The GPS Playbook

How a space-based technology generated the largest venture outcomes in history

Report by Space Capital and Silicon Valley Bank

Executive Summary

GPS is a space-based technology that has generated trillions of dollars in economic value and some of the largest venture outcomes in history.

The history of GPS provides us with a framework for understanding how space-based technology has become a platform for innovation on a global scale. Specifically, the development of technology layers on top of space-based *infrastructure* and the *distribution* of data for mass adoption, which unlocks thousands of unique *applications*.

Companies focused on the distribution of the Global Positioning System (GPS) laid the foundation for 82 companies to be founded between 1978 and 1999 raising over $29 billion in equity financing and creating early application layers that moved GPS into the mainstream. In total, the ubiquitous distribution of GPS, and resulting exponential growth in applications, created 764 companies that have raised $77 billion in equity financing and have a combined equity value of $405 billion.

The importance of the space-based GPS signal cannot be understated and is now universal in our everyday lives through applications built by Uber, Yelp, and Niantic, which represent some of the largest venture outcomes in history. A total of 137 companies generated an exit for investors with a combined exit value of $170 billion. The top 25 exits generated an average exit multiple[1] for early investors of 690x and three companies were amongst the top 10 venture exits of the past decade (Uber, Lyft, and Snap).[2]

GPS is converging with computer vision; ushering in a new era of precise positioning that will unlock millions of new applications, never before possible. One prediction is that computer vision will augment GPS, providing unprecedented precision, enabling mass adoption of augmented reality (AR) experiences as we mesh the physical environment with digital information.

Moreover, GPS provides us with a playbook for how Space-based technologies will create new investment opportunities. Based on our unique insight at the forefront of space investing, we believe that Geospatial Intelligence has the potential to be as large of an opportunity as GPS, with Communications potentially twice as large.[3] Therefore, using the magnitude and timeline of GPS as an analogy, we believe that over $1 trillion of equity value could be created in Space-based Communications and Geospatial Intelligence segments over the next decade.

This report takes a deep dive into the forces driving these changes, the players involved, and the impact this emerging paradigm will have on the economy.

1 Exit multiple defined as exit valuation / average of seed & series A valuations

2 Pitchbook, Access on February 29, 2020

3 Based on investment of $2.8 billion in Geospatial Intelligence satellites and $6.5 billion in satellite infrastructure to provide global high speed internet from space, Q4 2019 Space Investment Quarterly, Space Angels

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"Location-services is going to be a really big deal on the iPhone with the iPhone 2.0 software... it's going to explode."
–Steve Jobs

GPS:

The space-based signal we can't live without

It's hard to remember our life without GPS. The technology provides position and time keeping capabilities that power the complex systems underlying our modern global economy. Communications, finance, and logistics industries transformed under a global synchronous time that enabled our modern cellular networks, financial transaction timestamps, and unprecedented global trade.

GPS also created enormous value for an entire generation of companies that personalized marketing, transportation, and search based on a user's location. Google, Uber, and Yelp pioneered a new industry called location-based services (LBS). As the utility of GPS became more broadly realized, Russia, Europe, and China launched complementary systems that would form an expanded satellite constellation called the Global Navigation Satellite System (GNSS).[4]

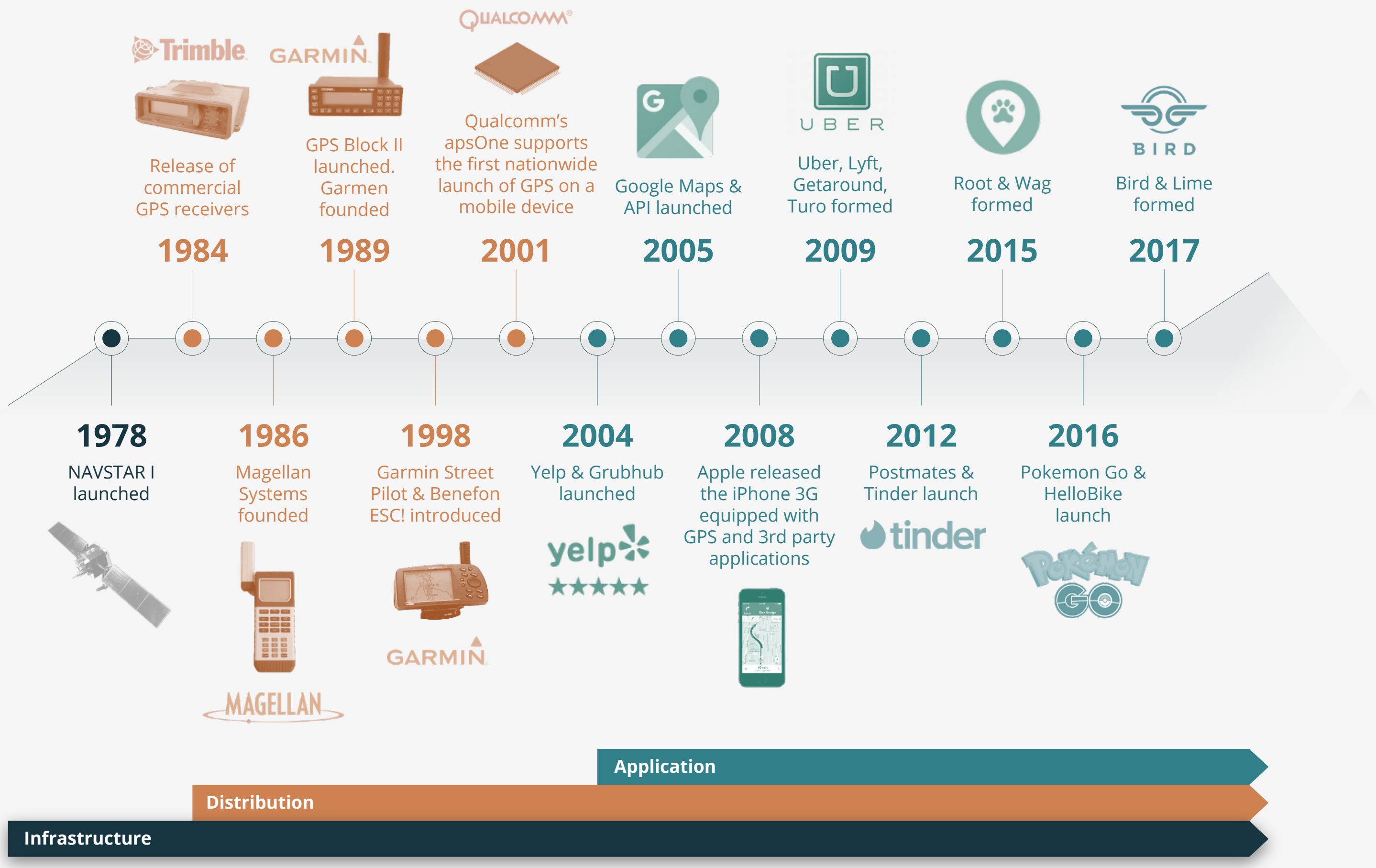
Space-based technologies have shown, time and time again, that they are the building blocks of innovation and enable economic activity. Early investments by the United States government into launch infrastructure unlocked space for the first time, delivering capabilities that put the first military and commercial satellites into orbit. NAVSTAR launched in 1978, providing the first GPS framework. Those early infrastructure investments in GPS satellites were leveraged by tech pioneers Trimble, Magellan, and Garmin, who not only made the signal more useful and accessible for the military, but also unlocked a new market for commercial purposes.

> The importance of this space-based signal cannot be understated and is now ubiquitous in our everyday lives through applications built by Uber, Yelp, and Niantic, which have accounted for some of the largest venture outcomes in history.

In June 2019, a report commissioned by the United States Commerce Department estimated that GPS has created $1.4 trillion of economic benefits in the U.S. alone since the system became available in the 1980s.[5] GPS has a complex history, beginning as a fringe navigation alternative, which the U.S. Air Force struggled to justify, given the high cost and low perceived utility. Ultimately, that signal would transform into a global technology platform responsible for three of the top 10 largest venture capital exits over the past decade. The evolution of GPS provides a model for understanding how other space-based technologies can become global innovation platforms that create exponential value. Specifically, the development of technology layers on top of space-based infrastructure to distribute data for mass adoption and unlock thousands of unique applications, that weren't possible before.

[4] Other Global Navigation Satellite Systems (GNSS), GPS.gov, Accessed on March 5, 2020

[5] RTI International, Economic Benefits of the Global Positioning System (GPS), June 2019



Space-based technologies are the building blocks of innovation. Credit: Space Capital

Three Pillars of Innovation:

How *Infrastructure*, *Distribution*, and *Applications* made GPS universal

Infrastructure

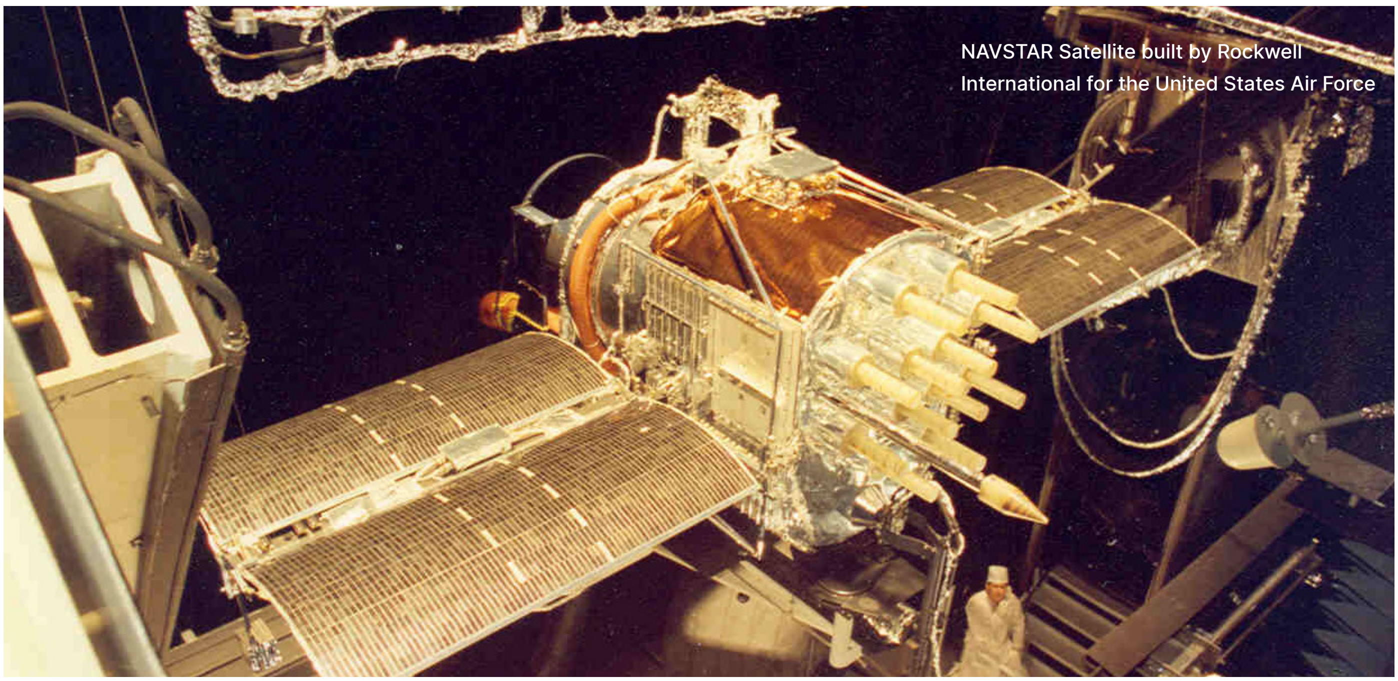
The United States Air Force continually resisted GPS, starting with Project 621B, an Air Force navigation program that was underfunded and neglected. The Air Force wasn't a big user of space-based infrastructure, according to Scott Pace, Executive Secretary of the National Space Council, who tracked early GPS use for the Department of Commerce.[6] While the Air Force builds and manages projects from space, the Army, Navy, and Marines rely much more heavily on space-based technology.

[6] Greg Milner, Pinpoint: How GPS Is Changing Technology, Culture, and Our Minds, W. W. Norton & Company, 2016

Infrastructure (cont.)

This tension meant that it was initially difficult for the Air Force to see GPS' utility, when it believed the question of navigation had largely been solved. A breakthrough came when GPS was reframed as a guidance system rather than just another navigation system, a tool that would enable the U.S. to conduct precise and accurate airstrikes. This was in fact the original view of the chief architects of GPS, who envisioned it as a precision guidance system.

The first prototype GPS satellite launched in June 1977 from Vandenberg Air Force Base. Less than a year later, at the Army's Yuma Proving Ground, the new technology was put to the test. Simulated bombing campaigns were carried out using GPS-guided delivery systems with a presumed margin of error of 50 feet. After reviewing the actual results, GPS demonstrated a 200x improvement over existing systems and established itself as the Department of Defense's new guidance infrastructure. From 1973 to 1999, the US government would spend more than $4 billion building and launching the first two generations of GPS satellites.


NAVSTAR Satellite built by Rockwell International for the United States Air Force

Distribution

Originally, the military had no intentions of opening the GPS system up to the public. But then in 1983, a Korean passenger jet carrying 269 people drifted 300 miles from its intended route and was shot down by Soviet defenses. The most likely cause for the course deviation was deemed to be human error. With the plane out of range of air traffic controllers, there was no way for the plane to realize it was off course. Four days after the tragedy, and realizing that a world-wide positioning infrastructure could have prevented the loss of life, President Ronald Reagan opened GPS to the public on September 16, 1983 with the Selective Availability executive order.[7] The Pentagon determined that the public version would have its accuracy limited to a radius of about 100 meters to ensure that only the U.S. military had the best data available. However, quickly after the Selective Availability executive order, the line between military and civilian use GPS began to blur.

[7] Juquai McDuffie, Why the Military Released GPS to the Public, Popular Mechanics, June 19, 2017

Distribution (cont.)

Trimble TrimPack and Magellan NAV 1000

> Together, these distribution companies laid the foundation for 82 companies to be founded between 1978 and 1999 raising over $29 billion in equity financing and creating early application layers that moved GPS into the mainstream.

Hewlett-Packard (HP), founded in 1939 in Palo Alto, California, had become a juggernaut in the instrumentation industry by the 1950s and solidified its position in the 1970s by integrating automated analyzers and ushering in the digital age. Over this period, the company doubled in size, becoming one of America's 10 largest manufacturers. In 1973, Ralph Eschenbach, a bright young engineer, transferred to the company's corporate lab to join a skunkworks program (research and development for radical innovation). By the end of 1976, Eschenbach had fully designed schematics for a GPS receiver, from the antenna to the signal. With these schematics, he built a prototype receiver containing an 8-bit processor connected to an HP 9825 desktop computer. Then in 1981, Eschenbach rented an RV to test the mobile capabilities of the protype and connected it to a chart plotter. Rolling onto interstate 280, which connects San Francisco to Silicon Valley, the receiver started collecting GPS data and dots began to appear on the chart, clearly tracking the unique path and turns of the freeway. HP was impressed with the receiver prototype, but ultimately passed on the technology in favor of pursuing the personal computer.[8]

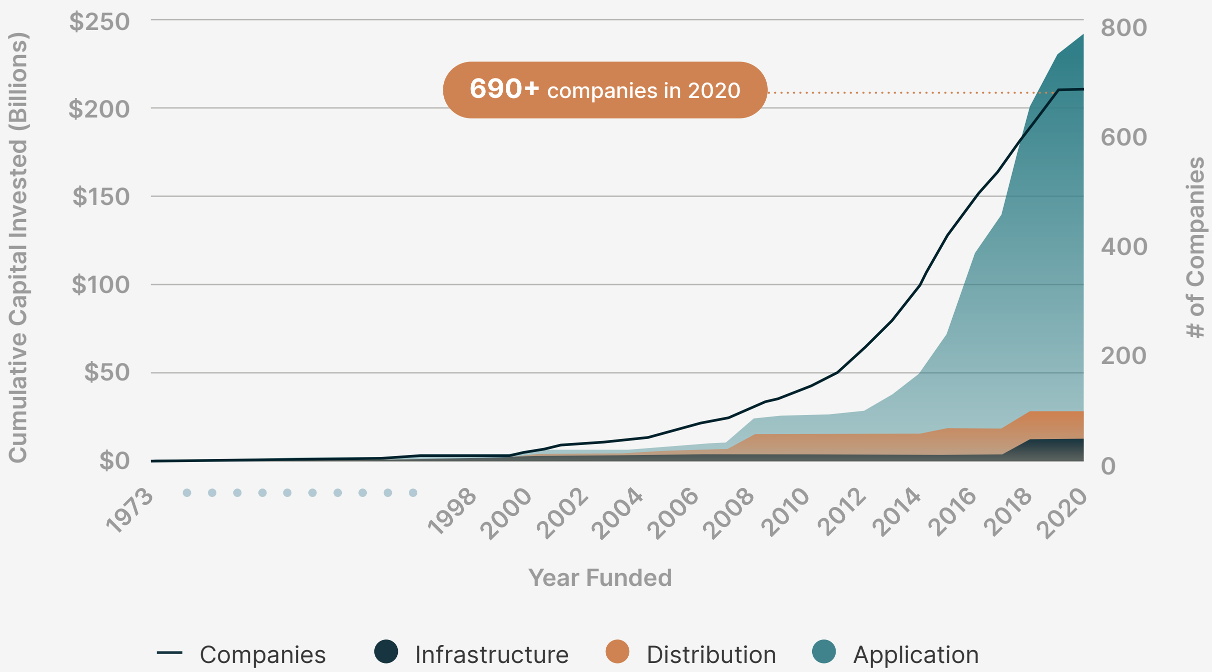
Charlie Trimble joined HP in 1964 after graduating from Caltech and learned a great deal from the innovative culture of the company. When he left HP in 1978 along with two colleagues, they had plans to develop a new LORAN receiver for the marine market and launch a new company to unlock the navigation industry. Trimble Navigation was thus born. Soon after, Ralph Eschenbach began advising the company on the benefits of GPS based on insights from his first prototype. In 1984, after mild success with its LORAN receivers, Trimble brought GPS technology to market with the release of the first commercial GPS products for accurate timing, off-shore oil drilling, and enhanced maritime navigation. Soon after, new companies from all over the world began building and offering new business products and consumer tools. Magellan Systems was founded in San Dimas, California in 1986, with the goal of bringing location accuracy to the masses. Although less accurate than Trimble's products, Magellan's first commercial handheld GPS receiver debuted in 1989 and found success with many users, like recreational boaters, who sought more approximate location services at a cheaper price. Garmin was founded in Lenexa, Kansas in 1989 and would go on to revolutionize the handheld location services industry by creating turn-by-turn navigation. This technology required greater precision than previously achieved by Magellan, and with both Magellan and Trimble at capacity filling military orders, Garmin was well positioned to capitalize on the commercial and consumer market. TomTom was founded in Amsterdam in 1991 and focused on the personal digital assistant (PDA) software for the consumer market, in particular early mapping software including EnRoute, Citymaps and Routeplanner.

[8] Greg Milner, Pinpoint: How GPS Is Changing Technology, Culture, and Our Minds, W. W. Norton & Company, 2016

Applications

In the 2000s, a series of key milestones in GPS technology allowed developers to build and distribute location-based applications to provide consumers with a powerful platform through which to experience them. What followed was the birth of location-based services (LBS) and a Cambrian explosion of entrepreneurial activity that gave rise to companies like Uber, Tinder, Doordash, and Bird.

Cambrian Explosion of GPS Applications



NOTE: Includes all capital raised including debt, equity, and government payments for GPS satellites

Beginning in May 2000, President Clinton announced the end of Selective Availability (SA), the program that intentionally degraded civilian GPS signals for national security purposes. This policy was largely symbolic, however, as commercial receiver technology had already achieved similar accuracy.[9] The real breakthrough came in 2001, when Qualcomm's assisted-GPS technology, gpsOne, was used to support the world's first nationwide launch of GPS solutions on a mobile device. gpsOne utilized signals from both GPS satellites and code-division multiple access (CDMA) cell sites to enhance location services availability, sensitivity, and accuracy in challenging environments. By 2005, gpsOne had been deployed on over 100 million cell phones.[10] Qualcomm's innovations unlocked early location-based applications including asset tracking, point of interest services, and personal navigation.

9 Matt Lake, Pentagon Lets Civilians Use the Best G.P.S. Data, The New York Times, June 15, 2000

10 Qualcomm Press Release, Qualcomm's gpsOne® Enhanced Navigation Software Further Improves Accuracy and Reduces Cost for Automotive and Pedestrian Navigation in the Wireless Phone, July 18, 2015

Applications (cont.)

Steve Jobs introduces iPhone 3G at Apple WWDC 2008

“Location-services is going to be a really big deal on the iPhone with the iPhone 2.0 software... it’s going to explode.”
–Steve Jobs[12]

In June 2005, Google quietly made the Maps application program interface (API) available to developers, encouraging them to integrate maps into their websites. In 2007, the company launched Google Maps for Mobile with the “My Location” technology, which enabled users to see their precise location on a map. At this point, only 15 percent of mobile phones sold were equipped with GPS.[11] Google’s My Location technology allowed users who didn’t have GPS-enabled phones to access location information through cell tower ID information. Google’s efforts in mapping for web and mobile were groundbreaking because they made LBS easy for developers to build upon and for consumers to use.

Perhaps the most important development of the decade came in 2008, when Apple released the iPhone 3G. Unlike its predecessor, the iPhone 3G came equipped with 3G, GPS, and 3rd party applications. This bevy of features was significant because they provided developers with a method of distribution for location-based applications and provided consumers with a powerful, beautiful platform through which they could experience them. Moreover, the iPhone was actually a camera, iPod, and cell phone in one device. This meant that new location-based applications that incorporated elements of these features could be developed.

This widespread distribution of GPS receivers spawned unprecedented entrepreneurial activity at the intersection of space and internet-based technologies with the launch of consumer applications like Uber, Lyft, and Foursquare. Uber[13] and Lyft[14] leveraged GPS-enabled driver and rider locations to facilitate ridesharing while Foursquare[15] used a user’s current location to deliver personalized recommendations. This confluence of technologies (both internet and GPS are required to enable these services) represented the beginning of a new era in the utility of GPS.

In 2012, Postmates[16] and Tinder[17] launched, leveraging GPS and internet technology to enable on-demand delivery services and location-based social searching. Postmates revolutionized the food delivery market by connecting couriers with customers based on location and demand, enabling cheap and quick delivery of goods. Tinder revolutionized the online dating world, simplifying the experience and heavily factoring in location. In 2015, Root[18] and Wag[19] expanded the novel applications of GPS technology to include car insurance and dog walking. Root utilizes location services on a user’s mobile phone to assess their driving behavior before offering a premium, while Wag connects dog walkers with dog owners and allows owners to follow the walk via mobile. These two companies represent examples of GPS enabling new markets and expanding the economic impact of the space-based technology.

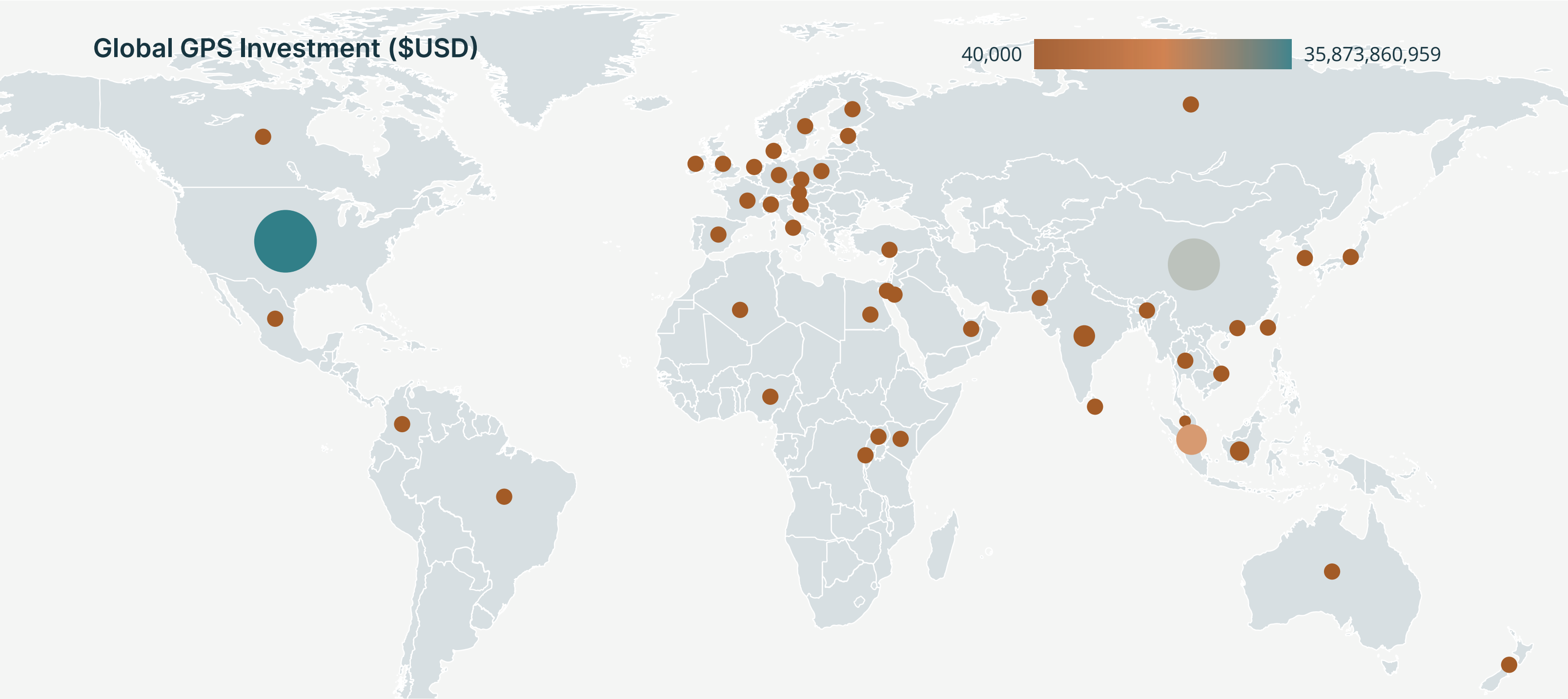
11 Rani Molla, How Apple’s iPhone changed the world: 10 years in 10 charts, Vox, June 26, 2017
12 Steve Jobs, Apple iPhone 3G Keynote, 2008
13 Uber Technologies, Inc. Form S-1, United States Securities and Exchange Commission, April 11, 2019
14 Lyft Privacy Policy, January 1, 2020, Accessed on March 5, 2020
15 Privacy on Foursquare, September 5, 2019, Accessed on March 5, 2020
16 Postmates Support, How Do I Accept and Complete a Delivery?, Accessed on March 5, 2020
17 Tinder Troubleshooting, I denied Tinder access to my location, Accessed on March 5, 2020
18 Root Insurance Co. FAQ, Do I need to leave GPS on during the test drive?, Access on March 5, 2020
19 Wag Dog Walking, What does it cost?, Accessed on March 5, 2020

Three Pillars of Innovation: How *Infrastructure*, *Distribution*, and *Applications* made GPS universal

Applications (cont.)

In 2016, Niantic[20] launched an augmented reality (AR) game that utilized user's locations within the game. This novel form of gaming required advanced use of GPS technology, and became the first prominent location-based AR game. The micromobility revolution began in 2017 with the founding of Bird[21] and Lime[22]. Both companies operate a fleet of personal transport vehicles and have achieved incredible utilization and scale, enabled by GPS technology for locating vehicles. These companies, which would not exist without GPS, were some of the fastest to reach a $1 billion valuation, indicating the scale of what is possible from leveraging GPS.

Global GPS Investment ($USD)



Uber	Lyft	Snap
4,244x	2,028x	507x

The top 25 exits generated an average exit multiple for early investors of 690x and three companies were amongst the top 10 venture exits of the past decade (Uber, Lyft and Snap).[23]

In total, the ubiquitous distribution of GPS and exponential growth in applications created 764 companies that have raised $77 billion in equity financing and have a combined value of $405 billion. While the United States has received 46% of global investment, five other countries received more than $1 billion in capital and generated at least one company with a valuation greater than $5 billion. The underlying industries that received the most investment include Transportation at 58% (Uber, Lyft), Application Software at 15% (Gojek, Momo), and Social Platforms at 7% (Snap, Tinder). A total of 137 companies generated an exit for investors with a combined exit valuation of $170 billion.

[20] Pokémon Support, Pokémon GO Plus system requirements and compatibility, Accessed on March 5, 2020

[21] Bird Platform, Hardware, Accessed on March 5, 2020

[22] Lime Programs, Accessed on March 5, 2020

[23] Exit multiple defined as exit valuation / average of seed & series A valuations

Positioning Today:

Poised for incremental change or exponential growth?

With roughly a decade of exponential growth in GPS applications, this is only the beginning. In 2019, smartphones were the most widely demanded GPS-enabled device with 1.8 billion units sold, followed by wearables, with 70 million units sold annually.

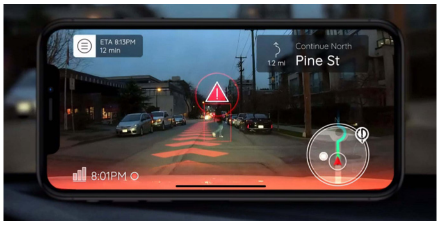
The total number of GPS-enabled devices in operation is expected to increase from 6.4 billion in 2019 to 9.6 billion in 2029 with Asia-Pacific continuing to account for more than half of the global market.[24] This growth is stimulated by trends in digitization, big data, the sharing economy, and artificial intelligence.

Leveraging improved receiver performance and miniaturization, a variety of new devices are building software solutions and services on GPS. Following consumer platforms and automotive solutions, drones have become a significant market for GPS, exceeding mature segments such as maritime, aviation and agriculture. The annual shipments of drones have tripled since 2016 and this growth is expected to continue into the next decade.[25]

Even while GPS infrastructure and distribution continues to improve, the next generation of applications are testing its technical limits, with the need for persistent coverage in dense urban areas, centimeter (cm) location accuracy for both indoor and outdoor environments, alternative solutions in GPS-denied environments, and protection against GPS spoofing attacks.

Augmented Reality (AR) is one of the first next generation applications that is offering a new layer of experience for LBS. The *first* generation of these AR LBS applications have been built on the current GPS infrastructure, with companies in Navigation and Gaming being the first to take advantage. But to realize the full-potential of AR, enhancements in positioning are needed.

Navigation



Phiar's AR Navigation app

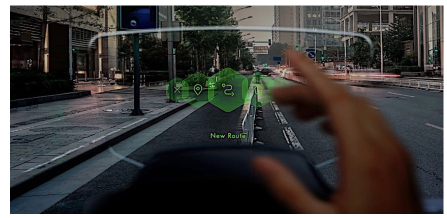
While navigation has primarily been delivered through maps, AR has the potential to recreate the experience in a more natural, intuitive way.[26] In January 2020, Palo Alto-based Phiar Technologies announced the start of a private beta of its AR driving app for iPhone users.[27] According to VentureBeat, Phiar's app "is designed to serve as an augmented navigation heads-up display that sits on a car's dashboard. Instead of filling a phone's screen with a 2D or 3D map, the app can superimpose guidance lines, arrows, and icons atop live camera feeds of streets."

[24] European Global Satellite Navigation Agency, GSA GNSS Market Report, 2019
[25] European Global Satellite Navigation Agency, GSA GNSS Market Report, 2019
[26] Huang, Gartner, Krisp, Raubal & Weghe, Location Based Services: Ongoing Evolution and Research Agenda, Journal of Location Based Services, 2018
[27] Jeremy Horwitz, Phiar launches AI-powered AR navigation app in invite-only iPhone beta, VentureBeat, January 23, 2020

Navigation (cont.)

Switzerland-based WayRay is another startup applying AR to automotive navigation using a slightly different approach. WayRay is developing holographic-display hardware that projects images directly onto the driver's dashboard. WayRay's technology also includes gesture control, allowing drivers to safely browse menus, pick or switch routes and choose relevant points of interest without peering at the dashboard.

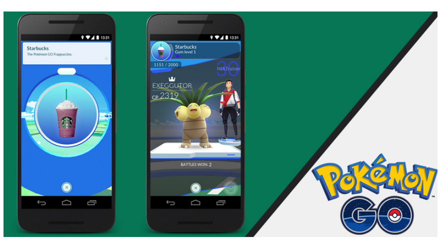
As cars become autonomous and driver/passenger attention is less focused on driving, the windshield becomes a way of consuming content, making the car ripe for application development. As such, WayRay has built an SDK to help developers build AR apps on top of the company's technology, potentially unlocking new applications in Social and Gaming.



WayRay's AR Navigation System

Gaming

Pokémon Go



Pokémon Go Advertising

Another area where AR has shown promise in LBS is Gaming. In 2013, former Google subsidiary, Niantic (formed by members of the teams that included Google Earth, Maps, and Street View), released Ingress - the company's first AR mobile game.[28] Ingress uses the mobile device's GPS to locate and interact with "portals" that correspond to the player's actual location. While this game wasn't terribly successful, Niantic was able to build on the map data created by Ingress to create Pokémon Go. Niantic was able to demonstrate the potential of augmented reality and location-based gaming. According to Sensor Tower, in 2019, Pokémon Go generated a record $900 million in player spending, bringing cumulative spending to $3.1 billion[29] since its launch in 2016.

In addition to in-app spending, Pokémon Go generates revenue through advertising - because Niantic's AR games require movement and exploration of the physical-world, the company can readily push real-world foot traffic to retail locations using location-based marketing. For example, in 2017, it was revealed that Pokémon GO's cost per visit (CPV) model has partners spending between $.15-$.50 per daily unique visit to sponsored locations.[30] Based on the number of visitors Niantic claims it drove to sponsored locations (500 million) in 2017, it's estimated that the company generated between $75 and $250 million from these partnerships.

In November 2019, Niantic doubled down on this strategy, announcing that it would allow small-businesses to sponsor their locations like their larger counterparts.[31] The self-serve platform 'Sponsored Locations', allows small businesses to feature their business as an in-game Sponsored Location, share promotions in-game, schedule mini-games, and provides analytics on player engagement.

[28] Casey Newton, The everywhere arcade: How Google is turning location into a game platform, The Verge, December 13, 2013

[29] Nick Statt, Pokémon Go never went away — 2019 was its most lucrative year ever, The Verge, January 10, 2020

[30] Josh Constine, Pokémon GO reveals sponsors like McDonald's pay it up to $0.50 per visitor, TechCrunch, May 31, 2017

[31] Dean Takahashi, Niantic enables small businesses to sponsor events in location games, VentureBeat, November 6, 2019

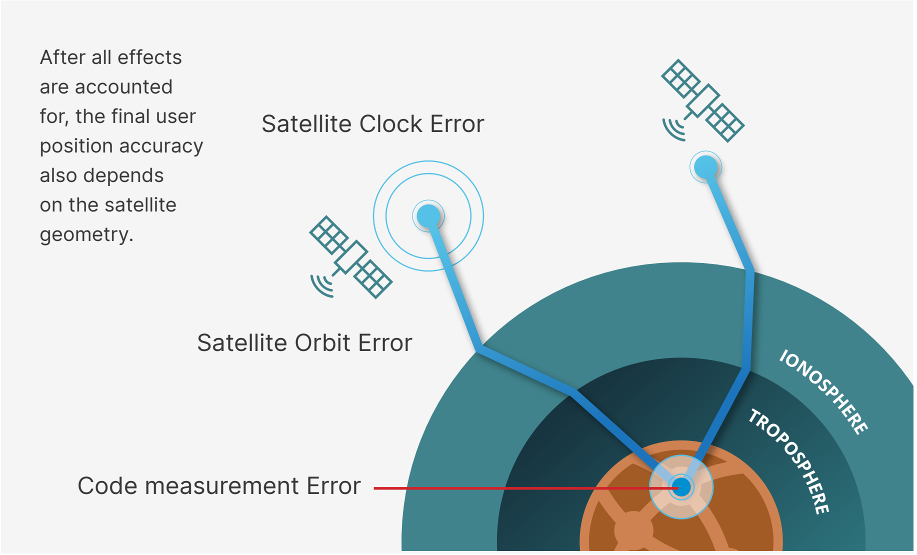
Gaming (cont.)

Niantic's success with Pokémon GO provides a template for future location-based AR games - both figuratively and literally. In November 2019, Niantic announced that it would make its Niantic Real World Platform, the underlying operating system that Pokémon Go runs on, available for developers to build on.[32] Additionally, the company announced that it was launching the Niantic Beyond Reality Fund to help developers bring AR projects to life. As a result, we expect to see more activity in this space.

Upgrading Infrastructure for Augmented Reality

With GPS III, the next generation of GPS satellites launched in 2020, signals will be up to three times more precise than the current generation, providing an unprecedented 1-3 meter accuracy.[33] GPS III also features a new civilian signal, L1C, that is interoperable with other international global navigation satellite systems (GNSS) (Europe's Galileo, Japan's QZSS, and China's Beidou), improving the reliability and coverage of the signal.[34]

Even with these improvements, new AR applications require even greater precision. Due to signal refraction in the atmosphere and satellite orbit/clock error, GPS accuracy will still be compromised. Additionally, these errors can be compounded in urban canyons where line-of-sight is often limited by tall buildings. In 2017, AWE and Super Ventures founder, Ori Inbar highlighted the limitations of GPS in AR.[35]



Effect	Magnitude	Mitigation	Post-mitigation impact
Satellite orbit/clock error†	1-2 m	None	1-2m
Ionosphere	Up to tens of meters	Ionospheric model*	Up to several meters
Troposphere	2-20m	Tropospheric model*	0-2m
Code measurement	1-3m	Filtering	0.5-1.5m
Phase measurement	0.5-10cm	None	0.5-10cm

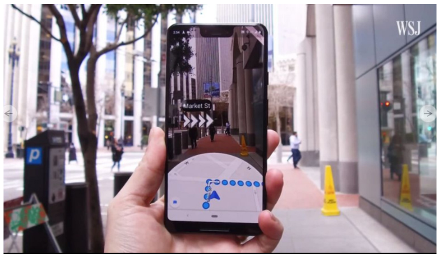
† As transmitted in GNSS broadcast messages

GPS Errors (Hemisphere, GPS World)

In order for AR to become mainstream, he believes that AR experiences must persist in the real world across space, time, and devices. For this functionality to exist, precise location and orientation data is needed. Without it, the physical environment and digital information won't properly mesh together.[36] To unlock this functionality, we are seeing a number of companies creating real-time 3D Maps of the environment using computer vision. These maps provide visual localization, but GPS provides a valuable constraint on the target area.[37]

[32] Niantic Labs Press Release, Creating the Future of AR Experiences on the Niantic Real World Platform, November 6, 2019
[33] Lockheed Martin, Unbelievable Accuracy: GPS III, Accessed site March 5, 2020
[34] Kelly Hodgkins, GPS 3 is the future of navigation, and it's set to roll out in 2023, Digital Trends, September 14, 2019
[35] Ori Inbar, ARKit and ARCore will not usher massive adoption of mobile AR, Medium, September 12, 2017
[36] Edward Miller, Building the 'AR-Cloud': Part One, Medium, December 18, 2017
[37] Open AR Cloud, State of The AR Cloud Report, 2019

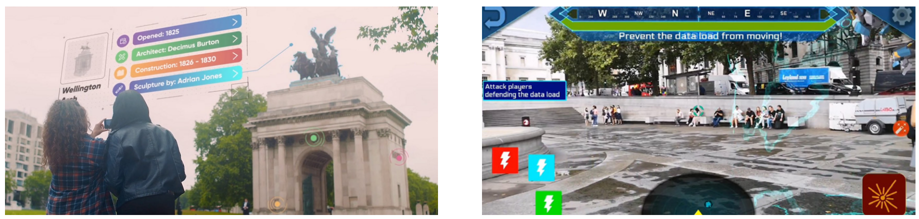
Upgrading Infrastructure for Augmented Reality (cont.)



Google Maps Live View

In August 2019, Google made Google Maps Live View (not to be confused with Street View), its new AR walking directions, available on Android and iOS. Google's Visual Positioning Service (VPS) initially uses GPS to narrow down a user's location and then leverages computer vision algorithms referencing Google Street View imagery to precisely localize a user.[38] Many can relate to the experience of following seemingly simple directions from the mobile navigation app of their choosing like 'Head South on Broadway', only to find the blue dot representing themselves traveling in the opposite direction. The highly precise positioning provided by the VPS allows the user to know precisely which direction they're heading in.

Google is not alone in trying to create a positioning service based on imagery. London-based Scape Technologies, recently acquired by Facebook, launched ScapeKit, a multi-platform software development kit (SDK) that allows digital content to be anchored to specific geographical locations.[39]

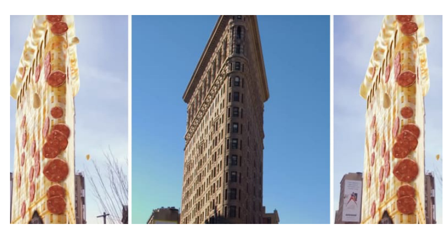


ScapeKit Applications

Fantasmo's CPS in action

Venice-based Fantasmo has created its own version of a VPS based on similar technology. In addition to enabling AR applications, the company has also found traction in robotics and micro-mobility. For example, Fantasmo's Camera Positioning Standard (CPS) allows micro mobility providers to better track their scooters and bikes. As the image below demonstrates, Fantasmo's CPS is able to precisely identify when the scooter mounts the sidewalk, while GPS alone still places it in the street. Fantasmo's technology is also useful for robotics; a robot traveling down the sidewalk, for example, needs to know the exact location of curb-cuts and ramps down to the centimeter. Moreover, Fantasmo is able to offer this solution using cheap cameras rather than expensive sensors like Lidar, allowing this technology to be deployed at scale, today.

The value of this infrastructure has not been lost on Social companies. At its Partner Summit in April 2019, Snap, long a pioneer in mobile AR, introduced 'Landmarkers'.[40] Like Google's VPS, the Landmarkers feature leverages GPS to determine the approximate location of a user and then matches images of the landmark from the user's camera with user generated data from public Snaps. Once identified, users can transform the landmark with AR.



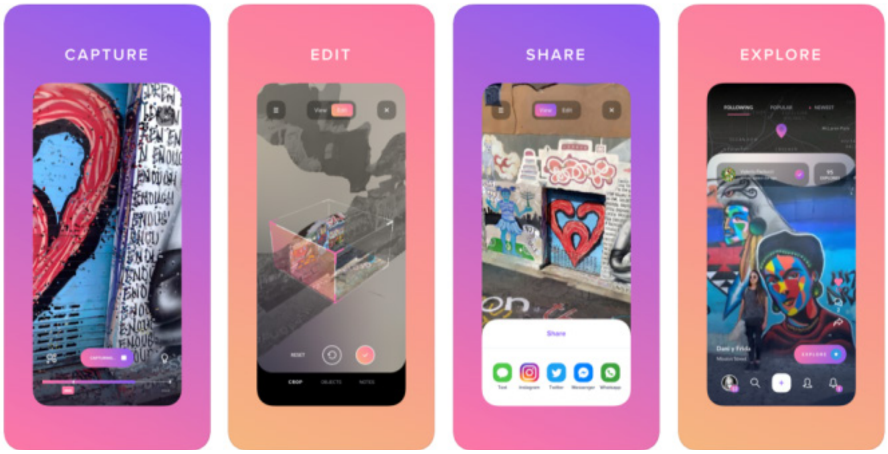
Snap Landmarkers

[38] Abner Li, Google details VPS, ML tech behind Maps AR navigation and making cameras another sensor, 9to5 Google, February 11, 2019

[39] Steve O'Hear, Facebook has acquired Scape Technologies, the London-based computer vision startup, TechCrunch, February 8, 2020

[40] Snap Inc. Press Release, Snap Inc. Announces New Augmented Reality and Camera Search Experiences, April 4, 2019

Upgrading Infrastructure for Augmented Reality (cont.)



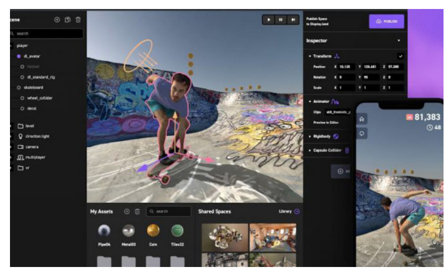
Ubiquity6's Display.land

In November 2019, San Francisco-based startup, Ubiquity6, announced the launch of its AR social network, Display.land.[41] According to the company, users can recreate any real-world environment in a photo-realistic, shared, digital space by simply capturing their location with their mobile camera. Through a combination of mobile video, motion and GPS sensors on the user's smartphone, Ubiquity6 creates a life-scale 3D scene in real time anywhere in the world. Users can choose to pin their scan to a map, allowing others to explore the space.

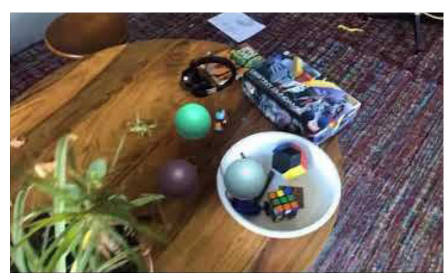
Developer Tools

In addition to the hyper-precise positioning provided by computer vision and GPS, the proliferation of AR requires developer tools that make AR content easy to create and enjoy. We continue to see activity in this space from both large tech companies and startups. In 2017, Apple announced the launch of ARKit; a set of tools that enable developers to produce applications for iOS devices.[42] In 2018, Google released ARCore to allow developers to build AR apps for Android devices.[43] At the April 2019 Partner Summit, Snap announced that it was adding its new 'Landmarkers' feature to Lens Studio, enabling developers to build AR experiences on top of physical locations.

Startups like 6D.ai and Ubiquity6 have also been active in creating new developer tools. In November 2019, in conjunction with the release of the company's 'Display.land' social app, Ubiquity6 announced it was releasing 'Display.land Studio' a free cloud editor and real-time 3D engine that empowers anyone to publish shared, persistent 3D, AR and VR experiences that can be played by anyone, from anywhere, on any device.[44] 6D.ai's 6D Reality Platform meanwhile, gives developers access to SDKs that allow them to create more realistic and functional AR applications.[45] For example, with 6D.ai, designers can achieve occlusion, or the effect of one object in a 3D space blocking another object from view.



Ubiquity6's Display.land Studio



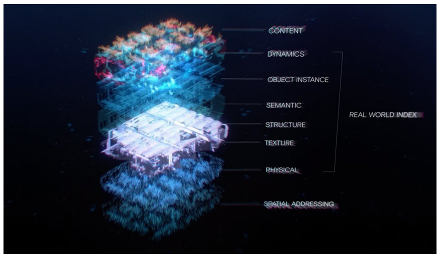
Demonstration of Occlusion by 6D.Ai

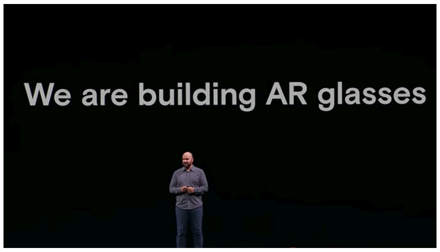
[41] Greg Kumparak, Ubiquity6's Display.land is part 3D scanner, part social network, TechCrunch, November 18, 2019
[42] Adi Robertson, Apple is launching an iOS 'ARKit' for augmented reality apps, The Verge, June 5, 2017
[43] Anuj Gosalia, Announcing ARCore 1.0 and new updates to Google Lens, Google, February 23, 2018
[44] Lucas Matney, Ubiquity6 launches a studio editor built for the real world, TechCrunch, January 14, 2020
[45] 6D.ai Developer Portal, Accessed site March 5, 2020

The Future Will Be Augmented (Reality):

Computer vision and GPS will combine to enable seamless AR experiences

The Cambrian explosion of mobile LBS entrepreneurial activity was predicated on ubiquitous, highly precise positioning, the presence of developer tools, and a multi-functional platform that resonated with consumers. AR has strikingly similar prerequisites. Once, and as these prerequisites are satisfied, we suspect there will be an explosion in AR entrepreneurial activity of similar magnitude.





Facebook announcement at 2019 Oculus Connect developer conference

As described, highly precise positioning is required to unlock persistence - a feature necessary for widespread AR adoption.[46] However, AR, unlike mobile LBS, requires a positioning infrastructure that leverages GPS and a real-time 3D Map of the environment. Companies like Fantasmo, Facebook, and Google are actively building out this map, not just in an attempt to create a VPS, but to own a piece of the virtual real estate that all future AR applications will be built on. Concurrently, there is a great deal of activity in AR developer tools. Just as the Google Maps API enabled developers to readily build LBS applications, ARKit, ARCore, Lens Studio, 6D.ai, and many others are making it easy for developers to build realistic, powerful AR experiences.

The third essential component in making AR the "next big thing" is creating the systems that produce AR experiences for users.[47] In other words, AR is waiting for its iPhone moment. In 2017, Apple CEO Tim Cook said the following about AR - "I regard it as a big idea like the smartphone.[48] The smartphone is for everyone, we don't have to think the iPhone is about a certain demographic, or country or vertical market: it's for everyone. I think AR is that big, it's huge." Apple is rumored to be releasing AR Glasses in 2023, but will face competition from other companies like Microsoft (Hololens), Snap (Spectacles), and Magic Leap (MagicLeap1). As the failure of Google Glass for consumers indicated, these companies will have to develop a product that is unobtrusive and sleek to gain widespread adoption. Facebook has been quite vocal about its plans for AR, announcing in September 2019, that the company plans to release AR glasses in the 2023-2025 timeframe. The company also announced it was working on a product called LiveMaps, calling it "the core infrastructure that will underpin tomorrow's AR experiences".

[46] Ori Inbar, ARKit and ARCore will not usher massive adoption of mobile AR, Medium, September 12, 2017
[47] Open AR Cloud, State of The AR Cloud Report, 2019
[48] James Vincent, Apple reportedly plans 2022 release for first AR headset, followed by AR glasses in 2023, The Verge, November 11, 2019

The Future Will Be Augmented (Reality): Computer vision and GPS will combine to enable seamless AR experiences

Facebook's Rendition of the Mirrorworld

Accompanying the announcement was a video demonstrating the experiences that LiveMaps will enable. In the video, several scenarios are presented where contextually relevant AR content is delivered in the real world. Curiously, glasses are not shown in the video, leading some to believe that the company is in fact working on AR contact lenses.

Most importantly though, this video offers a sneak peak of what is unlocked in AR when precise positioning, developer tools, and a powerful platform are built. It gives us a glimpse into the "mirrorworld". Coined by Yale computer scientist David Gelernter, the mirrorworld will reflect not just what something looks like but its context, meaning, and function.[49] In Ori Inbar's words, this world promises to "accumulate humanity's knowledge and make it accessible at-a-glance".

As information and consumer engagement moves away from screens and back to the real-world, new companies and business models will be created, transforming nearly every industry on Earth. And like Mobile, this phenomenon will be enabled by GPS technology.

History Repeats:

How the evolution of GPS provides a framework for unlocking the value in Geospatial Intelligence and Communications stacks

When GPS was developed 40 years ago, no one could have foreseen that the technology would give rise to a phenomenon like Pokémon GO, that combined GPS with new technology like AR. This game not only grossed more than $3.1 billion in revenue to-date, but also drove new types of location-based marketing and AR-based entertainment.[50] GPS demonstrated the incredible growth and value potential when the Space and Tech sectors converge.

Over the past decade, $2.8 billion has been invested into Geospatial Intelligence satellites.[51] Many of the first movers have pursued a vertically integrated model, collecting data, building distribution capabilities, and creating unique applications in-house. This approach has stymied innovation and limited market growth, which is reported to have generated roughly $3 billion in global revenues in 2018.[52]

[49] Keven Kelly, AR Will Spark the Next Big Tech Platform—Call It Mirrorworld, Wired, February 12, 2019

[50] Nick Statt, Pokémon Go never went away — 2019 was its most lucrative year ever, The Verge, January 10, 2020

[51] Space Angels, Space Investment Quarterly Q4 2019, January 14, 2020

[52] NSR, Satellite-Based Earth Observation Market Report, 11th Edition (EO11). Published September 2019

"Every time you figure out some way of providing tools and services that allow other people to deploy their creativity, you're really onto something."

–Jeff Bezos[61]

Similarly, the Space industry estimates of the market growth are merely incremental, forecasting just $7 billion annually by 2028 (8.2% annual growth), as they fail to account for the exponential power of increasing distribution.[53] Marketplaces have begun to emerge that aggregate geospatial data from multiple suppliers and provide easy access to developers through an API, increasing distribution of this data 10x.[54] SkyWatch* is a leading company in this area, with their initial product, EarthCache, making it simple for developers to integrate geospatial data into their workflows and for satellite operators to unlock new customers. An early application layer is already beginning to emerge with companies like Flurosat* - an analytics engine behind precision agriculture; and Arbol* - a marketplace for parametric insurance.

A similar pattern is developing in the Communications segment. A handful of venture-backed companies have raised more than $6.5 billion for satellite infrastructure to provide global high speed internet from space.[55] SpaceX[56] and OneWeb[57] already have satellites in orbit and plan to provide initial connectivity within the year. This achievement represents a convergence of the space and tech sectors through a new global infrastructure to connect, coordinate, and interpret our digital and physical worlds. The biggest names in tech are following suit with Amazon launching Project Kuiper and Alphabet scaling up Loon. Additionally, China's largest automaker is building a network of 500 satellites to provide high-speed connectivity to their products.[58] The critical distribution layer is beginning to take shape with the launch of AWS Ground Station[59] providing direct downlink to the cloud and Isotropic Systems* building compact direct-to-satellite terminals. The roll-out of 5G will significantly expand the distribution of satellite-based internet and work is already underway to provide seamless connectivity.[60]

GPS provides us with a playbook for how Space-based technologies will create new investment opportunities. Based on our unique insight at the forefront of space investing, we believe that Geospatial Intelligence has the potential to be as large of an opportunity as GPS, with Communications potentially twice as large.[62] Therefore, using the magnitude and timeline of GPS as an analogy, we believe that over $1 trillion of equity value could be created in Space-based Communications and Geospatial Intelligence segments over the next decade. We are still in the early days of this expansion and the industries that will be impacted are not entirely clear, but with GPS as our guide, building the critical distribution layer will unleash innovation and capital.

53 NSR, Satellite-Based Earth Observation Market Report, 11th Edition (EO11). Published September 2019

54 New Desk, SkyWatch raises $7.5M, unveils new platform to make satellite data accessible, Geospatial World, January 8, 2020

55 Space Angels, Space Investment Quarterly Q4 2019, January 14, 2020

56 Lauren Grush, SpaceX aims to provide internet coverage with Starlink constellation as soon as mid-2020, The Verge, October 22, 2019

57 Lauren Grush, Internet-from-space provider OneWeb says it will provide coverage to the Arctic by 2020, The Verge, September 4, 2019

58 Sean O'Kane, China's largest private automaker is building a satellite network now, too, The Verge, March 2, 2020

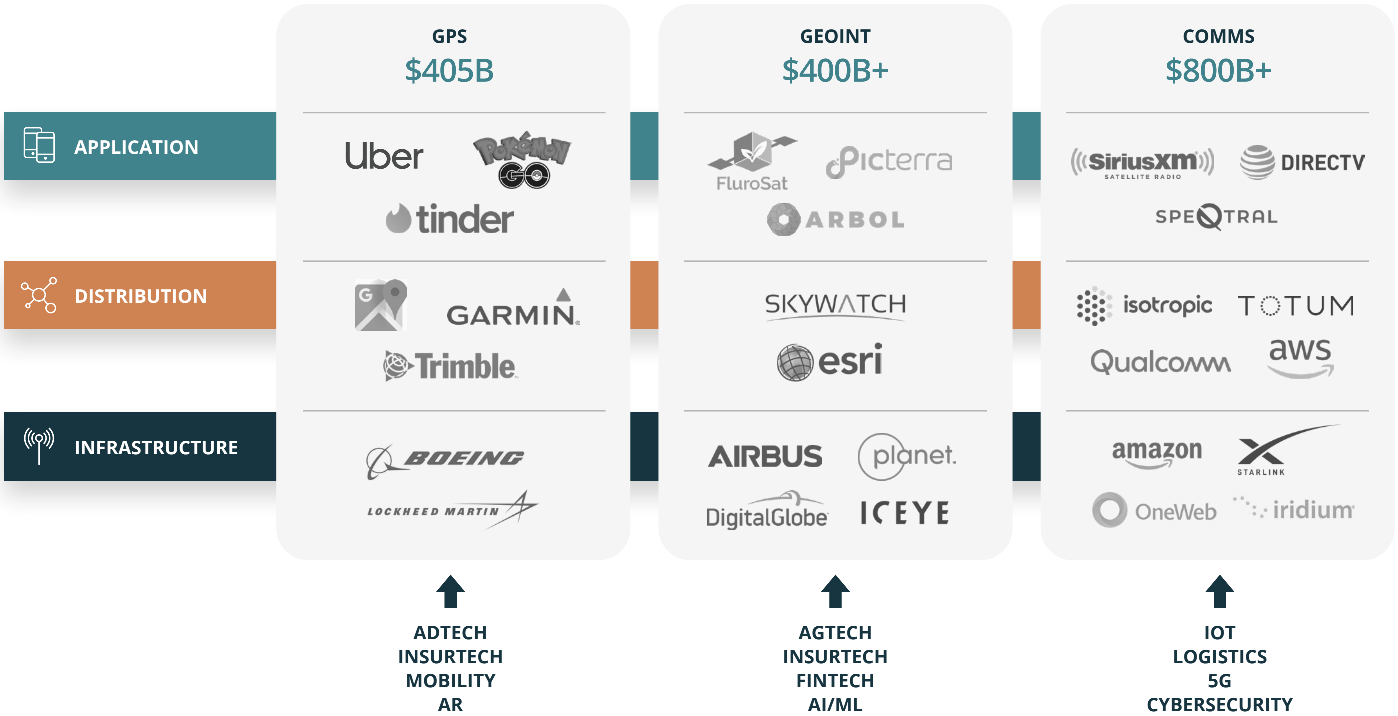
59 Alan Boyle, AWS Ground Station satellite control system is officially open for business, GeekWire, May 23, 2019

60 Kieran Arnold, The Promise of 5G, Space Angels Podcast, Accessed on March 5, 2020

61 Nick Statt, Amazon CEO Jeff Bezos thinks space can be the new internet, The Verge, October 20, 2016

62 Based on investment of $2.8 billion in Geospatial Intelligence satellites and $6.5 billion in satellite infrastructure to provide global high speed internet from space, Q4 2019 Space Investment Quarterly, Space Angels

History Repeats: How the evolution of GPS provides a framework for unlocking the value in Geospatial Intelligence and Communications stacks



Geospatial Intelligence and Communications stacks playing out like GPS. Credit: Space Capital

Authors

SPACE CAPITAL®

Space Capital

Space Capital is an early stage venture capital firm investing in the Space economy, specifically focused on unlocking the value in Space technology stacks such as GPS, Geospatial Intelligence, and Communications. We are actively investing out of our second fund and manage over $35 million in assets. Our sector focus enables us to be a true partner to our portfolio companies and unlock significant value far in excess of our investment capital.

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Silicon Valley Bank

For more than 35 years, Silicon Valley Bank (SVB) has helped innovative companies and their investors move bold ideas forward, fast. From robotics and autonomous vehicles to advanced semiconductors and space, SVB focuses on helping companies at the early convergence of hardware, software and artificial intelligence. SVB provides targeted financial services and expertise through its offices in innovation centers around the world. With commercial, international and private banking services, SVB helps address the unique needs of innovators.

Methodology

This report relies in part on the definitions and findings provided in the National Institute of Standards and Technology's research on the Economic Benefits of the Global Positioning System (GPS).[63] The nine industry segments responsible for the $1.4 trillion of economic value (in the U.S. alone) created by GPS form the initial filter through which we identified companies to include in this report. Each industry was analyzed to map the GPS use-cases, alternatives technologies, and notable companies to determine relevance. A summary of that analysis is provided on the following pages.

Materials

The report focuses on equity financed companies and their sources of funding. Space Capital has invested in several of the companies that will be mentioned in this report. All companies that are a part of Space Capital and its affiliate's portfolios will be denoted with an asterisk (*) at the first mention of the company.

This research was conducted using Space Capital and Silicon Valley Bank's proprietary dataset of equity financed companies. This data is gathered from a number of sources across many categories. No single piece of data can be added to the database until confirmed by multiple sources.

Design

This report focuses on the years 1973 through Q1 2020 to understand the development and rapid growth of companies built on the GPS infrastructure. The analysis focuses on companies that successfully attracted equity financing as a minimum threshold for credibility of their business model and market opportunity. This report does not consider those companies that have relied entirely on debt financing or other methods given the limited information available on these transactions.

Procedure

The population for this research began with Space Capital and Silicon Valley Bank's proprietary dataset composed of 764 GPS companies globally, each of which has been confirmed against multiple sources (including investment databases, private transactions, and confidential sources) before being added to the universe. Data was collected across these companies including capital raised, rounds raised, investor participation, financial performance, valuation, and exits.

[63] RTI International, Economic Benefits of the Global Positioning System (GPS), June 2019

GPS Use-Cases Analysis

Industry	Company Examples	Use Cases	Alternative	Rationale
Agriculture	Trimble, Novatel, John Deere, Raven, AGCO	GPS-assisted yield and soil mapping, GPS-assisted machinery guidance and control systems, GPS-assisted variable-rate technologies	Limited alternatives	Before GPS was available for commercial use, farmers had few technologies that allowed them to proactively manage their fields according to the fields' spatial characteristics.
Electricity	Siemens, Vizimax	GPS provided precision timing to monitor the daily operations of the power grid	Supervisory control and data acquisition (SCADA) systems	Before GPS the United States had a highly functional electricity system serving all customers. GPS then lowered the cost and increased the quality of electricity service.
Location-based Services	Uber, Google Maps, Pokemon GO, Tinder	GPS-assisted navigation, tracking, advertising, ridesharing, geosocial, information, communication, weather, social networking, gaming	Limited alternatives	The location information needed for location-based services (LBS) to operate is obtained from a combination of GPS, Wi-Fi hotspot, and cell towers. However, GPS is often the most critical of these.
Mining	Trimble, Hexagon, Topcon	GPS-assisted site surveying, extraction activities, mining operations, tracking, and safety	Variety of inferior alternatives	Before GPS the United States had a functional mining industry. GPS then lowered the cost and increased the productivity of various activities in the supply chain.
Maritime	Garmin, Inmarsat, iMarine	Navigation, port operations, and recreational boating	Loran-C	Loran-C provides sufficient accuracy that in the absence of GPS, most electronic navigation systems would have evolved using this alternative.
Oil and Gas	Trimble, Hexagon, Topcon	GPS-assisted exploration, drilling, tracking, safety, and maritime operations	Terrestrial operations: radio-based navigation systems, cellular navigation systems, pseudolites, and traditional surveying and mapping techniques. Offshore operations (near shore): similar technologies Deepwater operations: limited alternatives	Before GPS the United States had a functional oil and gas industry. GPS then lowered the cost and increased the productivity of various activities in the supply chain. However, GPS alternatives do not offer the range or precision required for deepwater operations.
Surveying	Geomax, Sokkia (Topcon), Topcon, Northwest Instruments, Spectra Geospatial, Leica Geosystems (Hexagon), Seco	GPS-assisted geometric calculations for identifying and mapping boundaries and land features	eLoran	Before GPS, surveyors used technologies that were effective at achieving high levels of accuracy, but with higher labor costs, longer time frames, and lower productivity levels.
Tele-communications	Frequency Electronics, Oscilloquartz, Symmetricom, ColdQuanta, Bliley Technologies, Chengdu, Spaceon, OPNT, Inmarsat, Speedcast, Verizon, AT&T	GPS enables synchronization of traffic between carrier networks and across wide geographic areas, initializing calls between wireless handsets, wireless handoff between base stations, carrier aggregation, directional antennas and adaptive transmission power control, and billing management	Limited alternatives	Advanced wireless networks (4G LTE and 5G) rely heavily on precision time and frequency signals from GPS. Although telecom network operators have used other sources of precision time and frequency in the past and still use atomic clocks extensively, the network infrastructure has evolved to rely heavily on GPS.
Telematics	Cambridge Mobile Telematics, Omnitracs	GPS-enabled in-vehicle equipment to remotely monitor vehicles for a variety of purposes	Limited alternatives	The high-precision capabilities of GPS are critical to unlocking most of the benefits of telematics. Even Omnitracs, the first Telematics company, was built on a private satellite network.

GPS Use-Cases Analysis (cont.)

Two technology groups were identified from this analysis, 1. those industries that primarily integrate GPS into their existing products/services with alternatives to the technology, and 2. those industries that create novel solutions resulting directly from GPS. The companies selected for the purpose of this report fall into group 2. Specifically, this report focuses on companies that fall within the Agriculture, Location-Based Services, Telecommunications, and Telematics industries.

Definitions

"Global Positioning System (GPS)"	A a network of monitoring stations and satellites that distributes a signal used for positioning, navigation, and timing (PNT). It is one Global Navigation Satellite System (GNSS) of several including GLONASS, Galileo, and Beidu.
"Commercial"	Private sector enterprises that bear a significant portion of investment risk and responsibility for activities and operate in accordance with typical market-based incentives for controlling cost and optimizing return on investment.
"Space Company"	A commercial entity that relies on space as a foundational building block in a product or service.
"Entrepreneurial"	A commercial entity that has raised nongovernmental equity financing to deliver a product or service.
"Early-Stage"	Seed and series A investment rounds and companies at a similar stage of development.
"Infrastructure"	A collective term for all hardware and software systems that constitute essential components of space-based infrastructure. This includes satellite production and launch capabilities, instrumentation, components as well as on-orbit operations. If any of these systems and services were to be interrupted for a significant period of time, the space-based infrastructure may be impared.
"Distribution"	A collective term for all hardware and software systems that support the access and distribution of space-based infrastructure and application development.
"Applications"	A collective term for all hardware and software systems that leverage space-based infrastructure and distribution to perform specialized tasks for an end market/s.

Top 25 GPS Companies by Valuation[64]

Rank	Company	Industry	Country	Equity	Entry Val	Last Val	Max Rev	Exit	Val Multiple
1	**Uber**	Transportation	United States	$13.7B	$0.0B	$75.7B	$11.8B	IPO	4244x
2	**Didi Chuxing**	Transportation	China	$11.6B		$57.6B	$0.4B	Secondary	
3	**Lyft**	Transportation	United States	$4.9B	$0.0B	$24.0B	$2.2B	IPO	2028x
4	**Snap**	Social/Platform Software	United States	$2.6B	$0.0B	$19.7B	$0.9B	IPO	507x
5	**Grab Holdings**	Transportation	Singapore	$8.0B		$14.9B	$1.0B		
6	**DoorDash**	Other Restaurants, Hotels & Leisure	United States	$1.8B	$0.1B	$13.0B	$1.0B		182x
7	**Microsemi**	Semiconductors	United States			$8.2B	$1.9B		
8	**HERE Global**	Application Software	United States			$8.1B		IPO	
9	**Uber China**	Transportation	China	$1.5B	$8.0B	$8.0B			1x
10	**Instacart**	Internet Retail	United States	$1.9B	$0.0B	$7.9B	$2.8B		310x
11	**Just Eat Holding**	Other Restaurants, Hotels & Leisure	United Kingdom	$0.1B		$7.7B	$0.6B	IPO	
12	**Ola**	Transportation	India	$1.7B		$6.3B	$0.3B	Secondary	
13	**Samsara**	Business/Productivity Software	United States	$0.5B	$0.1B	$6.3B			55x
14	**UCAR Technology**	Transportation	China	$1.7B	$1.3B	$5.5B	$0.3B	IPO	4x
15	**GO-JEK**	Application Software	Indonesia	$1.9B		$5.0B			
16	**Tinder**	Social/Platform Software	United States			$5.0B			
17	**Tele Atlas**	Application Software	Netherlands			$4.3B	$0.4B	IPO	
18	**Fitbit**	Electronics (B2C)	United States	$0.1B	$0.0B	$4.1B	$2.3B	IPO	671x
19	**Dianping.com**	Information Services (B2C)	China	$1.5B		$4.1B			
20	**Deliveroo**	Other Restaurants, Hotels & Leisure	United Kingdom	$1.3B	$0.0B	$4.0B	$0.6B		202x
21	**Niantic**	Entertainment Software	United States	$0.5B	$0.1B	$4.0B	$0.9B		38x
22	**Uber & Yandex JV**	Transportation	Russia			$3.8B			
23	**Root Insurance**	Automotive Insurance	United States	$0.4B		$3.7B			
24	**Momo**	Application Software	China	$0.3B	$0.0B	$3.6B	$0.2B	IPO	204x
25	**Broadcom**	Electronic Components	United States			$3.5B		IPO	

[64] Post money valuation as of last completed financing round.