaction sessions (y-axis) across time, as measured from first touch screen press (x-axis).

ure 1 is a still from this episode.) She encounters a video of Alan, an older male orangutan who had passed away nearly four years earlier. Madu is visibly transfixed for 20 long seconds, and then tries to interact further by touching his figure in the video several times. Of course, we do not know for sure what was going on in Madu's mind at the time, but at least to the zookeepers who know her best, it seemed like she was remembering her old habitat neighbor. Note that we did not include videos of Alan on purpose; we were simply pulling from the zoo's stock of orangutan videos. However, this incident does seem to support the idea that familiar stimuli can be uniquely engaging to orangutans, even (or perhaps especially) in the case of dearly departed old friends.

Another time, one of the orangutans was interacting with the app and seemed to be searching for a food reward, looking up at the feeder mechanism on the tree (used in other, reward-based applications), tapping on the tree, and even banging on the touchscreen with a fist. The orangutan appeared to be quite frustrated at the absence of a food reward! Despite this episode, however, several of the orangutans at other times did find the app interesting enough to be worth engagement, even without food rewards. This raises interesting questions about the longer-term impacts on learning and motivation of using food rewards to stimulate certain behaviors.

We conclude with three takeaway lessons from our case study of cognitive enrichment for captive orangutans.

Familiarity of stimuli. The use of photos and videos of familiar orangutans did seem to support interest and engagement in the orangutans using our app. Further evaluations of this principle would be extremely valuable for cognitive enrichment programs in general, including at other zoos, with other species, and in a variety of enrichment activities.

Modularity in design. The modular design that we implemented, especially in terms of enabling zookeepers to easily swap out image/video content without requiring any programming skills, seems to be a promising approach to enable technology-based enrichment activities to be modifiable. Studies of orangutan engagement over time will be informative, and we expect that the ability to regularly change app content will keep the novelty factor up.

Engagement with the public. There is continued debate on the pros and cons of adding technology to the daily experiences of zoo animals, not only with respect to the animals themselves but also with respect to the public education missions that most zoos have. Is it really teaching the public the right ideas about wildlife to show orangutans playing "video games?" There is no easy answer to this question, but Zoo Atlanta has aimed to strike a balance by establishing a "naturalistic" setting for their technology-based enrichment—the learning tree shown in Figure 2.

These applications can also serve to teach the public about the cognitive health of captive animals, and to showcase joint efforts by zookeepers and researchers to ensure that animals have a stimulating cognitive environment. The "coolness" factor of technology-based interventions may provide positive benefits for engaging the public (Perdue et al., 2012); for example, the video of the Madu-Alan episode described above was viewed on the zoo's social media page over 15 thousand times. In addition to media influence, zoo visitors can participate in weekly zookeeper-led showcases of the orangutans using the touchscreen in their exhibit, through which they have the opportunity to ask questions about orangutan behavior with the touchscreen and view real-time touchscreen interactions on an additional screen display that is located just outside the enclosure.

In summary, while non-technological cognitive enrichment activities also have their place, we expect that technology-based interventions will continue to provide valuable contributions for the study and care of captive zoo animals, as well as for basic research in cognitive science.

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