Binary Intelligence

Honors Great Questions Essay

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Can a number define a human? Your first response, like mine, is most likely a resounding "no." I instinctively revolt at the idea that a single number can define all the intricate complexities of a person's intelligence, culture, physical appearance, mannerisms, tendencies, talents, and so forth. Yet in today's society we often categorize people through the use of numbers; for example, as a college student I am defined in many ways by my Grade Point Average (GPA). Though a simple number, GPA reflects many things, such as my learning ability, dedication, work ethic, or intelligence. While GPA reflects many of these characteristics, it perfectly measures none of them: it simply gives society a better idea of who I am with respect to academic performance. Other numbers define my life as a student: standardized test scores, class rank, credit score, number of dollars in my bank account, salary of my parents, monthly income, financial aid, and number of credits, to name just a few. Put all of these numbers together and you begin to form an idea of who I am, and you may begin to make judgements about me. If I tell you I'm a student with a 2.0 GPA, a credit score of 750, a monthly income of $10,000, class rank of 20, and parents who make $30,000 a year, you might formulate the image of a student who is putting work before school, perhaps because his parents can't afford to help him. You might say he should better prioritize his life. You might also deduce he's at a small school or in a small program, since a GPA of 2.0 wouldn't put him at a class rank of 20 in most schools or programs. On the other hand, if I tell you I have a 3.99 GPA, make $800 a month, rank second in my class, and have parents who make $100,000 a year, a very different picture comes to mind.

While certainly a single number cannot define a human, can a set of numbers begin to give us an idea of the person behind the numbers? How well could we then describe a human if we had 100 carefully defined numbers about unique aspects of their character, personality, appearance, tendencies, and performance? How about 1000 numbers? 1 million? 1 trillion? In addition to numbers that define us, we often use numbers to represent us: a phone number and social security number are numbers that are uniquely tied to our identity, and used to distinguish us from others. But are we okay with being identified with a single number? How did the prisoners at Auschwitz concentration camp feel about the serial numbers tattooed on their bodies by Nazi guards [1]? Is it a good thing or a bad thing to be represented by a number?

Let's take just physical appearance for example. Can numbers accurately describe a person's face? Even given information such as the distance between their eyes, nose, mouth, size of their forehead, or angles of their cheekbones, it would still be hard to capture a person's face in a set of numbers. However, we can get an extremely detailed idea of what a person's face looks like with the roughly 8 million pixels in a 4K Ultra High Definition (UHD) photograph. A pixel is a number, meaningless by itself; yet arrange enough of them into a grid and assign them a color value, and you see a lifelike representation of a person's face, so clear that you could distinguish them from any other person that has ever lived. We sometimes refer to these ultra-high-definition photos as "life-like," which seems to suggest they resemble life, and perhaps imitate it, but still lack the essence that defines it.

Using high-resolution displays or printing options, we can replicate a human face with remarkable precision. Yet it's only a two-dimensional representation, so you might argue it isn't an accurate replication of a person's physical appearance. But have you ever been startled by a mannequin when you walked into a store or around a corner? You thought in that instant that the mannequin was actually a person, but it probably didn't take you more than half a second to deduce it was just an imitation of a person. If you're like me, then you probably laughed at yourself for being startled by a mannequin. Though oftentimes crude representations of a human, the mannequin had enough resemblance to trick you into thinking it was a real human, even for a brief moment.

Could we do the same thing with intelligence? A GPA, IQ, or SAT/ACT score are just numbers but they give us an idea of how intelligent a person really is, and we use them all the time. I disagree with anyone who believes that these numbers are sufficient to describe how truly intelligent a person is, for each contains its own biases and shortcomings. Yet if we gather enough data and enough numbers, 8 million for instance, could we generate a 4K UHD picture of a person's intelligence? It is common practice to copy or replicate an image of a human face, often with alterations or improvements. Can human intelligence be similarly replicated? If so, could it be improved upon?

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The Imitation Game

The field of artificial intelligence revolves around the idea that human intelligence can, in fact, be replicated. The idea of simulating intelligence with inorganic inventions is not unique to this century. In ancient Greek mythology Hephaestus, god of invention and technology, created Talos, a gigantic bronze warrior programmed to guard the island of Crete, who was imbued with life through a single artery or vein containing *ichor*, the life-fluid of the gods themselves. Interestingly, Talos falls into the category of what we now call "cybernetic organisms," which involves the synthesis of organic and inorganic components—a cyborg. Throughout the centuries, various civilizations used mechanical devices to perform "intelligent" tasks. Some suggest that the invention of the clock and the Guttenberg press are examples of the earliest forms of artificial intelligence, since these machines did by themselves what mankind could not. Sure, these are rudimentary tasks, but so are the first steps of a toddler, or the simple arithmetic of a young child. Later inventions include Pascal's arithmetic machine in 1642, the first digital calculator; the Lacquard loom in 1801, which could be programmed with punch cards; and Charles Babbage and Ada Lovelace's programmable calculating machines in 1832 [2] [3].

On the literary side, legends similar to Talos appear across centuries and cultures, such as the Jewish golem[1] and Frankenstein's monster. Other literary and philosophical works explored the idea of mathematically defining thought and logic, such as George Boole's *The Laws of Thought* in 1854, Gottlob Frege's *Begriffsschrift* in 1879, and Bertrand Russell and Alfred North Whitehead's *Principia Mathematic*a in 1913 [3]. While this idea of synthesizing intelligence from inanimate objects has sifted throughout centuries and cultures, the term "artificial intelligence" didn't get coined until 1956. In the following years and decades, interest in artificial intelligence exploded. Many of the brightest minds of the 1950s predicted that in just a decade or two, robots would be a normal part of everyday living, and supplant most of the tedious tasks of everyday life [4]. While those early predictions were obviously off, interest in artificial intelligence continues to remain and is becoming an increasingly important topic in today's technological landscape.

Perhaps the reason we are so intrigued with re-creating intelligence lies in our innate desire to create something new, something unique. The artist is driven by the image only he can see, and wants to share with the world; the author creates for the reader a new world of places, characters, ideas, and cultures; the inventor creates something he thinks the world needs but doesn't have; and the composer

[1] The golem is a magical creature within Jewish tradition and folklore, but mentioned only once in the Bible. In Hebrew, "golem" stands for "shapeless mass." A golem was a creature without a soul, such as Adam's body before his soul was implanted in it by God. A Golem was created by shaping it out of soil and brought to life through a ritual implantation of God's Divine Name. Golems in Jewish folklore were created to serve their creators.

strings together a set of harmonies and melodies that are uniquely his own. In Bloom's Taxonomy[2] for categorizing levels of intelligence, creation is listed at the top [5]. Can you recall when you first learned what a car was? Perhaps you learned how to identify different parts of the car, such as the windshield, wheels, doors, trunk, or engine. Maybe after learning some more you came to understand what those things did, and how they worked together. Then you learned how to apply it all together and actually drive the car. But driving the car is still a far cry from understanding exactly how the engine, transmission, powertrain, suspension, and electronic systems all work together to actually move you from place to place. After understanding all of that, being able to analyze and evaluate it to make improvements is still another level. Then, after traversing all these levels of understanding what a car is, the crowning proof of mastery over the concept of a car is to create one yourself.

Computers originated with the purpose of supplementing the power of the human brain. Credited as one of the fathers of the modern computer and artificial intelligence, Alan Turing worked with a group of fellow cryptanalysts[3] at Bletchley Park to create the Bombe, an electromechanical machine that deciphered the code generated by the German Enigma[4] machine during WWII. The decryption of the Enigma machine was beyond what any human or group of humans could accomplish, so

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[2] Bloom's Taxonomy, based upon a publication by Benjamin Bloom in 1956 titled *Taxonomy of Education Objectives,* identifies 6 categories or levels of cognitive processes in the learning process. These are commonly referred to by their descriptive "action words:" Remember, Understand, Apply, Analyze, Evaluate, and Create [5].

[3] A cryptanalyst is a person specializing in the solving of cryptograms or cryptographic systems, or communication in cipher or code.

[4] The Enigma machine was a message encrypting device used by the Germans in WWII. The device's messages, considered by the Germans to be unbreakable, were generated using a letter substitution system through the use of variables rotors and an electric circuit. In order to decipher the messages, the recipient needed to know the exact settings of the wheels. The version of the Enigma used by the German military had about 159 quintillion settings [54] [53].

a machine was invented that could replace the need for brainpower, at least for that particular task [6]. Computer science has always dealt with the idea of using a machine accomplish what the human brain cannot. In order for a computer to supplant the need for a human brain, it should have some sort of intelligence: we happen to call it artificial intelligence.

What really is artificial intelligence, and how closely does it replicate human intelligence? One definition is "the science of making intelligent machines, especially intelligent computer programs. It is related to the similar task of using computers to understand human intelligence, but AI (Artificial Intelligence) does not have to confine itself to methods that are biologically observable" [7]. Artificial intelligence is a loosely defined area of technology that deals with our attempts as humans to get machines, whether digital, analog, or a combination of the two, to be able to mimic human behavior. The discipline of artificial intelligence first started in the 1950s with the aforementioned Alan Turing, who after his work on the Bombe developed a theory of computation suggesting that a machine could simulate any conceivable act of mathematical deduction by shuffling symbols, such as a "1" or a "0." Modern computers at their core still do nothing more than shuffle 1s and 0s, they just do it at incredible speeds. Turing and his colleagues of the 1950s soon saw the need to quantify the ability—or intelligence—of the computers being developed.

The Turing test, also referred to as the "Imitation Game," is defined as "a proposed test of a computer's ability to think, and required that the covert substitution of the computer for one of the participants in a keyboard and screen dialogue should be undetectable by the remaining human participant" [8]. In other words, a machine is intelligent if a human being can't tell the difference between the responses of a machine from those of another human being. The strength of the intelligence is measured by how long the computer can carry on the mimicry without being detected. A weak or "stupid"

AI would be something similar to the mannequin that startles you in the department store: the AI gives an immediate impression of being human, but it only takes a few seconds to realize the deception. Strong or general AI, the elusive future of artificial intelligence, is where a person could not tell the difference between a human and an AI for an indefinite amount of time.

The Turing test is only one way of measuring artificial intelligence and operates under the assumption that a computer program is only intelligent if it acts like a human. Some say that no computer acts like a human, because fundamentally computers are dumb: all they know how to do is combine 1s and 0s; however, they do it at such an incredible rate they are able to perform extremely complicated calculations that no human could hope to rival. On the other hand, are humans and computers really that different? Isn't DNA, the blueprint of organic function and life, inherently digital?[5] Adenine, cytosine, guanine, and thymine, the fundamental pairs describing our genetic code,[6] are four "symbols" that define everything in our body. Are they just a quartic system rather than a binary one? Yet the fundamental structuring of human intelligence versus current artificial intelligence seems worlds apart, as evidenced by their unique abilities. For example, how long would it take you to add together 1 million numbers between 9 and 10 with 15 digits of decimals? What would be the likelihood of you making a mistake? The desktop computer I'm currently using to type this essay can generate and add a random sequence of 1 million numbers in a mere 0.02 seconds. Does that mean the computer is more intelligent than we are? You'd probably side with me in saying that the ability to add numbers together isn't a true reflection of intelligence. So if it's not, then what is a true reflection of intelligence?

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[5] Digital means having discrete states, as opposed to analog, which is composed of a continuum of possible values.

[6] The fact we use the word "code" for both the human genome and the fundamental programming of software is an interesting correlation.

For most humans, understanding language comes naturally, we learn it as children as a seemingly innate part of our development. Yet language interpretation is an extremely difficult task for computers, accomplished only in part by the most advanced AI systems in the world today. So are we more intelligent than computers?

Perhaps if we lay aside our more traditional idea of intelligence "as a pure and abstract concept and concentrate in seeing it as the power to solve problems, then we must take into account another factor: the 'working capacity'… the concept of intelligence, taken alone, is too abstract to be objectively measured. To make sense, it must be associated with some task" [9]. At specific tasks, computers are much better than humans, just through the sheer magnitude of their speed, or "working capacity." I'd say all of us are okay with letting computers be better than us at doing mathematical calculations, but are we okay if they begin to excel at other things as well, such as playing chess, driving cars, cleaning, trading stocks, or diagnosing cancer? What if they begin to excel at more than one thing? Are we okay with computers being more intelligent than we are?

Malicious Intelligence

Freeman Dyson, a theoretical physicist, once said "science is my territory, but science fiction is the landscape of my dreams" [10]. When it comes to artificial intelligence, some people have dreams, others have nightmares. In the 2004 film *I, Robot* Detective Spooner (played by Will Smith) is one of the only people in his society who distrusts the robots that have become an integral part of the futuristic society [11]. All of the robots in this society are governed by Isaac Asimov's three fundamental laws:

1. A robot shall not harm a human or through inaction allow a human to be hurt.
2. A robot shall obey a human except where it will violate the first law.
3. A robot shall preserve itself from harm unless it violates the first and second law.

However, there is an interesting conflict within the first law: there are many situations in which both parts cannot be simultaneously satisfied; for example, injuring an attacker to protect another human, or two people are at risk and only one can be saved. In the movie, Spooner and Susan Calvin (who works for the company designing the robots), discuss Spooner's previous accident[7] involving another person and a robot—the second example:

> Susan Calvin: "The robot's brain is a difference engine. It's reading vital signs. It must have done…"
> Detective Del Spooner: "It did. I was the logical choice. It calculated that I had a 45% chance of survival. Sarah only had an 11% chance. That was somebody's baby. 11% is more than enough. A human would've known that" *[11]*.

Most of the robots resolved the conflict through simple calculation: the humans they interacted with were to them simply a set of numbers and calculations. The human instinct to protect a child rather than an adult may be a key part of what constitutes our human intelligence. Perhaps these are factors of human intelligence that can never accurately be replicated by artificial intelligence. How can someone reduce to a set of mathematical and logical relationships the love of a mother for a child, who seems to "know" when something is wrong by simple "motherly instinct?" But is this actually intelligence? Are emotions an integral constituent of human intelligence? Bloom's Taxonomy lists the affective domain—dealing primarily with emotions—as one of the three central domains of learning, but does artificial intelligence need to replicate emotion to replicate intelligence? Rather than magnifying our intelligence,

[7] For those not familiar with the movie, years earlier Det. Spooner was in an automotive accident where he collided with another car and both were thrown into the river. A small girl was in the other car. A robot, witnessing the event, came to the rescue and decided to save Dt. Spooner rather than the girl.

emotions can also cloud reason and impair judgment: how often have you done something in a rush of strong emotion that you regretted afterwards?

These robots, on the other hand, only knew how to maximize outcomes, utilizing a classic utilitarian approach to ethical dilemmas, which is only one of several ways humans deal with them. VIKI, the AI in charge of the robotic network in *I, Robot*, similarly maximized the outcome on a more abstract level and decided that future harm to humanity would be prevented by removing their freedom, even if it meant injuring people in the short term. VIKI then overrode human control and began subduing all humans who resisted its jurisdiction. While *I, Robot* is a fictitious movie that will most likely not reflect the future of artificial intelligence, the analysis of science fiction sheds light on our cultural perceptions of artificial intelligence. The recurring theme of humanity being threatened by malicious artificial intelligence strongly suggests that we distrust AI, perhaps because we distrust anything—or anyone, for that matter—that doesn't display emotion.

A similar situation occurs with Ultron in the Marvel's 2015 film *Avengers: Age of Ultron*. Ultron, a malicious artificial intelligence, is created by Tony Stark to protect the world [12]. Ultron decides that the best way to protect the world is to eliminate humanity. Similar to VIKI, we see that the motivational drive of these AIs stems from a cold, emotionless application of logic to a specific mission or objective. It seems that the supreme "intelligence" of these creatures of digital wonder lacks true human intelligence, for could a truly intelligent human ever reach the same conclusion? Perhaps we conclude that nothing can be truly intelligent when its logical processes result in harm to humanity, which could also be of itself a limited definition of intelligence, hinging on the idea than human intelligence is ultimately superior. Many who once had faith in God or a supreme being stop believing that such a being could exist once they come face-to-face with the awful tragedies that take place around the world, since they can't reconcile the fact that God, who is supposed to be more intelligent than us, would allow or purposely inflict harm on humanity. But this logic operates on the same assumption that human intelligence, which includes self-preservation, is the true definition of intelligence. Therefore, we seem to dismiss the "intelligent" conclusions of these malicious artificial intelligences because they lack human emotion or innate interest in the preservation of humanity.

But could this actually happen? Can a robot develop malicious intent and turn against its creator and embark on a mission of world domination? Well, the robots in a study done by researchers at the Ecole Polytechnique Fédérale de Lausanne in Switzerland learned the ability to deceive. However, these robots were literally bred to develop this ability: they were placed in an arena and given the objective to find "food" and stay away from "poison," represented by lights on the arena floor. Over 50 generations of evolution, some robots learned to hide the fact that they had found food, thereby preventing other robots from finding it. However, here again we see a specific mission or objective that the robot mathematically tries to accomplish and optimize, without respect to any sort of moral code [13]. All robots are programmed with boundaries and limitations, and there are plenty of ways to incentivize what we consider positive moral behavior and penalize negative moral behavior. However, if we succeed in the development of sentient intelligence[8] such as VIKI or Ultron, then what will stop them from reaching similar conclusions? Even if they are preprogrammed to be benevolent, what will stop them from developing malicious behavior towards humanity? History is full of stories of "good" humans that, for a variety of reasons, develop malicious intent towards humanity or pursue destructive behavior on the basis of an overarching objective. Hitler tried to perfect humanity by the elimination of "inferior" humans. World militaries seek out terrorists on the grounds of freedom and liberty, while terrorists engage in their

[8] Sentient intelligence refers to intelligence that is consciously aware of its own senses

destructive objectives for what they perceive as the "greater good." So it seems that the self-development of malicious AI would be a successful replication of human intelligence. Do we want to replicate all aspects of human intelligence or should we try to improve it?

Returning to the films previously mentioned, in each we see an interesting juxtaposition of a malicious artificial intelligence with another benign artificial intelligence. Sonny in *I, Robot* has the ability to consciously think, like VIKI, but is not constrained to the three laws. He somehow has the ability to feel emotion, and it is those emotions that push him to reject the logical conclusion of VIKI and help Detective Spooner end its campaign for world domination. Similarly Jarvis, also an artificial intelligence created by Tony Stark, is instrumental in aiding the Avengers to defeat Ultron. In the end, artificial intelligence is guided by the directives it is given by the programmer and can be used for either good or bad.

Given that humans create and guide artificial intelligence through programming, does that necessarily mean we are more intelligent? Does that automatically place them in an inferior location on the echelon of intelligences? To do so would seem to limit the possibility of learning and progression. Technically each of us are "programmed" biologically through the combination of our parent's DNA, and then "programmed" socially by our parents and our society to become who are at the present time. To negate the viability of artificial intelligence superior to our own would seem to argue that a child cannot become superior to their parents or their own society. On the other hand, the DNA of a human child is not the direct result of human intelligence in the same way a computer program is. So if we attribute our existence to biology, are we inherently inferior to biology? Aren't we able to manipulate and alter biological processes, which we consider to be our creator? Does the fact that our "code" is biological rather than electrical make that much of a difference when we extend the discussion to include artificial intelligence as our creations? If we then move one plane higher and attribute our programming to God rather than purely biology, we then seem to accept the idea that the creation is inferior to the creator. But are we the Gods of artificial intelligence or simply the biology that puts it together, or the parents that organize it and facilitate its development?

Regardless of malicious or benevolent intent or our inherent location in the echelon of intelligences, all of the artificial intelligences portrayed in these movies demonstrate abilities above and beyond those of their human creators: VIKI flawlessly controls an enormous network of robots, Sonny is able to retrieve the nanites[9] from a force-field, Ultron coordinates a world-wide initiative to destroy the world, and Jarvis is able to keep tabs on all the technological needs of both Stark Industries and the Avengers. Humanity is not so much in danger from being eliminated by malicious robots, but rather by robots that can simply outperform them.

Outperforming Humans

Hans Moravec, a professor of robotics at Carnegie Mellon University, stated "I am sure that [robots] will outperform us in any conceivable area of endeavor, intellectual or physical" [4]. How did you learn to drive? If you grew up in the United States of America, and most other developed countries for that matter, you most likely needed to go to school and pass a test before you were legally able to drive. Why? Because we try to make sure we have intelligent drivers on the road, since good driving involves the need for attentiveness, instinct, control, and prevention.[10] Good driving is a fairly complicated skill that requires a lot of information processing and decision-making, yet modern artificial

[9] The micro-robots used to erase VIKI and stop her conquest of world domination.

[10] Granted, driver's education programs are certainly not perfect or even adequate in helping us develop or test our capacity in these abilities, but the attempt to do so at least indicates the importance we place on having intelligent drivers.

intelligences today are capable of successfully performing this task. In 2014, there was an injury every 1.25 million miles driven [14]. A few months ago, Google had driven its self-driving cars more than 1.8 million miles with only 13 minor fender-benders: that's a *fender-bender,* not an injury, every 138,000 miles [15]. Interestingly, each of the 13 incidents were caused by a human driver, typically running into the back of the car, proof that human intelligence is fallible and often unreliable. Obviously the track record of self-driving cars isn't perfect, but artificial intelligence doesn't need to be perfect to replace us; it just needs to be better.

A self-driving car doesn't sleep, doesn't get distracted, and doesn't drink alcohol. It is always monitoring road conditions and the vehicles around it. Humans only have two eyes to see what is going on around (mostly in front of) them, whereas self-driving cars "see" using maps, lasers, radars, and cameras to detect objects in all directions [16]. They simply have more information and can process it quickly, reliably, and predictably. Once more self-driving cars get on the road, it will be a relatively simple task for them to communicate with each other and further increase traffic safety, and given that 1.24 million people died from automotive accidents in 2010, the automotive sector needs a significant improvement in safety [17] [18].

Other than potentially saving a million lives per year, what other impact might self-driving cars have? In 2014 the transportation and warehousing industry sector employed about 4.7 million people in the USA, about 3.1 percent of the total workforce [19]. If self-driving cars prove to be safer and more reliable than human drivers, this substantial portion of the workforce will be replaced by artificial intelligences.

Transportation is only one job sector susceptible to being replaced by artificial intelligences or robots. Take a minute to think about all the mundane tasks humans do every day: taking an order at a fast-food restaurant, janitorial work, manufacturing factory lines, making phone calls, receiving phone calls, writing newspaper articles, serving drinks at a bar, and the list goes on. Most of these jobs not requiring high levels of human intelligence will likely be replaced by robots or computers with minds of their own, and many are already in the process of being replaced. These humans will need to develop new skills or abilities in job sectors not immediately threatened by artificial intelligence and robotics, primarily by gaining a better education.

So is sending everyone to college the answer? Laying aside the fact our secondary education institutions are already at or above maximum capacity and require a substantial amount of monetary investment, many professional jobs are likewise at risk of being replaced by AI. Perhaps you heard about Watson, IBM's top-of-the-line artificial intelligence, winning *Jeopardy!* back in 2011. Aside from being able to beat all humans at a TV trivia game, one of Watson's day jobs is learning to become a doctor. Watson is designed with "a singular ability to grasp the intricacies of the human language and answer exceedingly difficult questions" [20]. Watson is also designed to process and understand unstructured data, which makes up about 80 percent of data worldwide [21]. After passing through the initial training phase of winning *Jeopardy!,* Watson was directed towards mastering the field of medicine, which it did with remarkable success. Watson, like most computers, excels at gathering and processing information at a rate that is simply impossible for humans to match: it can, for instance, "process more information in a day than any human could in a lifetime. It can read all of the world's medical journals in less time than it takes a physician to drink a cup of coffee" [20].

When it comes to making accurate diagnoses, information is everything; Watson can simultaneously peruse patient records, track recent drug tests, keep tabs on medical breakthroughs, compute all of the possible side-effects of a diagnosis with any previous treatments, and stay up-to-date on the potency of new drugs or therapies. A few years ago, Watson had assimilated the contents of 600,000 pieces of medical evidence, read more than two million pages of medical journals, and had the ability to search through more than 1.5 million patient records [22]. Human doctors are great, but they simply can't process all that information for every patient with the speed and reliability of an AI such as Watson; besides, it would take a human doctor about 160 hours per week just to keep up with new medical knowledge. Watson can also easily take care of "utilization management," or working out how to do something for the cheapest way possible. Additionally, just like humans, AIs such as Watson get better with time, so the more diagnoses they make the better they will become [22].

While it makes sense that artificial intelligences may excel at data collection and interpretation, some may think that surely more abstract areas of human intelligence or performance, such as the fine arts, must be beyond the capabilities of AIs to replicate. Well, paintings by AARON, a robot developed at University of California San Diego by Professor Harold Cohen, have sold for hundreds or even thousands of dollars [23]. If I were to show you some of AARON's paintings, you probably wouldn't have the faintest idea that they were done by a robot. Pieces of music composed by computers have been played by the London Symphony Orchestra [24]. Underneath their "creative" surface, both art and music can be reduced to mathematical ideas, laws, constraints, and relationships. While a composer may seem creative, he's still following many rules that govern how the piece will sound and work together. A computer, with the right algorithm, can mimic almost the same process humans do. So, according to the Turing test, since the output of these robots is nearly indistinguishable from that of a human, they must be intelligent.

But what about caregiving? How could a robot ever replace the warm embrace of a mother, or the caring eye of a schoolteacher, tutor, nanny, or friend? Disney's recent movie *Big Hero 6* suggests that robots may be capable of being effective in these areas as well. Baymax, a large poofy white robot designed for healthcare, effectively helps the 14-year-old Hiro Hamada overcome severe emotional trauma after the death of his brother [25]. This suggests that in the future even caregiving may be understood well enough it can be reduced to a similar set of mathematical rules, constraints, and relationships, and thereby replicated by AI. Maybe a robot's separation of emotion from intelligence—assuming true intelligence is actually separable from emotion—may actually be a strength in situations where dependability, consistency, and reliability are key factors. Perhaps AI healthcare or caregiving could even be superior to that offered by humans, since an AI could be programmed to pick up on social cues and hormonal imbalances, and then offer the appropriate response. It could even personalize responses to each individual, just as Google personalizes your internet experience based upon past results. But would you want your grandmother watched over by a robot nurse or a human one? Consider that the robot nurse never sleeps, has all the necessary knowledge and skills, and never has an "off" day. While compassion—something we often perceive as a necessary element of effective caregiving—is an emotion and may therefore may lie outside the ability of AI to truly replicate, if the outward effect of their interaction with humanity it the same, does it matter whether or they actually experience the emotion of compassion?

So if information processing, analysis, creativity, and caregiving can all be replicated by artificial intelligence, is there anything a human can do that lies outside the capabilities of an artificial intelligence to replicate? Artificial intelligence relies on a problem being reduced to mathematical and logical constructs, bounded by rules and relationships; therefore, if something can be explained or modeled mathematically, it can be done by an artificial intelligence. So is there anything that can't be explained by science and mathematics? There is certainly a massive amount we do not yet understand, but over the next decades, centuries, or millennia, will we find anything that is simply impossible to explain through mathematics and science? As of right now, no good scientific evidence exists to negate the idea that all organic structure and behavior can be modeled or explained using physical laws (i.e. that all biology is computable) [4]. If we discover over the upcoming decades and centuries that biology indeed is computable, then everything we do could be done by a computer, and since computers are masters of optimization, they could probably do it better.

Superintelligence

Imagine now that we get to the point where artificial intelligences are fully conscious, or are self-aware and able to learn the way humans learn.[11] What if in the next 50–100 years we create artificial intelligences like VIKI, Sonny, Ultron, Jarvis, or Baymax? This type of AI, referred to in the industry as "strong" or "general" AI, would be capable of self-improvement, just like humans. However, these robots, by the sheer magnitude of their computational ability, could progress at a breath-taking rate, developing future robots with even more advanced abilities and intelligence. Even if we successfully got this robotic community to be friendly towards humans (setting aside the rise of malicious robots like VIKI or Ultron who are hell-bent on destroying or subduing humanity), they could soon surpass us in every aspect, and continually improve in an exponential fashion until human intelligence and ability become so negligible that we are left in the dust of our own creation and forced to accept our place as secondary constituents in our new bio-techno-sphere. This recursive self-improvement might lead to the development of a "superintelligence" that would simply be unfathomable and incomprehensible to the human mind. The point at which artificial intelligence passes beyond the ability of humans to comprehend or understand it is referred to as the "singularity of artificial intelligence." But doesn't this sound a little too much like a piece of science fiction?

[11] We have actually already started breaking ground in the area of robot consciousness. A recent experiment by Professor Selmer Bringsjord of New York's Rensselaer Polytechnic Institute got robots to successfully pass the "wise men" logic puzzle, which previously had been used as a standard to separate people from machines, since it is a fundamental test of consciousness, or self-awareness [51].

In his survey of science fiction, *The Dreams our Stuff is Made Of: How Science Fiction Conquered the World,* Thomas M. Disch writes, “It is my contention that some of the most remarkable features of the present historical moment have their roots in a way of thinking that we have learned from science fiction” [26]. Jason Pontin, editor-in-chief of *MIT Technology Review*, in an article about the predictive power of science fiction said, “Indeed, it is more useful to ask, What hasn’t SF [science fiction] predicted?” [10] In other words, just because it sounds like science fiction doesn’t mean it’s not possible; to the contrary, it actually means it’s highly plausible. If the singularity of artificial intelligence wasn’t a valid concern, it wouldn’t have been a topic of discussion in the Association for the Advancement of Artificial Intelligence (AAAI) conference back in 2009 [27]. While the reality of the actual realization of the singularity of artificial intelligence is still more science fiction than fact, it is still a major topic of debate within the AI community and one that must be seriously considered as we plunge further forward into our technology-driven future.

Do you, like me, at least shudder a little at the prospective reality of the singularity of artificial intelligence? Perhaps we fear the creation of anything more intelligent than ourselves because we are so firmly set on the assumption of our own superiority. But should we fear something ultimately superior to ourselves? Many in the world believe in the existence of a God or supreme being that is superior to humanity—a belief that comforts them and fills their lives with meaning and purpose—but we have a much harder time accepting the reality of a superior intelligence when it tangibly exists in our realm of experience. For example, we seem much more apprehensive about intelligent, autonomous robots than pieces of intelligent software: Ultron is much more threatening than Jarvis. On a similar vein, perhaps for this same reason Jesus Christ was rejected by the Jewish scholars of his day, for while they supposedly believed in God, they could not accept the physical representation of one.

I personally have no trouble accepting the existence of a real, tangible, intelligent God and may even believe in the possible existence of alien intelligence greater than our own somewhere with this vast universe, but I hesitate accepting the superiority of an emotionless intelligence of a machine. It seems to me that the full extent of intelligence extends beyond cognitive ability and must include emotional and spiritual components that constitute fundamental parts of intelligent decision-making processes. If we define intelligence to include these emotional and spiritual components and assume that these are somehow intrinsically beyond the ability of electronics to replicate (which hasn't been proven or disproven), then human intelligence can't be replicated by artificial intelligence, only mimicked.

Mimicking the Brain

Although a computer can mimic the power of the human brain, how intelligent is it? As opposed to previous definitions of intelligence as defined by scientific communities, Legg and Hutter concluded in their 2007 study that definitions of intelligence converge toward the idea that "intelligence measures an agent's ability to achieve goals in a wide range of environments" [28] [29]. The neuroscience and clinical physiology disciplines believe all of our intelligence, whether it be cognitive, emotional, spiritual, etc., exist within biological processes of the brain. Therefore, if the biological processes of the human brain can be reduced to mathematical relationships and a bunch of numbers, so can human intelligence.

The human brain is an extremely complex network of about 100 billion nerve cells [30], and is the most complex part of the human body [31]. While we still know relatively little about the brain, scientists have learned more about the brain in the last 10 years than in all the previous centuries combined. Coupled with our increased understanding of the human brain has been an increase in using it as a model for simulating artificial intelligence. Neural nets, a common architecture for modern artificial intelligence, use a large number of interconnected processing nodes working together to solve problems, much like the human brain, and also like the human brain, learn by example [32]. The brain learns by making adjustments to the synaptic connections between neurons, and this type of AI learns by establishing connections between its neural nodes. Neural nets have a remarkable ability to analyze and learn from complicated or incomplete data sets and are excellent at recognizing patterns and detecting trends more complicated than any human or other type of computer algorithm could find.

Even with modern computing power and sophisticated algorithm architectures such as neural nets, computers today cannot compete with the ability of the human brain in functions such as recognition, navigation, and adaptability [4]. In every example I have given in which a robot performed better than humans, it only performed better in a very limited, special-purpose area. According to Legg and Hutter, to be truly intelligent, it must be able to "achieve goals in a wide range of environments." Is the brain a universal machine or is it also special-purpose? According to Hans Moravec, through the passage of time and the slow refinement of the evolutionary process human brains became very good at navigating, recognizing, and adapting in order to survive, which for them meant eating, not getting eaten, mating, and protecting offspring. "Honed by hundreds of millions of years of evolution, the brain became a kind of ultra-sophisticated—but special-purpose—computer" [4]. Most if not all modern computers can be easily reprogrammed to do something completely different, but the human brain is not so easily "rewired." If we could take a few hundred of our neurons and arrange them in the same way a computer calculates, typical mathematical operations that take us minutes to complete would take milliseconds. Even the prodigies of mathematical calculation are millions or billions of times slower than a computer. Simply due to innate architecture, humans and computers excel at different things [4].

In order to compete with the theoretical total processing power of the human brain, computers need to be at least 10,000 times more powerful than they currently are [4].[12] Many computer scientists state that, based on our current trajectory of doubling the number of transistors per chip each year (known as Moore's Law), we should be able to reach this goal in about 20 or 30 years. Nearly all of the scientific community that predicts that artificial intelligence will reach or exceed human intelligence around 2050 assume the current rate of progress will continue. However, in early 2016, the semiconductor industry will abandon its pursuit of Moore's Law,[13] since by the early 2020s we'll be manufacturing devices on the 2-3 nanometer scale, where each feature will be about 10 atoms across. At that scale, uncertainties due to quantum mechanics will make the transistors "hopelessly unreliable." Also, due to problems dissipating heat at such small levels, CPU clock speeds have flat-lined since the mid-2000s [33]. Another significant issue, related to the heat problem, is that modern computer chips are extremely inefficient: they use up a lot of energy. Watson, arguably one of the most powerful artificial intelligences in existence, requires about 65,000 Watts of energy, whereas the human brain runs on about 20 [34]. In a future where energy efficiency and conservation will be at a premium, we simply can't maintain the current rate of progress, at least not with existing technology. If we simply look at intelligence as the accomplishment of cognitive tasks, human intelligence can't currently be replicated even in that regard due to this massive discrepancy of energy requirements.

[12] Based upon the speed of the human retina in capturing and interpreting information from the eye and relaying it to the brain.

[13] This does not mean that further development of the traditional IC (integrated circuit) will discontinue, but rather than focusing on the sheer number of transistors (Moore's Law), the industry will begin focusing on the creation of specialized circuitry for individual applications.

To narrow this discrepancy, IBM, among many others, has launched a research program attempting to design a neuromorphic chip, or a chip that replicates the brain's way of computing, by integrating memory storage within connections of artificial neurons. Their initial chip prototype has already learned on its own to play the archaic computer game Pong.[14] While their original goal was to "reverse-engineer the brain," Dr. Modha, the IBM computer scientist leading the research, said that "deciding what not to do is just as important as deciding what to do…we're not trying to replicate the brain. That's impossible. We don't know how the brain works, really" [34].

Perhaps our pursuit to make artificial intelligence replicate human intelligence is inherently flawed and foolhardy, because the human brain may not actually be reducible to a set of sophisticated electrical circuits. It seems apparent that artificial and human intelligences excel at different things, so why not play to each of their strengths rather than getting one to replace or replicate the other? Eventually artificial intelligence will integrate itself, even more than it now has, into our daily lives, and if both are uniquely good at distinct objectives, both human and artificial intelligence will be benefitted.

Distinct Domains of Intelligences

Howard Gardner, a developmental psychologist at the Harvard Graduate School of Education proposed in his Theory of Multiple Intelligences that humans "possess different kinds of minds and therefore learn, remember, perform, and understand in different ways." According to his theory, "we are all able to know the world through language, logical-mathematical analysis, spatial representation, musical thinking, the use of the body to solve problems, an understanding of other individuals, and an understanding of ourselves. Where individuals differ is in the strength of these intelligences—the so-

[14] I find it entertaining that it's a feat of accomplishment that a computer can learn to play a computer game. But at the same time, we as humans gain a great deal of entertainment from playing "human" games.

called profile of intelligences—and in the ways in which such intelligences are invoked and combined to carry out different tasks, solve diverse problems, and progress in various domains." [35] In summary, human intelligence can be separated into separate and distinct types of intelligences, and each individual has unique combinations of the strengths of these intelligences. While artificial intelligences may display aptitude in nearly all of these areas of intelligence, are they really the same? Is an AI that can compose music the same as a composer who does it because she loves it, or is a robot capable of complex movement equal to the dancer who is mentally, emotionally, and spiritually invigorated every time he goes on stage, or is the computer equal to an engineer who pursues impossible problems because she wants to change the world? Can a robot ever be a Shakespeare? If the output is the same, is there a difference? If the AI or robot passes the Turing Test and the observer cannot distinguish between the two, perhaps is doesn't matter whether one has emotions or not.

Maybe intelligence extends beyond the ability to perform tasks or process information. Returning to Bloom's Taxonomy, learning (which we assume is the necessary prerequisite to intelligence) is split into three domains: cognitive, affective, and psychomotor [36].[15] Some argue that AI, with time, can extend into all the levels of the cognitive domain, which include remembering, understanding, applying, analyzing, evaluating, and ultimately creating. Yet others argue that a computer cannot truly pass above the second stage: understanding. In a well-known counter-argument to general AI known as the Chinese Room Argument, John Searle contends that while a computer may, for example, receive strings of Chinese characters and carry on a conversation in Chinese with a native Chinese speaker, the computer

[15] The cognitive domain encompasses knowledge and development of intellectual skills, which includes recognition of facts up to evaluation and creation of new knowledge. The affective domain deals with how one approaches learning, and includes feelings, values, motivations, and attitudes. The psychomotor domain includes physical movement, coordination and use of motor-skills [52].

really doesn't understand Chinese: it just knows how to manipulate symbols. The abstract concept of "understanding Chinese" is outside the realm of computation. The argument refutes the idea that human brains can be reduced to a simple computation or numeric system, and states that computers can, at best, only simulate the biological processes of understanding and internalizing a concept or idea [37].

For example, the use of computers in education is becoming more and more common. Computers with sophisticated "intelligent" algorithms can read and grade a student's paper. However, the computer operates within defined bounds and rules, using algorithms to search for key ideas or phrases, check for grammar, and so forth. It is possible to write an essay that makes no sense at all, has no sense of cohesion or strength of argument, but will get a perfect score from the computer. Currently, a computer simply can't grasp the "strength of an argument" or "cohesion" as it processes the writing [38]. It can search for factors that denote the presence of a strong argument or cohesive essay, but can the actual abstract idea we perceive even without knowing the rules or what to specifically look for be represented by 1s and 0s? If a computer has a hard time grasping these relatively simple abstract ideas, perhaps the enormously complex and abstract nature of human consciousness, and therefore intelligence, is beyond the ability of numbers to replicate.

While a computer's grasp of the cognitive domain is arguable, it seems that the affective domain lies outside the realm of artificial intelligence. The affective domain encompasses the way we deal with things emotionally, such as feelings, values, appreciation, enthusiasm, motivations, and attitudes. The importance of this domain is only recently[16] coming to light within the educational community, as

[16] Recently meaning within the last several decades, which is a relatively short time in comparison to the existence of the learning process.

teachers and professors realize the need to teach attitude and instill motivation as well as transmit information.

Beyond the importance of feelings in the learning process, perhaps the perception of feelings and spiritual sensitivity is itself a form of intelligence. I once had the privilege to know an elderly woman named Eustolia, who lived in a small concrete home in a remote Mexican village. Eustolia could barely read or write and struggled understanding basic principles I tried to teach her. If measured simply by the cognitive domain, she was not intelligent. Yet this elderly woman had endeared herself in the hearts of all those around her and, through sheer optimism and goodness, made a meager living for herself and her sons. When it came to an understanding of one's self, others, and the spiritual world around her, it quickly became apparent how much more Eustolia knew than I did, despite the fact I was attending an extremely competitive university and near the top of my graduating class. Surely intelligence extends beyond what academic institutions attempt to impart to us. While Eustolia wasn't intelligent is the traditional sense of the word, she exhibited an ability to accomplish the task of perceiving others and herself (respectively identified as intrapersonal and interpersonal intelligence by Gardener) beyond those around her, so according to Gardener, was highly intelligent in those areas. However, returning to Legg and Hutter's definition that intelligence corresponds to an ability to accomplish a variety of goals, she wasn't intelligent, because she excelled only in these specific areas. Only time will tell if artificial intelligence, perhaps when combined with biological systems to constitute a cybernetic organism such as the mythical Talos, will be able to truly replicate emotional or spiritual components of human intelligence. To truly replicate human intelligence, they must incorporate this into the other domains and types of intelligence as well, such as the psychomotor domain.

Interestingly enough, the psychomotor domain also presents a significant challenge for robots [39]. While robots have made massive strides in the areas of machine learning and computational ability, they still struggle with even basic locomotion. Just watch the highlight reel of the 2015 DARPA Robotics Challenge and you'll probably laugh (like I did) at the sight of the best robots in the world falling over performing simple tasks such as opening doors, climbing out of cars, or walking up stairs. The control algorithms for locomotion are extremely complex and are something the human brain does instinctively. Even the complex motion of manufacturing robots can't really be deemed intelligent, because it is inflexible and unadaptable without human intervention. Typically these robots are enclosed in cages because they are so dangerous to humans. Even the more advanced example of self-driving cars is still a relatively simple type of locomotion: limited to two degrees of freedom[17] and a handful of inputs and outputs. The human body, on the other hand, is composed of a couple hundred degrees of freedom, and therefore capable of much more complex motion. It will likely be a long time before we see a robot move with the fluidity of Sonny, Ultron, or Baymax.

Replication or Replacement

So while it may not be possible to replicate all aspects of human intelligence, artificial intelligence certainly has the ability to replicate, or at least mimic, enough aspects of it to replace the need for some aspects of human intelligence. If robots live up to the expectation of the scientific community and end up being able to out-perform us in anything and everything, will that limit human progress? If any job a

[17] Degrees of freedom measures the number of independent motions a system can perform. A car can turn left and right and move forward or backward, and therefore has two degrees of freedom (neglecting the more complex internal motions of the suspension, drivetrain, and powertrain components). A human arm has seven degrees of freedom: three rotations of the shoulder, one of the elbow, one axial rotation of the forearm, and two rotations of the wrist.

human can do can be performed better by a robot, will that stop us from trying? I believe the integration of extremely capable, intelligent, and powerful AI will be a dividing point for humanity, and will indeed lead to a "fundamental restructuring of our society" [4]. Whereas some will take the excuse to sit back and let the robots work for them, others will grasp what is unique about human intelligence (which will only fully come to light as this transition actually takes place) and use it as an opportunity to learn and do what they truly love. The Disney film *WALL-E* highlights the dangers as well as the benefits of a robot-dominated society [40]. The human community in the movie humorously became extremely fat and lazy, while robots secretly took control. In the end, WALL-E's display of human-like emotion endears to him the human population and re-ignites the idea of their own humanity. Cleverly, for much of the movie, the robot WALL-E, through its display of emotion, seems much more human than the humans do, again suggesting the idea that intelligence needs to incorporate emotional components to be complete. On a similar vein, the android Lieutenant Commander Data in *Star Trek: New Generation* fits seamlessly into the hierarchical command structure of the *U.S.S. Enterprise* [41]. Eventually Data receives the ability to process emotions, but even before that time, his logical and computational ability are a unique and valuable resource for the crew, but clearly not supreme to the point of excluding the need for the unique abilities of the other members of the crew. Perhaps then humanity isn't replaceable, even by "superior" artificial intelligence, because in the end we are unique. The ultra-sophisticated complexity and harmony of our biological body may always be distinct from that of a mind (if you can call it that) composed only of electrons whizzing in a circuit.

For those who believe in the existence of a God or a supreme being, the existence of a supreme, omniscient, and omnipotent intelligence does not degrade or demean their feeble abilities to replicate it. Instead, many such individuals rely on it to cultivate and accelerate their own intellectual abilities. Similarly, if artificial intelligence surpasses our own, it may become a tool to help humanity progress and reach new intellectual frontiers. Additionally, since robots and AIs will have the ability to replace the need for humans to perform work, more time may be available to humans to pursue their dreams and aspirations, whether good or bad, such as in the move *WALL-E*. Just as specialization within a global economy increases the wealth of nations and individuals at the short-term expense of certain industries losing jobs and undergoing repurposing, AI specialization and globalization will likely have a similar net positive result on humanity. Rather than removing the need for human intelligence, perhaps future artificial intelligence will magnify it and expose more fully its inherent strengths and weaknesses, allowing for more rapid progress and development; maybe we don't need artificial intelligence to perfectly replicate human intelligence, we need it to augment and enhance it, and allow it to do whatever it does best.

Can human intelligence be replicated? Only time will truly tell. However, even now artificial intelligence replicates enough aspects to give the semblance of human intelligence, such that they are oftentimes indistinguishable in certain tasks. Although a UHD photograph captures the semblance of a landscape or a person's face, in the end it is still a replication, useful in its own regard in ways that the real face is not, otherwise we would not want it. Similarly, artificial intelligence may generate a UHD replication of human intelligence, useful in ways different from that of the original—and in many regards superior—but in the end AI is simply a replication made up of millions of numbers. Yet that replication has utility, accomplishing what human intelligence alone cannot. Perhaps human and artificial intelligences, when put together, constitute a binary intelligence, like 1 and 0, separate and distinct, but, when combined together, they could unlock the code that defines humanity.

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