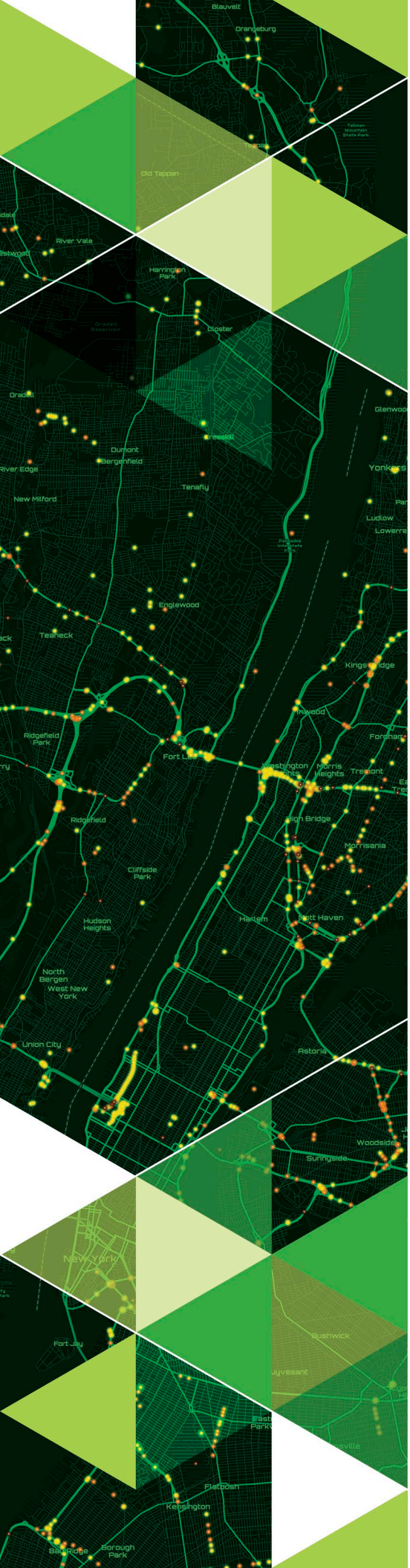

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Ten Requirements for a Comprehensive Imagery System

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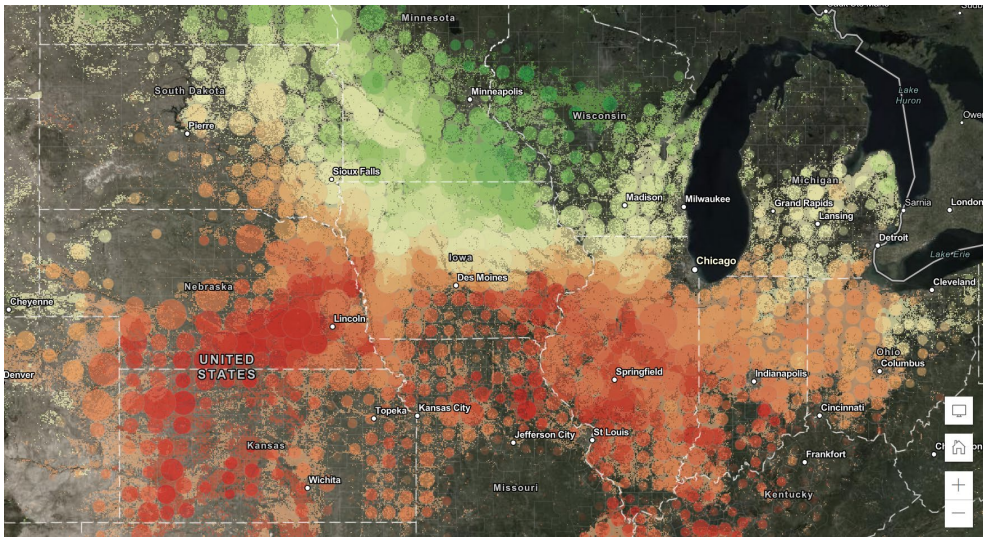
Ten Requirements for a Comprehensive Imagery System

Overview

Organizations in a wide range of sectors such as agriculture, energy, utilities, and defense use information derived from imagery to make critical decisions that impact their organization's success and often the community. Suitable access and analysis of imagery are therefore critical.

The volumes of imagery collected from satellite, aerial, drone, and terrestrial sensors are massive and will likely continue to increase in volume at a rate of about 20 percent or more per year. This exponential increase in available imagery challenges organizational best practices in managing, processing, analyzing, disseminating, and visualizing imagery data and the resultant information.

Time is an essential attribute of imagery. New imagery informs stakeholders of an environment's current state and has high value. Over time, the value of imagery initially drops as the imagery becomes stale but then increases in value as it becomes the base for understanding change, measuring trends, and making predictions. As the volume of imagery increases, so does the cost of storage, creating a predicament for organizations.



The image illustrates the result of a suitability analysis that examined the impact of climate change on corn production. Areas in green illustrate a high opportunity for corn suitability. Areas in red are high risk areas.

Traditionally, organizations owned and manage their imagery content so that they could gain an advantage by controlling access. The increasing availability of open public imagery datasets is a factor driving organizations to utilize cloud compute to enable the efficient sharing of datasets between multiple organizations as well as to gain the power of elastic computing services that the cloud can provide.

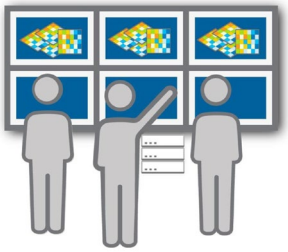
Organizations are also increasing the use of imagery services that provide web access to imagery or imagery-derived products. Imagery-derived products, such as the volume of wheat produced per country or impervious surface coverage for property parcels, are much smaller in size and serve as the basis for further visualization and analysis using geographic information system (GIS) technology. Using derived products requires more emphasis on data quality and data providence for the organizations collecting and processing the source data while also extending the need for highly interoperable systems to enable those consuming the imagery to retain confidence in the results. Organizations collecting imagery and those consuming imagery-derived products both need a comprehensive imagery system to ensure that the appropriate information is obtained on time. This paper summarizes the 10 key requirements for a comprehensive imagery system.

1. Managing Imagery

For organizations with collections of imagery, two image management modes are needed separately or in tandem: curator-managed imagery and user-managed imagery.

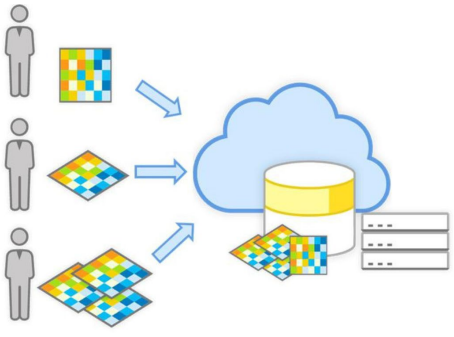
Curator-Managed Imagery

An organization may have large volumes of imagery managed, or curated, by a team or an individual that provides accessibility to others. In this mode, organizational imagery is pooled by a specialized team, which ensures data consistency and accuracy. The curator ensures the data has the appropriate attribution and makes the data accessible to others efficiently.



User-Managed Imagery

In the case of user-managed imagery, there are organizations with many users that need to maintain and share their imagery datasets. Traditionally, such datasets are small enough to be maintained on their desktop computers; however, as the data volumes increase exponentially and the total cost of ownership for maintaining infrastructure increases, organizations increasingly need to move to enterprise or cloud infrastructures for better storage and compute. In these instances, the data may still be managed by the original owner. The primary aim is to provide imagery hosting so that the storage and compute are not on desktop/laptop computers, and the compute and sharing are performed as services.

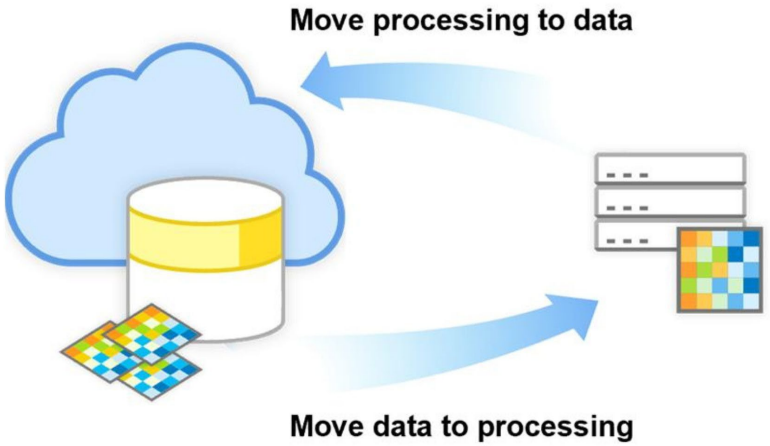


A comprehensive imagery system needs to be able to provide both forms of image management so the organization can adapt and scale as volumes increase and patterns of use change. Curators can utilize the extensive image management capabilities in ArcGIS® Pro to manage imagery, define processing to be applied, and share datasets as image services. User managers can also

simply upload and host imagery for sharing while simultaneously controlling who can access it.

2. Data and Compute Locality

Storing large volumes of imagery data requires appropriate infrastructure. Traditionally, images were stored on local computers or as network-attached storage; however, these do not scale efficiently and, as a result, most imagery is now stored in public or private cloud storage. Some organizations embrace the cloud by moving their data to cloud storage, while others are required to maintain their infrastructure or retain a hybrid approach.



Imagery storage is a key cost factor for organizations. Image processing and analysis both require compute, which can be intensive, and the data must travel from the storage to the compute, which can be slow. If storage and compute are not in the same location, then there are two options: move the image processing to the data or move the data to the processing location.

If the data is in the cloud, the processing should also be performed in the same cloud region. Typically, in cloud infrastructures, data movement within a cloud region is fast and doesn't incur additional fees, while any movement between cloud regions or over the internet is expensive (currently approximately $80/TB) and relatively slow.

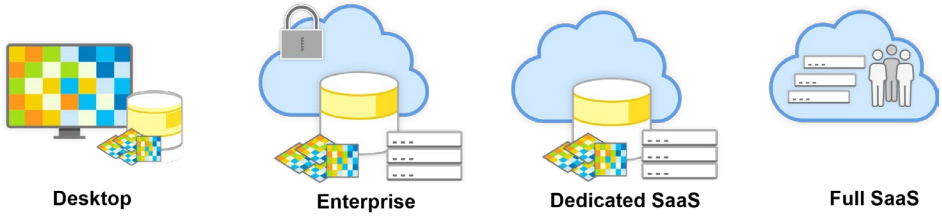
However, there are cases where it is better to move the data to the processing location. This occurs when the required compute is very intensive and specialized compute environments provide a performance or cost benefit. Moving the data to the processing location is also a necessity if the analysis requires datasets stored in different locations. This data movement can often be mitigated by moving the smaller datasets and ensuring that only the pertinent data is transferred. Therefore, there are valid reasons for organizations to use both cloud infrastructures and on-premises infrastructures.

A comprehensive imagery system needs to efficiently process and analyze data to meet data and performance requirements and keep costs down. ArcGIS can efficiently access imagery in the cloud, on-premises, or in local environments to ensure the compute is most efficient while reducing egress costs for cases where the data cannot be moved to the processing location.

3. Deployment Modes

There are many cases where organizations find themselves with limited or no access to the internet and, as a result, want to run all processes locally on a PC or laptop. For example, you may need to collect drone imagery in a remote area or perform visualization and exploitation of imagery for emergency response events with limited internet access. In these cases, you would be unable to perform image processing visualization and analysis as services in the cloud. There are cases where the extensive breadth of tools may not be available as services, or you might already be trained in using desktop software. Organizations may also initially set up and test processes using a desktop application and then scale the analysis in the cloud.

A comprehensive imagery system, therefore, needs to be able to run with similar functionality in different deployments. ArcGIS provides four different deployment options: a desktop application, an enterprise implementation, a managed software as a service (SaaS), and a full SaaS.



Desktop Application

ArcGIS Pro and the ArcGIS Image Analyst extension provide a complete imagery workstation to run in a desktop environment, providing access to the full gamut of ArcGIS management, visualization, and analysis capabilities. ArcGIS Pro also runs effectively on virtual machines in a cloud infrastructure, which enables fast and direct access to imagery stored in the cloud. Alternatively, organizations can use ArcGIS Pro as a client for one of the other ArcGIS deployments.

Enterprise Application

ArcGIS Enterprise and ArcGIS Image Server allow organizations to set up enterprise-wide implementations of ArcGIS running on-premises or in the cloud. These implementations provide a comprehensive imagery system behind firewalls that ensure conformance to the highest security and privacy standards where the organization is in full control.

Managed SaaS

ArcGIS Image Dedicated provides a managed SaaS solution to organizations that want to use public storage or manage their storage, but do not want to manage their compute infrastructure. The required elastic compute to serve, process, or analyze imagery is spun up next to the cloud storage in any Azure or Amazon Web Services (AWS) region. This strategy assures potentially massive compute without egress costs or the need to manage infrastructure. Additionally, Esri Managed Cloud Services implements ArcGIS Enterprise along with associated data management in any cloud that an organization needs.

Full SaaS

ArcGIS Image for ArcGIS Online provides a full imagery SaaS within ArcGIS Online. You can upload imagery in ArcGIS Online to efficiently host, share, and perform analysis without the need to set up or maintain any infrastructure.

All deployments of ArcGIS have the same core components to ensure a seamless transition for organizations that find themselves managing, scaling, or analyzing imagery across the entire imagery suite.

4. Sensor Support

A comprehensive imagery system must be able to directly handle imagery from different sensors and the associated metadata required to set up the appropriate processing to transform the data into different products. For most satellite sensors, this requires the support of rational polynomial coefficients and other ancillary metadata to perform accurate georeferencing and orthorectification. For frame cameras used in drone and aerial imagery, it is necessary to calculate image orientation before orthorectification. The imagery system needs to be capable of aerial triangulation, orthorectification, and other forms of georeferencing as well as mosaicking, seamline generation, and color balancing.

ArcGIS has extensive support for nearly all available sensors. Sensors not directly supported in ArcGIS can be added using Python raster types, which read the metadata, extract and normalize the attributes, and define the appropriate processing functions. ArcGIS also provides all the tools to generate not only orthomosaics but also true orthophotos and 3D meshes.

5. Cloud Optimization

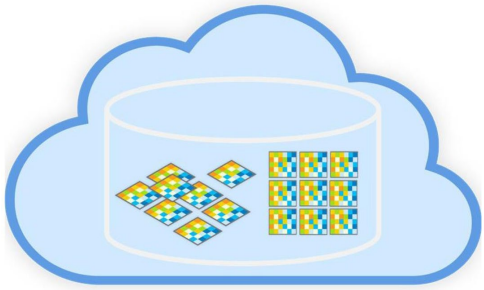
If you take a raw .tiff file available from most data providers or sensors, upload them to cloud storage, and then attempt to access them, performance will be very slow. This is because many image formats are not optimized for cloud storage. Cloud storage has very high reliability and throughput, but also high latency for access. It is often necessary to restructure the data into cloud-optimized formats, of which there are many. For example, a COG file is a cloud-optimized version of a GeoTIFF that ensures the data is tiled with pyramids. Depending on the data source and size, other more optimized formats exist, such as CRF and MRF. For multidimensional datasets, there are cloud-optimized formats, such as transposed CRF and ZARR. For other derived imagery products, such as 3D mesh and point cloud, there's a range of cloud-optimized formats enhanced for streaming data, including I3S.

Cloud storage is expensive for large volumes of data, so it is important to be able to appropriately compress the data. There are options for lossless, lossy, and controlled lossy compressions that can significantly reduce the size of the data and also increase access performance. The appropriate compression option can have a significant effect on total costs.

A comprehensive imagery system needs to be able to efficiently read and create such cloud-optimized formats, including suitable compression. ArcGIS supports more than 150 image formats, including multiple versions of GeoTIFF, such as COG. Esri is a pioneer in the development of cloud-optimized formats and structures such as MRF, CRF, and OGC I3S, as well as compression formats such as LERC, which provides controlled lossy compression. ArcGIS also includes extensive caching capabilities that speed up repeated requests, which also reduces the number of requests and egress from cloud storage.

6. Catalogs

Images no longer come in ones or twos but in thousands and millions. As a result, the ability to catalog all imagery and associated metadata is a requirement for a comprehensive imagery system. Unfortunately, there is no single standard for imagery metadata, so it is necessary to be able to go through many different structures to extract the appropriate metadata and provide a quickly searchable catalog. This resultant attribution needs to be flexible to handle the many ways an image's key attributes are represented, such as its size, bands, and bit depth, as well as how an image and its band frequencies are georeferenced.



Cataloging your imagery provides structure, so you're able to quickly query, search, and organize images.

With ArcGIS, metadata is ingested into mosaic datasets, oriented imagery catalogs, or LAS datasets, which are database models with schemas optimized for normalizing the metadata. The mosaic dataset schema is optimized for large collections of preprocessed or nadir (downward-looking) imagery represented spatially by a footprint polygon. Mosaic datasets reference the image locations and store the imagery metadata—as well as the processing parameters—to perform more complex processes, such as orthorectification. Data is then processed as you access it, reducing the need for multiple pregenerated derived products.

Mosaic datasets enable multiple mosaicking methods that control how overlapping images are handled. Millions of images such as the complete Sentinel 2 and Landsat archives can be handled in a single mosaic dataset, providing instantaneous access to any image with associated processing performed on-the-fly as the data is accessed.

Oriented imagery catalogs are a simpler data model optimized for non-nadir images that are best characterized as an exposure location with associated sensor orientation information that forms a 3D frustum to represent coverage.

This simple data structure enables scaling to billions of images collected from a wide range of commercial and consumer imagery sensors.

LAS datasets are cataloging data structures optimized to handle large collections of lidar and point cloud data that also have their specific attribute requirements.

A comprehensive imagery system needs to make imagery accessible while preserving metadata required to be correctly analyzed and visualized. The system also needs to allow users to search and discover these data models and source data. ArcGIS supports the crawling and reading of a wide range of metadata from different images and sensors and converts this into appropriate image properties and processing chains to enable appropriate access. The support also includes SpatioTemporal Asset Catalog (STAC), which is a relatively new standard for defining and storing metadata along with images and providing search and discovery. This standard is typically used for preprocessed imagery since few STAC profiles handle the complex orientations from sensor data.

7. On-the-Fly and Persisted Image Processing

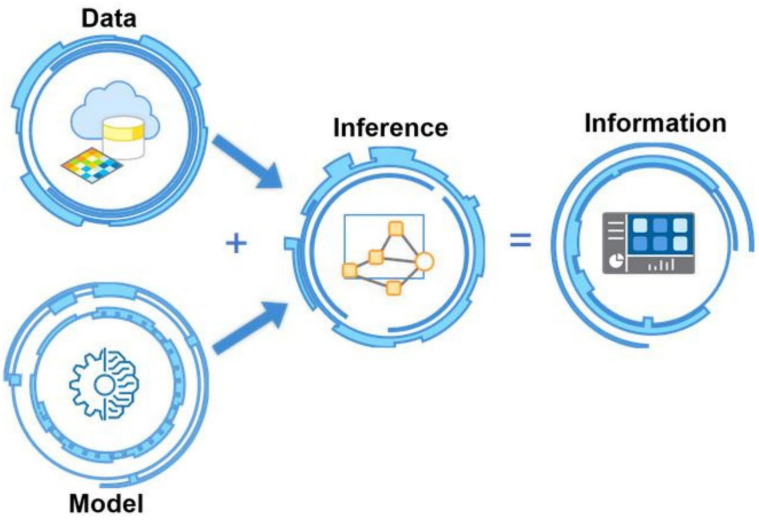
Image processing transforms imagery to make it more suitable for visualization and analysis. Processing can range from simple image enhancements to applying band indices and geometric corrections, such as orthorectification. Such processes often need to be applied to many different images simultaneously.

A comprehensive imagery system needs to be able to efficiently handle such image processing tasks. ArcGIS has extensive tools to determine processing parameters and efficiently implement image processing chains. On-the-fly processing quickly applies the required processing on specified pixels that will be viewed. This enables you to create multiple products from a single source without the need to process the complete datasets. You can also apply image processing to any required extent and store the results as a new dataset. Processing parameters are stored as a function chain within a mosaic dataset or as a property of a layer.

Image processing can be compute-intensive yet need to be highly elastic and capable of scaling to millions of images. As part of a project for Microsoft, Esri processed the complete Sentinel 2 archive. This required processing eight million scenes with each scene requiring 45 minutes of processing. The majority of the five million compute hours was performed over 10 days with more than 40,000 compute nodes running parallel. The ability to rapidly process extensive amounts of imagery is a testament to the capabilities of a comprehensive imagery system.

8. Analysis

Imagery management and processing are performed to enable users to visualize and, more importantly, analyze imagery to extract information. Imagery quantities are now too great for humans to visualize and manually extract features. Because of this, many analysis tools including machine learning and deep learning are used for image analysis.



Analysis tools range from local or regional functions to global functions. Local functions are those where the output for any pixel is dependent on a small geography or time range around that pixel. Most image enhancement, deep learning inferencing, image classification, and change detection are local functions. Regional functions are those that require input from a subset of the complete dataset such as computing regional statistics. Global functions are those where the output at any location could be dependent on the value of pixels anywhere in the dataset and are more complex to scale. Hydrological modeling analysis is an example of a global function. Additionally, the datasets for such analyses need to include both raster datasets and vector datasets. For example, if you have a set of parcels and want to summarize the yield for each parcel, you need a GIS capable of mixing both raster and vector datasets.

A comprehensive imagery system needs to be able to perform analyses on both small and large datasets; operate a wide range of analysis tasks with local, regional, and global functions; handle both raster and vector data; and be able to scale massively. ArcGIS raster analytics is unique in that it provides extensive local, regional, and global analyses against small and massive datasets while handling both raster and vector datasets. With ArcGIS, you can develop and test analysis on small areas and scale up analysis in the cloud, if required. The range of analysis tasks includes all forms of machine learning, deep learning, and tools developed and used by imagery and data scientists (e.g., change detection, suitability, and terrain analysis). The pedigree of both vector and raster analysis capabilities in ArcGIS is unmatched.

9. Dissemination, Interoperability, and Security

In many cases, such as in the event of a natural disaster, imagery has limited value if it is not accessible. For such cases, imagery may need to be made publicly accessible to millions or billions of users. Alternatively, in the case of confidential military or commercial data, imagery may need to be secure.

A comprehensive imagery system needs to be able to efficiently serve imagery as web services. Such web services should enable dynamic imagery with rendered content appropriate to the use requirements rather than a static image tile. ArcGIS provides you with multiple options to disseminate imagery. Source imagery can be served as dynamic image services; the client applications send

requests for imagery of a specific form, and the servers perform the required on-the-fly processing to access, process, and immediately return the required imagery. Imagery can also be served as tiled imagery, where the required preprocessed imagery is streamed to the client applications that then project and render the data as required. Additionally, static image tiles (or tile caches) can be served as simple imagery basemaps. A comprehensive imagery system also needs to support user identification, required access controls, and massive scaling abilities. ArcGIS provides a wide range of scalable web services that efficiently serve imagery and perform analysis. This can be implemented within ArcGIS Enterprise or by using ArcGIS Image Dedicated or ArcGIS Online.

10. User Experience

Being able to manage, process, and analyze imagery is all well and good, but you need to also provide the experiences to enable your end users to review that data and perform their analyses to come to the correct conclusions and decisions. A comprehensive imagery system must be capable of integrating all the different geospatial data to provide engaging experiences as desktop, web, and mobile applications.

ArcGIS provides a complete system of engagement, utilizing a wide range of web services, layers, web maps and 3D web scenes, and applications. Any spatial data source, including vector or raster datasets, can be served using efficient web protocols such as REST-based services, OGC WMS, WFS, feature services, or I3S. These services can be included in layers that define how the data is presented to the user. Web maps and 3D web scenes define which layer collections are displayed and enable user interaction. Web maps and 3D web scenes form the basis of applications that provide the generic or customized end-user experience optimized for visualization or the decision-making process.

ArcGIS provides not only the servers and services to serve the data but also an extensive set of APIs and development environments to enable a broad range of users by engaging desktop, web, and mobile applications. Custom applications can also be developed with ArcGIS to fit the needs of nonimagery savvy user bases.

Conclusion

To ensure success in exploiting imagery, organizations need a comprehensive imagery system. ArcGIS is the only comprehensive imagery system on the market that provides the breadth of capabilities required to enable organizational success. Other imagery systems may implement some of the requirements described in this paper, but there is no other system that can cover these 10 comprehensive imagery requirements. To sum things up:

- ArcGIS Image is a suite of products that covers the complete imagery system.
- ArcGIS Pro and the Image Analyst extension provide the complete desktop experience.
- ArcGIS Enterprise with Image Server provides a scalable enterprise deployment that can be implemented fully behind a firewall-managed environment within a public or private cloud.

- ArcGIS Image Dedicated is a subscription that provides access to image capabilities as a managed SaaS where Esri sets up the required compute next to your cloud storage without you needing to stand up or maintain your cloud infrastructure.

- ArcGIS Image for ArcGIS Online provides a fully managed SaaS environment enabling you to host your imagery in ArcGIS Online, share it privately or publicly, and perform a large range of analyses without the need to stand up or maintain any of your infrastructure.

Learn more about Esri's Imagery System.

About the Author

Peter Becker is Esri's group product manager for imagery. With 30 years' experience in the ideation, development, and implementation of imagery and mapping systems, he has been instrumental in the development of Esri's imagery portfolio. In the last 10 years, he has focused on scaling the ArcGIS Image suite in the cloud. Prior to joining Esri, he was the technical director for MAPS geosystems, an international aerial survey and mapping company.

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