35th Space Symposium, Technical Track, Colorado Springs, Colorado, United States of America
Presented on April 8, 2019

THE FUTURE OF UBIQUITOUS, REAL-TIME INTELLIGENCE – A GEOINT SINGULARITY

Dr. Josef Koller
The Aerospace Corporation, josef.s.koller@aero.org

ABSTRACT

When assessing the trends of global connectiveness, commercial remote sensing from space, and advances in artificial intelligence, the trends point towards a future where information and overhead imagery will become available to the general public in near-real time. The rise of large constellations with remote sensing satellites and capabilities ranging from synthetic aperture radar imaging, night-time imaging, and infrared imaging, is a global phenomenon. Coupled with artificial intelligence analysis, data from different sensors can be combined, processed and made useful for a specific user's needs on hand-held devices world-wide. Large constellations of communication satellites and a rollout of 5G in metropolitan areas will provide the data pipeline reaching users globally at broadband speeds. A scenario, coined the GEOINT Singularity, is a future where real-time Earth observations with analytics are available globally to the average citizen on the ground providing a tremendous wealth of information, insight, and intelligence. Civil application could include identifying an empty parking spot from space or tracking autonomous vehicles in smart cities. These developments will likely not be contained within the U.S. but will be a world-wide phenomenon. The opportunities seem immense but what would the availability of ubiquitous, real-time intelligence mean to the military operator and warfighter? The U.S. approach to commercial remote sensing is to regulate and limit the imagery that can be taken from space but international capabilities will not be easily stopped. Has the time come for the military operator to find better ways to hide, rather than telling someone not to look?

INTRODUCTION

The industrial revolution marked a major turning point in history: almost every aspect of daily life was influenced in some way. Our society has been undergoing a similar revolution from a mass production society to an information society where the line between physical systems, data, and cyber becomes ever more blurred. Advances in machine learning and artificial intelligence (AI) are influencing our behavior and interactions between humans and machines are becoming indistinguishable. Amazon's Alexa, Google's Assistant, and Apple's Siri are just a few examples. Google made headlines in 2018 by demonstrating how its Google Assistant was making a restaurant reservation on your behalf. The restaurant was real, but the person making the call was an AI system able to interact with humans on the phone.

This paper discusses how advances in artificial intelligence, satellite-based sensing and imaging, and an evermore connected world enable accelerated advancements that could lead to a society with real-time access to global information, services, and intelligence at their fingertips. Whether such a future is real or even achievable, is not debated here, but the trend is real. For the purpose of this paper, the term GEOINT Singularity is defined as ubiquitous intelligence available to the general public[*] in real-time (Exhibit 1). The paper discusses advances in three areas: remote sensing data, artificial intelligence, and global connectivity as enabling factors for a GEOINT

[*] Information could be either provided free of charge with a hidden revenue generation business model, where customers don't pay for a service but revenue comes from e.g. advertisement, or to a paying customer.

Approved for public release. OTR 2019-00538

Singularity. The paper also discusses how this would affect the military operator and warfighter. Some argue that the past of surprise attacks is gone and that it is getting more difficult to stage an attack in a world that is becoming more transparent[1]. Denial, deception and disinformation will be key in a future of global transparency.

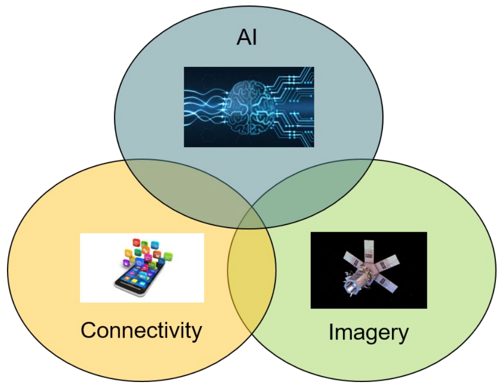

Exhibit 1: GEOINT Singularity is the convergence, and interrelated use, of capabilities in artificial intelligence, satellite-based imagery and global connectivity where the general population would have real-time access to ubiquitous intelligence analysis.

MAJOR TRENDS LEADING TO A GEOINT SINGULARITY

Commercial, Space-Based Remote Sensing

One prominent trend in remote sensing from space is not so much to increase resolution but to decrease the revisit time over any given location on Earth by distributing on orbit capabilities. Just like the popular Moore's law, predicting that the number of transistors in an integrated circuit doubles every two years, seems to have slowed down due to physics limitations, the trend of ever increasing resolution seemed to have slowed down as well. New companies are not competing as much on resolution today but rather compete on multi spectral capabilities, night-time sensitivity, infrared and synthetic aperture radar (SAR) capabilities, and on revisit time. Recent commercial initiatives do not seem to focus on increasing resolution but instead decrease revisit time by building constellations of satellites with a variety of capabilities instead of a single satellite. Companies seem to have concluded that it is more cost effective and profitable to launch a number of small satellites rather than to invest in a few, heavy Earth-observation platforms like WorldView 4 from DigitalGlobe (now Maxar)[†]. Planet, a U.S. company operating a constellation of Earth-observing small satellites, certainly adopted that early on with a mission statement to "image the entire Earth daily". Today, Planet has reached their goal by operating the largest constellation of small satellites with approximately 150 orbiting platforms[2].

Planet is likely to see competition. EarthNow, a company backed by SoftBank, Airbus, Bill Gates (Microsoft) and Greg Wyler (OneWeb and O3b Networks), plans to launch ~500 small satellites offering video coverage of the world with "live and unfiltered" footage of almost anywhere on Earth. The company will attempt to provide the footage to smartphone applications with little time delay with plans to track illegal fishing, animal migration patterns and forest fires. Other possible applications include mapping and guiding traffic flows through a "smart

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[†] Physics limitations are certainly a factor: due to the Rayleigh Criterion, a telescope has a theoretical resolution limit based on the diameter of the lens or mirror.

city" and real-time media reports of events happening in remote sites. Military operators should pay attention. EarthNow intends to sharply reduce design and production costs by using an upgrade of the basic satellite platform and assembly-line manufacturing techniques already devised for OneWeb. The company says that by incorporating substantial computing power on each platform, called "the Model T of spacecraft", it would provide more timely and useful video images than its rivals. Even though each satellite would collect colossal quantities of data – far too much to send back to Earth in real time – the software would be able to process it all onboard and only send back data that the user wants to see.

While EarthNow appears to have prominent backers with deep pockets, there is also competition in the international market. SatRevolution, a small Polish company funded by the European Commission, is planning to develop a real-time Earth observation constellation. The satellite would reach a resolution of 0.5m using single 6U CubeSat with a deployable telescope. The company plans to launch 82 of them achieving real-time electro-optical imaging with a revisit-time of less than 1 hour. Possible applications include crisis response, environmental monitoring, smart city support, logistics and traffic monitoring, among others. The imager would consist of a hyperspectral imaging detector with adaptive optics and on-board AI processing. The first satellite on orbit is scheduled for 2019 (full operational constellation by 2023) with a four hour revisit time and "real-time" capability by 2026. EarthNow, as a Polish company, would not be subject to U.S. regulation and could image and sell information as they wish, subject to Polish and European law and regulation.

Data Analytics

Imaging in different spectral bands, including short-wave infrared imaging (SWIR), night-time, or with synthetic aperture radar (SAR), or imaging with increasing revisit frequencies may not be the only concerns to the national security community and ultimately the military operator. Combining information from various spectral domains that provide orthogonal insights, or even with data from online records, Twitter, Facebook, and Instagram, as well as using advanced analytics, deep learning and artificial intelligence will be truly a game changer. Remote sensing satellites produce vast amounts of data. So much data in fact, that the former Director of the National Geospatial-intelligence Agency (NGA), Robert Cardillo, said that in about five years the agency would be dealing with "a million times more" data and in 20 years would need to employ 8 million analysts to handle the load. The solution to this trend is automation in the form of machine learning and artificial intelligence. While the more traditional remote sensing companies, such as Maxar, Planet, and Spire pursue both hardware in space and the analytics on the ground, other companies such as Ursa and Descartes Lab focus on data analytics alone.

The company Ursa Space Systems, founded by Adam Maher (CEO), recognized the disconnect between information-rich satellite data and those who could really use it. Headquartered in Ithaca, New York, Ursa decided on a different approach than building SAR satellites, realizing that there is a plethora of data already available. Ursa has been quite successful in analyzing existing data and making it usable for customers. For example, Ursa has developed a proprietary algorithm using purchased data from SAR satellite operators to analyze and estimate global strategic patroleum reserves. Typically, stockpiled petroleum reserves are officially reported by nations but are often deliberately inaccurate. Ursa can help investors understand what exactly is in storage. Low storage means high demand, high storage means oversupply and a potential price drop. There is an interesting aspect to this company from a regulatory perspective. Since Ursa is simply purchasing global data and not actually operating satellites they are not subject to the U.S. regulatory framework. Moreover, while some national security stakeholders may want to restrict U.S.-based SAR companies from selling specific data, Ursa and other companies can purchase data from non-U.S. companies. Such a restriction on U.S.-based data would clearly be inconsistent with any national policy designed to enable the competitiveness of the U.S. space sector.

Similar to Ursa, Descartes Lab is focusing on data analytics rather than building hardware. The company, headquartered in Santa Fe, New Mexico, views the increase and diversity of data as a resource. To harness the power of multiple orthogonal data sources and enable global-scale computation, Descartes Lab built a "data refinery" to clean up data sets, and developed a platform with deep learning and artificial intelligence capabilities. Using SAR data, for example, the company has built models to identify new construction sites on the ground regardless of weather conditions. It can also identify agricultural field boundaries and automatically classify the crop growing in each field. Descartes Lab has been noted as a company to watch as it is breaking industry barriers[3].

Artificial Intelligence and Machine Learning

Technology trends are accelerating and there are indications that a sixth wave of innovation is coming. The Russian economist Nikolai Kondratiev first postulated the major cycles of innovation in 1925. The five initial major economic cycles have been defined as the industrial revolution; the age of steam and railways; the age of steel and electricity; the age of oil, cars and mass production, and the age of information and communication. Each wave lasted from 40 to 60 years and consisted of alternating periods between high sector growth and periods of slow growth.

The sixth cycle is postulated by some as an increase in resource efficiency[4]. A new wave would be heralded by massive changes in the market, societal institutions and technology that all reinforce each other, centered around connected intelligence with new devices, new applications, new business models and new services. Space-based commercial remote sensing that create massive datasets, joined by artificial intelligence for analysis and product development will be just one aspect of the innovation wave. Current prices for electro-optical data can be bought for \$5/km^2 and prices are dropping at a rate of 3-5% per year according to EuroConsult[5]. New lower-cost data is expected to challenge prices as the electro-optical imaging supply is expected to expand rapidly in the coming years. Some economists claim that this will add to competition and make it possible for supply to start outstripping demand. However, new markets have opened up as data hungry AI has become more established and demand has increased. Further strengthening the trend is a noticeable shift from investment in new satellite operations to investment into new service companies aimed to exploit data based on change detection and predictive analysis.

Artificial intelligence and deep learning hold promise to enable consumption of satellite imagery services similar to how Geographic Information Systems (GIS) enabled the satellite remote sensing business to provide value to the consumers 15 years ago[1]. GIS will continue to play a role as a foundation in storing, manipulating, and managing spatial data, similar to cell phone service as a foundation providing the connectivity for apps on a smartphone. However, given the magnitude of data produced, AI will provide the analytics that combines various data sources, sifts through the myriad satellite-based information, incorporates data from a variety of sources, and may even be used for on-orbit processing. NGA has been focusing on bringing automation to its geospatial analysis for some time, lamenting the fact that for all of its ability to amass satellite and other data, parsing that data often comes down to human analysts having to search images and videos in a manual, time-consuming process.

General investments in AI are continuously growing. According to ABI research[6], the number of businesses adopting AI worldwide will increase significantly from 7,000 this year to 900,000 in 2022 with investments in AI growing at a rate of 4.5x. The future will make machine learning algorithms the norm for developing user applications rather than a specialty of science fiction movies. Recent advancements in machine learning and artificial intelligence are significant. While complex algorithms have been limited to big tech companies like Google, Amazon, and Microsoft, today AI is becoming affordable though a variety of open source software that allows building advanced self-learning systems.

Big data and machine learning are a match made in heaven. AI without training data is impossible and training requires a lot of data. The more complex a machine learning algorithm gets, the more training data it requires. Last year, for instance, NGA collected more than 12 million images and produced over 50 million indexed observations[7]. Artificial intelligence has a great appetite for more data and will be the primary consumer of an immense increase in available data in the future.

While today the U.S. may still be a leader in AI, China is catching up. Years ago, IBM Watson began as a research project and first attracted headlines as the algorithm that beat human contestants in the TV show Jeopardy. Today, Watson is used across many sectors around the world to boost revenue and efficiency, and even save lives. However, China may soon be leading the development of AI. A few years ago, Chinese technology entrepreneurs were focused on repeating (and copying) Western success stories. However in 2018, the total global investment into AI-focused startups amounted to $15.2 billion worldwide. China accounted for nearly half of that, while the United States only contributed about 38%[8]. China is determined to be the tech industry leader in AI.

Global Connectivity

Many have postulated that global connectivity and advanced networking will drive the development of new products and services. Next generation technologies such as 5G, low Earth orbiting satellite constellations, and meshed networks will support data-hungry consumers and bridge the digital divide. OneWeb, for example, founded in 2012, started with financial support from companies including Airbus, Coca Cola, Qualcomm and Virgin Group. The mission statement of OneWeb is to bridge the global digital divide by operating a global network of approximately 600 satellites in low-Earth orbit approved by an FCC license[9] granted in the summer of 2017. The first six demonstration satellites launched in 2019. Competition for global connectivity comes from SpaceX' Starlink which received FCC approval[10] for over 12,000 satellites for a space-based internet communication system. Terrestrial competition will come from 5G suppliers. Certainly, the trend of increasing global connectivity with broadband services is clear.

In addition to space-based and terrestrial-based networking advancements, access to intelligence, data, and analytics comes in the form of apps on smartphone devices. The Ericsson Corporation releases an annual global connectivity report[11]. In 2014, the report predicted that by 2020, 90% of the world's population aged over 6 years will have a mobile phone (Exhibit 2). In 2018, the Ericsson report assessed that mobile broadband providers service approximately 5.2 billion subscriptions globally today.

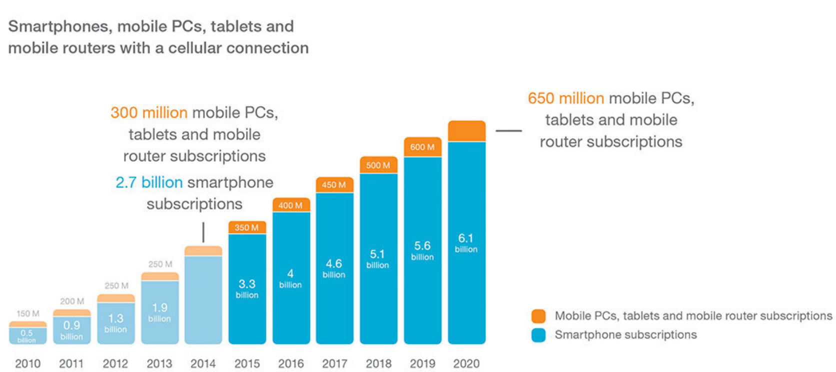

Exhibit 2: Prediction by Ericsson Corporation in 2014 of smartphones subscription serviced by broadband providers[10].

Combining the described trends of (a) increasing imaging data supply through new satellite companies entering the field, (b) advancing machine learning and artificial intelligence and (c) increasing global connectivity, the trend towards satellite-based information available in real-time to the general consumer is real – the GEOINT Singularity. While experts agree that increased commercialization of satellite-based commercial remote sensing is leading to more global transparency, the effect on national security and military operations remain under debate. Some argue that the increased transparency will increase the predictability of adversaries: staging areas for surprise attacks in the physical domain will become difficult. Of course, this is a double-edged sword. The question remains: as we trend toward more global transparency, how can a policymaker assist military operators and still maintain the benefit of surprise. Traditionally this has been attempted through licensing and license restrictions.

THE U.S. REGULATORY FRAMEWORK FOR COMMERCIAL REMOTE SENSING

The U.S framework for licensing commercial remote sensing systems was implemented through the National and Commercial Space Programs Act (2010) and the Land Remote Sensing Policy Act (1992) which essentially state that no U.S. person or entity may operate a remote sensing space system without a license that has been authorized and granted by the Secretary of Commerce. The responsibility to license is currently delegated to the Administrator for the National Oceanic and Atmospheric Administration (NOAA). In addition to the legal framework provided by law, additional specifics are provided through the Code of Federal Regulations (CFR) at 15 CFR Part 960 and policies such as the National Space Policy of 2010 (including changes made by the current administration) and NSPD-27 which is partially classified[12]. By law, the Secretary of Commerce can only grant a license that complies with all applicable international obligations (determined by the Secretary of State) and all national security concerns of the United States (determined by the Secretary of Defense). This is where interagency discussions take place. The Office of the Secretary of Defense will advocate to satisfy national security concerns and the Office of the Secretary of Commerce will promote commercial competitiveness. Notable license conditions include resolution limits over Israel, traced back to the Kyl-Bingaman Amendment, and resolution limits[13] of electro-optical imaging at 25cm. In addition to resolution limits, every license has a provision for the U.S. Government to invoke "shutter control". According to general license provisions, shutter control is invoked during periods of compromised national security or international obligations, the licensee may be required to limit data collection and/or distribution for specific times and specific geographic areas.

A COMPREHENSIVE RISK ASSESSMENT FRAMEWORK

When license conditions are determined through an interagency coordination process, in particular those pertaining to national security, the stakeholders evaluate risks and benefits. The risks to national security from overhead imagery and information being disseminated broadly can be wide ranging: adversaries could track the movements of U.S. and allied military equipment, detect patterns of training and operations; hyperspectral imaging can identify chemical compositions; short-wavelength infrared imaging can see through clouds; and SAR sensors can image at night. When determining risks to national security, one can define it to first order as risk of being seen or detected, R_d. The risk of an operation being detected during a specific time depends on two variables: the operation $Op(t)$ occurring at a specific time t, and a satellite remote sensing system looking at the specific time in the specific direction with the right sensor, i.e. an observation $Obs(t)$ occurring. Together, the operation and the observation, provide the risk of detection as in

$$R_d(t) = Op(t) * Obs(t)$$

In order to reduce the risk of detection R_d, the military operator can either choose not to operate or maneuver during a given time, or to somehow control the observation *Obs(t)*. Shutter control is an option to limit the observation and thereby minimize the risk of detection. The process for requesting shutter control or limiting an observation moving from a military operator to the Chairman of the Joint Chiefs Staff, to the Secretary of Defense, to the Secretary of Commerce is beyond the scope of this paper. Nevertheless, it is important to keep in mind that such restrictions only apply to U.S. entities operating in space and do not apply to high-altitude pseudo satellites or international space companies and foreign governments.

Capabilities of satellite remote sensing systems are not constant but continuously improve in various aspects. When assessing the risks to national security, simplified here as in "risk of detection" R_d, the process of determining appropriate license conditions traditionally only takes into account the capabilities of past and existing space systems. This often leads to the statement that "policy lags behind capabilities". While it may not be possible to account for specific capabilities of planned and proposed systems because they may or may not become reality, that should not deter the national security community from taking trends into account when assessing the risks to national security.

To put the broader context into consideration, the risk of detection by limiting an observation is really comprised of several terms, out of which only one is regulated, denoted by *r*:

$$Obs(t) = O_{US,space} / r + O_{HAPS,air} + O_{int,com} + O_{int,gov}$$

Where $O_{US,space}$ stands for commercial domestic space, $O_{HAPS,air}$ represents imaging from high altitude platforms and pseudo satellites, O_{int} is commercial international capability, and $O_{int,gov}$ for foreign governments. Commercial imaging capabilities are certainly increasing, not just domestically but globally. In the changing world of increasing imaging capabilities, the risk of detection by observation can only be held constant if regulations are increased and strengthened. However, this may be inconsistent with domestic policies of advancing competitiveness of the U.S. commercial sector. Often the risk from unregulated capabilities (international or aerial) is neglected and license conditions are imposed based on domestic commercial platforms, as if $Obs(t) = O_{US,space} / r$ alone. However, imposing stricter regulations may provide a false sense of security because the growth of international capabilities is neglected. On the other hand, increasing regulation is free of charge and has no immediate cost imposed on those who advocate for it.

$$Obs(t) = \frac{O_{US,space}}{r} + O_{HAPS,air} + O_{int,com} + O_{int,gov}$$

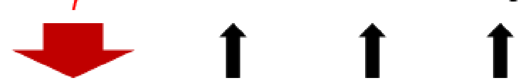

Exhibit 3: In order to keep the risk of detection by observation steady, regulatory restriction would have to increase and become more restrictive while international and domestic, unregulated capabilities increase risk as they become available. However, typically restrictions are lessened to enable new domestic capabiltites, hence, the risk of detection by an obersavtion overall increases. As restrictions are continuously eroded, the military operators seem to accept the additional risk.

Instead of increasing regulation, other mitigation techniques will have to be found in order to maintain commercial competivenss. Options to reduce the risk of detection to the military operator could include limiting the advancements on data analytics, artificial intelligence, and global connectivity itself to maintain a certain opaqueness and element of surprise. Those may not be options to Western Societies where the freedom of information is valued, and free markets and innovation are high priorities identified in national policies. Some argue that the risk of detection is assumed, how much risk although is likely unclear.

If increasing regulation is not a choice, what remains is to improve denial, deception (D&D), and disinformation techniques to maintain the advantage or element of surprise. Typical denial and deception techniques, such as camouflage, are well known to military operators and warfighters. However, when approaching a GEOINT singularity, traditional denial and deception techniques may not be sufficient and will have to be advanced in ways that cope with frequent and continuous observations in various bands of the electromagnetic spectrum. There won't be any more time windows without a satellite passing over and a capability that could detect the activity. The specific techniques of D&D are beyond the scope of this paper.

The approach of advancing denial and deception techniques instead of regulating the domestic commercial satellite remote sensing sector bears several advantages. Those advantages include (1) improving D&D techniques against domestic commercial capabilities will also advance D&D techniques against foreign military capabilities intrinsically. (2) Less regulatory burden will permit the domestic commercial remote sensing sector to remain innovative and competitive on a global scale. (3) Increased innovation will provide new capabilities for national security. (4) Commercial imaging can support public messaging. The downside of advancing D&D is cost whereas remote sensing license restrictions would appear cost neutral to those who advocate for it.

SUMMARY

This paper discussed how major trends in commercial remote sensing from space, advances in artificial intelligence and machine learning, and global connectivity could lead to a future of global transparency. Access to ubiquitous intelligence in real-time to the general public as a GEOINT Singularity should have military operators concerned. Traditionally, the national security community attempted to maintain a certain level of opaqueness or surprise by limiting commercial space-based imaging through regulation. However, that approach has provided a false sense of security and neglected developments that are not under U.S. regulatory control such as foreign commercial imaging companies and advancements of foreign military capabilities. This paper proposed a broader framework of assessing risks to the military operator by including imaging capabilities that are not regulated and instead focus on advancing denial and deception techniques.

Strengthening regulation only applies to the domestic commercial sector and can be summarized as a "don't look" directive. Given the advancements in three critical areas of artificial intelligence, global connectivity, and satellite imagery, a change to "hide!" may be more appropriate and future proof.

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