animal pollinators are required for the reproduction of nearly 90% of flowering plant species, yet how pollinator communities change with land use is poorly known (Ollerton, Winfree, & Tarrant, 2011). Syntheses show that while pollinator abundance and richness decrease in response to extreme loss of natural habitat.

The Grey Mite

The grey mite is a small arthropod are tiny, less than 1 mm (0.04 in) in length, and has a simple, unsegmented body plan. Its small size makes it easily overlooked; some species live in water, many live in soil as decomposers, others live on plants, sometimes creating galls, while others again are predators or parasites. The grey mite is a parasite and pest to several special of insects, but is best known as being lethal to crickets.

To address these research gaps, we collected a dataset of >13,000 specimens representing 245 mite species, from forested, agricultural, and urban landscapes distributed throughout 75,000 km2 of the northeastern United States. We first ask how abundance, species richness and community composition differ between forested and anthropogenic (agricultural and urban) land- scapes. We then determine whether forested and anthropogenic habitats are associated with different bee species traits. To identify which trait-land use associations are more likely to be robust to different regional species pools, we use a novel test that combines the fourth-corner trait-environment correlation with a phylogeneti- cally informed, permutational null model. [23]

The Grasshopper

Grasshoppers are insects of the suborder Caelifera within the order Orthoptera, which includes crickets and their allies in the other suborder Ensifera. They are likely the oldest living group of chewing herbivorous insects, dating back to the early Triassic around 250 million years ago. Grasshoppers are typically ground-dwelling insects with powerful hind legs which enable them to escape from threats by leaping vigorously. They are hemimetabolous insects (they do not undergo complete metamorphosis) which hatch from an egg into a nymph or "hopper" which undergoes five moults, becoming more similar to the adult insect at each developmental stage. At high population densities and under certain environmental conditions, some grasshopper species can change colour and behaviour and form swarms. Under these circumstances they are known as locusts.

The thorax and abdomen are segmented and have a rigid cuticle made up of overlapping plates composed of chitin. The three fused thoracic segments bear three pairs of legs and two pairs of wings. The forewings, known as tegmina, are narrow and leathery while the hindwings are large and membranous, the veins providing strength. The legs are terminated by claws for gripping. The hind leg is particularly powerful; the femur is robust and has several ridges where different surfaces join and the inner ridges bear stridulatory pegs in some species. The posterior edge of the tibia bears a double row of spines and there are a pair of articulated spurs near its lower end. The interior of the thorax houses the muscles that control the wings and legs.[1]

Ensifera, like this great green bush-cricket Tettigonia viridissima, somewhat resemble grasshoppers but have over 20 segments in their antennae and different ovipositors.
The abdomen has eleven segments, the first of which is fused to the thorax and contains the tympanal organ and hearing system. Segments two to eight are ring-shaped and joined by flexible membranes. Segments nine to eleven are reduced in size; segment nine bears a pair of cerci and segments ten and eleven house the reproductive organs. Female grasshoppers are normally larger than males, with short ovipositors.[1] The name of the suborder "Caelifera" comes from the Latin and means chisel-bearing, referring to the shape of the ovipositor.[2]

They are associated with the site's land use type. Site selection was not random but was strongly constrained by the requirements of the study design, as most landscapes in our region are fragmented and heterogeneous in land cover types at the scale of a 1,500 m radius. In order to ensure representation of the different forest types in our study region, we also stratified site selection within four major forest types in our region: Atlantic Coastal Pine Barrens, Northern Piedmont, Ridge and Valley, and Northern Allegheny Plateau (Omernik, 1987).

To sample pollinator communities at each site, we chose four mowed, grassy, sunny locations, where we placed arrays of six pan traps (6 9 4 = 24 total traps per site visit), in alternating colors of fluorescent blue, fluorescent yellow and white (Westphal & Bom- marco, 2008; Fig. S1b-e). Two of the four arrays also included a blue- vane trap (manufactured by Springstar), which may be more efficient at trapping fast-flying or large-bodied bees. We left traps to collect bees for 24 hr. We visited all 36 sites throughout the growing season in each of 3 years (2013–2015), in 3–5 sampling rounds per year for a total of 11 rounds extending from April to early October.

Bee specimens are fully curated and currently stored at Rutgers University. We identified bee species based on published taxonomic revisions (Bouseman & LaBerge, 1979; Coelho, 2004; Gibbs, 2011).

We believe that the main driver of this pattern is the removal of a temporal constraint on resource availability, and propose that this could be a general driver of community change in anthropogenic landscapes (Harrison & Winfree, 2015). In our system, the transition from temperate forest to agricultural and urban land use results in expanding the period of high light availability from springtime to the entire growing season, thereby also expanding the period of floral resource availability for bees (Motten, 1986; Ten Brink, Hendriksma, & Bruun, 2013). porttitor. Donec laoreet nonummy augue. Suspendisse dui purus, scelerisque at, vulputate vitae, pretium mattis, nunc. Mauris eget neque at sem venenatis eleifend. Ut nonummy. Fusce aliquet pede non pede. Suspendisse dapibus lorem pellentesque magna. Integer nulla. Donec blandit feugiat ligula. Donec hendrerit, felis et imperdiet euismod, purus ipsum pretium metus, in lacinia nulla nisl eget sapien.

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METHOLOGICAL CONSIDERATIONS

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We tested for different trait compositions across land use types using fourth-corner tests (R package ade4; Dray & Dufour, 2007). The fourth-corner test calculates the correlation between species' traits and the average environmental conditions of sites occupied by each species (i.e., the level of association of a species with each of our three categorical land use types), weighting by species' abun- dances (Dray & Legendre, 2008). We then tested the significance of the observed trait-environment correlations by randomizing land use type across replicate sites. This null model is sufficient to determine if different land use types have different trait compositions, which is our main question. However, randomly assigned null traits may pro- duce similar trait–environment correlations that reflect other compo- sitional differences between land use types, including differences in richness and abundance, species pool sizes, and patterns of beta diversity. In order to interpret our observed changes in trait compo- sition as evidence for ecological links between land use and traits per se, we used a second null model randomizing trait states across species. To control for autocorrelation in trait states among closely related species (Webb, Ackerly, McPeek, & Donoghue, 2002), we constrained species randomizations so that trait values were more likely to be exchanged between more closely related species (Har- mon & Glor, 2010; Lapointe & Garland, 2001). Using this null model in context of fourth-corner analysis has been recently suggested (ter Braak, Peres-Neto, & Dray, 2017), but to our knowledge has not yet been implemented. To calculate transition probabilities in the permu- tations, we used a species-by-species phylogenetic distance matrix based on the published genus-level bee phylogeny (Hedtke et al., 2013). The phylogenetic permutation method requires setting a parameter k ranging from 1 to ∞, where it converges with the stan- dard, phylogenetically uninformed species permutation model. We use k = 1 for the most conservative (constrained) null. We used 9,999 randomizations and only interpreted correlations between traits and land use types (or taxonomic families and land use types) if they were significant in both null model tests (ter Braak, Cormont, & Dray, 2012). We used a parallel analysis to analyze the relation- ships between taxonomic groups (genera and families) and land use.

In order to visualize trait composition, we calculated the commu- nity weighted mean (CWM) of each of our six trait values across species within each site. CWM is simply the mean of trait values across species weighted by the relative abundance of each species, and is closely related to fourth-corner analysis (Peres-Neto, Dray, & ter Braak, 2016).

3 | **RESULTS**

3.1 | Abundance and richness

We did not detect differences in the abundance and richness of bee community samples among different land use types, when averaging across time-of-year (Tables 1 and S4). However, forested and anthropogenic landscapes differed strongly in how abundance and richness changed within sites throughout the growing season. For abundance in forest, the coefficient on the first-order Julian day-of- year term (doy) was negative, while the coefficient on the second- order term (doy2) was positive, indicating a convex polynomial rela- tionship with Julian day-of-year (Table 1).

DISCUSSION

Recent research in global change ecology questions to what extent anthropogenic land use causes loss of abundance and species rich- ness, vs. replacement of original assemblages with differently adapted species (Dornelas et al., 2014; McGill et al., 2015; Newbold et al., 2015; Vellend et al., 2013). Here we explore this question for pollinators at large spatial scales for the first time. We did not detect a loss of bee abundance or species richness in anthropogenic land- scapes, suggesting that there was a preexisting pool of native spe- cies that can use these habitats. In contrast, we found dramatic differences between natural and anthropogenic landscapes in com- munity phenology, species and phylogenetic composition, and spe- cies traits. Specifically, the dominant species in the native forest landscapes are solitary spring-flying bees and their associated brood parasites. In agricultural and urban landscapes these species are replaced by late-season bees from different phylogenetic lineages.
We believe that the main driver of this pattern is the removal of a temporal constraint on resource availability, and propose that this could be a general driver of community change in anthropogenic landscapes (Harrison & Winfree, 2015). In our system, the transition from temperate forest to agricultural and urban land use results in expanding the period of high light availability from springtime to the entire growing season, thereby also expanding the period of floral resource availability for bees (Motten, 1986; Ten Brink, Hendriksma, & Bruun, 2013). Accordingly we found that bee abundance and rich- ness were concentrated in springtime in forests (April and May), but evenly distributed throughout the growing season (April–September) in open anthropogenic landscapes. Analogously, in arid regions where native plant growth is constrained by seasonal rainfall, the growing season in agricultural and urban land use is extended by irri- gating crops and ornamental plants (Buyantuyev & Wu, 2012; Leong & Roderick, 2015). In these systems, researchers have observed cor- responding temporal changes in abundance and richness of associ- ated insect communities (Gotlieb, Hollender, & Mandelik, 2011; Leong & Roderick, 2015; Neil, Wu, Bang, & Faeth, 2014).

Given that forest covered most of the landscape before the expan- sion of European settlements (Rudel et al., 2005), what are the origins of the native, late-season, open-habitat species? Some may have evolved as forest gap and riverine meadow specialists before finding themselves preadapted to the marginal or early-successional conditions common in anthropogenic habitats, as has been proposed for open- habitat species in previously forested regions of Europe (Klemm, 1996). Others may have evolved in biogeographic regions that are naturally open; for example, the squash specialist Peponapis pruinosa (Say) was originally restricted to southeastern United States and Mexico but is now common in northeastern agricultural landscapes due to widespread cultivation of its preferred host plant (Lopez-Uribe, Cane, Minckley, & Danforth, 2016). Similar origin stories have been suggested for birds and plants that currently depend on anthropogenic open habitats in both temperate and tropical regions (Foster & Motzkin, 2003; Marks, 1983; Mayfield et al., 2005). The conservation value of native biodiver- sity associated with anthropogenic habitats is a matter of debate, with high value generally ascribed to species that are threatened and declin- ing, unique to a small region, or perceived to be "natural" or what "should" occupy sites in the absence of (continued) anthropogenic pres- sure (McGill et al., 2015). In better-studied plant and bird taxa, the con- servation value of open anthropogenic-associated assemblages is generally considered high in temperate regions with a long history of human land use, where baselines for "natural" biodiversity likely shifted long before the earliest reliable records (Foster & Motzkin, 2003; Stor- key, Meyer, Still, & Leuschner, 2012). In contrast, in tropical forested regions, the open-habitat assemblages are considered to be early-suc- cessional, weedy species of low conservation value (Frishkoff et al., 2014; Tabarelli et al., 2012), probably because the relative value of pri- mary forest is so high (Gibson et al., 2011).

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(54) **SYSTEM ENABLING CONSTANT FORCE DETACHABLE INTERLOCK**

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(57) **ABSTRACT**

An image compression technique in which patterns identified, the means of separating the image components, the parameterization of the patterns, and the lower level numerical encodings are all designed around a narrow class of images, such as two-dimensional projections of three-dimensional visualizations of data generated by numerical weather simulations. The process analyzes an image in terms of perceptual constructs of the human visual system and searches for patterns among analyzed abstractions of the image. The image is then described in terms of the perceptual constructs and the patterns found among them. The image is re-represented by describing the image as a collection of parameterized versions of the patterns prevalent in that class of image. A resulting description is taken outside of the context of abstract patterns. Redundancies in the description are looked for and the data is re-represented so as to eliminate the redundancies and compress the description.

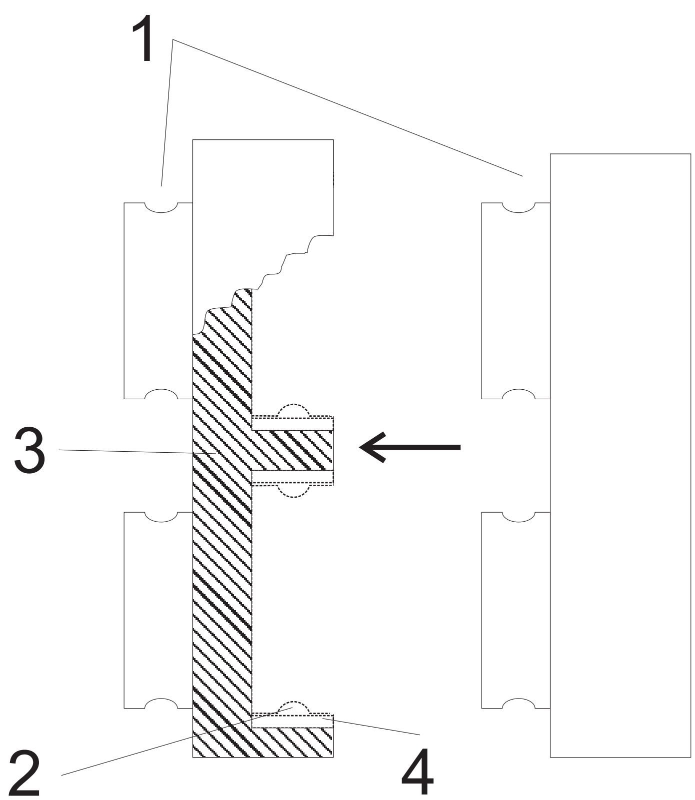


Figure 1

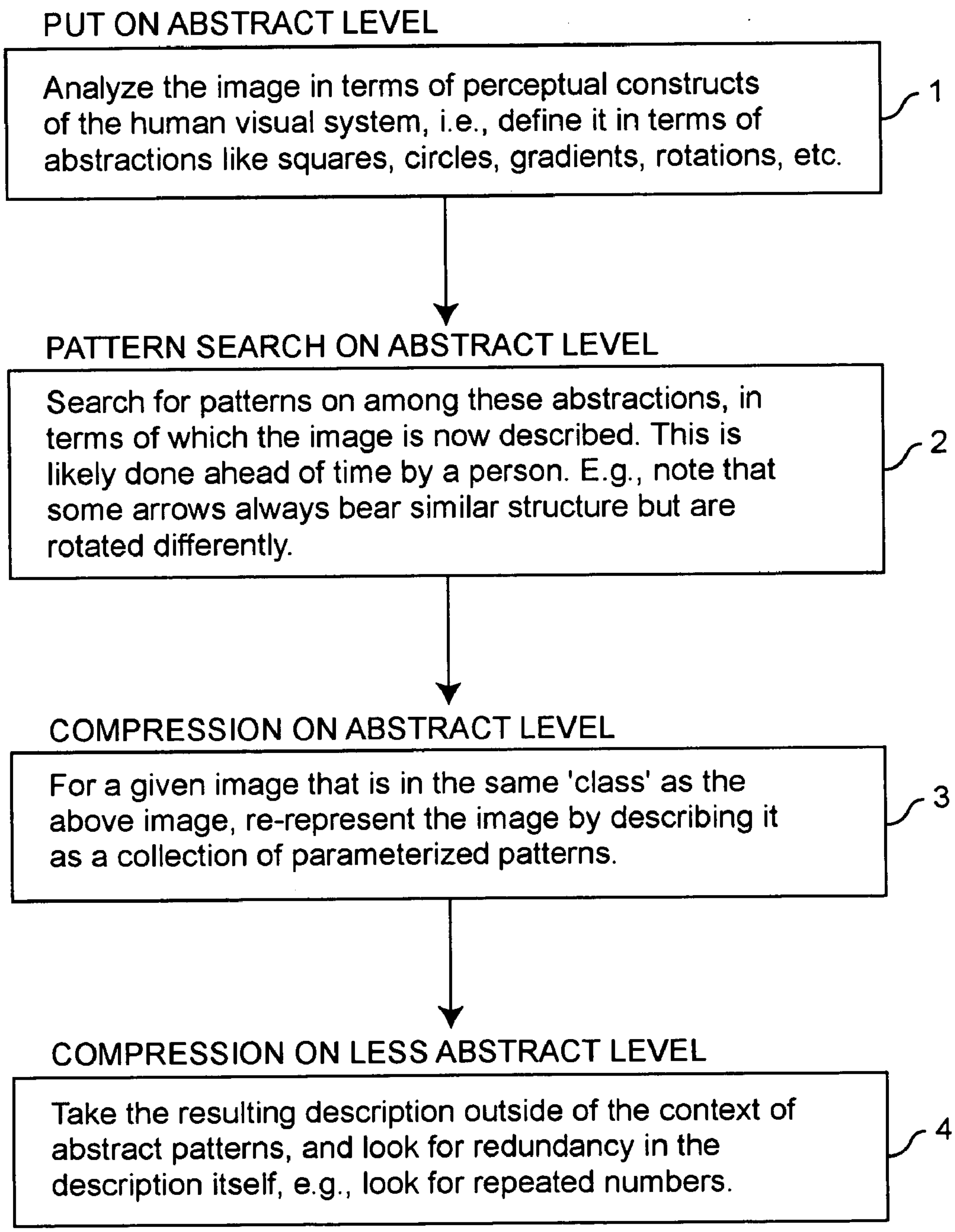

PUT ON ABSTRACT LEVEL
Analyze the image in terms of perceptual constructs of the human visual system, i.e., define it in terms of abstractions like squares, circles, gradients, rotations, etc.
1
PATTERN SEARCH ON ABSTRACT LEVEL
Search for patterns on among these abstractions, in terms of which the image is now described. This is likely done ahead of time by a person. E.g., note that some arrows always bear similar structure but are rotated differently.
2
COMPRESSION ON ABSTRACT LEVEL
For a given image that is in the same 'class' as the above image, re-represent the image by describing it as a collection of parameterized patterns.
3
COMPRESSION ON LESS ABSTRACT LEVEL
Take the resulting description outside of the context of abstract patterns, and look for redundancy in the description itself, e.g., look for repeated numbers.
4

Figure 2

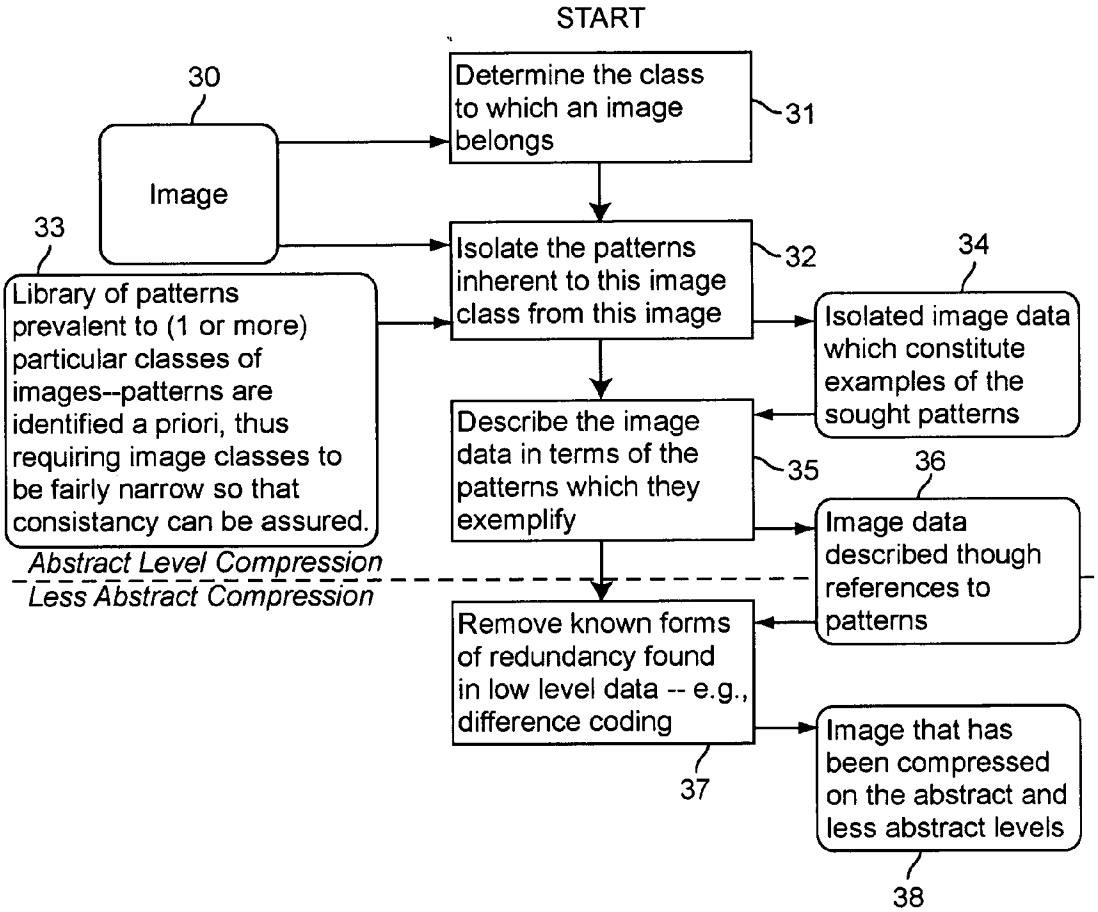
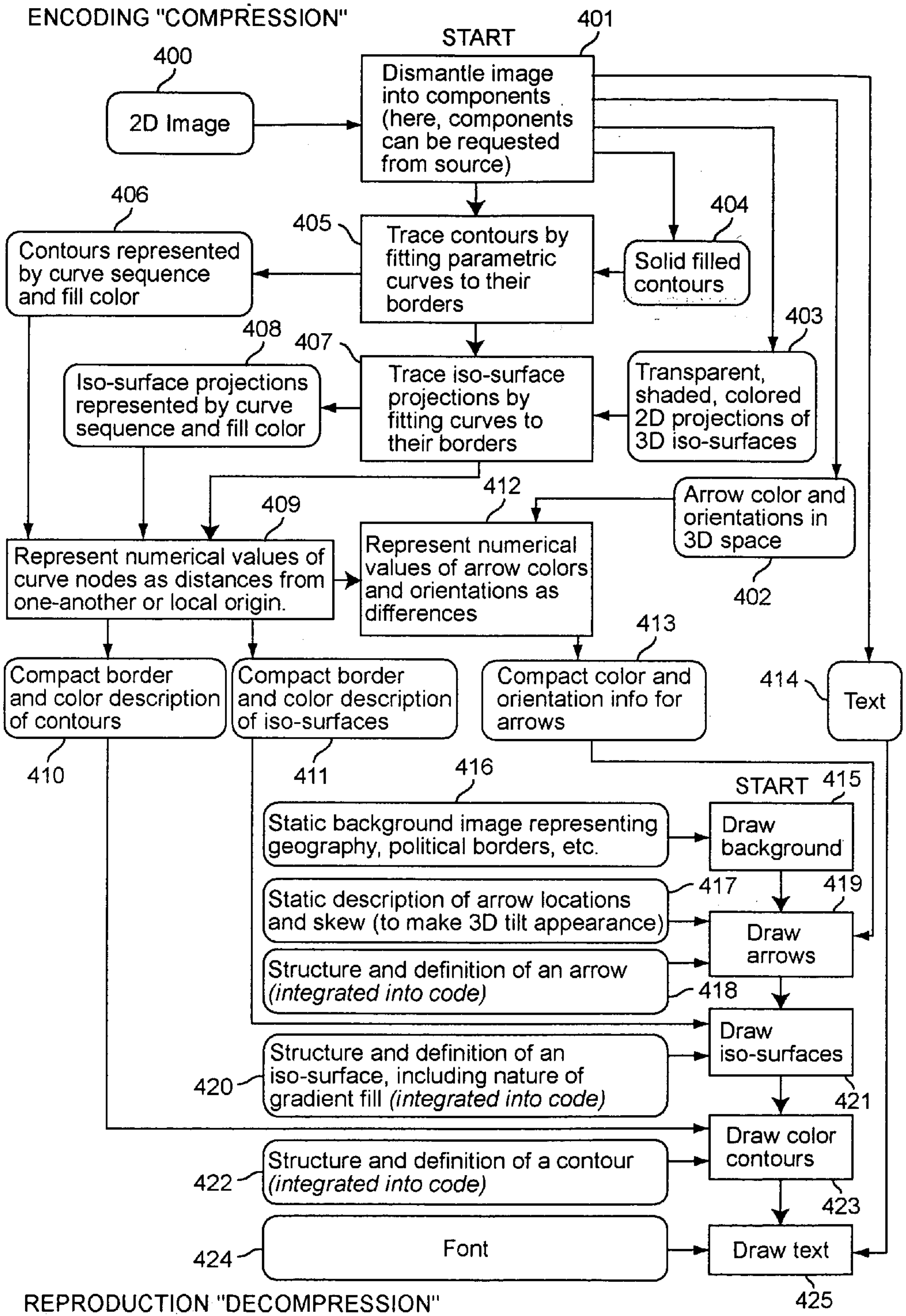

START
Determine the class to which an image belongs
31
30
Image
Isolate the patterns inherent to this image class from this image
32
33
Library of patterns prevalent to (1 or more) particular classes of images--patterns are identified a priori, thus requiring image classes to be fairly narrow so that consistancy can be assured.
34
Isolated image data which constitute examples of the sought patterns
Describe the image data in terms of the patterns which they exemplify
35
36
Image data described though references to patterns
Abstract Level Compression
Less Abstract Compression
Remove known forms of redundancy found in low level data -- e.g., difference coding
37
Image that has been compressed on the abstract and less abstract levels
38

Figure 3



ENCODING "COMPRESSION"
START
401
400
2D Image
Dismantle image into components (here, components can be requested from source)
406
405
404
Contours represented by curve sequence and fill color
Trace contours by fitting parametric curves to their borders
Solid filled contours
408
407
403
Iso-surface projections represented by curve sequence and fill color
Trace iso-surface projections by fitting curves to their borders
Transparent, shaded, colored 2D projections of 3D iso-surfaces
412
409
Arrow color and orientations in 3D space
Represent numerical values of curve nodes as distances from one-another or local origin.
Represent numerical values of arrow colors and orientations as differences
402
413
Compact border and color description of contours
Compact border and color description of iso-surfaces
Compact color and orientation info for arrows
414
Text
410
411
416
START
415
Static background image representing geography, political borders, etc.
Draw background
417
419
Static description of arrow locations and skew (to make 3D tilt appearance)
Draw arrows
Structure and definition of an arrow (integrated into code)
418
Draw iso-surfaces
420
Structure and definition of an iso-surface, including nature of gradient fill (integrated into code)
421
Draw color contours
422
Structure and definition of a contour (integrated into code)
423
424
Font
Draw text
REPRODUCTION "DECOMPRESSION"
425

Figure 4

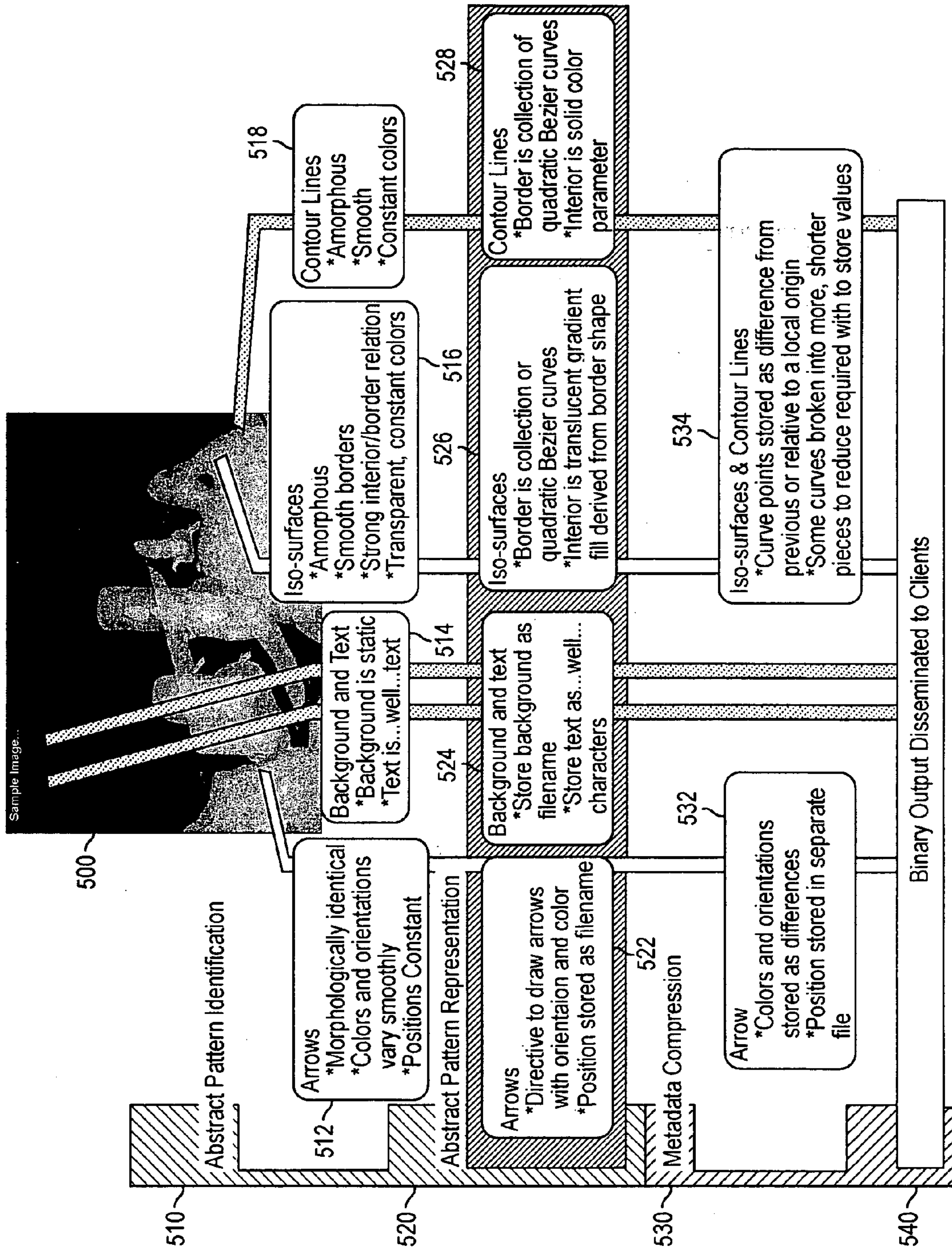

500
Sample Image...
510
Abstract Pattern Identification
512
Arrows
*Morphologically identical
*Colors and orientations vary smoothly
*Positions Constant
514
Background and Text
*Background is static
*Text is...well...text
516
Iso-surfaces
*Amorphous
*Smooth borders
*Strong interior/border relation
*Transparent, constant colors
518
Contour Lines
*Amorphous
*Smooth
*Constant colors
520
Abstract Pattern Representation
522
Arrows
*Directive to draw arrows with orientaion and color
*Position stored as filename
524
Background and text
*Store background as filename
*Store text as...well... characters
526
Iso-surfaces
*Border is collection or quadratic Bezier curves
*Interior is translucent gradient fill derived from border shape
528
Contour Lines
*Border is collection of quadratic Bezier curves
*Interior is solid color parameter
530
Metadata Compression
532
Arrow
*Colors and orientations stored as differences
*Position stored in separate file
534
Iso-surfaces & Contour Lines
*Curve points stored as difference from previous or relative to a local origin
*Some curves broken into more, shorter pieces to reduce required with to store values
540
Binary Output Disseminated to Clients

Figure 5

NARROW FIELD ABSTRACT META-DATA IMAGE COMPRESSION

BACKGROUND OF THE INVENTION

[0001] 1. Field of the Invention

[0002] The present invention generally relates to a technique for two-dimensional image compression and, more particularly, to an image compression technique which represents a narrow class of images with very high efficiency. The invention has particular advantage in the transmission of specialized data through low bandwidth channels.

[0003] 2. Background Description

[0004] Traditional strategies for two- and three-dimensional visualization have been effective in the development of interactive applications utilizing either workstation- or PC/game-class three-dimensional graphics systems with sufficient bandwidth for timely access to the data of interest. When remote access to the visualizations is required, the limited bandwidth becomes the primary bottleneck. To address this, data compression is considered as way of more effectively leveraging fixed and limited bandwidth for data transmission.

[0005] Data compression focuses largely on pattern manipulation. This is consistent with the entropy maximization principle of information theory. Clearly, by maximizing entropy, the number of patterns in a data stream are reduced, thereby removing redundancy and yielding a less bulky representation of the data. This operation entails the identification and re-representation of the pattern, the former being of particular difficulty. Hence, it is desirable to have the pattern identified a priori. For example, consider difference pulse code modulation (DPCM), in which the pattern of relative nearness of each succeeding value to its predecessor is exploited. By representing the data to remove the pattern, substantial reductions in required space may be made.

[0006] The human visual system is a source of the aforementioned pre-identified patterns for use in compression, some of which may be hierarchical. Therefore, levels of abstraction are introduced. The higher the level of abstraction, the more layers of human perceptual constructs are available to the compressor as starting points for pattern searching, and the closer the data are to their perceived meaning. In the present work, the image data are raster images depicting two-dimensional (2-D) projections of three-dimensional (3-D) scenes. Among the levels of abstraction for these data are bit-stream, pixel-map, 2-D geometry, and 3-D surfaces. Each implies different sets of redundancy when different sets of human perceptual constructs are used as starting points. For example, at the 2-D geometry level, a rectangular construct may be identified, and then re-represented as a directive for a rectangle followed by parameters.

[0007] At the least abstract (bit stream) level, virtually no human perceptual constructs are employed as a starting point for other patterns to be identified. Still, some patterns among the bits may be found, as seen by the performance of a generic compression algorithm (e.g., the LZW compression scheme).

[0008] At the pixel map level, some perceptual constructs are employed. These include the grid organization of the color values, the particular color space used, etc. In combination, simple patterns such as constant color areas of the image can be represented in a more compact way. The Joint Photographic Experts Group (JPEG) compression algorithm operates at this level by utilizing the reduced human perception of higher spatial frequencies of intensity values.

[0009] The 2-D geometry level of abstraction takes the context at the pixel map level and adds the perceptual constructs of geometry, such as lines, polygons, curves, etc. These patterns build on the basic constructs of color spaces, grids, etc. from the previous level. It is important to differentiate compression at this level from the common reverse-rasterization seen in the tracing applications available from companies like Corel and Adobe. The distinction is that the tracer uses a generic set of geometric patterns, while the compressor uses a set of geometric patterns most likely to be found in the images being compressed. Essentially, this is a custom metadata format, which will be very useful for compression of images having very similar types of geometric patterns. The 3-D surface level takes the geometric constructs identified at the previous level and matches the geometric patterns to projections of 3-D surfaces.

SUMMARY OF THE INVENTION

[0010] It is therefore an object of the present invention to provide an image compression technique in which patterns identified, the means of separating the image components, the parameterization of the patterns, and the lower level numerical encodings are all designed around a narrow class of images.

[0011] According to one application of the invention, images of the class exemplified by two-dimensional projections of three-dimensional visualizations of data generated by numerical weather simulations are compressed. These images are ideal candidates for compression at several levels of abstraction, especially the geometric. They compress well at the geometric level for several reasons: one being the lack of noise in the images, which increases both the reliability and simplicity of algorithms used to analyze the geometric structures of the image. Additionally, the ability to obtain only some elements of the image at a time, access to original geometry, etc., vastly simplifies the process of breaking the image into components.

[0012] Specifically, these components of which the image is composed tend to consist of several basic elements including 2-D projections of translucent 3-D isosurfaces, projections of color-filled contour bands, arrows facing various directions in 3-D space, text, and a constant background image.

[0013] One of the components for which the conception of a compressed representation is most beneficial is the 2-D projections of 3-D isosurfaces. There are several patterns that have been identified within these projections on the 2-D geometric abstract level. One is the nature of the projections' borders: these borders usually tend to be very smooth, and apparently continuous. Additional pattern is seen within the interior of these projections: the color is constant, and with a substantially constant transparency. Also, these projections represent generally convex 3-D objects, and as such their interior fill has a shaded appearance, that one can, to a high degree, approximate from nothing more than the shape of their borders. These patterns are therefore exploited by re-representation in several ways: The smoothly curved borders are re-represented as sequences of second order Bèzier curves; and the interior is represented by only a color parameter, since the shaded, translucent fill (which is derived entirely from the given border shape) is inherent to the definition of the "isosurface projection" pattern. Indeed, the nature of the isosurface projection can be said to be a pattern, composed of the lower level patterns given above, which themselves may or may not require additional parameters.

[0014] Color filled contours are compressed in much the same way as the isosurfaces, except their interiors are a solid color, not a gradient. The 2-D projections of arrows pointing to different directions in 3-D space are compressed at the 3-D surface level in a very simple way. The pattern of their morphological constancy from arrow to arrow allows them to be represented by a directive to generate an arrow, followed by a color and direction vector, the values for which are extracted directly from the numerical weather model. Additionally, the locations of the arrows remain constant from image to image (for a given geographical area), and therefore need only be transmitted for the first image; each subsequent image need only state which geography it relates to. Thus, a simple temporal pattern in the nature of the spatial organization of the arrows is also exploited.

[0015] The result of this re-representation of the image data is a custom metadata image format, which eliminates the pixel-map level of abstraction. It also introduces a new, lower level of abstraction, the metadata structures level. Here, all of the actual pattern references and parameters exist. Much like with the geometric abstract level, there is a considerable amount of pattern when the data are viewed on this level as well. For example, each of the control and end points for the Bèzier curve sequences tend to be located relatively near the previous point in each such sequence. Thus, this pattern is exploited by the simple technique of storing, for each control or end point, the vector distance from the previous point, or the vector distance from some common local origin—whichever will result in a more efficient representation. Similarly, the data representing the colors and directions for the arrows is stored by the difference from the previous, adjacent value, rather than in absolute terms. Techniques like these are critical in order to ensure that the image is maximally compressed, and not simply compressed on one level. When compressed at the abstract levels alone, one sample image required 3522 bytes. When additional compression at the metadata structures level was incorporated, the size was reduced to 1814 bytes. When this image was reconstructed and compressed with the JPEG algorithm at the lowest quality level with vertical subsampling, the size was 9915 bytes. When compressed with JPEG at a more reasonable quality level, the image was 16447 bytes. In contrast, compression on the bit-stream level alone by means of WinZip's highest compression level applied to a bitmap version of the image yielded a file of 36269 bytes. Thus, we see the benefit introduced by engineering an image compression scheme specifically around a narrow class of images that the scheme is intended to compress: It allows compression on the more abstract levels of representation of the data. One thus achieves dramatically better compression ratios, which are only further increased by performing an additional compression operation on the underlying data structures of the abstract, compressed representation.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016] The foregoing and other objects, aspects and advantages will be better understood from the following detailed description of a preferred embodiment of the invention with reference to the drawings, in which:

[0017] **FIG. 1** is an image illustrating a reconstruction of a data file representing a 2-D projection of a 3-D image compressed using the technique according to the present invention;

[0018] **FIG. 2** is a high level flow diagram of the compression technique according to the present invention;

[0019] **FIG. 3** is a data flow diagram of the compression stages according to the compression technique of the invention;

[0020] **FIG. 4** is a detailed flow diagram of the compression technique of the invention as specifically reduced to practice; and

[0021] **FIG. 5** is a data flow diagram illustrating the compression technique of the invention.

DETAILED DESCRIPTION OF A PREFERRED EMBODIMENT OF THE INVENTION

[0022] Referring again to the drawings, and more particularly to **FIG. 2**, there is shown, in general terms, the basic idea of the invention. The process begins in step **1** by analyzing the image in terms of perceptual constructs of the human visual system; i.e., the image is defined in terms of abstractions, such as squares, circles, gradients, rotations, and the like. Next, in step **2**, patterns are searched for among these abstractions (the abstractions are also, of course, patterns). The image is now able to be described in terms of a hierarchy of patterns. The lower level patterns are the perceptual constructs of the visual system; the higher level patterns are the patterns that exist among the lower ones. The immense difficulty of this task, combined with its only having to be performed at the inception of the compression scheme as a whole, makes it expedient for it to be performed by a person ahead of time. For example, consider the identification that some arrows always bear similar structure but are rotated differently. The analysis of the underlying geometry of the arrows (lines, fill colors, etc.) is the step of putting the image in the context of the patterns of the human visual system; the identification that a 3-D rotation can represent the non-color differences between any such "arrow" is the determination of the higher order pattern. In step **3**, for a given image that is in the same "class" as the image(s) on which the above analysis was performed, the image is re-represented by describing it as a collection of parameterized versions of the above patterns. Finally, in step **4**, this resulting description is taken outside of the context of abstract patterns and redundancies in the description are sought. This search is performed by looking at the actual numerical values, etc., by which the data are now represented. For example, a given numeric value may be recorded several times in a row, which would be an easily removable redundancy.

[0023] The data flow is shown in **FIG. 3**. The image **30** is input, and the process starts in function block **31** by determining the class to which the input image belongs. This analysis is required so that the system performing the analysis knows what patterns to expect—and how to identify them—within this image. The image **30** is further analyzed in function block **32** where the patterns inherent to this image class are isolated. This is done according to the manner prescribed for that particular class of image, by access to a library **33** of patterns prevalent to particular classes of images—in particular, the class to which this image belongs. Such patterns are identified a priori, thus requiring image classes to be fairly narrow so that consistency can be assured; i.e., if the image class is wide, then the patterns present, and the means of identifying them may change considerably from image to image. At this point, the image data that correlate to the various sought patterns are isolated and stored separately. This may involve complex steps of image analysis, or simply requesting certain data from the system that generated the image. These isolated image data are temporarily stored at **34**. In function block **35**, the image data are described in terms of the patterns which they exemplify. That is, the data themselves are discarded in favor of parameterized pattern references that, when followed through, produce something sufficiently close to the original data. These new image data—described through references to patterns—are temporarily stored at **36**. Then, in function block **37**, known forms of redundancy found in the low level data are removed. The output at **38** is the image that has been compressed on the abstract and less abstract levels.

[0024] The process, in more detail, as applied to a specific reduction to practice is shown in **FIG. 4**. The 2-D image **400** is input to start the process. In function block **401**, the input image is dismantled into components. These include arrow color and orientations in 3-D space **402**, transparent, shaded, colored 2-D projections of 3-D iso-surfaces **403**, and solid filled contours **404**. The process of dismantling the image into components is performed, in this case, by requesting each desired component from the computer system that generated the image which is under analysis. In function block **405**, the contours are traced by fitting parametric curves to their borders. In this case, the borders are fit with sequences of second-order Bèzier curves. The contours, each of which is now represented by a curve sequence and fill color, are temporarily stored at **406**. Next, in function block **407**, the iso-surface projections are traced by fitting curves to their boundaries, as was done with the contours. The iso-surface projections, each of which is represented by a curve sequence and fill color, are temporarily stored at **408**. Next, in function block **409**, the data temporarily stored at **406** and **408** are accessed and the data they contain, numerical values of the coordinates of the curve nodes, are processed so as to minimize, or at least reduce, the size of the values that must be recorded. This re-representation can be performed by exploiting the pattern that each curve node is relatively near its predecessor, by storing only the vector distance of a given point from the prior point. Alternately, point coordinates are be represented as distances from a local bottom-left origin, which allows the removal of the sign bit from the values stored that way. For each curve sequence, both of these techniques are evaluated to determine which provides the maximum efficiency. This newly generated, compact border and color description of contours are temporarily stored at **410**, and of the equivalent for the iso-surfaces are temporarily stored at **411**. In function block **412**, the data stored at **402** is accessed and the numerical values of arrow colors and orientations are represented as differences from the previous value—which exploits the relative nearness of each value to its predecessor. This compact color and orientation information for the arrows are temporarily stored at **413**.

[0025] The process in function block **401** also separates text, which is again given separately by the system that generates the images to begin with. It is temporarily stored at **414**. The data temporarily stored at **410**, **411**, **413**, and **414** is accessed in the next stage of the scheme, the decompression phase. In function block **415**, data representing the static background of the image representing geography, political borders, and the like are accessed at **416** and the background is drawn. In this embodiment, the geopolitical background is sent to the user only once, and kept in a cache. Similarly, the static description of arrow locations and skew (the skew is used to give the appearance of a 3-D tilt) at **417** is also sent only once. In order to actually draw the arrows, the location and skew information of **417**, as well as the structure and definition of an arrow (integrated into code) at **418**, and the data at **413** are accessed and then the arrows are drawn in function block **419**. The data (including border description and fill color) stored at **411** and the structure and definition of an iso-surface, including the nature of the gradient fill (integrated into code) at **420**, are accessed in function block **421** to draw the iso-surfaces. The data stored at **410** and the structure and definition of a contour (integrated into code) at **422** are accessed in function block **423** to draw color contours. Finally, the text stored at **414** and font at **424** are accessed to draw the text in function block **425**.

[0026] The process is summarized in **FIG. 5**. An image **500**, for example the image of **FIG. 1**, is input. This image is a 2-D projection of 3-D weather simulation which is characterized by image components that are readily separable with a static background for a given geography. The first level of compression **510** is abstract pattern identification. This comprises separation of arrows **512**, background and text **514**, iso-surfaces **516**, and contour lines **518**. The arrow are morphologically identical, their colors and orientations vary smoothly, and their positions are constant. The background is static for the given geography and may include political boundaries or other indicia. The iso-surfaces are amorphous and characterized by smooth borders, strong interior/border relations, and transparent, constant colors. The contour lines are also amorphous and characterized by smooth lines and constant colors. The next level of compression **520** is abstract pattern representation. This includes arrows **522**, background and text **524**, iso-surfaces **526**, and contour lines **528**. At this level of the compression technique, arrows are represented by a directive to draw arrows with an orientation, color and position, and the representation stored. The background is stored as a file name, and the text is stored as characters. The iso-surfaces borders are represented as a collection of quadratic Bèzier curves with translucent gradient interior fill derived from border shapes. The contour lines are represented as a collection of quadratic Bèzier curves with an interior solid color. The final level of compression **530** is metadata compression. This includes arrows **532** and iso-surfaces and contour lines **534**. The colors and orientations of arrows are stored as differences, and their positions are stored in a separate file. The curve points (or nodes) of iso-surfaces and contour lines are stored as differences from previous points or relative to a local origin, and some curves are broken into more and thereby shorter pieces. The final binary output **540** is disseminated to clients which can be done rapidly over narrow bandwidth communication links.

[**0027**] While the invention has been described in terms of a single preferred embodiment, those skilled in the art will recognize that the invention can be practiced with modification within the spirit and scope of the appended claims.

Having thus described my invention, what I claim as new and desire to secure by Letters Patent is as follows:

1. A method of image compression comprising the steps of:

analyzing an image in terms of perceptual constructs of the human visual system;

searching for patterns among analyzed abstractions of the image;

describing the image in terms of the perceptual constructs and the patterns found among them;

for a given image that is in a same "class" as the image, re-representing the image by describing the image as a collection of parameterized versions of the patterns prevalent in that class of image;

taking a resulting description outside of the context of abstract patterns; and

looking for redundancies in the description, then re-representing the data so as to eliminate the redundancies and thereby compress the description.

2. The method of image compression recited in claim 1, wherein the patterns identified, image components, parameterization of patterns, and lower level numerical encodings are all designed around images belonging to a narrow class of images.

3. The method of image compression recited in claim 2, wherein the narrow class of images are two-dimensional projections of three-dimensional visualizations of data generated by numerical weather simulations.

4. The method of image compression recited in claim 1, wherein the images are of the class exemplified by 2-D projections of 3-D weather model images, said method further comprising the steps of:

re-representing entities with smoothly curved borders and an interior fill that can be parameterized and is either largely derivable from other image data or constant, as curve sequences and parameters required to describe the interior; and

re-representing entity groups with constant structure that vary only in terms of a spatial parameter as references to the entity group, and a list of the values for the required parameters, each value being for each subsequent entity for the group.

5. The method of image compression recited in claim 4, wherein the spatial parameter is orientation or color.

6. A method of compression of two-dimensional projections of three-dimensional visualizations of image data comprising the steps of:

inputting a two-dimensional image;

dismantling the two-dimensional image into components;

tracing contours by fitting parametric curves their borders;

tracing iso-surface projections by fitting curves to their borders;

representing numerical values of curve nodes as distances from one another or a local origin; and

storing compact border and color description of contours and compact border and color description of iso-surfaces.

7. The method of compression of two-dimensional projections of three-dimensional visualizations of image data recited in claim 6, wherein the data are generated by numerical weather simulations.

8. The method of compression of two-dimensional projections of three-dimensional visualizations of image data recited in claim 7, wherein the step of dismantling the input image into components includes separation of solid filled contours, transparent, shaded colored two-dimensional projections of three-dimensional iso-surfaces, arrow color and orientations in three-dimensional space, and text and further comprising the steps of:

representing numerical values of arrow colors and orientations as differences; and

storing compact color and orientation information for arrows and separated text.

9. The method of compression of two-dimensional projections of three-dimensional visualizations of image data recited in claim 8, further comprising the steps of:

receiving the compact border and color description of contours, the compact border and color description of iso-surfaces, the compact color and orientation information for arrows, and text; and

decompressing the received information to generate a representation of the original two-dimensional image.

10. The method of compression of two-dimensional projections of three-dimensional visualizations of image data recited in claim 9, wherein the step of decompressing comprises the steps of:

accessing a static background image representing geography and drawing the background;

accessing a static description of arrow locations and skew, structure and definition of an arrow, and received compact color and orientation information for arrows and drawing arrows;

accessing structure and definition of an iso-surface and received compact border and color description of iso-surfaces and drawing iso-surfaces;

accessing structure and definition of a contour and received compact border and color descriptions of contours and drawing color contours; and

accessing received text and drawing text.

* * * * *

stored as differences, and their positions are stored in a separate ?le. The curve points (or nodes) of iso-surfaces and contour lines are stored as differences from previous points or relative to a local origin, and some curves are broken into more and thereby shorter pieces. The ?nal binary output 540 is disseminated to clients Which can be done rapidly over narroW bandwidth communication links.

[0027] While the invention has been described in terms of a single preferred embodiment, those skilled in the art Will recognize that the invention can be practiced With modi?cation Within the spirit and scope of the appended claims.

Having thus described my invention, What I claim as neW and desire to secure by Letters Patent is as folloWs:

1. A method of image compression comprising the steps of:

analyZing an image in terms of perceptual constructs of the human visual system;

searching for patterns among analyZed abstractions of the image;

describing the image in terms of the perceptual constructs and the patterns found among them;

for a given image that is in a same "class" as the image, re-representing the image by describing the image as a collection of parameteriZed versions of the patterns prevalent in that class of image;

taking a resulting description outside of the context of abstract patterns; and

looking for redundancies in the description, then re representing the data so as to eliminate the redundan cies and thereby compress the description.

2. The method of connecting recited in claim 1, where small air bubbles are incorporated into the Thin Film plastic wall of the Sending Block;

3.The method of claim 3, where the bubbles fit into corresponding indentations in the Receiving Block;

4. The method of image compression recited in claim 1, Wherein the images are of the class exempli?ed by 2-D projections of 3-D Weather model images, said method further comprising the steps of:

re-representing entities With smoothly curved borders and an interior ?ll that can be parameteriZed and is either largely derivable from other image data or constant, as curve sequences and parameters required to describe the interior; and

re-representing entity groups With constant structure that vary only in terms of a spatial parameter as references to the entity group, and a list of the values for the required parameters, each value being for each subse quent entity for the group.

5. The method of image compression recited in claim 4, Wherein the spatial parameter is orientation or color.

6. A method of compression of tWo-dimensional projec tions of three-dimensional visualiZations of image data comprising the steps of:

inputting a tWo-dimensional image;

dismantling the tWo-dimensional image into components;

tracing contours by ?tting parametric curves their borders;

tracing iso-surface projections by ?tting curves to their borders;

representing numerical values of curve nodes as distances from one another or a local origin; and

storing compact border and color description of contours and compact border and color description of iso-sur faces.

7. The method of compression of tWo-dimensional pro jections of three-dimensional visualiZations of image data recited in claim 6, Wherein the data are generated by numerical Weather simulations.

8. The method of compression of tWo-dimensional pro jections of three-dimensional visualiZations of image data recited in claim 7, Wherein the step of dismantling the input image into components includes separation of solid ?lled contours, transparent, shaded colored tWo-dimensional pro jections of three-dimensional iso-surfaces, arroW color and orientations in three-dimensional space, and teXt and further comprising the steps of:

representing numerical values of arroW colors and orien tations as differences; and

storing compact color and orientation information for arroWs and separated teXt.

9. The method of compression of tWo-dimensional pro jections of three-dimensional visualiZations of image data recited in claim 8, further comprising the steps of:

receiving the compact border and color description of contours, the compact border and color description of iso-surfaces, the compact color and orientation infor mation for arroWs, and teXt; and

decompressing the received information to generate a representation of the original tWo-dimensional image.

10. The method of claim 9 where the Connected Objects are of larger or smaller size than traditional children's toys;

11. The method of accessing a static background image representing geog raphy and draWing the background;

accessing a static description of arroW locations and skeW, structure and de?nition of an arroW, and received compact color and orientation information for arroWs and draWing arroWs;

accessing structure and de?nition of an iso-surface and received compact border and color description of iso surfaces and draWing iso-surfaces;

accessing structure and de?nition of a contour and received compact border and color descriptions of contours and draWing color contours; and

accessing received teXt and draWing teXt.