ArcUser

The Magazine for Esri Software Users

GIS and BIM Integration Leads to Smarter Communities 16

Imagery Superpowers 40

Mapping the Opportunity to Intervene Clearly 46

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Spring 2018 Vol. 21 No. 2

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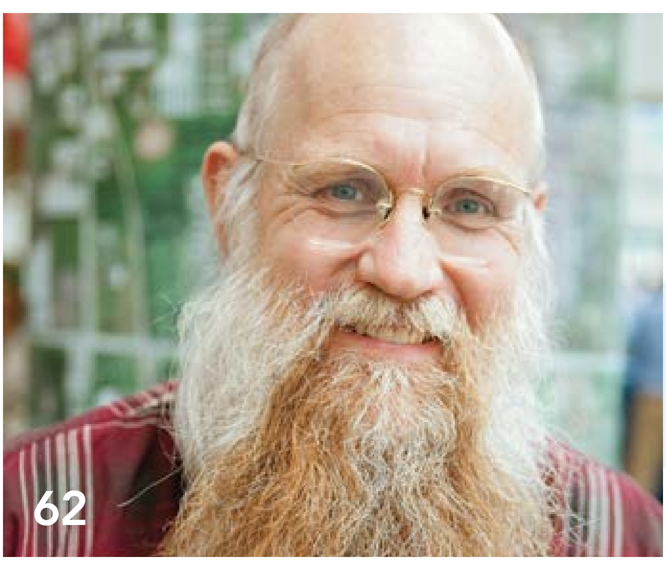

Faces of GIS

62 Systems that Serve

New Capabilities Support the Original Mission

For nearly 50 years, Esri has helped organizations achieve better outcomes by making processes simpler, faster, and cheaper using a geographic framework, or The Science of Where.

Initially these benefits were realized on the project level by integrating data, analyzing relationships, and producing new information for better decisions. Over the years, the application of GIS expanded from projects to departments then the entire enterprise and finally to collaborations between organizations. Accompanying this change in scale was an increase in availability. The ArcGIS platform now supports GIS across desktops, servers, mobile devices, and the cloud.

The ArcGIS platform continually incorporates new developments in IT. This issue includes articles about how GIS integrates some of the most promising and powerful aspects of IT such as artificial intelligence, real-time analysis of big data, integration of building information modeling (BIM), and scalable processing in the cloud so that enormous jobs that were previously impractical or just impossible can now be handled.

As GIS capabilities have expanded, so have its uses, as illustrated by the ArcGIS Common Patterns of Use poster included in this issue. The original common patterns—mapping and visualization, data management, sharing and collaboration, and decision support—have increased in number and now include field mobility, monitoring, analytics, design and planning, and constituent engagement.

These patterns of use provide the foundation for building smart communities and better outcomes not just for organizations but also for the world. Esri's commitment to this original goal is brought out in "Systems that Serve," an interview with Scott Morehouse. For many years the director of software development at Esri, Morehouse stepped back from this role to work with research and development teams at Esri that are developing GIS technology for urban systems and civic engagement. When explaining this move, Morehouse said, "I want to build systems that serve people—systems to guide, direct, or organize the civic process."

Monica Pratt
ArcUser Editor

ArcUser

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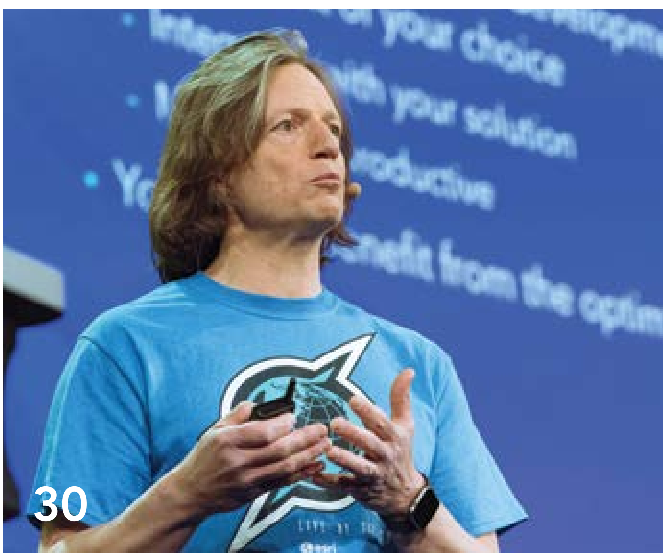
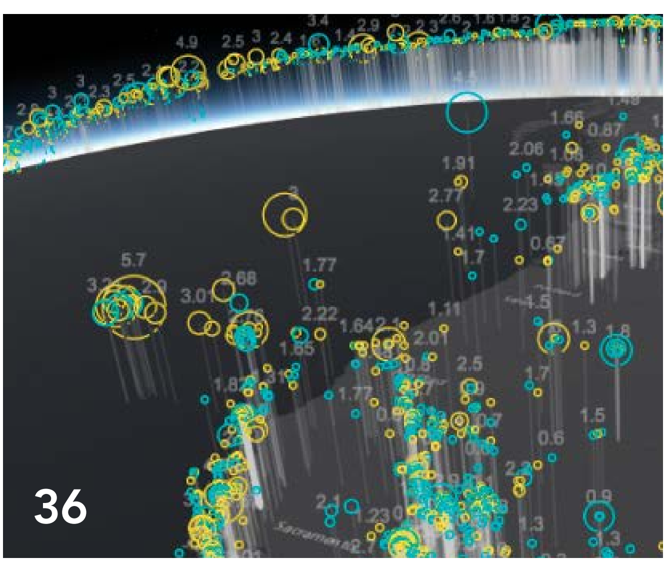
Departments





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Briefly Noted

→ Airbus WorldDEM4Ortho in ArcGIS Living Atlas of the World

Now available in ArcGIS Living Atlas of the World, global elevation data from Airbus Defence and Space is further enhancing Esri elevation layers and tools, such as Profile, Viewshed, and Summarize Elevation.

The world elevation image services (Terrain and TopoBathy) are a collection of multiresolution and multisource elevation data that can be used for visualization, such as multidirectional hillshade and tinted hillshade as well as analysis.

When using world elevation image services for visualization, the service will automatically display data from the best source for a given location, providing a seamless user experience. With this update, Airbus WorldDEM4Ortho will take priority over Shuttle Radar Topography Mission (SRTM) data when rendering visualizations.

Covering the earth's land surface (with the exclusion of Azerbaijan, Ukraine, and the Democratic Republic of the Congo), WorldDEM4Ortho is the most consistent and accurate satellite-based elevation model on a global scale. This dataset, which brings many improvements over areas with SRTM 30-meter coverage and areas above latitudes of 60 degrees north and south, is now available in world elevation layers and tools to all ArcGIS Online subscribers.

↑ Airbus WorldDEM4Ortho, the most consistent and accurate satellite-based elevation model on a global scale, is now available in ArcGIS Living Atlas of the World global elevation data.

→ Support Enhanced for the Use of Unstructured Data by ArcGIS

Esri acquired technology from ClearTerra that will give ArcGIS platform users the ability to easily discover and extract geographic coordinates from unstructured textual data like emails, briefings, and reports, instantly generating intelligent map-based information.

LocateXT, from Esri partner ClearTerra, allows analysts to rapidly scan through documents without having to spend hours reading, copying, pasting, and running spreadsheet formulas. It places results instantly into geospatial features. ClearTerra FindFZ technology provides enhanced search capabilities for the ArcGIS platform, incorporating the powerful techniques found in Internet search engines. Esri's acquisition of ClearTerra technology brings workflow-enhancing capabilities into the ArcGIS platform.

→ SAP HANA Supported by ArcGIS

Esri now supports the SAP HANA platform as an enterprise geodatabase. Esri and SAP customers will benefit from enhanced performance and scalability as well as full integration of both enterprise and spatial data. Whether on-premises or in the cloud, the Esri geodatabase powered by SAP HANA allows spatial data to be integrated and delivered across organizations and accessed from one place, which lowers administration costs and the total cost of ownership.

Customers of SAP and Esri who are running SAP, non-SAP, and Esri solutions will now be able to streamline their IT architecture with one underlying platform powered by SAP HANA. This integration brings location intelligence to enterprise data and applications so businesses become more successful by using spatial analytics and advanced visualization and by embedding geospatial data into core business processes.

→ Esri and Alibaba Cloud Bring Enhanced Location Intelligence to Cloud Users

Esri entered into a collaborative agreement with Alibaba Cloud, the cloud computing arm of the Alibaba Group, that will enable both organizations to deliver enhanced options to customers implementing Esri technology in Alibaba Cloud.

Esri president Jack Dangermond said the agreement recognizes successful implementations and the companies' shared belief that location intelligence in cloud infrastructure is pivotal in addressing customers' needs and solving real-world problems that require scalable computing, storage, and networking capabilities. Engineers from both companies can now collaborate on initiatives that will deliver the next wave of location intelligence innovation in the cloud.

Esri's sole authorized distributor in Mainland China, Esri China, has a proven track record in helping customers implement Esri technology in Alibaba Cloud. Esri China's president Francis Ho has witnessed the rapid migration of location intelligence capabilities to cloud infrastructure. Ho believes that this will continue because organizations are rapidly adopting GIS and combining it with the capabilities of cloud technology.

"We've seen our users achieve amazing results already with Esri technology in Alibaba Cloud," said Dangermond. The Ningxia Land and Resources Bureau has built its own foundational geospatial data platform using Esri's ArcGIS Enterprise technology in Alibaba Cloud.

Learn more about the Esri capabilities now available to Alibaba Cloud users by visiting go.esri.com/Alibaba-Cloud.

→ Esri Partners Honored

Three Esri partners were honored during the 2018 Esri Federal GIS Conference for their work helping the US government run more efficiently and transparently. The conference was held March 20–21 in Washington, DC.

The companies were recognized for their work in the Federal Small Business Specialty (FSBS) program by awards in three different categories.

Partner of the Year, ArdentMC, partnered with Esri to develop high-end geospatial mobile and web-based applications for government clients that provide situational awareness for natural and man-made events affecting national security.

Innovation Partner Award winner Innovate! Inc. is a Small Business Administration (SBA) 8(a)-certified woman- and minority-owned business that offers spatial data analytics, geospatial application development and integration, and cloud migration capabilities to the federal, state, local, tribal, and private sector markets.

Geodynamics, winner of the Collaboration Partner Award, is a woman-owned small business that provides state-of-the-art coastal and ocean mapping and geospatial analysis for engineering and natural resource management to the private, government, and academic sector clients.

To learn about the Esri Partner Network, visit esri.com/partners/join-partner-network.

↑ ArdentMC was recognized as Partner of the Year for its work in the Federal Small Business Specialty (FSBS) program.

Machine Learning in ArcGIS

By Lauren Bennett, Esri Spatial Analyst

Esri's continued advancements in data storage and parallel and distributed computing make solving problems at the intersection of machine learning (ML) and GIS increasingly possible.

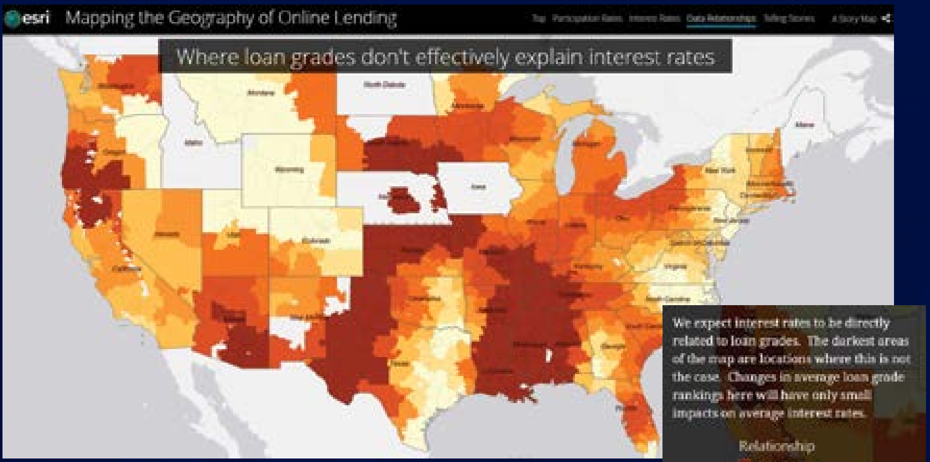
ML refers to a set of data-driven algorithms and techniques that automate the prediction, classification, and clustering of data. ML can be computationally intensive and often involves large and complex data. It can play a critical role in spatial problem-solving in a wide range of application areas from multivariate prediction to image classification to spatial pattern detection.

In addition to traditional ML techniques, ArcGIS also has a subset of ML techniques that are inherently spatial. Spatial methods that incorporate some notion of geography directly into computation can lead to deeper understanding. The spatial component often takes the form of some measure of shape, density, contiguity, spatial distribution, or proximity. Both traditional and inherently spatial ML can play an important role in solving spatial problems. ArcGIS supports the use of ML in prediction, classification, and clustering.

Prediction uses the known to estimate the unknown. ArcGIS includes regression and interpolation techniques that can be used for performing prediction analysis. ArcGIS has tools for empirical Bayesian kriging (EBK), areal interpolation, EBK regression prediction, ordinary least squares (OLS) regression, OLS exploratory regression, and geographically weighted regression (GWR). These tools can be used for tasks like estimating home values based on recent sales data and related home and community characteristics.

Classification determines which category an object should be assigned to based on a training dataset. ArcGIS includes many classification methods for use on remotely sensed data. The tools that use these methods analyze pixel values and configurations to solve problems delineating

↓ Based on the analysis of seven years of traffic accident data, the model predicted areas with the highest risk for accidents. These are shown in red. The analysis considered many factors associated with accidents: weather, time of day, speed limit, proximity to an intersection, and road characteristics. The locations of actual accidents are shown as red/yellow points.



↑ In his Esri Story Maps app, *Mapping the Geography of Online Lending*, author Jonathan Blum used the geographically weighted regression (GWR) tools in ArcGIS to explore the effect of loan grade rankings on average interest rates.

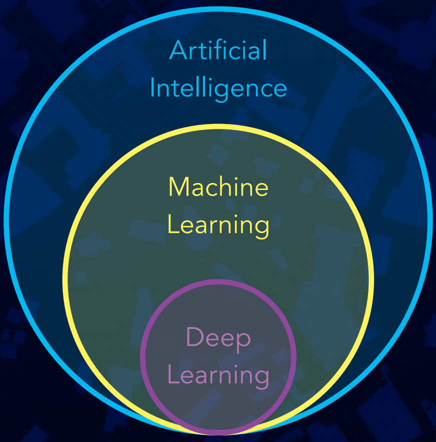
land-use types or identifying areas of forest loss. Maximum Likelihood Classification, Random Trees, and Support Vector Machine are examples of these tools.

Clustering groups observations based on similarities in value or location. ArcGIS includes a broad range of algorithms that find clusters based on one or many attributes, location, or a combination of both attributes and location. These clustering methods can be used for tasks such as segmenting school districts based on socioeconomic and demographic characteristics. Examples of clustering tools in ArcGIS include Spatially Constrained Multivariate Clustering, Multivariate Clustering, Density-Based Clustering, Image Segmentation, Hot Spot Analysis, Cluster and Outlier Analysis tools, and the Space Time Pattern Mining tools.

In addition to ML methods and techniques in ArcGIS tools, ML is used throughout the ArcGIS platform for enabling smart, data-driven defaults, automating workflows, and optimizing results.

For instance, the EBK Regression Prediction method uses principal component analysis (PCA) as a means of dimension reduction to improve predictions. The ordering points to identify the clustering structure (OPTICS) method in density-based clustering tools uses ML techniques to choose a cluster tolerance based on a given reachability plot. The Spatially Constrained Multivariate Clustering tool uses an approach called evidence accumulation to provide the user with probabilities related to clustering results.

↓ The relationship between artificial intelligence, machine learning, and deep learning



The field of ML is broad, deep, and constantly evolving. ArcGIS is an open, interoperable platform that allows the integration of complementary methods and techniques in several ways: through the ArcGIS API for Python, the ArcPy site package for Python, and the R-ArcGIS Bridge. This integration empowers ArcGIS users to solve complex problems by combining powerful built-in tools with any ML package they need—from scikit-learn and TensorFlow in Python to caret in R to IBM Watson and Microsoft AI—and still benefit from spatial validation, geoenrichment, and visualization of results in ArcGIS. The combination of these complementary packages and technologies with the systems of record, insight, and engagement that the ArcGIS platform provides is greater than the sum of its parts.

There are many key Esri initiatives for advancing and integrating ML methods across the platform. This road map includes methods such as random forests, neural networks, logistic regression, and time-series forecasting as well as simplified user experiences for integrating with popular ML libraries and packages. A continued focus on distributed processing will play a major role in these advancements.

In addition to building traditional ML into ArcGIS and improving the ease of integrating ML with ArcGIS, Esri is actively working to broaden the intersection of GIS and ML. This focus on innovation in spatial ML to develop algorithms and approaches that incorporate space into computation will continue to empower ArcGIS users to take advantage of the latest advances in technology and computing while still focusing on solving problems in a fundamentally spatial way.

Explore the many spatial statistics tools that employ machine learning at esriurl.com/spatialstats and visit the Spatial Statistics Forum on GeoNet.

About the Author

Lauren Bennett leads the spatial statistics software development team at Esri. Her role includes providing vision and direction for future analytical tools in the areas of spatial statistics, machine learning, and spatiotemporal analysis as well as involvement in the research, design, validation, documentation, and creation of educational resources for new tools. Other responsibilities include contributing vision for innovative analytical software development across the ArcGIS platform, teaching graduate-level seminars in spatial statistics, and evangelizing the value of spatial analytics. Bennett received a bachelor's degree in geography from McGill University, a master's degree in geographic and cartographic science from George Mason University, and a doctorate in information systems and technology from Claremont Graduate University.

Working with Temporal Data in ArcGIS

By Aileen Buckley, Esri Research Cartographer

Time is an important dimension in many types of geospatial visualizations and analyses. The temporal aspect adds *when* to the *where* and *what* of data and allows us to see change.

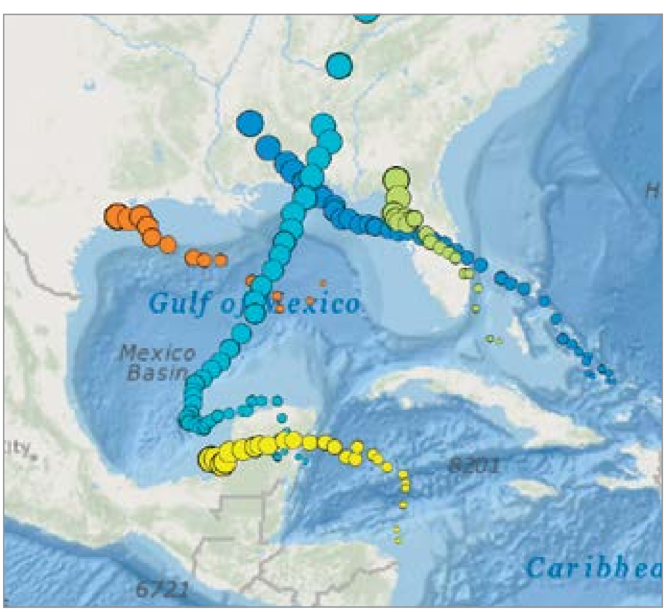
With temporal data, you can analyze and visualize moving things (planes, satellites, storms), events (accidents or crimes), readings that vary over time but originate from stationary sensors (precipitation readings or traffic counts), or the change in the characteristic of a place over time (population change in a census tract or the change in sea surface temperature). Although other cultures have different conceptions of time, we generally think of time as linear and unidirectional. Even events that are cyclic are conceived of as linear (last year, this year, next year) but repeating (winter, spring, summer, fall). ArcGIS treats time in a similar linear fashion.

Time is always relative to something: a clock, an event, or a state. Clock-driven time is synchronized to a specific clock and is an example of regular time data taken at regular intervals. Examples include 15-minute readings from stream gauges and regularly scheduled GPS fixes from animal-tracking devices. Event-driven time is synchronized to an event like dinnertime or before and after a hurricane or flood. State-driven time is synchronized to a change in state; examples include the melting of ice sheets, changes in the economy such as a period of inflation, or the change from one

Temporal Data Types

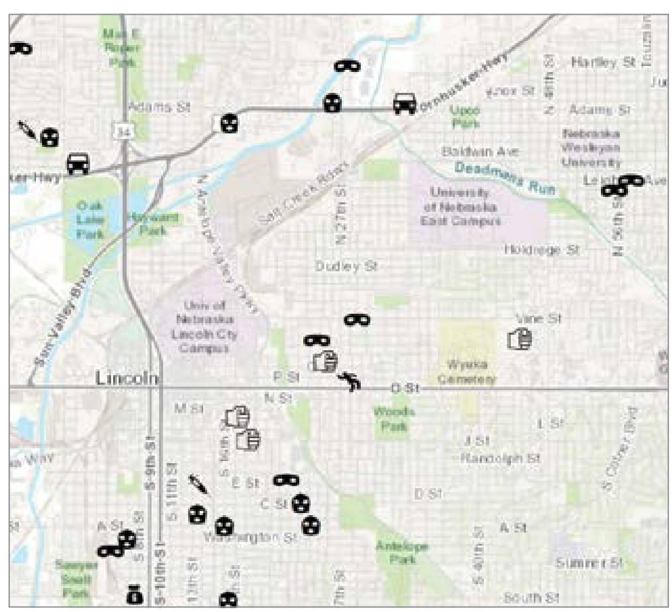
Moving Features

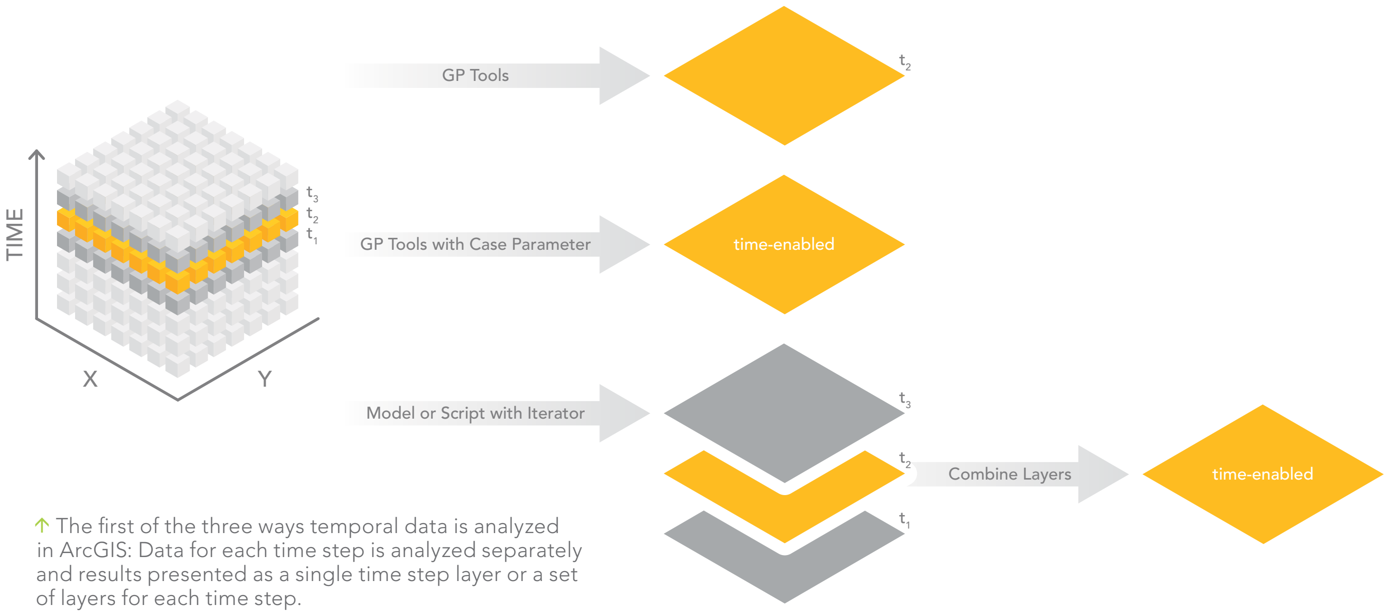
Features that move over space, like storms



Discrete Events

Features that represent events that happened at specific locations and times, like accidents





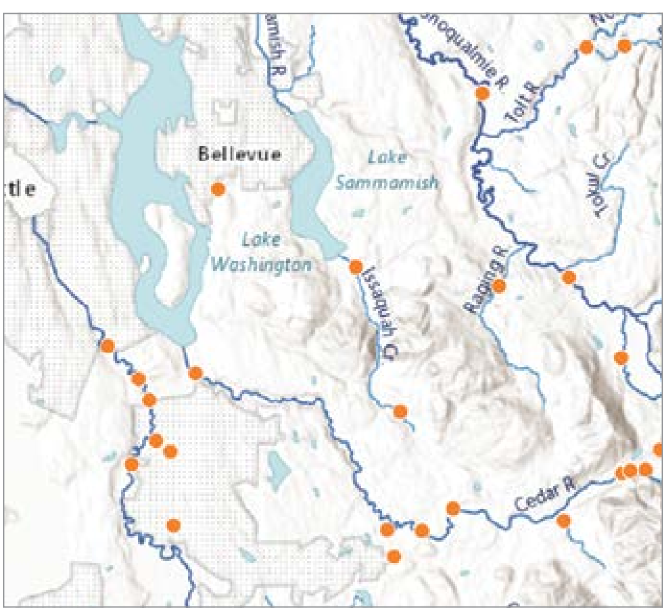
↑ The first of the three ways temporal data is analyzed in ArcGIS: Data for each time step is analyzed separately and results presented as a single time step layer or a set of layers for each time step.

governmental regime to another. Time can be recorded as an instant (a single point in time) or a duration (an interval of time with start and end instants). The interval between recorded time instants can be regular (a 15-minute interval for stream gauges or a decade for a census) or irregular (the incidence of crimes or the change in political boundaries).

Time measurements are either calendar or noncalendar based. An example of calendar time is the Gregorian calendar, which is based on the amount of time it takes the earth to orbit the sun (approximately 365 days) and the earth to rotate on its axis (24 hours). The format can be as simple as year (YYYY) or as complex as decimal fractions of seconds (YYYY/MM/DD hh:mm:ss.s).

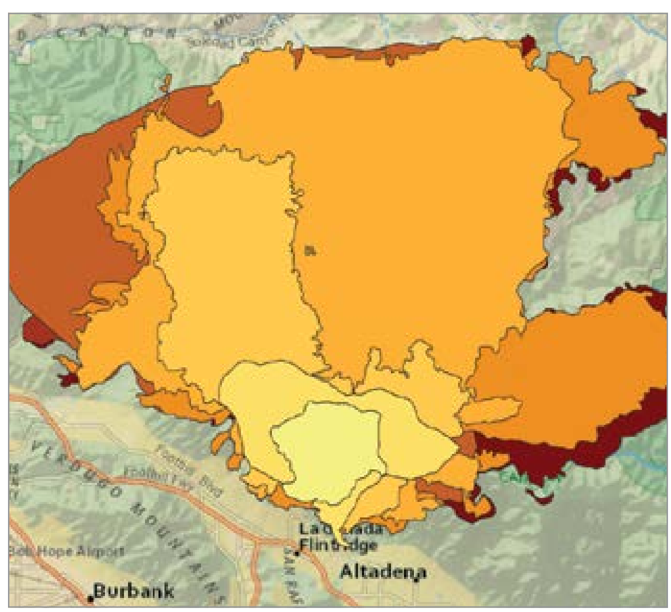
Stationary Recorders

Features representing sensors that stay in place and record changes, like live stream gauges



Change/Growth

Features that represent change in an area over time, like a fire perimeter



Although this is the most widely used calendar in the world today and most people understand it well, it is difficult to compute from because it is not metric or in base 10. There are variations in some measures (such as the number of days in a month) but not in others (there are always 60 minutes in an hour and 60 seconds in a minute).

Noncalendar time is synchronized to a specified time instant. The time instant chosen as the origin and reference point from which time is measured is called an epoch, and time measurement units are counted from the epoch so that the date and time can be specified unambiguously. An example of noncalendar time is the computer system time used in Unix, Java, and Oracle, which reflects the count of seconds since January 1, 1970, which is also 00:00:00 in Coordinated Universal Time (UTC).

GIS Integrates Temporal Data

Time is built into ArcGIS Pro, ArcMap, the ArcGIS Runtimes, and portal so the temporal dimension of geospatial data can be used for analysis, simulation, and modeling across the ArcGIS platform. Geoprocessing tools can be used to manage time-aware data and analyze space-time data. Space-time data can be visualized in ArcGIS Pro, ArcMap, ArcScene, ArcGlobe, and ArcGIS Online.

Supported temporal data types include feature layers, mosaic datasets, Network Common Data Form (netCDF) layers, tables, raster catalogs, tracking layers, streaming layers, network dataset layers with traffic data, and service layers with historical content and updating data feeds. In ArcGIS, time information is stored as attributes (for feature classes and mosaic datasets), or it is stored internally (as with netCDF data).

For feature classes, time is enabled and configured through the Time tab on the feature layer's properties. For features, the shape and location of each feature may be constant, but attribute values can change over time.

Alternatively, both the shape and location of each feature may change over time. If the shape and location do not change, there are two ways in which the data can be stored: as duplicated features with unique time values or unique features that are related to a table with time values.

An example is a dataset of the 100 largest cities in the United States by decade. In this case, cities might be duplicated each time they are included in the list of 100, or a single set of cities could be related to a table with the decades in which they appear in the list. If the shape or location changes, each feature must be stored along with its time value. An example is a dataset with the burn extents for a wildfire.

Mosaic datasets store rasters that represent change over time. While time is enabled and configured using the mosaic dataset's properties, the time attribute is stored in the attribute table of the Footprint layer of the mosaic dataset.

NetCDF is a file format for storing multidimensional (x, y, z, t) data in an array with x and y representing space and t representing time. The z dimension stores one or more attributes such as temperature, salinity, pressure, and wind speed. For netCDF feature layers, the layer time is specified using a time dimension or attribute field. For netCDF raster layers, layer time is specified using the time dimension.

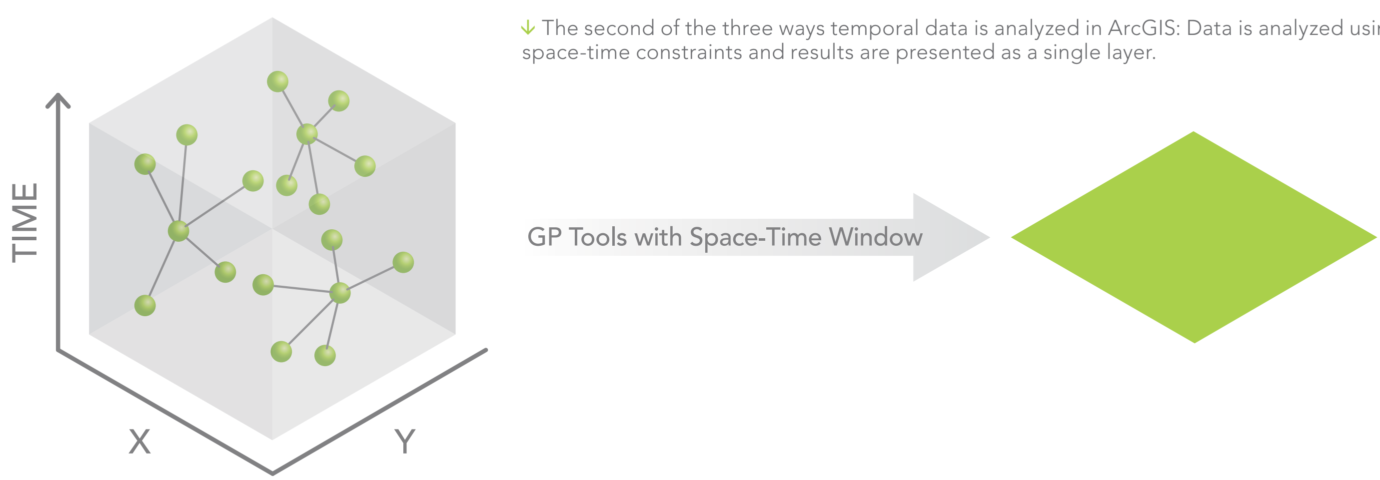
Temporal data and information products based on temporal data can be shared in a variety of ways through maps, map layers, packages, and more. These can be viewed as static images or dynamic visualizations, and they can be shared as either paper or other print products or in digital format. Temporal data is increasingly being used in web map layers, web maps, story maps, and other online products.

Best Practices for Managing Temporal Data

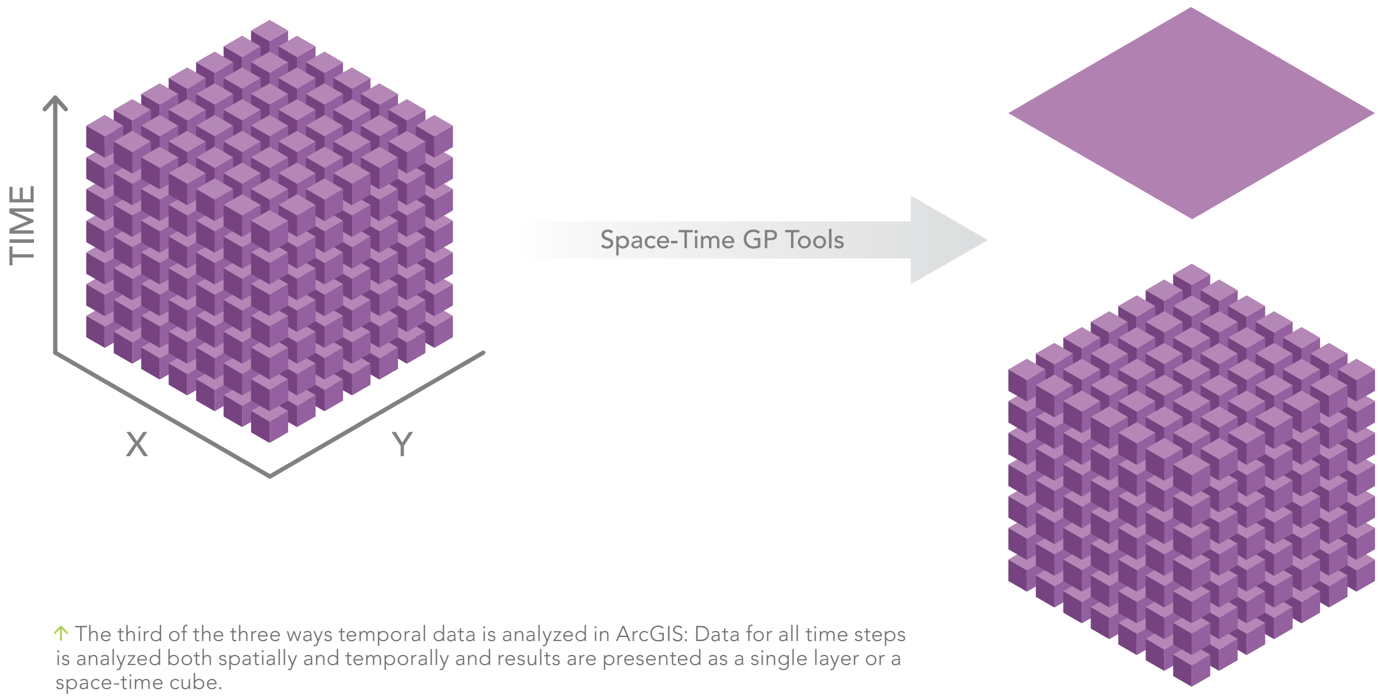
How temporal data is stored and managed affects its use by ArcGIS. Use the following best practices to avoid issues.

Whenever possible, store time values in a date-type field for the most efficient query performance and more sophisticated database queries. Date display is only supported for the time extent of AD100 to AD10,000. To work with dates outside this extent, convert your values into a numeric format and use the range slider to visualize the data.

To convert time values stored in a text or numeric field (short, long, float, or double), use the Convert Time Field geoprocessing tool. This tool converts the values to a supported or custom-defined date format and



↓ The second of the three ways temporal data is analyzed in ArcGIS: Data is analyzed using space-time constraints and results are presented as a single layer.



↑ The third of the three ways temporal data is analyzed in ArcGIS: Data for all time steps is analyzed both spatially and temporally and results are presented as a single layer or a space-time cube.

records it in a new date field. For example, "July 9, 2016" in a text field would become "2016/07/09" in a date field with the format YYYY/MM/DD.

Convert time attributes stored in multiple columns to rows using the Transpose Fields geoprocessing tool because ArcGIS works with temporal data in row format. This tool is useful for working with census data, which often uses multiple columns to store temporal attributes.

Daylight saving time is a challenge to work. This is because some areas use it, while others do not; the variations can be in offsets other than a single hour; and the rules and boundaries change frequently. Therefore, it is better to store time attributes in standard time rather than daylight saving time. Index time attributes for faster query performance.

Visualizing Temporal Data

In ArcGIS, visualizing temporal data is a two-step process. First, enable time on a layer and configure the associated time properties, such as specifying the time attribute or attributes, setting the time extent by selecting the first and last time instants to be displayed, and indicating the refresh rate for live feed data. Other settings can also be used, for example, to manage for differing time zones and daylight saving time. Once this step is done, you have created a time-enabled layer.

Second, use the time slider to control visualization of the time-enabled layer by playing, pausing, stepping forward or back, setting the time step (the span between time instants that the data is visible), and more. The time slider control will automatically appear in any map or scene that has time-enabled layers. You can also use the time slider to configure additional settings to control the display of the data in the map.

Analyzing Temporal Data

There are three ways in which temporal data can be analyzed in ArcGIS:

- The data for each time step is analyzed separately, and the individual analysis results are presented as a single layer for a single time step or a set of layers, one for each time step.
- The data is analyzed using constraints in both space and time, and the results are presented as a single layer.
- The data for all time steps is analyzed both spatially and temporally, and the results are summarized in a 2D layer or presented as a 3D layer in which time is displayed in the *z* dimension.

How temporal data is stored and managed affects its use by ArcGIS.

Taking the first approach, the analysis is dependent on the time step that has been specified, so if yearly data is analyzed by decade, then each result will reflect the analysis of 10 years' worth of data.

There are three ways in which this type of analysis can be performed. First, all geoprocessing tools honor the time settings for time-enabled layers so only those features that fall temporally within the time extent set in the time slider will be processed. The results are then displayed as a single layer on a map.

Second, with some tools (for example, Mean Center and Directional Distribution), the time attribute can be used as the case field to repeat the analysis for each time step. *[The case field is the field in the input used to calculate statistics separately for each unique* *attribute value.]* These results are presented as a single layer, and time can be enabled on the case field, which is copied into the output feature class.

Third, a model or script can be created using an iterator to specify that the analysis should be repeated for each time step. This approach results in separate outputs for each time step. The separate outputs can then be combined (for example, using Merge or Append for feature classes or adding the rasters to a mosaic dataset) so that the final result can be time enabled and visualized using the time slider control.

Certain geoprocessing tools take the second approach to analyzing space-time data. These tools use a spatial weights matrix that defines feature relationships in terms of a Space-Time Window with a specified critical distance and a fixed interval in time. The tools that use this matrix include the Hot Spot Analysis, Cluster and Outlier Analysis, and Grouping Analysis tools.

> Temporal maps and data can be shared as packages.

The Hot Spot Analysis tool creates a map of clusters in both space and time of significantly high (hot) or low (cold) values. The Cluster and Outlier Analysis tool identifies the similarity (as the spatial clustering of either high or low values) or the dissimilarity (as spatial outliers) of features. The Grouping Analysis tool groups features based on feature attributes.

The third approach uses a set of tools in the Space-Time Pattern Mining toolbox and includes the Emerging Hot Spot Analysis, Local Outlier Analysis, and Fill Missing Values tools. The Emerging Hot Spot Analysis tool identifies hot and cold spots and determines if they have a temporal trend (new versus persistent versus historic hot spots). The Local Outlier Analysis tool determines if features have belonged in clusters or been outliers over the entire time extent of the dataset. The Emerging Hot Spot Analysis and Local Outlier Analysis tools require that the data be in a space-time cube format.

The Fill Missing Values tool, located in the Utilities toolset that is designed to be used with the Space-Time Pattern Mining toolbox, replaces missing values with estimates based on spatial neighbors, space-time neighbors, or time-series values.

The two other tools in the Space-Time Pattern Mining toolbox can be used to create the space-time cube depending on whether the input is a set of points or polygons.

The space-time cube can be viewed in either 2D or 3D using the Visualize Space Time cube tools (also found in the Utilities toolset for the Space-Time Pattern Mining toolbox or with an add-in called the Space Time Cube Explorer.

For more traditional time series analysis, you can take advantage of the extensibility of the ArcGIS platform with its capabilities to easily transfer data to open-source analytical software. For example, you can use ArcPy utility functions, such as FeatureClassToNumPyArray, to analyze the data in Python, or the R-ArcGIS Bridge to analyze the data using R.

Sharing Temporal Data and Maps

Temporal maps and data can be shared as packages. Temporal maps can also be shared as a set of exported graphic images, each representing a different time step, or a temporal map series in which a collection of map pages, one for each time step, are built from a single layout. Time-enabled web layers and web maps can also be created. These will automatically be displayed with a configurable time slider control in the ArcGIS Online Map Viewer.

With ArcMap, exporting time-enabled web layers requires the use of a GIS server. With ArcGIS Pro, you can publish hosted feature layers that include temporal data directly to ArcGIS Online. Time for these layers is enabled on the item page for each layer. Mosaic dataset images can be exported from either ArcMap or ArcGIS Pro as an image service—this requires the use of a GIS server.

Animations can be used in ArcGIS to create, edit, and export a temporal visualization. With animations, you can navigate through a display, follow the view along a path, move point features along a path, and visualize time-enabled data from a static or moving camera. Because you can use any combination of these, animating time-enabled data can create intriguing and informative dynamic displays of temporal phenomena.

In ArcGIS Pro, animations can be exported to a video or folder of frames using draft, preset, or custom settings. The draft option exports the animation to an AVI movie for previewing before a final version is created.

The preset options export to commonly requested formats including YouTube, Vimeo, Twitter, Instagram, HD720, HD1080, and GIF. Manual settings for the format, resolution, frames per second, and quality of the video export can be saved as custom presets for a project. Because the options for video export in ArcGIS Pro are so versatile, a best practice is to import your time-enabled ArcMap document into ArcGIS Pro to generate a video.

Conclusion

The ArcGIS platform gives you control over your temporal data from start to finish, allowing you to manage, analyze, and visualize information about space and time in insightful and effective ways. Esri is continually developing tools for using temporal data so you can work with your space-time data.

About the Author

Aileen R. Buckley is a cartographic researcher on the ArcGIS Living Atlas of the World team and a member of Esri's virtual science team. She holds a doctorate in geography from Oregon State University. Contact her at abuckley@esri.com and follow her on Twitter at @cartatesri.

Thanks to Esri staff Kevin A. Butler and Lauren Scott Griffin for their help ensuring the accuracy of the analysis section of this article.

Timely Lessons

Visit Learn ArcGIS (learn.arcgis.com) to work two lessons that will give you hands-on experience using temporal data in ArcGIS.

- Depict Land-Use Change with Time-Enabled Apps
- Cartographic Creations in ArcGIS Pro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GIS and BIM Integration Leads to Smart Communities

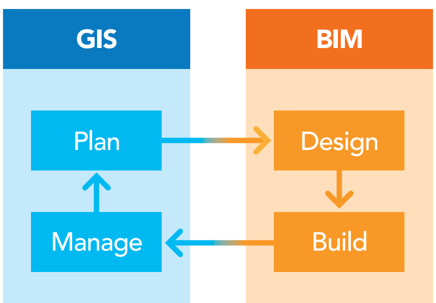
By Chris Andrews, Esri Product Manager for 3D

Esri's partners, customers, and international support teams have shown an undeniable and urgent interest in creating greater integration between building information modeling (BIM) and GIS.

BIM has been around since the 1970s. The early BIM information technology industry tended to focus on the paper documentation that drove construction and design processes, resulting in computer-aided drafting (CAD) products that helped users create drawings.

The architecture and engineering industries are moving beyond drawings toward 3D models with project-centric attribution as the focal point of communication during construction and design. The architecture, engineering, and construction (AEC) industry now focuses more on BIM, an information-rich approach that attempts to capture project details in a robust model that may include graphics about the designed real-world asset along with rich metadata for purchasing, scheduling, and even simulation of how assets may behave in their environment after construction. BIM has become the process for increasing efficiency and saving costs through collaboratively creating and using detailed information about built assets throughout their life cycle.

↓ GIS and BIM are often erroneously represented as related sequentially throughout the asset life cycle. This perspective leads to misunderstanding that the interface between GIS and BIM workflows can be simplified.



The Data Life Cycle

GIS and BIM evolved as information technologies that serve distinctly separate parts of the life cycle of the organizations that operate and build infrastructure and communities. Those organizations strive to remain within budget while achieving desired results.

The traditional view of the life cycle of an asset is a sequential process. The asset is planned, designed, constructed, and then maintained. This process implies a tidy data handoff between steps, but this does not accurately represent how data flows through cities and organizations as they manage the creation, updating, and eventual decommissioning of buildings and infrastructure. A more accurate representation of the flow of data—one that is driving the integration of BIM and GIS—looks at how GIS and BIM data is used.

Spatial information about assets and communities informs planning and investment. It helps find ways to accommodate change and growth in the community while maintaining the health of citizens, the business community, and the environment. Geodesign provides the framework for analysis and decision-making using spatial information and GIS technology throughout the life cycle of a community.

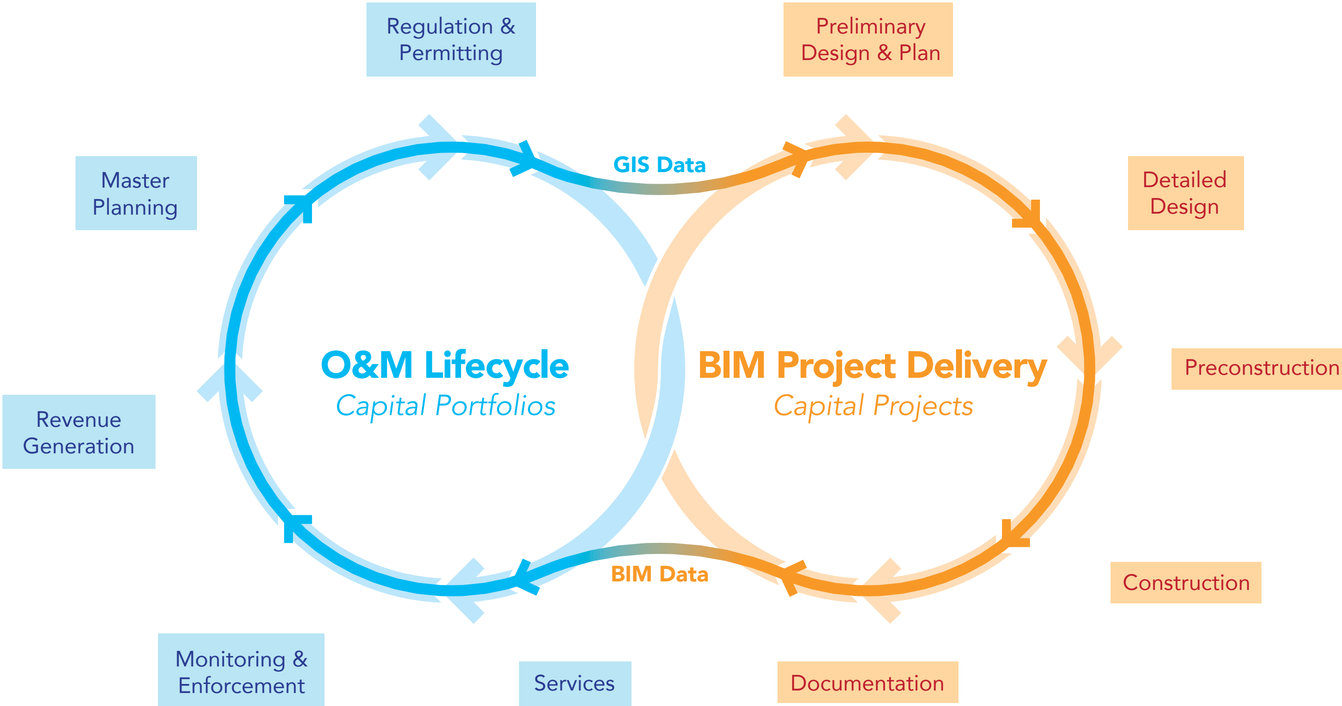
Communities need to be able to continuously adapt to provide the services that enhance quality of life. These services include providing access to education, a healthy environment, and economic opportunity for citizens. BIM can supply more detailed information for analyzing and planning that will improve decision-making processes.

Smart Communities Need Data

As the world experiences rapid urbanization and population growth, communities have become the focal point for much of the research into the flow of information between the operational and capital asset construction workflows. Communities that meet the needs of citizens using a strategy that includes consuming, analyzing, and using information about the natural and built environments in the decision-making process are termed smart communities.

Smart communities foster a data-rich environment. They make data accessible to citizen, business, and government groups while meeting privacy needs and supporting public safety. Data-rich communities work to actively or passively detect change. That change can be in noise levels, transportation needs, or utility usage.

Most communities that are considered smart already use GIS. Many of these smart communities are already actively investigating BIM-GIS integration because they realize that a more streamlined flow of information between operational and construction life cycle data will allow them to more accurately plan, fund, and maintain community infrastructure assets.



↑ A more accurate representation shows that GIS and BIM data flows throughout the operational and construction life cycle of assets.

Improvements in 3D

The most frequently requested improvements in 3D capabilities in GIS the last few years have been for better integration and interoperability between BIM and GIS. With the introduction of ArcGIS Pro, new 3D layer types, a web-based 3D viewer, and many other new features of the ArcGIS platform, Esri has been rapidly responding to customer demand for 3D capability in GIS. 3D has become established as a core feature of ArcGIS, and thousands of users are contributing scene layers and other 3D content in ArcGIS Online as well as using new 3D apps, such as ArcGIS Earth.

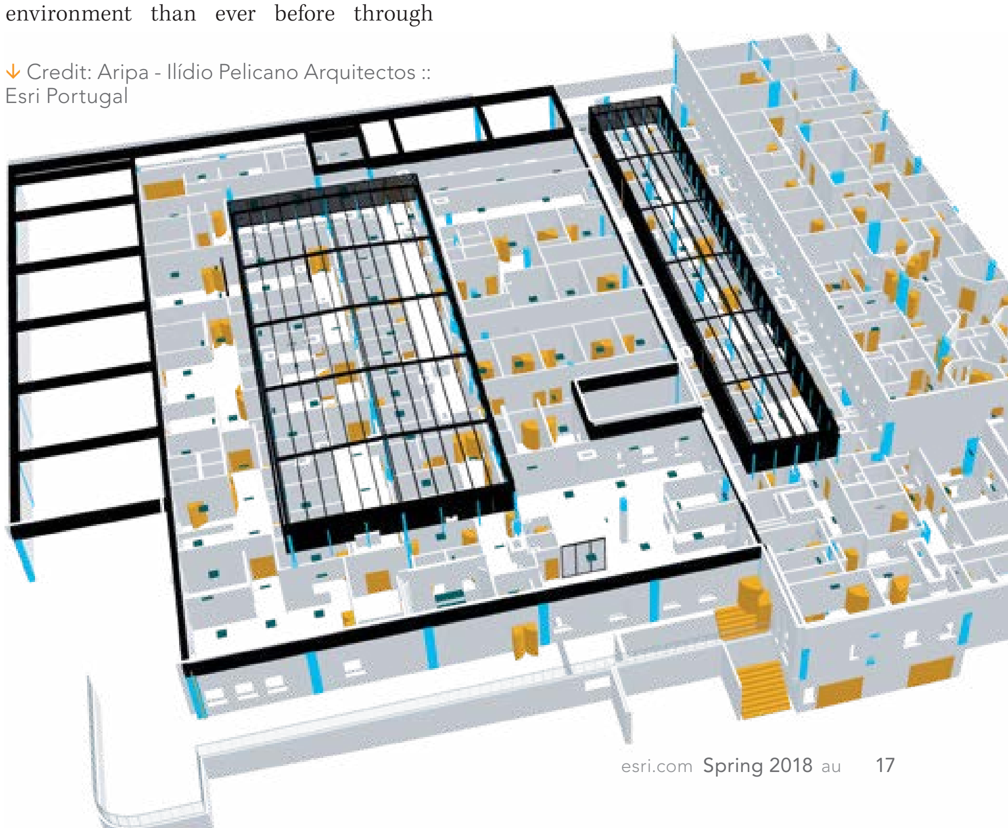
3D lets users see projects and data as they appear in the real world. Most 3D experiences—especially in the consumer market—are found in gaming and interactive systems. In these systems, users need to understand their location in the real world or an immersive virtual environment.

When using GIS in 3D, users expect to be able to inspect and interact with their data as if they were in a gaming environment. In 3D GIS, users often feel that they should be able to explore across scales that range from global to their front porch. BIM data is becoming widely accepted as a primary source for capturing assets at the resolution of detailed buildings and infrastructure so these assets can be represented realistically in 3D in GIS.

More users are working with 3D GIS, and they expect to be able to accurately represent the world around them. Some users believe they will achieve a more accurate digital representation of their systems and environment than ever before through reality-capture information and design data. BIM information has become a critical component that many users expect to employ for accurate representations of buildings and infrastructure.

On the other hand, AEC firms and other organizations that design and build

↓ Credit: Aripa - Ilídio Pelicano Arquitectos :: Esri Portugal



capital assets focus more on the ability to stay within budgetary and schedule requirements on projects. Their ability to continue functioning depends on the degree of control they can exercise over the project delivery process. The models, schedules, and detailed asset information created during the BIM process enable better control. GIS information used as context for the designed asset's environment offers the opportunity for BIM practitioners to achieve better outcomes during design and construction.

Working with industry partners, Esri has developed a more representative model of the flow of information throughout communities, AEC services providers, and organizations that help design and construct infrastructure and assets. This model illustrates a continuous flow of information throughout all stages of the life cycle of the asset, showing that capital improvement projects initiated with GIS information help inform design and conclude with BIM information flowing back into the operational life cycle to inform analysis and planning.

BIM-GIS Integration Pain Points

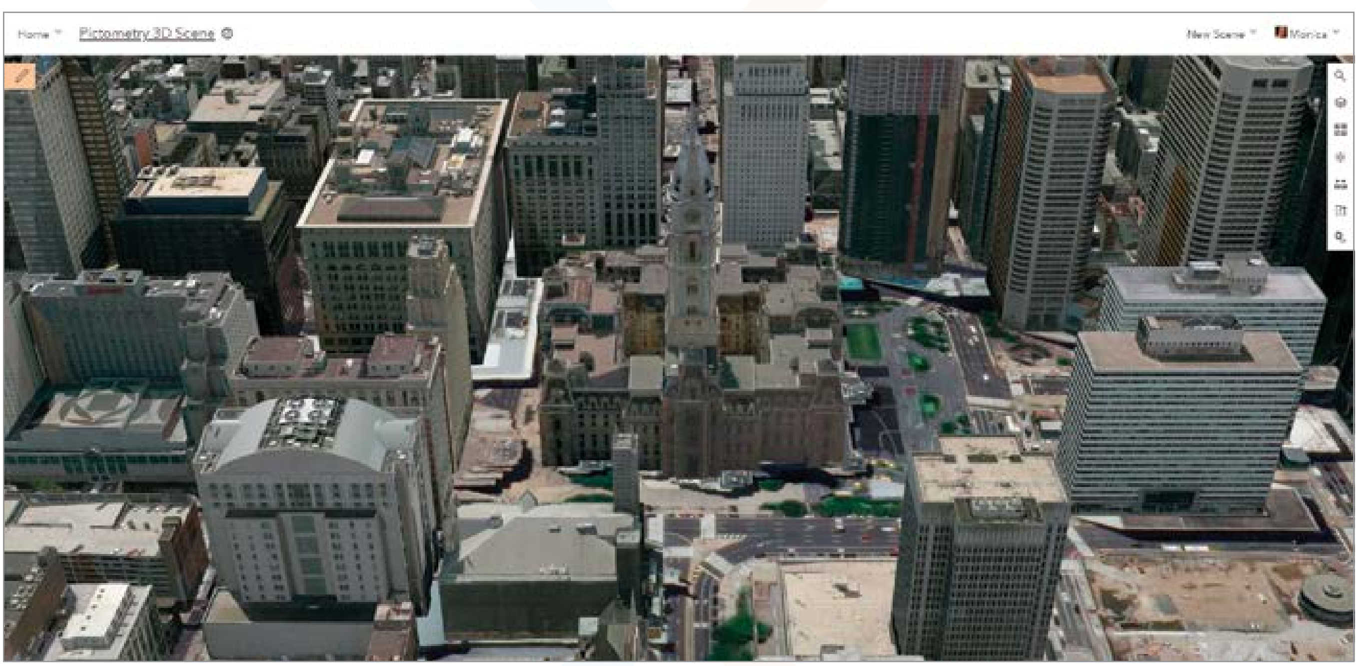
Since the dawn of digital mapping and computer-assisted drawing technology, the need to integrate BIM and GIS has been recognized. There are many classic pain points that practitioners encounter when attempting to combine design and operational data. On the design side, architects and engineers typically have difficulty accessing up-to-date GIS information for accurate context or current conditions. They often discover problems with data duplication and conflicting data because file-based workflows are used to exchange data.

On the operational side, GIS staff frequently deal with difficult workflows and significant data loss that occurs when converting BIM information into GIS data layers. Differences in spatial scales and the graphical richness required in BIM environments mean that GIS staff are often asked to perform heroic feats of integration. They must attempt to merge many dense BIM models with GIS data into a single visualization and analysis experience. AEC projects typically generate large quantities of documentation during construction and after assets are commissioned that will be useful during the life cycle of assets. This documentation is often not accessible to users through GIS dashboards and analysis tools.

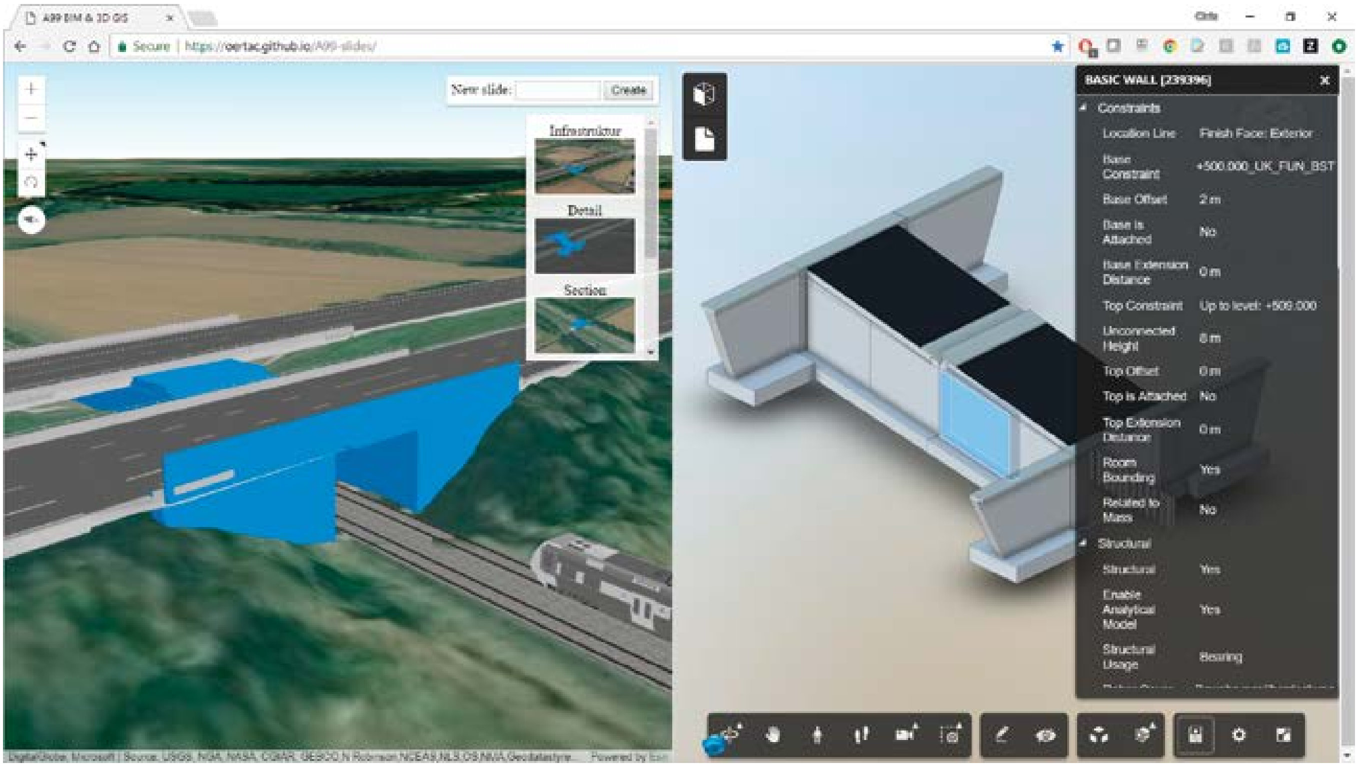
Esri recognizes that it can't solve these industry problems alone. Consequently, Esri has been working with multiple AEC industry vendors that are experts in BIM technology. In November 2017, Esri and Autodesk announced an industry collaboration to research and build new workflows between products from each company to their common customers to achieve better integration between BIM and GIS and address many of those pain points.

Esri's work with Autodesk will include transforming the project life cycle, providing continuous context of the site and the environment around BIM projects, and detecting site change. In addition, improvements are planned for the overall process for designing and visualizing the real world in 3D and building technologies to help optimize infrastructure operation. Ultimately, Esri's work will encourage the use of its open platforms for innovation and sharing.

Esri has made progress in providing an open platform for the flow of data. Its significant contributions to 3D technology and standards should drive innovation associated with BIM-GIS integration and, more broadly, in GIS. After several years of research and development, Esri released Indexed 3D Scene layers (I3S) under Creative Commons licensing as an open specification in April 2015. An Open Geospatial Consortium, Inc. (OGC) Community Standard, I3S enables the distribution of large 3D datasets over the Internet and on local devices.



↓ Esri has been rapidly responding to customer demand for 3D capability in GIS with new 3D layer types, a web-based 3D viewer, and many other new features of the ArcGIS platform, as illustrated by this web scene of the city of Philadephia.



↑ Esri and Autodesk are already experimenting with integration options such as this prototype integration of the ArcGIS Online and Autodesk BIM 360 web viewers.

Bentley Systems, Incorporated, can create I3S data with its product ContextCapture and users can publish and access the data in ArcGIS Online through Esri's open ArcGIS REST API (GeoService REST). Esri is looking forward to further collaboration with Autodesk, Bentley, and other industry leaders to help simplify workflows and improve outcomes for GIS users.

What's Next for BIM and GIS

BIM and GIS together have the potential to lead to smarter outcomes for communities and more efficient projects for AEC services providers. This will require more than just the collaboration of software vendors. Local governments and asset management organizations will need to establish specifications for BIM information that introduce attributes early during the design process to be used later in operations and management workflows.

For major urban areas, this will mean creating multiple standards across transportation, utilities, and architecture projects that may impact many agencies. Working with Autodesk and others, Esri will have to build workflows that allow users to reliably access, update, and use standardized BIM data in spatial context throughout the life cycle of assets.

Work done by Esri customers and partners provides great examples of creating value from the integration of BIM and GIS information. Based on their feedback, Esri is working to make it easier for GIS professionals to query, visualize, and connect timely BIM data in familiar GIS experiences. Similarly, Esri is already working on delivering better access for architects and engineers to GIS data from within industry-standard design and construction tools.

Esri users should be able to combine geospatial information, field auditing, data capture workflows, and detailed design information to achieve comprehensive awareness and understanding of the projects that will sustain and improve the world around us.

About the Author

Chris Andrews is the product manager for 3D across the Esri ArcGIS platform and leads a team of product managers focused on BIM, urban planning, city modeling, and globe 3D visualization. During his 20-year career, he has focused on exposing the value of GIS throughout organizations by combining cutting-edge technology with ease of use to put powerful capabilities in users' hands without requiring specialized technology expertise. Andrews has worked with customers in the law enforcement, defense, real property, and AEC industries. He holds a bachelor's degree in geology-biology and a master's degree in ecology and evolutionary biology from the University of Rochester.

COMING TOGETHER TO DESIGN RESILIENT COMMUNITIES

By Carla Wheeler, *ArcWatch* Editor

The world's population is on track to spike by more than two billion people over the next 30 years, placing more stress on the planet and its resources.

It's crunch time for geodesign.

That was Esri president Jack Dangermond's message to attendees of the Geodesign Summit held January 23–25, 2018, at the Esri campus in Redlands, California. Dangermond drove home the event's theme, Resilient by Design, saying that our planet is on the precipice of change that—if unaddressed—will negatively affect the environment, biodiversity, infrastructure, and people's well-being. That's why it's imperative that design professionals work toward creating more resilient, livable communities using geodesign techniques and technologies.

"Things are not going in the right direction on so many levels," Dangermond told an audience that included urban planners, landscape architects, and GIS professionals. "We need better design, wouldn't you agree? We need to not only do better design, we *[also]* need to integrate our best knowledge and science into it."

Geodesign uses stakeholder input, creative design techniques, rigorous methodologies, and spatial analysis and mapping to find the most suitable, environmentally friendly, and sustainable options for how to use space.

BIM and GIS—Better Together

Human ingenuity has already led to the era of digital transformation that's currently changing how organizations—including those that use GIS technology—do business. Cloud computing, big data, the Internet of Things (IoT), artificial intelligence (AI), machine learning, and Web GIS are in the mix, along with a strategic vision on how to bring everything together to achieve a mission.

"Integrating geodesign into everything we build requires well-thought-out technologies that work and help people," Dangermond said.

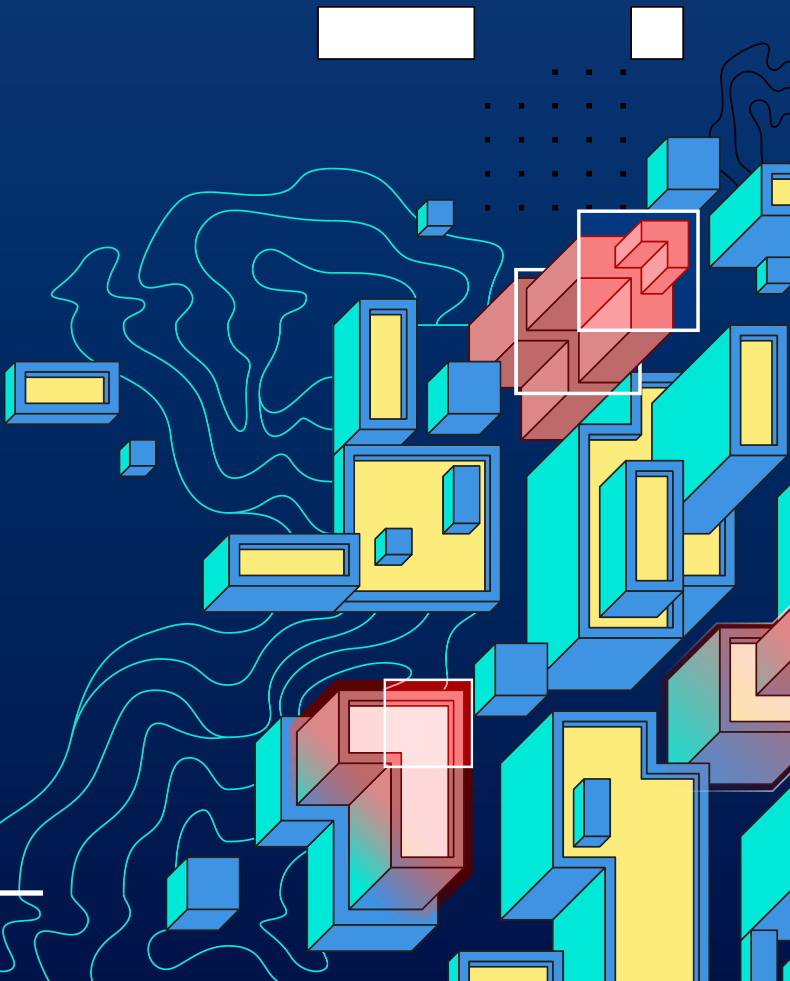
Bringing GIS and building information modeling (BIM) software—often each an island unto itself—much closer together would help the architecture, engineering, and construction (AEC) industry. That's why buzz is building over plans to integrate BIM and GIS data and workflows.

Late last year, Esri and Autodesk announced a strategic partnership to better connect the BIM and GIS platforms, with the aim of giving AEC professionals the ability to create better, more efficient, and sustainable designs, especially in 3D. Autodesk develops software for the AEC community, such as Revit and AutoCAD Civil 3D, which are used by architects and engineers to design real-world assets according to BIM patterns and practices.

"Based on demand from users and partners, we know there's a tremendous demand for GIS and BIM interoperability," said Chris Andrews, 3D product manager for Esri. (See the accompanying

↓ "Based on demand from users and partners, we know there's a tremendous demand for GIS and BIM interoperability," said Chris Andrews, Esri product manager for 3D.

↑ Theo Agelopoulos, director of infrastructure strategy and marketing at Autodesk, emphasized the need to eliminate the existing barriers between BIM and GIS and improve the user experience.



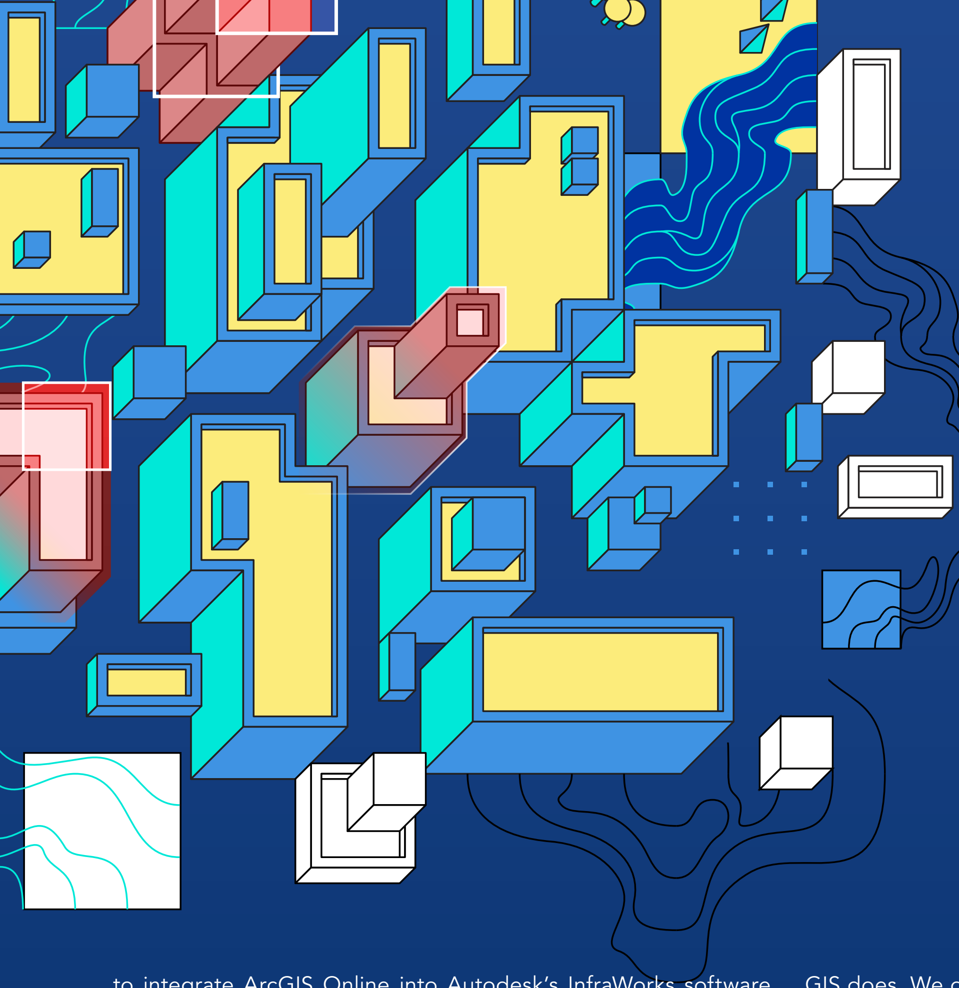
article by Andrews, "GIS and BIM Integration Leads to Smart Communities.")

BIM users can work with GIS data, and GIS users can work with BIM data now, but the process was described by Autodesk's Theo Agelopoulos as "painful." He says that will change.

"A majority of our customers are architects, engineers, and contractors, and they are designing buildings and infrastructure such as roads, airports, dams, and plants. The assets they are building have geospatial context—they exist somewhere in the real world," said Agelopoulos, director of infrastructure strategy and marketing at Autodesk. "Creating a more seamless connection between BIM and GIS would allow those customers to do a better job designing and building."

For example, when designing a bridge, having the context for the surrounding terrain from the GIS data would help ensure that the bridge is going to be built in the best location, Agelopoulos said. Initiatives such as integrating BIM and GIS will "produce a better context model earlier on in the design process to enable a smarter and more optimized design," he said. "We want to better consume Esri's data to provide that project insight to help engineers do more *[and]* better with less."

The AEC industry needs to be patient, however, because the integration will take time and be incremental, though there are plans



to integrate ArcGIS Online into Autodesk's InfraWorks software later this year.

"It's going to be a marathon, not a sprint," Agelopoulos said. "But we will eliminate the existing barriers between BIM and GIS and improve the user experience for our mutual customers."

One person who looks forward to a connection between BIM and GIS workflows is Christine Wacta, a professor of architecture at Savannah College of Art and Design (SCAD) in Savannah, Georgia, and a PhD candidate in geospatial information science. Wacta said her PhD studies focus on BIM and GIS.

"BIM and GIS have to work hand in hand," Wacta said, following a presentation she gave at the Geodesign Summit. "Those two tools should be together because they are not competing."

Wacta said that she has advocated for using GIS in her architecture classes and has taught her students to use Esri CityEngine to create 3D models from 2D GIS data. Her students have used both Esri and Autodesk software in their architecture courses. Models created with Esri CityEngine give architects and urban planners a realistic view of their projects, helping them see where a building that is proposed might cast shadows, reflect heat, or even block views for nearby residents.

Having GIS data available in software for BIM would help in site analysis, Wacta said. "In architecture, we do all the things that GIS does. We do site analysis, but we do it with our ears and our eyes and our feelings," she said. "GIS makes you work smart and not hard. With BIM, we work too hard. I send the students to go trace buildings when the building footprints are already *[available]*. It's *[often on]* the city's website, and it's free. Why don't we make the students' lives easier so they can spend more time on design rather than busywork?"

Geodesign That Improves Urban Planning—and People's Lives

The summit delved into many aspects of geodesign and supporting technology and content. Geodesign benefits from communities' having access to data and apps that they can use to develop green infrastructure plans.

Making people's lives better is a goal for The Trust for Public Land. (TPL) "Our mission is *[conserving]* land for people," said Breece

←← Christine Wacta is a professor of architecture at Savannah College of Art and Design (SCAD) in Savannah, Georgia, and a PhD candidate in geospatial information science whose work focuses on BIM and GIS. She believes BIM and GIS should work hand in hand.

← Breece Robertson, the director of planning and GIS for The Trust for Public Land, works on programs that create green infrastructure to help reduce the impact of climate change.

Robertson, the director of planning and GIS for the national conservation organization, which was founded in 1972. "We create parks and protect lands for healthy communities for generations to come."

One TPL program, Climate-Smart Cities, aims to create green infrastructure to help reduce the impact of climate change. One of the program's projects is Green Alleys. TPL reports that there are 900 miles of alleys in Los Angeles. The Green Alleys project transforms uninviting, concrete alleys into safe, green, community spaces. Working with a decision support tool that uses ArcGIS technology—and factoring in other information and community input—TPL identifies areas that would benefit from green alleys.

Not only are the alleys cleaned and spruced up with greenery, but the impervious surfaces are also removed and replaced with pavement that reflects light and is more permeable. This helps to keep the alleys cooler and reduce the runoff of water into storm drains.

Green alleys can serve as a type of park, said Fred Gifford, TPL's GIS director. "As Breece is saying, these areas are all built up. There are not a lot of options except for tearing down houses to put in parks," he said. "Alleys are one underutilized piece *[of property]*."

One of the Green Alleys pilot projects was in the Avalon neighborhood of Los Angeles. "This area needed connectors for walking and biking and commuting," Robertson said. "But mostly, we were thinking about green alleys as a way to activate social cohesion in these neighborhoods—to give people a place to gather *[and]* places *[where]* they could safely walk to the store."

The Green Alleys project illustrates the Geodesign Summit's focus on sharing ideas on applying The Science of Where—the science of geography and the technology of GIS—to make better design decisions.

"We aren't talking about the better design of a road or a bridge or even a city," Dangermond said. "It's about the better design of all that we do. If we do it right, we can transform how our cities operate."

Though the challenges seem daunting, Dangermond said he sees reasons for being optimistic. "We can make a huge impact on the way it turns out, because human ingenuity will kick in, and we will create a sustainable future," he said.

Esri writer Matt Ball contributed to this article.

↓ The Green Alleys project, sponsored by The Trust for Public Land, transforms uninviting, concrete alleys into safe, green, community spaces.

Do You Want to Retrofit Your City?

By Christopher Thomas, Esri Director of Government Markets

My colleagues and I have been spending a lot of time exploring what a city of the future will look like.

There are so many technologies, infrastructure constraints, and social aspects to consider, to say nothing of pressing issues such as demographic shifts, aging infrastructure, and climate change. The trend for smart communities suggests the need for a digital transformation to allow decisions to be based on an abundance of data and made with greater agility. In smart communities, mobility will be a priority, and people and infrastructure will be constantly connected through the Internet of Things (IoT).

While we contemplate this vision of the future, trends are accelerating at the speed of, well, technology. States, cities, and counties are excited about the promise of new infrastructure funding and a shift in thinking from maintaining existing infrastructure to rethinking infrastructure altogether.

This is a challenge for elected officials, executives, midlevel managers, planners, engineers, and nearly every discipline in government. If you are regularly engaged in discussions about adapting your communities for the future, you understand this dilemma. Organizations such as the Regional Transportation Alliance of Southwestern Pennsylvania are demonstrating the need for addressing the future through building livable and sustainable communities. If you are just beginning to think about evolving the urban fabric, consider the following questions that deal only with a future in which autonomous vehicles are the norm.

- Will we still need disabled parking spots or will a car simply drop you off at the front door?
- Will we need all those parking spaces at the mall if the car drops you off and picks up another passenger?
- Will we need traffic lights with the traditional red, yellow, and green lights if the intersection communicates directly to the vehicle?

These are all part of a larger question: Are we truly prepared for IoT, where everything is connected? If you think these are strange questions, look at the tallest building in your community—the one with all the communication devices on the roof. Governments were not prepared for the telecommunications boom and this is evidence of that. Instead, governments opted for a quick retrofit to place new technology on top of existing infrastructure.

Consider that we have spent years placing utilities underground so they are hidden, only to have unsightly cell towers pop up at a rapid rate. Then we developed strict aesthetic guidelines to disguise those cell towers (unconvincingly, some may say) as trees.

If industry analysts looking at the development of smart communities are correct, everything will be "sensorized" to collect data on road conditions, air quality, traffic flows, mobile devices, and constituent feedback. Infrastructure itself will actively collect, store, monitor, and use data. These factors need to be considered when building and designing new infrastructure.

I believe disciplines such as geodesign will take a greater role in everyday urban, regional, and infrastructure planning. Geodesign principles take a more holistic approach to planning and work to balance gray and green infrastructure, explore impacts in 3D, and compare alternative scenarios to develop more livable and resilient communities. Infusing design with a blend of science- and value-based information, geodesign helps designers, planners, and stakeholders make better-informed decisions through impact assessments and evaluation of alternative scenarios.

The Geodesign Summit is an event dedicated to the exploration of this concept. This year, it was held January 23–25 in Redlands, California, on the Esri campus. See the accompanying article, "Coming Together to Design Resilient Communities" to learn more about the discussions that took place this year.

Technology is changing quickly, and these infrastructure issues need to be addressed sooner rather than later; otherwise, you may be trying to retrofit your community.

↓ If you question the need to prepare for the changes the IoT will bring, just look at the tallest building in your community—the one with all the communication devices. It attests to government's lack of preparation for the telecommunications boom.

GIS for Digital Transformation Is the Start of Smart

By Brett Bundock, Managing Director, Esri Australia, Brisbane

The concept of digital transformation is being recognized across government as the key to streamlining processes and improving results. For local government authorities, digital transformation involves leveraging advanced data analytics to deliver more intuitive services and create smarter communities.

Fundamental to this process is the technology and know-how to extract and manage actionable intelligence from big data. Looking at local government authorities around the world, you can see that GIS technology is increasingly being used as a key platform to do this.

GIS works with Internet of Things (IoT) technology to map and analyze data from physical, connected devices—including smart devices, vehicles, cameras, sensors, and satellites—to reveal a real-time operating picture.

According to a survey of executives published in 2017 by McKinsey & Company in "Taking the pulse of enterprise IoT," although 92 percent think IoT technologies will generate a positive impact over the next three years, 54 percent report companies use 10 percent or less IoT data. GIS technology can boost this usage rate by translating IoT data into actionable insights.

Using these insights to proactively improve service efficiency is the first major step in transforming conventional communities into truly smart cities. These insights can range from alerting law enforcement of a crime as it unfolds to intuitively managing traffic light signals to reduce road congestion. While the digital transformation of major metropolitan regions, such as Los Angeles, Dubai, and Singapore, is already well under way, for many local governments, challenges remain.

According to "What is Holding Back the Digital Revolution?" a 2016 report by the Harvard Business Review in association with Genpact, only one-third of the executives in the study said they see significant results from digital transformation in their organizations. In both the private and public sectors, many decision-makers see digital transformation as a technology issue that will be undertaken by the IT department and don't realize that the process must start in the boardroom. The key to a successful digital transformation lies in taking a broader strategic view that requires mobilizing the necessary digital technologies and securing organization-wide stakeholder buy-in.

If you're part of a local government that has a culture that is unprepared for or resistant to change, you may need to enlist expertise in the early stages to guide the organization through the digital transformation process.

If a government leadership manages and implements change effectively, is willing to experiment, and can learn from mistakes, it will be at the forefront of success and see significant improvements in metrics such as customer satisfaction, profitability, and efficiency.

About the Author

Brett Bundock's passion for the science of GIS has led to a career that has spanned four continents and more than three decades. As the managing director of Esri Australia, Esri Singapore, Esri Indonesia, Esri Malaysia, and MapData Services, Bundock is regarded as one of the most influential contributors to the Asia Pacific region's spatial industry. He holds a bachelor of arts degree in geography, cartography, and government administration, as well as a graduate diploma in mapping and surveying studies.

ArcGIS Is Making Redistricting More Efficient and Transparent

A simple online subscription solution is helping governments meet the challenges associated with the redistricting process.

Every decade, the lines that determine congressional, state legislature, and local government districts in the United States are redrawn based on decennial census data. Although historically the process has been opaque, often politically charged, and largely ignored by the public, it is a vitally important process because it tremendously affects who can and will be elected to represent citizens on the local, state, and federal levels.

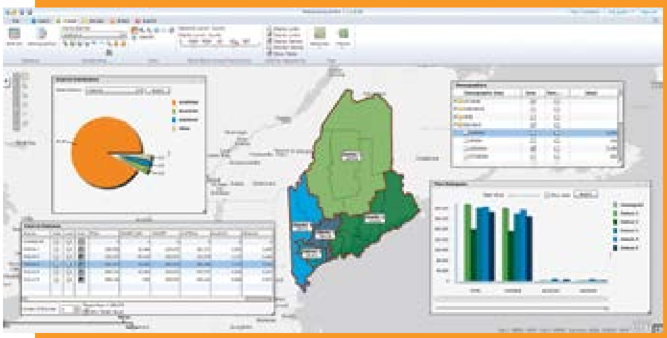
Every year, the geographic distribution of people changes. People are born, retire, die, or relocate. When that happens, it often necessitates redrawing districts to accommodate these changes. The redistricting process is made more challenging because governments must balance competing considerations when redrawing boundary lines each decade.

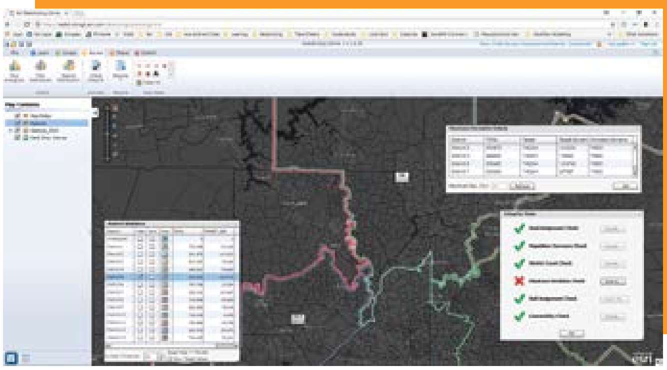
Congressional and state legislature districts must have equal population to comply with the US Supreme Court "one man, one vote" rulings. To comply with the Voting Rights Act of 1965, districts should reflect race and ethnic diversity. States and local governments can add other constraints such as contiguity and compactness relating to district shape, respect for political boundaries, geographic features, communities of interest, and political fairness.

Because the process is based on who lives where, it is an intrinsically geographic one that requires the integration of many factors, which can be addressed most effectively with GIS. It's no surprise that GIS was applied to redistricting activities as soon as it became commercially available in the 1980s. GIS-based redistricting solutions have been evolving since that time.

The Esri Redistricting Online solution is a software-as-a-service (SaaS) subscription. This application now gives state and local governments, the public, and advocacy groups unprecedented access to the redistricting process. This capability can provide complete government transparency. Interactive Web GIS is the perfect technology for drafting redistricting maps because the effects of boundary changes on associated populations can be tested interactively and worked on collaboratively.

Esri provides reliable current-year estimates and five-year projected population figures, so governments don't have to wait until the US Census Bureau delivers demographic data to states in 2021. Use Esri data to better understand the trends and factors at work in a region, assess redistricting scenarios, and build consensus. Once district boundaries are finalized, the demographic data used for this process remains valuable and can be used to improve election management.





↑↑ Balance various redistricting requirements and immediately see the effect of changes on plan goals using Esri Redistricting Online

↑ Comprehensively view the status of the statistics associated with each district in a plan

This online solution promotes transparency and engagement by allowing proposed redistricting scenarios to be shared online with others in government, constituents, and the media using a system of secure access.

To learn more about Esri Redistricting Online and obtain an evaluation subscription, visit ArcGIS Marketplace (marketplace.arcgis.com) and search for *redistricting*.

Get Help Accomplishing Your Goals

Have you ever wished you had a technical expert who could help you optimize your GIS implementation?

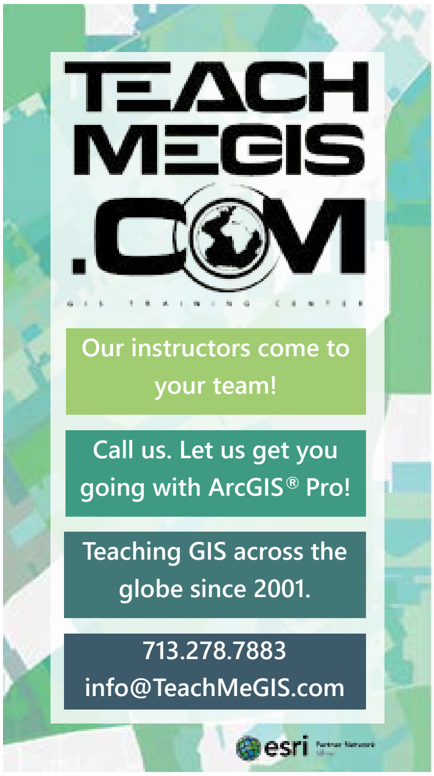
If your organization subscribes to the Esri Enterprise Advantage Program (EEAP), an Esri staff member with expertise in Esri software and your industry area will be assigned to you. This person will be dedicated to making your GIS program successful.

EEAP is a scalable framework to help organizations maximize their investment and implement Esri technology in a way that meets specific organizational needs. The key component of this program is the Esri Technical Adviser assigned to the organization, who acts as your facilitator, advocate, and leader.

The technical adviser becomes familiar with your GIS capabilities: your Esri platform implementation, applications, release levels, and geospatial initiatives. In coordination with the Esri account manager, your technical adviser prepares for and facilitates an annual account planning session and provides advice on GIS strategies, architectures, product selection, and release planning.

Working with your organization, your adviser prepares a technical work plan that outlines the organization's vision, objectives, and goals and comes up with a list of activities needed to execute that plan. To achieve your goals, your adviser identifies the components that you need from focused consulting and training to Premium Support Services and Esri Managed Cloud Services. Throughout the span of the subscription, your adviser maintains proactive communication and helps coordinate activities.

To learn more about EEAP, visit esri.com/services/eeap, send an email to eeap@esri.com, or contact your Esri account manager at your local Esri office.



esri THE SCIENCE OF WHERE™

ArcGIS COMMON PATTERNS OF USE

Mapping & Visualization

Understand locations and relationships with maps and visual representations

Data Management

Collect, organize, and maintain accurate locations and details about assets and resources

Field Mobility

Manage and enable a mobile workforce to collect and access information in the field

Monitoring

Track, manage, and monitor assets and resources in real time

Analytics

Discover, quantify, and predict trends and patterns to improve outcomes

Design & Planning

Evaluate alternative solutions and create optimal designs

Decision Support

Gain situational awareness and enable information-driven decision making

Constituent Engagement

Communicate and collaborate with citizens and external communities of interest

Sharing & Collaboration

Empower everyone to easily discover, use, make, and share geographic information

DEVELOPERS WITH A PURPOSE

By Monica Pratt, *ArcUser* Editor

Esri's recent Developer Summit showcased the latest innovation in mapping and GIS for software developers.

The summit, held March 5–9, 2018, in Palm Springs, California, was an opportunity for developers to find out how Esri has been expanding and further incorporating capabilities such as machine learning, big data, 3D functionality, data science tools, and immersive technologies into the ArcGIS platform. The event was also an opportunity for Esri to highlight where its development efforts are heading in the coming year.

The theme was "by developers, for developers," with the goal of bringing Esri's own software developers together with the geodevelopment community across the world. For geodevelopers, this was an opportunity to learn best practices that will make them more successful. For Esri, this was an opportunity to share how it builds software and works with the community to shape the software.

This year's event brought together more than 2,500 geodevelopers, which speaks to the growing importance of the technology. Beyond being the largest gathering of geospatial developers, Esri president Jack Dangermond characterized the conference as a "collection of developers with purpose."

He said that, looking at the caliber of the attendees, "Clearly you are making a huge difference in your organizations, and in turn, in our field. You're making the world a better place by enhancing communication, making processes more efficient, and improving decision-making."

In presentations during the Plenary Sessions and throughout the week, Esri development staff shared what they have accomplished in the past year, what they are currently working on, and how developers can benefit from their work.

One of Esri's goals has been to develop tech in a way that works very effectively for developers. One of the biggest takeaways—and a theme that ran throughout the presentations—was that leveraging the Web GIS pattern is the best way to work faster and smarter.

Most custom applications are built to access services directly, and that typically means writing a lot of code. Instead of writing code to access all the information in services, just use a map. In a couple of lines of code, all that information is available through the map. By letting end users edit web maps, you can let them configure your applications to match their needs and save you effort.

Web GIS also lets you leverage the authoritative content in an organization. Using a map lets data flow seamlessly between applications you develop and the rest of the ArcGIS platform. This also simplifies administration of your app by letting you apply the permissions and user roles for that organization that have already been established.

Developer Programs

In addition to the Web GIS pattern, Esri has been working to provide developers with a great experience. ArcGIS provides an arsenal of developer tools that support an array of SDKs and APIs and makes the ArcGIS platform more accessible. It also gives developers resources that get them up to speed and current with rapidly evolving technology.

If you are not already a member, your first step should be to join the ArcGIS Developer Program (ADP) by going to developers.arcgis.com. The Essentials subscription, which costs nothing, gives you credits, access to online web builders, membership in a large and collaborative GIS developer community, access to web and native client APIs and SDKs, reference documentation, access to a library of developer samples, and membership in an early adopter community.

Four additional subscription plans—Builder, Professional, Premium, and Enterprise—provide additional capabilities for a yearly subscription fee.

Once you have joined ADP, you can access developer tools. Esri has been maturing its developer framework that now has six ArcGIS Runtime SDKs for native app development and three APIs.

Euan Cameron, who leads Esri's developer programs, emphasized the powerful reasons for pursuing native development using the ArcGIS Runtime SDKs. "There's nothing that gets you closer to the native power of the device." Native development not only provides the best performance, but it can also leverage device capabilities as well as access all device peripherals via their native SDKs. Native apps also provide the best debugging experience and allow offline use of ArcGIS.

↑ David Cardella, Esri product manager, explains the benefits available with the ArcGIS Developer Program.

Esri provides six ArcGIS Runtime SDKs: Android, iOS, Java, macOS, .NET, and Qt. With version 100.x releases, these SDKs have evolved to better leverage the Web GIS pattern so you can use maps, layers, and scenes that have already been created and users, roles, and groups that are already established in an organization.

If you build apps using the SDKs and the geoinformation model, your apps will seamlessly integrate with your end users' ArcGIS workflows to provide optimal solutions. For example, you can create focused applications that extend the suite of field mobility apps that Esri provides.

AppStudio for ArcGIS is a native application builder that converts web maps into mobile apps for Android, iOS, Windows, OS X, and Linux. Those apps can be branded and made available through app stores. Configure apps using templates and wizards entirely online in a browser without any coding. Alternatively, you can customize an app's source code, piece together components from existing apps and samples, or write QML code from scratch using AppStudio for ArcGIS (Desktop Edition).

The ArcGIS API for JavaScript is powerful and well supported with many samples and widgets. The 4.x release of the API integrates 2D and 3D, so you can build full-featured 3D applications from web maps and web scenes that include terrain, integrated mesh layers, and 3D objects as well as imagery and feature layers. These data types can be used for analyses such as viewshed or line-of-sight. New configurable 2D and 3D app templates speed up development. It takes just a few lines of code to implement the many responsive widgets that are available.

The ArcGIS API for Python supports automation in ArcGIS Enterprise deployments and time-critical workflows for ArcGIS Online applications. Data-driven Python scripts can add users, privileges, and roles and create groups, configure the portal, and establish collaborations between ArcGIS Online organizations.

With its integration with Jupyter Notebook, the ArcGIS API for Python was designed to bring data science to Web GIS. It facilitates machine learning and deep learning workflows through the creation of reproducible research for sharing and collaboration.

To support The Science of Where, ArcGIS continues to offer additional data science capabilities. Insights for ArcGIS offers an interactive, ready-to-use analysis experience. More than 1,200 geoprocessing tools are available in ArcGIS Pro that can be used with Python packages and the R-ArcGIS bridge in analytical workflows to provide a deeper understanding of what happened, where it happened, and what will likely happen in the future. Information products can be created in ArcGIS Pro that visualize and disseminate the results of analyses.

As Esri's technology expands to include enhanced visualization and analysis of imagery, real-time, and 3D data, Esri's developer tools have been extended to support these new capabilities. For example, the ArcGIS Runtime SDKs optimize the use of 3D content with scene layers using the I3S standard via online services or via a scene layer package on the device to support use offline.

Because Esri is always pushing the envelope, its developers are working on more immersive GIS applications that incorporate virtual reality (VR) or augmented reality (AR). These applications take advantage of dedicated chipsets that are already available in mobile phones that support these capabilities. Support for a stereo display rendering mode enables VR. Background transparency functionality has been added so that featues can render on top of a camera feed, making AR feasible.

Many Resources

In addition to SDKs, APIs, builders, and tools to speed the development process, the ArcGIS Developer Program website (developers.arcgis.com) has been redesigned to better answer the two most common questions asked by developers: what can Esri technology do, and how do I get started?

The site not only tells what services are available, like generating directions or performing spatial analysis, but also provides live samples. These samples let you interactively test ArcGIS capabilities such as calculating drive times, routing to the closest facility, or generating a travel cost matrix. Live samples have links to resources for learning more about using geospatial data for analysis and visualization and how the SDKs, APIs, or other tools are used.

One terrific learning resource for developers is Esri Dev Labs. Introduced last year, the site provided several dozen brief, highly focused tutorials that were free. The labs are still free, and their number has grown to more than 100.

None of these tutorials take more than 15 minutes. They guide you through the three phases of building geospatial apps: importing and preparing data, designing and configuring maps and layers, and developing mapping applications using ArcGIS tools. These bite-size lessons are presented in a browsable format that allows you to filter by functionality, platform, and how recently the lab was added.

The example apps on the Esri GitHub repository give start-to-finish lessons in app development. These full-fledged apps illustrate best practices for using ArcGIS and can be used to kick-start a project. Each example app has complete documentation so you can really understand the problem and the app that was created to solve it.

Success Stories, a section of the ADP website, gives you another way to learn. Each story gives a detailed account of how an organization solved a problem using ArcGIS development tools. Stories are categorized by industry and links provided to resources on concepts illustrated and the software used.

Because you are developing on the ArcGIS platform, all the constantly expanding capabilities for visualization and analytics in ArcGIS are available to you. You can take advantage of Esri's complete mapping, location, and analytics platform for your geodevelopment projects by joining the ADP.

↑ The 2018 Esri Developer Summit (DevSummit) was the largest gathering of developers in the event's 13-year history.

WHY THEY CAME TO DEVSUMMIT

By Carla Wheeler, *ArcWatch* Editor

Once a year, Palm Springs, California, becomes the center of the geospatial technology universe.

Esri hosts its annual Esri Partner Conference in the city's convention center, immediately followed by the wildly popular Esri Developer Summit (DevSummit).

In March, more than 2,000 geospatial app developers, information technology (IT) managers, Esri partners, and others, packed workshops and the Plenary Session. They also watched a Keynote Address about artificial intelligence (AI) given by Joseph Sirosh, corporate vice president of the Artificial Intelligence and Research Group at Microsoft.

Esri's ArcGIS program manager Jim McKinney said this year's event attracted a record crowd. One of the attendees, Stu Rich, thought he knew why.

"I think what you are seeing is that Esri's technology is maturing rapidly and becoming more accessible," said Rich, the chief technology officer (CTO) of PenBay Solutions, an Esri partner. "And there is a rapidly growing group of developers that understand the value they can drive on top of that set of Esri's capabilities. Their ability to enhance and configure and deploy really compelling solutions based on Esri's technology is exciting. It's amazing what can be done today, and that is certainly driving the growth *[of the summit]*."

Rich said that DevSummit workshops now delve into technology that integrates with GIS, going far beyond a narrow focus on traditional GIS. "You've got sessions here on remote sensing, raster analytics, machine learning, and artificial intelligence," Rich said. "You've got such breadth *[of session topics]*, that it attracts a very wide and diverse group of developers from across many, many business domains."

The following attendees shared why they came to Palm Springs this year and what most interested them about this year's conference. (Some comments were edited for clarity and brevity.)

Xin Chen
Systems and Programming Supervisor, South Coast Air Quality Management District (SCAQMD) from Diamond Bar, California

Why did you come to DevSummit?

SCAQMD assistant deputy executive officer Ron Moskowitz has placed a high priority on a project to increase our GIS capabilities. Our number one objective is to present air quality information to the public in a meaningful way. We monitor and calculate hourly air quality for the region, so that data has to get out.

During the last year, we have increased our presence on ArcGIS Online. For example, we migrated our air quality map to the cloud-based mapping platform. By leveraging the Esri cloud, we no longer have to worry about server capabilities. Esri takes care of everything such as scaling during periods of high demand. We have also completed the initial installation of our on-premises ArcGIS Enterprise system.

At the SCAQMD, we want to continue to leverage Esri's capabilities. We are here to learn in depth about the application architecture and the development tools available. Esri also offers a whole suite of very powerful ready-to-use applications such as Workforce for ArcGIS, Collector for ArcGIS, and Survey123 for ArcGIS. We are here to learn about how to use these apps for field force automation, as well as public engagement.

Currently, we are trying to build a mobile application, and we are here to explore Esri's mobile capabilities. It's great to see this year's DevSummit has a special focus on mobile—it's exactly what we wanted to learn. Three of our staff are splitting up sessions trying to figure out what's the best approach. We were also able to have an in-depth meeting with Eric Bader from Esri's ArcGIS Runtime team, who helped a lot in that regard.

What are the cool things you've seen?

The point clustering capabilities in ArcGIS API for JavaScript demonstrated at the Plenary Session. Clustering helps to improve the visualization of large point datasets—common at AQMD. You can have a richer and more meaningful map with a faster response time. Immediately, we picked that up and said that's something that helps us.

To learn more about using ArcGIS Arcade, see the accompanying article by Ekenes, "Portable Arcade Expressions Help Securely Create Client-Side, Data-Driven Web Maps," in this issue.

Jean-Yves Lauture
President and CTO, Eos Positioning Systems from Terrebonne, Quebec, Canada

Why did you come to DevSummit?

Can I say the weather first? The friendliness of all the Esri staff. You always feel good coming to an Esri event. Everybody feels welcome.

Eos Positioning Systems manufactures high-accuracy GNSS receivers compatible with iOS, Android, and Windows *[devices]* and compatible with all Esri mobile products like Collector for ArcGIS and Survey123 for ArcGIS. Esri is avant-garde—innovating always in the market—and they listen to their users. The testing, development, and support teams are extremely responsive to the public.

What are the cool things you've seen?

The Esri-Autodesk partnership to integrate BIM *[building information model]* and GIS. There was a big gap [*between the two technologies]* to be bridged, and that's happening now.

Cody Barrett
Senior Designer/Developer, HNTB Corporation/Iowa Department of Transportation (Iowa DOT) from Ames, Iowa

Why did you come to DevSummit?

I'm an embedded consultant *[from the infrastructure solution firm HNTB]* for the Iowa DOT *[Department of Transportation]* GIS group. This is my first year at the Developer Summit. I currently assist in developing custom applications for internal clients. I'm interested in new functionality that is coming out, especially the ArcGIS API for Python. I think the *[API]* will be helpful for not only maintaining your ArcGIS Online organization *[and]* publishing content but also for data analytics and GIS analysis. At the Iowa DOT, we are always striving to improve processes and create dynamic solutions that fit the business needs of our internal customers.

What are the cool things you've seen?

One cool thing that came from *[Esri Web GIS/Mapping product engineer]* Kristian Ekenes. At the Plenary Session, he demonstrated clustering using ArcGIS Arcade. *(Arcade is a lightweight and secure expression or scripting language written for use in the ArcGIS platform to customize visualization and labeling.)* I like how it summarizes the cluster in the pop-up and you can browse through the features within each individual cluster. It's a simple yet effective way to visualize data in a readable format.

Portable Arcade Expressions Help Securely Create Client-Side, Data-Driven Web Maps

By Kristian Ekenes,
Esri Product Engineer

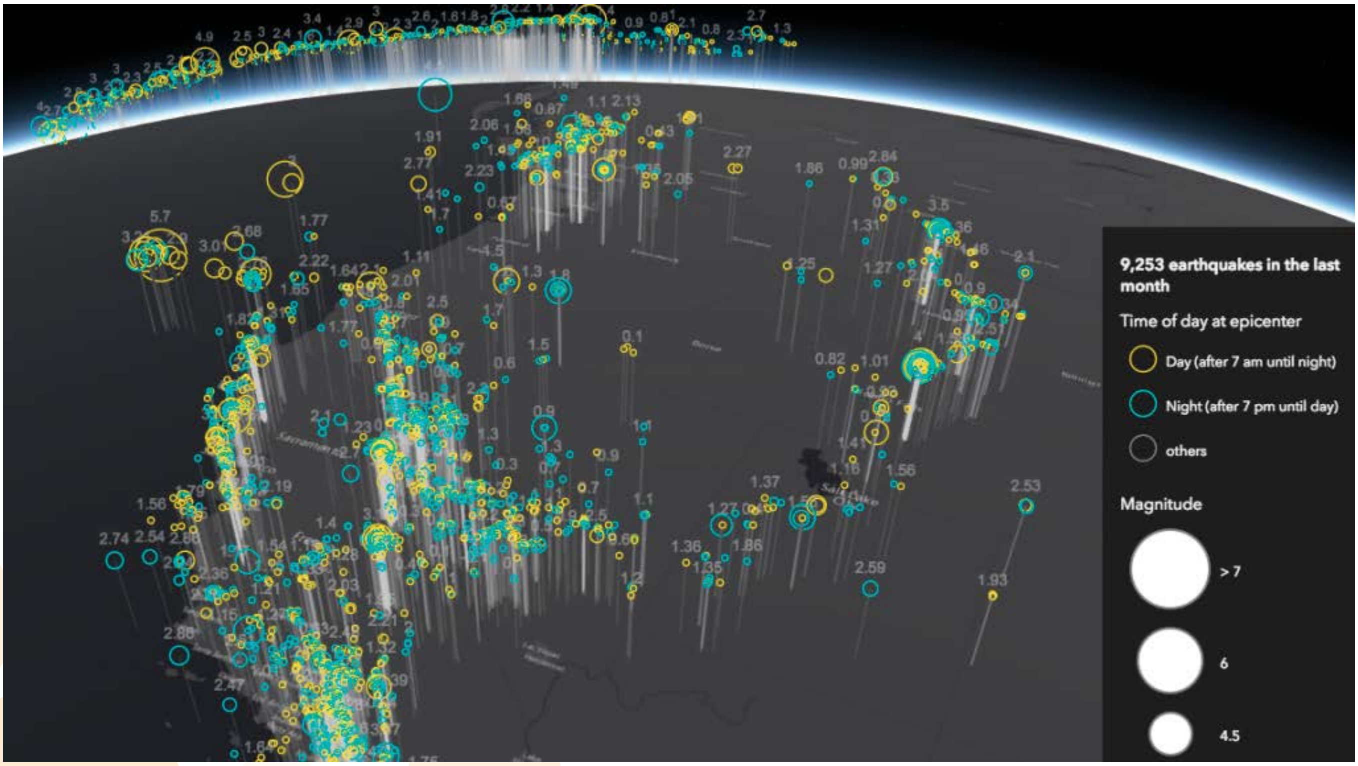
ArcGIS Arcade—an expression language used to evaluate and return data values in pop-ups, labels, and data-driven visualizations securely across the ArcGIS platform—gives you flexibility in the development process without requiring that you make changes to the feature layer.

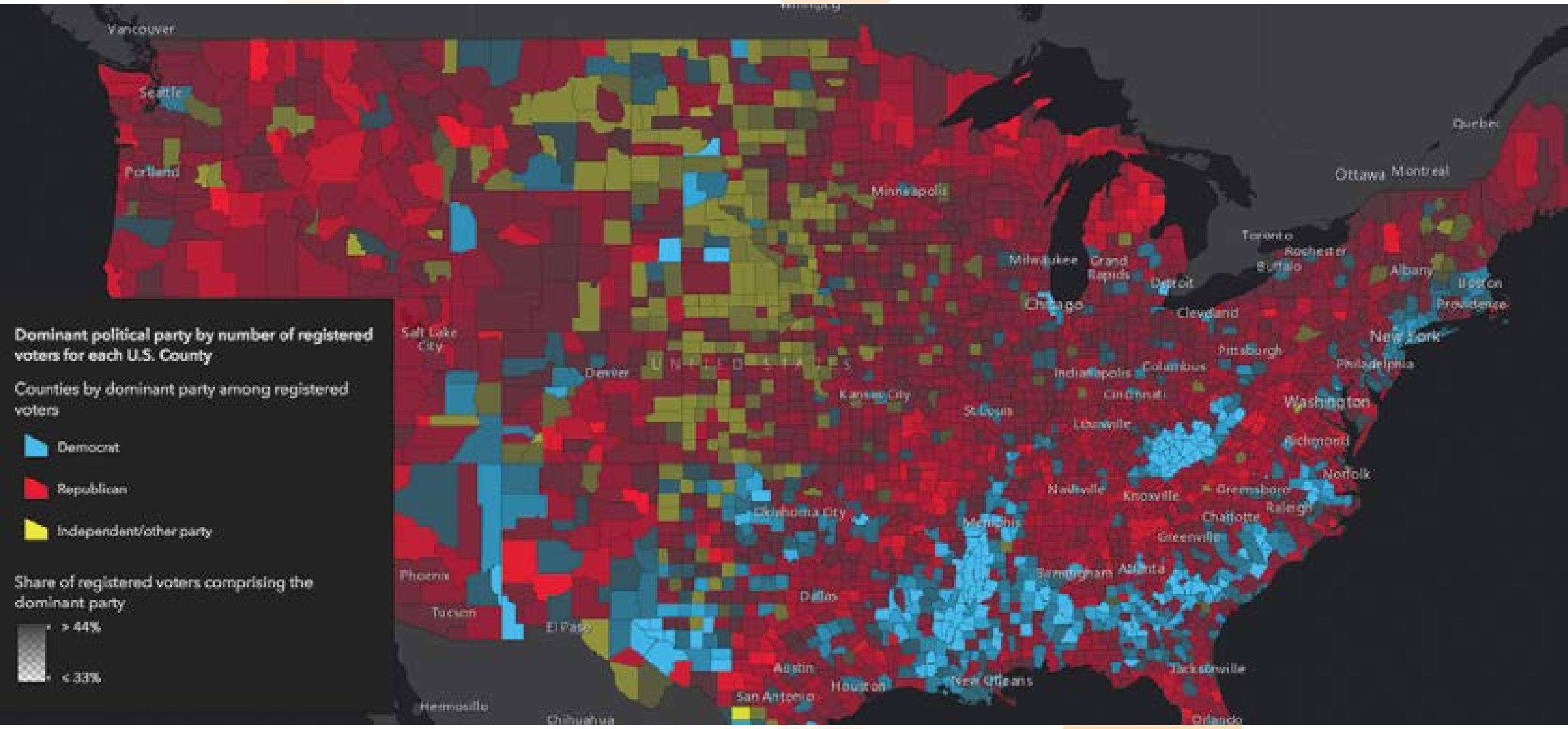
Similar in syntax and simplicity to spreadsheet formulas, Arcade is a powerful tool that lets you display and visualize information beyond what is immediately available in a dataset by visualizing and displaying new data values. These data values are calculated on the client side and can be formatted the way you want even if you don't own the layers containing the data.

If you are already familiar with developing custom web applications using the ArcGIS API for JavaScript, you may already know that you can evaluate custom values for visualizations and pop-ups on the client side using JavaScript functions. However, those functions can't be shared across apps and can't be saved to layers and portal items. Perhaps a more important point is that doing this with JavaScript would be insecure.

What makes Arcade particularly powerful is that expressions

↓ An Arcade expression was used to generate time-of-day visualizations of real-time earthquake data from the US Geological Survey that spans multiple time zones and is symbolized by the time of day at each earthquake's epicenter.





↑ This web map uses Arcade to visualize the relative predominance of each political party in each US county based on the party with the largest number of registered voters in that county.

can be persisted on feature layers, portal items, and web maps. Expressions written using Arcade in ArcGIS Pro, ArcGIS Online, ArcGIS Runtime, or even in custom web apps written with the ArcGIS API for JavaScript can be seamlessly used again and again across the ArcGIS platform.

If you've been putting off getting started with Arcade, a few minutes reviewing the following examples will show you how Arcade can be useful for some common scenarios.

Normalization

Most geospatial data visualizations use normalization. In normalization, one numeric attribute value is divided by another to minimize the influence of differences in the size of areas or the number of features in each area. For example, if I want to visualize the population for whom a second language is spoken at home for each census tract in the United States, I can use Arcade to perform the normalization using the following expression.

```
($feature.SECOND_LANGUAGE / $feature.POPULATION) * 100
```

Arcade is especially useful for accomplishing this if I don't own the dataset. Since this expression executes on the client, no changes to the service are necessary, and all processing happens at runtime.

Rounding

Note that the previous expression didn't specify the precision of the returned value, so it may return values containing more significant digits than desired. Modifying the expression using Round, an out-of-the-box Arcade function, will round the value to the nearest tenth.

```
Round(($feature.SECOND_LANGUAGE / $feature.POPULATION) *\
100, 1)
// returns 31.8
```

Casting

One of the frustrations users have with some datasets is that the data isn't represented properly: numbers stored as strings, strings that aren't formatted, dates that are broken up and stored in multiple fields, and yes and no values that are stored as ones and zeros. Fortunately, Arcade has Text(), Number(), Date(), and Boolean() functions that (conveniently) let you cast field values as the desired type.

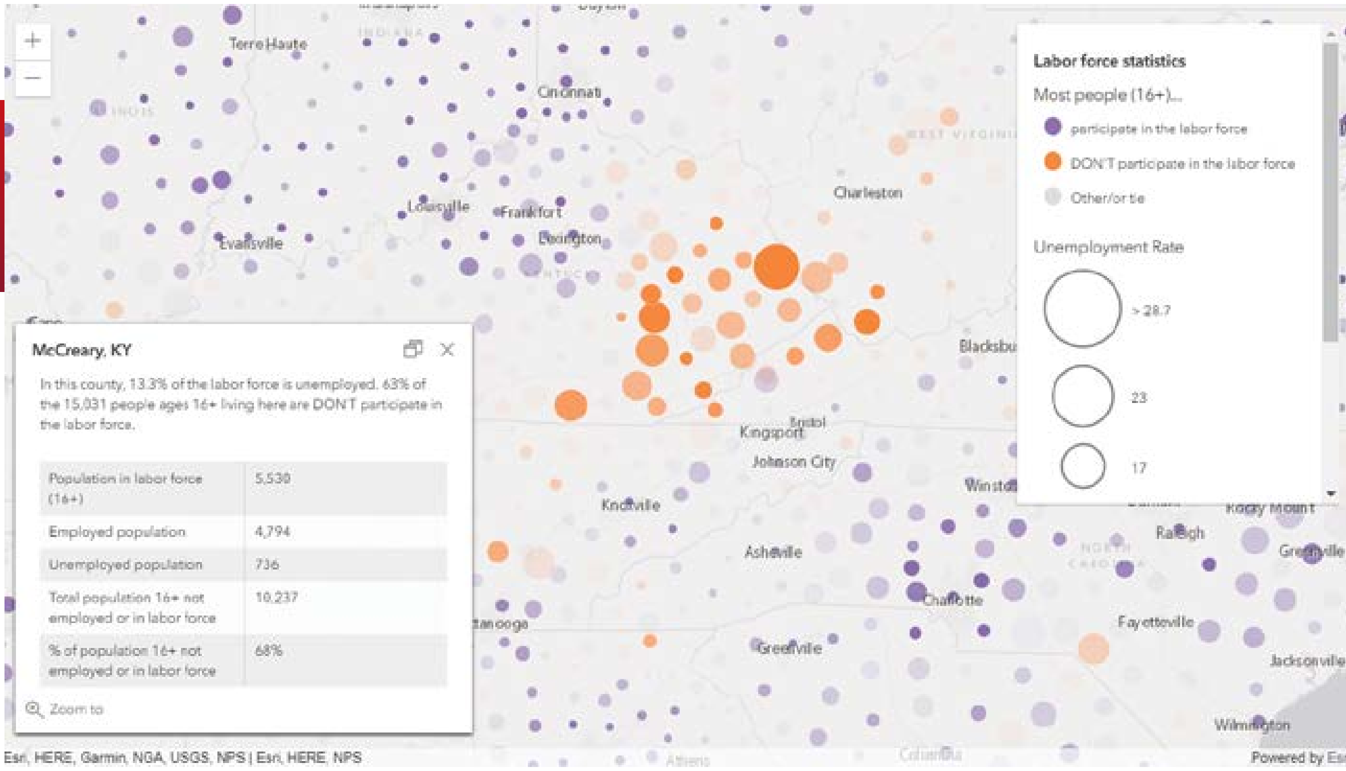
If you have values that have been stored as the incorrect type, you can cast those values as the correct value type so they can be properly visualized as shown in the examples in Listing 1.

```
Number('28324')
// returns 28324 as a number, not a string

// e.g. for the value '39.99%'
Number($feature.PER_ASIAN, '#.##%')
// returns 0.3999 as a number

Text(1234.55, '$#,###.00')
// returns '$1,234.55' as a formatted string
```

↑ Listing 1: Casting data in Arcade



↑ In this web map, an Arcade expression visualizes statistics for participation in the labor force based on predominance (do or do not participate) and rate.

Logical Evaluation

Arcade contains six functions intended to simplify the syntax for logically evaluating values. While the syntax in Listing 2 is correct, it takes several lines of code to determine if a score is high or low based on a field value.

```
var rank;

if($feature.score >= 50){
 rank = "high";
} else {
  rank = "low";
}
return rank;
```

↑ Listing 2: Logical evaluation without Arcade functions

Arcade conveniently simplifies this common workflow with the IIF() function, which reduces seven to eight lines of code down to just one. The same evaluation in Listing 2 is shown in Listing 3. Be sure to check out When(), Decode(), and the other useful logical functions in the Arcade documentation.

```
IIF($feature.score >= 50, "high", "low");
```

↑ Listing 3: Logical evaluation using the IIF() functions in Arcade

Complex Expressions

Arcade is designed to be lightweight and simple. Once you're familiar with the syntax, you can write powerful expressions in just one or two lines. However, you can also write longer, more complicated expressions in Arcade that can include custom functions and even geometry operations.

A sample in version 3.23 of the ArcGIS API for JavaScript documentation called Geofence with Arcade details how to create a geofencing app using Arcade on a StreamLayer's renderer. The *ArcGIS Blog* website has featured posts that describe how to create predominance visualizations, time visualizations, and weather formulas using Arcade expressions. Search online for these posts by their titles to learn more about using longer Arcade expressions.

- "Creating a predominance expression with Arcade"
- "Unwinding the clock: Visualizing time with Arcade"
- "Thematic point clustering for data exploration"
- "Using Arcade in web apps"

When Not to Use Arcade

While Arcade gives you unprecedented flexibility in customizing layer styles and pop-ups, even layers owned by others, it shouldn't be used in every case even if it is permitted.

If you have full ownership of a layer containing the data you want to visualize in a web app and that data is already stored in a clean, acceptable way, you don't need to write Arcade expressions. You can store values used for the data-driven visualization, pop-ups, and labels in service fields, so there is no need to write Arcade expressions for formatting or casting values.

The examples in this article use Arcade for normalizing, rounding, and casting when you don't have privileges for the dataset you want to use and need a quick way to modify field values.

It's also important to keep in mind that not every function included in the Arcade language should be used in all available profiles or contexts for which they can be used. Arcade provides 32 geometry functions and, in theory, any of them could be used in any profile: visualization, labeling, or pop-ups.

However, remember that Arcade executes on a feature-by-feature basis, so executing multiple geometry operations for each feature may not provide an optimal user experience if used in visualization and labeling profiles. It may be more appropriate to reserve more complex expressions using multiple geometric operations for the pop-up profile, because with that profile, the expression will execute only when a feature is clicked.

The Future

The December 2017 release of Arcade (version 1.3) introduced more than two dozen geometry functions that include measurement operations, overlay operations, and topological testing functions. Many geometry functions, such as the overlay and testing functions, require more than one input geometry. In the current release of Arcade, you can manually construct geometry objects as needed within the expression, such as calculating the distance from one hard-coded point to all points in a layer.

Future releases will provide methods that allow you to access other geometries within the same layer, related tables, and features in other layers. Additional functionality will continually be added to Arcade, but you can take advantage of the out-of-the-box functions right now. You can also go outside the box by writing your own functions.

About the Author

Kristian Ekenes is a product engineer on the ArcGIS API for JavaScript team.

IMAGERY SUPERPOWERS

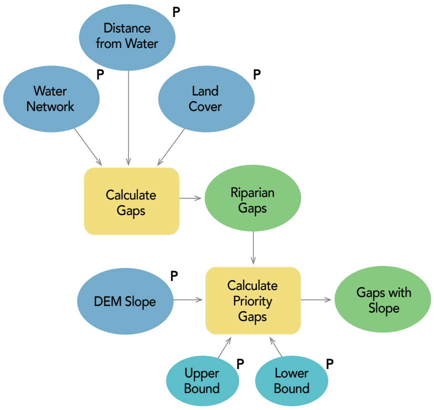
Raster analytics expands imagery use in GIS

By Jeff Liedtke, Product Engineer, Esri Raster Team

Aerial, drone, and satellite imagery is more available than ever before and can add valuable information and context to GIS projects. However—before the raster analytics capabilities in the ArcGIS platform—incorporating massive imagery workflows into your GIS could be overwhelming.

Esri developed raster analytics capabilities so that you can quickly process large imagery collections and extract and share meaningful information for critical decision support. The capabilities of ArcGIS Enterprise are extended with ArcGIS Image Server configured for the roles of raster analytics and dynamic image services to host distributed processing and storage. In this scalable environment, you can implement computationally intensive image processing that used to be impractical, impossible, or cost-prohibitive.

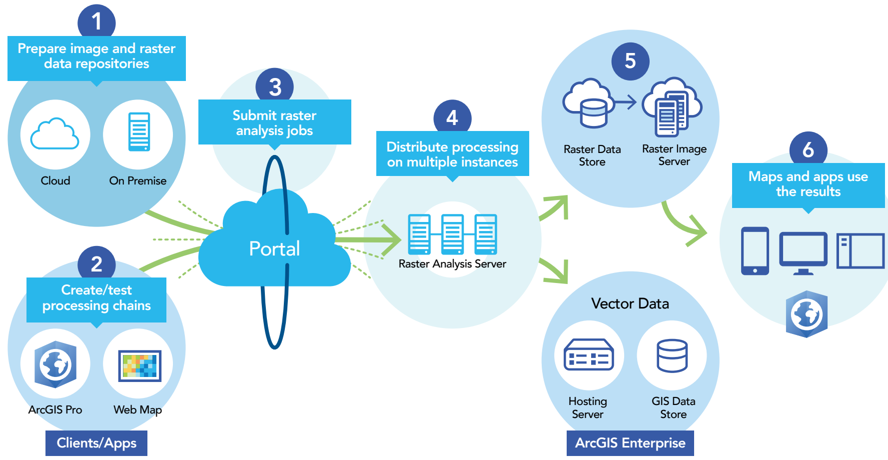
Raster analytics can be run locally to fully utilize your existing ArcGIS Image Server on-site. However, using the scaling capabilities of Raster Analysis Server and Raster Image Server in a distributed cloud computing environment maximizes efficiency by exploiting the elastic processing and storage capacity of cloud computing and storage platforms such as Amazon Web Services (AWS) and Microsoft Azure. With this elasticity, you can increase or reduce capacity depending on the size and urgency of projects. Image processing and analysis jobs that used to take days or weeks can be completed in minutes or hours, bringing imagery projects that were impossibly large or daunting within reach. (See the accompanying article, "Tackling a Monumental Project.")



↑ Raster function chains can be interactively created in the ArcGIS Pro Raster Function Editor pane.

With this system, you can apply standard raster processing tools and functions in ArcGIS, build custom functions and tools, and combine multiple tools and functions into raster processing chains to execute custom algorithms on large collections of raster data. Results are stored, automatically published, and shared across your enterprise.

This flexibility in processing and storage capacity lets you meet demanding project timelines and tight cost requirements. Resources can be ramped up to meet a surge in demand, then released when no longer needed.



↑ The raster analytics processing workflow

Power, Extensibility, and Availability

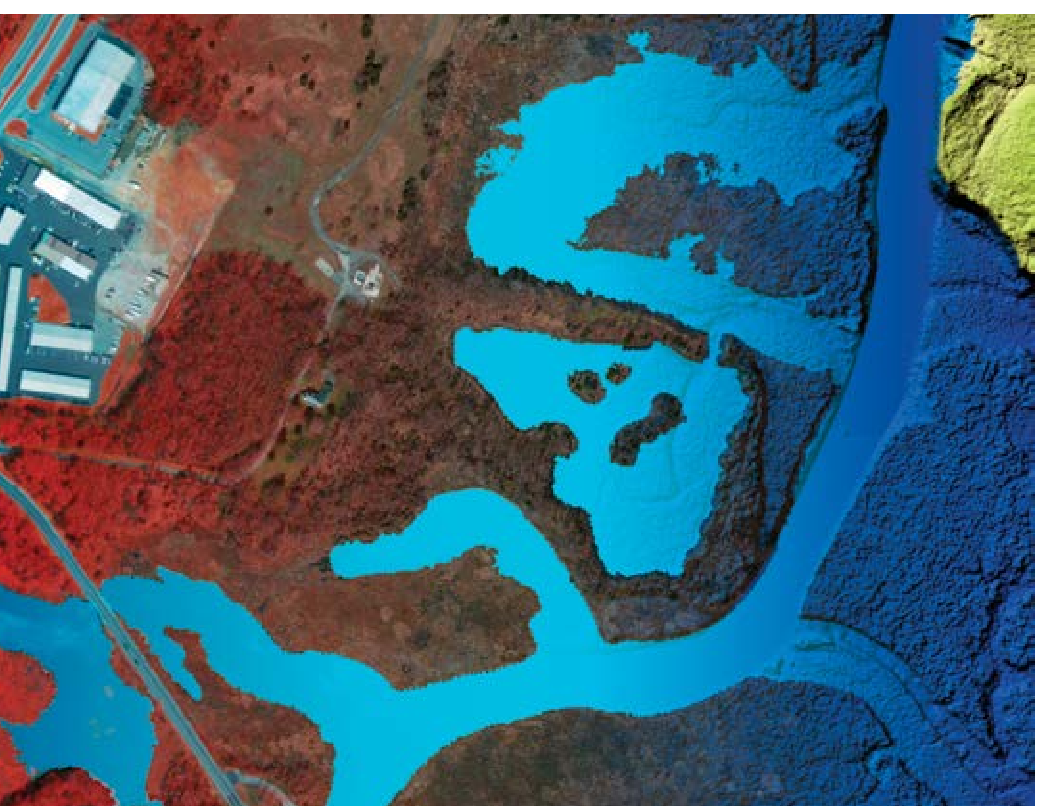
To enable raster analytics, ArcGIS Image Server is configured to perform distributed computing in a processing and storage environment that maximizes processing speed and efficiency. Built-in tools and functions cover preprocessing, orthorectification and mosaicking, remote-sensing analysis, and an extensive range of math and trigonometry operators. These functions process multispectral and hyperspectral imagery, multidimensional scientific data addressing data cube type problems, and temporal data for time series analysis.

Advanced raster analysis processing chains can be built from the more than 200 functions and tools that are available out of the box and saved as raster function templates.

You can write custom functions that extend the platform's analytical capabilities and deploy custom image processing algorithms to address unique applications and problem sets. Developers can build production processing workflows by utilizing the ArcGIS Enterprise REST API, ArcGIS Server REST API, or ArcGIS API for Python with raster function objects using code samples found on the ArcGIS for Developers (developers.arcgis.com) website or scripts available from the Esri repository under the arcgis.raster.functions module on GitHub.

Custom processing chains can also be built using the Python Raster Function that allows you to write image processing algorithms in Python and execute them in a distributed environment. (See github.com/Esri/raster-functions/wiki/PythonRasterFunction.)

Raster analytics integrates image processing and analysis with the rest of the ArcGIS platform, streamlining and simplifying collaboration and sharing. Users across your enterprise can contribute data, processing models, and expertise to an imagery project, and the results can be shared with individuals, departments, and organizations in your enterprise.



Removing Barriers

Efficient and powerful processing of large image and raster data collections using compute-intensive processing chains allows users to address projects and jobs that were out of reach in the past. This lowers the bar for smaller or midsize companies, allowing them to undertake projects that were exclusively the province of large, well-resourced organizations. Limited processing and storage resources are no longer barriers for organizations that want to take advantage of opportunities that have demanding image processing requirements and delivery time frames.

Elasticity in the deployment of raster analytics provides scalability in terms of speed as well as dataset size. Sometimes the requirement is that data be quickly processed for applications such as emergency management support, processing multidimensional scientific data from sensors, or constant monitoring by drones.

Another important benefit of this ability to scale rapidly is surge capacity. This has always been an operational challenge for contractors and service providers. Resources and costs can now be tailored to specific projects. Leveraging cloud resources enables an organization to address acute capacity needs without high capital investment, maintenance costs, or risks.

When an organization wins a project, it can quickly ramp up to a level appropriate to the project's time frame and budget, complete the project, and then release resources when they are no longer needed. Experience estimating time and cost for certain types of projects will become more refined over time, making an organization more competitive and lowering risk and liability.

Raster Analytics under the Hood

Image Server configured for the role of raster analytics provides software and user interfaces to organize and manage processing, storage, and sharing of image and raster data, maps, and other geographic information on a variety of devices. This integrated system manages the dissemination and storage of results on-premises and behind the firewall for classified deployments, in cloud processing and storage environments, or in a hybrid environment that uses a combination of on-premises and cloud.

The foundation of raster analytics is ArcGIS Enterprise, which includes an enterprise GIS portal, ArcGIS Data Store, and ArcGIS Server, as well as Image Server configured for raster analytics, raster data store, and ArcGIS Web Adaptor. ArcGIS Enterprise integrates the components of the raster analytics system to support scalable, real-world workflows.

Scale powerful processing and storage capabilities by deploying ArcGIS Enterprise in the cloud via AWS or Microsoft Azure. For example, you can automatically scale capacity up and down according to conditions you define or automatically disperse application traffic across multiple instances for better performance. Esri makes deployment easier by providing Cloud Builder for Microsoft Azure or AWS CloudFormation with sample templates to configure and deploy your system in the cloud.

Running a Raster Analysis Job

Using the user interface in ArcGIS Pro or web map viewer, running raster analysis jobs is straightforward. You simply submit your job, and the way you defined and set up your portal determines how the processing and storage is distributed across the available servers, instances, and data stores.

The raster analysis workflow begins with preparing your image and raster data for efficient processing. This involves registering your data and converting it to a distributed version for optimized, distributed processing and storage, but distributed storage is not mandatory. The data is converted into Cloud Raster Format (CRF), a tiled format that is optimized for performance.

Raster analysis will work with your existing data, but it will not be as efficient as when you use optimized data. Optimal performance is achieved when your source data has been prepared and staged in the data store. Tools are provided to convert your data files into a distributed version of the data, which optimizes it for efficient distributed processing and the storage of published results.

Develop, test, and optimize raster processing chains using the more than 200 functions and tools in ArcGIS Pro or web map viewer. With the raster function editor in ArcGIS Pro, you can interactively build and test a processing chain, preview results, and verify those results in a dynamic processing environment. With ArcGIS Pro, you can also create customized functions using Python.

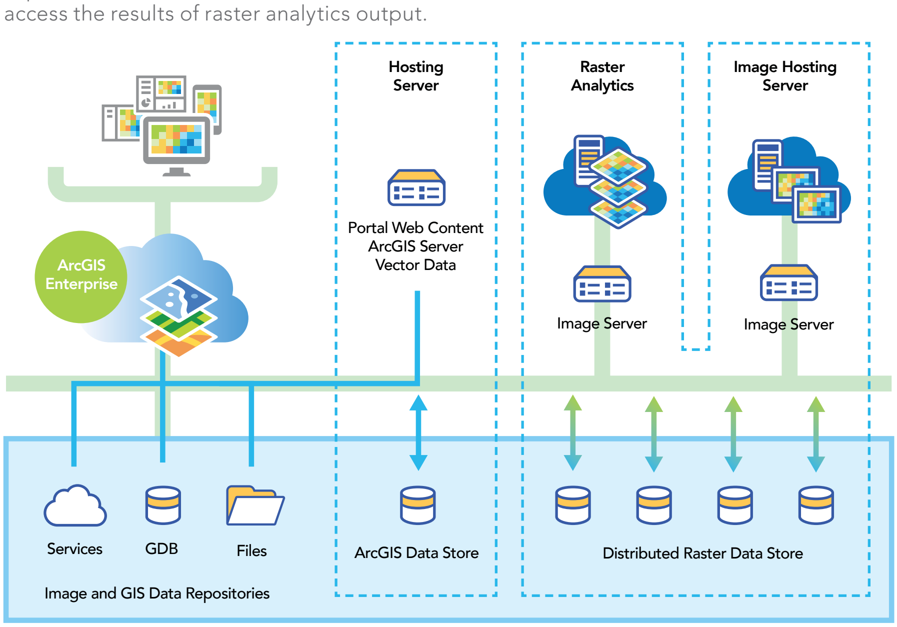
When you are satisfied with your processing chain, you can save it as a raster processing template. Processing templates can be shared with your organization through ArcGIS Enterprise. Once a processing chain has been optimized, submit it to the ArcGIS portal, which manages the distribution of processing, storage, and automatic publication of results.

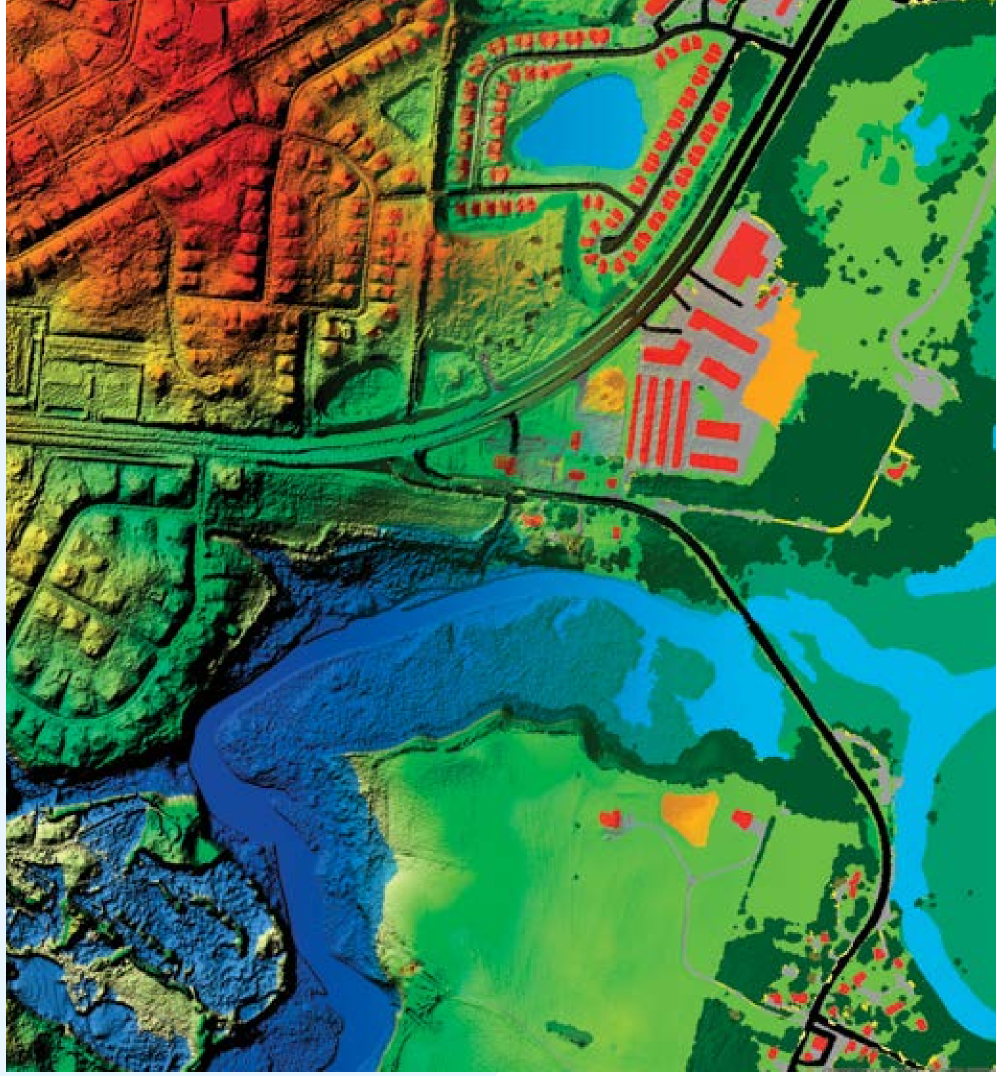
You submit a raster analysis processing job by specifying the portal and naming the output web image layers. The job is sent to the Raster Analysis Server for distributed processing using your processing chain and the raster data prepared and stored in the raster data store repositories.

The raster output from the Raster Analysis Server is *automatically* published to the distributed Raster Data Store, while any vector output is published to the GIS Data Store. Since the analytical results from your raster analysis job are automatically published, they are immediately available to your enterprise for sharing and further analysis.

Raster analytics components and relationships

ArcGIS Server with Image Server is the combination of licenses that enables creating and hosting of image services (Image Hosting Server). When an ArcGIS Server with Image Server is federated with an ArcGIS Enterprise server (Hosting Server), the raster analytics capabilities become available. These servers use ArcGIS Server data stores to store and access the results of raster analytics output.





Deploying Image Server

The ideal deployment of Image Server with raster analytics is composed of three (or more) server sites that perform the primary roles of the portal host server, raster analysis server, and image hosting server. Two licenses are required for raster analytics: ArcGIS Enterprise and Image Server.

The hosting server is your portal's server for standard portal administration and operations such as managing and dispensing processing, storage, and publication of results to raster analysis servers, image servers, and data stores. It also hosts ArcGIS Data Store for GIS data and allows users to publish data and maps to a wider audience as web services.

Raster analysis jobs are processed by image servers dedicated for raster analytics, composed of one or more servers, each with multiple processing cores. The image processing and raster analytics tasks are distributed at the scene or subscene level depending on the tools and functions used. Image Server manages the processing results to either ArcGIS Data Store on the hosting server for feature data products or to the raster data store for imagery and raster data products. The raster data store can be implemented using distributed file share storage or using cloud storage such as Amazon S3 or Microsoft Azure Blob Storage.

The image hosting server hosts all the image services generated by the raster analysis server. It includes the raster data store and returns results requested by members of your enterprise.

Templates and system configuration apps assign the roles of the servers and data stores and also set the permission structure for all the users across your enterprise. This facilitates optimal flexibility in configuring and implementing your raster analytics system to address specific projects. Multiple servers can be scaled up for raster analytics processing and storage as required.

This architecture can be varied according to your requirements and budget. For instance, the image hosting server and the hosting server may be the same server. The image repositories can be local drives on the ArcGIS servers, already in one of the server's data stores, or in a cloud repository such as an Amazon S3 bucket where Amazon AWS hosts repositories of published imagery and raster data. *(For the latest information on how to configure ArcGIS Enterprise for raster analytics, refer to the online help for ArcGIS Enterprise.)*

Making the Previously Impossible, Possible

Because raster analytics is integrated with and takes advantage of, components of the ArcGIS platform, it utilizes the rich set of analytical capabilities of ArcGIS Desktop and turbocharges processing by distributing the storage and processing of rasters. These capabilities create a powerful, distributed raster processing, storage, and sharing system that can be scaled to fit any project having demanding requirements.

A paradigm shift in imagery use has occurred. With raster analytics, organizations—both large and small—are empowered to address projects with diverse and demanding requirements that were previously impractical by scaling operations in an efficient and cost-effective manner.

TACKLING A MONUMENTAL PROJECT

The Chesapeake Bay is the largest estuary in the United States. To support watershed and storm water management and conservation for this vast area, as well as reduce pollution of the bay, the Chesapeake Conservancy, a nonprofit organization, needed to produce one-meter-resolution land-cover maps covering the 100,000 square miles of the Chesapeake Bay watershed.

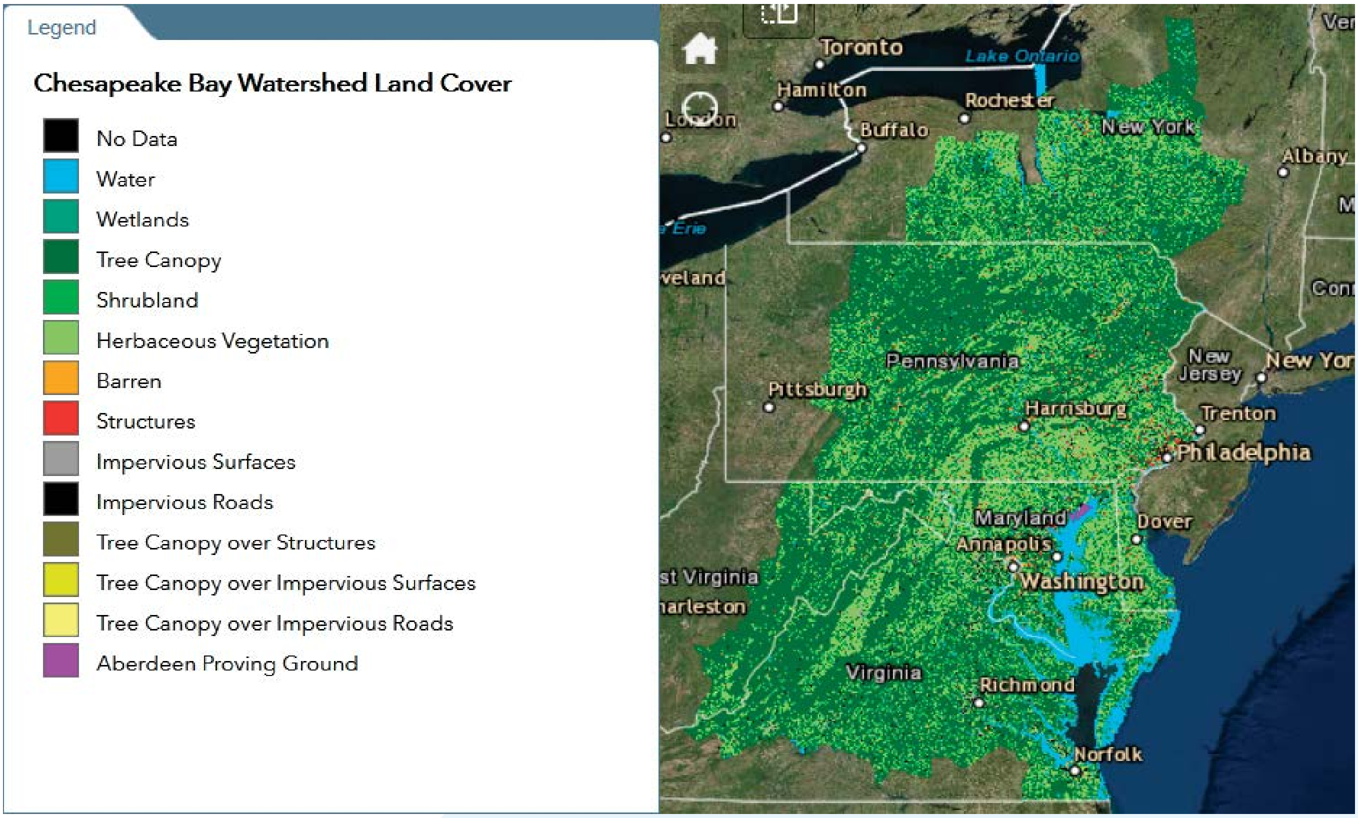
Working in partnership with the University of Vermont and WorldView Solutions, the Chesapeake Conservancy needed to process over 20 terabytes of raster data and categorize it into 12 land-cover types to produce this essential dataset. This monumental project was completed using local machine resources in 2016 after 10 months.

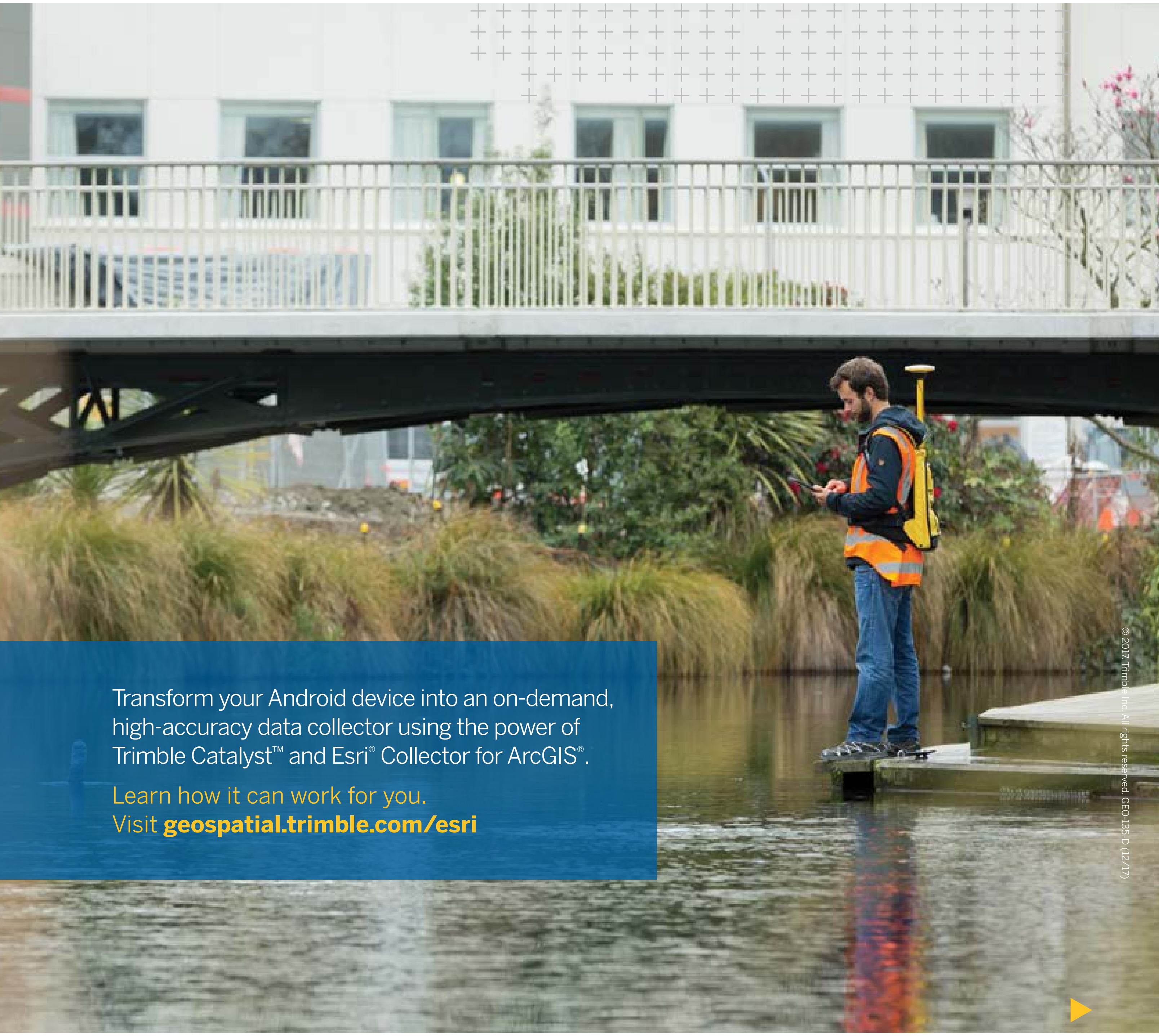
However, this land-use dataset needs to be updated frequently to account for the annual addition of 100,000 new residents, supporting infrastructure, services, and businesses. The costs in dollars and time to produce updates was too high using local machine resources. The Chesapeake Conservancy needed a way to quickly produce updates in a semiautomated manner.

The Chesapeake Conservancy is performing the land-cover updates using raster analytics in the cloud, a methodology that is more efficient and cost-effective. Processing chain templates built using ArcGIS Pro perform preprocessing, image segmentation, and random trees classification. The jobs are submitted from ArcGIS Pro to the portal, which manages the distributed processing, storage, and publication of results in the cloud.

Using raster analytics in the cloud, two terabytes of National Agriculture Imagery Program (NAIP) multispectral imagery are processed into the classification schema in 150 hours. Previously, using local machines, the same job took more than 2,500 hours—or three and a half months—to process. The Chesapeake Conservancy can accomplish updates in a timely and cost-effective manner, without having to spend resources to acquire, configure, and maintain a large computing and storage infrastructure locally.

↓ One-meter-resolution land-use map of the Chesapeake Watershed (Image courtesy of the Chesapeake Conservancy)





Mapping the Opportunity to Intervene Clearly

By Jim Herries, Esri Geographer

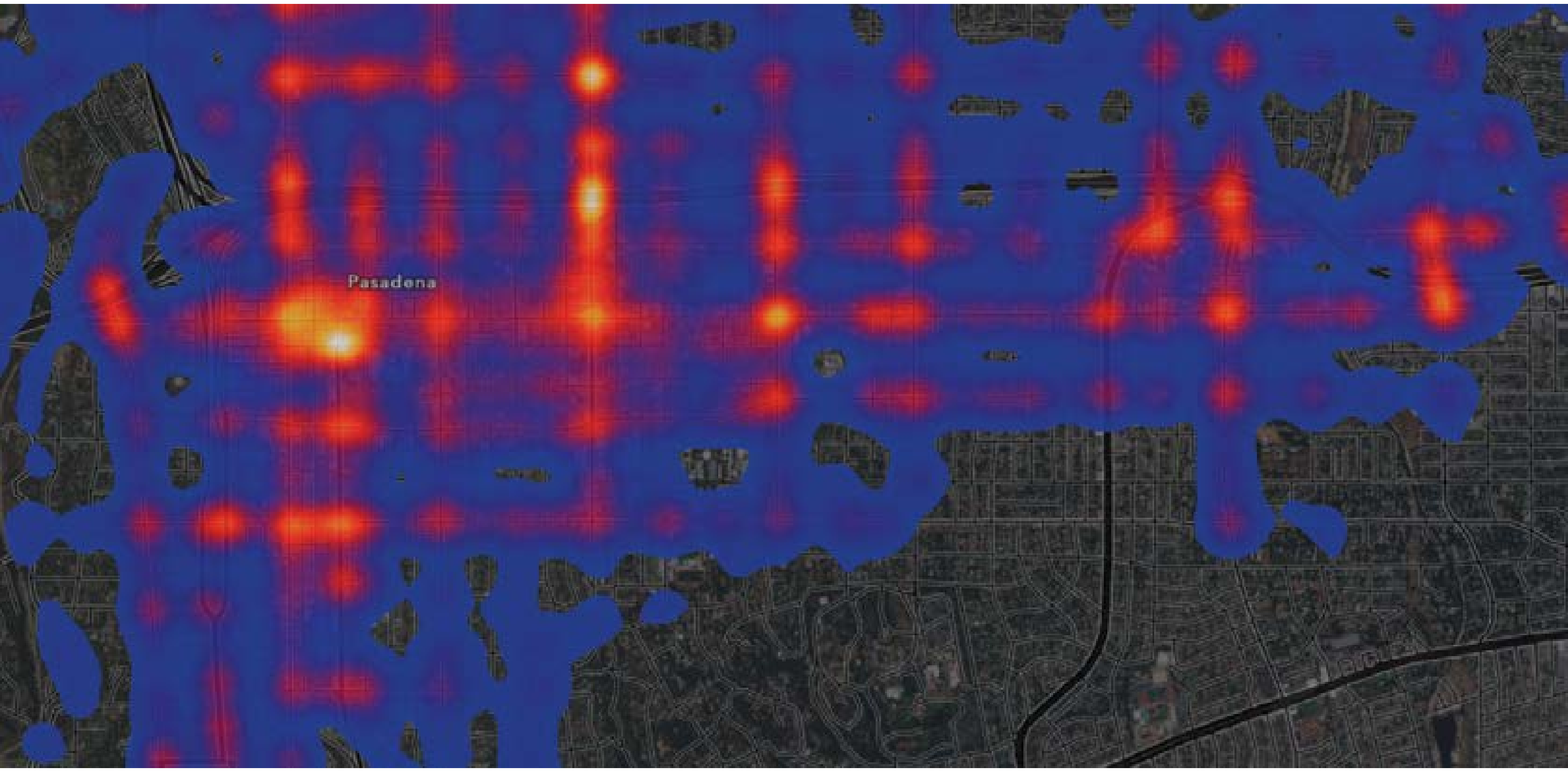
People craft policy to bring about change. If you are a GIS analyst or someone who manages or directs a team of mapping and GIS staff, you are in a unique position to deliver high-quality maps and information products in support of policy initiatives.

Mashing up some data onto a map is not a policy map. A map of 100,000 traffic accident locations in a year is eye-opening and may even show which intersections seem to have more accidents than others, but that is not a policy map. It's just a map of data.

It's a good start, though.

Putting some data on a map is always a good idea because it starts the process of thinking spatially. The first time data is shown on the map—if the map is any good—that process starts to raise questions about the nature of the data and any patterns that initially appear. The reality is that there may be many things contributing to the situation. Your job as a mapmaker or someone who directs

↓ Figure 1: A quick mashup of traffic accident locations



↑ Figure 2: The same traffic accident location data displayed as a heat map

the analysis of problems is to explore, analyze, and clearly present each contributing factor.

Steven Goldsmith, former mayor of Indianapolis and former deputy mayor of New York City, is a thought leader and a proponent of policy mapping. When I showed him a map of household incomes by neighborhood and asked him to explain the difference between my lovingly crafted map of incomes and a policy map, he summarized it nicely, "A policy map is a map where the opportunity to intervene is clear."

Whenever we think about policy maps, we keep that objective in mind: whatever the map's topic, make it clear where there is an opportunity to intervene. When we make policy maps, we do just three things:

- We portray a subject in a factual manner.
- We do this to reveal opportunities to intervene.
- We share any results or outcomes of ongoing interventions.

Over time, we have looked at why teams and projects fail to leverage mapping and GIS to support discussions on issues and policy making. In many cases, these teams had all the data they needed, but they didn't know how to map it, analyze it spatially, or fine-tune the map to show what's important.

Very often, a little more effort is all that is needed to articulate the geographic nature of the problem being addressed through policy as well as how well and where that policy is having an impact.

Where Do You Start?

The maps in figures 1, 2, and 3 all clearly show that more accidents occur near intersections. Mapping this data helps create awareness of the need for policy changes.

After seeing any of these maps, a policy maker would ask additional questions such as:

- What's a normal number of accidents?
- Do we have a problem, and is it with cars, bikes, or pedestrians?
- What is the effect of the infrastructure?
- What can we improve?

Normally, we start a policy map by mapping the issue that we're trying to address. But there are additional areas that are worth investigating and bringing into your spatial thinking when creating policy maps. Let's use the traffic accident example to walk through these areas.

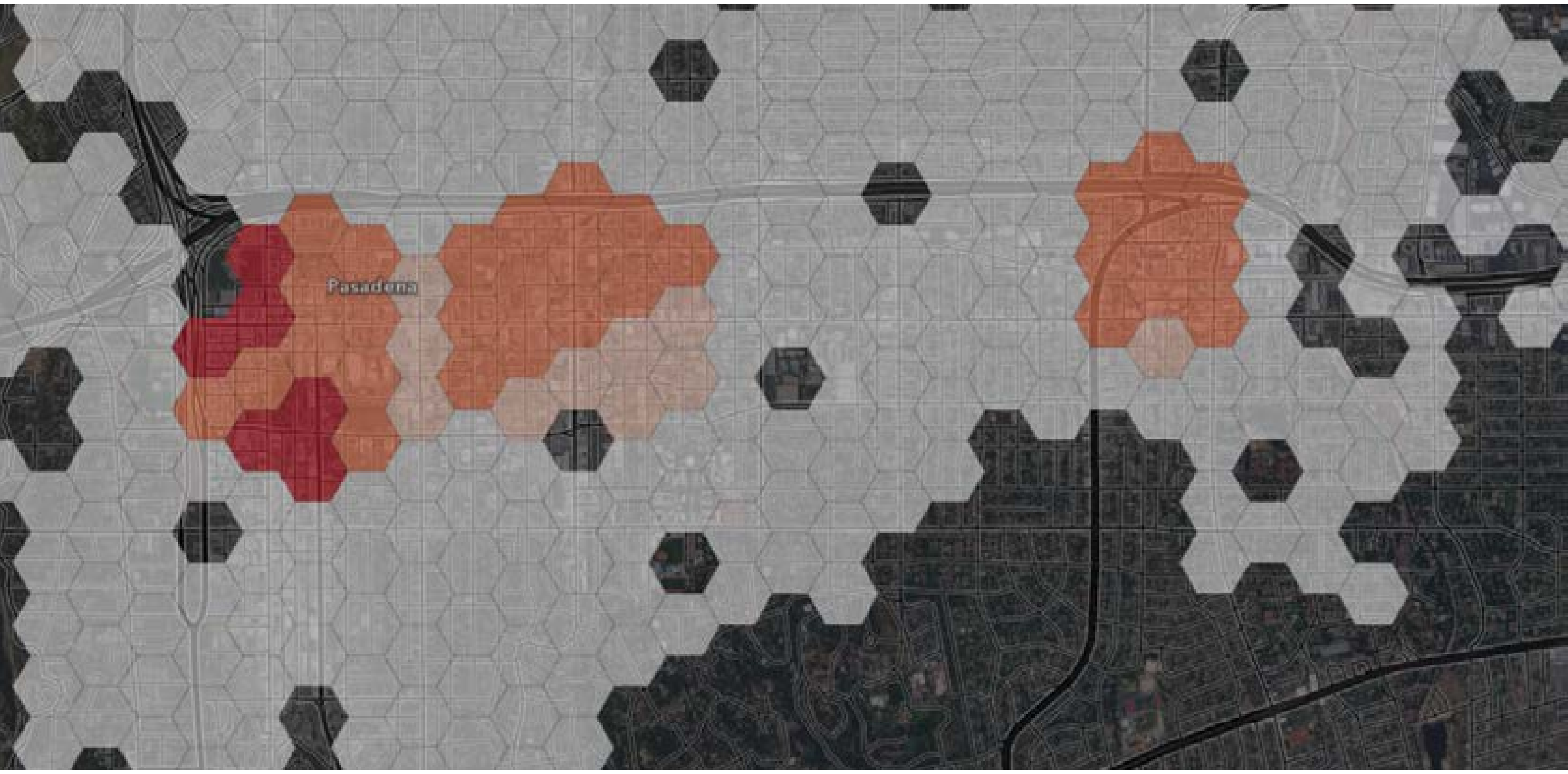
Consider the effects of unclear expectations. How many accidents are considered normal and how does this city, street, or intersection compare to that expectation? It's easier to set policy and measure success when expectations are understood or at least discussed.

Map the Symptoms

The visible symptoms of a problem are usually what get our attention first. A car accident is a very visible problem, so it's useful to see where all accidents for a specific time period have occurred.

The map in figure 1 is a quick mashup of accident locations. The map in figure 2 shows the same data as a heat map. In figure 3, the same data is mapped overlaying an artificial grid of hex bins and symbolizing by the number of accidents per hex bin. While these maps are fine for developing interest in the subject, none can inform policy making. Why is that?

These maps are not actionable. They don't establish a basis for comparison. With the heat and the hex bin maps, at the least we



↑ Figure 3: The same traffic accident location data shown again in a grid of hex bins

can clearly see the six areas with the highest concentration of accidents. When looking at either of these maps, it's natural to ask why.

Map a Meaningful Measure

Policy makers need good information to understand whether they are treating symptoms instead of treating the real problem. In addition to raw counts of problems, they need meaningful measures. How do you discover and apply more meaningful measures?

What's missing from the maps above is a sense of how many accidents occur relative to the number of cars driving each section of road. Without that type of measure, the increase in the number of accidents might simply be caused by an increase in the number of cars for a given month or year. Existing traffic safety policy may be performing well given that growth in traffic. The key is to understand what's expected, and create the map that depicts the right measures of the core problem (accidents per daily traffic volume in this case) so that any unexpected patterns will become apparent.

> "A policy map is a map where the opportunity to intervene is clear."
>
> Steven Goldsmith
> December 2015

The spatial component is the key to mapping the problem. The causes of accidents that occur in the middle of a lonely stretch of highway are likely to be different from the causes of accidents that occur at intersections. Although plotting the accident locations on the map makes the intersection accidents visible, an analyst can use GIS to take the next step. By selecting all accidents geocoded near an intersection (say, within 100 meters), those accidents can be categorized as intersection-related.

Why is this so important? Because factors related to location may have an effect. New York City found that bike-car incidents have a much higher likelihood of serious injury on streets with speed limits above 25 miles per hour. Locating incidents on a map with correct street speed limit attributes showed a serious injury pattern related to speed limits. With this information, street network and bike lane plans could be better evaluated.

Map the Enabling Infrastructure

Accidents involving cars, bikes, and pedestrians don't happen just anywhere. They happen on streets and other paths created and maintained by public and private organizations. This enabling infrastructure has characteristics that we can show on a map.

What is enabling infrastructure? In the case of the sinking of the *Titanic*, the ocean was the enabling infrastructure. The iceberg that caused the *Titanic* to sink floated on it, hiding most of the iceberg from view. *Titanic* was sunk, not by the visible problem above the water but by the hidden ice below the waterline.

There could be hidden causes of traffic accidents that are worth mapping and understanding. Weather is often a factor in accidents that might be overlooked. Many problems in our cities are made possible—or perhaps inevitable—by some enabling infrastructure. That could be poorly designed road intersections or railway and road intersections.

Some percentage of car accidents near schools happen as parents rush to get to and from the schools. The map in figure 4 shows the same accident location data in relation to school locations. Looking at these accidents from the perspective of a school principal or parent, these accidents are cause for alarm. Many occur within a short walk of schools and could perhaps suggest a policy initiative to drive that number down to zero, if possible.

People can make reasonable policy decisions only if they understand the enabling infrastructure involved. That infrastructure varies with the problem being addressed. It could be financial (low incomes or low mortgage rates on easy terms), structural (old bridges), or caused by human behavior (low voter turnout). Maps that provide context to policy decisions can be invaluable.

There's a lot of open data—data that can be freely used—that is ready for analysis and interpretation in a focused map to illuminate some part of the infrastructure in question. There are lots of ready-to-use maps that can be found in the ArcGIS Living Atlas of the World that can inspire your thinking. For example, in the map in figure 5, a set of transit stop locations were turned into a map that shows who that infrastructure serves with the addition of demographic information.

When you hear citizens or policy makers talking about an issue, listen for a discussion of the enabling infrastructure. Of course, they won't talk about it in that way—you have to listen for it.

Map the Hidden Causes

GIS is special. You can use it to map the data and analyze that data statistically and spatially to provide additional insights. You need a GIS—not just a mapping system—to understand the geographic component of the problem or its causes. GIS will help you understand what's going on and set realistic goals that policy can help achieve.

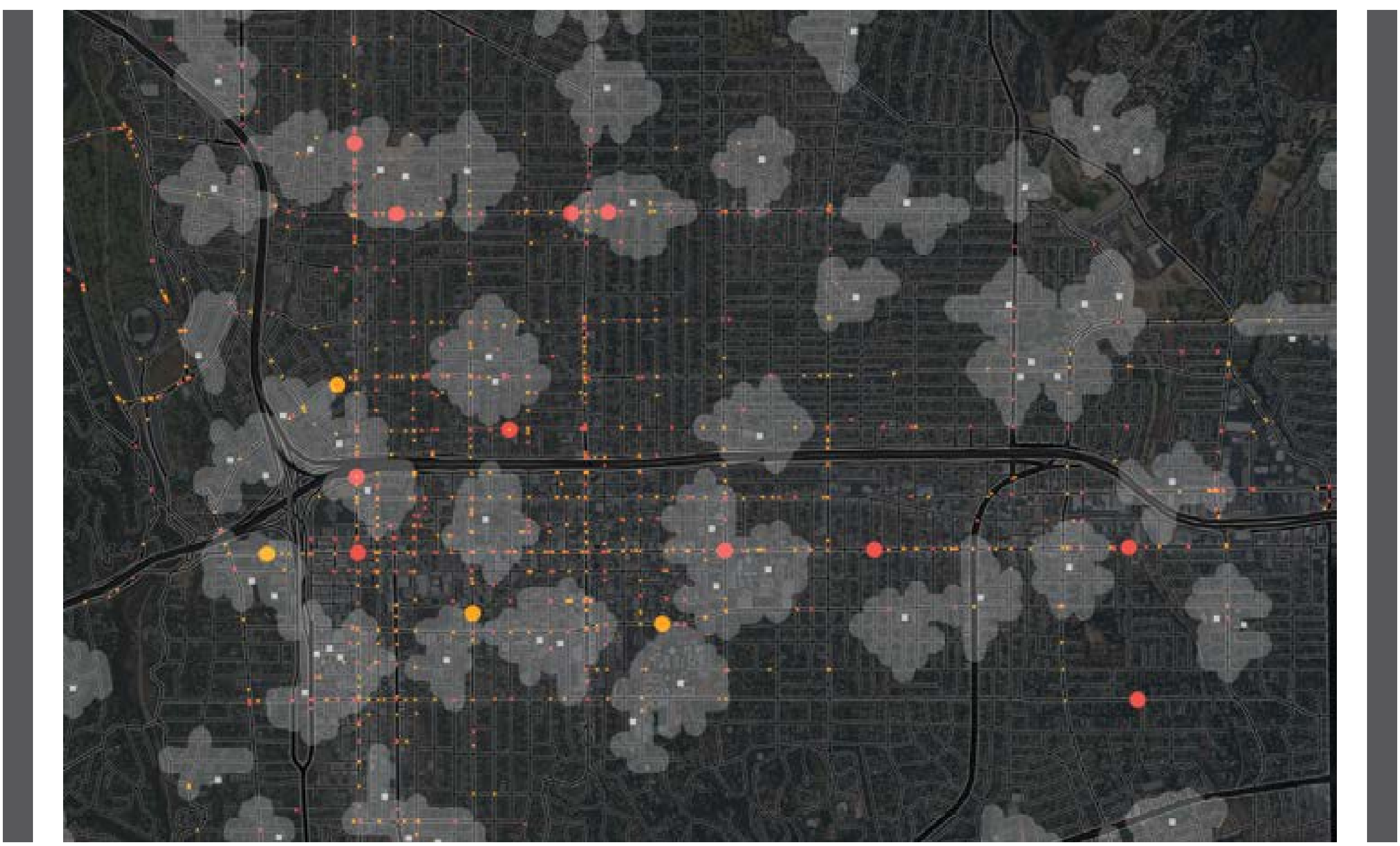
In our example, once the map begins to suggest that intersections are more problematic in your city than normal or as compared to other cities, some root causes may suggest themselves, especially once you show that map to local traffic engineers and other city employees.

These people are subject matter experts who are likely to be good at identifying hidden causes and perhaps hidden solutions. Questions will naturally arise when these people see the right maps. What's different about your city's traffic control around intersections? Do the streets align to the setting sun? Do accidents increase during the weeks when the sun is blinding drivers at a certain time of day? If that is the case, showing those intersections on the map with their accident rates and counts will drive the message home.

Map the Resistance

There are always reasons not to change—the budget, the schedule, a lack of support for change, and the ever-popular "We've always done it this way." When significant resistance is a factor, it's useful

↓ Figure 4: This map shows the same data and the car accidents that happened near schools as parents rushed to get to and from the schools.



to map that resistance.

Natural phenomena often resist man-made infrastructure and policy. Think about how recent floods and hurricanes disregarded the belief or disbelief local populations had in climate change. Water went where terrain and gravity said it could go.

Economic resistance is also real. Injections of capital require a long-term perspective. Every national retailer understands this when siting a new store or closing an existing one. Policies that aim to stimulate local economies need to reflect an understanding of existing economic conditions.

People can be resistant to change. Sometimes it's worth mapping who stands to gain and lose from a change in policy, as shown in figure 5, which reveals who will benefit from the locations of public transit lines. If nothing else, this will help you evaluate how the proposed change will affect people and businesses and perhaps give you an opportunity to find better solutions.

Map the Expectations

Whether expectations are unclear or clearly stated, it's important to map them. Good policy maps clarify expectations and track progress toward them. Doing the up-front work to move beyond mapping incidents and defining and mapping meaningful measures pay off when you can articulate a policy strategy and track progress toward stated goals.

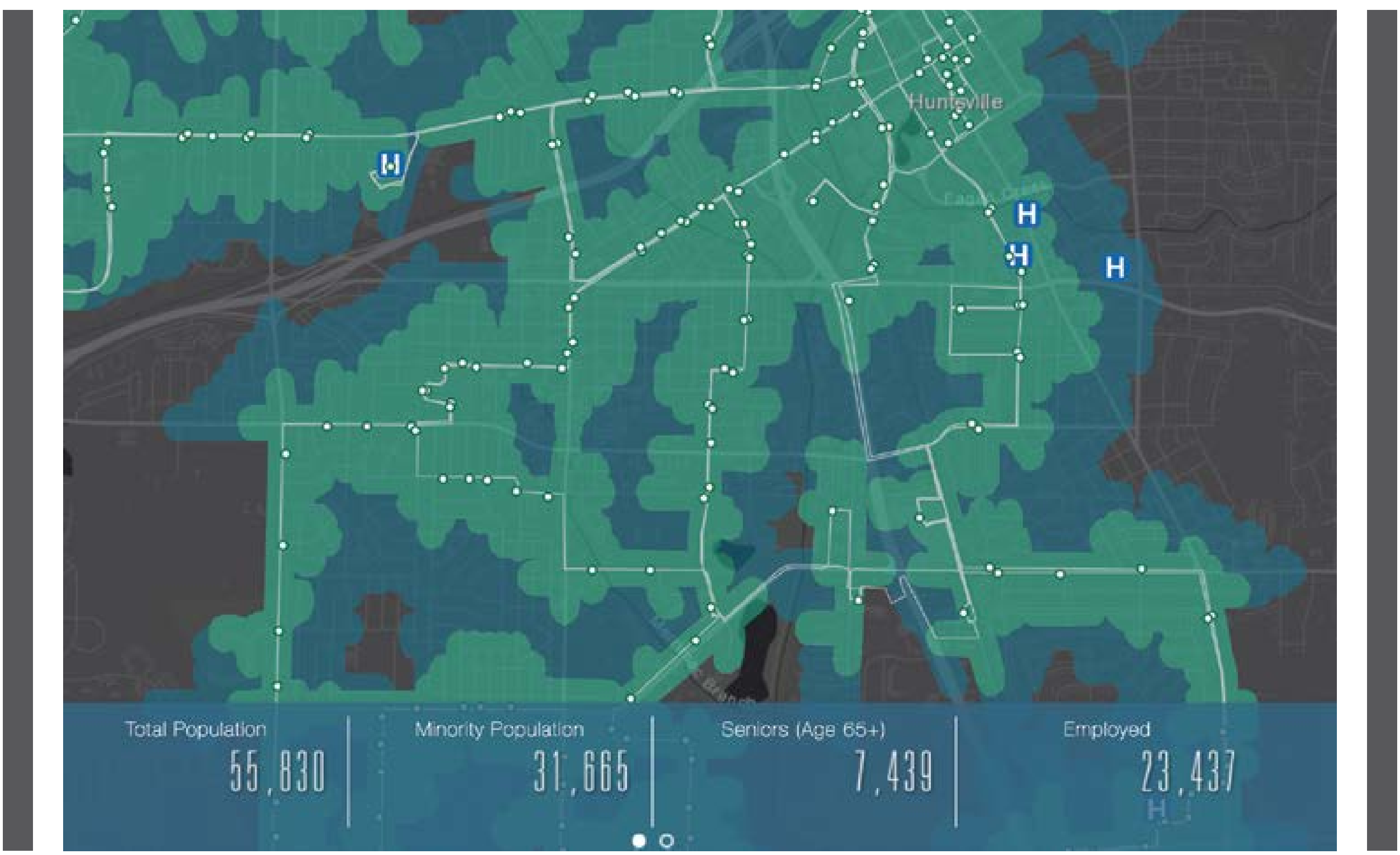
The Clean Streets LA initiative by the City of Los Angeles took the broad objective of having cleaner streets and mapped not only the initial evaluation of every Los Angeles street but also the latest updates, as shown in figure 6. This collaborative work involves citizens, city employees, and policy makers who are all invested in clarifying expectations and being accountable for progress.

What You Need for Policy Mapping

Whenever we walk through the policy-making process with someone, they are always happy to discover that they already have almost everything they need to start. They already have some issues they are interested in mapping and may have the data. When they map the symptoms of the issue, they start to see things on the map that raise questions. As they track those questions, they show the maps to subject matter experts within their organization, other stakeholders, and—at some point—the public. More questions arise. They begin thinking about the enabling infrastructure and its contribution to all or some of the symptoms. Spatial analysis often reveals significant variation, but it's just as useful to learn there is no spatial variation, if that is the case.

As root causes and hidden causes emerge, so does the opportunity to shape policy to target specific concerns. For area-wide concerns, such as clean streets, this is a chance to communicate how the work will proceed and ensure there will be equity in response to problems. Where resistance exists, the map can inform strategies on how to handle that effectively.

↓ Figure 5: Mapping transit stop locations with demographic data creates a map that shows who is served by the transit system.



Every policy with stated goals benefits from tracking progress toward those goals. Successes are valuable, and failures are warning signs that perhaps the problem was not as well understood as thought. All work done to understand and articulate the relevant issues should culminate in maps that track progress toward stated goals.

About the Author

As a geographer at Esri, **Jim Herries** makes maps every day. He works with customers and Esri software developers to identify pain points in the mapmaking process and eliminate them. He listens for map ideas when he talks to people about their data, the problem they are trying to solve, and the analysis they believe will help them solve it. Herries received a bachelor's degree in journalism from Lindenwood College in St. Louis, Missouri, and received a master's degree in geography from Ohio State University as a student of Dr. Duane Marble.

→ Figure 6: The Clean Streets LA initiative by the City of Los Angeles mapped not only the initial evaluation of every Los Angeles street but also the latest updates.

Test Georeferencing Transformations

By Mike Price, Entrada/San Juan, Inc.

What you will need

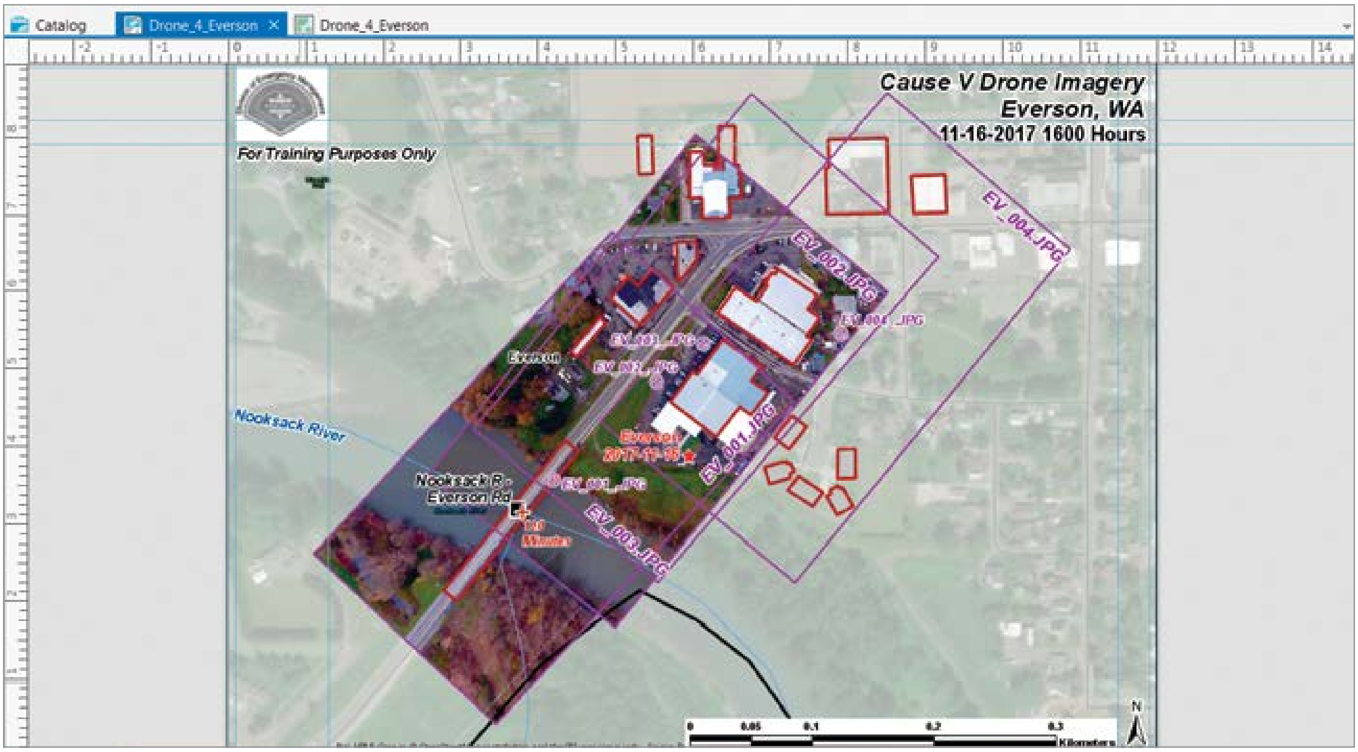
- ArcGIS Pro 2.1 license
- ArcGIS Online for organizations account
- Sample dataset downloaded from *ArcUser* website
- An unzipping utility

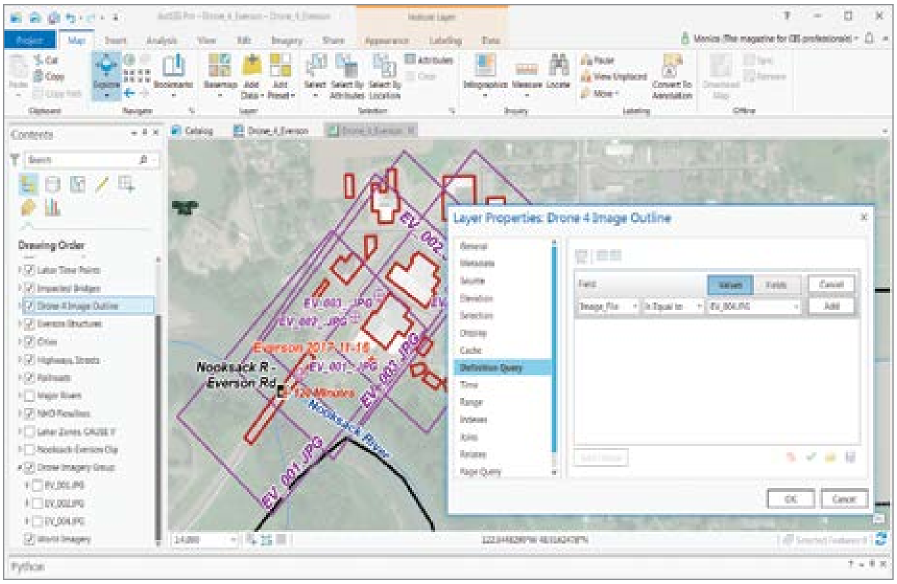
This exercise continues to explore georeferencing in ArcGIS Pro. The previous exercise, "Georeferencing Drone-Captured Imagery," in the Winter 2018 issue of *ArcUser* showed a simple imagery georeferencing workflow that imported an MXD document into ArcGIS Pro. In that exercise, two images were georeferenced by interactively connecting the ground control targets on the raster with vector control points.

This exercise shows how to georeference an image by importing a file containing 29 carefully surveyed ground control points into ArcGIS Pro. The number of well-distributed control points will let you explore the effects of all transformations available in ArcGIS Pro.

The current and previous exercises use drone imagery that was captured in November 2017 during the Canada-United States Enhanced Resiliency Experiment (CAUSE V), which was conducted along the Washington-British Columbia border. The drone imagery used in this exercise is part of a large imagery

↓ Open the Drone_4_Everson.aprx file, which should show the two images that were georeferenced in the previous exercise.





← Create the query definition "Image_File is Equal to EV_004." Once it is applied, you should see only the image outline for EV_004.

dataset captured along the Nooksack River and in the town of Everson, Washington, by TacSat Networks of Garden City, Idaho.

For more information about CAUSE V and an overview of georeferencing fundamentals, read "Georeferencing Drone-Captured Imagery" in the Winter 2018 issue of *ArcUser* magazine.

Getting Started

Begin by downloading and unzipping the sample dataset for this exercise from the *ArcUser* website (esri.com/arcuser) to a local drive. Note that folders are organized and named to separate the imagery captured by individual drones in specific project areas during the CAUSE V drill. When you are georeferencing your own drone images, consider creating a similar file structure and naming convention.

Start ArcGIS Pro, navigate to the Cause_V_controlpts_4/Drone_4_Everson folder, and open the Drone_4_Everson.aprx file. Make sure the map is in layout mode. It should show the two images that were georeferenced in the previous exercise, "Georeferencing Drone-Captured Imagery," which is available online in the winter 2018 issue of *ArcUser*.

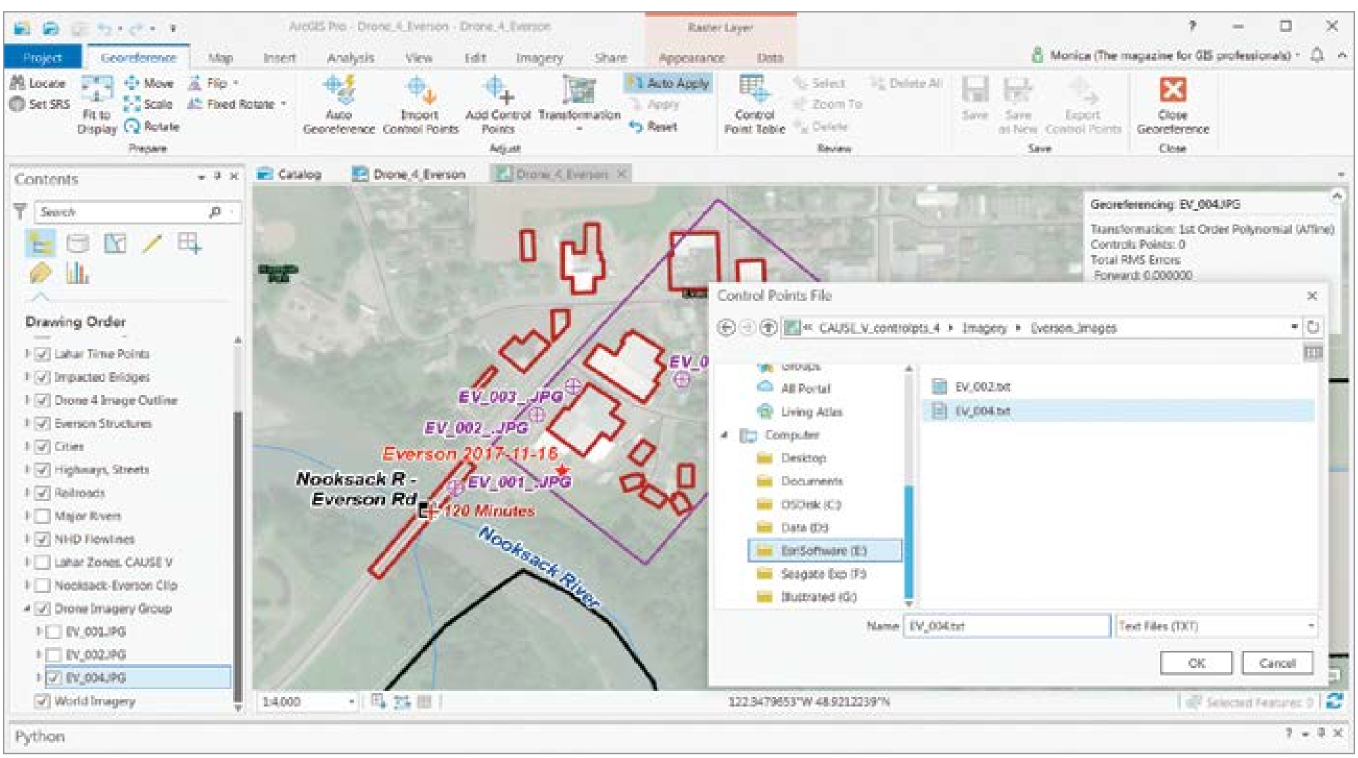
Carefully study the image outlines shown in the Drone 4 Image Outline layer. In this exercise, ground survey control points that have been saved to a text file will be imported to georeference the EV_004 image.

Adding the EV_004 Image

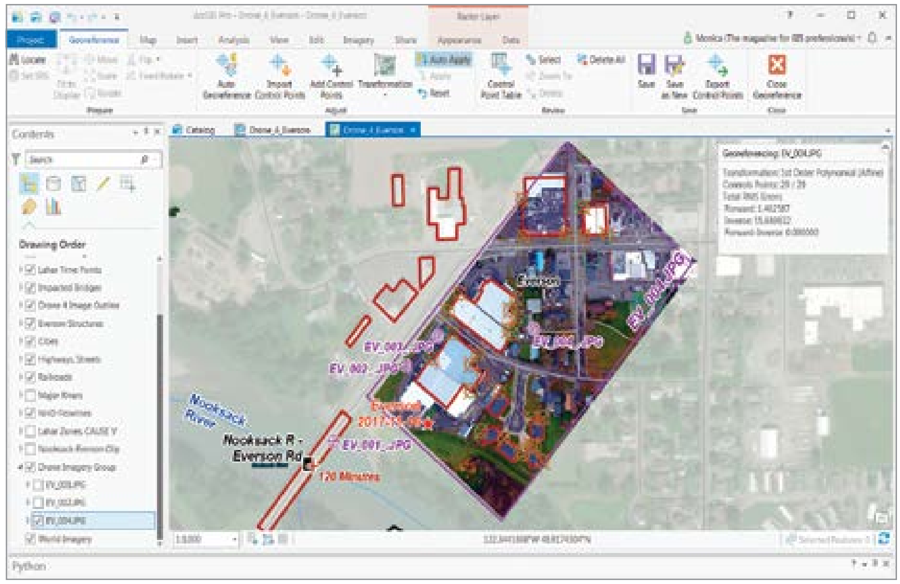
Switch to the Drone_4_Everson Map frame, click Add Data, and navigate to \CAUSE_V_Drone_4\Imagery\Everson_Images\. Select EV_004.JPG and click OK.

Once the image is loaded, place it

↓ Click the Imagery tab, click the Georeference button to open the Georeference ribbon, and click Import Control Points. Navigate to \CAUSE_V_Drone_4\Imagery\Everson_Images\ and select EV_004.txt.



→ Once the EV_004.txt file containing control points is applied, the EV_004 image immediately appears inside the Drone 4 Image Outline.



immediately below the EV_001 and EV_002 layers in the Contents pane. Reorder image layers so they are in numerical order from 001 to 004. Select all three images, right-click, and add them to a new group and rename it Drone Imagery Group. Turn off all image layers. Save the map.

In the Contents pane, right-click Drone 4 Image Outline, select Properties, and open the Definition Query wizard. Create the query Image_File is Equal to EV_004 using either the drop-down selector or the SQL window. Once this definition query is applied, you should see only the image outline for EV_004.

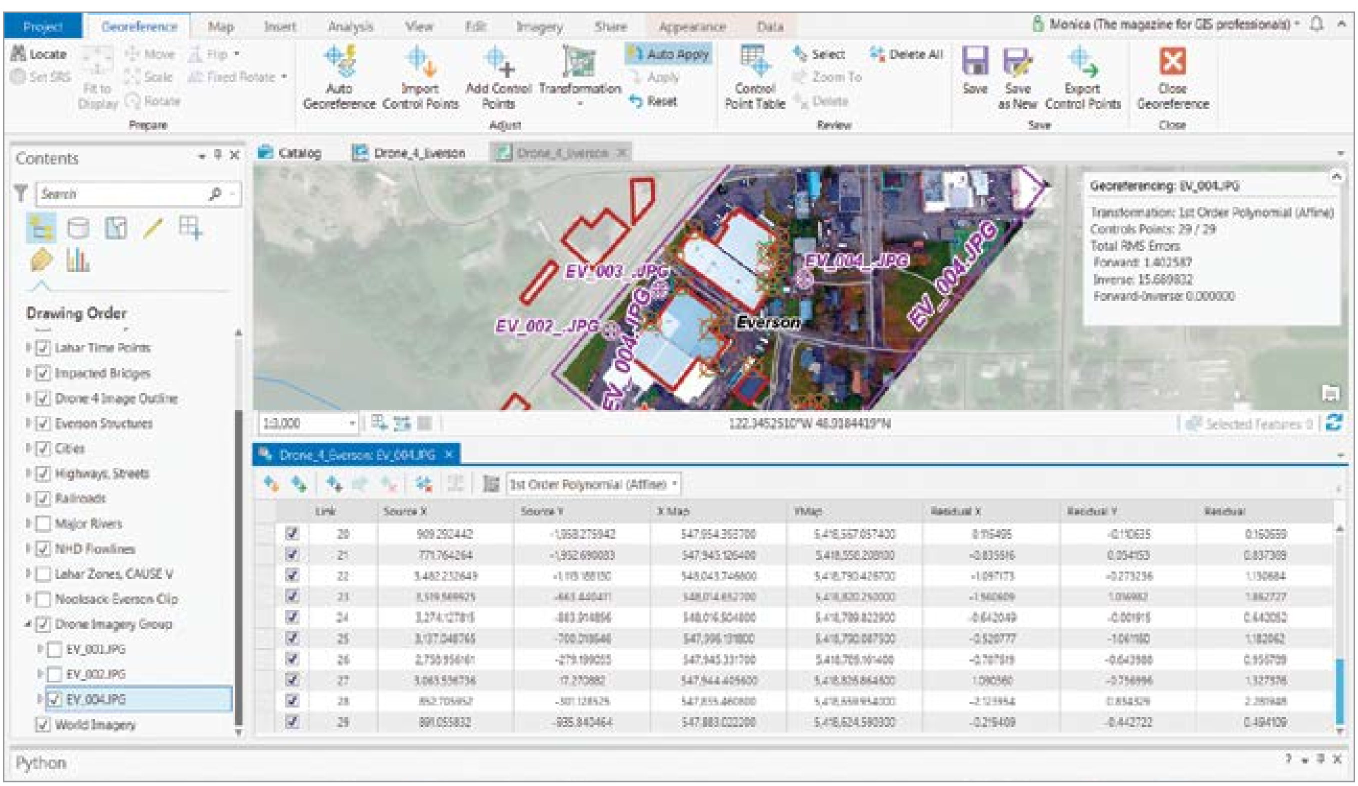
Instead of interactively georeferencing the image as taught in the previous exercise, this exercise will georeference EV_004 by importing control points from a text file located in the Everson_Images folder.

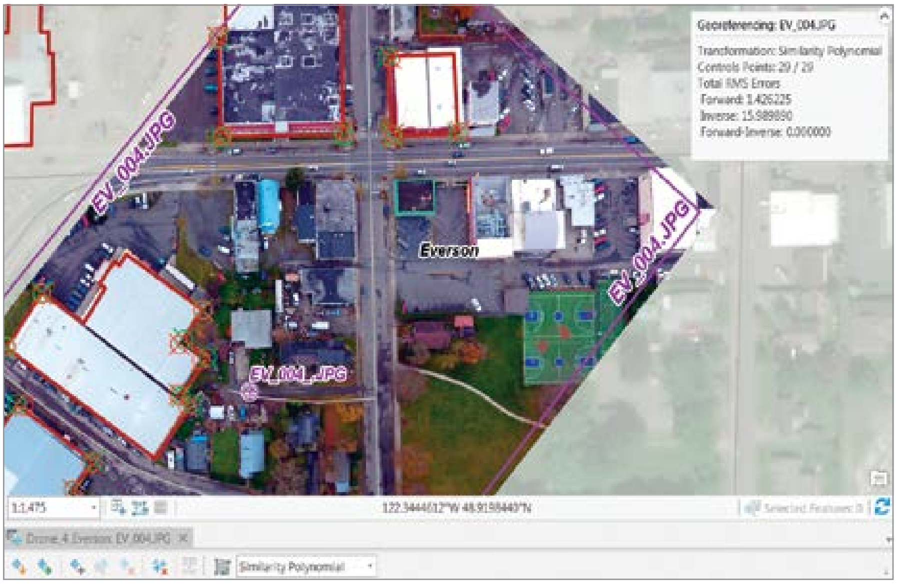
Importing a Control Points File

In the Contents pane, turn on the EV_004 image and select it. Click the Imagery tab, click the Georeference button to open the Georeference ribbon, and click Import Control Points. Navigate to \CAUSE_V_Drone_4\Imagery\Everson_Images\ and select EV_004.txt. Click OK. The EV_004 image immediately appears inside the Drone 4 Image Outline.

Study the green control point target symbols in relation to red targets on the image. These symbolized and labeled survey points represent actual locations of red crosses at ground level. The survey control for the image is positioned at ground level

↓ On the Georeference ribbon, click Control Point Table to open the table showing all the imported control points. Note the transformation drop-down, which shows the default transformation as 1st-Order Polynomial (Affine).





← The Similarity Polygon, a first-order transformation, tries to preserve the shape of the original raster, so the overall rectangular shape is preserved but the internal error is typically higher.

on the highway surface and *at ground corners—not rooftops*—on the image. Because this image was taken at a low elevation, buildings lean away from the center of the image, so only some ground-level corners are visible and rooftop corners are distorted. Save the project.

Testing Transformations

With 29 well-distributed control points for the EV_004 image just imported, all ArcGIS Pro transformation methods can be tried. On the Georeference ribbon, click Control Point Table to open it. This table shows all the imported control points. The default transformation of first-order polynomial (affine) is shown in the drop-down on the table frame. This drop-down will be used to apply the other available transformations. For more on transformations and how they affect georeferencing, read the accompanying article, "Understanding Raster Georeferencing."

Locate and open the Transformation drop-down and study the available transformation methods. The next section of this exercise explores each transformation method (except zero-order polynomial) by selecting each transformation from this drop-down. Adjust the size of the control points table and zoom out to an extent that enables you to see the EV_004 image and Drone 4 Image Outline to observe the effect of each transformation. You can zoom in to the red and green targets to see how they line up as each transformation is applied.

Do not close the Georeferencing information box, located in the upper right of the map area. Initially it lists measurements for the default transformation, first-order polynomial. This box provides a running count of control points and total RMS errors.

As you apply the different transformations available in ArcGIS Pro, note the effect on measurements listed under total RMS errors. Forward shows errors in the same units as the data frame's spatial reference. Inverse shows errors in pixel units. Forward-Inverse is a measure of how close accuracy is, measured in pixels. All residuals closer to zero are considered more accurate. RMS error is a good assessment of a transformation's accuracy, but a low RMS error does not necessarily mean an accurate registration. A transformation may still contain significant errors caused by a poorly entered control point. Study the Georeferencing window to review the RMS error for each transformation.

Select Similarity Polynomial

The Similarity Polynomial, a first-order transformation, requires a minimum of three points. It tries to preserve the shape of the original raster, so the overall rectangular shape of EV_004 is preserved but the internal error is typically higher than other polynomial transformations since the preservation of shape is more important than the best fit. The Forward-Inverse Error is zero.

Select the First-Order Transformation (Affine)

Also called an affine transformation, the first-order transformation simply shifts, rescales, and moves the image. In the early CAD world, this was called "rotate, scale, and move." If more than three points are used, the error typically increases, although the overall transformation may improve, especially if many accurate points outweigh one or two poorly placed points. Forward-Inverse error is typically zero. The fit within the image frame is slightly rotated.

Select the Second-Order Transformation

This transformation requires six points. It applies a simple quadratic formula (x-squared) to calculate raster cell position. This transformation usually produces a better fit within the image frame and lower Forward and Inverse scores. The image is warped within and near the control points, and the corners match the polygon frame rather well.

Select the Third-Order Transformation

This transformation requires at least 10 points and uses a more complex x-cubed formula. Fit within and around well-placed points is generally very good. However, the raster may be excessively warped along margins. Forward and Inverse scores are typically similar to second order values. Forward-Inverse often appears higher because of excessive edge warp.

Select the Adjust Transformation

Requiring at least three points, this transformation is optimized for both global least-squares fitting (LSF) and local accuracy. It combines a polynomial transformation with a triangulated irregular network (TIN) interpolation. The Adjust transformation performs a polynomial transformation using two sets of control points and adjusts the control points locally to better match the target control points using a TIN interpolation technique.

Select the Projective Transformation

The Projective transformation can warp lines so that they remain straight, so lines that were once parallel may not remain parallel. This transformation is especially useful for oblique imagery, scanned maps, and some imagery products such as Landsat and DigitalGlobe. A minimum of four links are required to perform a Projective transformation. When only four links are used, the RMS error will be zero. When more points are used, the RMS error will be slightly above zero.

Select the Spline Transformation

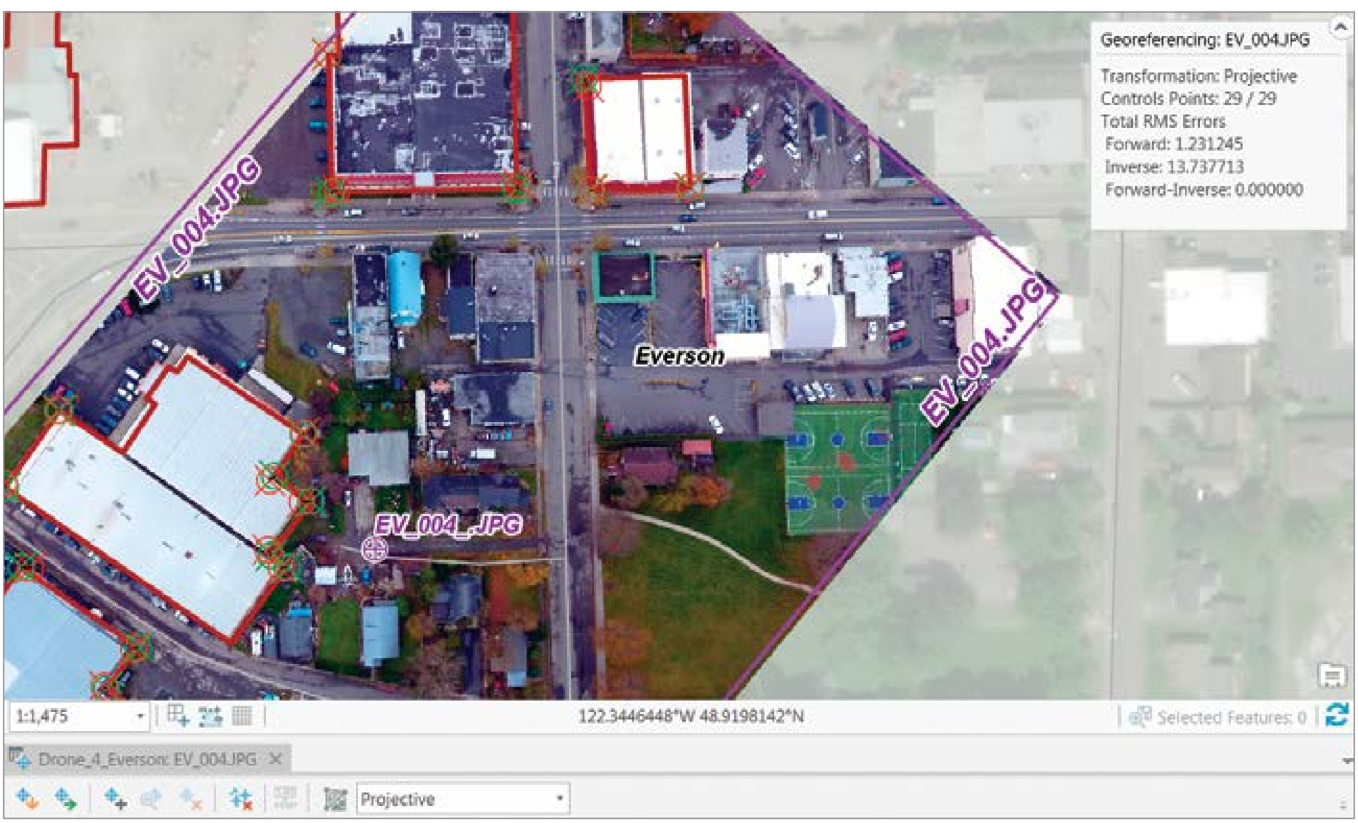
Spline transformation is a true rubber sheeting method that is optimized for local but not global accuracy. It is based on a spline function, a piecewise polynomial that maintains continuity and smoothness between adjacent polynomials. Spline transforms the source control points exactly to target control points, so error is minimal. Pixels that are a distance from the control points are not guaranteed to be accurate. This transformation is useful when the control points are important, so those control points must be registered precisely. A spline transformation requires a minimum of 10 points.

Now that you have seen the effect different transformations have on georeferencing, click Close Georeference to complete this exercise and save the project. You may export the map as a PDF or another graphic file as described in the previous exercise using the transformation you like best.

Congratulations, this exercise is complete!

← The Adjust transformation is optimized for both global least-squares fitting (LSF) and local accuracy.

↓ The Projective transformation can warp lines so they appear straight, making it especially useful for oblique imagery, scanned projected maps, and large rasters.



↑ Spline transformation is a true rubber sheeting method that is optimized for local, but not global, accuracy. It works best with numerous distributed, carefully placed points.

How to Save Georeferencing Information

You can save georeferencing information using one of the options in the Save group on the Georeference ribbon. However, note that these options—Save, Save As New, and Export Control Points—produce different results. The one you choose will depend on what you want to do with the raster.

Save stores the transformation information in separate files using the root name of the image. The type of auxiliary files depends on the original raster format and the selected transformation type. Save does not resample the source raster.

Save As New creates a new raster dataset georeferenced using the map coordinates and spatial reference. You may want to use Save As New if you will be using the raster with software that does not recognize an Esri world file.

Export Control Points creates a file containing control point information. Use it to create or update control information for use with an imported raster in the future, as a backup, or to share control points for the raster with another user.

To summarize, you will most often use Save to update the source raster's control points and transformation, but use Export Control Points to save the control points to a text file.

Summary

In this exercise, you applied many well-distributed control points that were saved in a text file to georeference an image. You studied the effects of various transformations available in ArcGIS Pro and know how to save georeferencing information with the raster or as control points in a text file for reuse.

Acknowledgments

Again, thanks to the CAUSE V team for giving me the opportunity to participate in this fine exercise. I especially thank Whatcom County Emergency Management and Sheriff's Office in Washington for all their support. Special thanks to TacSat Network Corporation for providing the drones, operators, and communications.

Understanding Raster Georeferencing

You will usually georeference raster data using existing spatial data (target data), such as georeferenced rasters or a vector feature class that resides in the desired map coordinate system. The process involves identifying a series of ground control points—known as *x,y* coordinates—that link locations on the raster dataset with locations in the spatially referenced data.

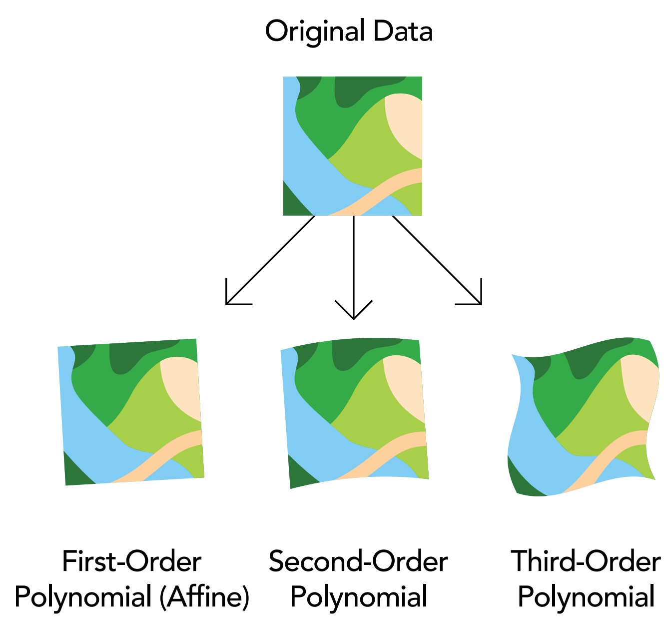
Control points are locations that can be accurately identified on the raster dataset and in real-world coordinates. Many different types of features can be used as identifiable locations such as road or stream intersections, the mouth of a stream, or corner of an established field. The control points are used in conjunction with the transformation to shift and warp the raster dataset from its existing location to the spatially correct location. The connection between one control point on the raster dataset (the *from* point) and the corresponding control point on the aligned target data (the *to* point) is a control point pair.

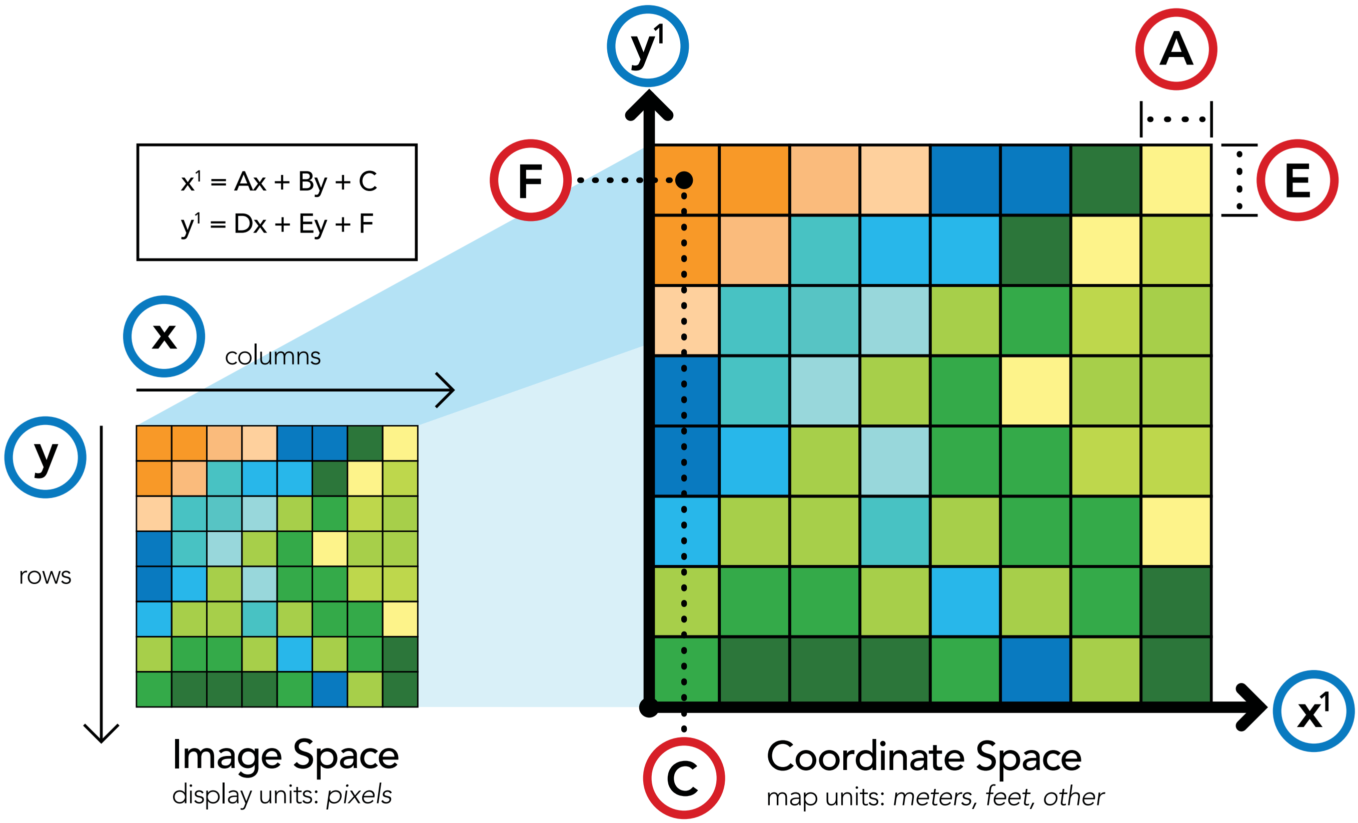
The number of links you need to create depends on the complexity of the transformation you plan to use to transform the raster dataset to map coordinates. However, adding more links will not necessarily yield a better registration. If possible, you should spread the links over the entire raster dataset rather than concentrate them in one area. Typically, having at least one link near each corner of the raster dataset and a few throughout the interior produces the best results.

Generally, the greater the overlap between the raster dataset and target data, the better the resulting alignment, because you'll have more widely spaced points with which to georeference the raster dataset. For example, if your target data only occupies one-quarter of the area of your raster dataset, the points you could use to align the raster dataset would be confined to that area of overlap. Thus, the areas outside the overlapped area are not likely to be properly aligned. Keep in mind that your georeferenced data is only as accurate as the data to which it is aligned. To minimize errors, you should georeference to data that is at the highest resolution and largest scale that is appropriate for your application needs.

When you've created enough control points, you can transform the raster dataset to the map coordinates of the target data. Depending on the number of control points, you can use one of several types of transformations available in ArcGIS Pro to determine the correct map coordinate location for each cell in the raster.

Polynomial transformations use a polynomial built on control points and a least-squares fitting (LSF) algorithm. These transformations are optimized for global accuracy but do not guarantee local accuracy. Polynomial transformations yield two formulas: one for computing the output *x*-coordinate for an input (*x,y*) location and one for computing the *y*-coordinate for an input (*x,y*) location. The goal of the LSF algorithm is to derive a general formula that can be applied to all points, usually at the expense of slight movement of the two positions of the control points. The number of the noncorrelated control points required for this method must be one for a zero-order shift, three for a first-order, six for a second order, and ten for a third order. The lower-order polynomials tend to give a random type error, while higher-order polynomials tend to give an extrapolation error.





x is the column count in image space.
y is the row count in image space.
x^1 is the horizontal value in coordinate space.
y^1 is the vertical value in coordinate space.

A is the width of the cell in map units.
B is a rotation term.
C is the x^1 value of the center of the upper-left cell.
D is a rotation term.
E is the negative height of the cell in map units.
F is the y^1 value of the center of the upper-left cell.

A zero-order polynomial is used to shift your data. This is commonly used when your data is already georeferenced, but a small shift will better line up your data. Only one control point is required to perform a zero-order polynomial shift. It may be a good idea to create a few control points, then choose the one that looks the most accurate.

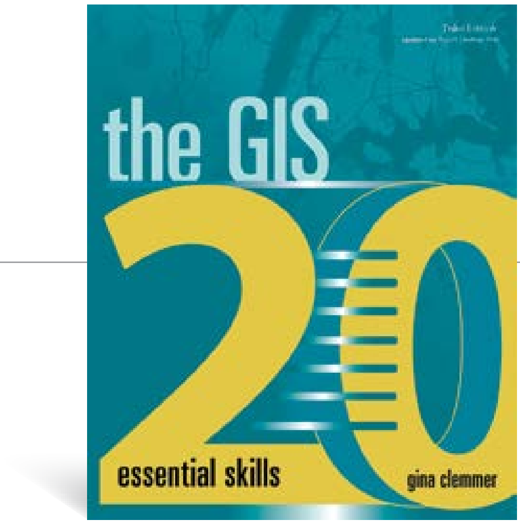
The first-order polynomial transformation is commonly used to georeference an image. Use a first-order, or affine, transformation to shift, scale, and rotate a raster dataset. This generally results in straight lines on the raster dataset mapped as straight lines in the warped raster dataset. Thus, squares and rectangles on the raster dataset are commonly changed into parallelograms of arbitrary scaling and angle orientation.

With a minimum of three control points, the mathematical equation used with a first-order transformation can exactly map each raster point to the target location. Any more than three control points introduces errors (or residuals) that are distributed throughout all the control points. However, you should add more than three control points, because if one control is inaccurate, it has a much greater impact on the transformation. Thus, even though the mathematical transformation error may increase as you create more links, the overall accuracy of the transformation will increase.

The higher the transformation order, the more complex the distortion that can be corrected, but transformations higher than third order are rarely needed. Higher-order transformations require more links and will involve progressively more processing time. In general, if the raster needs to be stretched, scaled, and rotated, use a first-order transformation. If the raster dataset must be bent or curved, use a second- or third-order transformation.

A Quick Start Guide to Mapping with GIS

By Gina Clemmer



The GIS 20: Essential Skills, Third Edition, helps those who are new to GIS or unfamiliar with it to quickly learn how to perform the basic GIS tasks of mapping, thematic mapping, and geocoding.

The author, Gina Clemmer, has been teaching these basic skills for two decades to students of all ages and backgrounds. The 20 lessons in this book are based on her experience. The result is a book that avoids using jargon and employs a project-based approach. "This book is an extension of my passion to help everyday people quickly learn the fundamentals of ArcGIS," Clemmer wrote in the preface. "Once you see the power of GIS and see that you yourself can create maps easily, you simply can't unsee it. GIS will change the way you think about presenting data and solving problems."

She avoids discussions of the inner workings of GIS and focuses on providing clear, step-by-step instructions on how to perform the most commonly used tasks and functions such as downloading shapefiles and using essential tools in the software, preparing data for a map, geocoding addresses, making thematic and other types of maps, mapping latitude and longitude points collected with a GPS, using aerial photography in maps, and publishing maps.

Clemmer is the president of New Urban Research, Inc., a social research and training company based in Portland, Oregon. She has spent her career teaching GIS to anyone and everyone from New York City executives to the inhabitants of Alaska fishing villages so they can use GIS for making better decisions.

The GIS 20: Essential Skills is available in print (ISBN: 9781589485129) and as an e-book (ISBN: 9781589485136) from Esri Press (esri.com/esripress) or online retailers.

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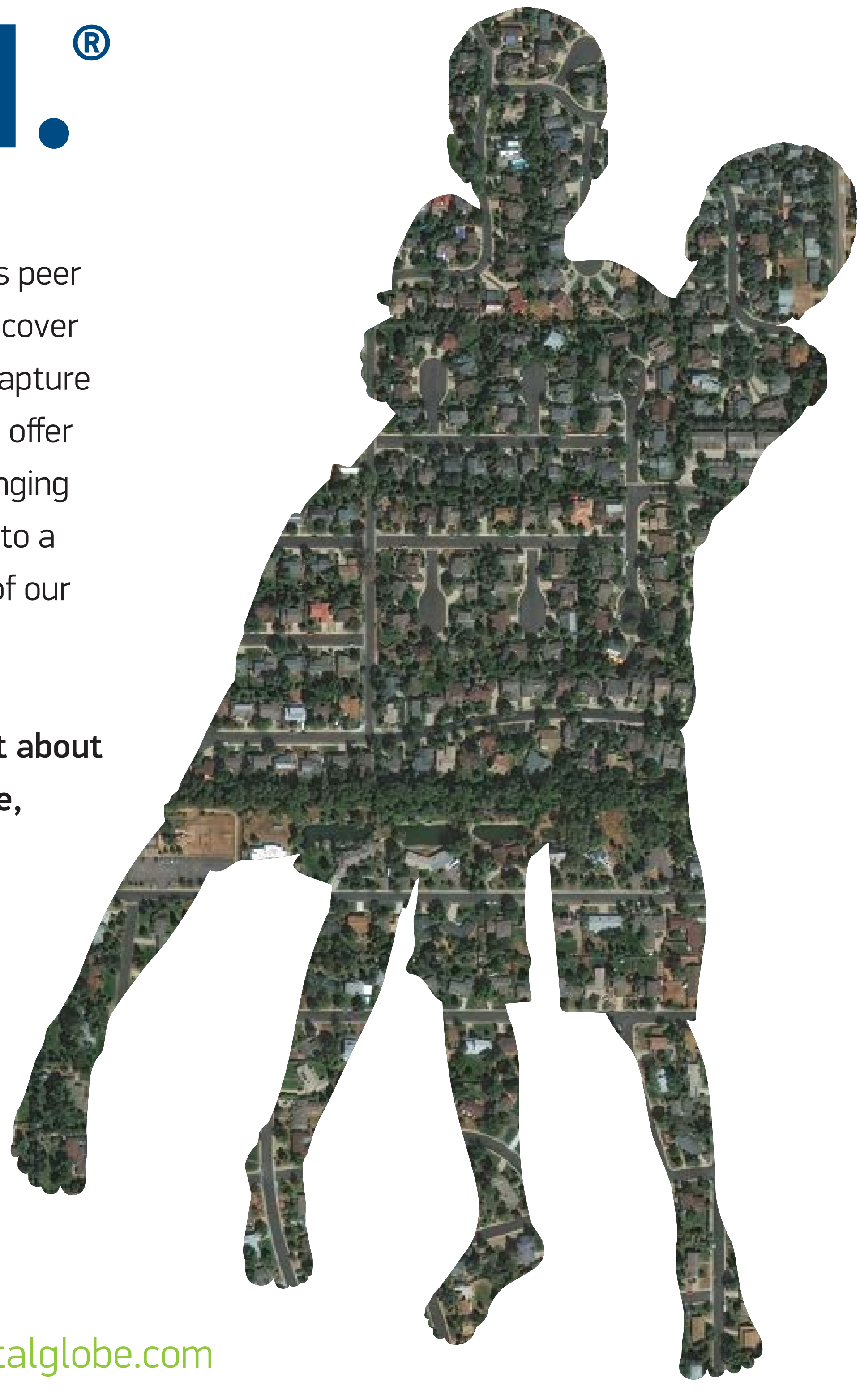

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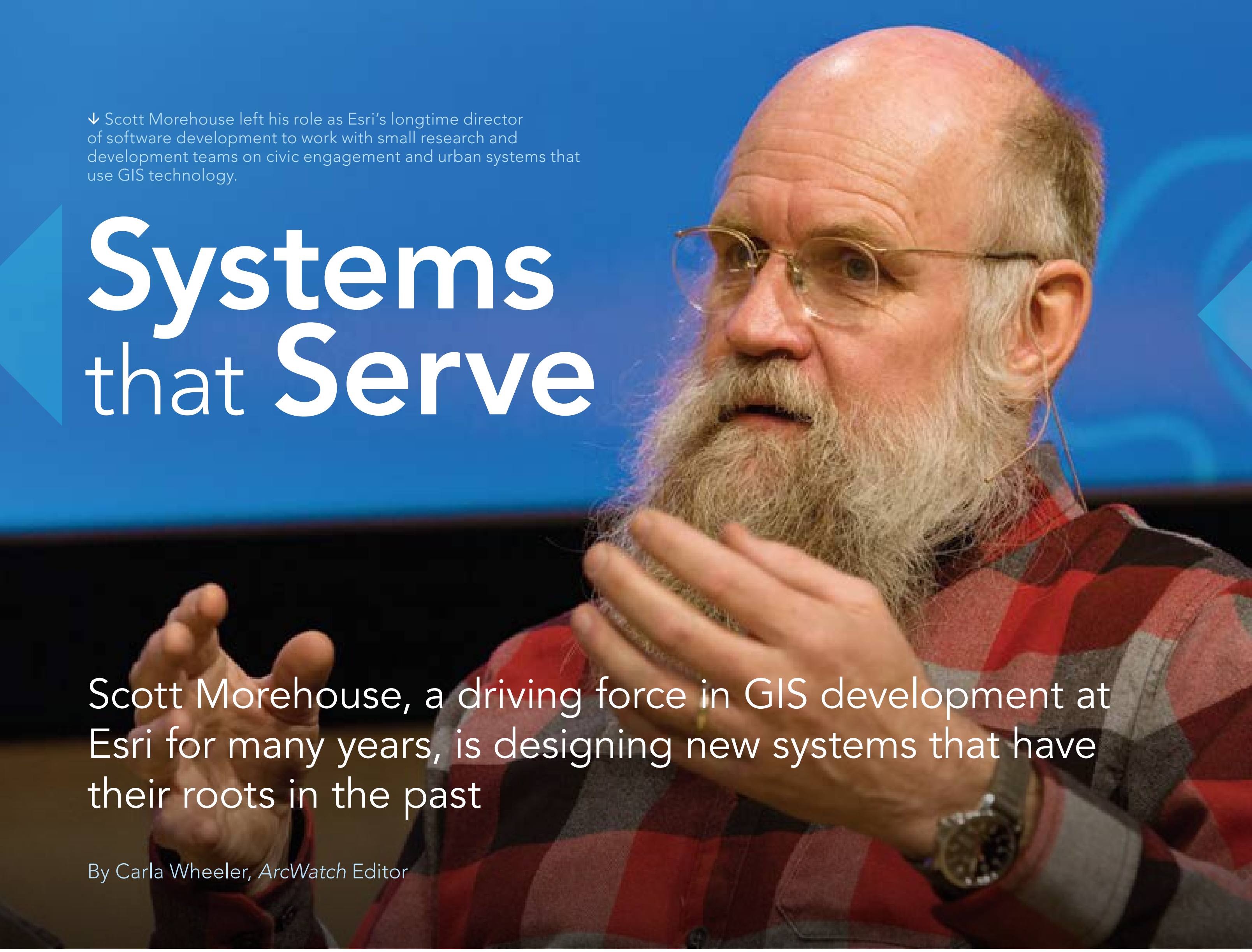


↓ Scott Morehouse left his role as Esri's longtime director of software development to work with small research and development teams on civic engagement and urban systems that use GIS technology.

Systems that Serve

Scott Morehouse, a driving force in GIS development at Esri for many years, is designing new systems that have their roots in the past

By Carla Wheeler, *ArcWatch* Editor

Scott Morehouse has spent more than three decades steering the software development ship at Esri. If you use ArcGIS, Morehouse had a big hand in bringing your software to life.

A geographer and computer scientist, Morehouse cut his teeth on computer mapping at the Harvard Laboratory for Computer Graphics and Spatial Analysis at Harvard University in the late 1970s. That's the same lab where Esri president Jack Dangermond worked years earlier, though the two men never crossed paths there.

The lab, part of the Harvard Graduate School of Design, was an incubator for ideas on how to design and build computer mapping software. Morehouse was part of the team that developed ODYSSEY, a vector GIS and a forebearer of Esri's first commercial GIS, ARC/INFO.

After meeting Morehouse at a conference at Harvard University, Dangermond hired the smart, young software developer in 1981 to design and launch ARC/INFO. Later, he worked on developing the ArcGIS product line.

Five years ago, Morehouse changed his role as Esri's director of software development. He shifted his focus to small research and development teams at Esri that use GIS technology for civic engagement and urban systems. While the projects are new, the ideas behind them are rooted in Esri's original mission when it started as a land-use consulting company in 1969: fostering well-informed urban design.

Morehouse and Dangermond both started their careers with a strong interest in data-driven land-use planning coupled with the idea of civic engagement. Morehouse's work on frameworks for the Urban and Hub systems he is currently involved in stems from that interest. Esri recently launched the ArcGIS Hub product to support participatory government and has moved into the 3D GIS sphere in urban landscape modeling.

In an onstage conversation during the 2018 Geodesign Summit, held in January at Esri headquarters in Redlands, California, Dangermond asked Morehouse about this move, saying, "You're rethinking the whole game?"

"I've gone back to basics," said Morehouse. "I want to build systems that serve people—systems to guide, direct, or organize the civic process."

Morehouse recently took time to talk more extensively about these projects. *[His comments were edited for brevity and conciseness.]*

What's your role today at Esri?

Morehouse: I direct the Esri research and development centers in Washington, DC; Zurich, Switzerland; and Beijing, China. I have two initiatives I am working primarily on now: one is the Hub system framework, which is the environment for the citizen engagement and collaboration. The other is this urban system framework, which is about envisioning and supporting the development/redevelopment/planning process.

What does "going back to basics" mean to you?

Morehouse: We invent systems to solve problems and serve a community of people. That's fundamentally where the GIS idea comes from: creating a system that can work with maps and geographic information that helps people do their work. It's a cool set of concepts that have been used across different domains: cartography, forestry, military planning, city operations, and many others.

With our new work with the research and development of the Urban system and the Hub system, I've taken the same principles *[into account]*. If we want to create a system that helps a community of people work with their elected officials and their city government to more effectively manage their built environment and to accomplish other civic goals, what would that system look like?

Many people are applying a more generic GIS concept in urban governance and urban planning and local government use cases. As things have become more sophisticated from a technology standpoint, we realized that creating a system that focuses on the user's needs, concepts, and workflows—and takes advantage of everything that we've done with the GIS platform—would be really useful and valuable.

So rather than have each customer assemble a civic engagement system from scratch using various ArcGIS software products, Esri could deliver basically a ready-made civic engagement system?

Morehouse: There's an opportunity for Esri to deliver this as a well-designed system with a commitment to sustain it with initiatives and user experiences.

The cities of Los Angeles and South Bend, Indiana, have begun to implement this *[Hub]* idea. Hub is like GIS. It's an idea for a process, and it is also technology that Esri is developing as a commercial off-the-shelf *[COTS]* framework or a product. And it's also an implementation that individual cities can do.

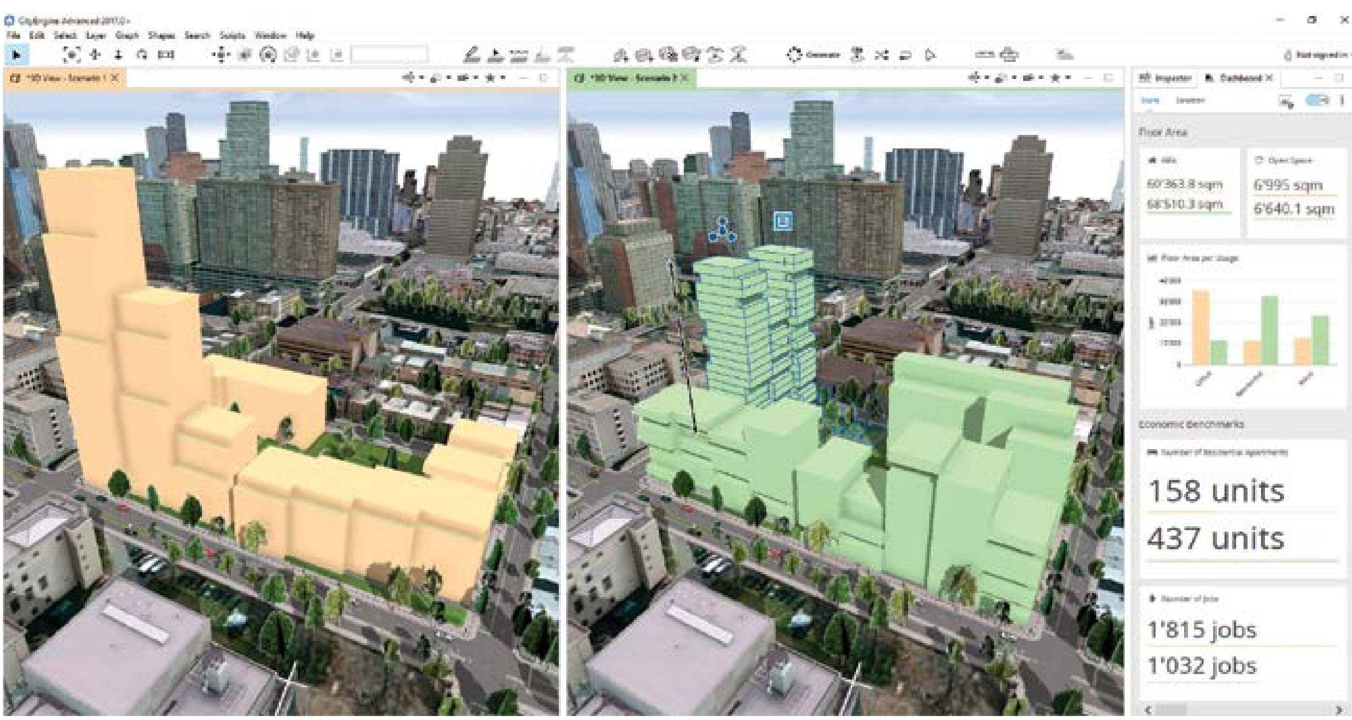
How do open data capabilities fit into the Hub idea?

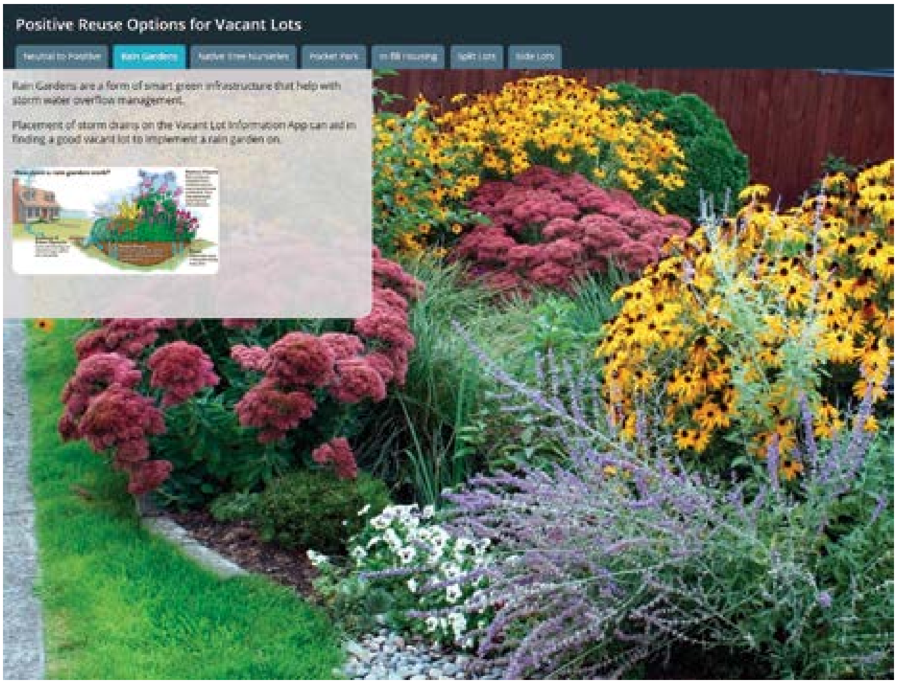
Morehouse: The addition of open data capabilities to the ArcGIS platform was the germ of getting people together around the table. If we just put some data in the middle of the table, then everybody could gather around that data. The activists and the startup companies and the different *[government]* departments could at least have a more intelligent conversation because it was data driven.

Everyone said, "This is great." We thought that if we put the data there, wonderful things would just happen. And if you were *[savvy]* enough to know how to turn a spreadsheet into something interesting, you could do something there.

How many people *[can]* take a spreadsheet of trash collection *[data]* and turn it into understanding? *[The question is]*, "How can we create a sustainable system framework for such applications?"

↓ A 3D model of an urban landscape is useful for communicating more information about that landscape.





↑ Initiatives, such as reuse of vacant lots, can improve the green infrastructure in communities to make them more livable and sustainable places.

So something beyond creating open data sites needed to be done to spur more collaborative civic engagement?

Morehouse: Open data is an incredibly important part of the idea. However, Esri believes that intentional design of good systems is a hard job. It doesn't just emerge magically from making data available. Design and a sustained implementation are essential parts of the process. So we said, okay, if having the information accessible and available in this collaborative way is a great idea, what is it that people really want to do? And how do we just not make these things be giant data dumps of semiobsolete information?

That's what led us from open data sites to the Hub. With the Hub, the notion is that you basically have a purpose for making information available and for collaborating. And the purpose is what we call an initiative. Initiatives could be centered around affordable housing, homelessness, or whether building a new basketball stadium is a good idea.

If a city or utility wants to involve a community of collaborators from outside its organization—such as startups and citizens—what are the initiatives they want to tackle? An example people often use is Vision Zero for pedestrian safety. *[Vision Zero is an initiative promoted by the City of Los Angeles through its GeoHub.]* The vision is reducing pedestrian deaths. We can organize a lot of information and activities around that: identifying and fixing dangerous intersections, learning where and why pedestrian accidents are happening, and finding ways to get bicyclists and drivers to safely share the road.

Are there currently tools in ArcGIS Hub to collaborate interactively on initiatives?

Morehouse: Yes, there are collaborative tools within ArcGIS Hub, and more will be added. For a traffic safety initiative, you will be able to see, for example, a dashboard with traffic accident statistics, a map produced from an analysis that shows the safe streets and less safe streets, and an analysis of what have been identified as dangerous intersections. And then, here is a question *[to answer]*. Are there any dangerous intersections near you? If so, you can report them through this survey form. And here's a series of meetings that will be taking place where you can meet the people who are drawing the stripes on your road that separate the bicycles from the cars. You can talk to them about what they are doing in your neighborhood.

Will Hub systems be designed to get people more deeply involved in the planning process?

Morehouse: People who are interested in participating and contributing can do so at a deeper level. Say you are in a bicycle club and you have a passion as an activist to help *[planners]* get the design right—you can join the group that's associated with this initiative and do more: get access to data, make your own maps, and contribute those to the initiative page. That's already starting to happen.

What's coming next?

Morehouse: We've created this contextual Hub framework. We've made the data available. But it's still difficult for people to build apps for the initiatives and figure out how to do this well. So we are building more functionality into ArcGIS Hub. Many *[organizations]* want to do surveys for their initiatives, where people can report things like dangerous intersections or report street trees that are damaged and need their cages fixed. So, we are going to build on it—not just build more initiatives but build user experiences that allow people that use the system to configure and manage their own initiatives.

What types of configurable user experiences will Esri provide?

Morehouse: We will provide opioid *[abuse]*, homelessness, and Vision Zero initiative templates. There are also two economic development initiatives. One will help governments attract businesses to their communities. This is a template or framework that a city could use to feature or highlight their vacant office space or industrial or commercial land and attract investment. Every community has prime real estate they want developed and *[officials]* want to help people choose *[sites]* wisely. This initiative—with an accompanying configurable app—gives city governments the ability to show businesses that might want to locate

↑ An economic development initiative can help governments attract businesses to their communities by showing businesses what the city can offer.

in their community what the city can offer.

The second economic development initiative and app are designed to help cities showcase amenities and neighborhoods to help people who are considering a move to a community make informed choices as to where they want to live. People will be able to explore information about various neighborhoods, such as school and transit options.

The recent ArcGIS Hub release includes the two economic development initiatives, along with the tools to support them. We are in the early days with this Hub system. Over time, we will be doing more and more.

Please provide an overview of a 3D urban system powered with real-time information.

Morehouse: The Urban system framework is different from the Hub but related. People are very interested in and need to understand the life of their city or town—what's happening now—and *[want to]* use that *[real-world information]* to plan and manage the development of the city as a good place for people to live and work. This starts with understanding in context. Where is the economic activity taking place? Where are the people who are at risk—the elderly, the sick, the homeless? Where is the infrastructure breaking down? Where are the roads in need of repair?

A lot of things can be considered as—if you will—instrumentation that you can place in the context of a model of your city. So, you can say, "Here's my city and I can see where the at-risk people are and the elderly. I can see that *[information]* now in relation to our services in a 3D environment"—just how you communicate what's going on.

You have this picture of your city that you can visualize with what we are calling indicators. There are indicators that relate to the population. There are indicators that relate to the way the city is operating: Where is the trash collection *[happening]*? Where are we resurfacing roads? There are indicators that relate to the physical infrastructure of the city, to economic investment and revenue, and so on.

You want to be able to understand and visualize not only the state of this "urban landscape" but also the actions that we *[as residents]* are paying for or that we *[as city officials]* are managing or that we *[as planners or architects]* are supposed to design well.

All the people around the table are interested in the health and life of the city, as well as where the projects are and what the zoning is. That is another aspect of this Urban system we are looking at—it puts it in the context of making maps that communicate meaningful information.

Why is it important to consider city operations in 3D?

Morehouse: Because 3D just is what it is. Why is it important to know that the emergency medical services team goes to the eighth floor instead of the door of a building? If I am a real estate person, why is it important to know the price per square foot on the first floor versus the price per square foot on the fiftieth floor? Fundamentally, it's clear that these things about how a city works start being three-dimensional.

The urban system framework starts with the principle that cities are three-dimensional. The only reason they were ever shown on 2D maps is because they did not have three-dimensional vellum when they started making *[planning]* maps in 1880. If the designers and planners of 100 years ago had what we have now, they would have

↓ The urban system framework starts with the principle that cities are three-dimensional.

done things differently.

Cities are three-dimensional first. What does that mean? The value of apartments in a building aren't the same. The higher floors that overlook the park, for example, are more valuable than the lower floor. And more and more, mixed residential/commercial *[projects]* need to be fundamentally in a three-dimensional *[view]*. The units being rented, having values assigned, going through permit approvals, or generating 911 calls are spaces in buildings. They are not polygons on a map.

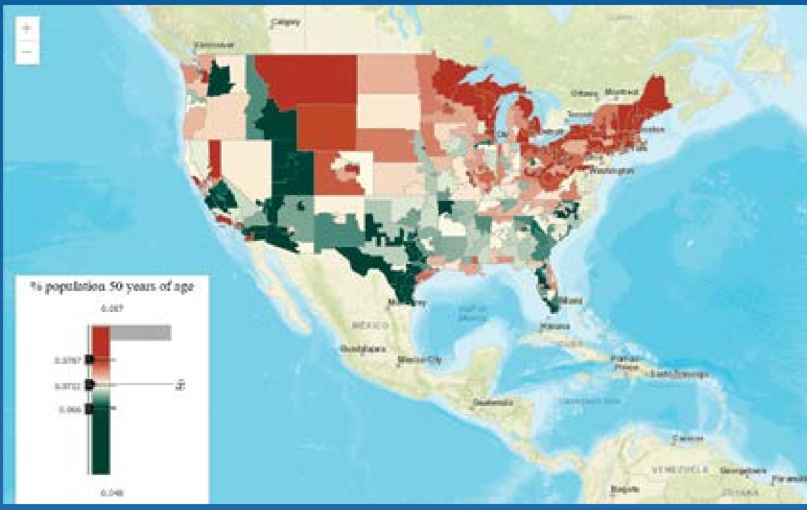
Are there other reasons that 3D models are important?

Morehouse: A 3D model of an urban landscape is also useful from a communication point of view. How many times have you seen the choropleth maps of census tracts—you know those colored polygons that show income, poverty, population density, and so on? And you are never quite sure where your house is because they are census geography. It doesn't grab you.

But imagine if you saw a three-dimensional model of your city in which each set of buildings was colored by how many 911 calls were responded to at that building or how many permits were issued for kitchen remodels in this condo complex versus that condo complex.

Have you seen these walkability maps that people make for their city that show green areas where you can walk? Imagine if the buildings were colored by walkability rather than just the polygon colored by walkability—that would actually grab you—that building would be good to live in because it's green.

Training for Aspiring Web App Developers



↑ Introduction to Web Development Using ArcGIS API for JavaScript introduces the Smart Mapping functionality available in ArcGIS API 4.x for JavaScript.

An updated version of a popular instructor-led course to help GIS professionals with little to no programming experience acquire requisite skills to build high-performing web apps has been released by Esri Training Services.

The first two lessons in Introduction to Web Development Using ArcGIS API for JavaScript cover basic concepts of HTML, Cascading Style Sheets (CSS), and JavaScript to ensure that all attendees have a solid and shared knowledge foundation. The previous version of the course assumed attendees had experience working with HTML, CSS, and JavaScript.

For attendees who already have that foundation, the first two lessons will be useful in understanding how HTML, CSS, and JavaScript are implemented using ArcGIS API 4.x for JavaScript.

The updated course also uses a more structured and highly interactive instructional approach. In each lesson, the instructor presents conceptual material and facilitates group breakout sessions. Attendees brainstorm together to solve application scenarios and complete activities such as code snippet examinations. Based on what they have learned at that point in the course, attendees identify the functionality enabled by the code snippet, explain the elements in the code structure, and together discuss how they might use that functionality in their own web apps.

The instructor then demonstrates the coding workflow for the API functionality highlighted in each lesson's hands-on exercise. Attendees repeat the workflow steps on their own using CodePen, a popular website that provides an environment for writing, previewing, and sharing code. Code solution files are provided in case attendees get stuck.

The course emphasizes the progressive development of skills through practical application. The goal is to ensure attendees gain confidence and a deep understanding of the framework for developing web applications using ArcGIS API 4.x for JavaScript—not simply to complete rote steps by following detailed exercise instructions.

According to course author and education specialist Jamie Powell, "This course is going to help a beginner, someone who's never really worked with code, get up and running with ArcGIS API for JavaScript at a high level. It's not hard. Anyone can do it, with the right instruction."

ArcGIS API 4.x for JavaScript is a powerful tool for creating modern, cross-browser web applications that feature ArcGIS maps and functionality. By the end of this class, attendees will be prepared to leverage the API to create custom web applications that feature 2D and 3D maps and provide functionality for end users to search and query map layers, display layers using qualitative and quantitative symbology, and understand how the ArcGIS Smart Mapping interface (used to apply cartographic best practices to map data) can be incorporated into custom web apps.

Learn more about this course and view the class schedule at go.esri.com/iweb.

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Using GIS to Bring Citizens and Scientists Together

By Monica Pratt, *ArcUser* Editor

While enjoying Arizona's recreational opportunities, residents and visitors can help preserve its streams, washes, rivers, and lakes in just a few minutes using a free smartphone app.

With the Arizona Water Watch Monitoring app, volunteers just answer simple yes/no questions about a nearby water body and take a couple of photos. The app, created in Survey123 for ArcGIS, uses the smartphone to automatically capture location and observation date. In just a few minutes, residents and visitors can contribute to the state's well-being.

Arizona is a desert state. Water is one of its most precious resources, so understanding and preserving Arizona's water bodies is vitally important. The Arizona Department of Environmental Quality (ADEQ), a state cabinet-level environmental agency, is tasked with protecting the state's public health and environment by preventing air, water, and land pollution and ensuring environmental cleanup through its planning, permitting, compliance management, monitoring, assessment, cleanup, and outreach activities.

In 2016, the state enlisted the help of volunteers in this important work by launching a citizen science program called the Arizona Water Watch (AZWW). The program was started by ADEQ water quality scientist Meghan Smart. It trains volunteers to collect water quality samples from streams and lakes around the state and requires monthly time commitments and audits.

This program has been successful, but Smart wanted to give volunteers a way to participate in citizen science at a less intense level. She thought an app targeting people who might not have time to collect water quality samples but could gather data when they were recreating would be valuable. Smart asked the GIS team at ADEQ if they thought they could create the app.

Debby Crouse, a senior GIS analyst with ADEQ, said developing the app with Survey123 for ArcGIS took a little more than a half hour. Survey123 is a simple and intuitive form-centric solution for creating, sharing, and analyzing surveys that are fully integrated with the ArcGIS platform. Surveys can be filled out on the web or a mobile device, even when it is disconnected. Later, survey results can be securely uploaded to ArcGIS for further analysis when connectivity is restored.

"Our GIS department has been working steadily to deploy many tools to our Air, Water, and Waste sections using Collector *[for ArcGIS]*, Survey123, and online maps and apps through ArcGIS Online," said Crouse. The Arizona Water Watch Monitoring app was the result of a brainstorming session at a meeting that had been called to introduce the available apps to some agency staff members.

"From the beginning, Meghan and I were in touch, continually improving the app and the data that would be collected," Crouse said. Smart enjoyed the process, noting "The GIS team was exceptional to work with."

Released in November 2017, the Arizona Water Watch Monitoring app was designed for use by volunteers ranging from elementary school students to seniors. The app lets anyone become a citizen scientist and collaborate with professionals in scientific research. Since the existing AZWW program was robust and established, the app was well received.

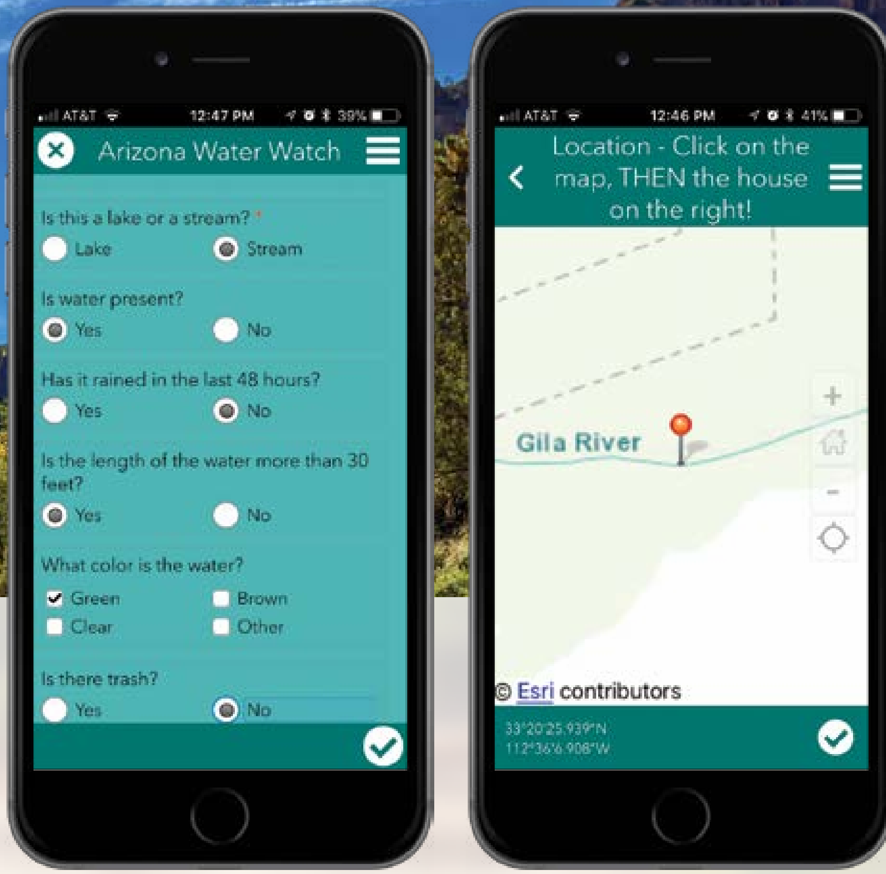
The data collected with the Arizona Water Watch Monitoring app is verified and added to a statewide GIS map that is used by ADEQ scientists to update flow patterns in streams and washes, address water quality issues across the state, and identify water bodies for future studies.

"The data will be downloaded quarterly, shared on our website, and then used to update our flow regime GIS shapefiles annually. This will help keep our basemaps up-to-date," said Smart.

One of the things Smart thinks the app should be able to help ADEQ do is learn more about intermittent streams. These

→ Residents and visitors can help preserve Arizona water bodies by using the Arizona Water Watch Monitoring app to answer simple yes/no questions about nearby streams, washes, lakes, or rivers.

→→ The smartphone automatically records the location, date, and time data with the survey form.



streams, which don't flow year-round, are understudied.

"If citizen scientists can notify us when these streams are flowing or not flowing, that really helps us understand the flow regime to target water quality samples in the future. We are also piloting using the app for wet/dry mapping this June."

The AZWW program benefits participants who have the opportunity to collaborate with scientists. Harnessing the curiosity and good intentions of people to solve today's problems has helped citizen science grow and is part of a larger trend in a society that is becoming more peer-to-peer: people are increasingly makers as well as consumers. Through work on citizen science projects, the lives of nonscientists can be enhanced in a manner similar to the enjoyment they experience from participating in activities relating to sports or art.

Thanks to the growth of the Internet and the nearly ubiquitous adoption of smartphones and other mobile devices, the kinds of projects that can benefit from citizen science have expanded. By collaborating with the public to crowdsource data and experiments, scientists can tackle projects that address both local and global problems in disciplines that range from astronomy to microbiology. Because so many crowdsourced projects involve data collection or verification, they are "what is where" activities that greatly benefit from the use of GIS, especially with the expansion of the ArcGIS field apps.

The Arizona Water Watch Monitoring app benefits ADEQ by fulfilling several of the agency's stated operational goals: deploying Lean Six Sigma management, leveraging e-technology, and increasing outreach. "The app is a great example of all three goals," said Smart.

For the past five years, ADEQ has been undergoing a Lean management transformation. It has been striving to reduce waste and improve services while protecting and enhancing public health and the environment in Arizona. The app improves the data collection process and decreases the time needed to update the GIS layers. "It embodies the very concept of Lean," said Smart.

By using a smartphone, something that is familiar and accessible to the public, the app leverages existing technology to accomplish its goals. Smart believes the app "will increase the amount of data we can collect while simultaneously decreasing paper waste."

The app has the added benefit of increasing public outreach by providing a less time-intensive way volunteers can help protect Arizona's water bodies. Launched during the winter, usage of the app is expected to grow during spring, the prime time for enjoying Arizona's recreational opportunities and fabulous weather. Not only are citizens using the app, but ADEQ staff are also using it while they are in the field.

"We are excited to be able to bring high tech to our employees and our citizen scientists that will help our workflows become more lean and efficient," said Crouse. "The app also enables the Water Division to gain valuable data that wasn't even possible before. We are seeing that it is already a catalyst within the agency for similar apps throughout the various sections."

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