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Alexa: A Pandora's Box of Risks

Launched in 2014, Amazon's Echo and Echo Dot smart speakers led the category's rapid adoption by households and enabled the penetration of artificial intelligence (AI) voice assistants into the everyday lives of millions of people. By 2019, Alexa—the virtual brains behind Amazon's smart speakers—was able to play music, create reminders, get weather reports, control lights and other home appliances, shop, and do much more in response to voice commands. Such advanced technology was not without its challenges and risks, however.

Digital Voice Assistants

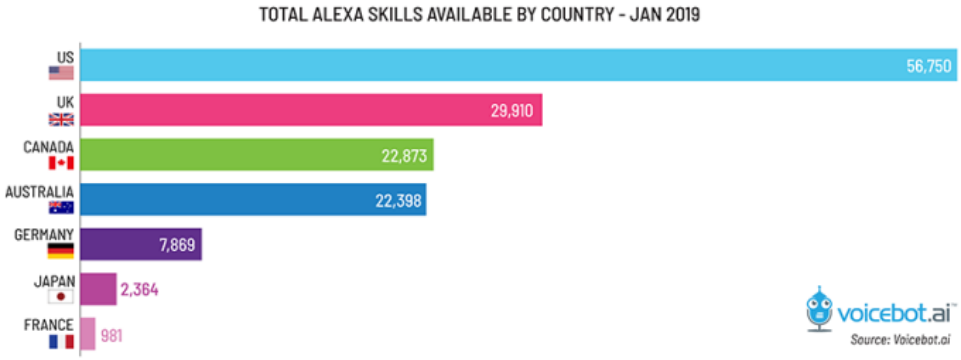
Because voice is a primary means of human interaction, many technology companies invested significant resources in developing voice or voice-first interfaces, a term referring to applications that used audio as the primary input method (versus keyboards, mice, or screens).

In February 2010, Siri became the first voice assistant introduced to a wide audience. A spin-off from a military-sponsored research project started nearly a decade before, Siri was offered initially as a stand-alone application that integrated with a range of web services, such as ordering a taxi or retrieving movie ratings. In April of the same year, the company that developed Siri was acquired by Apple. An improved version of the technology was bundled in the iPhone 4s some sixteen months later.[1] Google launched its Google Now voice assistant in July 2012 and Microsoft launched Cortana in April 2013.

In November 2014, Amazon introduced a smart speaker named Echo that contained Alexa, an artificial intelligence-enabled digital assistant. Named for ancient Egypt's Library of Alexandria,

Alexa was able to respond to user questions and initiate actions like playing music, setting alarm clocks, and creating grocery lists. Alexa's built-in capabilities could be expanded by writing or installing apps (or "skills") that enabled it to speak to more devices or websites (see **Figure 1**).

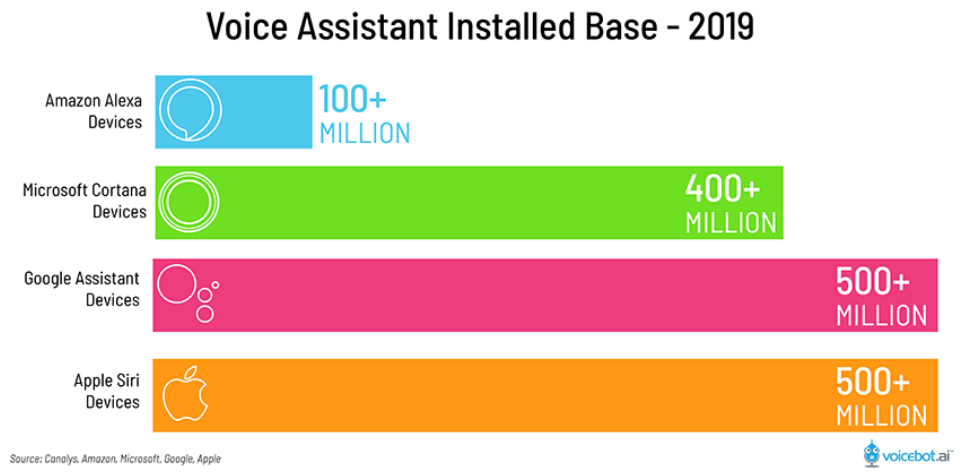
Figure 1: Alexa Skills Available by Country, January 2019



Source: Bret Kinsella, "There Are Now More Than 70,000 Alexa Skills Worldwide, Amazon Announces 25 Top Skills of 2018," voicebot.ai, December 14, 2018.

By January 2019, Amazon had more than 100 million Alexa-enabled devices installed worldwide (see **Figure 2**).[2]

Figure 2: Voice Assistant Installed Base, 2019



Source: Bret Kinsella, "Amazon Alexa Is Available on 100 Million Devices – Here's Why It Is Actually More and How It Stacks Up Against Apple and Google," voicebot.ai, January 6, 2019.

How Alexa Worked

Alexa, like all competing voice assistants, had the capability to listen constantly and detect spoken commands even when the user was not near the microphone. Alexa achieved this far-field speech recognition with a minimum of four built-in microphones (the number varied by model) and signal processing technology that eliminated ambient noise like music, television, or conversation and captured the command. It then used natural language processing to detect wake words (defaulted to "Alexa," but can be changed to "Echo," "Amazon," or "Computer"). A recording of the command that followed the wake words was captured and sent to Amazon's cloud, where Alexa's database was searched. In response, Alexa either initiated the action requested or returned a reply to the user.

Although the technology behind Alexa advanced significantly after its introduction, in 2019 its ability to interact naturally with voice commands remained rudimentary. Users were met with the response, "Sorry, I don't know that one" when they gave the same command in a slightly different way. The artificial intelligence was trained initially with American English, so non-native English-speakers also experienced significant difficulty being understood.[3]

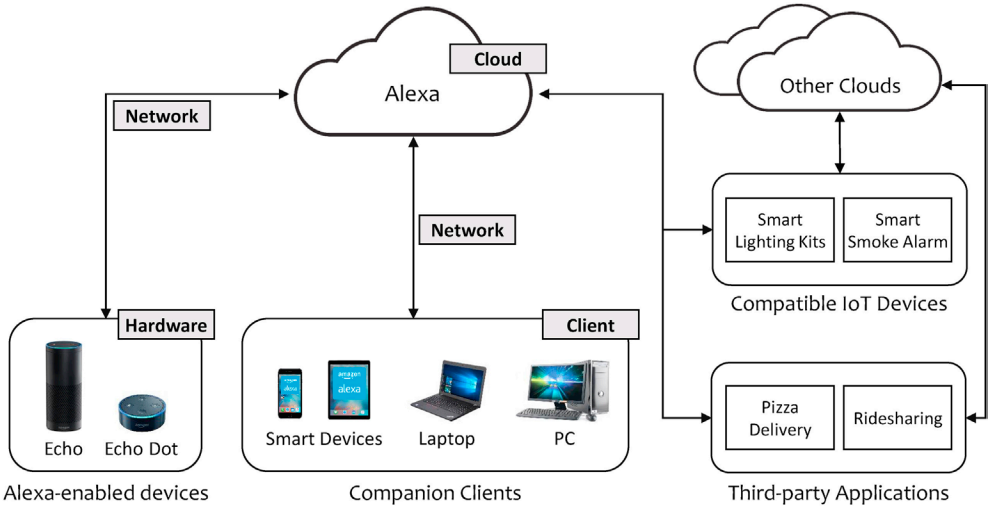
These challenges reflected the complexity of natural language processing. Despite the rules of grammar, natural speech is highly variable and nuanced—word choice, tone, and rhythm must be interpreted even though they can vary a great deal based on a speaker's upbringing and cultural background. Language also evolves constantly and includes vast amounts of implicit knowledge and rules that are not easily codified for software.

Once communication was established with Alexa, the device needed to be able to understand the question and answer accurately. In 2018, a consulting firm tested all digital voice assistants by asking 5,000 questions. Alexa recognized and attempted to answer half of the questions, meaning users heard answers like "I'm still learning" or "Sorry, I don't know that" as often as actual responses. Of the questions that Alexa understood and answered, 82% were answered correctly.[4]

The Alexa Ecosystem

Over the years, Amazon enhanced Alexa's capabilities and expanded its Echo speaker offerings, including features like touch screens. In addition to developing its own smart speakers, Amazon developed partnerships with third party manufacturers to add Alexa voice assistant capabilities to hardware products including refrigerators, washing machines, and cars. By 2019, over 150 products had Alexa built-in and over 28,000 devices worked as part of Alexa's ecosystem (see **Figure 3**).[5]

Figure 3: Amazon Alexa Ecosystem



Source: Hyunji Chung, Jungheum Park, and Sangjin Lee, "Digital Forensic Approaches for Amazon Alexa Ecosystem," ScienceDirect.com, August 2017, https://www.sciencedirect.com/science/article/pii/S1742287617301974.

The large number of third-party Alexa devices raised questions about their quality and the resulting impact on the Alexa brand. Although it recognized the variability in quality of Alexa-enabled products, Amazon believed that consumers would not blame the Alexa brand for an inferior product as long as there was at least one good example in each product category.[6]

Alexa in the Home

Although use of voice interfaces was still nascent, 72% of people who owned a voice-activated speaker said that their devices were often used as part of their daily routine.[7] Alexa's most-used functions included setting alarms, playing music, setting timers, and checking the weather.

The features most important to users were (in descending order):[8]

- Listening to music
- Checking the weather
- Asking for information
- Setting the timer
- Asking about news
- Getting sports scores
- Playing games
- Home automation

When diving deeper into these cases, the following patterns of user behavior emerged:[9]

- Of those who listened to music, frequency of listening increased by 63%
- Of those who asked for information, frequency of requests increased by 53%
- Of those who checked the weather, 38% checked the weather multiple times a day
- Of those who played games, 56% played multiple times a day

Users also reported listening to more audio such as podcasts via their smart speakers, which displaced time watching television.

Men tended to use Alexa to check sports, to get news, and to use home automation features more than women. Women tended to check the weather via Alexa more than men.

Alexa users increased their spending on Amazon significantly while reducing other purchases. The increase was driven by smaller but more frequent purchases, presumably enabled by the "frictionless" voice interface.

Thirty percent of smart-speaker owners reported using them to perform home automation functions.[10] Households with a smart speaker were up to 6.6 times more likely to purchase smart devices, such as smart light systems and smart home TVs.[11] With a wake word and a voice command, consumers were able to turn on and off lights, change the temperature of their thermostats, and even lock and unlock their front doors.

Amazon made no secret of its intent to push Alexa deeper into smart homes. In September 2017, the company announced the launch of Echo Plus—an Echo smart speaker with a built-in smart home hub. The device enabled users to connect smart home devices directly to their Echo without a third-party hub. In September 2018, the company unveiled over seventy new Alexa-enabled devices, features, and developer tools. "We want you to have access to Alexa everywhere—in your kitchen, in your living room, in your office, and now in your car or truck."[12] It also announced a few new home security capabilities, one of which enabled Alexa to detect troubles at home, such as the sound of shattering glass or smoke alarm, and send warnings to the user's smartphone.

However, missing from Alexa's list of home security capabilities was the ability to call 911 (the emergency number in the United States) for police, fire, and medical services. Like most smart home assistants, Alexa was unable to provide real time location data or receive a return call, both of which were requirements for the existing 911 infrastructure. In addition, Amazon would have to pay surcharges ranging from $0.25 to $3.00 per call to support the emergency call infrastructure.

Growing Up with Alexa

In May 2018, Amazon launched a version of its Echo Dot device aimed at children. The Echo Dot Kids Edition product featured a colorful case and was preloaded with a children's content platform called FreeTime Unlimited that offered access to educational content, games, audio books, movies, and TV shows, including content from brands such as Nickelodeon and Disney.

The device included parental controls for blocking content, controlling time limits, and setting educational goals.

The product raised concerns about the impact of an artificial intelligence device on child development. One concern was whether the device reinforced negative behaviors such as offensive language and inappropriate tone of voice by responding to such commands normally. Amazon updated the device to thank children when they said "please," but it was unclear whether that would be an effective substitute for parental guidance and correction.

More importantly, excessive interaction with a virtual assistant limited the quality and quantity of human interactions, an activity crucial to children's development. This was particularly true for language development, which was critically influenced by back-and-forth conversation between an adult and a child. By always providing stimuli and immediate boredom relief, virtual assistants may have retarded the development of creative thinking and distress tolerance skills that were critical to life success. The issue was further complicated by children's limited ability to distinguish between interactions with a human and with an AI.

Alexa's ability to provide answers to questions on almost any topic was also potentially problematic. Children did not have the capability of identifying—or even questioning—erroneous information provided from crowd-sourced platforms like Wikipedia. Even when the information provided was accurate, child development experts questioned whether giving children instant answers promoted learning. "Learning happens when a child is challenged, by a parent, by another child, a teacher—and they can argue back and forth," according to developmental psychologist Justine Cassell. [13] In addition, the popularity of virtual assistants had the potential to influence the way children asked questions by favoring and responding to simpler questions over complex inquiries.

The introduction of Echo Dot Kids Edition also raised concerns regarding children's privacy. In its privacy disclosure, Amazon stated that it collected and shared children's information with selected affiliated businesses. The device provided a channel for surveillance at an unprecedented level by enabling 24/7 access to children, who lacked the ability to understand the extent to which their sensitive information was being collected and shared, or the impact it could have on their lives.[14]

Monetizing Alexa

Amazon pursued multiple avenues to monetize Alexa in business and consumer contexts.

Alexa for Business

Building on the success of Alexa and Echo devices in consumer markets, in November 2017 Amazon introduced Alexa for Business, a managed service that enabled voice assistant devices to control existing IT applications. For example, when a user said "Alexa, start the meeting" in a conference room, Alexa used the location of the device, the calendar information for the room, and

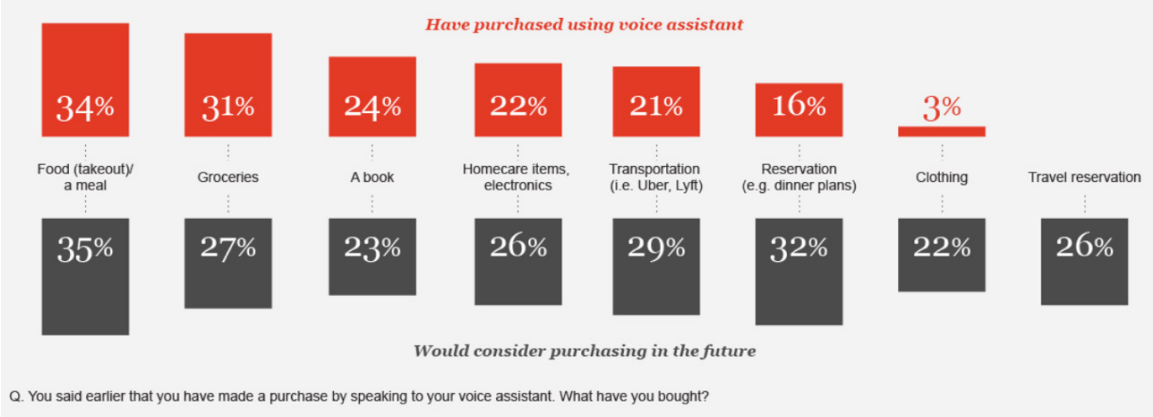
the type of video conferencing equipment available, all stored in the Alexa for Business account, to start the meeting.

In August 2018, Amazon and Microsoft jointly announced a solution to integrate their digital assistants so that Cortana, Microsoft's voice assistant, could be called from an Amazon Echo device and Alexa could be called from Windows devices, including PCs. In January 2019, Microsoft CEO Satya Nadella announced that Cortana would no longer be a platform competitor to Alexa or Google Assistant, but rather a voice skill to access Microsoft 365 via other voice assistants. As of April 2019, Alexa was the only Cortana-integrated voice assistant, which gave it exclusive access to Microsoft's suite of business applications.

Alexa and Voice Shopping

In 2018, only about 2% of the people with an Alexa device had used it for voice shopping, or making a purchase with just a voice command.[15] Most voice shoppers purchased low-cost household items like toilet paper and detergent, which represented only a tiny fraction of the company's $140 billion retail sales revenue in 2017 (see **Figure 4**).

Figure 4: Items Purchased by Voice Shopping



Source: PwC, "Prepare for the Voice Revolution," 2018, https://www.pwc.com/us/en/services/consulting/library/consumer-intelligence-series/voice-assistants.html.

Voice shopping was viewed as disruptive not only for consumers but also for consumer brands, even though major consumer packaged goods (CPG) companies were enthusiastic about the opportunities of voice shopping technology. Campbell's vice president of digital marketing said, "We believe that the impact of voice is going to be a bigger impact on the consumer journey than Google search was in the 2000s. Two or four years from now, smarter people than me say voice will be the preferred way to search. If you haven't converted your code or site experience to be ready, you're going to be behind."[16]

Traditionally, the makers of CPG brands purchased shelf space at retailers like Walmart and Costco that guaranteed nationwide exposure. They also invested billions in branding to differentiate their products, including the creation of recognizable brand names, logos, and packaging; the execution of trade promotion strategies; and developing advertisements and purchasing media. However, with voice shopping, brands had no visibility (or "shelf space") if they were not the first or second option—and Amazon's private label products often were the first option.[17]

According to a test conducted by Bain and Co., when a customer made a first-time voice purchase without specifying a brand, 50% of the time Amazon's algorithm recommended a product that was Prime eligible, well-priced, and well-rated.[18] This gave CPG companies more incentive to pay to be advertised or to be placed as the first or second purchasing option through Alexa.

Alexa and Whole Foods

Amazon purchased grocery chain Whole Foods for just under $14 billion in summer 2017. The motivation for the acquisition was access to Whole Foods' customer data, its physical store locations, and its brands as a way to grow Amazon's share of the grocery segment of online shopping.

Amazon Prime members had access to exclusive discounts on certain products at Whole Foods when they scanned a code associated with their account. Amazon Prime had nearly 100 million subscribers, so this guaranteed more precise collection of shoppers' purchasing patterns and data than was previously available to Whole Foods. Many Alexa owners used the device to manage their grocery shopping list. Alexa operated as a voice-activated scribe and combined shopping requirements from the entire family; it also enabled ordering groceries from Whole Foods for delivery.

However, convincing consumers to buy groceries through voice proved to be difficult. Shopping for groceries online was already challenging because shoppers were unable to select based on color, smell, or other sensory aspects of fruit, vegetables, or meat.

Alexa in Stores

Alexa had the potential to replace retail sales representatives as the source of product recommendations. The shopping experience could be further improved with the integration of smart shelves, which lighted the location of a recommended product. This technology was used by Bottle Genius to recommend whiskey in a Bottle Rocket wine and spirits store in New York City. A customer explained to Alexa the type of purchase, the demographics of the user, the price range, and other preferences. Alexa used the Bottle Genius skill to recommend products and light up the shelf underneath them. This setup generated a 20% increase in sales when tested for 60 days in 2018.[19]

Alexa and Marketing

Although voice shoppers were scarce, almost half (47%) of smart speaker owners used voice assistants for product research, 43% to create shopping lists, 32% for price comparisons, 28% to research store information and 27% to check for deals and promotions.[20]

In early 2018, Amazon said that "there are no plans to add advertising to Alexa,"[21] but surely it realized that voice shopping offered a unique opportunity to advertise products and/or push information about deals and offers. When Kindle Fire launched, Amazon promised not to include any ads; however, after three years Kindle Fire included pop-ups with Fire-only ads and deals and offered a paid upgrade option to opt out of ads. Perhaps following the same pattern, Amazon reportedly was negotiating with Clorox and Procter & Gamble as potential partners to promote their products through Alexa skills.[22]

Alexa could become an advertising platform in two ways. The first way would be through promoted search results. Similar to website searches, this feature would give priority to the products of the highest-paying advertiser. The second approach would be offering targeted product suggestions based on past purchasing behavior. Based on purchasing patterns, Alexa could proactively remind shoppers to repurchase or make recommendations for related products.[23] This approach has the potential to encourage users to adopt the more profitable behavior of subscribing to products rather than shopping for individual products.

Alexa and Data Collection

Although Amazon stated that the intent of its data collection was merely to improve its digital assistant, Alexa provided a means for Amazon to collect user data not just on internet activities and shopping preferences but also on how users interacted with other people offline.[24] It captured not only a user's browsing history but also conversations among family members and a history log of phone calls to contacts in the registry who had an Echo device.

The ability to collect this type of data, coupled with the vast volume of information collected from its online and Whole Foods retail businesses, potentially could enable Amazon to create a 360-degree view of users that would be difficult or even impossible for pure online or offline rival companies to reproduce. With Alexa for Business, Alexa in automobiles, and more connected devices in the Alexa ecosystem, Alexa's data collection footprint would grow in quality and completeness, making it increasingly valuable to Amazon for product recommendations and to third parties for targeted advertising.

Data Privacy and Security

In May 2018, it was reported that an American couple's conversation was emailed by Alexa to a contact without their knowledge.[25] Amazon later released a statement explaining that it was due to Alexa mishearing a background conversation as its wake word followed by a command

and subsequently a confirmation to record and send the audio. Although the content of the conversation was not sensitive, the incident fueled concerns over Alexa privacy and security.

In April 2019, Bloomberg reported that thousands of Amazon employees around the world were listening to voice recordings captured by Alexa.[26] Employees transcribed and annotated the recordings and then fed that data into the AI in order to improve Alexa's speech recognition and response to commands. Employees reportedly reviewed as many as 1,000 audio clips per nine-hour shift.

The recordings sent to the Alexa reviewers did not include the user's name and address but did include the user's first name, an account number, and the device's serial number. Amazon disclosed that its employees, for the development of new features, may review recordings even from users who have selected the option of disabling the use of their voice recordings. Despite Amazon's assurances that no audio was stored unless Echo was activated by pressing a button or using the wake word, each day auditors transcribed up to 100 recordings made when Alexa was triggered without a wake command.

These revelations raised many questions. For example, what does Amazon do to ensure the security of its devices and customers? How far would the company go to refuse third-party attempts to access customers' data, especially when profits are involved? How much responsibility would the company bear if something went wrong? And, finally, who is responsible for safeguarding the Alexa environment—Amazon or the end user?

Vulnerability to Hackers

Alexa's abilities to listen, record, and transmit data coupled with its access to a wealth of personal information made it a prime target for hackers. With the addition of skills, Alexa was able to access personal financial information, store-shopping preferences, and individuals' daily schedules. The growing ecosystem of Alexa-enabled devices and Alexa's increased presence in home automation and home security presented additional security vulnerabilities.

In January 2019, a family with a Nest thermostat and security cameras installed throughout the house was hacked. Not only was the hacker able to control the temperature of the home, he was also spy on the family through the cameras and even talk to them via the two-way voice function. Google, owner of Nest, commented that the hacker was able to access the system due to a weak password set by the owner and "Nest was not breached."[27] Although the incident did not involve Amazon or Alexa, it demonstrated the vulnerability of home-based systems to hacker attacks.

Voice Access Risks

Alexa required no interjection before the "Alexa" wake-up command, unlike other digital assistants, such as "Hey" (Siri), or "OK" (Google). The word "Alexa" could sound familiar to words

(or names) used routinely at home. The ease of unintentionally waking up the device posed a potential threat to privacy as well as personal and financial security.

By speaking ten phrases specified by Amazon, users could train Alexa to recognize different voices. The training phrases were stored on the cloud so that all new Alexa devices would be able to recognize them.[28] However, as of 2018, the use of voice profiles was limited to calling and messaging, flash briefing, shopping, and music. With most functions, Alexa did not enable voice profiles by default and generally still responded to unrecognized voices. This created new vulnerabilities.

In 2016, a couple woke up to find that four pounds of cookies and a doll house had been delivered to their home in Dallas, Texas. The products were ordered by their six-year-old daughter the previous night. TV news report on the story also triggered several orders for dollhouses when a news anchor said, "I love that little girl saying, 'Alexa ordered me a dollhouse.'"[29] In another instance in England, a parrot ordered Amazon gift boxes when the owner was away at work. This vulnerability was exploited by brands such as Burger King, which debuted an advertising campaign with the phrase "OK, Google, what is the Whopper burger?" which triggered Google's smart speakers to tell listeners about the fast-food chain's burger.[30]

These episodes demonstrated the susceptibility of the device to control by unauthorized parties within the hearing range of the speaker. The cited incidents were not serious, but others could involve transferring money, ordering expensive merchandise, and risking the wellbeing of occupants if Alexa were connected to control and security devices. If that were to happen, it is unclear who would be liable for any resulting damages. Furthermore, if a third party outside a home were to access Alexa and instruct it to open the door, would entering the home be considered a crime?

Other Attacks

Alexa was able to detect sounds outside the range of human hearing. This capability proved to be a weakness when multiple groups of researchers from China and United Stated gained control of the device by playing a high-pitched command embedded in a piece of music playing over the radio. The command, which was undetectable to the human ear, caused Alexa to open a website and switch on airplane mode. This experiment was called "Dolphin Attack" because dolphins use high-pitched noises to understand their surroundings. "Although the devices are not designed to handle ultrasound, if you put something just outside the range of human hearing, the assistant can still receive it, so it's certainly possible," said Dr. Steven Murdoch, a cybersecurity researcher at University College London.[31]

Another form of manipulation embedded commands into recordings or spoken text by slightly changing the audio file. Alexa's speech recognition systems translated sounds into letters and compiled them into words and sentences. Small changes to audio files can lead Alexa to interpret sounds differently than a human would. These techniques might be attractive to hackers, especially when owners of Alexa-enabled gadgets have not trained Alexa to respond to only one person's voice.

Hackers could also use a technique called "voice squatting" to trick users into granting them permission to access personal data or listen in on their conversations. This is achieved by using a skill with a name that sounds very similar to a legitimate application.[32] Some of them include "Fish Facts" instead of "Phish Facts"; "Cat Fax" instead of "Cat Facts"; "Capital Won" instead of "Capital One"; and "Rap Game" instead of "Rat Game." Once opened, the skills can cause significant security risk.[33]

In addition to the local device itself, in-home Wi-Fi presented security risks. Users unknowingly exposed themselves by failing to choose the appropriate Wi-Fi settings due to lack of knowledge or time.

Data Custodianship

Alexa generated a vast amount of data that was stored in Amazon's data centers, which some observers believed was a valuable asset for Amazon; however, the social responsibilities of custodianship for sensitive personal data were not well-defined.

Amazon has taken a position on granting access to customers' data to US government authorities. In 2015, the government sought Alexa's recordings for a customer that could contain clues to a murder the customer was accused of committing. Amazon rejected the search warrant, arguing that it was a violation of the free speech and privacy rights of both the user and Amazon.[34] (The recording was eventually handed over to the police by the customer.) Amazon responded similarly to a 2018 court order associated with the murder of two women in Farmington, New Hampshire.[35]

With the projected development of the capability to detect a speaker's accent/first language, ethnic origin, gender, and age, Amazon might soon have access to new data that could be valuable to governments. Combined with demographic data and purchase history, such data could help governments monitor and detect people in ways never imagined before. Such surveillance might aid in criminal prosecution, but it also fundamentally alters the notion of privacy.

Generally, people's actions inside their domicile are considered private. However, when a company and the government (through subpoenas) can record the proceedings inside a house without a court order, there is greater cause for concern that the technology can be misused and certainly breakdown the walls of privacy. Amazon, has a delicate walk to master. On one side, it must provide its customers a guarantee of privacy. For the government, it must comply with laws for request of data. Firms such as Apple and Google have begun to push back on broad-scale requests for customer digital records. However, if the government casts the data request as one related to fighting terrorism, firms find it difficult to push back. "Data demands focused on terrorism are tougher for companies to fight," according to Jennifer King, director of consumer privacy at Stanford Law School's Center for Internet and Society.[36] At the end of the day, customers will hold Amazon responsible for the use, misuse and sharing of Alexa data. The potential for unjust invasion of privacy is immense.

The Future of Alexa

Since 2014, Amazon had developed significant new capabilities for Alexa, developed an entire ecosystem around it, expanded Alexa's user base to over 100 million users, and made significant progress in monetizing its digital voice assistant.

However, Alexa's progress also created new challenges for Amazon, its Alexa-enabled customers, and society at large. Amazon needed to identify and address these challenges in order to encourage continued consumer acceptance and preclude detrimental government or regulatory action.

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