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Interim Report — Digital Nautical Chart

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The Defense Mapping Agency (DMA) has tasked the Naval Research Laboratory (NRL) to develop a product specification for a Digital Nautical Chart (DNC) database. The DNC will be used by the Department of Defense in nautical Electronic Chart Display and Information Systems. This paper will describe the structure and content of the DNC database.

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ABSTRACT

The Defense Mapping Agency (DMA) has tasked the Naval Research Laboratory (NRL) to develop a product specification for a Digital Nautical Chart (DNC) database. The DNC will be used by the Department of Defense in nautical Electronic Chart Display and Information Systems. This paper will describe the structure and content of the DNC database.

The DNC database will be implemented in DMA's Vector Product Format (VPF). VPF is a generic geographic data model designed to be used with any geographic data model in which vector data can be represented using nodes, edges, and faces. VPF is based upon the georelational model, combinatorial topology, and set theory. VPF is a new data model, upon which only prototypes of the Digital Chart of the World and Digital Terrain Data databases have been produced.

The DNC database will use DMA's Feature and Attribute Coding Standard to describe chart data and will include all features now found on paper Harbor, Approach, and Coastal charts. Additional data may be included to support Navy requirements. The DNC will be a seamless, tiled database.

The initial use of the DNC will be in the Navigation Sensor System Interface (NAVSSI) now being developed by the Naval Sea Combat Systems Engineering Station in Norfolk, Virginia and the Naval Air Development Center in Warminster, Pennsylvania. The goal of NAVSSI is for the electronic chart to replace the paper chart as a legal means of ownship navigation plotting. NRL has worked closely with the NAVSSI project in the development of DNC specifications.

A draft DNC product specification was completed by NRL in September 1991. An early prototype database covering two charts in the Norfolk, Virginia, area was produced by DMA in late 1991, and was followed by a second prototype in early 1992. This second prototype covers four charts in the Norfolk area and is now under evaluation.

ACKNOWLEDGMENTS

INTRODUCTION

As the Navy's lead laboratory in Mapping, Charting, and Geodesy, the Naval Research Laboratory (NRL) was tasked by the Defense Mapping Agency (DMA) to develop a draft product specification for a Digital Nautical Chart (DNC) database. This paper describes the DNC database design, intended use, and prototype production schedule as of late 1991.

The DNC database is intended to be used in the Navigation Sensor System Interface (NAVSSI) aboard U.S. Navy ships. The NAVSSI project is a new system being designed with two primary objectives; processing/distribution of navigation data and the display/operation of electronic charts. NAVSSI will be the Navy's Electronic Chart Display and Information System (ECDIS). The goal of NAVSSI is to replace paper charts as a legal means of ownship navigation plotting (Greer, 1991).

The DNC will be a seamless, vector database distributed on CD-ROM. DNC will eventually provide worldwide coverage at every scale now used for marine navigation. In order to serve as a legal replacement for paper charts, the database will include all features currently shown on National Ocean Service (NOS) and DMA charts.

The DNC is implemented in DMA's Vector Product Format (VPF). VPF is an evolving standard, intended to be a general, user-oriented data format for representing large spatially referenced (geographic) databases. The DNC is expected to be produced by DMA, and so was designed to take advantage of DMA's existing production facilities.

VPF OVERVIEW

VPF is intended to be a standard format for DMA's production and distribution of vector data. VPF uses a georelational data model to provide an organizational structure for any digital geographic database in vector format. VPF establishes a standard data model and organization, providing a consistent interface to data content. The DNC product specification determines the precise data contents of feature tables and their relationships (Environmental Systems Research Institute, 1990).

A VPF database is composed of tables and directories that form a layered model. A VPF table is the organizational structure for all data content in VPF and consists of the following parts: a table header, which contains metadata about the table and the column definitions; the table contents, which contain the actual rows that make up the table; and a row ID.

Figure 1 depicts a schema that defines the principal structure of any table in VPF (Defense Mapping Agency Systems Center, 1991).

Table Header	

Metadata and column definitions:
 	
 a. Table Description
 b. Narrative File Name (optional)
 c. Column Definitions:
   column name
   column text description
   field type
   key type
   value description table name (optional)	

ID	Table Contents
Indicates the starting position of each row.	Data matching the column definitions.

Figure 1. VPF Table Structure.

Figure 2 depicts the relationships between databases, libraries, coverages, feature classes, and primitives in VPF. A collection of libraries makes up the database while a collection of thematic coverages makes up each library. Databases and libraries are used primarily to help organize data access, whereas coverages are used to define the relationships between features. Topology is incorporated at the coverage level to define spatial relationships between features. Since topology is present only at the coverage level, this presents difficulties in determining thematic coverage contents for the DNC. Geometric and cartographic primitives are at the lowest level. These primitives define the spatial aspects of entities. Also at this level are feature classes, which contain thematic information that helps apply meaning to the primitives. Both feature classes and primitives make up the thematic coverages.
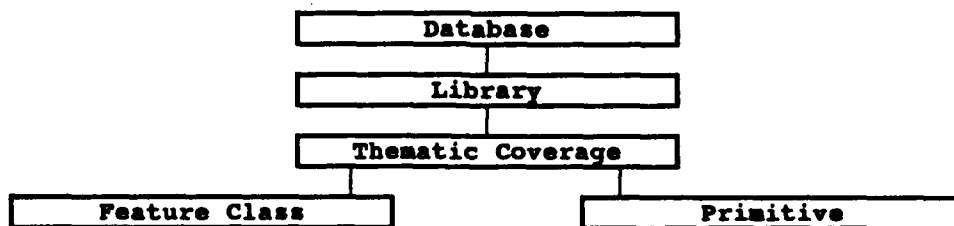

Figure 2. VPF Layers.

A database is a collection of related libraries plus additional tables that define data that is common to all of the libraries.

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A library is a collection of coverages that share a single coordinate system and scale, have a common thematic definition, and are contained within a specified spatial extent. All of the tables and coverages making up the library are contained within a single directory.

At the database and library levels, various tables are required to define the database geographic extent, sources, accuracy, security, etc. At the thematic coverage level feature tables, value description tables, and primitive tables define features and attributes along with their spatial relationships.

A coverage is a set of feature classes (consisting of primitive and attribute tables) whose primitives interconnect according to coverage topology. A coverage is analogous to a single map sheet in conventional cartography. At this level, features are represented by a set of one or more primitives plus a row of attribute data. Every feature will have one primary row in a feature table that uniquely identifies it. Value description tables (VDT) relate the possible numeric or character values contained in the feature table to possible attributes for the features.

VPF defines three geometric primitive types; faces, edges, and nodes. The primitive tables contain the actual latitude and longitude values of the faces, edges, points, or text comprising the feature. Index tables are used to decrease access times for variable length files.

DNC IMPLEMENTATION

The DNC database is implemented in VPF and will be distributed on CD-ROM. The DNC is based on the feature content of the paper Harbor, Approach and Coastal charts produced by DMA and uses the Feature and Attribute Coding Catalog (FACC) to define features, attributes, and attribute values. FACC is a Digital Geographic Information Exchange Standard (DIGEST) coding convention and will be used by DMA in production of various digital charts. Figure 3 shows the VPF structure levels and DNC implementation.

The database directory level contains the database header table and the library attribute tables. The database header table contains the database name, originator, security classification, and other information concerning the database. The library attribute tables contain the library names and geographic extent of the libraries.

```
┌─────────────┐                              ┌─────────────┐
│    VPF      │                              │    DNC      │
│ STRUCTURE   │                              │IMPLEMENTATION│
│   LEVEL     │                              └──────┬──────┘
└──────┬──────┘                                     │
┌──────┴──────┐                              ┌──────┴──────┐
│  DATABASE   │                              │    DNC      │
└──────┬──────┘                              │  DATABASE   │
                                             └──┬───────┬──┘
┌──────┴──────┐              ┌───────────────┐ │       │ ┌─────────────┐
│   LIBRARY   │              │   HARBOR,     │ │       │ │   BROWSE    │
│             │              │ APPROACH OR   │─┘       └─│   LIBRARY   │
│             │              │   COASTAL     │          │             │
│             │              │   LIBRARY     │          │             │
└──────┬──────┘              └───────┬───────┘          └──────┬──────┘
┌──────┴──────┐              ┌───────┴───────┐          ┌──────┴──────┐
│  COVERAGE   │              │      13       │          │      2      │
│             │              │   COVERAGES   │          │  COVERAGES  │
└──────┬──────┘              └───────┬───────┘          └──────┬──────┘
┌──────┴──────┐              ┌───────┴───────┐          ┌──────┴──────┐
│FEATURE CLASS│              │   FEATURE     │          │   FEATURE   │
│             │              │   CLASSES     │          │   CLASSES   │
└──────┬──────┘              └───────┬───────┘          └──────┬──────┘
┌──────┴──────┐              ┌───────┴───────┐          ┌──────┴──────┐
│  PRIMITIVE  │              │       5       │          │      5      │
│             │              │  PRIMITIVE    │          │  PRIMITIVE  │
│             │              │   TYPES       │          │   TYPES     │
└─────────────┘              └───────────────┘          └─────────────┘
```
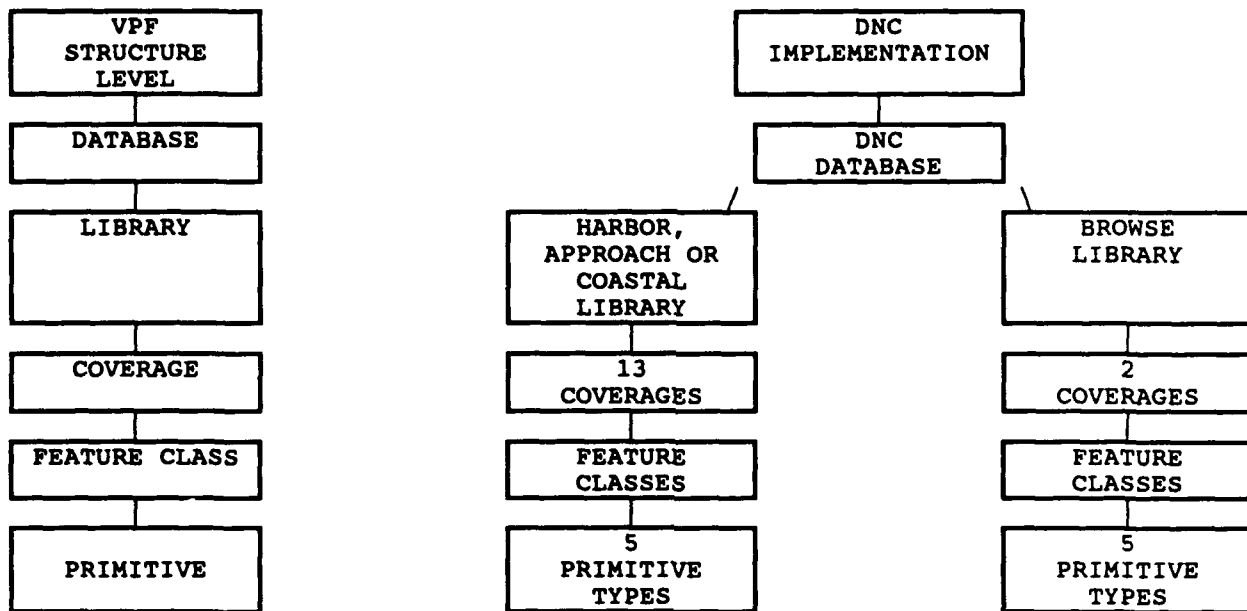
Figure 3.   VPF structure levels and DNC implementation.

The DNC database is divided into libraries based on source
chart scale. Since traditional paper nautical charts are not
produced in standard sizes or scales, the DNC groups paper chart
sizes into four scale bands and uses an equal-area tiling scheme
(see Figure 4). The lower left (southwest) corner of each tile
is identified using the World Geographic Reference System
(GEOREF). This system divides the Earth into quadrangles or
tiles, the sides of which are specific arc lengths of longitude
and latitude. The GEOREF identifier is used as the filename in
the appropriate library of the database.

ID	LIBRARY (chart type)	TILE SIZE	CHART SCALES
A	GENERAL	3°	< 1:500,001
B	COASTAL	3°	1:75,000 to 1:500,000
C	APPROACH	30'	1:25,000 to 1:100,000
D	HARBOR	15'	1:10,000 to 1:50,000

Figure 4.   DNC libraries and tile sizes.

The library directory level includes a library header table,
a coverage attribute table, and a geographic reference table.
The library header table contains information identifying the
contents, extent, projection, units, security source, and data
quality of the library. The coverage attribute table contains an

ID, coverage name, description, and topological level for each coverage within the library. The geographic reference table includes four subrecords that define the geographic parameters of the library. These subrecords are the following: geographic parameters, projections, registration points, and diagnostic points.

In addition to the these libraries, the DNC will include a BROWSE library containing original paper chart boundaries, data quality information, coastline, major ports, and CD-ROM coverage information.

The DNC is divided into 13 thematic coverages. These coverages are shown in Figure 5. (Coverage names are subject to change.)

COVERAGE NAME	DESCRIPTION
Cultural Landmarks	manmade features on land of interest to marine navigation
Earth Cover	shoreline, foreshore, open water, etc.
Environment	tides, currents, magnetic variation, etc.
Hydrography	depths, bottom characteristics, etc.
Inland Waterways	inland shoreline, lakes, ponds, etc.
Land Cover	vegetation, snow, ice, etc.
Limits	general information, caution, avoidance, and navigation limits
Aids to Navigation	buoys, lights, etc.
Obstructions	rocks, wrecks, etc.
Port Facilities	berths, piers, etc.
Relief	elevations on land
New Hazards	updated static coverage features
Data Quality	metadata concerning positional and attribute accuracy

Figure 5. DNC thematic coverages.

Within each coverage are feature tables for each feature class (area, line, point, and text) and corresponding primitive tables. A sample line feature table is shown in Figure 6. This table contains FACC codes for each feature within the coverage, related feature attributes, and a key into the associated primitive table. Figure 7 shows an integer value description table that relates integer values found in the feature table to actual attribute values. A sample edge primitive table for line features is shown in Figure 8.

```
{Header length};\
HYDLINE.␣␣␣␣, Hydrography Line Feature Table;-;\
ID=I,1,P,␣ow ID,-,:\
F_CODE=T,5,N,FACC Code,CHAR.VDT,:\
ACC=I,1,N,Accuracy Category,INT.VDT,;
CRV=I,1,N,Depth Curve or Contour Value,INT.VDT,;
UNI=I,1,N,Units Category,INT.VDT,;
VDC=I,1,N,Vertical Datum Category,INT.VDT,;
VDR=I,1,N,Vertical Datum Record,INT.VDT,;
```

1	2E010	1	10	1	1	1
2	2E010	1	10	1	1	1
3	2E010	1	20	2	1	1
4	2E010	1	20	2	1	1
.	.	.	.	.	.	.

Figure 6. Partial hydrography line feature table.

```
{Header length};\
INT.VDT, Hydrography Integer Value Description Table;-;\
ID=I,1,N,Row ID,-,:\
TABLE=T,12,F,Feature Class Table Name,-,:\
ATTRIBUTE=T,10,F,Attribute Name,-,:\
VALUE=T,5,F,Attribute Value,-,:\
DESCRIPTION=T,50,F,Attribute Value Description,-,;
```

1	HYDLINE.LFT	ACC	001	Accurate
2	HYDLINE.LFT	ACC	002	Approximate
3	HYDLINE.LFT	ACC	003	Doubtful
4	HYDLINE.LFT	EXS	001	Definite
5	HYDLINE.LFT	EXS	002	Doubtful
6	HYDLINE.LFT	EXS	003	Reported
7	HYDLINE.LFT	HDI	009	Depth Known by Other Than Wire
.	.	.	.	.

Figure 7. Partial hydrography integer value description table.

Column name	Column name description
ID	The row id primary key
*.LFT ID	Line feature table id
START_NODE	Start node foreign key to entity node table
END_NODE	End node foreign key to entity node table
RIGHT_FACE	Right face foreign key to face primitive table
LEFT_FACE	Left face foreign key to face primitive table
RIGHT_EDGE	Right edge foreign key to following edge
LEFT_EDGE	Left edge foreign key to following edge
NEXT_EDGE	Next edge in a line network, foreign key to edge primitive
COORDINATES	Edge coordinates

Figure 8. Schema for edge primitive table.

UPDATING THE DNC

A primary concern in the production of any digital nautical chart is the management and application of chart updates. Several methods for updating and correcting the DNC have been studied by the Defense Mapping Agency (Wagner, 1992).

There are primary categories of chart updating methods: (1) interactive entry of updates, (2) semiautomatic entry of updates, and (3) automatic entry of updates.

Interactive entry of updates is probably the least complex of the three methods, and also the least elegant. In this method, the present method of distribution of chart update information by electronic and paper means would continue. Each system developer using the DNC would then be responsible for developing the software required to interactively update the DNC on that particular system. Each user would then update the DNC in a manner similar to that in use now for paper charts.

Semiautomatic entry of chart update information involves the distribution of correction data via modem, floppy disk, etc. The data is then entered into the system and displayed as overlay information, readily distinguishable from the original data. The original data is not altered. This method is more complex in that it requires properly structured data from the Hydrographic Office.

The third method of chart updating, the automatic method, is the most complex. As in the previous method, chart updates are

distribute: in the proper structure via modem, floppy disk, etc. However, the chart corrections are integrated with the original data and are indistinguishable from the original data when displayed.

In both the semiautomatic and automatic methods the update data may be organized around either feature types (thematic layers) or areas (tiles). If the updates are distributed as feature updates, the system software must be capable of adding, modifying and deleting individual features within a thematic coverage. This requires complex software capable of restructuring multiple VPF tables. If the updates are distributed as tile updates, then an entire cell is replaced with a corrected cell. This method requires much less sophisticated system software, in that only metadata tables must be modified. All tables specif: to the updated tile are replaced.

A plan for distribution of DNC updates which supports either the semiautomatic or automatic methods has been proposed by DMA. In this approach, two types of coverages are defined; a static coverage and a dynamic coverage. Since 90% or more of current corrective information applies to navigational aids, area limits, this method would specify these thematic coverages to be "dynamic." All other coverages would be designated "static." Static coverages would not be updated weekly, but all information for the dynamic coverages would be updated on a weekly basis. An additional "New Hazards" dynamic thematic layer would be added to handle the case where a change is required to a static thematic coverage. This weekly update would include all dynamic coverages world-wide, and would be distributed in VPF on one or two CD-ROMs by the Defense Mapping Agency.

The Naval Research Laboratory is now investigating the optimum method for structuring static and dynamic coverages, and determining possible product specification and VPF standard modifications necessary to support this method for updating the DNC. However, no final decision has yet been made regarding an DNC updating strategy.

DNC PROTOTYPE PRODUCTION

The Environmental Systems Research Institute, Inc. (ESRI) in Redlands, California, is producing the DNC prototype for DMA. Three prototypes are planned.

Prototype 1A was produced in late November 1991. It contains two 5' x 5' subsets extracted from data that has been digitized by ESRI for DMA's Digital Chart of the World (DCW) Prototypes 2 and 3. These data were converted to VPF and distributed on floppy disk. Prototype 1A uses the DCW attribute codes, however, rather than the DNC FACC codes.

Prototype 1B was produced in late January 1992. It is structured in VPF and contains the full data sets digitized for DCW Prototypes 2 and 3. Prototype 1B utilizes FACC codes for attribute definition and is distributed on magnetic tape.

Prototype 2 is expected in late April 1992. It will contain six charts of the Norfolk area; one at the Coastal scale, two at the Approach scale, and three at the Harbor scale. Prototype 2 will conform completely to the DNC product specification and will be distributed by DMA on CD-ROM.

The Naval Sea Combat Systems Engineering Station plans to evaluate the DNC database in the NAVSSI system on board an aircraft carrier in the late summer of 1992.

ISSUES

As of June 1992, several issues remain concerning the final design of the DNC database. All of these issues have been addressed, and it is hoped that most of them will be resolved during the prototyping process.

- The use of FACC may present problems in efficiently representing the feature content of NOS paper charts. NOS produces charts of U.S. waters, while DMA produces charts of foreign waters. Since the NOS and DMA charts are produced using different methods, it may be necessary to develop new FACC codes to represent features that are present on NOS charts, but not on DMA charts.

- It is not yet clear what data volumes may be expected when storing nautical charts in VPF format. The data density required to adequately represent features on the NAVSSI screen has not yet been addressed. Current requirements for digitizing paper charts are based on production of new paper charts, rather than an ECDIS, and may not be appropriate for electronic charts.

- The matter of chart marginalia has not yet been resolved. As several paper charts are digitized and merged into one seamless database, how and when does one present chart marginalia? Which margin notes will apply to which portions of the electronic chart?

- How should text that is not directly associated with any specific feature (such as "Gulf of Mexico" or "Shoaling") be stored? A bounding rectangle would allow the area to be queried by a user, but a bounding rectangle may be impossible to define. If the text is associated with a specific point, then it may be lost when the area that is to be displayed covers only a portion of the feature.

- The issue of chart updates has not been resolved. Although the weekly production of new CD-ROMs to reflect the

Weekly Notice to Mariners may seem cost effective, it may not be satisfactory for units that are deployed at or under the sea for long periods of time. The distribution of chart updates by electronic message and/or floppy disk as an additional thematic coverage may be feasible, but many technical issues remain unresolved.

CONCLUSION

The DNC will provide the U.S. Navy with a standard vector database for marine navigation, mission planning, and tactical and strategic operations. Several issues remain concerning DNC, including the determination of thematic coverages, storage and representation of cartographic text and marginalia, and chart updates. However, with the production of several DNC prototypes and the deployment of the NAVSSI by mid-1992, the Navy will be well on the way to fielding an effective ECDIS.

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