A Vending Machine for Crows

By Joshua Klein

New York University, Interactive Telecommunications Program
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Thesis Statement

As human beings continue to expand our habitats over more and more of the earth's surface we are forcing other species to either adapt to us or die. Some species adapt better than others; crows are one of them. But rather than embracing these adaptations we tend to either domesticate or decimate these co-evolving species. I would ask if instead we can implement mutually beneficial systems for us both.

Crows are an unusually good candidate for this; they are highly intelligent, culturally adaptive, increasingly prolific, and can learn from each other. With no human interference it should be possible to create an interface for exchange in which both the crows and humans benefit, without domestication or its associative costs. This document explains how.

Personal Statement

As the dominant species human beings are faced with making a choice as to how they co-evolve with the rest of this planet's inhabitants. To date we have done poor work of it, allowing our rapidly increasing models of consumption to overtake and destroy the habitats of thousands of species. Unfortunately, many opponents to these economies would have us simply cease civilizations' progress, as though going back in time or freezing our technological and social advances would solve the problem. What I propose is something altogether different: rather than rescinding the fruits of our society's labor I suggest that we find ways to enable cultural co-evolution with the species we have displaced.

This is not always possible - it is unlikely, for example, that we could find an immediate or mutually satisfying way to profit with the bog turtle, for example. Instead, the concept of cultural co-evolution is a realistic approach to mitigating the damage of our choices as a species by regarding wild animals as separate and worthwhile species in their own right. By creating symbiotic systems we encourage the examination of this conflict from the affected species' point of view, and in turn create a more balanced and holistic understanding of the ecosystems we affect. This allows us to make better long choices for everyone involved. In the process we create cycles of profit, for both species.

Background

Corvids (the family including crows, ravens, jays, and other passerine birds) represent an unusual example of both biological and cultural adaptation in response to the selective pressures human beings have put on them. The relationship between humans and corvids of different types goes back thousands of years, and they feature prominently in our history, arts, and literature as heroes, tricksters, and occasionally as gods.

In modern times crows are largely regarded as vermin, along with most other synanthropic, hyper-adapted species such as rats, cockroaches, and pigeons. However, unlike these other species crows have developed an unusually flexible set of urban-specific adaptations including cultural evolution, logical and deductive thought, and learning transmission. These adaptations make them extremely good candidates for cooperative systems in that they can learn complex behaviors without human intervention and can teach those skills to each other. Moreover, corvids are found everywhere on the planet except for the southernmost tip of South America and the ice caps on the poles. (Clayton and Emery, 2002) When you couple this with their prolific breeding patterns (which are increasing worldwide as a result of urbanization (Marzluff, et all, 2001), high mobility (crows often migrate thousands of miles), and cognitive flexibility you have a highly significant labor force.

The alternative to finding some sort of employ for this species is a long, costly, and difficult genocide: crows have become hyper-adapted to human civilization by feeding off our waste, and unless we undertook making that waste completely unavailable to them (a nearly impossible task given their intelligence) we need to consider how to manage their growing populations. The first big step towards doing so is to understand their significance and impact on the habitats we have created.

A vending machine for crows is a solid candidate for addressing these topics. For humans, it hits a sweet spot that's easy to relate to - it brings up feelings about money and hunger that every human has. It's also autonomous - it doesn't create an artificial relationship between crows and humans. As such it skirts issues of anthropomorphism and allows crows to exist as wild animals connecting to the human world through an objectified interface. Thus, while we can easily relate to crows' excitement over finding a coin and take pleasure in their happiness over exchanging it for a peanut, there is little temptation to wander over and chat while they complete their transaction - the crow would flee as surely and with as much fear as any wild animal. Additionally, the device generates fungible revenue for human beings - revenue which is otherwise lost as a cost to their economy. By generating a profit the device emphasizes the larger system in which both humans and crows are participating, and does so in terms of economics all human beings are intimately familiar with.

For crows, the vending machine is an easily-learned, reliable food resource with little competition from other species as they are one of few that can learn to use it. Additionally, peanuts are a nutritious (more so than leftover McDonald's garbage), easily cached food which can be kept for later times when resources are low. The machine has the added benefit of encouraging crow's cultural adaptations and providing a clear window into their societies. From it we can learn how they transmit learning from parent to young, and within and across groups. It has the potential to illuminate the boundaries and extent of their intelligence and to provide a clearer understanding of nonhuman logic and deductive reasoning - particularly given their different brain structures. Finally, it is not unhopeful to say that the crow vending machine might provide some groundwork for other sustainable and symbiotic systems.

Reasoning

Crows are unusually good candidates for the use of a vending machine. Their increasing populations, cultural adaptations, logical and deductive reasoning abilities, their teaching and learning mechanisms, and their social structures all conspire to create an unusually adaptive and clever animal. Aside from primates, there are few species with the particular skill sets present in crows. We will discuss these factors below, beginning with the first reason humans have to notice crows – there's lots of them.

Population

The question of crow populations relies on the human. Human beings continue to expand over existing ecosystems the world over - according to United Nations estimates, by 2050 the urban population worldwide will equal today's existing population of roughly 6.5 billion people. (United Nations, 1996) Furthermore, this growing urbanization is typically found in close proximity to large cities, (Alberti et all, 2001) with continuing human population growth further increasing the number and size of urban centers and sprawl all over the world. (Donnelly, Marzluff, 2004) Because of increasing urbanization and the ongoing shift from rural regions to urban centers, the urban population multiplied tenfold this last century alone. (Marzluff, et all, 2001) Human expansion in Seattle's metropolitan areas, for example, are expected to grow 40% in the next 30 years, converting forests into suburbs and suburbs into urban areas. In developed countries the trend for development is towards suburban or exurban growth, causing a strong gradient of human density. This urbanization has become the second most frequently cited cause of species endangerment in the United States, and is a major reason for the rapidly increasing crow population. (Czech, Krausman. 1997). By "suburban" we used McGowan's definition of territories comprised of more than 75% residential or commercial use. (McGowan, 2001) As this growth occurs, synanthropic species (species which can cohabitate well with humans) such as crows continue to increase in numbers while other species die off. (Donnelly, Marzluff, 2002)

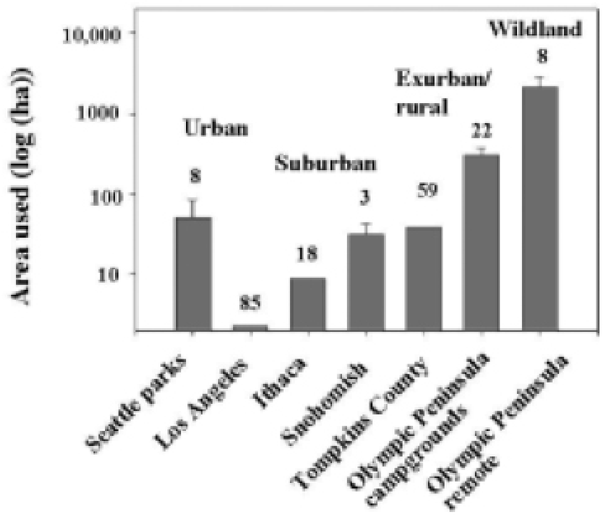
Bird communities in urban environment are much less diverse than in comparable rural and urban areas. This is primarily because the habitat no longer meets some species' requirements and some species are unable to exploit the humans who have displaced previously available resources. (Marzluff, et all, 2001) Similarly, bird populations are strongly effected by factors such as nest predators, brood parasitism, and the availability of food - all factors which change rapidly in the transition from wild or rural to suburban and urban environments. (Donnelly and Marzluff, 2004) This urbanizations changes normal selective pressures to favor very different characteristics than those found in the wild. Species that can exploit urban environments will have more dense and stable populations than those which cannot. (Beissinger and Osborne, 1982) Many corvid populations (such as magpies, jays, and crows, for example), are human commensals whose populations are increasing worldwide as a result of their ability to exploit human food resources. (Konstantinov and Gabenko, 1982) In fact, American crows (the most common type of crow in the U.S.) typically breed no more than 5km from humans, (Johnston, 2001) and have been expanding their populations significantly across the US continent. (Sauer, et all, 1999)

Part of this is because suburban environments provide lawns rich in earthworms and light forest-field areas with many suitable invertebrates for consumption. (McGowan, 2001) The bigger part of the increase, however, is because of the migration of crows from rural and suburban habitats to urban ones. As we will show, crows are more likely to breed in larger numbers in the suburbs – but those crows are tending to move into the cities, where they are establishing denser communities. This migratory pattern is perfectly suited to exploiting the ongoing habitat expansions being conducted by human beings by using the suburbs as rich breeding grounds, thus rapidly increasing overall crow numbers by shifting the young to higher density urban environments.

There are many reasons for this. For example, one advantage presented by urban and suburban areas is that there is typically a prohibition on shooting in urban areas. This reduced persecution allows crows to take advantage of the small stands of trees from which to keep watch as well as a higher general warmth presented by cities. (Knight et all 1987) Similarly, urban and suburban areas also typically have less overall predators. For example, urban and suburban areas in Syracuse, New York had approximately one third as many Red-tailed Hawk and Great Horned Owl nests as in rural areas. (Minor and Ingraldi, 1993) Suburban environments are also a better place to rear their young. According to McGowan, suburban nests had more nest success than rural nests. (McGowan, 2001)

Finally, in areas of crow habitation far from human populations crows typically require much larger areas for foraging, which likely limits population size. In other words, when looking for a territory to co-opt, cities present a much wider range of options. (Marzluff et all, 2001)

According to Marzluff, urban crows may need only 10% of their former space for breeding, (Marzluff et all, 2001) and even suburban crows have smaller territories more closely placed to each other. (McGowan, 2001) For example, crows in suburban areas defended territories roughly 8.7 ha in size as opposed to 37.7 ha in rural areas. Furthermore, in suburban areas nesting density was higher at 11.5 territories per square kilometer vs. 2.6 territories per square kilometer in rural areas. (McGowan, 2001)



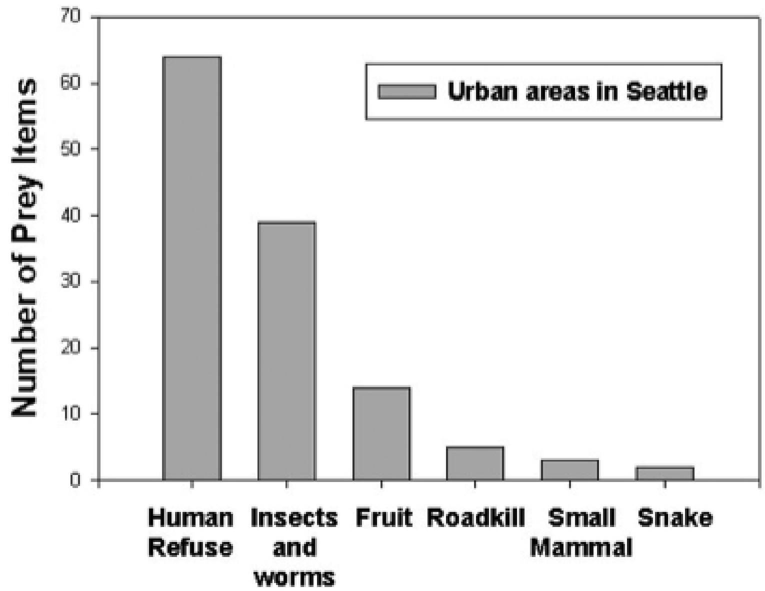
From Marzluff, et all. 2001: Causes and consequences of expanding American Crow populations

Interestingly, reproduction (and thereby population growth) is highest in suburban and rural areas - it appears that surplus crows from suburban and rural areas are moving into urban settings where human foods are easily obtained and highly concentrated. This is possible due to crow sociality and cultural adaptation - i.e., urban crows have adapted in surprisingly few generations to living in close quarters in cities. In this way, crows' social systems may be especially conducive to expanding urban populations. (Marzluff and Angell, 2005)

Additionally, crows tend to stay in habitats similar to those they were raised in. As McGowan says, "Birds raised in one habitat tended to breed in the same habitat." Still, within those habitats crows are free to range fairly widely in search of available territories - a crows may make its next as little as 76 meters or farther than 65km from where it was hatched. (McGowan, 1996) This frees crow populations to expand flexibly, moving into territories as they become available whether they be near or far.

This is not to say suburban and urban environments are optimal for crows. For one thing, suburban crows typically had higher nest successes, but fewer and smaller young than in rural and wild environments. In other words, they had nests with young more often, but less and smaller young when they did. On the other hand, their survival rates are higher than that of rural crows. (McGowan, 2001) This is particularly true in young crows (from hatching until fledging); after their first year annual survival rates were roughly the same in both areas. This pattern of fewer and smaller young in urban and suburban nests may be due to the lower quality of food in urban as opposed to rural areas. (McGowan, 2001)

In Seattle, for example, 65% of crows' diet was of human refuse, as opposed to crows on the Olympic Peninsula whose diets consisted of roughly 35% human refuse regardless of how far they lived from small settlements and recreation areas. (Marzluff et all, 2001)



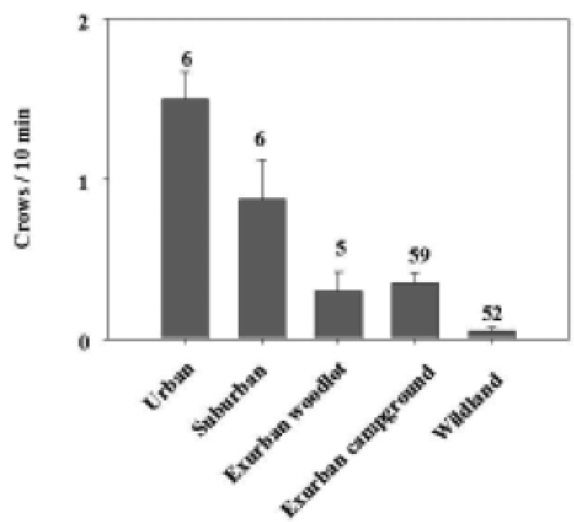
From Marzluff, et all. 2001: Causes and consequences of expanding American Crow populations

Unfortunately, while human refuse is an abundant food source it has much less nutritional value than food sources found in the wild such as invertebrates, insects, etc. It is interesting to note that crows from wild areas were observed flying tens of kilometers to reach human food sources - so although human food is not as good for them, it is strongly preferred. (Marzluff et all, 2001)

Another important aspect of suburban and urban environments is that food availability for suburban crows may be less predictable. McGowan has found that suburban food sources are less reliable than rural sources, making suburban and urban crows more susceptible to drought and similar environmental costs. (McGowan, 2001) Finally, there are many predators such as raccoons, gray squirrels, and red-tailed haws who have adapted well to human habitation and are similarly supported by human refuse and environmental conditions.

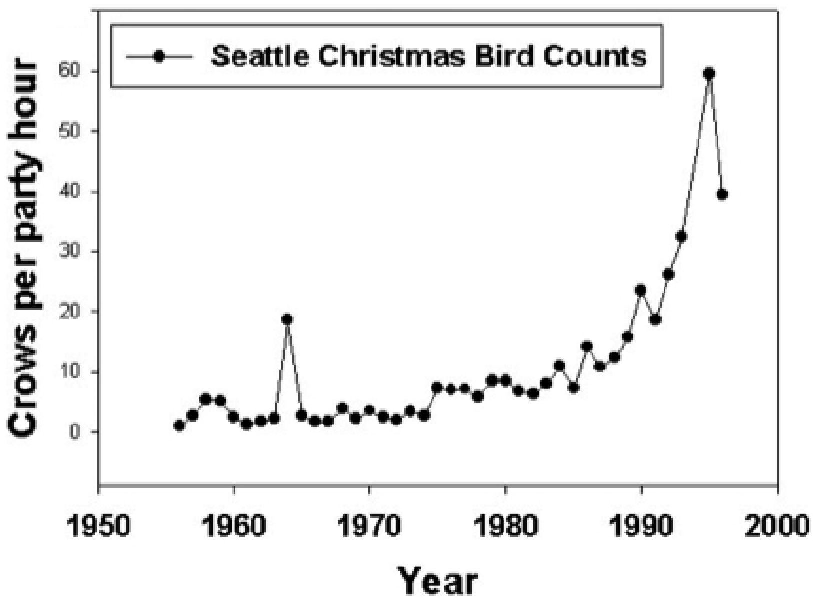
Finally, urban environments have their own special dangers, with many unnatural hazards such as windows, car collisions, and high concentrations of toxins. As Marzluff says, "Urban environments are rapidly changing, challenging places for any animal to inhabit. The adaptability of crows is impressive, but appears to be just adequate to keep pace with the urban fast lane." (Marzluff et all, 2001)

Despite these obstacles young crows raised in suburban areas continue to contribute to the growth of original and expanding urban populations. Because of this migration into cities, U.S. crow populations are increasing in urban areas but remaining basically constant in exurban and fully wild areas. This trend has been verified over the last 40 years. For example, in one study by Marzluff he found that urban areas had approximately 30 times greater crow abundance than in wild lands. (Marzluff et all, 2001)



From Marzluff, et all. 2001: Causes and consequences of expanding American Crow populations

Interestingly, demographic models of crow population growth estimate that urban populations should grow slowly, at rates less than 5% per year, but that suburban crow populations may support rapid population increases. Instead, we see suburban and rural populations growing as expected, exurban and wild populations remaining small and stable, and bird counts in urban areas suggesting exponentially increasing populations. (Marzluff et all, 2001)



From Marzluff, et all. 2001: Causes and consequences of expanding American Crow populations

We haven't seen that in recent years because of the West Nile Virus, which appears to be falling back in terms of causes of crow mortality. If that's the case, then according to Marzluff's estimates urban environments could support as many as 6.5 crows per city block (See Note:1), and we could exceed that carrying capacity in only 35 years. (Marzluff et all, 2001) That's a lot of crows.

Intelligence

So we have a lot of crows and are going to be having a lot more. That doesn't mean they're the best candidate for vending machines – we also have lots of pigeons in the world. Instead, what really distinguishes crows as potential synanthropic co-evolutionaries is their intelligence. Crows (and corvids in general) demonstrate some of the highest level of logical thinking and deductive reasoning seen in any non-primate species. In many ways their intelligence rivals, or even exceeds, that of the great apes. (Heinrich and Bugnyar, 2007) (In fact, their brains are proportionally the same size as the chimpanzee brain.)

For example, most corvids cache food for later, and nutcrackers have been proven to be able to remember literally thousands of such food cache locations – a task well beyond the average chimp. Similarly, in laboratory tests crows have demonstrated spontaneous tool creation to obtain food, such as by the now semi-famous New Caledonian crow "Betty" who, completely unprompted, fashioned a hook out of a piece of wire to reach a piece of meat in a tube. (Kacelnik et all, 2006)

In Sendai City in Japan crows have learned to drop nuts onto pedestrian crosswalks and then wait until the lights turn red to collect the bits crushed by cars. In another case, rooks in England discovered that two birds together can pull the garbage can bag from the outside to dislodge its contents onto the ground. (Clayton and Emery, 2002) In one scientific experiment, a German ethnologist named Otto Koehler taught a raven to count to six by allowing it to match the number of objects presented with the number of marks on the lids of some containers; if it opened the correct box it would obtain a food reward. (Savage, 1995)

Much study has been given over in recent years to determining if these abilities are innate (biologically determined), or if they are learned. A recent study by Bernd Heinrich discovered that in a laboratory setting some ravens would study cognitively demanding situations for as little as 30 seconds before correctly performing a complex, multi-step solution on the first try. (Heinrich and Bugnyar, 2007). This was further tested when Bernd and Bugnyar tied a piece of meat to a string. In some tests they tied the other end of the string to perch, and in others they simply let it hang on the perch. When the birds had pulled the meat up to the perch they scared them off. In those cases where the string was tied to the perch the birds dropped the meat – in those cases where it was not, they kept the meat and flew off with it. This demonstrates that the ravens had a mental model of the situation and could act on it – a rare feat in the animal world.

One of the biggest breakthroughs in the study of corvids intelligence (and part of the reason behind the recent upswell in research in this area) is due to something called "a theory of mind." A theory of mind is the understanding that other beings also have thought and knowledge, and that ones behavior can be adjusted to account for the knowledge and thought of said other beings. (Prior and Güntürkün, 2005)

To give an example, if crow A were to hide a nut under a clump of grass and notice that crow B had seen it do so, then crow A would know that crow B knew where the nut was and would be likely to steal it as soon as crow A left. (Daily et all, 2005) As a result, crows engage in copious feinting and hiding behaviors when caching foods within sight of other crows. What's interesting about this is that until 2005 it was largely assumed that only primates had a theory of mind. That's when Dr. Nikki Clayton of Cambridge University presented at the Ethological Conference in Hungary, demonstrating in a well-regarded study that corvids also have a theory of mind. (Daily et all, 2005)

This is significant not just because the field of cognitive psychology had thought that only primates had this ability but that they had also located the exact part of the brain where this ability was held - in the frontal lobes. Crows do not have frontal lobes. This puts an entirely new light on half a decade's worth of research and medicine. It also makes crows one of very few species with such specialized and advanced cognitive abilities but without primate brain physiology.

It is interesting that brains of very different size and structure should have evolved such a similar response to selection pressures. (Iwaniuk et all, 2004) As has been pointed out by Emery, crows represent a case of convergent cognitive evolution despite divergent neurological evolution. (Emery, 2004) This doesn't explain **why** they are so clever, however. The best theories that address that question base themselves on the adaptive tradeoffs for learning vs. innate, biologically programmed behaviors.

As Heinrich puts it, "such animals evolved in a complex and unpredictable environment in which prewired responses were inappropriate." (Heinrich and Bugnyar, 2007) Corvids are highly social animals, and as indicated by the theory of mind they can recognize each other. Living in such a social environment is indeed complex, and has been cited by some as a powerful indicator for the development of higher intelligence. Of particular interest in terms of their social structure is the fact they crows will often steal from each other, a habit mitigated by status, blood relation, circumstances of food availability, and number and composition of crows present. Such factors are indeed ever-changing.

It is worth noting that for most of their history crows and ravens have depended largely on carrion, and, by proxy, on the predators that created it. Young ravens are known to bite the tails of wolves in a kind of highly-charged (and very dangerous) form of play, and crows are known to travel long distances to seek out owls to harass. (Kilham, Lawrence, 1989) such behavior, far from being suicidal, gives these birds first-hand experience with gauging the response times, tolerances, and reactions to stimuli for the much larger and more dangerous predators upon which they rely.

This ongoing environment of ever-changing short-term circumstances has provided ample reason for corvids to become learned generalists. Being able to pick up short-term behaviors and methods of interaction has become favored over generations of reinforced, hardwired behaviors. It has been further and forcibly reinforced by the arrival of human beings on the scene, with their erratic, rapidly evolving new technologies, habitats, and attitudes towards crows.

So now we know that crows are clever and adaptive. But are they going to be able to learn the skills needed to operate a vending machine?

Learning

Crows are extremely flexible learners who participate in cultural learning and teaching as part of their complex social groups. Crow yearlings and post-yearlings will often remain at or return to the nest to help raise the next generation of young with the parents. (Clayton and Emery, 2002) In some cases, these young may remain at home for up to five years or even longer. This cooperative breeding behavior is very rare in birds; in fact, only a handful of species in North America share this trait, and none of them are as widespread as the crow. (McGowan, 1996) On average, a successful family will raise an average of three young from a nest (as many as six and as little as one.) Of those, on average two will survive their first year, after which they may depart to raise another family. Often, however, those two young will likely be with their parents the next year along with some younger siblings. In this way the family groups grow quickly, often becoming as large as 15 crows in a single family group. (McGowan, 1996)

This is not to say that crows spend all their time at home; young, unmated crows often depart for new territories, and especially in the winter may spend up to weeks at a time away from the home territory interacting with other groups of crows. These are typically large flocks roosting at night in wintertime, but may also be groups of other unmated crows looking for food. (McGowan, 1996) This extensive developmental period before becoming fully independent allows crows significant opportunities to learn essential skills for survival, particularly given that they are able to associate with both non-relatives and kin and to learn from all different group members. (Clayton and Emery, 2002)

The socialization they get from both family and foreign birds is important as techniques and tool use may be socially transmitted. (Kenward et all, 2006) As Stöwe has found, young crows spent significantly more time manipulating new objects when they are in groups than when they are alone. (Stöwe et all, 2005) Several experiments have demonstrated the effect of social influence on corvids. In one, human foster parents demonstrated object manipulation to New Caledonian crows who then picked up the behavior simply by observation. (Galef 1988; Heyes 1994) One experiment in which the human foster parents demonstrated twig manipulation resulted in the tutored birds carrying twigs twice as often as untutored birds. (Kenward et all, 2006)

Another way in which crows learn is through simple interaction, or play. This "play" allows crows to learn critical object affordances, and as such it makes sense that this behavior would be inherently rewarding. (Hailman 1967) We have already noted that crows will engage in risky behavior to learn about large predators, and also that they readily accept tutoring. This raises the question of unprompted behaviors and whether they are simply manifestations of predetermined biological behaviors, or if they represent the foundation of experimental learning.

Garant has noted that "experimental manipulation can even cause precursor behaviors to be replaced earlier by the directly functional behavior" (Garant et al. 2005). I.e., that given the opportunity to play with materials, crows will learn the correct way to interact with them much more quickly than biology could allow. This suggests that crows do not inherent hard-wired motor patterns (such as a specific way to build a nest, or eat a food, or attract a mate) so much as a tendency to find certain kinds of behavior rewarding. (Hailman, 1967)

To put this another way, initial behaviors may be inherited, such as dust bathing, which is often done in the absence of any existing stimuli (such as dust), and is only later connected to the use of dust as they encounter those materials and learn to use them. (Kruijt 1964). Crows may be prompted to certain kinds of play in order to learn certain fundamentals, much in the way that babies must learn that square pegs go in square holes by repeatedly poking pegs at holes. (Kenward et all, 2006) In the process they learn more about the boundaries of the materials and situations they encounter than could be genetically expressed, and this learning can be more flexibly applied. (Hailman 1967). It is important to note that just because a behavior isn't inherited doesn't mean there is no opportunity for advanced cognition - in many ways this manner of play is identical to that of human children and can lead to the establishment of similar mental models. (Garant et al. 2005)

In the last few years the great increase of study into crow intelligence has shown that they are flexible learners who can adopt new behaviors through observation, tutelage, and play. They have many inherited behaviors which lead them to experiment with materials and situations to discover their affordances, but also have a flexibility of mind and ability to form mental models which makes them strikingly flexible. Their logical and deductive reasoning is striking, as is their tool use – all of which make them good candidates for learning to use devices such as vending machines.

But there is one other aspect to crow culture which makes them particularly well suited to an autonomous teaching machine - their social groups.

Social Groups

Crows tend to form three main groups (not counting yearly winter roosts). These are; mated pairs, family groups, and unmated groups. In order of expanding utility to this project:

Unmated Groups

Unmated groups consist of young, curious crows that congregate in large, semi-fluid groups to obtain resources. As these groups encounter new resource opportunities the lowest-ranking crow will usually be the first to attempt to obtain it. If that crow succeeds, the alpha crow will often fly in, take the food from him/her, and then repeat the behavior. Then the next ranking crow is allowed, and then the rest in rough order of hierarchy. (Lorenz, 1949) If the crows discover a similar food resource at a later time they will usually repeat the original behavior in an attempt to obtain the food; if any crows who were not present the first time around are now at the site they can learn the behavior through observation of their fellow crows.

Winter roosts are handled in much the same way; large groups made up of all three social group types congregate into a larger group into which individual group members often scatter. In this environment the status of each crows is largely fixed, and learning occurs as with unmated groups (albeit with more complex dynamics due to individual group learning/teaching relationships such as parent/young). In this way crows can learn new means of resource obtainment from each other in very large social groups.

Mated pairs

Mated pairs are crows that have paired up for purposes of reproduction. Usually these crows will stake out a territory which they will defend from other crows. Because crows mate more or less for life (or until an unsuccessful breeding), and because they live for a fairly long time (between 17-21 years) (McGowan, 2001), this makes them reliable, localized partners in sharing resource obtainment strategies. Similarly, because pairs of crows are unable to defend against large groups of unmated crows they usually choose territories outside those of unmated groups, which leads to constant expansion of this knowledge as mates pair off.

Family groups

Family groups are simply a mated pair with young. Note that these young may stay in the nest for a long time, may leave, strike up a life of their own, and come back for extended periods, or may visit on occasion. Regardless of the terms, the family unit is important because, much in the same way of unmated groups, family groups share experience in obtaining resources with each other. Given that unmated birds visit their mated parents this means there is ample opportunity for them all to learn new skills from each other which can then be passed on to both migratory unmated groups (in the case of the young) or territory-holding mated pair partners. In both cases adults teach the young a multiplicity of skills, and young can import new skills to their parents. (Kirpluk, 2005)

Given these three types of grouping it should be possible to put the device in an area near any one type, and once the group has progressed through Stage 4 to then place other devices in neighboring territories and have the learning follow. For example, because unmated groups are semi fluid and occasionally mob mated pair's territories, they provide ample opportunity for mated pairs to witness new behaviors of resource obtainment such as that presented by the vending machine. Mated pairs can teach their young, who will then spread to other territories. Finally, mated pairs or family groups that use the device can demonstrate its use when unmated groups are in the area availing themselves of other resources – a time when the vending machine would be especially useful to those that can use it. In this way a slow expansion of device units should be possible up to the carrying capacity of that urban area's lost change.

Availability of resources

It is worth a word here to establish that there is enough change available for crows to make use of the vending machine without needing additional human intervention. After all, if we're specifically giving them the change to use the machine there is little reciprocity to the system.

As of this writing there is upwards of $215,529,091 USD (5.5% attrition rate for $1,185,410,000 of coins issued in 2006 – see Note:2) lost in spare change each year in the US alone, the majority of it in urban environments. There is no hard data yet available on how much of this change could be reasonably recovered by crows, but if one assumes a conservative 1% return for any given city that still yields $2,155,290.91.

If one assumes that each machine produces two peanuts per feeding, with an average return of one coin per entry and an average value of entry of roughly ~$0.07 (See Note:3) and an average cost per peanut of $0.002 (See Note:4), then there should be enough return to afford 89,468 feedings a day.(See Note:5) (Note that this does not include the initial cost of the machine nor its maintenance.) That should be more than enough to train and feed as many crows are interested in obtaining coins, and further should balance out to represent a small but significant part of the crows diet.

Note that this is important – while initially the vending machine will represent a bonanza of free food, as the crows are trained it will instead become a reliable but not necessarily frequent source of high-quality food. Coins are not so readily available that crows can use the device whenever they want, but should be available enough to keep the device consistently used.

So we have lots of very smart crows that can learn well and can express what they learn to each other. How do we teach them to use the device in the first place?

Methodology

The central method to the vending machine is operant conditioning, also known as Skinnerian training (after B.F. Skinner), or “shaping.” The idea is that you reward an animal for approximating a behavior, and then subsequently reward it again each time its behavior more closely approaches the desired outcome. This method rests on the simple principle that whenever something reinforces a particular activity of an organism, it increases the chances that the organism will repeat that behavior. (Skinner, 1951, pp. 26-27)

Here’s an example; let’s say you want to train a dog to fetch a ball. First you might reward the dog when it happens to look in the direction of the ball. Next you would reward it when it happened to run in the direction of the ball. Then again when it ran to the ball, and finally again when it picked the ball up and brought it to you. This is a gross simplification, but it outlines the principle.

What is interesting about operant conditioning is that Skinner characterizes it as being behavior which is spontaneously emitted, as opposed to being something which is explicitly prompted by an outside force. (Peterson, 2000) Given this understanding, the most efficient way to train an animal is to capitalize on its natural behaviors. In the example above, that may be a dog’s natural tendency to pick up ball-sized objects in its mouth and carry them. In a crow, it may be its natural attraction to shiny objects. (Note that it has been hypothesized that crows are in fact more attracted to eggs, which are small and bright, than coins. That said, their tendency to horde small shiny objects is well documented.) (Lorenz, 1949)

It is important to note that it need not be a human operator which shapes the behavior of the animal in this case; inanimate, physical environments can do just as well. Young squirrels, for example, learn to open hazelnuts more efficiently over time through practice and experience. (Eibl-Eibesfeldt, 1963). Crows are prime candidates for this sort of training, as explained above, especially when it builds on natural behaviors.

In is our supposition that a device purposefully designed to utilize step-by-step operant conditioning based on intuitive, natural crow behaviors will be quickly mastered. Which brings us to…

How the device works

The vending machine is a sturdy device consisting of a box from which protrudes a perch, a food tray, and a funnel. The whole thing is made out of sealed wood or plastic so as to minimize noisy clanging which might result from using metal components while retaining the ability to leave it out in the rain. Based on established Skinnerian training principles the action of the device is divided into four stages. These are:

1. Food and Coins Always Available

At this stage the device pushes up a few peanuts and one or two coins onto the feeder tray whenever pressure on the perch is *released*. This ensures that the device always has food whenever it is examined by a potential client. It also ensures that both the sound of the device and its mechanical operation occur in close proximity to the feeding act. Please note that the feeding tray is hinged with a light spring such that the pecking action of the client is sure to cause it to drop whatever coins or peanuts are not caught in the first peck. Also note that these "lost" peanuts and coins then go down the funnel.

2. Food and Coins Available On Landing

Herein the action of the device is identical, except that food and coins are issued only when the perch is depressed, as opposed to released. This means that the crows must endure the sound and mechanical action of the device in order to obtain a peanut. Otherwise the action is identical; any lost food or coins go down the funnel.

3. Coins Available On Landing

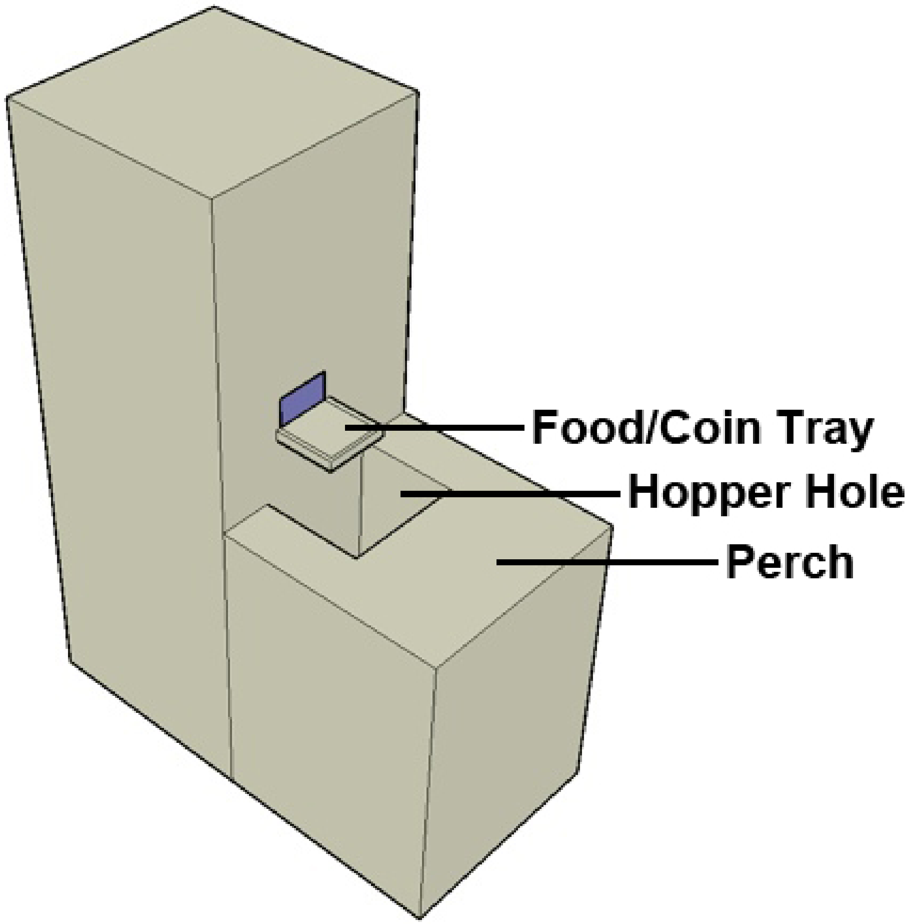
This is the highest-risk segment of the machine's operation. At this point we must endanger our operating capital by making coins alone available whenever the bird lands. However, should a bird peck at the tray and cause a coin to fall down the funnel, the device then produces some peanuts. This stage is designed to cement in the clients' mind the relationship between coins going down the funnel and peanuts being made available.

4. Coins Available On Deposit Only

Finally we shift the device into its intended, and long-term state of only providing peanuts when coins go down the funnel. Nothing is otherwise provided and our clients are now capable of acting as true employees. It is important to note the multiplying potential of encouraging others to participate; during the training period any peanuts which are not eaten in the first peck are discharged out the side of the device, meaning that the more learned crow can standby and observe his fellows practicing, thus obtaining nuts with zero effort. This compound benefit also occurs once the final stages are complete in that less competent crows are sure to err in their delivery of the coins, meaning that the savvy crow user will have more coins to use the more crows he or she gets to participate.

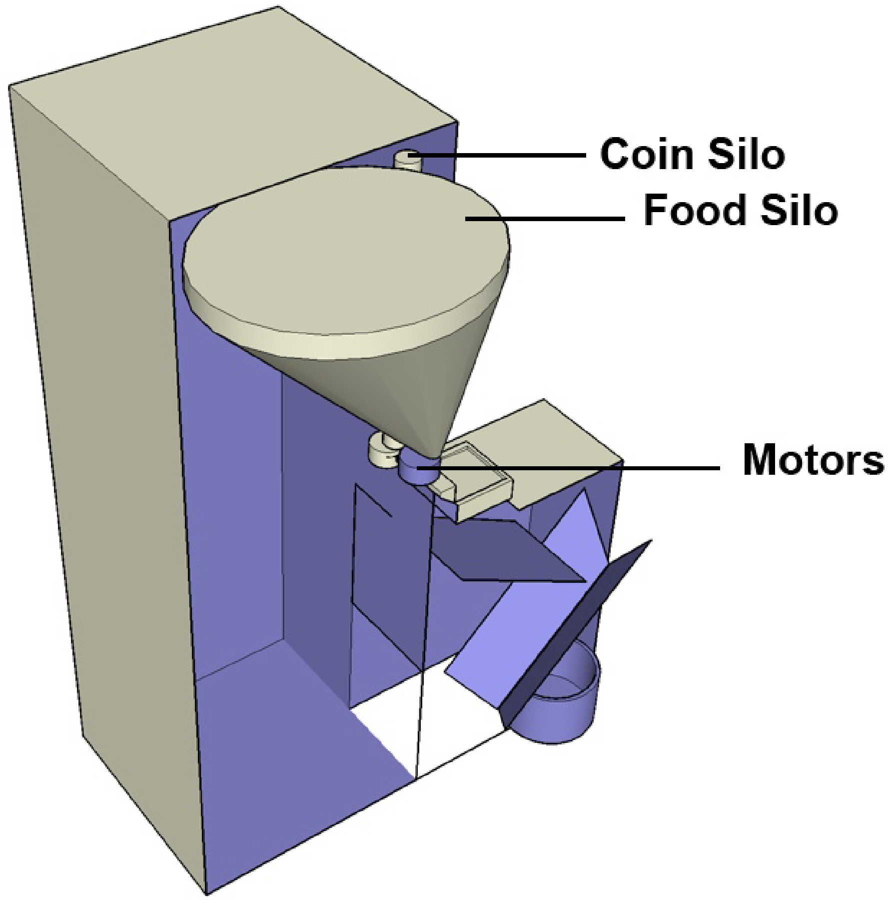
Implementation

Diagram A: Outside View



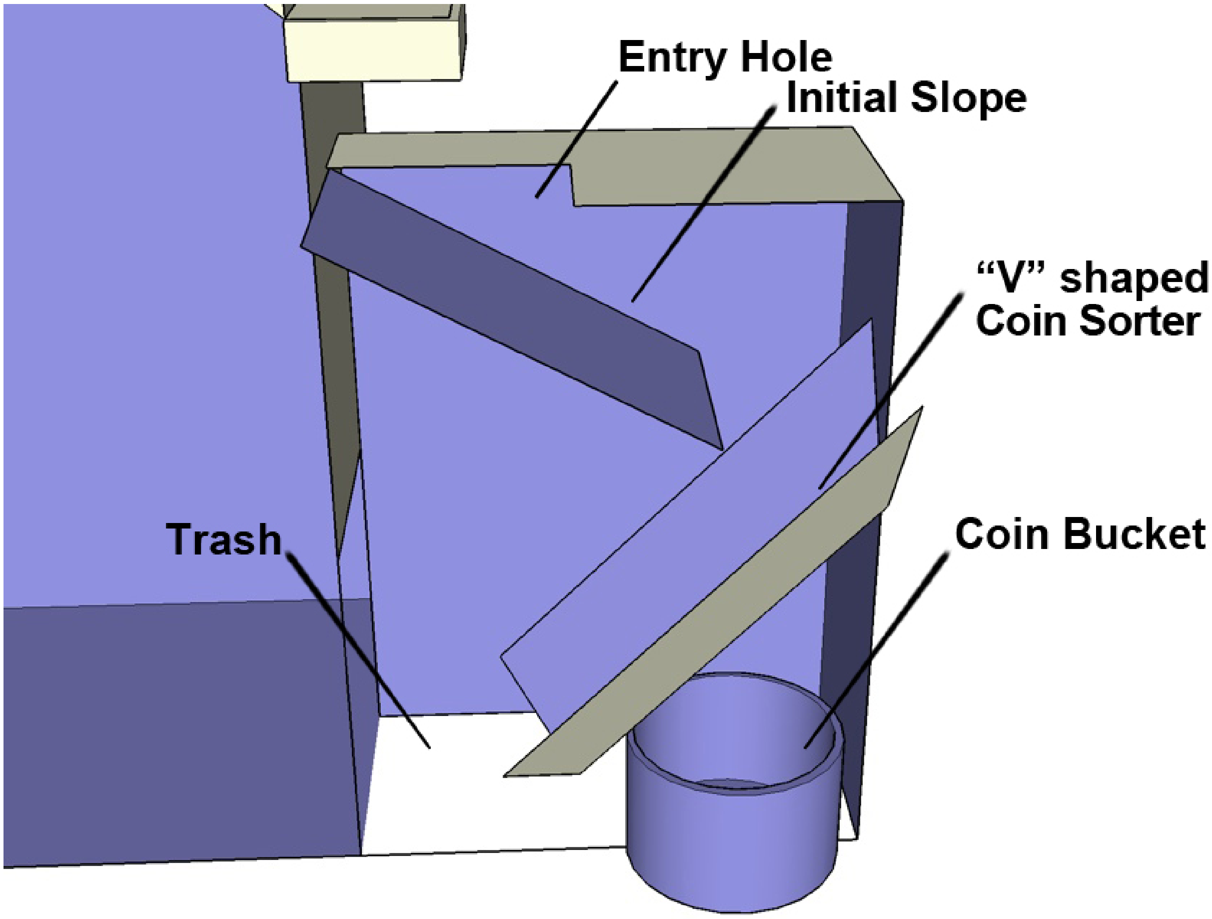
From this illustration it is possible to see the components with which the crows will interact. The food/coin tray is where the coins and food come out - note that it is sloped downwards toward the front of the device. The hopper hole is where coins are deposited and the perch is sized such that only one crow at a time should be able to use it; this is to discourage thievery by other crows and to allow focus on the task at hand. The perch is also raised such that other crows or predators standing on the ground nearby are more easily observed, and the overall device is made narrow to prevent it from blocking an excessive amount of the surrounding area from the crow's view.

Diagram B: Whole Device, Half View.



Here the gross inner components are described; the tube containing coins, the food hopper (designed for easy removal and replacement to speed the stocking process), and the motors which drive the dispersal of both onto the food tray. Note that this uses the standard "gravity feeder" methodology common to most commercial feeding mechanisms. This is to prevent clogging and jamming of the device and also to keep the overall design as simple as possible for maintenance and production purposes.

Diagram C: Sorting Mechanism, Half View



From here we can see the sorting mechanisms’ gross details. The entry hole discharges onto the initial slope, and may be covered with chicken wire to prevent crows from clogging it with any refuse the crows may put in it in their experimentation. From there the initial momentum is spent in rolling down the slope and hitting the rear of the sorting mechanism before rolling into the “V” shaped corn sorter. This sorter has a slot at the bottom of the “V” to allow coins, which have by now slid to the reversed apex of the trough, to pass through and into the coin bucket. Everything else falls forward to be discarded later.

Note that this means that any peanuts which roll into the sorting mechanism are lost to the crow, which prevents them from gaming the system by simply dropping trash into it during earlier stages of learning.

In addition, but not illustrated here, are a series of sensors which detect the presence of a crow on the perch, the arrival of trash (or items which did not fit through the slot and into the coin bucket), and the arrival of coins. This is processed by a circuit board mounted in a sealed enclosure on the inside of the box which also controls the action of the motors for dispersing coins and peanuts. The entire assembly is powered by a 12-volt power cord which can be plugged into any household current supply. All the actions of the device are logged and can be downloaded from the circuit board at a later date via a standard USB cable.

Conclusion and future implementations

At the time of this writing (May, 2007) all the crows are nesting. This makes them unlikely to try to new things, unwilling to travel to new areas, and uninterested in experimentation. The up side of this is that in June, when the young have hatched and fledged, we will have a whole new population that will be interested in using the device and too naïve to know better. The adults will also be more likely to try the device as they'll have several new mouths to feed and are likely to take advantage of any new food sources they can find.

At present there are four main venues we're scheduled for testing this device:

1) Dr. Anne Clark and the University of Binghamton, NY has been working with the local zoo to finalize funding for a permanent exhibit called "Clever Corvids." She would like to have this device included as part of it. This is great news as it working with captured crows will allow us to make good, first-level gross adjustments to the machine. For example, if the perch is too small, or if the peanuts are bad tasting to crows, etc. This sort of data may be unobtainable in working with wild crows as they are more likely to just fly away.

2) Dr. Kevin McGowan has a group of banded, wild crows in the suburbs of Ithaca, NY that he may be willing to volunteer to this cause. This would be great news as it would allow us to see firsthand how different social groupings interact with the machine.

3) Natalie Jeremijenko has a rooftop exhibit in Chelsea, New York, NY where she would like me to install the machine. This area is already complete with several installed cameras to facilitate long-term observation, and would be a fabulous opportunity to observe hyper-urbanized crows as they interact with the device. In many ways this location represents an ideal location for the purposes of this project.

4) Dr. Carolee Caffrey and University of Harvard, Boston, is interested in helping me get enrolled in their doctoral program this coming fall. If that works out I will have both time and location as she has both captured crows and a local population. This would certainly help in gathering more scientifically rigorous results over the long term. Her interest is primarily in studying how learned patterns are passed through crow populations – a task this device is well suited for.

5) Finally, Dr. Ha at the University of Washington has recently finished a grant in which he traveled the world to most of the major crow types to gather blood samples. He has suggested that this device would be an excellent tool for establishing a baseline of intelligence in same. This is especially true given that the device presents no opportunity for direct human interaction; tests of intelligence are often swayed by subconscious cueing behavior on the part of the human testers. By precluding human intervention the device avoids this.

Regardless of which of the above take place, the first goal is to determine the optimal method and arrangement of steps in training crows to use the device. Once that has been determined we will be able to use it to study how crows pass this new knowledge around, and also to make comparisons between different types of crows and the rate at which they obtain this new behavior. It should be an interesting ride.

Joshua Klein
May 6, 2007

NOTES

1) How did we figure out the carrying capacity of a city block?

500 urban ha2 have a greater than 5,000 crows carrying capacity
5,000 crows / 500 ha2 = 10 crows urban per ha2
1 hectare = 1.544 408 634 square city block [East U.S.]
10 crows / 1.544 city blocks = 6.476683937824 crows per city block.

This is based on calculations made at: http://www.onlineconversion.com/area.htm

2) How did we calculate the amount of lost coins available? We got the amount of coins issued by the US Mint:

http://www.usmint.gov/about_the_mint/coin_production/index.cfm?flash=yes&action=production_figures&allCoinsYear=2006

Then we added them up:

$82,340,000 in pennies
$75,120,000 in nickels
$282,800,000 in dimes
$735,250,000 in quarters
$2,200,000 in fifty-cent pieces
$7,700,000 in dollars

$1,185,410,000 total

We used an estimated 5.5% attrition rate (published in the 1999 issue of Chance News, here:

http://www.dartmouth.edu/~chance/chance_news/recent_news/chance_news_8.07.html#kill%20the%20penny

That gives us a total of:

$215,529,091

3) How did we estimate the average value of each coin entered into the system? Like so:

0.01 - penny
0.05 - nickel
0.10 - dime
0.25 - quarter

0.50 - fifty-cent piece

0.91/5 = 18.2 average value.

We weighted this amount for the average relative availability of each coin, (see http://www.dartmouth.edu/~chance/chance_news/recent_news/chance_news_8.07.html#kill%20the%20penny) estimating the average return per entry to be ~0.7.

4) How did we calculate the cost per peanut? Easy, we counted them! A bulk purchase of cooking peanuts at your local bulk food store will cost you $5 for approximately 2500 peanuts.

$5.00 / 2500 peanuts = $0.002 per peanut.

And that's before you get large-scale buying discounts!

5) We got the number of feedings possible per day like this:

$0.07 (average coin value inserted) - $0.004 (cost of two peanuts) = $0.066 average profit per feeding

$2,155,290.91 yearly change available (0.1% of total available) / 0.066 = 32,655,922.88 feedings per year

32,655,922.88 feedings per year / 365 days per year = 89,468.28 feedings a day

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