S57 ECDIS DATA PRODUCTION AND UPDATE
USING AN OBJECT-ORIENTED SPATIAL DATABASE

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ABSTRACT

The availability of commercial object-oriented spatial database technology opens up new possibilities for generation and maintenance of the highly structured Hydrographic data needed for ECDIS (Electronic Chart Display Information Systems).

The IHO S57 standard for ECDIS data lays down strict rules for the content, structure and relationships of the spatial data entities of the ENC (Electronic Navigation Chart) which form the heart of a modern ECDIS system. Reliably generating this ENC data is a task which has proven to be largely beyond the capabilities of traditional feature-based GIS or CAD systems, particularly when the complications are included of generating the necessary minimal 'change-only' updates for regular data maintenance.

This paper outlines the capabilities of a modern object-oriented spatial data production system, and highlights those aspects of object-oriented versioned spatial database technology which have shown to be important in the generation and update of S57 ENC. This includes validation methods for data integrity enforcement, display methods for dynamic representation using attributes and relationships, process methods for structure building, and version differencing for update generation. Examples are taken from a typical ENC production flowline in current use at the UKHO.

1. INTRODUCTION

1.1 Laser-Scan and Hydrography

Laser-Scan has been involved for many years in the specialised world of Hydrographic Charting. Since the late 1970s the UK Hydrographic Office (UKHO) have used Laser-Scan software to produce their renowned range of "Admiralty Charts". Today they use Laser-Scan LAMPS for producing and updating the 3500 paper charts that cover the whole world at a variety of scales. In addition to the paper products, LAMPS is used to produce associated raster data products, such as the ARCS (Admiralty Raster Chart Service) products on CD-ROM.

The latest trend in navigation technology involves the use of Electronic Navigational Chart (ENC) data in a shipboard computer to provide intelligent charting. Given correct ENC data for the area around the ship, the computer can not only display an up-to-date chart of the area, but can give warnings to the crew of forthcoming danger.

Such a system, called an Electronic Chart Display and Information System (ECDIS) does this by tracing the future route ahead of the ship through the ENC data, and determining dangers, such as heading towards rocks or into shallow water. To do this, it needs to know the current position and course of the ship, often using the Global Positioning System (GPS) satellites, and combines this information with the ENC data.

A shipboard ECDIS system can only work if supplied with up-to-date, accurate ENC data for the area of its voyage, and UKHO have selected Laser-Scan's object-oriented LAMPS2 system as the basis for its production flowline for world-wide ENC data.
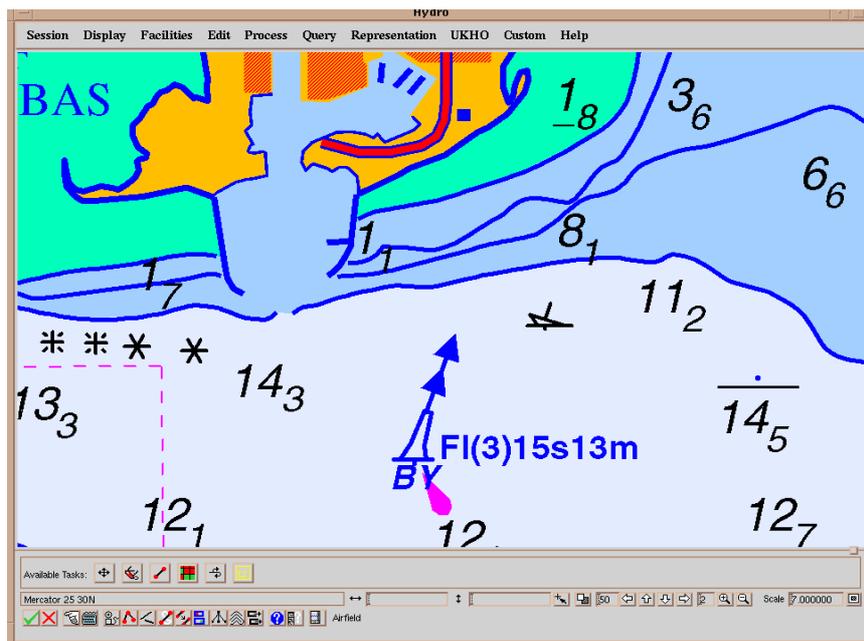
Example of Vector Chart Data in LAMPS2
(Base chart data courtesy of UK Hydrographic Office. Crown Copyright)

1.2 Why use an object database for charting and ECDIS ?

A chart or an ECDIS display is a model of part of the surface of the Earth presented as a graphical illustration. Charts and ECDIS are produced for specific purposes and will tend to exaggerate relevant features while minimising or suppressing irrelevant detail.

In the past, hydrographic cartography was done by capturing and compiling the data needed to produce a particular chart, usually using file-based feature mapping software. Increasingly though, the wasteful nature of such one-off capture has been

recognised, and there is a move to a database-centric approach in which a geospatial model of the world is captured, stored, and updated. Starting from the database, it is then possible to produce a range of products at differing scales and to different specifications [Woodsford 1995].

In addition, the S57 Hydrographic data transfer standard [IHB 1996] and its ENC Product Specification [IHB 1996 Appendix B.1] together define a richly structured object model for hydrographic data for use in ECDIS systems. To produce commercial quantities of this data to the strict quality standards of the IHO and the hydrographic agencies, within commercial cost limitations is a demanding task.

Traditional relational databases are not designed for holding the complex data models and large volumes of data involved in building and ensuring the ongoing integrity of a real-world geographic mapping database. Neither is it easy to produce a range of cartographic products from such data using the static representation facilities found in traditional GIS and mapping software.

Recently however, the advent of Object-Oriented (O-O) geospatial databases and associated charting products provides the technology to step into a new world of active objects and product-independent geodata storage. The later sections of this paper cover the O-O paradigm in more detail and put forward its strengths for hydrographic databasing and ENC production. They use as an exemplar, the Gothic O-O database and LAMPS2 mapping system from Laser-Scan [Laser-Scan 1994].

1.3 ENC Data Model

The standard for ENC data for use in ECDIS systems is mandated by the International Maritime Organisation (IMO) and is defined in International Hydrographic Organisation (IHO) Special Publication 57 (S57) [IHB 1996]. Edition 3.0 of S57 was published in September 1996, replacing the previous S57 V2 (DX90) and is frozen for four years. S57 Edition 3 includes a data model, an object and attribute catalogue, and a transfer format. The data model is complex:

- Spatial objects are nodes, edges, or faces, and describe geographic position information. They must conform to a strict topological structure of connectivity and adjacency.
- Feature objects describe the characteristics (attributes) of a real-world entity (a coastline, a sounding, an anchorage area). They refer to spatial objects to locate themselves. More than one feature object can refer to a given edge or node, sharing a common set of (X,Y) coordinate geometry. An example is a depth contour and the two depth areas either side of it.
- There are hierarchies of collection objects, only the bottom level of which will have geographical position information (e.g., a complex traffic separation scheme may be made up of a collection of simpler traffic separation schemes, each of which is made up of traffic lanes).
- Capturing, building and maintaining the object, attribute and relationship data needed to produce a valid and up-to-date ENC in S57 is a challenging task. The data needed is very different to the simple feature data used in the more traditional task of producing conventional paper charts.

1.4 UKHO and ENC

UKHO committed to producing world coverage of ENC data in S57 for ECDIS [McPherson, 1997]. It then recognised the need for software to handle the complex object-based S57 ENC data, and selected Laser-Scan's Gothic LAMPS2 for this task. On their development system of five workstations, UKHO used LAMPS2 to set up a production flowline for S57 ENC data generation.

Using this flowline they initially produced several S57 test dataset cells, including the world's first S57 Edition 3 comprehensive sample dataset. This is an extended electronic equivalent of the IHO standard INT 3 chart of Micklefirth and Port Rimon (an imaginary location which has one of almost every type of nautical feature from a glacier to a coral reef!). It has been adopted by the IHO as the definitive examples of S57 (the "ENC test data set" or TDS), and is available for download from the IHO web site at http://www.iho.shom.fr. It contains base cells of different usages, update cells, and test cases for error handling.

Once their initial flowline was proven, UKHO commenced a rollout into volume ENC production. They currently have some 25 LAMPS2 licences and are expanding. They are in production of S57 datasets, and as of July 1998 have completed over 65 cells.

With the cooperation of the UKHO, Laser-Scan has taken on the UKHO's S57 flowline and ENC tools, based on LAMPS2, and repackaged it for use by other Hydrographic agencies. This product "Laser-Scan/UKHO LAMPS2 Hydrographic ENC Tools" has been supplied for Hydrographic ENC work to the South African Naval Hydrographic Office (SANHO), and to the U.S. National Oceanic and Atmospheric Administration (NOAA).

2. OBJECT-ORIENTATION

2.1 Object-Orientation and object data model

In an O-O database, real world entities are abstracted and held as objects. All objects belong to object classes. For each class there may be many objects, but each object belongs to only one class. The class defines what values can be held by an object. Values can be simple datatypes (integers, strings, dates, etc.) together with more specialist types (geometries, locations, rasters, tables). Furthermore, objects can hold structural information or references between objects.

A key, and defining, concept of O-O is that of methods defined on objects. These methods are bound to behaviours. When a method on an object is invoked by sending a message to the object, the behaviour bound to it is executed, possibly using values and references also held by the object. The ability to define behaviours as part of the database schema, rather than as part of the application, is a fundamental concept of the O-O paradigm.

A further key concept of O-O is that of inheritance, which provides the means to define a new object class in terms of existing classes. The new class inherits the characteristics (values, references, behaviour methods) of its parent class or classes, unless superseded or redefined. Using inheritance, hierarchies of classes can be created and maintained in a systematic manner.

True O-O has gained much popularity in software engineering and computer graphics [Taylor 1990], and is making ground in GIS. O-O is now appearing in cartography and geodata production, including hydrography. In reality, however, there are still few commercially available systems that support all the key elements to a level that can successfully support ENC applications.

2.2 Methods and behaviours

Methods are central to the O-O technology. Each object class will have inherited basic methods from its parent classes, and can have other methods and specific behaviours for standard methods defined on itself. Methods are of several types:

- Value methods (also known as derived attributes) return an answer to a message. The results appear as attributes on enquiry, e.g. area, length, description
- Reflex methods occur automatically at milestones in an object's lifecycle: creation, modification or deletion (before and after). They are used to set up consequences of actions.
- Validation reflex methods enforce integrity, and allow you to put your own rules on each object class (see later section).
- Change to a referenced object is a reflex method which can trigger the propagation of effects from one object to another. Display methods give active representation (see below)
- Process methods happen at operator request. They are used to carry out data cleaning, data checking, polygon formation, generalisation.

2.3 Validation methods for data integrity

Data integrity is a major issue for agencies who invest large amounts of money in capturing and maintaining a large geospatial database. It is clearly vital to ECDIS and ENC data on which the safety of mariners and passengers may depend. The object data

model allows the agency to define its geodata logic and business rules as reflex methods in the database schema. This means that the database will enforce these rules as the objects are entered into the dataset, and whenever they are modified.

Whenever an object is being modified, messages are sent automatically to the object at the various stages:
- a message before the modification is started, so that it can check that it is allowable (e.g. can't move a lighthouse unless you are a supervisor).
- a message after the modification is finished, so that it can check that it has been done validly (e.g. can't edit a contour so that it crosses another contour).

If any of the validation reflex methods return a "not OK" result, then the complete transaction is rolled back as if it hadn't started. Note that such validation methods in the database are not just applied during interactive edit, but also during other operations such as bulk data loading from external data sources (e.g. legacy data).

2.4 Display methods and active representation

In an O-O mapping system, the appearance of an object on the screen or on hardcopy is generated at draw time by execution of an arbitrary 'display method' defined on the object class and stored in the database under the direct control of the customer. This contrasts with the traditional approach as indicated in the following table.

O-O Active Representation	Feature Representation
Dynamic - objects can draw themselves differently each time	Static - defined by feature class
Defined in the database	Defined in the applications program
Can be defined and enhanced by the customer	Can only be enhanced by the software supplier
Can be influenced by combinations of attributes	Indexed by single feature code attribute
Can be influenced by attributes from other referenced objects	Each feature is represented in isolation
Can adapt to external influences (e.g. required map scale)	Not adaptive

The functionality and benefits of active object representation are discussed in previous papers [Hardy & Woodsford 1997]. Active representation is used extensively in the ENC production flowline, to provide feedback to the operator about the correctness of feature coding, attributes, and relationships between objects.

Active representation is not only useful in ENC production, but can be valuable in combination with other O-O techniques when producing multiple mapping, charting and geodata products from a product-independent database. Data view selection, map generalisation, furniture generalisation, and product-specific alternatives are all tools in the armoury of the O-O multi-product map, chart and geodata producer [Hardy 1998].

The advent of the object-oriented paradigm opens up new strategies for generalisation, in which behaviours allow the object to decide for itself what to do, e.g. it can inspect its relationships with its neighbours to decide whether to move itself. However, as the object modifies itself, any objects which are directly linked to it or spatially adjacent can also be told to reassess themselves, so that effects propagate. Generalisation is relevant to ENC production as different 'usages' are needed as a ship leaves harbour for the open sea, giving less detail but covering wider areas, and aggregating what were individual objects (buildings etc.) into high level entities (urban areas etc.).

2.5 Object Versioning and Long Transactions

One of the problems of traditional relational databases is that their transaction model is designed round the rapid lock-update-unlock scenario common in financial and business transactions. However, completing the update of geodata and mapping for an area is often a long drawn-out process, taking several hours, days, or even weeks [Hardy 1995]. In the interim, the half-updated state must not be allowed to be used for production tasks, but also the unchanged data must not remain locked

The object database, with its encapsulation of all the data and behaviour for each object, lends itself to a different transaction model. In this, each user has a stable view of a 'version' of the dataset. Only changes made by that user are stored in the version, the unchanged objects are accessed from the previous version. Versioning of datasets within an object database solves the problem of long transactions and allows the sharing of very large data volumes between multiple users needing write access [Woodsford and Hardy 1997].

*Dataset versions*   *Long transactions*
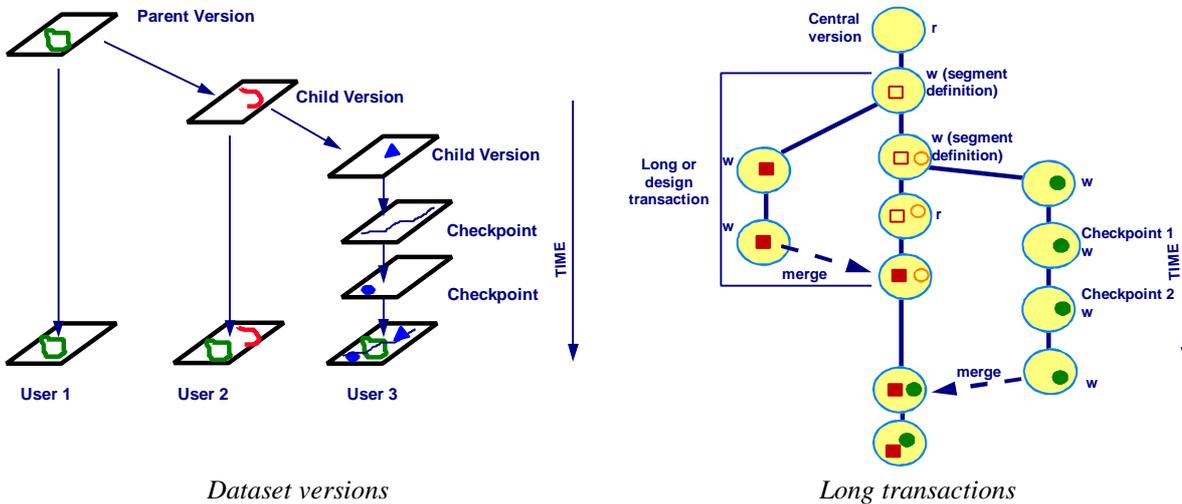
In the diagram on the right above, two users each reserve a segment of a continuous dataset for update, and after several checkpoints (e.g. when they stopped for lunch), the changes are merged to give an updated central (mainstream) version. This is discussed further in [Woodsford 1996].

Within the ENC flowlines, versioning allows multi-user update access to a continuous dataset of master features. In addition, it is central to the production of incremental update (ER) issues, as the information as to which objects have changed since a previous EN issue is directly available to the export process.

2.6 Topology and Structure

The Gothic object spatial database uses methods and object references to implement in-built support for topology structure. The user can choose Spaghetti or Structured for each class, and then define snapping tolerances between pairs of classes. The database will then apply these rules and create the necessary links and nodes as objects are digitised or imported.

Link/Node topological structure   *Areas made up of faces, referencing links*
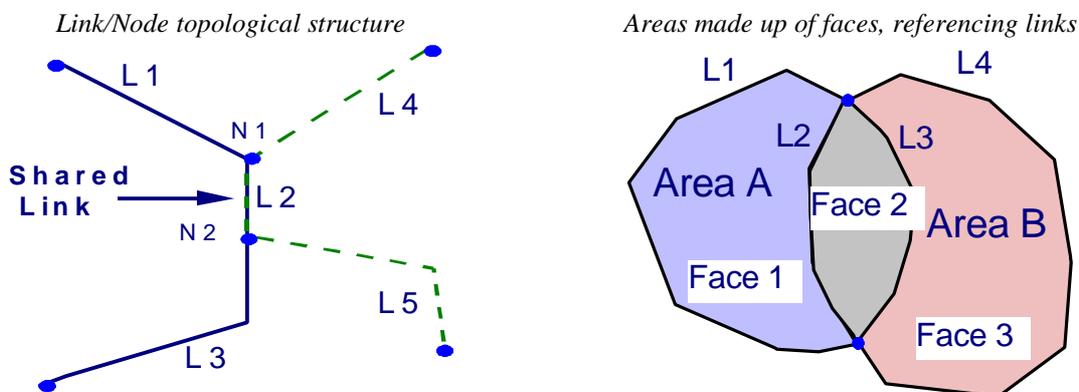
Uniquely, the topology is maintained automatically as the data is edited, avoiding risks of overshoots, undershoots, slivers etc., and obviating the need for subsequent error-prone building of coverages. Polygons can be formed out of existing linework, either directly or as a set of faces (the atomic entities of area).

Topology support is key to implementation of the S57 data model with its concepts of feature objects and spatial objects (nodes, edges, faces). The Gothic database provides the necessary topology primitives and automatic structure maintenance facilities. These are applicable to data stored in chart projections, or in the Lat/Long space mandated by S57, as LAMPS2 will transform data as needed into a cartesian 'calculation space' (or family of spaces, such as UTM) in order to carry out snapping.

3. ENC PRODUCTION

3.1 ENC Production Flowline

A typical LAMPS2 ENC production flowline, similar to that implemented at UKHO, involves the following major stages :

- Initial data capture, processing, validation and preparation, leading to a database of validated hydrographic data. This data may also be used for purposes other than ENC, such as producing conventional paper charts.
- Product-specific processing and subsequent export of requisite data from the database to S57 Edition 3.0 to form an initial ENC for publishing.
- Updating the database, then subsequently publishing an S57 incremental update instruction based on the differences since the initial ENC. This last stage will be repeated as needed to keep the ENC up to date.

Each of these stages is discussed in a section below:

3.2 Initial Data Capture and Preparation

This will usually involve the following steps:

- Setting up a dataset in the Laser-Scan Gothic object-oriented database, using an S57 data model. The schema of the dataset will know about all the S57 object classes, their attributes, their relationships to other objects, and their method behaviours.
- Digitising principal features from existing charts. This will often be hastened by importing spaghetti graphical chart vector data from an existing chart production flowline.
- Initial validation of principal features. Much validation is done automatically by validation methods in the database. For example these can detect area features which are invalidly self-intersecting (figure-of-eight shaped). Other validations can be done by process methods which can check for items below a size threshold, etc.
- Editing to complete the necessary features for ENC, using specialised editing and digitising menus and icon palettes. These present the otherwise cryptic S57 names for object classes and attributes (e.g. SLCONS) on the screen in words and icons understandable by the hydrographic operator.
- Adding the many attributes required by S57, either automatically where possible, or using a special attribute browser which allows possible values for attributes to be selected (e.g. colour = red, green, or white).
- Turning chart notes into INFORM attributes on relevant objects.
- Visually checking the content, using an ECDIS-like active object representation implemented using Gothic's O-O representation methods.
- Building area (polygon) objects such as depth areas, from the structured line objects such as depth contours and coastlines. This is done for Group 1 (skin of the earth), and for Group 2 polygons.
- Building the collection objects such as traffic schemes.
- Further validation using process methods which can check things such as whether all mandatory attributes are populated and have valid values.

- Transfer from chart space (e.g. Mercator projection) into the WGS84 Lat/long space needed for S57 or for databanking. As part of this several charts may be combined into a single S57 cell, or into a continuum of cells.

3.3 ENC Product Preparation and Cell Export.

The next stage starts with the validated hydrographic data in the Gothic database, and will usually involve the following steps:

- Extracting, if necessary, the area covered by the cell or cells from the main database into a product-specific dataset.
- Constructing and attributing metadata objects such as coverage and extent areas, or data quality areas.
- Pre-processing prior to S57 export, e.g. to build the collections of similar soundings into aggregated sounding objects, each of which will be output as a 3D coordinate record to S57.
- Export to S57 transfer format, which involves outputting first the spatial objects in fixed order, then the feature objects with their references to spatial objects, then the collections, with their references to feature objects, all encapsulated in the ISO8211 data descriptive language.

3.4 ENC Incremental Update

One of the fundamental concepts of S57 is incremental update. When there is some change to an ENC cell after it has been published in S57, only the changed object parts (additions, deletions, modifications) are issued as an S57 update message rather than sending the whole dataset again.

LAMPS2, being built on the Gothic object database, is well placed to support this ability which most mapping and GIS systems would find very hard to implement. This is because a Gothic database is 'versioned', so that only changes are stored from one version to the next through time. LAMPS2 uses this ability to determine which objects have changed and in what manner, in order to export just the changes as an incremental S57 update dataset.

Incremental update also relies on persistent object identifiers as the mechanism for marking objects to be changed. The Gothic database maintains unique internal object identifiers and hence provides a good framework for implementing incremental update.

The steps involved in producing an incremental update are as follows:

- Identify the changes necessary using the compilation facilities of LAMPS2, such as the ability to overlay new versions of source documents as raster backdrops. Editing the Gothic dataset from which the initial ENC was exported, using the usual LAMPS2 interactive tools.
- If necessary, rerunning any pre-process steps, for example re-grouping of soundings.
- Export to S57, as was done for initial ENC publishing, but this time requesting that only changes since the previous version are exported. Gothic will determine those objects which have changed and write the necessary update instructions to S57.

It is a basic assumption of the S57 update mechanism that the ER profile RUIN messages should replace or modify the minimum number of objects affected by the change. The recent support in LAMPS2 of topological merging allows optimisation of ER update volumes, by tracking changes to the spatial objects (links and nodes) rather than just feature objects.

3.5 ENC Flowline example screens

The following example screens are taken from a session using the LAMPS2 ENC tools, displaying the ENC test dataset of Micklefirth as adopted by the IHO, courtesy of UK Hydrographic Office. Crown Copyright.

The first shows a typical chart-like active representation from data in an S57 data model. The object classes and inheritance relationships are shown in the "display by class" form, and the pulldown menu of ENC facilities shows how facilities such as polygon formation are accessible. Note also the ENC task bar at the bottom of the window.
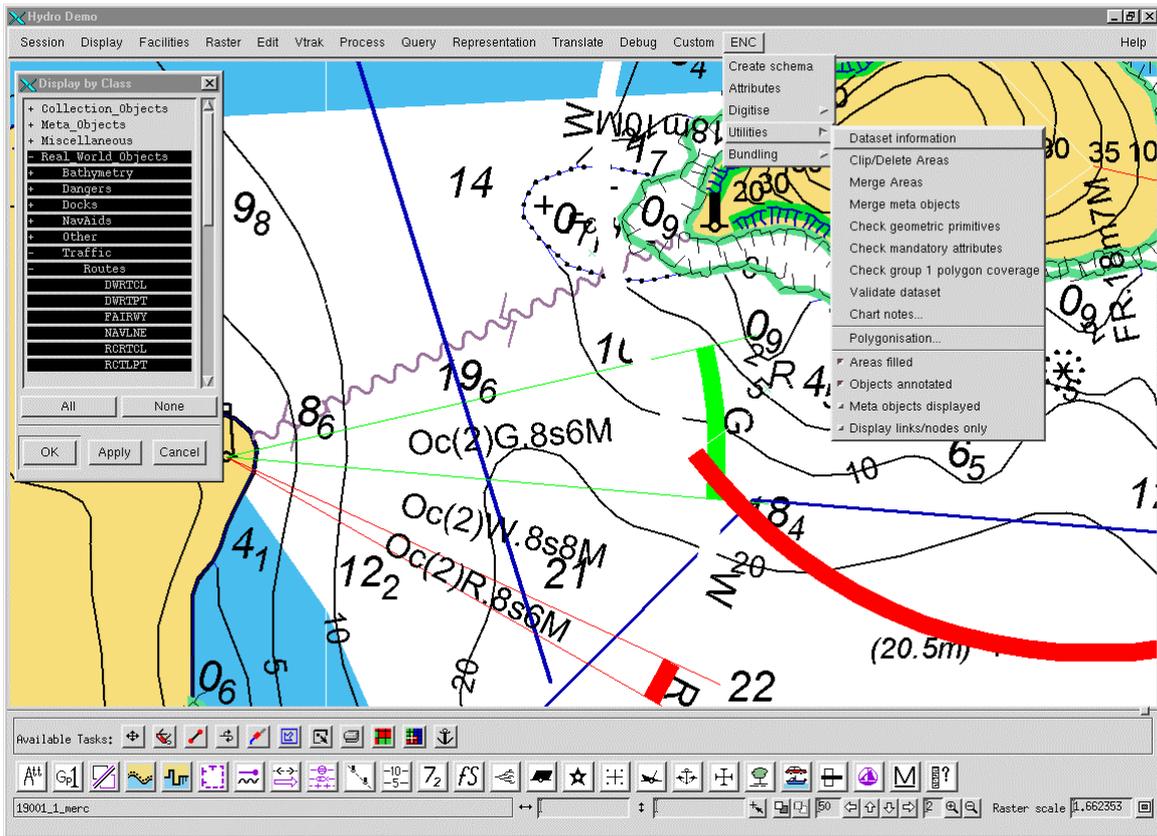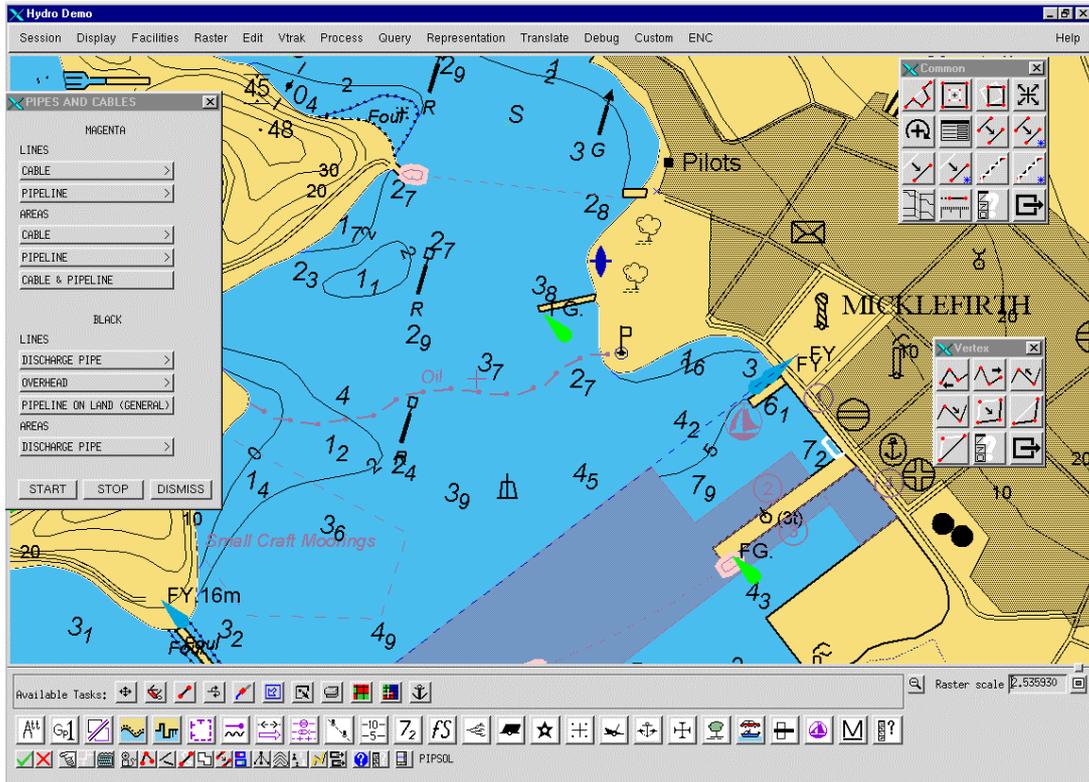
ENC facilities menu and chart-like active representation

The next screen shows the attribute browser with the attributes of a group 1 polygon object (Canals).
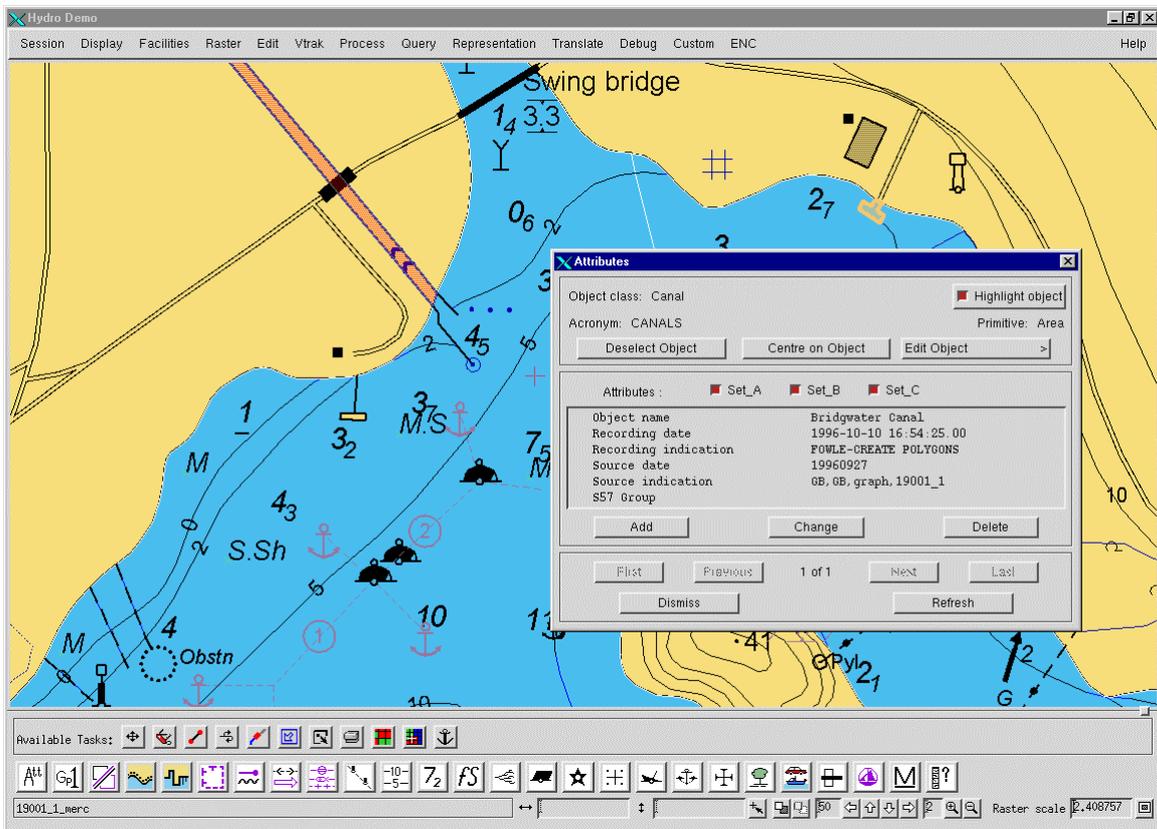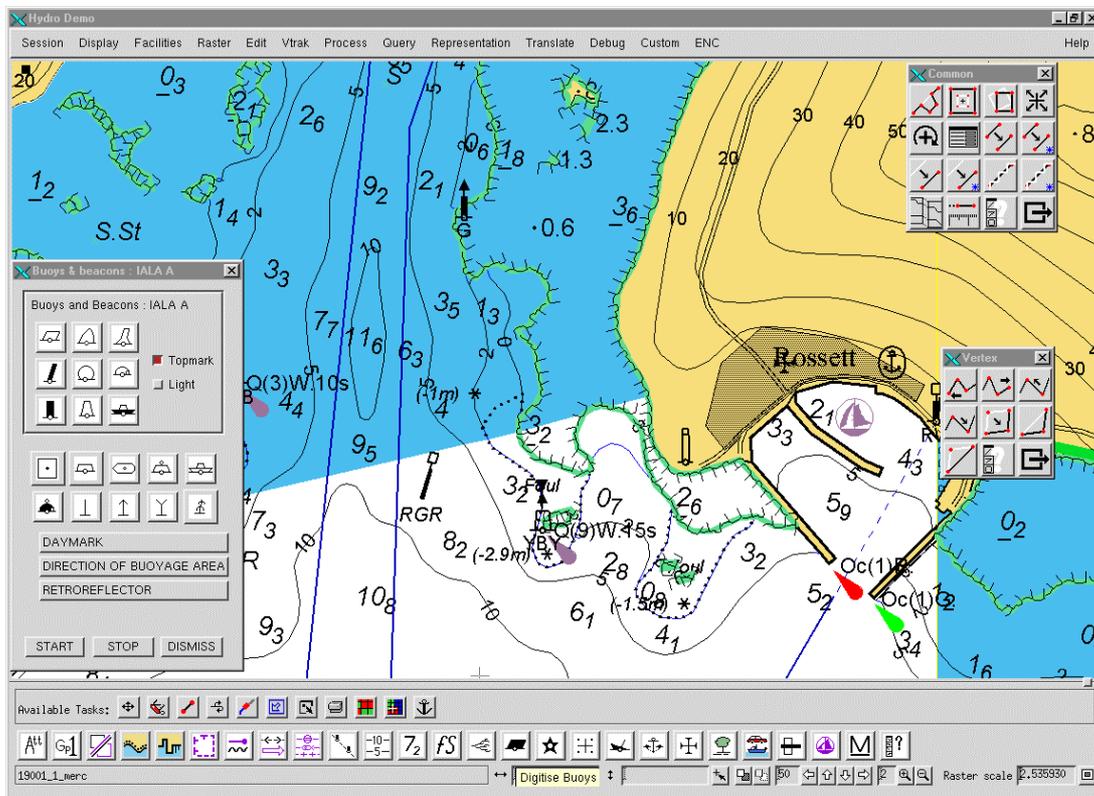

Attributes for Canal object

The next screen shows one of the digitising icon palettes, and a newly digitised pipeline.

Digitising a pipeline

The final screen shot shows an icon palette for digitising buoys and similar navigation marks.

Icon palette for Buoys

3.6 ENC Distribution

The ENC data (both EN cells and ER updates) coming from the flowline described above has to be fed efficiently into distribution channels to get to the shipborne ECDIS systems that need it. This distribution may be directly from the producing agency, but the IHO has proposed a World ENC Database model made up of a number of Regional ENC Centres (RENC), for storing and distributing ENC data. The hydrographic offices of NW Europe are establishing the first such RENC, which is operated on their behalf by the UK and Norway.

Although in theory, the RENCs could handle data purely in S57 format, it seems likely that they will need over time to hold master data in a revisable form for reasons of quality control and update. The object database lends itself well to being able to load S57 data from external sources, retaining all the complex attribution, object relationships, and metadata within its versioned object datasets. It is also well suited to the data management tasks involved in handling large volumes of time-varying spatial data, and to the generation of valid EN cells and ER updates from mixed data sources.

4. BENEFITS

4.1 Why Object-Orientation for ECDIS data production?

The description of O-O given in earlier sections applies to almost any geospatial data application [Woodsford 1995b]. The particular strengths of O-O spatial database and active object mapping in respect to ECDIS and ENC production relate to:

- Complex data modelling, covering the intricacies of the S57 object data model, which allows the real world to be modelled in the object database.
- Versatile modelling in a versioned schema, allows use of common datasets for both ENC production, for chart production, and for other geodata products such as DNC.
- Data storage and retrieval, including object versioning, long transactions, and version differencing, which allows handling of change through time and efficient generation of change-only updates.
- Efficient capture, generation and maintenance of the ENC objects, using ergonomic tools allows cost-effective creation of ENC data for ECDIS
- Topological structure, including automatic creation and on-the-fly maintenance of links, nodes and faces allows support of the spatial objects of S57 and creation and maintenance of clean structured data.
- Validity checks and data integrity enforcement through database methods avoid operator blunders and ensure that the data produced is of high quality and suitable for ECDIS.
- Object-Oriented generalisation methods simplify the task of generating derived products, such as smaller scale usages from the base data.
- Active representation shows object attributes in enhanced chart cartographic form, allowing the operator to check data structure and attribution for conformity with ENC standards.

5. CONCLUSIONS

- Object-oriented mapping and charting software as typified by Laser-Scan's LAMPS2 provides a set of versatile capabilities which enable a range of visual and data products to be generated from a common spatial database.
- These capabilities, together with the power and flexibility of the Gothic object-oriented data model, allow structured object data such as S57 to be manipulated, and data production flowlines to be implemented for applications like ENC.
- The combination of the UKHO's ENC production flowline built on LAMPS2 provides a modern object-oriented environment designed specifically for ENC production. In addition to the well-established use of LAMPS2 for ENC production by UKHO, LAMPS2 has been chosen by the U.S. National Oceanic and Atmospheric Administration (NOAA), and the South African Naval Hydrographic Office (SANHO) for their ENC production tasks.

- The market is demanding that hydrographic agencies provide S57 ENC products in addition to their traditional paper charts and raster chart images. Object technology typified by Gothic LAMPS2 is the chosen tool which allows agencies to meet this full range of hydrographic requirements.

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