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Potential Futures for Information

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Abstract

Information is one of the most powerful tools available today. All advances in technology may be used, as David Sarnoff said, for the benefit or harm of society. Information can be used to shape the future by free people, or used to control people by less than benevolent governments, as has been demonstrated since the mid-1930s, and with growing frequency over the past 50 years. What promised to once set people free and fuel an industrial revolution that might improve the standard of living over most of the world, has also been used to manipulate and enslave entire populations. The future of information is tied to the future of technologies that support the collection of data, processing those data into information and knowledge, and distribution. Technologies supporting the future of information must include technologies that help protect the integrity of data and information, and help to guarantee its discoverability and appropriate availability—often to the whole of society.

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Acronyms and Terms

CRU	Climate Research Unit
DOE	Department of Energy
GB	Gigabyte
GISS	Goddard Institute for Space Studies
GPS	Global Positioning System
HDD	Hard Disk Drive
IEEE	Institute of Electrical and Electronics Engineers
ISBN	International Standard Book Number
ISIS	Islamic State of Iraq and Syria
IT	Information Technology
MIT	Massachusetts Institute Technology
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
SSRN	Social Science Research Network
TB	Terabyte
US	United States
USAF	United States Air Force

1 Introduction

> *“There’s a war out there, old friend. A world war. And it’s not about who’s got the most bullets. It’s about who controls the information. What we see and hear, how we work, what we think…it’s all about the information.*
>
> *“The world isn’t run by weapons anymore, or energy, or money. It’s run by little ones and zeros, little bits of data. It’s all just electrons.”*
>
> Quotes from actor Ben Kingsley, playing the character *Cosmo*
> in the 1992 Universal Studios move, *Sneakers*

The 1991 Gulf War was described by some as the first space war, or the first war in which space systems and their products provided a differentiating capability [1]. By 2003, the United States was more dependent on space systems, but the war in Iraq and the parallel actions in Afghanistan were dominated by information with space systems providing an enabling capability. During these conflicts, the United States possessed overwhelming military power, but bringing that to bear on the enemy proved challenging as they were difficult to distinguish from the surrounding population, and they had the advantage of selecting the time and location of their next strike. A flood of new sensors and complete information dominance eventually led to tactical success, but the military actions were difficult and protracted.

The value of information has been understood for as long as humans have walked the earth. Prehistoric people needed to know where to hunt migrating animals. Early civilizations thrived with the knowledge of how to cultivate crops and domesticate animals. Early rulers learned that knowledge of their adversaries’ plans and activities could mean the difference between life and death. It is no wonder that spying has been described as the second oldest profession [2]. Even in the modern world, information is critical to the success of governments and businesses. Information is power, information buys time, and information provides opportunity.

Over millennia, humans have transitioned through a number of distinct, and sometimes not so distinct, technological ages [3]. What constitutes a technological age is not consistently defined, but in general, an accumulation of scholarly thought suggests that humans have moved through the stone age; the bronze age; the iron age; the industrial age; the post-industrial silicon age, which includes nuclear technology, space systems and computers; the automation age (not yet autonomy); and the present data age.

Curiously, the list includes a data age but no information age. It is argued here, that humankind is only now beginning to turn significant quantities of data into useful information. Hence, the era characterized by the early internet with many sensors and widespread use of computers actually constitutes a pre-information age, or, as identified here, a data age. As for information, we are possibly in the early stages of an information age, where computers and sensors are ubiquitous, and data, processed into useful information and knowledge, finds widespread use in guiding economic, social, and societal choices. However, it is equally possible that what might be an evolving information age will be eclipsed by an age of autonomy, with machines making decisions on their own, rather than as simple automated systems. Autonomy, however, requires significant information for machine-based decisions, and as such, an age of automation cannot exist without a concurrent, possibly subservient, information age.

Hence the exact nature of the information age, and how it will develop and evolve are uncertain, as social, political, economic, and technical forces will all play a part in shaping it. Someone might ask, what then will be the future of information and how will it differ from the simple growing availability of data as has been the case for the past 25 years?

Predicting the future is a perilous business. “It is hard to predict, especially the future” has been attributed to many pundits, among them Yogi Berra and Mark Twain. The actual quote, which is often paraphrased, first appeared in volume four of the autobiography of Danish politician, Karl Kristian Steincke, published in 1948 [4-5]. A brief review of predictions regarding the future of information technology systems is more amusing than informative [6-7]. One quickly finds that most attempts to predict specific outcomes and even market trends have failed miserably, yet predictions of general technological capabilities, such as those described by Moore’s Law [8] and Kryder’s Law [9], have been approximately correct for decades; at least until recently.

Given the terrible record of successful predictions by very intelligent and well informed industry leaders, no attempt will be made to predict the future. Rather, presented here is one possible look at the future, based on a specific set of assumptions and observations about the current state of data and information. There are other potential futures that should be considered. Rather than planning for the future by believing in the accuracy of any one specific prediction, strategic planning activities should attempt to position an organization to do well given a variety of potential future states, while mitigating the negative impact of less desirable possible future states.

To help guide a consideration of potential future states for information, it will be helpful to first review what is believed to be the current state.

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2 Background

2.1 The Current State of Data

An interesting data point on the current state of information comes from a 2011 study conducted by the United States Air Force (USAF) [10]. The problem they described, was that they were "swimming in sensors, drowning in data, yet starved for information." The hope was for the study to identify technical solutions that could alleviate the perceived problem, but the real issue proved to be one of a human and organizational nature. Rather than process and exploit available data when an information gap was identified, a new sensor was developed specifically to fill that gap. This practice resulted in more data than could easily be stored, processed, or exploited—an error that appears to be repeated in a number of areas.

Informally stated, a few of the findings from the USAF study were:

- It is easier to build a dedicated sensor than process non-optimal data from another sensor.
- Data collection capability exceeds storage capacity.
- Data storage capacity exceeds processing capabilities.
- Future processing gains are often dwarfed by future increases in data collection.

One of the consequences of the behavior behind these findings is that data stored with the intent of processing at some future date, almost always remain unprocessed and unexploited, and as most military data are time sensitive, the stored data quickly become less relevant.

While the USAF experience represents only one data point, the findings appear to have some relevance to the current state of information in many places. It is often easier, and less expensive, to simply store data (often without the essential metadata indexing) with the intent of examining it at some point in the future, than it is to fully process it in the present. It is also important to note, however, that information and data are inextricably linked. To examine the future of information requires one to examine the future of data. This in turn, requires a consideration of the present state of data.

Today, the ubiquitous information system, once described as the "information superhighway," is the internet. Most users of the internet are only familiar with a small subset known as the "world-wide web," or WWW. The WWW is the part of the internet that is indexed by search engines and readily discoverable and accessible to casual users. The larger internet includes what some refer to as "the deep web" and "the dark web." The deep web is that portion of the internet that is not indexed and difficult to discover, but still can be accessed, if one knows the access paths. The dark web is where nefarious content and activities reside, including large volumes of data that the owners do not want attributed, accessed, or discovered [11].

The current size of the internet and the volume of internet traffic are difficult to quantify with much accuracy, and are effectively beyond quantitative comprehension. Table 1 presents a few such measures of the internet. The values are derived from several sources, and many competing sources present slightly different values for these numbers, but the order of magnitude for each entry is essentially correct.

Table 1. Evidence for the Size of the Internet

Item of Interest	Size	per	Year	Ref
Deep Web Storage	7,500 TB	Total	2014	12
Deep Web Pages	550 B	Total	2014	12
WWW Storage	19 TB	Total	2014	12
WWW Pages	1 B	Total	2014	12
Internet Traffic	1.1 ZB	Year	2014	13
Twitter Tweets	500 M	Day	2016	14
Re-Tweets	40 M	Day	2016	14
New YouTube Hours	4 M	Day	2016	14
FaceBook Messages	4.3 B	Day	2016	14
FaceBook Likes	5.75 B	Day	2016	14
Instagram Likes	3.6 B	Day	2016	14
Google Searches	6 B	Day	2016	14
Email Messages	205 B	Day	2016	14

The portion of the internet referred to as the “world wide web” is but a small fraction of the total internet content. Only these 19 TB or so of storage are indexed, searchable, and hence, discoverable. Of these 19 TB, it is estimated that only 5% consists of text-based materials where the content itself can be indexed and searched. The remaining 95% of the WWW consists of images and video materials that, at present, can only be searched based on human-generated metadata.

While much of the world’s historical information is not presently available on the internet, it is assumed here that in the future, most of human history will be digitized and stored on the internet. The size of this data set is unknown at present.

2.2 The Current State of Critical Hardware

While the size and level of internet activity is important to comprehend, of equal importance is an understanding of the technology that currently powers the internet and future growth potential and limitations. Most predictions regarding future trends of information technology have failed miserably, but Moore’s law has proven remarkably durable, providing a relatively accurate yardstick for measuring the density of transistors on integrated circuits. Moore, a co-founder of Intel and the Fairchild Semiconductor Corporation, noted in 1965 that the density of transistors on integrated circuits had doubled every year for the past decade [8]. He used these data, and his knowledge of the industry, to predict that the trend would continue for another decade. In 1975, Moore revised his estimate for the next decade to a doubling in density every two years.

A plot showing the remarkable durability of Moore's prediction, spanning five and one-half decades, is seen in Figure 1. What is interesting about Moore's law is that it spans many changes in technology. As one technology was reaching its limitations, another came along to continue the trend. This trend is shown as a series of consecutive technology S-curves, as seen in Figure 2 [15] (this will be better illustrated below, when discussing Kryder's Law). While we refer to Moore's observation and prediction as a law, it is not a governing principle of semiconductor physics or integrated circuits. Rather, it is a trend noticed in empirical observations of transistor density over time.

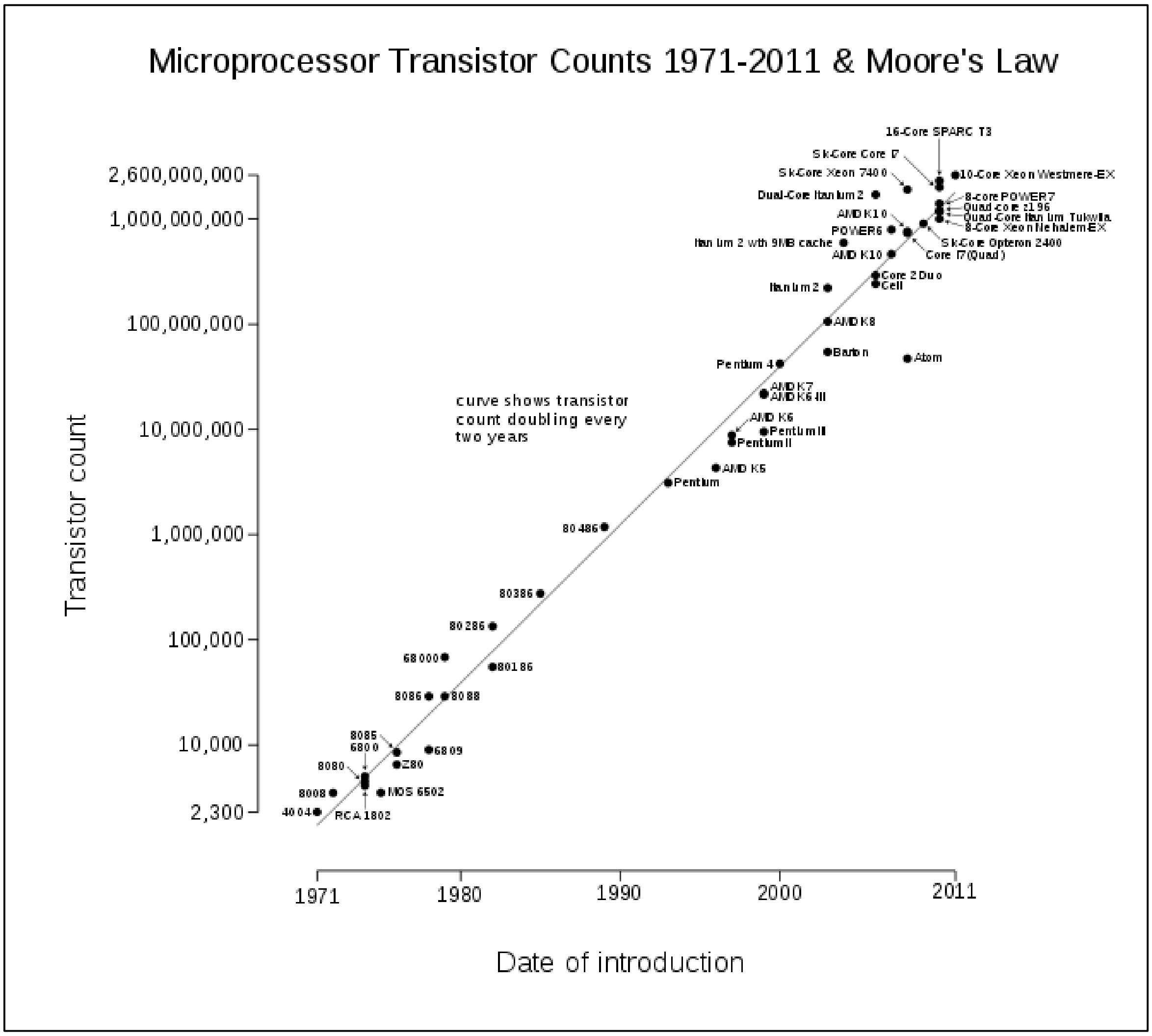

Figure 1. Graphical Illustration of Moore's Law [Wikimedia Commons]

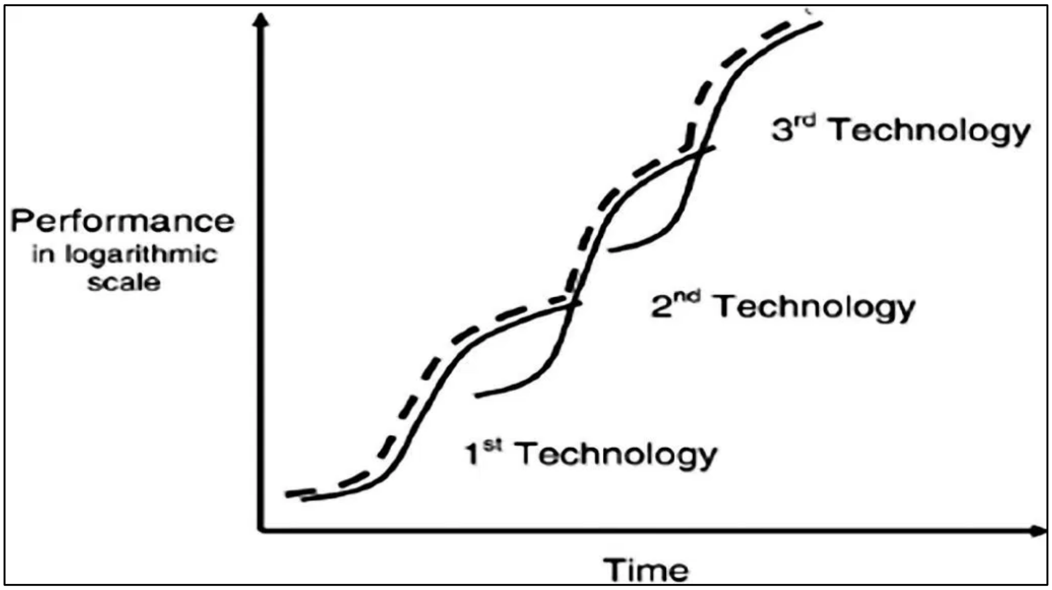

Figure 2. Showing How Individual S-curves (logistics functions) Combine Over Time to Produce an Effective Exponential Gain

At times, Moore's Law is mistakenly stated as resulting in a doubling of computational capabilities every 18 months, but this observation was actually made by David House, an executive at Intel, who noted that a combination of increased transistor density and decreased transistor size would result in a doubling of computational power [8].

Moore's law will someday come to an end as transistors will push up against quantum limits related to electron wavelengths in crystalline materials. As of 2017, there appear to be only a few generations of higher density chips remaining before the limit is reached, but after that, computing power can only increase with novel architectures or the emergence of a revolutionary, non-electronic, technology. However, while this prediction garners wide support from today's leading technologists, the same prediction has been made repeatedly every few years for the last decade [16]. Ingenuity driven by economics has a way of defeating predictions which speak to so-called "fundamental limits"!

House's adaptation of Moore's law is important to the current state of the internet as the processing units control sensors and convert sensor outputs into useful data. They also control the retrieval and transmission of data across the internet. Faster processors result in higher internet data transfer rates, thereby allowing more content to be carried across the same communication channel.

Closely related to Moore's Law is Kryder's Law, named after Mark Kryder, who in 2005 predicted that hard disk drive (HDD) storage density would increase by more than a factor of two every two years [9]. Kryder based this projection on observations of HDD storage capacity between 1990 and 2005. Unfortunately, Kryder's Law did not hold for very long, and beginning as early as 2011, HDD bit storage density began to deviate significantly from projections [17]. At present, the cost per GB of storage is still decreasing, but at a relatively slow rate, whereas before 2010, the cost per GB of storage was decreasing at an exponential rate. Still, Kryder's Law demonstrates validity over roughly a 20-year span of technology development. Similar to Moore's law, Kryder's Law was sustained by a series of new technologies, each of which helped to sustain the exponential growth as previous technologies reached their natural limit of performance. This is shown well in Figure 3.

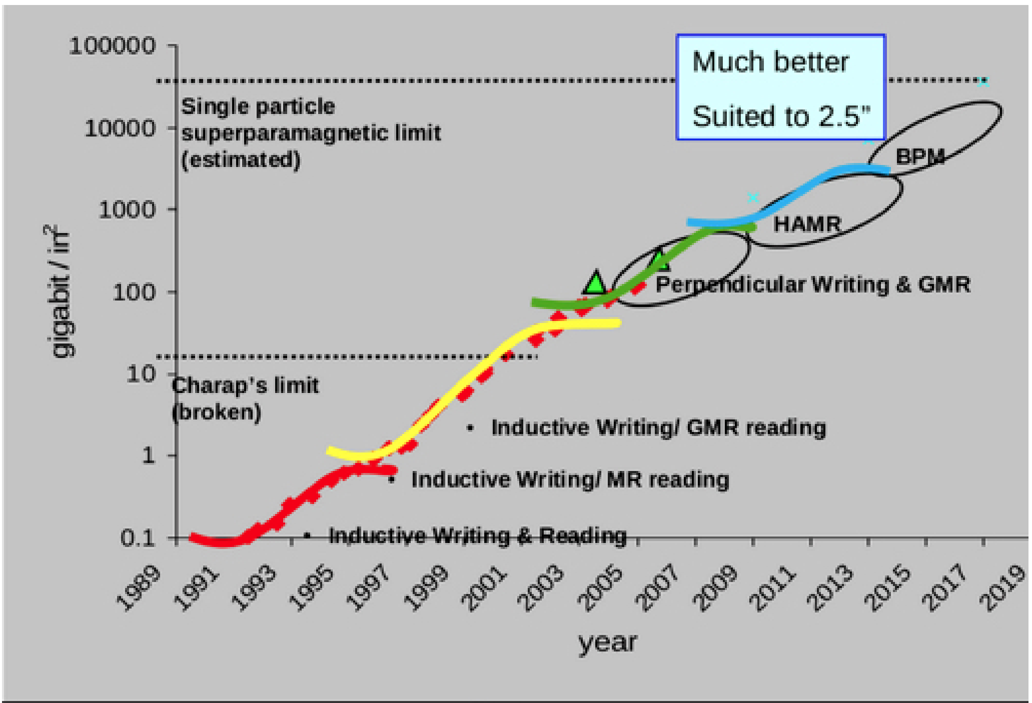

Figure 3. Overlapping S-curves Contributing to Kryder's Law [17]

Much less well known than either Moore's Law or Kryder's Law is Keck's Law [8]. This projection is based on past observations of network data transmission throughput. Keck's Law predicts that network capacity, measured in terms of network speed, doubles approximately every nine months. At present, this trend is expected to continue for a number of years.

The final infrastructure-related performance parameter to consider is that of HDD access rate. While HDDs have increased greatly in storage capacity over the last 27 years, the rate at which they can randomly access data has not improved significantly [18]. This results in a data bottleneck for all information networks. There are some hardware architecture schemes that help to reduce the impact of this deficiency, but the HDD access rate has been, and remains to be, one of the limiting factors for the modern data system. New Solid-state Disk Drives (SDDs) are "blindingly" fast and have storage densities approaching those of HDDs, but they are not, as of yet, in widespread use and their cost is significantly higher than competing HDD technology.

2.3 The Current State of Data Processing

Wirth's Law is a little different from the preceding three. Wirth noted that as each gain is made in computer storage and processing speed, software bloats to consume most of the newly available resources [19]. The net result is that computers are not much more capable for general use than they were a decade ago. While specialized code written for high-speed calculations and massive throughput of data continues to improve in overall computational capability, most generalized computer tasks have not seen significant gains in performance for 10-15 years, with some tasks actually taking longer than in the year 2000 [20].

Beyond Wirth's Law, it is well beyond the scope of this paper to address all the current trends in the software used to process data into information. In general, most past efforts were quite focused within the confines of some funded program, which would include sensor, transmission path, storage, processing, and exploitation of the resulting information. The data were collected for a specific reason, they were processed for that same reason, and they produced information to fulfill a specific need. Often more data were collected than could be transmitted, more transmitted than could be stored, and more data were stored than could be processed. Operators would frequently talk about data "falling on the floor."

At present, there are numerous government and commercial efforts looking at gains that can be realized by analyzing large data sets. These so-called "big data" efforts are intended to find information in a larger, holistic, data set that were not obvious in smaller data sets and that could not be found by the reductionist approach of looking at ever more fine details within a given data set. Beyond big data lie problems that are being examined with complex disparate data sets. Such approaches have shown promise for finding evidence of emergent behavior in large systems as well as helping to reveal subtle, hidden interdependencies in the physical, social, or economic systems on which the data were collected.

One of the greatest limitations of data processing is that the algorithms and programs used must be either dedicated to a given data stream, or easily customized. It is, in general, not possible to use the processing software developed for one application to support another without some effort to re-engineer the software and verify the results. When attempting to process an unknown data set, significant documentation, or significant investigation, is required to interpret the various data fields before they can effectively be used. Perhaps the greatest challenge is with unstructured data sets where one cannot use a simple algorithm to read the data into a processing application.

2.4 The Current State of Information

Today, as always, information has value to those seeking wealth or power. The exact value depends upon the wealth or power that can be gained or lost as a result of having or not having that specific information. The internet has proven to be a highly-effective tool for broadly distributing general information in digital form, but information deemed to be of value is often hidden from public view, or carefully stored behind applications that limit, or charge, for access.

What is most disturbing, at present, is the significant appearance of misinformation over the past decade. Misleading information and false information have always been a concern, but their use was mostly limited to psychological operations and propaganda in military operations and international relations [21]. Over the past decade, we have seen a significant alteration of data and information by governments and interested parties, to mislead their own citizens or competitors and shape public opinion and policy. While such shenanigans have always been present in politics, the digital universe makes it extremely easy to alter information, or create outright false information and then rapidly disseminate that to the masses. It is one thing when a private individual puts out false information, but another matter entirely when a government intentionally lies to its citizens or the world, or a private organization attempts to mislead large segments of the population to change public opinion, thereby influencing public policy. In the past, it was perfectly acceptable for different groups to view the same data and come to different conclusions. Today, through the “magic” of digital manipulation of data and information, everyone can have their own facts as well.

By looking at the behaviors of administrations in the United States, the phenomena of state-sponsored misinformation really took hold beginning in 2009. A prime example is found in the presidential statements (promise) to the public during the debate leading up to passage of the “Affordable Care Act,” stating that “if you like your doctor, you get to keep him,” even though this was known to be false by the President at the time the statement was made [22]. Another example was the administration’s official statement that the terrorist action in Benghazi Libya, that resulted in the death of four US citizens, including the Ambassador, was the result of a spontaneous protest over some YouTube video critical of Islam. History has shown those statements to be false and it was later learned that the government officials making the statements knew they were false at the time [23].

To present a fair perspective, the executive branch statements made to Congress and to the United Nations, leading up to the 2003 US invasion of Iraq might also be considered as fake information. In the years that followed, many asked why no such weapons of mass destruction were found in Iraq. This event was somewhat different as there was incomplete intelligence suggesting such weapons existed [24]. While there were claims that the intelligence data were manipulated to mislead the Congress, these claims were never supported with evidence. More than a decade later, chemical weapons dating to the Saddam Hussein era were found while Iraqi forces, backed by US airpower, were expelling Islamic State of Iraq and Syria (ISIS) fighters from Iraq [25].

Other than government agencies, the past 10-15 years have seen private organizations manipulating data and information to influence public opinion, public policy, and laws. The most notable examples all come from the controversy surrounding global warming and climate change. No matter what side of the issue one wants to support, there are well documented examples of data manipulation and changing of information. The email-gate incident revealed that individuals at the Climate Research Unit (CRU) in Britain were actively seeking to exclude contrary opinions from professional journals and applying subtle corrections to their own data to enhance the appearance of any global temperature change [26]. Wikipedia web pages related to global warming have been systematically edited to remove contrary opinions and to remove evidence that the well-known and historically documented medieval warming period was actually warmer than temperatures experienced over the past century [27-28]. Recently, the National Aeronautics and Space Administration (NASA) was caught applying corrections to temperature data covering more than a century. Somehow, in 2012, NASA determined that the temperature in January of 1880 was actually less than the actual measurement made in 1880 [29].

In February of 2017, a government employee became a whistle blower when he revealed that The National Oceanic and Atmospheric Administration (NOAA) had faked data to show greater warming [30] in support of the Obama administration's pursuit of the Paris Accords (known as the Paris Climate **Treaty** to all other signatories, yet another example of intentional misinformation from a president and his administration). A few days later, this news was denounced by NOAA as itself being fake, as it was then claimed that no manipulation of the data occurred [31]. Whether you believe one side or the other, here are two stories that illustrate the problem with fake or misleading information. At least one of the stories is incorrect, but each had an effect on public opinion.

For those readers believing these are isolated incidents, the Australian Bureau of Measurements recently started an investigation into data manipulation in that country [32], and a Canadian court is likely to hold Michael Mann, inventor of the famed "Hockey Stick" model in contempt of court for failing to provide details of his analysis techniques as evidence in a libel suit [33]. It is likely that Mann is reluctant to open his work up for public scrutiny as researchers from the Massachusetts Institute of Technology discovered an error in his principal component analysis routine that will produce a hockey stick output from even a random input [34].

To make matters worse, when someone questions the integrity of a climate scientist's data, or the results they have achieved by processing and interpreting those data, it is now commonplace to attack the integrity of the one who questions the results. A recent article in a respected peer reviewed journal went so far as to hint that questioning global warming was similar to Holocaust denial and that the individuals doing so were most likely racist [35]. Calling someone a climate change denier evokes mental images of a Holocaust denier. The Holocaust was a real event that has been exceptionally well documented. Those who deny it clearly have a less than reputable political agenda. Calling someone a climate change denier does nothing to resolve the issue. Contrary to what is heard from some information sources, the science behind climate change is not settled and the entire scientific method is designed to encourage and continue debate until the results are repeatable, reliable and defendable. On the other side, those who question the science behind climate change have called its supporters, "science deniers" [36]. Calling someone names to avoid having to defend one's own analyses is itself a form of fake or misleading information. Calling someone a science denier similarly clouds the real issue and only serves to polarize those without the education necessary to understand either side of the argument.

The topics of climate change, global warming, and anthropogenic greenhouse gasses are important conversations to have, but it is extremely important that the debate be conducted with integrity. Changing of data, calling names, and modifying historical information to support one's opinions is an unacceptable practice. Scientists know that science, unlike politics, is not resolved by plebiscite. Scientists do not "vote" on controversial scientific findings to resolve them. The mere use of slogans such as "X% of scientists believe" is a political and not a scientific sentence.

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3 Potential Futures for Data, Processing, the Internet, and Information

As stated above, this paper makes no attempt to predict a specific future state for data, data/information processing, the internet and its associated hardware, or for information itself. Rather, a range of possibilities is explored for each of these major components of the information world by decomposing them into a number of key characteristics. The decomposition is not claimed to be unique or completely descriptive, but should form a representative basis for examining each major topic area. No attempt is made to examine specific futures based on combinations of characteristics. Rather, the reader is encouraged to select the characteristics of greatest interest and explore the range of potential futures for their own purposes.

3.1 Potential Futures for Data

Data have a number of important characteristics, including quantity, quality, discoverability, value and availability, security, and integrity. One might also think about the required ability to collect, transmit, store and retrieve data, but those are not characteristics of the data themselves, but rather of the internet hardware and supporting infrastructure.

The quantity of future data stores can range from less than the present, to more than the present. Since most readers would agree that any thought of less data is not useful, it is perhaps, more appropriate, to consider a future with the quantity of data ranging from somewhat more (linear growth) to significantly more data (explosive growth, non-linear on a logarithmic scale). Certainly much more data will be generated in the future, with the internet of things and the internet of everything, but if storage costs continue along current trend lines, will everyone be able to store these data, or will most data be available in a transient stream for one to either use or lose at the time? Explosive growth will require significant changes in the supporting infrastructure, or new memory technologies.

Data quality is an interesting topic that could be the subject of a lengthy study of its own. At present, a lot of data are available on the internet, but for the most part, there exists no metric by which to assess the quality of these data. The time honored methods of science to include a variance measure and a discussion of systematic error are largely ignored in this pre-information age [37-39]. This is not to say that any particular data set is of questionable quality, there simply exists no universal measure. Data quality can be impacted by the quality of the system generating the data, noise introduced in transmission, compression and storage of the data, the storing of processed data rather than the raw data (loss of fine detail, or what, at the time, seem like unimportant details), formatting of the data (unstructured data are more difficult to use than highly structured data), and a myriad other factors.

In the future, data quality can range from lower to higher, when compared to the data available today. One would hope that data quality will improve as that benefits everyone, but that is not necessarily the case. It is highly likely that future data quality will be about the same as it is today as there is no obvious forcing function to drive the quality to a higher level. An important and useful future development, however, would be some method for potential users to assess data quality without having to extensively investigate the provenance of the data themselves. The public has become used to pseudo-scientists presenting data in confusing language intended to achieve a perception of goodness rather than to convey the complexity that often exists. For example, weather predictions for a 20% chance of rain tomorrow might mean rain 20% of the time, rain over 20% of the reporting area, or simply that there is a low chance of rain.

Twenty years ago NOAA decided to spend its budget on upward-looking radars to get more data rather than purchase more computing power. They presented arguments to demonstrate that more computing power would not improve their forecasts, yet somehow society is expected to believe that more computing power enables very precise climate predictions for decades in the future. For NOAA, increasing the number of sensors failed to improve forecasts as their models did not sufficiently account for the chaotic nonlinear nature of the atmosphere. Today multiple models are run with varying initial conditions and multiple paths are presented to the public with the FALSE interpretation that the "correct" path is somewhere in the middle of the mess instead of explaining truthfully that each path is highly sensitive to initial conditions because weather is a nonlinear chaotic process. By doing this, climate scientists present to the public the perception of thoroughness, integrity and precision, when in reality, the models are incomplete and their sensitivity to initial assumptions undocumented. This is an example of the worst form of misuse of data to camouflage complexity and give the false impression that the future is predictable.

At present, the discoverability of data can be a real problem. Search tools such as Google, Yahoo, and Bing are incredibly powerful and provide users with ready access to a huge volume of data. However, most of the time, these search engines provide data overload, returning so many results that the average user simply cannot, or will not, sort through all of them. Organizations that want their website to appear near the top of any relevant search can work with the search engine providers to achieve such a competitive advantage, although this usually requires some form of payment. Similarly, individuals familiar with how the search engines operate can craft their website content to have a better chance of naturally occurring higher on the list, but many times the results of a search are so large that only the first few entries get examined. In the future, searches within the results of a prior search are likely to be necessary.

One future concern is that as the internet grows in size, the rate of change for stored data will similarly grow, thereby reducing the currency of web index data used to power search engines (think of the Google Big Table), or require web crawling applications to work more often or to simply have more such applications operating at any one time. One potential technology need might be for a hierarchy of web crawling systems responsible for rapid inspection of small portions of the web and reporting updated results to some "mother ship" for inclusion in an up-to-date master search table.

Another interesting future state for data is that it will simultaneously become more discoverable and less accessible. This could occur if the value of the data increased significantly. Owners would want the users to find their data, but then limit access only to those willing to pay.

The future value and availability of data are considered together as they have an interesting potential relationship. In the future, the value of data will depend on what information can be harvested from the data and how actionable that information is. Highly desirable information will make the underlying data more valuable. One can easily imagine a future where low value data have low availability as no organization will have much of an incentive to keep the data up to date or easy to access. Moderate value data will possibly be easy to access as the real value will be derived from the advertising that surrounds these data. High value data will likely be easy to discover, but difficult to access. There are other potential future states for value and availability. One key question is whether or not new technologies will significantly change the value of specific data, or change their availability. It is not difficult to imagine underground wiki-type websites, sort of a parallel copy of the accessible internet, but where individuals who have paid for access to data or information, make it available to other users so they do not have to pay. Who might develop this technology, and what web-based technologies might be needed to combat this subtle form of data piracy?

Data security will be a significant issue in the future, much like it is today. One cannot go a week without learning of another large-scale data breach where the personal information of individual customers or taxpayers has been compromised and is likely in the hands of a foreign government or criminal organization. The real problem today is that the security for most data resides within the operating software for the electronic information system they are stored on. Such security features are easy to defeat either via direct attack, or through operator oversight or outright error. The advantage lies with the attacker.

Looking to the future, it is possible that the security of the software operating data storage and retrieval systems will increase, but a highly desirable future would have the security reside within the data itself. The obvious answer here is some form of encryption for data at rest. This has its own problems and increases the burden on processing systems as the data must be decrypted "on the fly" to be useful. This will invite new computer attacks that look for data that are temporarily decrypted, but encryption at rest is nonetheless a viable future for data security. One interesting unintended consequence of widespread use of data encryption is that older data might eventually become permanently locked, where no one can access the data as those entrusted with the decryption keys have either forgotten or departed. How long will "dead data" be stored and who will decide that the data are actually dead?

The final data characteristic considered here is that of integrity. In the past, this did not appear to be of significant concern, but in the present the prospect of false or manipulated data is very real and this concern is likely to continue into the future. As data become more valuable and decision support systems requiring data inputs become more ubiquitous, the importance of reliable data increases significantly. Similarly, the value of high-quality false or misleading data for a nefarious user will increase as well. In the present, the only data system apparently designed specifically to address data integrity is the block chain technology behind digital currency, and there are no guarantees that it will not itself be hacked or fooled at some point in the future [40]. It does, however, appear to be remarkably robust and might serve as the basic technology backbone behind future data integrity developments.

The importance of data integrity cannot be overstated. With the digital universe, creation of fake and misleading data is within the hands of almost every internet user. At some point, society needs to have reliable data upon which it can base policy decisions. Without data integrity, public policy will degenerate into nothing more than mob rule, and he who has manipulated the thoughts and emotions of the mob most effectively will prevail.

In the present, because of the data integrity issue, the future of society looks somewhat bleak. In the more distant past, data were difficult to acquire and transmit. As a result, the only source of information was from the local magistrate, lord, or king. With the invention of the printing press, it suddenly became possible to widely distribute printed material [41]. The distribution of data and information across societies increased rapidly, and as a result or as a coincidence, the technological revolution was born and the quality of life increased across the developed world. Looking to the future, the widespread use of manipulated data can easily lead to a highly polarized society in which governments, or well-funded non-government organizations use data as a weapon to obtain or maintain control of a population.

3.2 Potential Futures for Data Processing

While data have a number of key characteristics, data processing is more difficult to decompose as the approach one would follow depends highly upon the specific data and the desired end use. Software development currently is, and has always been, a combination of both art and science. While computer programs are a logical series of instructions to be followed in some sequence, these algorithms are expressed in a language that makes the programs, more or less, literature. Those who study literature understand that it is an art, even though the languages may have highly technical syntax. While a processing algorithm can be expressed graphically as a flowchart, such presentations are not unique, and the complexity of the code derived from a specific flowchart can vary significantly depending upon the language used, the skill of the coding team, and the management structure imposed upon the coding team.

Project managers responsible for software find such development tasks most challenging. At present, it is very difficult to predict the complexity of a final software application, or the time required for its development and testing. Government-sponsored software efforts are almost always over budget and beyond their intended schedule. The situation in industry does not appear to be significantly better as delays in the release of new versions of an application or operating system are frequent, if not commonplace.

Beyond the obvious problems with the current state of software development and the resulting impossibility of predicting a future state, it is possible to consider potential futures for data processing without considering the underlying software development. Ignoring, for the moment, potential problems with data security, integrity, quality, discoverability and availability, the future is likely to include more data and more types of data from many more sources. Data processing systems will potentially have access to many more sources of data and a significantly greater quantity of data, than are available today. To think about the complexity of working with such a volume of data, and the complexity of processing such a volume of data into information, it is useful to turn to the world of complexity science [42].

The traditional view of science and the use of data to support scientific investigation is what has come to be known as a reductionist approach. Reductionism is the philosophical concept that suggests an association between complex phenomena and less complex underlying fundamental phenomena, where the complex can be decomposed into its constituent parts. Each part can then be examined in detail to provide insight into the original complex phenomena [43]. This approach has been the basis of most scientific thought dating back millennia, and it has proven to be an extremely successful approach. Beginning, however, in the 1940s, researchers began to ask the opposite question. What happens when a group of discrete phenomena are examined in terms of the whole [44]? How do these parts interact, and what phenomena of the complex system are missed by examining the parts in isolation.

When looking at a set of data, one can imagine the situation where something appears linear on small scales, but proves to be highly nonlinear on large scales. A classic example is the parabolic trajectory of a projectile in the presence of a gravitational field. Very short segments of the path appear nearly linear, especially with the presence of measurement noise, but when viewed with a larger dataset, the curved nature of the path becomes evident. This is a simplistic example, but it well illustrates what can happen when large data sets are analyzed instead of smaller sets. “Big Data” is one of the popular terms, but what is really important is the more holistic view that big data provides when compared to small data.

"…there is no big picture…just a lot of little pictures. Reduce everything to its most elemental form – molecules – and then, you know what it all means."

Quote from actor David Ogden Stiers, playing the character *Dr. Sid Kullenbeck*
in the 1985 Universal Studios move, *Creator*

With this insight, one can envision a future where new data processing approaches are required to examine very large datasets. Even today, many computational problems are so large that one cannot fit the entire problem into the random access memory of a computer all at once. Future analysis efforts may attempt to tackle such large data sets that even massively parallel computers cannot fit the entire problem into memory at one time. Efficient algorithms for seamlessly handling pieces of a problem will be necessary. Also, very large data sets offer the promise of discovering previously unknown interdependencies and signals of interest. Future processing will require greater capability in the area of pattern matching, and more importantly, identification of previously unknown patterns.

When discussing data, it was mentioned that one of the greatest challenges at present is the ability to process unstructured data. When working with huge datasets in the future, it is possible that data that appear structured on a small scale will, in fact, be unstructured on a large scale. This almost seems counterintuitive, but the thought lies in the concept that new patterns might emerge for which the data structure is not ideal for representing. In the future, the ability to access and process unstructured data might provide a significant advantage. Included within the category of unstructured data are images and video streams.

3.3 Potential Futures for Internet Hardware

As noted above, most previous attempts to predict the future of technical developments in the area of computer and internet hardware have failed miserably. Today it appears safe to say that we have pushed the current "microelectronic-based" technology to near its limits. Some technical experts believe we are within one human generation of the end of advancements in these areas as we are approaching hard and fast physical limits. This, however, does not preclude the emergence of new technologies. What they are and how they will be implemented remains to be seen. Some of the possible approaches include optical computing and quantum computing, but it is equally likely that an entirely new technology will be developed out of some, yet to be discovered, physical phenomena.

3.4 Potential Futures for Information

The potential futures for information strongly parallel those for data presented above. Information can be examined by its key characteristics of quantity, quality, discoverability, value and availability, security, and integrity. Rather than repeat the bulk of that material here, it is more useful to go beyond this and examine how information and data interact.

An initial insight might be gained from examining the mathematical relationship between data and information. While the topic is much too broad for this paper, the concept of Fisher Information is a useful starting point as it provides a mathematical equation that helps to link data with its information content [45]. All data contain errors, both systematic and random. Some errors, such as noise, are easy to understand while systematic errors can be more difficult to uncover. For random errors, the data are said to include a variance about the true information. This variance partially masks the desired information, requiring some effort to account for, if not eliminate. According to the Fisher theory, the information content of a data set is proportional to (α symbol) the inverse of the variance.

$$I \; \alpha \; \frac{1}{\sigma^2}$$

where I is the information and σ^2 is the variance of the underlying data set. This equation must be used with some caution, however, as there are mathematical examples where the exact same noise added to different time-varying signals results in significantly different variance, even though the data sets actually contain the same amount of information. The problem results from the variance needing to be calculated relative to the underlying signal rather than being calculated from the raw data itself.

For non-numeric data, there is no single definition of variance. One substitute would be some measure of how volatile, or contentious, the intended information is. A topic that is the subject of a current, possibly heated, debate would likely have multiple returns on a Google search with widely varying content. Another possible metric would be to look at how often edits are made to pages on Wikipedia. A topic that has no controversy should have very few edits per day, whereas one that is quite contentious would, most likely, have multiple competing edits every day or two. Table 2 includes results of Wikipedia page edits for eight topics, including five that were thought to be contentious and three that should be without controversy. Presented with each topic is a measure of the number of Wikipedia edits per day for the most recent 100 and 500 edits. Note that some topics change at an astonishing rate while others experience long periods without a change. These data provide no insight into the nature of the change, only that some change was made. One might suspect that the information presented on a contentious topic is less reliable than information on a non-controversial topic.

Table 2. Wikipedia Change Statistics for Eight Topics [46-53]

	Edits Per Day		
Topic	**Most Recent 100 Changes**	**Most Recent 500 Changes**	**Total Edits Shown in Wikipedia**
List of Confederate Monuments	>100	250	500+
Paris Agreement	1.471	1.742	500+
Global Warming	1.042	0.823	493
Climate Change	0.383	0.228	489
Hockey Stick Controversy	0.084	0.286	500+
Fischer Information	0.079	0.103	500+
Apostle Islands	0.030	0.028	132
Washington Island, WI	0.029	0.033	135
Statistics as of August 18, 2017, per Wikipedia websites for the respective topics			

Another measure would be to look at how the change statistics for a single topic vary over time. For this exercise, consider the topic of "Lists of Confederate Monuments." The change statistics for this topic are shown in Table 3. Note that in the past, this was a non-contentious topic, but recently, hundreds of edits are being made per day, making the information less reliable.

Table 3. Change Statistics for Single Wikipedia Page [46]

		End Date	**Start Date**	**Edits Per Day**
Most Recent Changes				
	100	18-Aug-17	17-Aug-17	>100
	500	18-Aug-17	16-Aug-17	250
	1000	18-Aug-17	3-Apr-17	7.299
	1326	18-Aug-17	16-Mar-10	0.369
Oldest Changes				
	100	16-Apr-12	16-Mar-10	0.131
	500	1-Jul-17	16-Mar-10	0.188
Statistics as of August 18, 2017, per Wikipedia website				

Another aspect of the interaction between data and information was briefly mentioned above with the concept of metadata. Some think of metadata as being simply data about data, but in reality, it is information about data. At present, metadata is critical when searching for images or video (and in some cases, audio) content. Metadata are manually generated and require human interaction. If the future holds a significantly greater accumulation and storage of data on the internet, then the importance of metadata will increase significantly. Further, the automatic generation of metadata would prove to be most useful.

Beyond metadata, i.e., information about data, lies the new concept of meta-information, this being, information about information. The concept is easy to understand as most government reports now include something known as an executive summary. The underlying thought is that as information itself becomes larger and more complex, meta-information will become necessary for the efficient searching and access to the more detailed information. As with metadata, the automatic generation of meta-information will be essential. Early example of meta-information are the indexed search tables used by Google, Yahoo, Bing, and others, to enable their internet search capabilities.

As with data, perhaps the greatest need for the future of information are tools and technologies that enable and ensure information integrity. Partial information, manipulated information, false information, and fake information are significant threats to a free and prosperous future. Any organization looking for work areas where they might make a significant impact on the future should consider research and development of technologies that contribute to information integrity.

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4 Summary

No matter what age of civilization and technological development we are in at present, or transitioning into for the future, data and information will play a central role. Data and information must be treated like free speech. They must be readily available and those making them available must be held responsible for their quality, security, and integrity. Without data integrity, information becomes useless as the distributor can convey any message desired to influence, manipulate, or control a society.

Throughout time, people have faced a number of fears. In prehistoric times, it was the fear of things with teeth lurking in the night. In medieval times, it was the fear of disease and witchcraft. In more recent times, we have had to face the fear of nuclear annihilation. What is, perhaps, the most dangerous of all things that threaten a civilization, is a new idea. Ideas can be powerful forces to shape change in a society, yet they can be modified, distorted and subverted, or they might be outright evil ideas from the start. Through the use of misinformation, distortions and outright fake data, ideas can be used to control a society, in many cases with the willing approval of the masses who do not understand the truth.

In his 1949 novel, *1984*, George Orwell described a dystopian future in which the government, personified as "Big Brother," controlled the masses by telling them what to think and what to do [54]. In the year 1984, the Apple Computer Corporation sponsored a commercial during the third quarter broadcast of Super Bowl XVIII, advertising their new Macintosh personal computer [55]. Their message was that the Macintosh computer would provide information to the masses and help the year 1984 from becoming the 1984 society as described by Orwell.

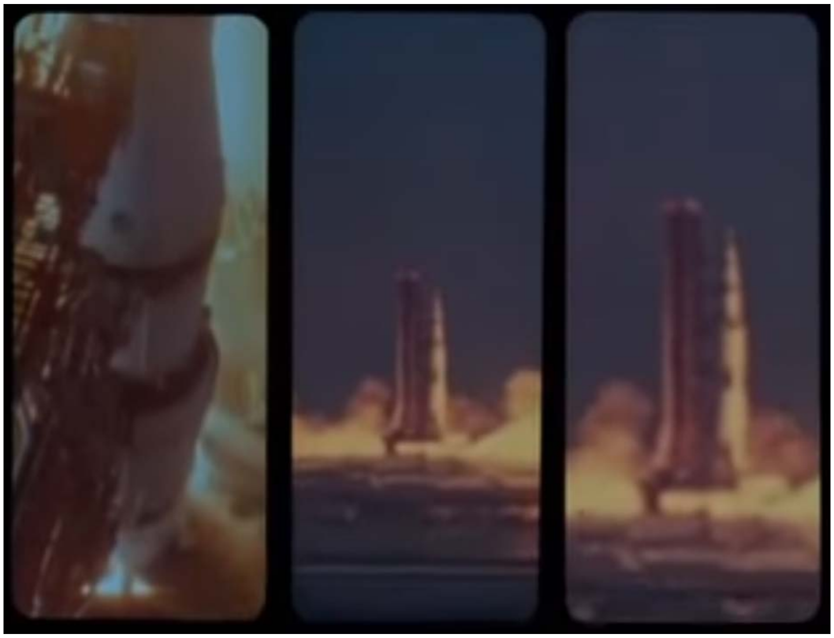
In the 33 years since Apple promised a better future, the same technology that was hoped to deliver us from the clutches of an all-powerful central government has, in some places in our world, been turned against the citizens and today is used to collect data on their every activity. Through the use of data and information, the potential for the control and conformity Orwell feared is more real than it was in 1949, or in 1984. Today, in the year 2017, we face an even worse possible future, as global power brokers (including centralized governments) seek to achieve conformity and control. Through the manipulation of information and the repressive censorship of "political correctness," a small number of actors are working to limit free speech, and ultimately limit political dissent [56].

Image from the first Macintosh computer commercial

"On January 24th, Apple Computer will introduce Macintosh. And you'll see why 1984 won't be like "1984."

Text from the first Macintosh computer commercial.
Aired during Super Bowl 18, January 22, 1984
(although the first public broadcast actually took place
just before midnight, December 31, 1983 in Twin Falls, Idaho.)

So then what is the future of information? One possible future is rosy, suggesting that ubiquitous access to free information on almost any topic will provide a level of knowledge and transparency that will thwart any totalitarian regime and allow humankind to prosper. A middle ground suggests that the future will be somewhat like today. Information will be readily available, but quality information that can be relied upon will still require the consumer to, at some level, beware. The potential dark side of our information future is the possibility of widespread data manipulation to produce information tailored to further specific efforts intended to influence, manipulate, and control various segments of society. When manipulation becomes commonplace and rampant, it will be impossible to trust any source of information and there will be almost no bedrock to help society differentiate truth from fantasy.



"What kind of world am I going to find?
Will it be real or just all in my mind?"

Lyrics from the opening theme *Suspension*
From the 1979 Universal Pictures movie *Buck Rogers in the 25th Century*

In Soviet Russia, the two government-sponsored newspapers were Известия (News), and Пра́вда (Truth), but the citizens knew that all information coming from their government was questionable, and, as such, had two common sayings.

Известия Ни Пра́вда	(no truth in the news)
Пра́вда Ни Известия	(no news in the truth)

In western societies today, one finds both information and misinformation coming from official sources. At the same time, highly polarized commercial news and information sources present equally incongruous descriptions of current events. Both practices leave the citizens to wonder which is true, or to select the source that more closely aligns with their own prejudice. Neither situation is healthy for a free society. Without data and information integrity, multiple competing realities will prove hazardous to the future of the societies themselves.

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