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GIS Based Census Mapping Approaches: Australian Experience[*]

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GIS Based Census Mapping Approaches: Australian experience

Introduction

This paper outlines the approach the Australian Bureau of Statistics has used to achieve efficiencies in census mapping using GIS technologies. The current processes have evolved since the mid 1990s when the Bureau first embarked on this journey, and each census has seen increased efficiencies in terms of quality of mapping and reduced costs.

The paper will only focus on the census mapping for census collection operations for the recently completed 2006 Census of Population and Housing and explain the process and data sources used.

The paper provides detailed technical explanation of the processes followed with the intention of providing a detailed understanding of the process.

ABS uses GIS technologies for a range of other Census purposes such as coding of address data and in the dissemination of the Census data. These areas are not discussed in this paper.

The Need for Maps to Conduct an Efficient Census

The Census is the largest statistical collection undertaken by the Australian Bureau of Statistics (ABS) and one of the most important. There are two broad objectives that underpin the Census. The first of these is to accurately measure the number and key characteristics of people in Australia on Census Night and the dwellings in which they live. The second is to provide timely, high quality and relevant data for small geographic areas and small population groups, to complement the rich but broad level data provided by ABS surveys.

Census collectors are required to deliver census forms to each household and track and record their activity at each residence using the Australian Bureau of Statistics (ABS) Collector Record Book. To ensure complete and accurate coverage of their area, a separate map of each Collection District (CD) is required for inclusion within the Collector Record Book relating to that CD. There are approximately 39,000 Collection Districts covering Australia.

Conducting the field operations component of the Census is very resource intensive and expensive, so the efficient design of Collector Districts and communication with the collectors and their supervisors of the areas they are responsible for can save substantial amounts of time and money. The geography section is responsible for applying GIS technology to this area to assist with this process.

Spatial Data Requirements

An accurate up to date digital map base showing the correct level of detail to identify individual blocks of land is a vitally important prerequisite for an efficient census mapping system. In Australia, topographic mapping is a responsibility of Federal and State Government mapping agencies, and it is fair to say that prior to 1996 there wasn't a national topographic database at a scale suitable for census mapping. The Australian Bureau of Statistics was instrumental in the formation of the Public Sector Mapping

Agencies (PSMA), a consortium of the State and Federal mapping agencies that jointly responded to an ABS tender to build and maintain such a database.

Today, PSMA Australia Limited has evolved into an unlisted public company wholly owned by the State, Territory and Australian Governments. They combine reliable spatial data from Australia's governments with leading-edge technology to create national spatial information datasets.

PSMA Australia's digital mapping information used by the Australian Bureau of Statistics includes:

Administrative Boundaries
The Administrative Boundaries dataset is comprised of five themes:

- Australian Bureau of Statistics (ABS) Boundaries
- Electoral Boundaries
- Local Government Areas
- Suburbs/Localities
- State Boundaries.

Transport and Topography.   The
Transport component of this dataset encompasses the roads, rail, rail stations and airport infrastructure networks across the entire nation of Australia. The roads layer includes more than 1,000,000 kilometres of named roads. The rail and rail station layers depict the national rail network (including tram lines). The airports layer also includes landing grounds.

The Topography component of this dataset is made up of two themes—hydrology and greenspace. Two layers of hydrology are made up of water bodies, major rivers, minor waters and oceans. The two greenspace layers are urban parks plus national parks and other reserves.

Points of Interest
The Points of Interest dataset contains in excess of 212,000 points of interest with feature code and name attribution

CadLite
The CadLite dataset incorporates names of suburbs and boundary locations as well as land parcels from across Australia. This dataset is a graphical index of digital cadastral boundaries, excluding easements and road drainage easements.

CadLite can be used to reference other geographic and land administrative data available from respective jurisdictions. It contains approximately 10.5 million land parcels—each represented by a polygon from which are generated an area and the polygon centroid. It does not contain any road information, addresses or property details, contextual information such as coast, rivers or cultural features unless they form a cadastral boundary.

G-NAF (Geocoded National Address File)   G-
NAF is Australia's first authoritative geocoded address index for the whole country, listing all valid physical addresses in Australia. It contains approximately 12.6 million physical

addresses, each linked to its unique geocoded (specific latitude and longitude of the address). Data used to build G-NAF comes from contributors including the Australian Electoral Commission, Australia Post and Australia's government mapping agencies and land registries. It is the single, national authoritative source for:

- validating customer-provided address (assisting in fraud prevention)
- identifying the geocode for spatial analysis (creating maps to plot and analyse services and customer locations)
- assembling and maintaining large address files (reducing duplications and costs, increasing efficiency and improving mail delivery).

The current version of G-NAF does not distinguish between residential and non-residential addresses. This greatly limits its usefulness for the purposes of census collection operations.

Spatial Data Management   Data
from the PSMA is loaded into the ABS Master Spatial Database, which is used as the authoritative source of spatial data for the organisation. Updates are received quarterly. The updates from PSMA are supplied as a set of highly normalised tables. These normalised tables are then connected together to form a summarised set of tables that contain the columns of information that are required by the users. The summarised tables are accessed by the users through a set of views. Views are used to maintain a consistent naming convention and table structure which enables applications to be built that can access consistent set of Oracle views. The views can also be quickly pointed to each new version of the data with minimal disruption to their work. (Figure 1)

Figure 1. Table structure of Master Spatial Database
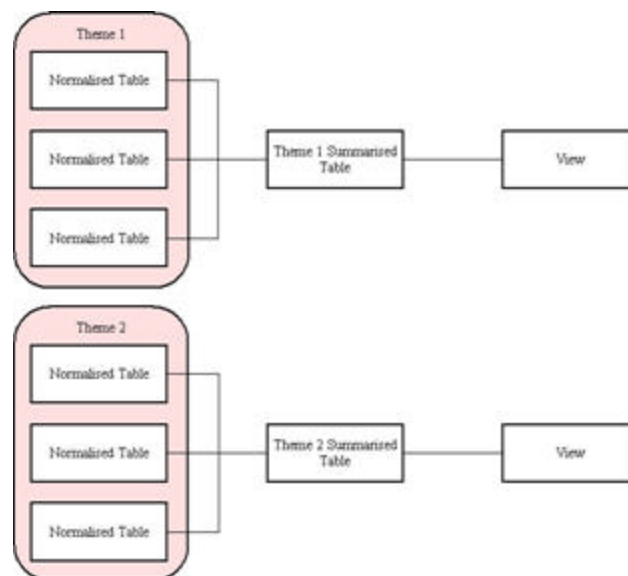
For simplicity the database is split into two schemas the first schema contains the Census boundary tables. This schema occupies approximately 40Gb of space on the Oracle database. The schema contains a historical set of statistical boundaries plus the current

statistical boundaries that are being edited and maintained by the Geography section. The second schema occupies approximately 58Gb of space on the Oracle database and is used to store the topological basemap supplied by PSMA. Access to the tables stored on the database is controlled by a series of data roles and user roles. (Figure 2)

Figure 2. Schemas for the Master Spatial Database
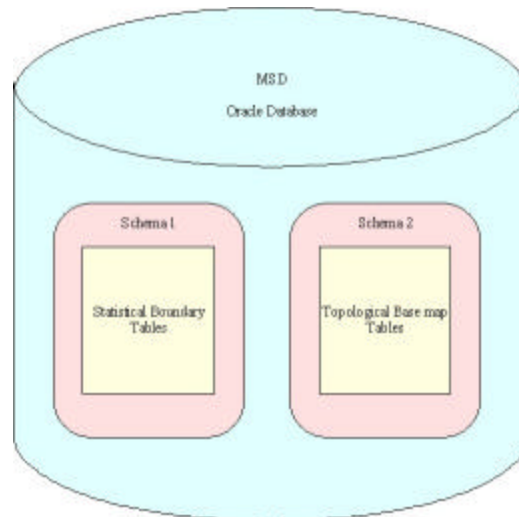
GIS Software   The current software utilised includes the following:

MapInfo Professional (Version 8.5). This is a comprehensive desktop mapping tool used for the creation and editing of spatial data, spatial analysis and map presentation.

MapBasic (Version 8.5). This is a software package with functionality to customise and automate the MapInfo desktop-mapping software. The software contains a development environment to write programs in the MapBasic programming language. The development environment includes:
  - A text editor to type programs.
  - The MapBasic compiler to produce an 'executable' application.
  - The MapBasic linker for creating large, complex applications that can be divided into separate modules then 'linked' together into one application

MapInfo MapX (Version 5.0). This is a mapping ActiveX (OCX) control that allows for the addition of mapping capabilities to applications. It can be used with Visual Basic and C++ in the development environment to produce MapX applications.
MapX is based on the same mapping technology used in other MapInfo products such as MapInfo Professional and can use existing ABS MapInfo formatted tables.

Maplex (Version 3.4). This is a fully automated cartographic name placement software solution used for the production of maps. Maplex can automatically place features, point, line, and area labels on a fully symbolised map in accordance with user preferences.

SAFE Software- FME (Feature Manipulation Engine) Suite 2006. This software provides simple and powerful data translation and manipulation functions. It is mainly used in the

ABS to translate large volumes of spatial data stored in one format (eg. MicroStation DGN or XML) into another format (eg. Oracle Spatial or MapInfo format). It is also used for performing quality assurance checks on spatial data, for example checking for topological errors.

The Process of Census Collector Design and Map Production
Geography section supports the Census Field Operations section of the Census program in these elements of the Census. A diagram of the CD design and map production process is provided at Figure 3 and the details of how GIS has been applied to various elements of the process is described more fully below.

Figure 3 High level process diagram for CD design and map production
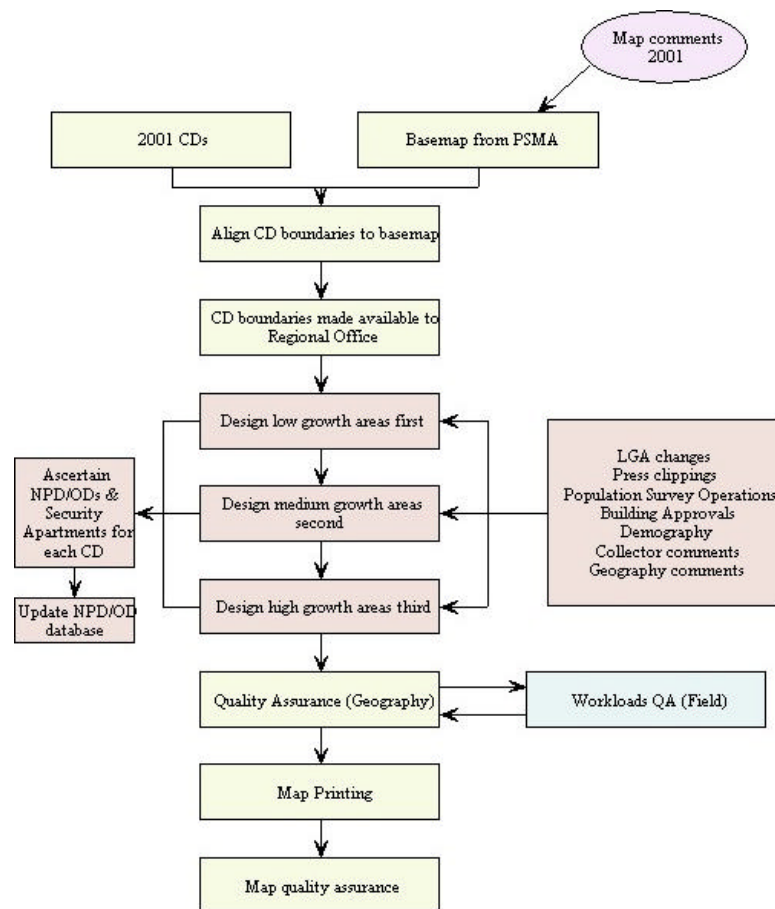
NPD - Non Private Dwellings
ODs – Other Dwellings

CD Alignment

Load 2001 CDs
The first phase of this project is to set up the Collection District Record Database tables on Oracle. This is done by taking a copy of the 2001 CD boundaries and copying them in to the 2006 Oracle tables, to create the initial 2006 CDs. The tables are then structured with

the fields required by both Geography and Census Field and these fields are then populated with the values, whether they be dwelling and person counts, or codes relating to higher level geographic units. This is carried out for each State and Territory in Australia.

Review Map Comments
One of the major issues when reviewing CDs for an upcoming Census is the accuracy and coverage of the basemap data. An exercise is carried out whereby all Collector maps which have had comments or diagrams written on them by the Collector have their images captured. The Geography team then reviewed each of these maps and created a repository of any issues which related to basemap accuracy and coverage. Once this task was completed this information is then fed back to the PSMA.

Update Basemap
The PSMA along with the State and Territory mapping jurisdictions then review this feedback and make amendments to the various basemap layers as they feel appropriate. This updated data is then re-supplied to the ABS and loaded into Oracle. This is then downloadable in Mapinfo tab format.

Align 2001 CDs to New Basemap
Alignment is the process where CDs from the previous Census are aligned to the basemap feature they followed at that Census. However in the intercensal period many features are captured more accurately which causes some features to shift from where they were previously located. As a result the CD boundaries need to be re-aligned to these features.

For alignment, design and quality assurance purposes each State and Territory is broken up into smaller regions with the aim of aligning, designing and then quality assuring areas of low growth first, then areas of medium growth and finally high growth areas towards the end of the project. The aim is to ensure that areas of high growth are designed as close as possible to the Census to ensure accurate estimates of dwellings and to try to ensure that the collection area itself is of a manageable size.

Aligners are allocated an area to work on and then download the necessary data from Oracle. This includes all the relevant basemap features as well as the CD boundaries themselves. Once the data has been downloaded the aligners use software specifically written in MapBasic to examine each CD and realign them as required. The software produces a list of CDs to be examined and the software zooms in to each CD. During this examination process aligners come across cases where the boundaries don't align to a basemap feature as shown below where the CD boundary (in red) is no longer following the road (in black).

Figure 4. Misalignment of CD boundary with topographic base

This misalignment can be corrected in two ways. The first way is to snap each node (represented by the black squares) of the CD boundary to the corresponding node on the road layer.

Moving nodes individually is an acceptable method of aligning a CD boundary when the number of nodes isn't too high however when a large number of nodes are involved this becomes a very time consuming task. The second method of aligning a CD to a basemap feature is by using a cutter which aligns multiple nodes in one action. An example of a cutter is shown in Figure 5 below.

**Figure 5. Using a cutter to align multiple points to a feature**
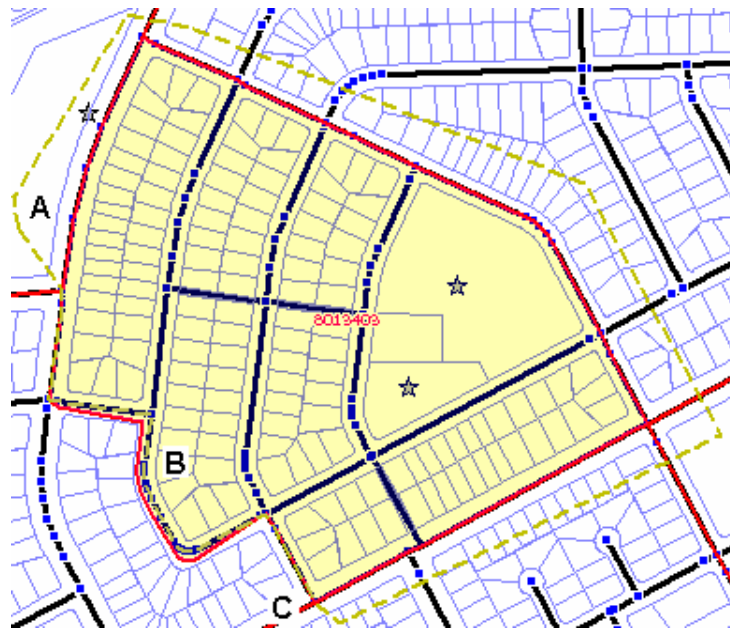
In this diagram the cutter (yellow hashed line) starts outside the boundary (Point A), follows the basemap feature where the misalignment has occurred (Point B), exits the boundary (Point C) and the cutter is then drawn around the outside of the boundary and is completed back at Point A. The operator then chooses a Specific Program (CD Adjust) which aligns back to the basemap feature.

Once it has been determined that a CD has been aligned it is saved and the system moves on to the next CD in the list. The CD that has just been examined is then copied to another table, with the records in that table being shaded. The purpose being that the boundaries of these CDs have been examined and therefore don't need to be examined again. Figure 6 shows the light coloured CD that still requires inspection.

Figure 6. Screen showing operator which CDs have been aligned (dark)
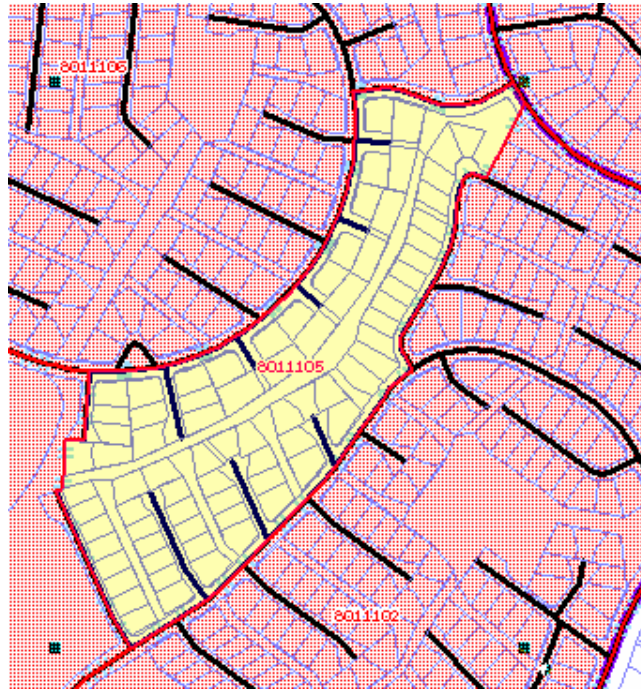
Once this process is completed the boundaries are checked for topological errors such as spikes, overlaps and gaps, and these errors are fixed. This is a manual process involving moving individual nodes. Once the topological errors have been corrected the CDs are now available to be re-designed as necessary.

CD Design

The design process involves staff in regional offices examining 2001 CDs to ensure they are still effective collection units, as well as meeting the CD Design criteria, and amending them where necessary. Due to restraints in time and the resources available it is not possible to examine every CD, so we need to try and focus on certain CDs. To do this the designers are provided with lists of CDs they need to examine such as lists of CDs where the actual dwelling count is +/- 10% greater than the estimated dwelling counts that were calculated prior to the previous Census. Another source used to extract lists of CDs to examine is CDs where there has been a change of more than 20% in the number of cadastral parcels. The designers are also provided with statistics on building approvals, as CDs where there have been a number of building approvals indicate that there may have been significant growth which means that the previous CD boundary may no longer meet the design criteria.

Designers also need to carry out investigative work of their own, for example contacting local councils and State/Territory Planning Departments to try and determine areas where there has been growth and redesign may be necessary. Described below is the process by which we provide lists of CDs where the change in cadastral parcels is more than 20%

First step is to open the CDs table for a State/Territory, in this case the ACT, as well as the latest cadastre table, and the cadastre table that existed at the time of the previous Census in MapInfo. An SQL query is then run to determine the number of cadastral parcels in each CD at the time of the last Census and as they stand now.

The SQL query will create a record for every cadastral parcel, and will list which CD that cadastral parcel lies in. Another SQL query is used to give an actual count of the number of cadastral parcels for each CD. The cadastral counts for 2001 and 2006 are then compared and represented as a percentage change.

Figure 8. Calculation of change in cadastral parcels per CD

CDCODE_2001	CAD_06	CAD_01	DIFF
8,012,502	135	68	49.6296
8,024,405	157	80	49.0446
8,012,505	235	140	40.4255
8,013,601	59	80	35.5932
8,010,530	316	227	28.1646
8,021,204	8	6	25.0000
8,010,534	274	207	24.4526
8,024,202	226	172	23.8938
8,012,306	57	44	22.8070
8,012,806	55	67	21.8182
8,021,403	327	268	18.0428

Once the investigative work has been carried out, and the designers have determined the boundary changes they need to make, they then need to use the software provided to make the changes to the CDs.

There are basically three different sorts of amendments they can make. Firstly they can split a CD to create two new CDs, conversely they can amalgamate two CDs to create one new CD. The final option they can use is to adjust a portion of one CD to another and this is shown below. In the diagram below we wish to move the area enclosed by blue from CD 3161904 to CD 3161903. As with alignment, a cutter tool is used to select this area.

Figure 9. Using a cutter to identify an area to amalgamate with another CD
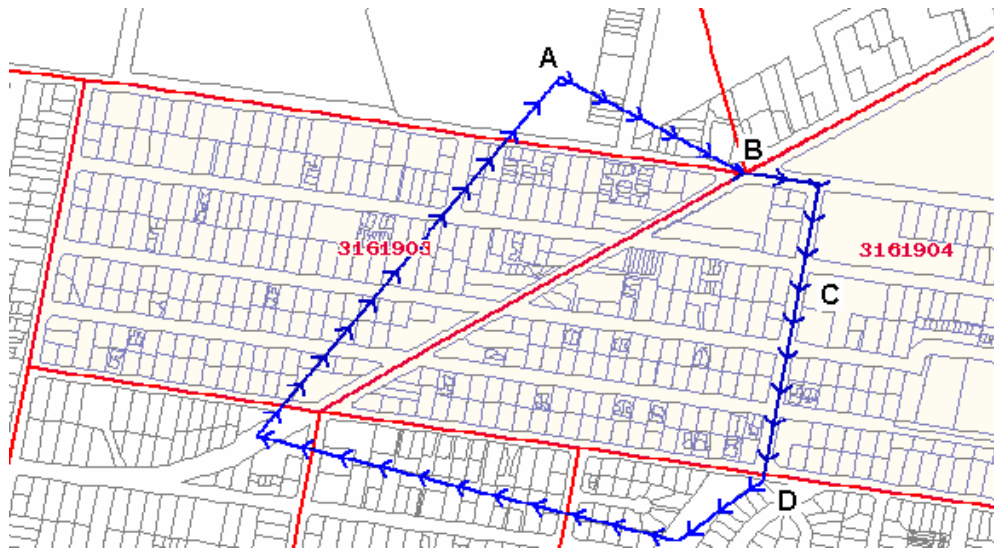
The designer then selects the boundary adjust function, nominates the donor CD and the area is moved to the receiving CD. The adjustment takes place and the new boundaries will appear as shown in Figure 10 below.

Figure 10. The resultant redesigned CD
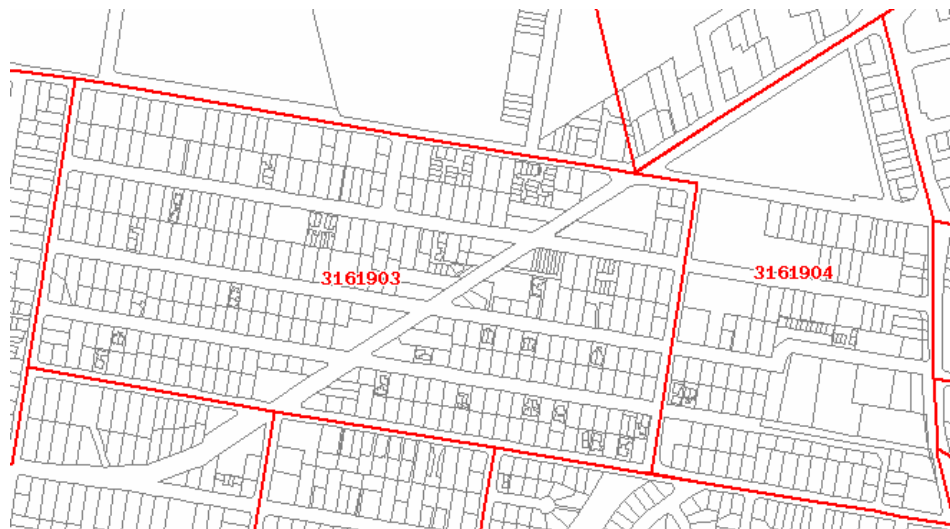
During the course of design the associated information attached to the CDs also needs to be updated. This includes updating the estimates of total dwellings and persons, as well as special dwellings such as Non-Private Dwellings (NPDs), and Other Dwellings (ODs) as these types of dwellings may be required to be enumerated differently from most other dwellings. In cases where NPDs and ODs are known to exist, their details also need to be updated on a separate database as these details will later be used by the Census Management Unit to determine whether they need to be enumerated differently.

All other updates performed to the associated information attached to the CDs are carried out during the design process, and this information can be updated when a CD is being split, two CDs are being amalgamated, an area from one CD being moved to another CD, or if the designer feels that this information needs to be updated despite the CD boundary not being modified. This is carried out using a dialogue similar to the one shown in Figure 11 below.

Figure 11. Updating CD attributes

Using this dialogue the designer updates any information as required, and this information is then saved back to the Oracle table.

Once all amendments have been carried out, and any associated information has been updated designers are then required to allocate CDs to Collector, Area Supervisor and District Manager Workloads. In some cases more than one CD can be enumerated by the same Collector. A group of Collectors are managed by an Area Supervisor, who are in turn managed by the District Manager. Once this has been completed the CDs are now ready for the quality assurance phase.

Quality Assurance

Quality assurance is a 3 phase process where a series of reports are run to ensure that the CD Design criteria have been adhered to. Where anomalies are found these are resolved with the designer, and the reports re-run until no issues arise.

The alignment process is then repeated to ensure that any changes made by the designer align to a discernible feature on the ground where possible. Once the alignment phase has been completed topological errors are then searched for and corrected as required.

The CDs are then passed on to the Census Field area and they run a series of reports over the CDs based on their workload allocations to again ensure that the CD design criteria has been adhered to. Any issues are discussed and resolved with the designer and once this is done the CDs are then ready to move on to the Map Printing phase of the project.

Map Printing Process

Given the scale of this operation, it is essential that the maps are optimally designed to support the census collector.

The purpose of the 2006 Census map production project was the creation of unique, full colour maps for each Census Collection District (CD), Area Supervisor Workload (ASW) and District Manager Workload (DMW) within Australia.
The CD map has two purposes. Firstly, it clearly and unambiguously displays the area for which the collector is personally responsible. Secondly, it assists the census collector to navigate around the CD and locate each dwelling, or potential dwelling, where someone could be living on census night.

There are approximately 26,150 collectors who have responsibility for one or more collection districts. Collectors are recruited locally and can be expected to have a reasonable knowledge of the area. While every attempt is made to map important landmarks, a Census map is not a general purpose topographic map and has been designed with the main purpose of data collection.

Each map produced needed to be clearly labelled and where possible, fit inside an A3 Collector Record Book. For large rural areas, A2 maps with insets were produced. Each map was printed twice resulting in 69,548 A3 maps 7,840 A2 maps 5,818 inset maps, 6,678 ASW maps and 102 DMW Maps. In addition, there was approximately 3,000 reprints for training, lost maps and corrections.

Map Production
Maps were generated utilising the Census Map Production System 2006 (CMPS2006). Each map displays the ABS Collection District boundary over a topographic base with a level of detail suited to the size of the individual district. Inset maps for large rural CD were also included with the ABS Collector Record Book to enhance the level of detail.

This project had several complex issues to overcome. A process needed to be developed which would produce individual maps with well presented labels for areas ranging in scale from 1:1000 to 1:2000000. Due to the large number of maps and the short time frame, this process had to be completely automated. In addition, the logistics of producing, printing, collating, storing and validating 100,000 maps had to be developed.

Development of CMPS2006 took approximately one person six months, and a further person two months for Maplex rule-base development, symbology and integration testing. The system was completed in June 2004 and integrated several platforms and proprietary software.

Map Production started on the 5th of May 2005 and completed on the 7th December 2005. During this time the production team, consisting of 45 staff members, averaged 250 maps per day.

The quality of CD maps was a major contributor to the success of the 2006 Census field operations.

Methodology.
During the development of the CMPS2006, it was determined through investigation and the testing of existing mapping and graphics technologies, that no single software suite could be acquired and easily tailored to support all of the required functions of an automated map production system. The functions required of the CMPS2006 included spatial editing tools for input data preparatory work, cosmetic map correction, determination of the optimum map scale and paper size, producing a unique map legend with inclusion of logos, symbolisation of a vast array of spatial data, text placement of a large number of labels in an automated fashion and the ability to produce output to a PDF for each collection map.

It was determined that MapInfo Professional and MapBasic could satisfy most requirements, with the exception of label text placement. Mapinfo Professional was unable to meet the label placement demands of a high quality census collector's map without significant cartographic intervention. An additional software package, Maplex (produced be ESRI) was adopted to meet the requirements of a fully automated cartographic label placement software package, allowing the user to have complete control over label placement and display. Maplex saved significant time and production costs by eliminating the need for manual cartographic intervention and brought a level of sophistication seemingly unmatched by any other product available at the time.

Adobe Distiller was used to convert the final Postscript files (PS) to Portable Document Format (PDF) for viewing and printing.

MapBasic was used to program several modules that added tailored menu items to the standard MapInfo Professional interface. This customised interface simplifies the map production process and includes functions for downloading data from the Oracle based Master Spatial Database, separating data, quality assurance, building insets, producing map layouts, creating Maplex input files, joining PostScript, building symbology and sorting output files.

The large number of spatial datasets required for the mapping system were stored in the Master Spatial Database (MSD). Approximately 18 tables per State are required resulting in over 10 gigabytes of information for all of Australia.

In order to produce maps for the whole country, basemap and boundary data was separated into 126 areas to facilitate easier management which contained approximately 350 CDs. CD design continued through the map production process and monitoring software developed and deployed within the MSD was used to notify the map production team once an area had been designed and passed through a QA process. Once an area was ready for map production a five stage process was employed to produce the maps.

Stage 1 - Data preparation
This stage of the map production process involved the collation of data for the area covered by all the CD's within the selected management area. Data is extracted from the State datasets stored within the MSD and complete coverage of the selected area is obtained.

The quality of input data has a marked affect on the quality of automatically generated maps and data limitations inevitably lead to some compromises. However, the only data

edits performed on 2006 data was the removal of some points of interest data which had been duplicated.

For cosmetic reasons, data for parks and hypsometric tints (indicating the relative height of the area covered by the CD) are split by the CD boundary into an internal and external class during this stage.

Stage 2 - Map layout and Maplex file generation
Stage 2 encompasses the main production processes of the CMPS2006. There are two main outputs, firstly, an individual map layout which includes the CD map, legend, logo's, scalebar and a QA strip is produced and exported as a PostScript file. Secondly, datasets translated into the format required by Maplex are also produced.
 The "Produce Layouts and Maplex Files" component of the CMPS2006 is the most complex module of the entire system. In order to produce individual map layouts and Maplex files this MapBasic module performs the following tasks:

Determine the type of map and area(s) selected
Produce a Maplex batch file
Build an ASW level map
Separate tables into individual object types (line, polygons and points) and feature codes
Determine page size, orientation and Maplex rule-base
Produce the final map and apply the symbology
Produce any inset maps
Create layouts and the QA Strip
Produce the final PostScript files
Create input files for Maplex

The Maplex component of the CMPS2006 is relatively straightforward. This module cuts the large jurisdiction based datasets into CD sized files and saves the selections in the MapInfo Mid/Mif text format and then translates the data line for line into the Maplex Map format, another text based format. The process also creates a text file that contains a list of CDs, their locations, and their applicable rule-bases that is subsequently read by Maplex in the next step to enable label creation in batch mode.

Stage 3 - Label Generation
The third stage is the most impressive in terms of technological sophistication. However, in terms of development resources this stage is less demanding than Stage 2, as there was no programming required, only the creation of rule -bases.

Maplex is a fully automated cartographic name placement software solution. Maplex users have complete control over label placement and display, being able to choose from a vast array of options which are saved in rule-bases. Using many of the available labelling options, six rule -bases were created to accommodate six different map scale ranges. These scales were named urban small, urban mid, urban large, rural small, rural mid and rural large.

The Maplex batch mode is used to automatically generate point, line, and area feature labels according to the 6 rule-bases. Maplex is also used to symbolise point features such as churches and hospitals to ensure associated labels don't print over the symbols. Although labels and point symbols are produced using Maplex, the ability to symbolise line and area features is not utilised as this is undertaken in Stage 2 through the MapInfo layouts.

Stage 4 - Joining map layout and label files and printing

This stage merges the MapInfo layouts produced in stage 2 with the Maplex labels produced in stage 3. This simple MapBasic module joins postscript files and performs edits to register the labels correctly to the layout. The final result is a PostScript file which is then converted to the final PDF file using Adobe distiller.

All maps were printed, collated and checked in a map production room using either a Lexmark C912 for A3 maps or a HP Designjet 4000ps for A1/A2 maps.
 Maps were stored on the network as PDF files. These files were sent to the printers using Acrobat.

Stage 5 – QA Checking

Once printed, the maps were sorted and the print quality was checked. The maps were then packed into boxes for Census Field staff to do the final QA checks. These checks are performed on the hard copy maps rather than viewing the electronic files on a PC. This ensures both print quality and data quality checks were performed simultaneously. The reject rate was approximately 2%.

During production, maps were rejected for the following reasons:

Duplicate Points of Interest (POI) data were found in some areas of Queensland. The duplicated data was removed and the maps were reproduced. During ASW map production, some of the ASW labels were either too small or not clearly visible. These labels were corrected in MapInfo by using leader lines for the obscured ASW labels. At the start of map production, insets were created based on cadastre which resulted in an excessive amount of insets being produced. Once the G-NAF file was made available and used for inset creation there were very few rejects.

Due to inset boxes being resized by the system so that they would fit on an A3 page, some inset boxes extended past the area displayed on the A2 map. As a result, some insets needed to be moved or resized. On rare occasions, CD labels were misplaced due to a large CD surrounding a much smaller CD. These were corrected in Adobe professional. As a result of having a perforation on all A3 pages, some slipped during printing. Rejects were simply reprinted. Other technical faults occurred with the printers such as low toner etc which produced some rejects. Some maps where rejected due to changes to the boundaries or associated information after initial production.

Figure 12. A sample CD Map for use by collector
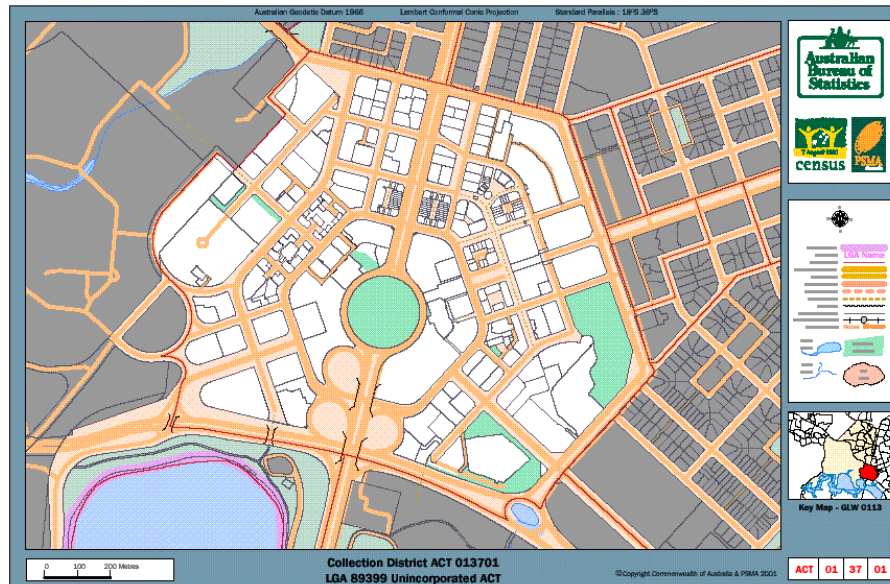
Conclusion

The cartographic and GIS capability that has been developed in the Geography Section of the Australian Bureau of Statistics has contributed significantly to the successful undertaking of recent census. The quality of maps used in the census has a major influence on the quality and reliability of census data.

Development of a strong relationship with the providers of topographic base mapping means that efforts can be focussed on statistical mapping, classifications of geographic areas, analysis and outputs rather than building and managing the topographic base itself.

The CMPS2006 integrated several platforms and proprietary software with applications developed in-house. It was also dependant upon, the complementary skills of staff within the Census program to produce the ideal compromise between cartographic representation, cost effectiveness and purpose.

GIS technology has enabled efficiencies to be gained through automation of routine procedures and it is necessary to invest in the skilled people, technology and data to realise the potential benefits.

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