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A Geographic Information System (GIS) ideally answers not only rudimentary queries relating to *where*, but eventually also *when* and *why*. The validity of the information depends on data accuracy, in terms of both space *and* time. Data *Acquisition*, or at least quality assurance, preceding *Analysis* and *Presentation* is therefore an intellectual purview if not a professional responsibility.

*PurVIEW*—distilled from a decade-long, in-depth experience in system development and practical applications in photogrammetric computer workstations—is designed to deliver the net technological benefits to GIS and earth scientist communities, particularly the ease in digitizing feature objects directly from geo-referenced stereoscopic source imagery, first-hand, unencumbered by the esoteric photogrammetry of old.

Adopting such PurVIEW might remove the stigma in many new implementations as *a solution in search of data*, or elevate existing GIS from stagnating in a state of *flat-earth* 2-dimensional abstraction onto true modeling of a 3-dimensional real-world. Convenient systematic data updating will ultimately impart the 4<sup>th</sup>-dimension—*time*—into the intelligent model of the world that is GIS.



## Reality Check

GIS, a development founded on computer graphics in the '60s, predated digital mapping by more than a decade. This time gap necessitated the conversion of already obsolete cadastral or base maps into a digital *infrastructure*, an interim solution fraught with imbedded errors until retrofitted instrument and digital mapping output slowly became industry norm... However, digital maps are not immune from compiling errors and omissions, if residual instrument and operational errors, from sighting to imaging through restitution, are ignored. Without much recourse, accepting the base data *on faith* was a way of life, debasing thematic features yet attached....

Shouldn't a GIS pass your own *Reality Check*, first?



## Finally, within your PurVIEW

- **Plug—IT—In**

A decade ago, computer-based *photogrammetric workstations* rose above the R&D horizon, rapidly replacing mechanical instruments and transforming industry outlook. The *chassis* of such a workstation is a desktop computer, little different from your own. A *plug-in* now extends your view to include the same or newer geo-referenced stereoscopic mapping imagery.
- **Visual Reality, on Demand**

The image input—air- or space-borne—for a photogrammetric workstation is of course digital, but by default, so are all output and meta-data files, including the critical image *orientation* or geo-referencing parameters. A mouse-click not only precisely *recalls* the set-up of the stereoscopic mapping views, but also any new imagery with such standardized parameters now simultaneously acquired in late-model cameras or new digital imaging systems.
- **Virtual Z**

DEM was an archived photogrammetric *staple* for available digital orthophotos, but lately also acquired new, *en masse*, using RADAR or LiDAR systems direct. Real-time interpolation of such data, wherever the cursor roams, not only extracts Z-values—the 3<sup>rd</sup> dimension—often missing in terrain coordinates, but also for any imaged features yet unmapped or mapped only in 2D, all without needing awkward input devices.
- **What You See is What You Got**

Supported in all photogrammetric workstation is rigorous stereoscopic *super-imposition* of existing or new mapping over the image models, revealing changes or compilation defects in real-time. Such QA power is now in your control, likely supportable by monitors already in use on your desktop.
- **Do It Yourself, With QA**

Whether plotted as hardcopies or recorded digitally, photogrammetric mapping or *feature extraction* is merely interpreting and documenting specified image objects. Geo-referenced imagery and quality DEM supporting WYSIWYG mapping is *preemptive QA*. Aerial mapping—an important base data source for GIS—is no longer dependent on 3<sup>rd</sup> parties.

## ▶ Looking Forward

While a GIS could rely on topology rules for correct extrapolation of geographic relationships, feature attributes—e.g., distance, slope, azimuth, area...—are wholly dependent on accurate feature positioning. Adding thematic data onto a base now proven or rendered accurate establishes a GIS on rigorous grounds. Exploiting a technology that conveniently supports direct 3D plotting of imaged features liberates a GIS from even poor detailing in the original base maps. A new GIS era has begun.

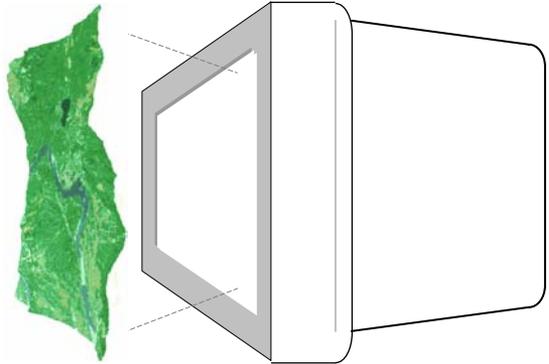
### From 3D...

3D mapping collects also Z data, not merely *flat-earth* X/Y coordinates. Supported by many CAD systems, it has been a standard in digital mapping for decades. However, visualizing such data is still cartographically limited to contour lines, perhaps augmented by visual cues such as relief shading or even perspective rendering..., all static 2D display techniques.

### ...to beyond

Transcending all such *simulations*, stereoscopic display provides a photo-realistic bird's-eye view of the terrain with the mapped features correctly super-imposed, enlivened by instantaneous zooming and dynamic roaming with real-time 3D cursor coordinate display, ...all unimaginable capabilities for GIS, until now.

Editing existing, or compiling new data  
with active *Virtual-Z* input  
over a geo-referenced image backdrop  
under real-time stereo-superimposition  
is QA in real-time



### ❶ From Mono- to Stereoscopic Vision

Standard CRT monitors are adapted for stereo viewing through an *Open GL* video-driver operating at  $\sim 120\text{Hz}$ . The left and right eye perspective views are alternately presented each at 60Hz, and viewed through synchronized LCD *shuttering* eyewear, or full-screen LCD lens with cross-polarized spectacles.

Common monitors— $1600 \times 1200 @ > 80\text{Hz}$ —support such display at an adequate resolution of  $1024 \times 768 @ 120\text{Hz}$ , providing *flicker-less* clear views on a 20" viewable area. Higher band-width monitors popular in CAD or GIS applications can support stereoscopic display resolutions finer than  $1280 \times 1024 @ 120\text{Hz}$ , approaching the limits of human visual acuity of 1 arc minute.

## ►► Applications

### □ ...in Forestry

Previous mapping superimposed on new imagery serves as the *training-set* for interpretation, entailing substantial savings in preliminary field work. From the stereoscopic image models: adjusting or re-plotting species polygons, estimating species mixtures, determining polygon slope, elevation and aspect, sampling tree heights, evaluating site conditions, updating or upgrading planimetric map details; and eventually, extracting a coordinate list for unambiguous *test-set* visitations, ensuring the validity of the proofing field work.



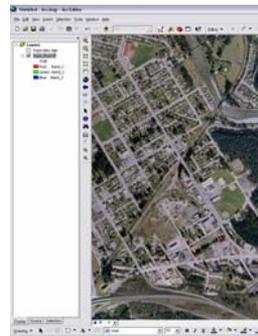
### □ ...in Geology

Extracting location coordinates in the image models for field sample collection not only improve efficiency but also ensures positive correlations with observable image characteristics, facilitating surficial geology typing. Observable features such as *strike* and *dip* can be directly delineated, with slope, elevation and size established, and formation heights or strata thickness measured. Also, GPS geo-referenced seismic, aero-magnetic, geo-chemistry and other field data can be accurately plotted, perhaps imparting new insights into the geomorphology imaged.



### □ ...in Urban Engineering

Cadastre in contiguous buildings can be directly mapped. Plotting street hardware such as lighting, signage, inspection covers, and hydrants, indicative of under-ground installations is helpful in correlating abstract engineering records. General map updating and upgrading maintain data investments. Convenient estimation of slope, elevation and distance, essential in road work and other maintenance tasks, reduce inefficient field visits. Establishing transmission tower visibility, modeling signal shadowing and *umbrella* effects help in wireless communication engineering.



## □ Position matters

GIS can be just a generalized language for geography, or a rigorous representation of reality. Fundamental to both are the features in question, traditionally abstracted from generic mapping second-hand, then converted into individual representative objects with topology painstakingly inserted, eventually reconstituted as thematic representations for the analysis.

Mapping, reproduction and eventual digital data conversion errors inadvertently occur, resulting in feature positional error and degrading the GIS analysis in the outset. Even if the feature position errors were not compounded during the processes, some knowledge of the original mapping standards will ensure appropriate data usage within the level of generalization intended.

### 📍 Mapping Errors

Hardcopy mapping was designed for a horizontal accuracy of  $\pm 0.5\text{mm}$  at plotting scale, with vertical spot accuracy within  $\frac{1}{2}$  the customary contour interval. Digital mapping supports variable hardcopy scales with accuracy tolerances restated as X, Y and Z *Positional Accuracy*.

While stable-base films were used from map plotting to plate-making, data accuracy was compromised as such originals were seldom released, or made available for data conversion.

In urban GIS applications where source mapping at scales  $>1:2,000$  were common, *dialo* drum-printer reproduction typically used impart *affine* distortions  $>0.5\%$ , translating into unacceptable, and *unsystematic* positional errors  $>10\text{m}$ .

Mapping Scale	Contour Interval	Positional Accuracy		
		X	Y	Z
1: 500	0.5m	0.25m	0.25m	0.25m
1: 1,000	1.0m	0.50m	0.50m	0.50m
1: 2,000	2.0m	1.00m	1.00m	1.00m
1: 5,000	5.0m	2.50m	2.50m	2.50m
1:10,000	10.0m	5.00m	5.00m	5.00m
1:20,000	20.0m	10.00m	10.00m	10.00m
1:50,000	50.0m	25.00m	25.00m	25.00m

## ⊘ Omission

Data omission fundamentally invalidates information developed. Not only is such defect *unobservable*, and so far also unverifiable without considerable field work. If the data sources are old—as often is the case—then no amount of field visits now could retroactively ascertain its completeness...

Fortunately, maturing digital technology in photogrammetric mapping is now accessible to overcome such a crippling defect.

### 📍 Orthophoto

Comparing the source data with imagery of the same date or vintage is always possible, but opens more questions regarding feature positioning unless the imagery has been rectified into the same map projection. Such *digital* orthophoto is but a *pixel veneer* over a topographic model and map-like in nature, where 2D data can be accurately aligned.

### 📍 Stereoscopic Image Model

Geo-referenced stereoscopic image models for computer desktops—providing views akin to observing a user-scalable photo-realistic globe replete with surface topographic minutiae—are a by-product in digital photogrammetry, but largely unknown to end-users. Within such views, even 3D source data can be correctly superimposed.

Data *Error & Omission* could be a technological limitation of the time or simply be a result of negligence. Regardless, tools are now available to adjust, complete or otherwise *retrofit* the fundamentals in a GIS—the elementary data—before its credibility is being challenged.



## Minimize Errors & Omissions

Viewed under stereoscopic superimposition, immediately noticeable are:

- 2D feature objects all appear flat at a plane beneath the 3D image surface.
- Global positional disagreement between imaged features and mapped objects—perhaps caused by mismatched map control coordinate systems.
- Isolated disagreements between imaged features and mapped objects—either due to timing difference between imaging and mapping, or due to:
  1. *Omissions*— imaged features not mapped
  2. *Misinterpretations*— mapped features not imaged
  3. *Digitizing errors*— positional disagreement

In any case, isolated deficiencies can be removed by adjusting or re-digitizing the feature objects in question, ideally without disturbing the data structure or topology already established.



## A new Page

More than a decade ago in an industry unprepared, a dramatic technological disturbance in photogrammetry occurred. This so-called *softcopy revolution* was really just the transition from film to digital imagery within another true revolution—*analytical photogrammetry*—that started some 40 years earlier...

The first *analytical* stereo plotters (early 60's) were unaffordable for the exotic control-computers. Commercialized some 20 years later, such instruments still cost as much as a decent family home. Now, transformed into the digital domain, the *instrument* is virtually software operating in ubiquitous desktop computers, but became far more sophisticated than was ever conceived.

Such *virtual instrument* photogrammetric workstations replicate or automate all apparatus ever devised, with the untaught production procedures imbedded and blunder-prone secretarial support tasks eliminated... A new age has begun.

### ◀ Some backgrounds

Photogrammetric developments have always revolved around the fundamental challenge of precisely *orienting* or geo-referencing individual images arbitrarily acquired in a 3-dimensional air space. If the imaging position and aim direction for each scene could be accurately recorded, and now possible via integrated Inertial Measurement Units (IMU)—essentially precise gyroscopes/accelerometers combined with *kinematic* GPS—much of photogrammetry, including the painstaking and esoteric *Aerial Triangulation* (AT) process, could be by-passed. The age of direct geo-referencing has arrived.

Indeed, the standard orientation parameters for each image, recovered in *analytical* AT are simply:

- Coordinates for the sensor position at the instant of imaging, notated as  $X_0, Y_0, Z_0$ ; and
- Angular values for the sensor aim imparted by the platform dynamics—yaw, pitch and roll—notated as  $\kappa$  (kappa),  $\phi$  (phi) and  $\omega$  (omega).

After much *de rigueur* denial and emotional debates, the only issue remaining is: *how refined and precise would such parameters need be?* Despite dogmatic academic pursuits for photogrammetric perfection, mapping is acceptable if all cumulative errors are within specified Positional Accuracy—essentially the total *error budget*.



Such tiny geo-referencing meta-datasets imbedded in the image files are the ultimate photogrammetric QA parameter, transmittable anywhere, at any time, and precisely *invoke-able* by anyone via a simple mouse-click..., with the much touted *vigorous* image orientation now conveyed by default.



## Handicap removed

The now ubiquitous computer workstation is far less intimidating than the rarefied stereo plotters, but operating a 3-channel (X/Y/Z) input device still seems unnatural. While mastering the technique is not difficult, training environments are limited to a few technical institutes, or apprenticeships with photogrammetric practitioners. The implication is obvious if unintended: accurate mapping requires *expert* input control by the trained few.

However, a map is a model of reality. Few would argue that a feature object, if naturally residing on the terrain surface, should be conformal to the terrain model surface when mapped. Real-time interpolation of the local DEM data or a *Triangulated Irregular Network* (TIN), wherever the mouse cursor traverses, extracts arbitrary elevation values without the *third* (Z) input control.

Such concept transforms 3D mapping into direct feature delineation on the *virtual* surface of a *scalable photo-realistic globe*. The mapping is, by default, conformal to the topographic minutiae of the earth spheroid, and with quality assured by the precise image geo-referencing and quality DEM.

### New age DEM

Quality-assured DEM, a prerequisite wherever the populous orthophoto has been produced, can be obtained from archives. Auspiciously, not only is space-borne digital imagery commercially available, but also is air-borne geo-referenced digital imaging now operational—with DEM data acquisition possible in the same platform. *Radar altimetry* and *laser ranging* are the leading technologies.

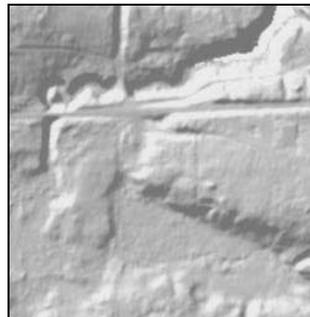
- Radio Detection And Ranging (RADAR) is an *active* sensor system. The long wavelength sensor energy penetrates cloud covers and even vegetation canopies. Aerial *Interferometric Synthetic Aperture RADAR* (IfSAR) DEM—typically at 5m *posting* with  $\pm 1\text{m}$  vertical accuracy—and space-borne NASA *SRTM*—at 30m or 90m posting with  $\pm 15\text{m}$  vertical accuracy—are now deployed in many regional mapping programs.
- Laser is used in aerial Light Detection And Ranging (LiDAR) active sensor systems and can generate measurements as rapid as 100kHz. With correct aerial platform altitude and speed, the accuracy ( $\pm 15\text{cm}$ ) and density of the torrential data *point-shower*—even after filtering out air-borne or non-surface *contacts*—is more than adequate for all but the most demanding mapping applications.

Both sensor technologies can generate data so dense that at commensurate display scales the image simulates a *bare-earth* view of the terrain surface, with detailing far exceeds photogrammetric DEM. In many market/regions, such data is now available on a retail basis, and the NASA SRTM data is free...

Surface from photogrammetric DEM



Surface from LiDAR DEM





## Essential Tools

Despite its exotic past, photogrammetric mapping is essentially digitizing—*documenting*—stereoscopic image interpretations. Much like *heads-up* orthophoto digitizing, it is now possible directly on the computer screen, albeit in a stereoscopic view window. The geo-referenced image model functions as the *working surface*, where X/Y/Z positions characterizing the features are occupied in sequence with the *floating* cursor. The coordinate values extracted—manual *posting* or input frequency set in distance-mode—form *isolated*, *lineal* or *areal* objects and observable as real-time 3D vector displays.

Point-to-point digitizing, with the mapping technician—or now any image interpreter—selecting the critical locations in point placement, was a practical technique in creating such *point*, *point-string* or *point-string enclosure* objects. Pointing acuity and digitizer resolution—if supportable by the source image resolution—underwrites the horizontal accuracy in the mapping, while the vertical accuracy can now be based on the DEM substrate, or dependent on user *stereo-acuity* in the occasional manual deviation.

- Isolated objects—e.g., fire hydrants—conceptualized as points in discrete positions are often nominally represented by point symbols or *cells*.
- Lineal objects—e.g., roads—symbolized as centre-lines or plotted as edges are formed by strings of points in various style, thickness and colour.
- Areal objects—e.g., parking lots—if thought to span appreciable areas even at intended generalization levels are enclosed by strings of points forming individual closed polygons.

Such digital map manuscripts created within the GIS environment may be further enhanced cartographically, whether the mapping objective is upgrading, updating, direct editing or retrofitting, all without data translation or data structure disturbances, *and* unencumbered by CAD/GIS interoperability issues.



### Positional Resolution

Stereoscopic viewing at the original scanning or imaging resolution, coupled with instantaneous user-selectable magnification, allows the observation and interpretation of fine features that might have been excluded in standard mapping or *lost* in *re-sampling* in digital orthophoto processing.

Stereo monitor resolution is not related to the manufacturer's hardware specification but rather the software video-driver resolution supportable at 120Hz. The resulting stereo monitor *dot pitch*, ranging from a coarse >0.4mm (~1.5 arc minute) in lower grade 96kHz bandwidth monitors still in use, to the finest at <0.3mm (~1 arc minute) in the best monitors, approaching the limits of human visual acuity.

A fine effective stereo monitor dot pitch under suitable magnification enhances the pointing acuity, ultimately the map *positional resolution*.



### Viewing and Digitizing

Digitizing image features in a static monitor view—such as in *heads-up* orthophoto feature digitizing—is akin to tracing features in a paper map. The once challenging facility was view zooming—now standard.

Also, any current computer can support automatic stepping-over—step-panning—to the adjacent segment within the conceptually continuous or seamless map surface, enhancing operational convenience considerably.

Smooth *roaming* in 3D raster image space—once exclusive to high-power UNIX *Workstations*—is now supportable by any desktop computers. As a result, *dynamic panning*—the floating cursor remain fixed in the view window center while the underlying image model migrates—is now standard, allowing convenient inspections of long or large features before commencing digitizing actions, much improving mapping productivity.

## I/T data

The key to this new professional purview is quality *Image/Terrain (I/T)* data.

### Image Data

*Ground Sampling Distance (GSD)*—i.e., pixel size—and geo-referencing accuracy are important. A GSD at approximately  $\frac{1}{4}$  map horizontal position tolerance is appropriate. Finer GSD, while tempting, entails higher costs.

- ① **GSD limits** the smallest feature discernable, and a cluster of  $4 \times 4$  pixels is considered the threshold of shape recognition—e.g., the *round* shape indicative of man-holes will not be apparent if composed of too few *square* pixels—and positive identification precedes valid documentation.

Comfortable *parallax-free* stereo viewing requires homologous feature details in a stereoscopic image model to match within 4 GSD, a result of *rigorous* image geo-referencing which also ensure *absolute* map positional accuracy.

- ① **Imagery geo-referencing** is performed by vendors. Aerial imagery is geo-referenced through accurate recovery of the imaging optical perspective center position ( $X_0/Y_0/Z_0$ ) and aim angle ( $\kappa/\phi/\omega$ ), either through the AT process or from direct IMU measurements. Space-borne imagery is similarly geo-referenced by correlating data from platform *ephemeris* (the record of imaging positions/time) and sensor *attitude* (aim angles referenced to a star field).

### Terrain Data

Photogrammetric DEM of a correct *Order*—accuracy grade—or denser if not higher grade RADAR or LiDAR DEM are interpolated to extract Z values for arbitrary X/Y cursor positions. Allowing for interpolation/round-off errors, such *Virtual-Z input* should still be within the standard accuracy tolerance of  $\pm \frac{1}{2}$  contour intervals or the restated numeric Z positional error limits.

- ① **Manual Z** - Manual deviation from an I/T-model surface is sometimes necessary, such as when mapping non-surface features (e.g., roof tops) or measuring object height attributes. In standard 60% forward overlap aerial imagery, the camera lens *focal* length to image *base* (f/b) ratio magnifies measurement ambiguity, degrading data accuracy.

Camera	Type	f/b
152mm	Film + post scanning	1.65
305mm	Film + post scanning	3.32
ADS-40	Digital Line Scanner	1.28
DMC	Digital Frame Camera	3.13
UC <sub>0</sub>	Digital Frame Camera	3.70

## Summation

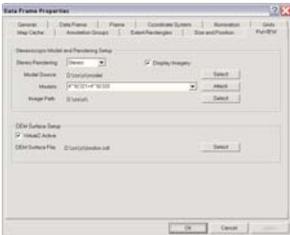
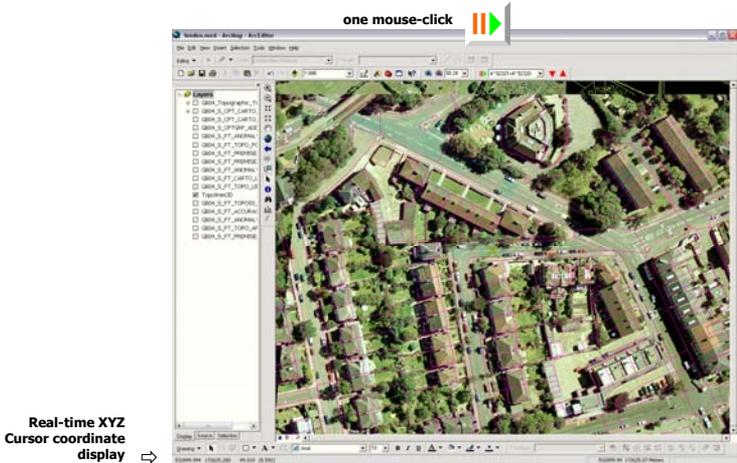
In new aerial I/T data acquisition, finer image GSD is likely to cost more while DEM density imparts little cost difference in RADAR or LiDAR operations, unlike conventional photogrammetric extraction.

In selecting data off-the-shelf, cost factors vary widely dependent on data currency, market conditions and popular demands.

**Basic data quality** can be specified simply:

<b>Image Data</b>	<b>GSD</b>		$\leq \frac{1}{4}$ X/Y positional tolerance
	<b>Geo-referencing</b>	Aerial	$X_0/Y_0/Z_0 = 1$ to 1.5 GSD; $\kappa/\phi/\omega \leq \frac{1}{2}$ arc minute
Space-borne		Vendors' proprietary standards	
<b>Terrain Data</b>	<b>Z – Accuracy</b>		90 ~ 95% $\approx 1$ to 2 GSD unit value
	<b>Density</b>	RADAR or LiDAR	Highest available
		Photogrammetric	Terrain dependent, 4 ~ 8X positional tolerance

PurVIEW is a fully integrated stereoscopic image display and viewing extension for ESRI ArcGIS 9. Within the ArcMap window, *geodatabase* contents can be directly accessed and reviewed superimposed on standard geo-referenced 3-dimensional image models, revealing errors and omissions, or natural changes.



Quality off-the-shelf geo-referenced imagery and DEM *data staples*—precisely invoked with a simple mouse-click—assure accurate *ArcMap-Direct* feature digitizing, using standard or customized tools.

*Virtual-Z*™ digitizing technology—through back-ground DEM interpolation—enables:

- 3D mapping with real-time cursor coordinate display.
- *Dynamic-3D*™ display for stereo editing of 2D GDB/maps.

Transcending flat-earth orthophotos, without CAD conversion or inter-operability issues and within the topology defined..., *retrofitting* obsolete or substandard 2D data can now be executed upon fuller studies of the technical issues, or immediately—the efficiency ideal of *GIS-Direct*™ is now within your professional purview.

**PurVIEW**™ is a product of  
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