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Concept Maps

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CONCEPT MAPS

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Abstract

This paper describes a representational mechanism for constructing 3-dimensional large scale spatial organizations suitable for applications in areas such as cartography and land use studies, photo interpretation for reconnaisance and surveillance, and geological modeling for resource analysis. It focuses on the representation and utilization of map information as a knowledge source for photo-interpretation, in particular, the description of a highly detailed, large scale geographic area: Washington, D.C.. Methods of data acquisition, query specification and geometric operations on map data are discussed. These ideas have been implemented into a working map database system, CONCEPTMAP, as a component of MAPS: (Map Assisted Photo-interpretation System), our ongoing research in interactive photo-interpretation work stations.

1. Introduction

Consider the problem of building a system capable of generating answers to representative map database queries such as:[2]

- "How many bridges cross the Potomac River between Virginia and the District of Columbia."
- "Display images of National Airport before 1976."
- "What is the closest building to this geographic point."
- "Where is this geographic point."

Possible solutions to the query problem range from pre-computation and storage of potentially huge numbers of spatial relationships, to dynamic computation involving both costly search and complex geometric analysis. We favor dynamic (on demand) computation of geometric relationships, *constrained* by user defined structuring of map features and utilizing natural spatial decomposition. However, whatever the query resolution mechanism, a representation for the rich variety of man-made and natural features must underlie any such system. Further, in order to be relevent to the needs of the photo-interpreter, the results of the query should be portrayed in terms of the display of digital imagery, at the appropriate image resolution. While many queries can be answered as purely "factual" responses, (ie. *8 bridges cross the Potomac between Virgina and District of Columbia*), in our system we are able to quickly show the user the location, relative position, and scene context directly through our aerial imagery, as well as providing the necessary textual and descriptive information. This is a key point of departure from many "geographical" or "spatial information systems" [3, 4, 5]in that they simply provide tabular lookup for geographic "facts", and vector-based display of digitized map data.

Our map database consists of a collection of *concepts* each describing large spatial features such as political areas (*states, counties, towns...*), business and residential areas, parks and natural features (*rivers, streams, lakes...*). The same *concept* representation is used to hierarchically describe man-made features *airports, power stations, universities, industrial sites...* A window-oriented raster image display facility, BROWSE [9], is the man-machine interface for the concept map database and is used to create, edit, and display concept features superimposed on 2D aerial photography, and to generate arbitrary 3D scene views.

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[2]We are not concerned with the natural language issues of such queries, our query interface is based on a combination of query template matching, geometric specification, and interactive coordinate input through raster image display.

In this paper we will explore many of the issues raised in map feature representation and query resolution, and describe the current implementation of the CONCEPTMAP database of the Washington D.C. area. In the following section we give an overview of the MAPS system components.

2. MAPS Components

MAPS represents ongoing research in the areas of interactive aids for photo-interpretation, image/map spatial databases, and image understanding. Various components of the system have been described in [7] [*integration of terrain, imagery, and map databases*], [8] [*system goals and design*], and [9] [*BROWSE window-oriented display system*]. For completeness we will highlight the major capabilities of the MAPS components, but the reader is referred to the above for more detail.

2.1. Image Database

We have been working with an online database of approximately 40 aerial mapping photographs providing spatial and temporal overlap, centered over the Washington D.C. area. Each photograph has been digitized with a 100 micron aperature to approximately 2200x2200x8bits/pixel. Original photography scales range from 1:12000 to 1:36000, and we have recently acquired and begun to integrate 20 new digitized images at 1:60000 scale into the database. Associated with each image are several files, among which are:

- **scene description file.** Contains scene and image formation information such as *camera type, aircraft platform data, geodetic corner points, digitization data,* and *source of data.*
- **correspondence file.** Contains image/map correspondence points for known ground control points. This file is interactively generated and modified by the image-to-map correspondence component.
- **coefficients file.** Contains image-to-map camera calibration coefficients, error function description, and reference to the associated correspondence file.

2.2. DLMS Database

We have adapted and restructured a geodetic based polygon feature database (DLMS Level I) [1] and a digital terrain elevation database (USGS DTED) provided by the Defense Mapping Agency, to allow for efficient feature access based on geodetic coodinates or feature attributes. This database (DLMS3D) provides a fairly coarse description of major natural and cultural terrain features and is used as a background basis for 3D display of urban scene simulations.

2.3. BROWSE Window Oriented Display

BROWSE is a window-oriented display manager which supports raster image display, overlay of graphical data such as map descriptions and image processing segmentations, and the specification and generation of 3D shaded surface models. Digitized imagery from black and white and color aerial mapping photographs is displayed by BROWSE at multiple levels of resolution and allows for dynamic positioning, zooming, expansion or shrinking of the image window. Map data represented as vectors and polygons can be superimposed on the imagery through image-to-map registration. Access to collateral map databases and terrain models may be accomplished using the BROWSE graphical interface. Finally, the window representation gives a convenient communication mechanism for passing image fragments to image interpretation programs, which generally run as separate processes. The results of such processing can be returned to BROWSE for further processing by the user.

BROWSE is used regularly as a front-end for image processing and database programs in the MAPS system and also as a general purpose image display facility.

2.4. Landmark Database

A landmark database (LANDMARK) containing approximately 180 ground control points over the Washington D.C. area has been created. Each landmark entry consists of the geodetic coordinate *<latitude, longitude, elevation>*, a textual description of the landmark, and a representative image fragment which defines the ground position for the interactive user. Entries in the landmark database may be selected by *name, geodetic location,* or by *interactive menu selection* from a raster display of image fragments.

2.5. Image-to-Map Correspondence

An interactive image-to-map correspondence component (CORRES) uses the landmark database, the image database, and BROWSE window display primitives to allow a user to graphically select a landmark and indicate the corresponding point in the new image. After the specification of the first corresponding point, CORRES can generate an initial guess of the map coverage using *flight line, image scale* and *digitization data* from the scene description file stored in the image database. Landmark candidates are graphically superimposed on the new image, allowing novice users to select landmarks with little domain knowledge. Since each landmark has an associated image fragment we could extend these interactive techniques to a more semi-automatic system which would perform image fragment matching to calculate a set of local correspondence points within the landmark area, possibly resulting in a more robust match.

2.6. Hand Segmentation

An interactive human segmentation system (SEGMENT) was one of the earliest tools developed for the MAPS system. It allows the user to specify the position and shape of a map feature, as well as capabilities to edit and display segmentations in multiple levels of detail. Segmentation files are used as intermediate representations for the map database. Facilities to convert *image based* descriptions into *map based* descriptions or to project map based descriptions onto new imagery are provided.

2.7. Machine Segmentation

An experimental coarse-fine segmentation system (MACHINESEG) using region-growing and edge profile analysis has been successfully used to extract map features such as buildings, roads, and bridges from our aerial imagery. MACHINESEG uses a coarse hand or map segmentation to specify the area within which a detailed machine segmentation should be performed. The user can accept, reject or edit the segmentation descriptions as they are generated.

2.8. Feature Mensuration

A simple image based feature measurement system (PHOTOGRAM) is currently under development to provide accurate map feature ground measurement data for integration with the map database. This system uses the BROWSE window display system and the image database to calculate *linear distance*, *rectangular area*, *polygon area*, and *radial distance*.

3. Map Database

The *concept map* database component of MAPS is central to providing access to imagery, guiding photo interpretation, and processing queries about manmade and natural features. Through the image-to-map correspondence process, map knowledge can be applied to any image, and the spatial relationships of sets of imagery can be established. The concept map provides a framework within which individual map features can be associated with high-level semantic map descriptions. Concept maps capture the spatial arrangement in urban areas of neighborhoods, political, and geographical boundaries. For example, terms such as "Northwest Washington", "Georgetown", "Foggy Bottom", "Alexandria, Virginia" are often used to describe general areas within and around Washington D.C. They provide an important mechanism for symbolic access into an image database, e.g., "display images of Georgetown later than 1976". However, depicting precise boundaries of conceptual features from aerial imagery is a difficult problem. In many cases boundaries are ill-defined and highly dependent on the user's own spatial model, which often corresponds to a hierarchy of *levels of detail* among map features. The CONCEPTMAP database allows users the flexibility of describing this hierarchy in terms of a geodetic coordinate system, independent of any particular image, while using the imagery directly as the medium of input.

Concept map features can be directly used to partition large scale spatial areas based on natural spatial relationships such as *containment*, *subsumed by* and *intersection*. Using these relationships, which often arise in database queries, rather than artificial cellular or raster organizations traditionally used for spatial decomposition appears to better model the performance of human map interpreters. Additionally, as we will describe in Section 6, many queries into the map database can be resolved at the symbolic level through manipulation of spatial relationships without resorting to geometric computations. In the following section we will describe the representation and organization of concepts in the map database.

4. Concept Map Representation

Each entity in the concept map is represented by a concept schema. The schema is given a unique ID by the database and the user specifies a 'symbolic' print name for the concept. Each concept may have one or more role schema associated with it. The practical effect of multiple roles is to allow for differing views of the same geographic concept, ie., "northwest washington" has a roles of *residential area*, as well as *political* while sharing the same 3D map description. A principle role is assigned by the user, indicating a preferred view, or a role whose 3D map description defines the concepts' spatial extent. Figure 1 gives the organization of the concept schema. The CONCEPTMAP database is composed of lists of concept schema, with access functions based on *symbolic name*, *geodetic coordinate* and *spatial relationships*.

4.1. Role Schema

The role schema depicted in Figure 2 contains the definition of a *role name* and further specification by *subrole name*, a description of *role class* (ie., buildings may be *government*, *residential*, *commercial*, etc.). The *role type* attribute addresses the issue of whether the role is *physically* realized in the scene (image), or is a *conceptual* feature such as cultural (neighborhood), political, or geographic boundaries. Further, *role type* allows the user to define a role schema as a collection of *aggregrate* physical or conceptual features. For example, the concept "district of columbia" has role type *aggregrate-conceptual*, with aggregrate roles, "northwest washington", "northeast washington", "southwest washington", and "southeast washington". This mechanism allows the database to *explicitly* represent concepts which are strictly

```
CONCEPT SCHEMA
------------------
|Concept ID       |  <assigned by database, unique ID>
|  Concept Name   |  <user defined 'symbolic name' string>
|  Role Count     |  <number of roles defined for concept>
|  Principle Role|  <default role interpretation for concept>
|  Role List      |  <list of role id's>
|    Role ID 1    |
|        :        |
|    Role ID n    |
------------------
```

Figure 1: Concept Schema

```
ROLE SCHEMA
------------------
|Role ID          |  <assigned by the database>
|  Role Name      |  <major role (bridge, airport, university...)>
|  Subrole Name   |  <further specification of role>
|  Role Class     |  <generic class (industrial, govenment...)>
|  Role Type      |  <physical or conceptual, single or collection>
|  Role Derivation|  <method by which role was added to database>
|  Role Mark      |  <internal use during database query>
|  Role 3D ID     |  <assigned by database for lat/lon/elevation desc
|  Role Defn ID   |  <assigned by database for role attribute specifi
|  Aggregrate List|  <list of user-defined component roles>
|    Role ID 1    |
|        :        |
|    Role ID n    |
------------------
```

Figure 2: Role Schema

composed of other concept roles, and can be used in query resolution as a form of inheritence. That is to say, attributes such as *population of* "district of columbia" can be calculated by examining the attribute values of its aggregrate roles. Similar operations based on geometric calculation of spatial containment provide a more flexible mechanism for such analysis.

Other role schema attributes are *role derivation* and *role mark*. Role derivation accounts for the method by which the role and 3D ID descriptor were added to the concept map database. Role mark is used to mark nodes during query search, and during creation, deletion and modification. Each role schema contains a unique 3D ID which defines a set of <latitude/longitude/elevation> triples which position the role in map space. The 3D description allows for *point, line,* and *polygon* features as primitives, and the aggregration of primitives into more complex topologies, ie. regions with holes, discontinous lines, and point lists. Figure 3 gives a list of the current role schema attribute values.

4.2. Further Role Specification

Associated with each *role name* there is a detailed *role property template* which further specifies role context dependent attributes or the *subrole.* For instance, for the role name *residential area* the subroles may be *single family, mixed housing, apartment complex, rural.* The role property template contains slots for population, housing density, roof and tree cover as a percentage of area, and other attributes. In the absence of specification by the user, default attribute values are used, within the context of the subrole. Users may dynamically create new subroles, and use existing or newly specified attribute defaults. The addition of a new role name and associated role property template requires intervention by the system maintainer. Figure 4 gives a list of the current subrole attribute values for the roles **buildings, bridges,** and **airport.**

Figure 5 gives a partial list of the current concept symbolic names and associated role ids. As of this writing there are 110 concepts with 183 roles in the CONCEPTMAP database. We plan to incrementally increase the complexity of the database both in terms of number of map features represented and the richness of the underlying representation.

```
ROLES:                      16 role names:
   unknown             university           building             water
   bridge              political            road                 park
   reservoir           sports complex       airport              hospital complex
   residential area    geographic           industrial area      parking lot
ROLE-TYPES:                 5 role types:
   unknown             physical             aggregrate-physical  conceptual
   aggregrate-conceptual
ROLE-CLASS:                 8 role classes:
   unknown             industrial           transportation       natural feature
   residential         government           cultural feature     commercial
ROLE-DERIVATION:            5 derivation classes:
   unknown             hand-segmentation    landmark-description machine-segmentation
   terminal-interaction
ROLE-MARK:                  9 mark classes:
   none                geo-query            template-query
   new-concept         new-role             modify-concept
   modify-role         new-3D               modify-3D
```

Figure 3: Role Schema Attribute Values

```
ROLE: building          State information for role (1):
Sub role file: /usri0/vdata/maps/building.dyn
   unknown                    performing arts complex     museum
   office building            railroad station            dormitory
   government building        administration              memorial
   concert hall               terminal building
ID file status: KEY: 'BULD'  Min: 1   Max: 38   Active: 32   Next: 39
*****************

ROLE: bridge            State information for role (2):
Sub role file: /usri0/vdata/maps/bridge.dyn
   unknown                    railroad                    pedestrian
   automobile
ID file status: KEY: 'BRDG'  Min: 1   Max: 8   Active: 8   Next: 9
*****************

ROLE: airport           State information for role (5):
Sub role file: /usri0/vdata/maps/airport.dyn
   unknown                    commercial                  military
   operations building        terminal                    runway
   hangars                    navigational beacons
ID file status: KEY: 'AIRP'  Min: 1   Max: 10  Active: 10  Next: 11
*****************
```

Figure 4: Subrole Attribute Values: building, road, airport

5. Some Examples

In this section we will briefly describe three sample concept map entries taken from the Washington D.C. concept map database. These examples illustrate the flexibility of the concept map representation and were created by interactive query to the database.

5.1. Map Feature Concept

Figure 6 shows a typical map feature entry in the CONCEPTMAP database. This entry, 'washington circle', (a traffic circle in the Foggy Bottom area) was created during an interactive terminal session. Figure 7 gives the *<latitude, longitude, elevation>* description for the 'washington circle' conceptmap entry which is defined in the role schema as 'D3ID3' and was created by interactive specification of image points in database image 'dc38617'. Using the image-to-map correspondence for 'dc38617', geodetic coordinates are calculated. Ground elevations are calculated by lookup and interpolation from our digital terrain elevation database [1]. The original image coordinates are saved for possible refinement, and are accessable through the 'D3ID' attribute.

Figure 8 gives the conceptmap entry for 2D feature description for 'washington circle'. Simple shape features such as *centroid, area, perimeter*, and *fourier coefficients* are calculated from the role schema D3ID in map coordinate space and are used by our MACHINSEG system in conjunction with the D3ID to specify location and shape of map features.

```
CONCEPT1     tidal basin  WATER1
CONCEPT2     district of columbia  POLI1  RESI2
CONCEPT3     northwest washington  POLI2  RESI1
CONCEPT4     macmillian reservoir  RESV1
CONCEPT5     southwest washington  POLI3
CONCEPT6     northeast washington  POLI4
CONCEPT7     virginia  POLI5
CONCEPT8     maryland  POLI6
CONCEPT9     kennedy center  BULD1  BULD8
CONCEPT10    ellipse  PARK1
CONCEPT11    washington circle  ROAD1
CONCEPT12    state department  BULD2
CONCEPT13    executive office building  BULD3
CONCEPT14    white house  BULD4
CONCEPT15    treasury building  BULD5
CONCEPT16    department of commerce  BULD6
CONCEPT17    arlington memorial bridge  BRDG1
CONCEPT18    rfk stadium  SPORT1
CONCEPT19    museum of history and technology  BULD7
CONCEPT20    key bridge  BRDG2
CONCEPT21    kutz bridge  BRDG3
CONCEPT22    george mason bridge  BRDG4
   :
   :
```

```
CONCEPT55    national airport  AIRP1  BULD17  AIRP3  AIRP4
CONCEPT57    u.s. capitol  PARK8  BULD18
CONCEPT58    alexandria  POLI7  RESI5
CONCEPT59    old town alexandria  RESI6
CONCEPT60    washington navy yard  INDU2
CONCEPT61    bolling air force base  AIRP5
CONCEPT62    andrews air force base  AIRP6
CONCEPT63    american pharmaceutical association  BULD19
CONCEPT64    national academy of sciences  BULD20
CONCEPT65    federal reserve board  BULD21
CONCEPT66    national science foundation  BULD22
CONCEPT67    civil service commission  BULD23
CONCEPT68    interior department  BULD24
CONCEPT69    district building  BULD25
CONCEPT70    lafayette park  PARK9
CONCEPT71    constitution hall  BULD26
CONCEPT72    national press building  BULD27
CONCEPT73    23rd street  ROAD9
CONCEPT74    constitution avenue  ROAD10
CONCEPT75    virginia avenue  ROAD11
CONCEPT76    c street  ROAD12
CONCEPT77    22nd street  ROAD13
   :
   :
```

Figure 5: Washington D.C. CONCEPTS and Role IDs [partial list]

```
Concept: 'washington circle'
Concept id: 'CONCEPT11'            1 roles (principle role: 0)
[0] washington circle
Role ID: 'ROAD1'                   Role Defn ID: ''
        Role name: 'road'          subrole: 'traffic circle'
        Role class: 'transportation'    type: 'physical'
        Role deriv: 'terminal-interaction'
        Role mark:  'none'
        3D Role ID: 'D3ID3'      3D Role pointer @0
```

Figure 6: Washington Circle

```
14 Points  Generic name:  'dc38617'  Feature type: 'areal'
maximum coordinate:  lat N38 54 10 (487)  lon W77 3 3 (829)
minimum coordinate:  lat N38 54 7 (62)   lon W77 2 59 (325)
point 0   elev: 16 meters   lat N38 54 9 (52)    lon W77 3 3 (829)
point 1   elev: 16 mete·    lat N38 54 10 (29)   lon W77 3 3 (131)
point 2   elev: 17 mete.s   lat N38 54 10 (464)  lon W77 3 2 (265)
point 3   elev: 17 meters   lat N38 54 10 (487)  lon W77 3 1 (397)
point 4   elev: 17 meters   lat N38 54 10 (428)  lon W77 3 0 (529)
point 5   elev: 18 meters   lat N38 54 9 (752)   lon W77 2 59 (656)
point 6   elev: 18 meters   lat N38 54 9 (88)    lon W77 2 59 (325)
point 7   elev: 17 meters   lat N38 54 8 (101)   lon W77 2 59 (369)
point 8   elev: 16 meters   lat N38 54 7 (294)   lon W77 3 0 (227)
point 9   elev: 16 meters   lat N38 54 7 (62)    lon W77 3 1 (92)
point 10  elev: 16 meters   lat N38 54 7 (83)    lon W77 3 2 (286)
point 11  elev: 16 meters   lat N38 54 7 (555)   lon W77 3 3 (270)
point 12  elev: 16 meters   lat N38 54 8 (554)   lon W77 3 3 (715)
point 13  elev: 16 meters   lat N38 54 9 (52)    lon W77 3 3 (829)
```

Figure 7: Washington Circle 3D Database Entry

```
clockwise
area = 12.201516 square sec        perimeter = 12.704613 sec
fractional fill = 0.791007         compactness = 13.228246
centroid:            lat N38 54 8 (772)  lon W77 3 1 (527)
centroid of border:  lat N38 54 8 (771)  lon W77 3 1 (531)
length of major axis (fitted ellipse) = 4.323209 seconds
length of minor axis (fitted ellipse) = 3.587450 seconds
major angle (fitted ellipse) = 0.001446 radians (0.08 deg)
minor angle (fitted ellipse) = 1.572243 radians (90.08 deg)
fourier coefficients (order 1 to 9):
 1).  ax: 0.2383    bx: 1.7778    ay: 2.1423    by: -0.2884
 2).  ax: -0.0074   bx: -0.0017   ay: -0.0028   by: -0.0035
 3).  ax: 0.0343    bx: 0.0517    ay: 0.0509    by: -0.0117
 4).  ax: 0.0016    bx: -0.0045   ay: 0.0012    by: 0.0007
 5).  ax: -0.0029   bx: -0.0124   ay: 0.0136    by: 0.0034
 6).  ax: 0.0008    bx: -0.0088   ay: 0.0104    by: 0.0014
 7).  ax: 0.0091    bx: 0.0031    ay: 0.0108    by: 0.0031
 8).  ax: -0.0097   bx: -0.0030   ay: 0.0126    by: -0.0099
 9).  ax: -0.0036   bx: -0.0032   ay: 0.0088    by: 0.0011
```

Figure 8: Washington Circle 2D Shape Descriptors

The photograph in Figure 9 was created by CONCEPTMAP as a result of the query "*Display all images containing 'washington circle*". Using the BROWSE subroutine package as primitives, a display frame is created composed of windowed image fragments centered around the map feature. Once displayed, any of the windows can be manipulated using commands within CONCEPTMAP. Thus, the user can select one or more of the image fragments, *expand* the size of the window to obtain more image context, *move* a window for side-by-side comparison, *zoom* in for more detail, or *adjust* the center of the window.

5.2. Landmark Concept

Figure 10 lists the concept map entry for 'george mason bridge'. The role schema attribute *role derivation* specifies this concept as being a 'landmark-description'. When listing this role entry the concept schema attribute *concept name* is used to index into the landmark database (LANDMARK) [8] to produce the textual description which defines the landmark entry. This allows entries in our landmark database to be directly accessible through the concept map.

```
Concept: 'george mason bridge'
Concept id: 'CONCEPT22'            1 roles (principle role: 0)
[0] george mason bridge
Role ID: 'BRDG4'                   Role Defn ID: ''
        Role name: 'bridge'        subrole: 'automobile'
        Role class: 'transportation'    type: 'physical'
        Role deriv: 'landmark-description'      mark: 'unknown'
        3D Role ID: 'D3ID14'     3D Role pointer @0
latitude 38 52 43 300
longitude 77 2 22 500
elevation 12 meters
1140.1482 in /visf/washdc/asc/dc1419/1bw.img
landmark image at resolution 1

                  george mason bridge
Definition:  A bridge spanning the Potomac River in southwest DC.
Located adjacent to the Jefferson Memorial and the Rochambeau Bridge.

Description:  The George Mason Bridge, also known as one of the
twin 14th St. Bridges, carries the westbound lanes of U.S. 1
across the Potomac from 14th St. on the east bank to the Jefferson
Davis Highway on the west.  The landmark image is oriented with
north at the top.
```

Figure 10: Role Schema: George Mason Bridge

5.3. Multiple Role Concept

The concept 'national airport' is an example of a more complex organization of role schema. Figure 11 shows the current concept description for 'national airport'. The principle role AIRP1 defines this concept to be a commercial airport, whose boundary should be interpreted as a aggregrate-physical feature, that is a collection of physically realizable boundary descriptions. Within the context of the area represented in 'D3ID59' will be found all roles which comprise this concept.

The other roles define the airport terminal building, a runway, and a collection of hangars. The terminal building 'BULD17' and the airplane hangar 'AIRP4' have boundary descriptions associated with them, while the runway 'AIRP3' role has none. Geometric queries on the concept map database would find the terminal building and hangar as *contained* within the principle role of the concept 'CONCEPT55', "national airport". However, a symbolic query asking for all the roles

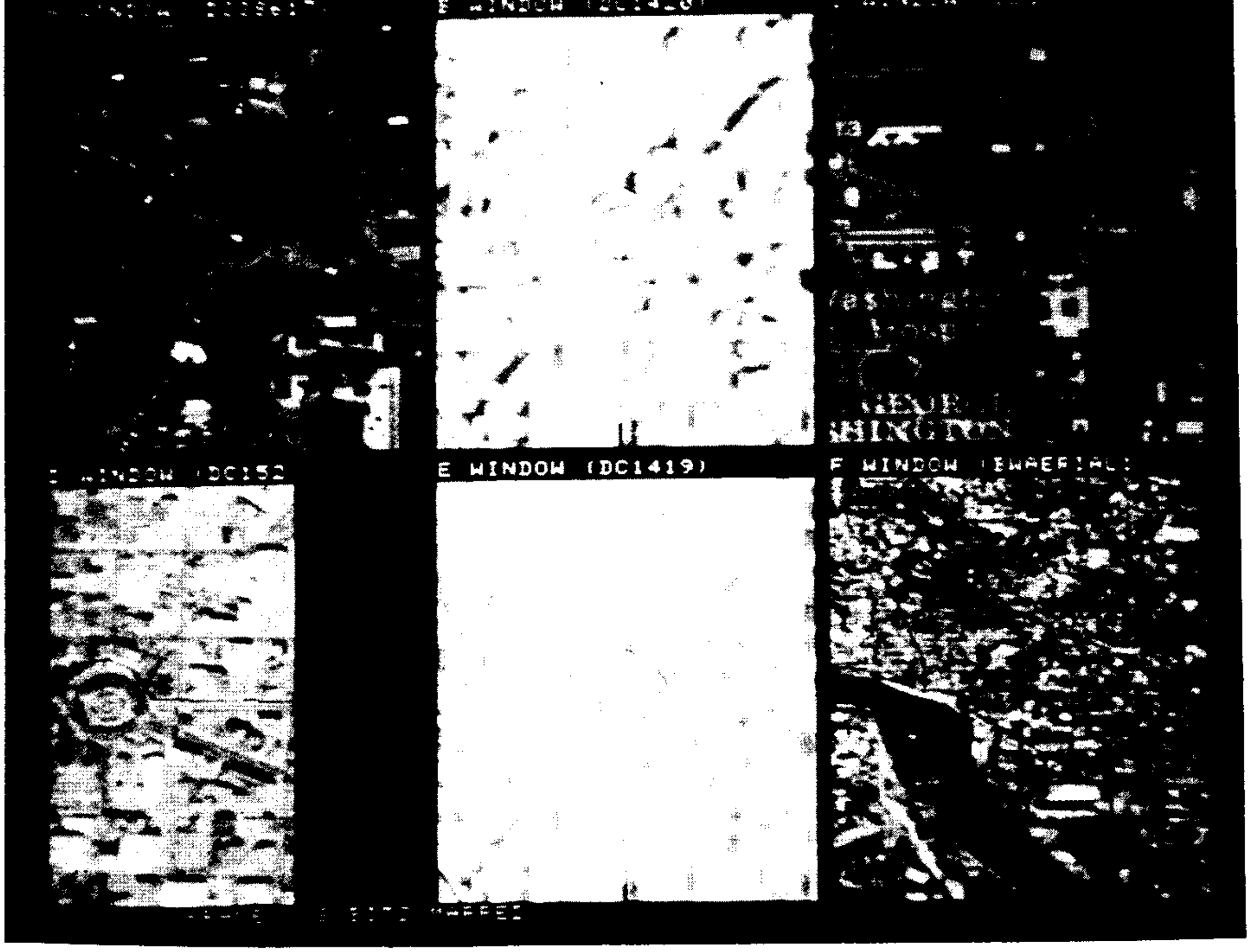

Figure 9: Database Retrieval of Multiple Views

associated with the principal role for concept 'CONCEPT55' would find the runway as well at the other two roles. The relative merits and limitations of strict user defined symbolic representation vs. using geometric queries to build plausible symbolic relationships is an area for future research.

We have begun to create detailed models for *airports* and *industrial area* roles, initially as a guide to the interactive user, but expect to integrate such static descriptions into an active query component in the future. We are calling such descriptions *site description models.* Currently, users are free to describe as role schema those portions of the airport description model that are of importance, without a requirement to create a completely specified airport *site description model.* Figure 12 details a preliminary organization of an airport description model.

We see this work as a natural development towards including in the concept map representation explicite modeling of physical relationships between site structures, functional descriptions of structures, and functional relationships (processes) between collections of model structures.

6. Map Query

There are four database access primitives which can be employed singularly or in combination to extract the positional, factual, or relational attributes required to answer the queries posed in the beginning of this paper.

```
Concept: 'national airport'
Concept id: 'CONCEPT55'          4 roles (principle role: 0)
[0] national airport
Role ID: 'AIRP1'                  Role Defn ID: ''
        Role name: 'airport'     subrole: 'commercial'
        Role class: 'transportation'    type: 'aggregrate-physical'
        Role deriv: 'hand-segmentation' mark: 'unknown'
        3D Role ID: 'D3ID59'     3D Role pointer @0
[1] national airport
Role ID: 'BULD17'                 Role Defn ID: ''
        Role name: 'airport'     subrole: 'terminal'
        Role class: 'transportation'    type: 'physical'
        Role deriv: 'terminal-interaction'      mark: 'unknown'
        3D Role ID: 'D3ID60'     3D Role pointer @0
[2] national airport
Role ID: 'AIRP3'                  Role Defn ID: ''
        Role name: 'airport'     subrole: 'runway'
        Role class: 'transportation'    type: 'physical'
        Role deriv: 'hand-segmentation' mark: 'unknown'
        3D Role ID: ''   3D Role pointer @0
[3] national airport
Role ID: 'AIRP4'                  Role Defn ID: ''
        Role name: 'airport'     subrole: 'hangars'
        Role class: 'transportation'    type: 'physical'
        Role deriv: 'terminal-interaction'      mark: 'unknown'
        3D Role ID: 'D3ID61'     3D Role pointer @0
```

Figure 11: Concept Schema for National Airport

```
                                    AIRPORT
            /             /            |          \            \
       /              /                |           \             \
misc.               runway tarmac   buildings   parking lots    temporal structures
  structures            |          /   |   \                       /     |    \
   /  \                 |     terminal | operations          airplanes   |  fuel trucks
fuel  navigational      |            hangars                    /|\           \
tanks   beacons         |                              commercial | private   baggage trucks
                       / \                                     military
                 runways   taxiways
```

Figure 12: Role Definition Template for AIRPORT Role

6.1. Signal Access

Display or list all concepts within an interactively specified image area. Signal access requires an explicite *image-to-map* correspondence. Image coordinates are used to calculate map coordinates which are used to search the concept map database. Figure 13 is a display frame created by CONCEPTMAP as a result of an interactive user query to display the area around a set of storage tanks near the Washington D.C. navy yard. The query area is superimposed as a blue overlay in each of the display windows, the area of interest is centered in each window, and displayed at the highest resolution that fits within the window partition. Signal access queries are purely dynamic, involving only the BROWSE window manager and the image database and do not use the concept map symbolic data structures.

6.2. Symbolic Access

Display or list all concepts with a given symbolic name. Requires explicite mapping of a user defined name, ie(*memorial bridge*) into the map coordinate system. As we described in section 5.1, the role schema 3D ID gives us a direct mechanism for searching the image database.

6.3. Role Template Access

Given a completely or partially specified role schema, find all roles in the concept map database which satisfy the specification. The user can specify additional constraints based on the role property template if the *role name* and *subrole name* have been specified. The result of a template access is a list of role schema ID's. These may be printed or displayed by the user as described above.

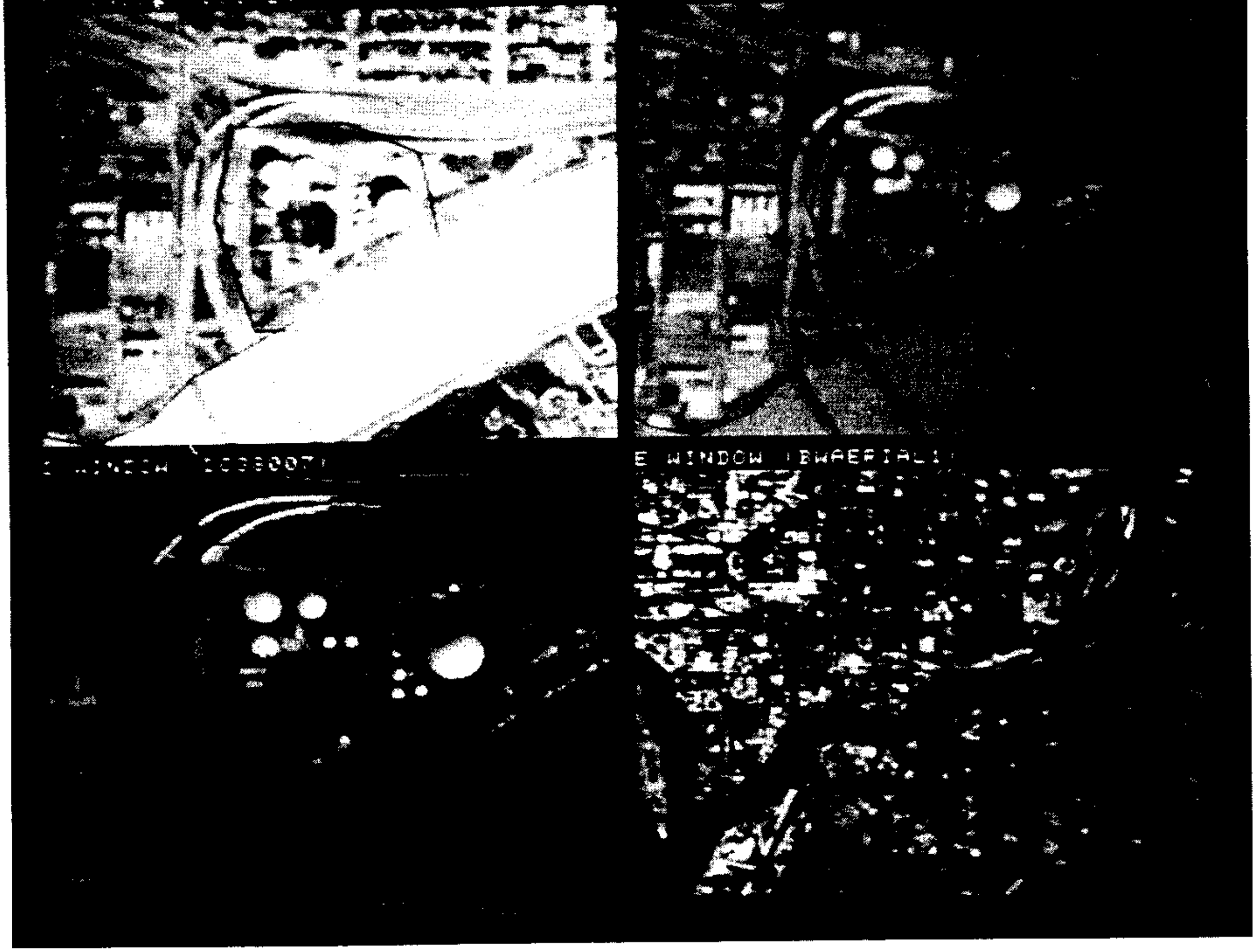

Figure 13: Signal Access Display

6.4. Geometric Access

Using the 3D role latitude/longitude/elevation description, compute geometric properties such as *containment, subsumed by intersection, adjacency,* and *closest point.* A list of role schema ID's which satisfy the geometric constraints is created. In the case of *intersection* and *adjacency* a temporary role schema with 3DID is generated with the results (point, line, polygon) of the geometric operation for each pair of database role schema.

6.5. Integrating Access Methods

In order to generate answers for several of the map database queries posed at the beginning of this paper, we must actually perform sequences of symbolic, signal, template, and geometric access functions. There are clearly difference costs associated with each method, geometric computation being the most expensive, symbol to signal being the least expensive. We currently require that the user specify the sequencing of access methods, with CONCEPTMAP providing automatic storage of temporary results in the form of querylists of role schema which satisfy a primitive query. Let us analyze those sample queries in terms of our query primitives.

- "How many bridges cross the Potomac River between Virginia and the District of Columbia."
  Get symbolic level from symbolic level with template and geometric constraint
- "Display images of National Airport before 1976."
  Get image from symbolic level
- "What is the closest building to this geographic point" [*point to screen*].
  Get symbolic level from template, signal, and geometric constraint
- "Where is this geographic point." [*specify geodetic coordinate*]
  Get signal and symbolic level from signal constraint

6.6. Hierarchical Query Resolution

Consider the query "*where is the intersection of 31th and m street*". One approach is to simply find the 3D map descriptions for each of the roles (*symbol to signal*), and perform a geometric operation to calculate a ground coordinate position. The concept map provides the capability to use symbolic geometric relationships to generate the following response:

```
<greater washington d.c.>
<district of columbia>
<northwest washington>
<georgetown area>
<georgetown business district>
<lat N38 54 18 (374)   lon W77 3 41 (213)   el
```

When the actual geodetic location of an intersection is required, a geometric operation must be performed, unless it is defined as a map concept. However each of the other responses resulted from a traversal of a *containment tree* which is maintained by the concept map database. The containment tree is precomputed from all map concept features having polygonal 3DID descriptions using the geometric relationships of *subsumed by* and *contains*. Features having a clear hierarchy of *level of detail* such as political and cultural (neighborhood) concepts can form the basis for partitioning of other map features to improve query performance and to better model the spatial organization as more than just a collection of independent concepts.

For this reason, we would like to explore building hierarchical descriptions using the concept map database. We can anticipate its use as a knowledge source for more complex matching, for instance in symbolic scene recognition. For example, the occurrance of role descriptions for *oil tank farm*, *power transformers*, and *cooling towers* within close physical proximity, indicates the area may be *power plant* or *industrial*.

7. 3D Map Display

A central problem for a variety of cartographic tasks is flexible access to 3D map databases [6]. Tasks include inspection and verification of spatial databases, incremental update, and feature enhancement. CONCEPTMAP provides tools for the selection of ground area either through image-to-map correspondence (ie. describing the area to be portrayed via digital imagery) or direct specification of map coordinates. The photograph in Figure 14 shows a full frame window containing a two dimensional map image of an area around Washington D. C.. This 13 color-class thematic image[3] shows areas such as forest and park (green), water (blue), residential (yellow), and high density urban (brown). It was generated by scan conversion of a polygon map database provided by the Defense Mapping Agency (DLMS Level 1) [1].

In this application, the user indicates a rectangular area of interest in the map image, specifies the center point (west of National airport), viewing position (from the southeast), and view angle. This is done by tracking a cursor on the display to minimize the amount of knowledge that the user must have of the actual 3D coordinate system.

The photograph in Figure 15 shows the result of the 3D map generation. For each image point in the area specified by the user, a map coordinate is calculated (latitude, longitude, elevation). A 3D surface description is generated using the thematic color from the map image, and this description is passed to a 3D shaded raster graphics display program [2]. The resulting map image is then displayed by BROWSE.

The CONCEPTMAP database provides 3D map feature descriptions for the generation of cartographically accurate urban scenes. The DLMS scene as generated in 15 is used as a base map, onto which we project our map database features. The photograph in Figure 16 shows a view of the Foggy Bottom area with the observer looking towards the southeast from above the intersection of Virgina Avenue and 23rd Street. Buildings in the scene are (from left to right) *constitution hall* (clipped to the scene viewport), *interior department*, *civil service commission*, *bureau of indian affairs*, *federal reserve board*, *state department* and *national academy of science*. Roads are *virginia avenue* (bottom right to center left), *C street* (center left to middle right), and *constitution avenue* (running along the light/dark terrain boundary). The linear feature running between the *interior department* and *civil service commission* and occluded by the line of buildings in the rear of the scene is the boundary of the map description for '*foggy bottom*'.

8. Conclusions

We have discussed the current implementation of a large scale spatial map database organized around a *concept map* representation which provides for the hierarchical description of complex natural and man-made features. User defined views are supported by allowing concepts to take on multiple roles, while maintaining a consistent 3 dimensional map coordinate representation. We have shown how the CONCEPTMAP database can be used for flexible access into an image database, display of 3D urban scenes, and for query into spatial databases. We believe that this work has applications in a variety of task domains where knowledge representation can be viewed in terms of 3 dimensional spatial organizations, particularly in cartography, photo-interpretation, and geological modeling.

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[3] Reproduced in stunning black and white.

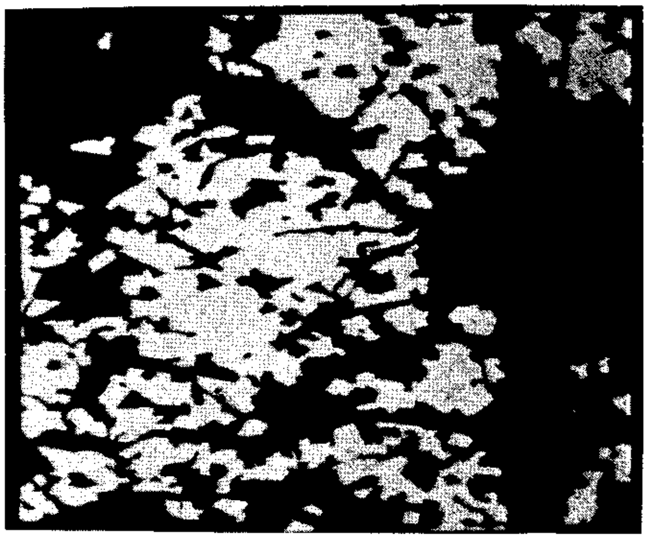

Figure 14: 2D Washington D.C. Terrain Map

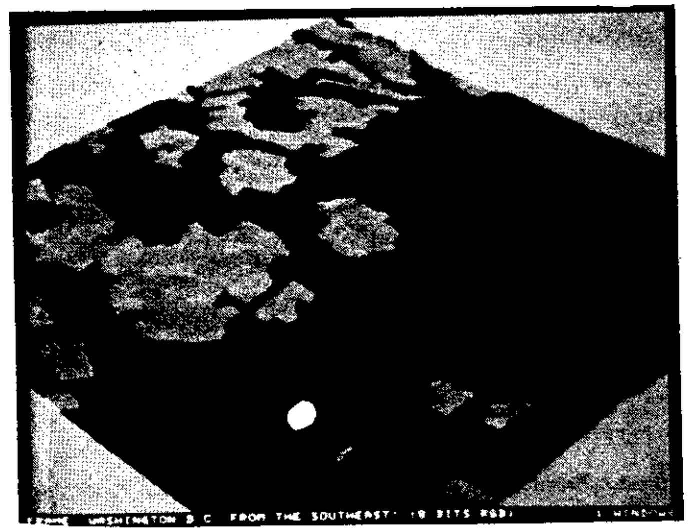

Figure 15: 3D Washington D.C. Terrain Map

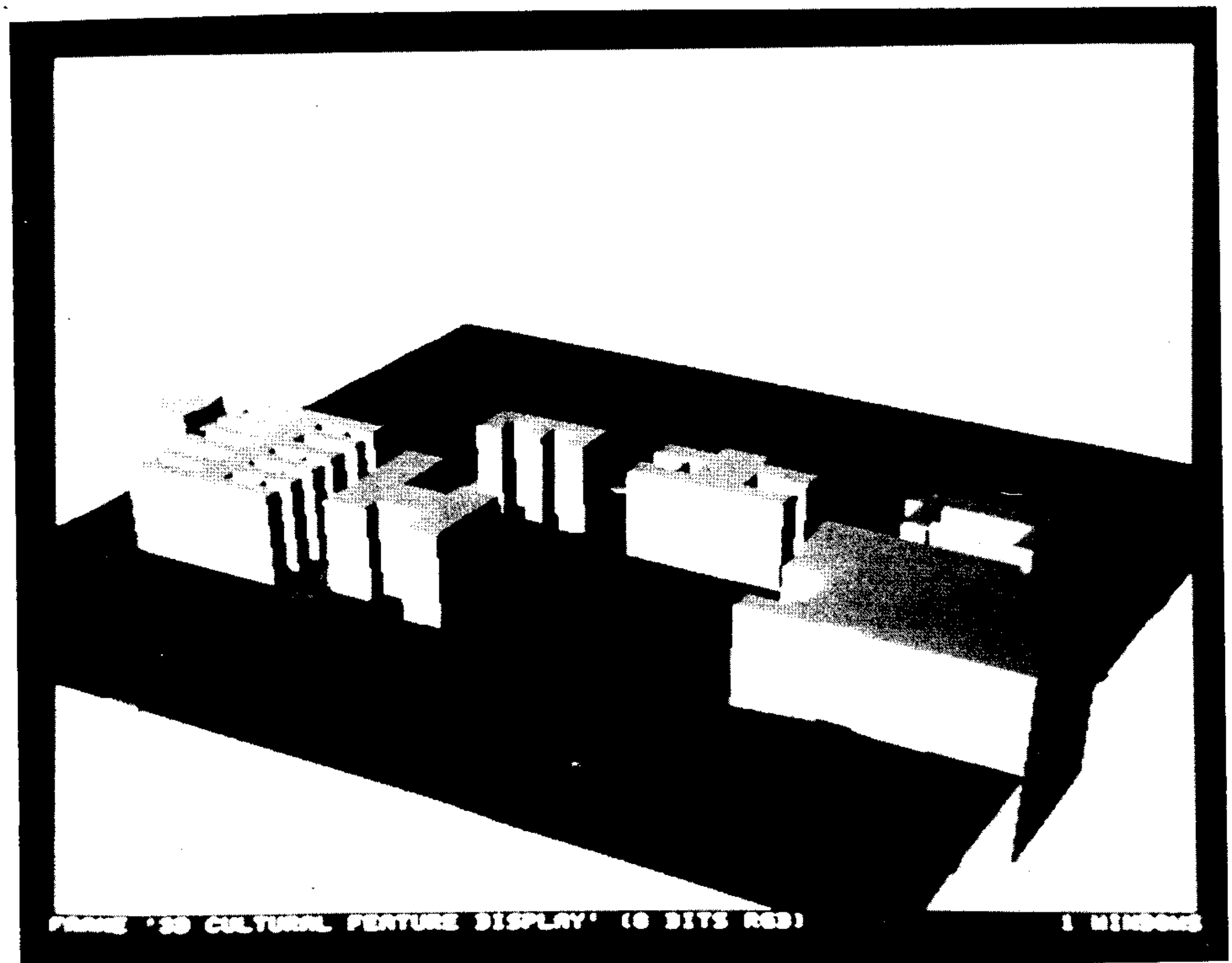

Figure 16: 3D View of Foggy Bottom Area

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