COMPUTERIZED SIMULATIONS FOR
INTRODUCTORY GEOGRAPHY
INSTRUCTION: INTERNATIONAL POPULATION

by

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(ABSTRACT)

Few introductory geography courses offer laboratory sessions. Computer-aided instruction (CAI) techniques offer good means of satisfying the need for laboratory instruction in geography, by providing graphical manipulation of representations of geographic processes. Traditional classroom approaches are unable to provide such graphical manipulation. This paper focuses on the design and implementation of the International Population module, one of six computerized laboratory modules being developed to support introductory geography instruction as proposed for project GeoSim. This module illustrates the effects of age distribution, as well as birth and death rates, on population growth for selected countries from around the world. The student is presented with key themes involved in population dynamics through assorted graphs and figures. Population projections for each country can be computed, and students may modify birth and death rates to investigate resulting effects on projected populations. The module uses Macintosh Toolbox routines to support a highly interactive window-based, menu-driven graphical interface which runs under the Macintosh II System.
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Chapter 1

INTRODUCTION

Geography is unique among disciplines in its focus on the spatial aspects of physical processes and human actions. While geographic knowledge is necessary for understanding historical and contemporary events, dozens of studies point out the incompetence of U.S. students in geography. The number of geography majors is low compared to other natural and social science disciplines, so colleges and universities are producing few knowledgeable individuals in the geography discipline [Cars90,Shaf90].

Many geographic processes are dynamic and thus difficult to present in a traditional classroom setting. Fortunately, the manipulation of geographic information by computer has been studied intensively, with many models of geographic processes well understood. Thus, computer simulations of geographic processes can be developed that illustrate the principles and processes involved. In addition, these simulations can allow for decision making and interactive learning by the students.

Members of the Departments of Geography and Computer Science have initiated project GeoSim: computer-aided instruction (CAI) software for the teaching of introductory geography [Cars90,Mira91,Shaf90]. The intent of project GeoSim is to reverse the current decline in geographic awareness among students, and eventually the public at large. It will apply the immense capabilities of Geographic Information Systems (GIS) and simulation to the
teaching of geography, beginning at the first geography course. In this manner, aspects of geography are made available to a wide range of students in a way that stresses dynamic processes over static information.

The initial focus of project GeoSim is to provide an integrated series of interactive GIS-based computer modules to be used in laboratory sessions for existing courses in college level introductory geography. These modules must meet several criteria [Cars90]:

1. They must be highly interactive, allowing students to make decisions and manipulate geographic data in a way that encourages learning while keeping the student's interest.

2. The modules must be easy to understand - naive computer users must be able to use them with virtually no training.

3. An effective geography tutoring system will be supported by a Geographic Information System as well as a database system to allow for sophisticated manipulation of geographic data, provide tailoring of modules to the geographic location of the class, and to support creation of future modules.

4. The system must run on equipment of as low a cost as possible (under the constraints of the previous criteria).

5. Finally, the modules must relate to the student, i.e., exercises should include real-world data and sufficient flexibility so that the exercise can be done using data for the student's own city, state or country.

Based on the preceding criteria, the following six modules have been chosen [Cars90].

Mental Mapping explores the mental maps of students by asking them to locate various places in the world by pointing at positions on an outline map drawn on the computer screen. A prototype of this module has been designed and implemented using the X Window System [Mira91]; further extensions incorporating DVI Technology are currently under way.

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International Population, the focus of this report, allows students to explore the population structures and projections of countries from around the world and to investigate the effects that changes in birth and death rates have on these projections.

Reduction of Commuting Time lets the student determine optimal paths for automobile commuters living in the suburbs of a major city to arrive at their work places in as short a time as possible. It allows the student to plan the routes by associating neighborhoods with a series of roads, or creating new roads to reduce bottlenecks.

Nuclear Accident teaches about weather patterns and the interconnectedness of nations by allowing the student to explore the consequences of a nuclear accident at any power plant in the world. The module simulates the movement of the resulting radiation cloud and computes the costs to human populations, agriculture, etc. for areas affected by radiation.

Population: Migration and Political Power in the United States relates migration patterns among counties of the U.S. to data on place characteristics. It simulates past trends in migration among counties based on census data from the 1960-1990 period in the form of animated maps of the U.S. by country that change population categories over time.

Orientation, Position Finding, and Orienteering teaches map orientation skills. The instructor sets up the desired course using a map of the orienteering terrain and places markers to define the course [Cars90].

The software for these modules will run at three levels of hardware configuration ranging from IBM compatible, Macintosh II, or X Window Systems with a small hard disk through
CD-ROM and Digital Video Interactive (DVI) equipped machines. Since implementations will be provided for three popular interface systems, the modules can be run on a wide variety of personal computers and workstations.

This paper describes the prototype design and implementation of the International Population module using the Macintosh II System and a first level hardware configuration.
Chapter 2

THE INTERNATIONAL POPULATION MODULE

2.1 General Description

The International Population module is a simulation tool which allows students to explore the population growth and age distributions of nearly any country or region from around the world [Cars90]. These countries represent a range of sizes, world locations, and development status. The student will learn how changes in birth rate, death rate, and distribution among age groups affect population growth. Students will also be able to compare different countries, relating their knowledge of these countries’ role in the world to the dynamics of their population’s growth.

This module provides an interface which gives the student access to the important numbers involved in the population dynamics of a country, and the capability to modify these numbers and observe resulting changes. The student may view population-related data displayed for each country. Standard models are used to simulate the growth or decline of each country’s population over time, based on the birth and death rates of the population’s age distributions. The student may change these birth and death rates, either directly or
through average completed family size and life expectancy numbers, and investigate any effects that these changes produce on a country’s population as projected by the models. Alternatively, the student can observe the effects that current rates have on future growth, or view official projections of growth for these countries.

While the model used to convert birth and death rates to population growth is important to the final success of the module, the primary focus of this prototype stage was to create the interface. The population model design facilitates later modification, when required, to present more realistic and sophisticated projections.

2.2 Prototype Description

The International Population prototype is a menu-driven, window-based, interactive event-driven software application. The prototype implementation uses the “C” programming language [Kern88] and Macintosh Toolbox routines [Brya90,Cher88,Rose90] in the Macintosh II A/UX environment. The toolbox routines provide the interface graphics and manage the application’s events, windows, and menus. The prototype also runs under the Macintosh Operating System (Mac OS) environment and is compatible with MultiFinder, software which allows several programs to run at the same time. This compatibility allows other applications or miscellaneous desk accessories to run by changing the module application into a background process.

Prototype software modularization separates simulation code from the graphical code dependent on the Macintosh Toolbox routines. Eventually the prototype will be ported to the X Window and Microsoft Window environments as well. The separation of simulation and graphical code will contribute to ease of portability when this occurs, and also allows interface development to be done independently of population model development.

2.3 Educational Importance

With the use of the International Population module, a student will gain knowledge
about the population structures of various countries from around the world. We present this information in a manner that exposes the student to the important factors involved in the population dynamics of these countries.

Initial data provided for each individual country allows students to gain an understanding of the current population, age distribution, estimated life expectancy, and completed family size of that country. Estimated birth and death rates provided for each ten year cohort allow the student to understand the distribution of deaths and births across the age groups.

The student then observes how a country’s population might change over time, by plotting the population size at five year intervals. By allowing students to change the birth and death rates used in the population projection, and then replottting the new projection, students gain knowledge about the correlation between birth and death rates and the future population of a country.

Students may view the data for two different countries at one time, allowing them to gain comparative knowledge about countries. By simultaneously viewing the information for two countries, a student may perceive differences in population size and structure.

The interactive dynamic presentation of information made possible by this module has advantages over a static classroom presentation. Static presentation provides students with numbers and rules, but limited interaction, limiting the gain of knowledge to memorization of the numbers and rules presented. In contrast, our computer simulation provides students with the opportunity to interact with the information. Since students may change information directly and view the results of these changes, they are more apt to gain an understanding of the significance of this information and to retain any knowledge gained [Rape89].
Chapter 3

INTERFACE DESIGN

3.1 Design Criteria for the International Population Module Prototype

To facilitate the needs of the International Population module and to incorporate some of the Human-Computer Interaction (HCI) principles deemed necessary for a good interface [Shne87], the interface includes the following features:

1. Necessary information for the realization of key themes involved in population dynamics, displayed in a cohesive format and kept simple enough so as not to overload the student with information.

2. A highly interactive environment, providing the student with quick feedback.

3. Context-sensitive on-line help to facilitate ease of use, and provide introductory tutorial help for novice students.

4. Color to make the interface more attractive and effective.

5. Sufficient data and complexity arranged in a way that allows students to explore the module as desired.
3.2 User Profile

The target audience of the International Population module is introductory-level college geography students. These users, as well as unpredictable users from outside of this group, may have little or no experience with the use of a Macintosh computer and the mouse-driven applications which run on it. The module is thus geared for the novice computer user. In addition, since this is an instructional aid rather than a software tool, we expect users to work with the module only once or twice. Thus, regardless of their computer expertise, they will certainly be unfamiliar with this particular package.

An introductory tutorial on use of the mouse and control buttons (which more experienced users may bypass) provides the novice user with help at the beginning of the module. The user may access this help at any time from within the body of the module as well. In addition, context-sensitive help guides the student through the entire module.

3.3 Construction and Layout of the International Population Module Prototype

Various windows, graphs, and figures comprising the International Population module present the necessary population dynamics information to the student (see Figure 3.1).

A 630 x 454 pixel background window contains the two 600 x 200 pixel Country Display windows. Below the Country Display windows is the 600 x 25 pixel Message window containing a text area for the context-sensitive on-line help. This text area presents various operating instructions to the student, based on the current state of the module.

A 180 x 155 pixel Population Pyramid Graph sits on the left side of each Country Display window. The interface displays death and birth rates for each of the age groups to the left and right sides of this graph, respectively, such that each rate lines up with its associated age group bar.

The right center of each Country Display contains a 182 x 110 pixel Total Population
Click on SIMULATE to run the simulation, OPTIONS to choose from among the available simulation features, or SET to change the life expectancy or completed family size.

Figure 3.1: Complete Module Layout
Graph. To the right of this graph is a Population Display box which displays the current population for up to three separate simulations.

The lower-right hand corner of each Country Display contains two control buttons. The simulation button allows execution of the three simulations. The option button presents a window through which students may choose various Country Display features.

Below the Total Population Graph are boxes displaying the current life expectancy and average completed family size. Control buttons initiating changes to these values sit to the right of each box.

Four menu headers exist at the top of the graphics window. These headers represent pull down menus (Apple Menu, Quit Menu, General Info Menu, Help Menu) which provide various functionality as described in section 3.3.3.

3.3.1 Population pyramid graph

When the student selects a country for display, the initial Population Pyramid Graph is constructed, depicting the age distribution of the country using the 1990 age group popula-
tions. The interface used to present this graph is shown in Figure 3.2. A population pyramid with male and female cohorts to either side of the centerline is a traditional presentation for age/sex cohorts [Stoc76].

To construct the Population Pyramid Graph, the program calculates the percentages of the total population represented by the number of males and females in each age group. It then converts these percentages into widths for the bars for each age group. The conversion generates an offset from the centerline of the graph, and the actual width depends on the percentage marked for the graph boundary. Recalculation and redisplay of the Population Pyramid Graph occurs at each update step of a simulation to reflect the new age group populations projected for the new five year interval.

The initial boundary percentage used for the graph is 20 percent. This figure allows for visible contrast among a typical distribution of age groups. If one or more of the cohorts exceeds this percentage limit, the boundary percentage increases to 40, and the widths for the age group bars change accordingly. Selection of a new country for display, or execution of a new simulation whose age groups are all smaller than 20 percent of the whole, resets the boundary percentage to 20 percent.

3.3.2 Total population graph

When the student selects a country for display in a Country Display, the 1990 population is plotted in the Total Population Graph. The interface used to present this graph is shown in Figure 3.3.

Doubling the 1990 population and rounding to the nearest ten or one hundred million produces an initial upper bound for the graph. The initial population will thus be approximately in the center of this range. Scaling produces a y-coordinate location for the initial population’s plot point. We store this plot value in a record structure tied to this simulation run, making it available for future screen updates.

The x-coordinate location for the plot point is preset to line up with a tick mark located at the graph’s bottom. The point is plotted in the total population graph, and the year for
the population is displayed below this tick mark.

Two locations in the Population Display Box display the 1990 population. The value displayed above the Population Display Box remains unchanged, so the original 1990 population is always available for viewing. The population within the Population Display Box changes with each update to reflect the latest population projected. Up to three simulations may be plotted together in the Total Population Graph and Population Display Box; each has a distinct display location within the Population Display Box for projected populations, thereby keeping the different projected populations available for simultaneous viewing.

Each update of the Total Population Graph at each five year interval adds a new plot point to the graph. Connecting the various plot points produces a graph of population growth or decline. The x-coordinate location for each new plot point is preset to move over one tick mark. Every second step of the simulation (10 years), the year of the projected population is displayed below this tick mark.

Each simulation may run until the year 2050 (thirteen plot points). When a new simulation runs, the plot for the previous simulation remains, and a new 1990 plot point displays for the new simulation. A Simulation Reset option clears the graph of old plots and displays the 1990 plot point for a new simulation.

The plot for each of the three simulations occurs in a distinct color for contrast.
jected populations are displayed in the Population Display box in the same color as their associated plot line.

The upper bound for the Total Population Graph doubles each time a projected population exceeds the current upper bound. This causes recalculation of all plot points, based on the new upper bound, and redisplay of the simulation plots to reflect the rescaling. Each time this occurs, a new scale line is added to the graph to indicate a doubling of the population (see Figure 3.4). The value for this line will be the old upper bound.

3.3.3 Controlling the module

All student interaction with the module is mouse-driven via various pull-down menus, windows, and control buttons, thus eliminating the need for keyboard input. Immediate feedback is provided for each action taken by the student.

The module uses four pull down menus providing various functionality (see Figure 3.5). The standard APPLE pull down menu provides the following functionality:

1. The “Hide Intl_Population Windows” option closes and removes all module windows from view, so other tasks may execute. When invoked, this line is replaced by “Intl_Population”.

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Figure 3.5: Pull Down Menus
2. The “Intl_Population” option activates the module and brings it to the front. This option reactivates the module if the “Hide Intl_Population Windows”, “CommandShell”, or “Finder” option was previously selected and deactivated the window.

3. The “CommandShell” option (in A/UX) activates a command shell window and brings it to the front. The International Population module window will disappear and become temporarily inactive. This window is used to access the UNIX System.

4. The “Finder” option activates the Mac OS windows and brings them to the front. These windows contain other executable Macintosh applications. The module window will disappear and become temporarily inactive.

5. The apple desk accessory options perform Macintosh accessory functions.

6. The “About MultiFinder…” option presents the student with a dialog box containing information about MultiFinder.

Except for the first two, these options are all standard parts of the Macintosh windowing environment. A “Quit” option is available through the QUIT pull down menu choice. This option allows the student to exit the module.

The following functionality is available through the GENERAL INFO pull down menu choice:

1. The “GeoSim: Info” option presents the student with information about Project GeoSim. This option is common to all GeoSim modules.

2. The “INTERNATIONAL POPULATION Info” option presents the student with information about this module, including the version number and date of compilation.

3. The “Technical Info” option presents the student with a tutorial on technical aspects and formulas used in the simulation.

The following functionality is available through the HELP pull down menu choice:
OPTIONS
Select a country for the display window
Reset the simulation
Modify birth/death rates
Initiate alternate simulation
Initiate expected scenario

CANCEL

Figure 3.6: Window Menu for Display Features

1. The “Tutorial Help” option allows access to the introductory tutorial help windows (also presented at the beginning of the module).

2. The “Options” option presents the student with detailed information about the available display window features available through the “Options” button on the display window.

3. The “Simulate” option presents the student with detailed information about executing a simulation.

4. The “Set” option presents the student with detailed information about modifying the values for life expectancy and average completed family size.

5. The “Apple Menu” option presents the student with detailed information about the options available through the APPLE pull down menu.

When a student clicks the mouse on the “Options” control button on the display window, a new menu is displayed that allows the student to select one of six Country Display features by double clicking on that feature (see Figure 3.6). Features currently available are in green text, while those currently unavailable are in black italics. A double click on an unavailable feature produces no effect. The following functionality is available in the proper contexts:
1. "Select a country for the display" displays a new window which consists of an alphabetical listing of the countries available for display (see Figure 3.7). Double clicking on one of these country names retrieves the data for that country from the database and displays it in the display window. If the student chooses Cancel instead, no selection occurs. Initially, this is the only option available until a country is selected.

2. "Reset simulation" resets the display window to its initial state for the current country.

3. "Modify birth and death rates" creates an increase and decrease button for each birth and death rate, which the user may then use to modify these rates directly. When activated, a pair of controls appear beside each of the appropriate birth/death rates. The control labels are a "+" and "-" for increase and decrease actions, respectively. As the student clicks the mouse in these control buttons, the rates change accordingly. When these control buttons are active, this option changes to "Dispose rate controls".

4. "Dispose rate controls" disposes of the control buttons used to modify the birth and death rates. Once selected, the option changes back to "Modify birth and death rates".

5. "Initiate alternate simulation" allows execution of a new simulation. The 1990 population is replotted, and a new population projection begins.

6. "Initiate expected scenario" automatically presets values for the life expectancy and completed family size to be reached by a certain year. The values are obtained from the database for the country and represent an official projection of growth as stated in the database source. When the simulation is subsequently executed, the life expectancy and completed family size (and their related birth and death rates) will change at each step of the simulation until the simulation reaches the target year (see Section 4.3.2).

7. The student may exit the window without choosing any feature by clicking the mouse on the "Cancel" control button.
<table>
<thead>
<tr>
<th>Albania</th>
<th>Argentina</th>
<th>Australia</th>
<th>Austria</th>
<th>Bahamas</th>
<th>Barbados</th>
</tr>
</thead>
<tbody>
<tr>
<td>Belgium</td>
<td>Belize</td>
<td>Bolivia</td>
<td>Brazil</td>
<td>Bulgaria</td>
<td>Caledonia</td>
</tr>
<tr>
<td>Colombia</td>
<td>Czechoslovakia</td>
<td>Denmark</td>
<td>Egypt</td>
<td>Fiji</td>
<td>Greenland</td>
</tr>
<tr>
<td>Guam</td>
<td>Guernsey</td>
<td>Hungary</td>
<td>Iceland</td>
<td>Iraq</td>
<td>Ireland</td>
</tr>
<tr>
<td>Italy</td>
<td>Japan</td>
<td>Jersey</td>
<td>Kuwait</td>
<td>Malawi</td>
<td>Malaysia</td>
</tr>
<tr>
<td>Malta</td>
<td>Mauritius</td>
<td>N. Martinique Is.</td>
<td>N. Marian</td>
<td>Netherlands</td>
<td>New Zealand</td>
</tr>
<tr>
<td>Pakistan</td>
<td>Poland</td>
<td>Portugal</td>
<td>Qatar</td>
<td>Reunion</td>
<td>Romania</td>
</tr>
<tr>
<td>Sao Tome</td>
<td>Seychelles</td>
<td>Spain</td>
<td>Sweden</td>
<td>Switzerland</td>
<td>Tunisia</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>United States</td>
<td>West Germany</td>
<td>Yugoslavia</td>
<td>Zimbabwe</td>
<td></td>
</tr>
</tbody>
</table>

Figure 3.7: Window Menu for Country Selection

When the student clicks the mouse on the “Simulate” button, one step of the current simulation runs. The student may also click the mouse and hold down on the “Simulate” button, causing the simulation to run continuously.

When a simulation reaches the thirteenth plot point (year 2050), any further clicks of the mouse in this control button invoke a display message. This message indicates to the student that the current simulation is finished. The “Run alternate simulation” (if available) and “Reset simulation” options allow the student to proceed with a new simulation in the display window.

When a student clicks the mouse on the “Set” control button located beside the Completed Family Size box, a window is displayed in which the student can set a target value for the completed family size to reach by a certain year (see Figure 3.8). The program displays the current value for the completed family size and activates increase and decrease control buttons though which the student may select the intended value. When the student clicks the mouse in these control buttons, the value changes accordingly. The program displays the current year as well, and activates similar increase and decrease control buttons to allow the student to select the year by which the change should complete. When the student is
Set the value to which the completed family size is to be changed and the year by which the change is to be completed by clicking in the corresponding INCREASE and DECREASE control bars.

![INCREASE](4.9) 1990 [INCREASE]

![DECREASE] [DECREASE]

Figure 3.8: Completed Family Size Modification Window

satisfied with the values selected, the modification window may be exited by clicking the mouse in the “OK” control button.

The “Set” control button located beside the Life Expectancy Box is used similarly by the student to set a target value for the life expectancy to be reached by a certain year.
Chapter 4

MODEL IMPLEMENTATION

4.1 General Description

International Population displays population dynamics information for countries in each of the two Country Display windows. When a student selects a country for one of these windows, the program retrieves data for that country and stores it in a record structure in main memory. Both the initial display of 1990 information for the country and all subsequent population projection modeling use this data. The data retrieved consists of the 1990 population, 1990 age group populations, infant mortality rate, life expectancy for the year 2000, and completed family size for the year 2000. The program then computes individual age group birth and death rates, life expectancy for the year 1990, and completed family size for the year 1990, storing these data in the record structure as well. All data stored in the record structure, except for the computed values, remain unchanged so that they may reinitialize the Country Display if a student chooses the “Reset simulation” option. When a student modifies one of the birth or death rates, the program stores the new value directly in the record structure, updating the pre-existing data. Changes to life expectancy and completed family size occur in a similar manner. The program then recomputes these values to reinitialize the Country Display when a reset occurs.

Up to three simulations representing a country’s possible population projections may
appear together in a display window. Each population projection begins at the year 1990 and runs in five year intervals up through the year 2050. For each simulation, a record is kept for each fifth year of the simulation. Maintaining each record, rather than updating the same record, retains information on each individual step of the simulation required by screen update routines. These records contain the current (modeled) population, population of age groups contributing to this population, current year in the projection, and an integer value used for plotting the population onto the graph. By maintaining these plot positions for each population, the program need not recalculate them each time the graph is redrawn by a screen update routine.

When a student selects a country for display, the program loads the record for the first (1990) year of the simulation with the 1990 population and 1990 age group populations retrieved from the database. Each one year step of the simulation calculates new age group populations and a resulting total population; these are displayed when the fifth year is reached. The program then stores the new data in the appropriate record structure.

4.2 Completed Family Size and Life Expectancy Models

4.2.1 Completed family size

When a student selects a country for display, the program uses the current birth rates stored for that country to calculate an estimated completed family size. The completed family size (total fertility rate) is an age-sex adjusted measure of fertility which takes account of age detail within the childbearing ages. It is the total number of children a woman is expected to bear in her lifetime. The program calculates this value by summing the birth rates for the 10-19, 20-29, 30-39, 40-49, and 50-59 age groups and dividing the sum by one hundred (this model is based on [Stoc76]).

Once initial data for a country are displayed, the program allows the student to directly modify the birth rate for each age group. Since the completed family size is based on these
birth rates, modification to any birth rate dictates recalculation of the completed family size. The time required to recalculate and redisplay a new value after each incremental change of any birth rate would be too great for the interface to handle while simultaneously providing rapid response to the user. Thus, a recalculation of the completed family size occurs only after approximately three seconds have elapsed since the student has last modified one of the birth rates.

If a student selects the "Reset simulation" option, the program reinitializes the data displayed in the Country Display. It recalculates the original values for the birth rates, and recalculates the completed family size as well to correctly reflect these original rates.

4.2.2 Life expectancy

When a student selects a country for display, the program uses the current death rates stored for that country to calculate an estimated life expectancy for people born during the current year. Life expectancy is defined as the expected number of years to be lived measured at birth. Calculations begin with a working population of 100,000 people. The program calculates the number of people who die at each age, ranging from age 0 through age 110, according to the following formula:

\[
\text{number of deaths} = \\
(\text{death rate of the age group containing this age} / 1000) \times \text{working population}
\]

The working population decreases by each calculated number of deaths before the next calculation occurs. To calculate the contribution to life expectancy of the population lost, the program multiplies each number of deaths by 0.5 less than the current age, and adds this to the running total. The deaths at age 0 represent the infant deaths; thus the program multiplies this number by 0. Subsequent averaging of the accumulated values produces the estimated life expectancy (this model is based on [Stoc76]).

Automatic recalculation of the life expectancy occurs in the same manner as for the completed family size when a student modifies any of the death rates or resets the simulations.
run in a Country Display.

4.3 Population Projection Model

International Population's projection model is simplistic but sufficient for the purposes of a proof of concept prototype. The model maintains an array of one year cohorts, starting with the 0th year (infant) and ending with all population age 80 or over grouped in the 80th year.

Initial country selection loads the age array with 1990 populations derived from the 1990 ten year age cohort populations. Each age receives a percentage of its respective age cohorts's population. The middle age of each ten year age cohort receives 10 percent of the age group population. Linear interpolation based on the difference in the populations of the current and next ten year age cohorts then determines the populations for the remaining ages.

4.3.1 The aging process

Internally, the simulation model works in one year time steps. Each step of the simulation "ages" the population by updating the age array and deriving the projected age group populations and total population from the updated array. Every fifth year, the new projection is used to update the Country Display. The "aging" process subtracts the number of deaths from each age, ages the population one year by shifting every value up one year in the array, and adds the new births to the 0 age group (see Figure 4.1). Note that the 80+ age group is the sum of the surviving 79 and 80+ age groups from the previous year.

The model uses the current birth rates to calculate the number of births resulting from each age group. The number of new births for the year is then calculated as the sum of these numbers of births. The following formula calculates the numbers of births:

\[
\text{new births due to an age group} = \\
\left(\frac{\text{age group birth rate}}{1000 \, \text{females}}\right) \times \text{age group female population}
\]
The model assumes the female population for the age group to be one half of the age group population.

The model uses the current death rates to calculate the number of deaths occurring in each age. The number of deaths occurring in the 0 age group is calculated as a special case using the infant mortality rate. This is necessary to accurately reflect the large proportion of yearly deaths in a population that result from infant deaths. The following formula calculates the numbers of deaths:

\[
\text{number of deaths in an age} = \frac{\text{death rate of age group}}{1000} \times \text{population of group}
\]

The populations of each age then decrease by these numbers.

### 4.3.2 Automatic modification of birth and death rates

The birth and death rates used in the projection model may change automatically as a simulation proceeds. Students can use the “Set” control buttons described in Chapter 3 to select values to which the completed family size or life expectancy must change, and the
year by which the change should complete. At each step of the simulation, the program then changes the completed family size or life expectancy by a certain percentage. It also changes the birth and death rates used in the calculation of these values. This happens before the population is aged, thus the projection uses the new birth and death rates. If the simulation has passed the target year (or no target values were selected by the student), the projection model uses the current birth and death rates without modification.

When a student chooses a value for the completed family size to reach by a specified year, the program calculates a delta value. This delta value is based on the percentage the completed family size must change each year. It determines how much the completed family size must increase or decrease each year to achieve the desired value. The program calculates delta values for each of the birth rates involved in the calculation of the completed family size as well, such that each birth rate changes by the same percentage each year by which the completed family size changes. The change in birth rates is thus spread uniformly across the age groups.

At each step of the simulation the completed family size and each birth rate change according to their respective delta values. The program displays the new values in the Country Display. The “aging” process then uses the new birth rates. This process continues until the simulation reaches the target year, after which birth rates will no longer change without new directions from the student.

When a student chooses a value for the life expectancy to reach, the program calculates similar delta values for the life expectancy and each death rate. Death rate deltas cause increases in death rates when a decrease occurs in the life expectancy, and vice versa.

The program bases the change in death rates on the same percentage used to determine the change in life expectancy. While such an approach is adequate for birth rates, there is not such a simple relationship between life expectancy and age specific death rates. Because of this, the death rates calculated do not accurately reflect the newly calculated life expectancy. To solve this problem, the program modifies the death rates iteratively until they become an accurate reflection of the life expectancy. At each iteration, the program
determines the percentage by which a life expectancy calculated from the death rates differs from the correct one. It then changes the death rates by this percentage. This process is repeated until the rates converge to accurate values. Convergence typically occurs in about three or four iterations.

The student may change the completed family size or life expectancy immediately, as opposed to over time, by selecting the target year to be the current year of the simulation. This invokes an immediate change in the birth or death rates used in the projection model.

If a student selects the “Initiate expected scenario” option, the program automatically presets target values for the completed family size and life expectancy to reach by the year 2000. These values are the year 2000 completed family size and life expectancy data retrieved from the database.

4.3.3 Model weaknesses

A major weakness of the model implemented in the International Population module results from the birth and death rates used in the population projections. The data from a specific year derives these rates, as described in Chapter 5, making them static. A more realistic projection necessitates the use of natural trends in the birth and death rates.

The populations projected by the model are not precise because of the resolution of the data used in the model. The implementation maintains birth and death rates for ten year interval age groups. In a more realistic projection, these rates would be more diverse. The model also uses each particular birth and death rate for an age group indiscriminately for both males and females, thus distinction between these two groups is absent. These resolution problems result from a decision to limit detail of information presented by the module interface. For example, sex specific populations and death rates could be maintained. However, we decided not to do so in order to keep complexity to a minimum. We hope that most users will find that the current interface provides the right number of choices. In addition, the original source data limited resolution in some cases. For example, our data provided only five year age cohorts and their associated birth and death rates.
One additional model weakness involves changes to the life expectancy and completed family size values. The birth and death rates associated with these values are each changed by the same percentage. The distribution for the changes made to these rates should be more diverse to reflect natural trends.
Chapter 5

BUILDING THE DATABASE

The International Population module requires many pieces of data about each country to initialize the population model. These are 1990 population, 1990 age specific populations, individual five year cohort birth and death rates, and an infant death rate. We used country specific databases created from a combination of two sources [Doco90,Unit90]. Certain data required for the projections is not directly available in the databases used by the module, and must be derived from existing data.

5.1 Databases

5.1.1 Input

In its present stage, the International Population module requires two types of input files. The first type of input file contains the data for a country and is in our general reader format (section 5.4) as illustrated by the example country database located in Appendix A. Each such file contains the data for a single country, with the country’s name as the file name. The module does not currently use all of the available data currently contained within the files; unused data are available for future developments or by other GeoSim modules. International Population currently uses the following data:
1. year 2000 life expectancy and total fertility rate (completed family size)

2. midyear population estimates for use in birth and death rate derivation

3. year 1990 total age group populations

4. total live births for the age groups in an arbitrary year

5. total deaths for the age groups in an arbitrary year

These databases have been organized for human as well as machine readability. They support self-documentation, and present data in clear tabular and tagged formats. These aspects enable their potential use by other users for many different purposes.

The second input file is a group of input files containing the text for the various module help screens. Each file contains the text for one independent series of help screens. They are standard ASCII text files which can be modified to change the content of one or more help screens when necessary.

5.1.2 Output

The output file produced is a record of a student’s progress through the module. It includes significant actions taken by the student, such as selection of a country, execution of one or more simulations, and modification of any birth and death rates. The Country Display window in which the action took place is also recorded by specifying UPPER DISPLAY or LOWER DISPLAY after the action. This file includes information detailing what features of the module users tend to investigate most frequently, and information useful for debugging purposes. Ultimately, the instructor can use information in this file for grading purposes. An example student’s response file is as follows:

country selected – Canada (UPPER DISPLAY)
simulation #1 executed (UPPER DISPLAY)
life expectancy targeted to 80.0 by 2010 (UPPER DISPLAY)
simulation #2 executed (UPPER DISPLAY)
birth rate for 10-19 age group changed to 17(UPPER DISPLAY)
simulation #3 executed (UPPER DISPLAY)
country selected – Australia (LOWER DISPLAY)
simulation #1 executed (LOWER DISPLAY)
"expected" scenario initiated (LOWER DISPLAY)
simulation #2 executed (LOWER DISPLAY)
country selected – USA (UPPER DISPLAY)
simulation #1 executed (UPPER DISPLAY)

5.2 Included Data

The program retrieves 1990 total population and 1990 age group populations necessary for both display and modeling purposes directly from the database. It also retrieves the number of infant deaths per 1,000 live births directly from the database, and uses this number as the death rate for the 0 year age population.

Data for an estimated life expectancy at birth and average completed family size for the year 2000 come directly from the database. These figures model an "expected" population projection, representing an official projection of growth as presented by the database sources.

5.3 Derived Data

Birth and death rates for each of the age groups are necessary to model population projections. This data is not available from our sources, and must be derived from data which is available.
The program can retrieve the number of total births and deaths occurring in selected age groups from arbitrary years directly from the database, as well as midyear population estimates for selected years. If midyear population estimates exist for the arbitrary years from which the numbers of births and deaths come, this data can be used to derive birth and death rate figures.

The numbers of births resulting from the females in selected age groups exist in the database in the following intervals: 0-15, 15-19, 20-24, 25-29, 30-34, 35-39, 40-44, 45-49, and 50+. These numbers come from a census or survey conducted in a specific year, as indicated in the database. Birth rates are derived for the following ten year intervals: 10-19, 20-29, 30-39, 40-49, and 50-59. Thus it is necessary to convert these numbers of births from groups in the database into the numbers of births for age groups used by the simulation. If this information were stored in the database in the age groups required by the simulation, no conversion would be necessary. We do not store the age groups required directly in the database, however, because we want to use whatever data is actually available in the database. This prevents the database from becoming degraded, and retains the all available data resolution for future changes to the simulation. The model assumes a zero birth rate for the remaining age groups.

In order for the program to derive birth rates for the age groups used in the simulation, the population of each of these age groups for the specific year indicated in the database must be known. Only the midyear population for this year exists in the database, so these age group populations must be derived as well. The program derives them from 1990 age group populations such that their distribution is similar to that of the 1990 distribution. The following formula calculates these age group populations:

\[
\text{age group population for the arbitrary year} =
\]

\[
(\text{age group population for 1990 / 1990 population}) \times \text{arbitrary year population}
\]

32
The following formula then determines the birth rate figures:

\[
age\ \text{group birth rate} = \frac{(\text{number of births occurring in the arbitrary year} \times 1000)}{\text{age group population for the arbitrary year}}
\]

These formulas produce birth rates which are the number of births per 1,000 people. The implementation maintains these birth rates as the number of births per 1,000 women, as is traditional. The population model assumes that half of each age group population is female, thus each of the age group birth rates doubles to produce the correct figure.

The numbers of deaths occurring in selected age groups for a specific year exist in the database in the following intervals: Infant, 1-4, 4-9, 10-14, …, 74-79, and 80+. Death rates are derived for infants and for the following age groups: 1-9, 10-19, 20-29, …, and 80+. Once again we must convert from database age groups to simulation age groups.

A derivation of death rates for each of the age groups is done in a fashion similar to that used to derive birth rates. The implementation maintains death rates as the number of deaths per 1,000 people, as is traditional [Stoc76]).

5.4 General File Format Reader

A general purpose database reader has been developed which is intended for use by all modules of project GeoSim. It supports ASCII files with documentation and both tabulated and tagged data fields. The files supported are in human readable, as well as machine readable, format. Thus, others can potentially use the database contents for purposes beyond those of this module (see Appendix A for an example country database). In addition to the general reader functions, each module also provides module specific reader functions, and a keyword list. The specific reader functions will interpret the pieces of data read by the general reader. The general reader has been incorporated into the International Population
implementation to read the databases associated with the module.

When a database is to be read, the module calls the general reader, sending it the following arguments:

1. a reader function specific to the module

2. a file pointer variable

3. a keyword list consisting of the tag field names which are important to the retrieval of information in the module's databases

4. the size of the keyword list

The general reader scans the database looking for keywords present in the keyword list, ignoring all irrelevant data. If the reader encounters a #, it considers all text following on that line to be comment text, and ignores it.

When the reader locates a keyword, the keyword and program control pass to the specific reader function which knows how to interpret the data following that keyword. If the keyword is a tag field name, data to be retrieved follows, and the reader function calls the appropriate general reader routine to read the data. Four such routines have been developed.

`rd_integer()` interprets the next piece of data as an integer value and returns it to the calling routine.

`rd_real()` interprets the next piece of data as a floating point number and returns it to the calling routine.

`rd_string_eol()` interprets the next piece of data as a string. It scans through characters until reading either an end of line character or a #. After removal of all beginning and trailing spaces and the compression of all interior spaces, `rd_string_eol()` returns the string to the calling routine.

`rd_string_intr()` also interprets the next piece of data as a string. It scans through characters until reading two consecutive spaces. After removing all leading spaces and the
two trailing spaces, the routine returns the string to the calling routine. This routine may read strings containing (single) interior spaces, and which are not the last piece of data on the line.

If the general reader locates the keyword *format*, this indicates that tabulated data follows. When control passes to the specific reader function, it first calls another routine of the general reader to read a list of keywords. The general reader reads and returns all keywords following *format* until it reaches the keyword *endformat*, indicating the end of the format keywords. The contents of this list indicate to the specific reader function what data is present in the table. The specific reader function then uses the four general reader routines described above to retrieve the tabular data which follows. This proceeds until the general reader reaches the keyword *endformat*, indicating the end of the current tabular data.

### 5.4.1 Aggregate database generator

The general reader and International Population module specific reader function have been incorporated into the implementation of an additional program as well. This program constructs “region” databases in a format acceptable by the International Population module. These “region” databases are aggregates of country databases currently used by the module. The program receives as input the names of the country databases to be included in the aggregate, and automatically outputs the new aggregate database.

The general reader and module specific reader are used to retrieve the pieces of data from each country to be included in the aggregate. The program then combines this data to construct the new “region” database. Numbers representing populations are simply totaled to produce the new population numbers for the aggregate database. Birth and death rate numbers for the aggregate are calculated as weighted averages of the birth and death rates in each of the country databases included in the aggregate.
Chapter 6

CONCLUSIONS AND FUTURE WORK

The International Population prototype provides students with an introduction to the population structures of selected countries from around the world. It also provides a comparative perspective of this information and introduces students to some of the key factors involved in population dynamics.

The module employs a highly interactive interface, providing the student with immediate feedback for any actions taken. The interface provides a window-based, menu-driven operating environment, eliminating the need for keyboard input. Context-sensitive help to facilitate ease of use for the student is also present in the interface.

6.1 Future Developments

The International Population prototype is currently in the "proof of concept" phase. Future plans are to port the prototype to run on IBM compatible and X Window Systems. The module will be integrated with other modules in the GeoSim series, and enhanced with DVI technology. The separate databases used by the different modules will eventually become more sophisticated and integrated.
Future work involved directly with the module itself will consist of enhancement to the interface. The simulation modeling used in the prototype has been designed for modification such that possibly more realistic population projections may be produced.

Other future work might involve additional output capabilities to further track student progress. A more extensive module tutorial will eventually be written to supplement the already existing on-line help provided to the student.
REFERENCES


[Mira91] V. Miranda, Computerized Simulations for Introductory Geography Instruction: Mental Mapping, Masters Project, Department of Computer Science, Virginia Polytechnic Institute and State University, Blacksburg VA, 1991.


Appendix A

EXAMPLE COUNTRY DATABASE
name= Canada
size= 1000  # Population in thousands

year= 1990  # Demographic Indicators: 1990
births= 14  # Births per 1,000 population
deaths= 7  # Deaths per 1,000 population
natural_increase= 0.7  # Rate of natural increase (percent)
annual_growth= 1.1  # Annual rate of growth (percent)
life_expectancy= 77.3  # Life expectancy at birth (years)
infant_deaths= 7  # Infant deaths per 1,000 live births
total_fertility= 1.7  # Total fertility rate (per woman)

year= 2000  # Demographic Indicators: 2000
births= 12  # Births per 1,000 population
deaths= 8  # Deaths per 1,000 population
natural_increase= 0.4  # Rate of natural increase (percent)
annual_growth= 0.8  # Annual rate of growth (percent)
life_expectancy= 79.2  # Life expectancy at birth (years)
infant_deaths= 6  # Infant deaths per 1,000 live births
total_fertility= 1.7  # Total fertility rate (per woman)

# Midyear Population Estimates (Population in thousands): 1950 to 2050

format  year pop
        tamrof

<table>
<thead>
<tr>
<th>Year</th>
<th>Population</th>
</tr>
</thead>
<tbody>
<tr>
<td>1950</td>
<td>13737</td>
</tr>
<tr>
<td>1960</td>
<td>17909</td>
</tr>
<tr>
<td>1970</td>
<td>21324</td>
</tr>
<tr>
<td>1980</td>
<td>24070</td>
</tr>
<tr>
<td>1985</td>
<td>25181</td>
</tr>
<tr>
<td>1986</td>
<td>25373</td>
</tr>
<tr>
<td>1987</td>
<td>25644</td>
</tr>
<tr>
<td>1988</td>
<td>25939</td>
</tr>
<tr>
<td>1989</td>
<td>26239</td>
</tr>
</tbody>
</table>

41
1990  26538
1991  26835
1992  27129
1993  27419
1994  27705
1995  27987
2000  29301
2010  31464
2020  33128

endformat

# Average Annual Period Growth Rate (percent)
# not currently used by the International Population module

# Growth
# Period  Rate
format
  period rate
tamrof
  1950-1960  2.7
  1960-1970  1.7
  1970-1980  1.2
  1980-1990  1.0
  1990-2000  1.0
  2000-2010  0.7
  2010-2020  0.5

endformat
# Midyear Population, by Age and Sex: 1990 (Population in thousands)

\[
\text{year= 1990}
\]

<table>
<thead>
<tr>
<th>AGE</th>
<th>TOTAL</th>
<th>MALE</th>
<th>FEMALE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>26538</td>
<td>13080</td>
<td>13459</td>
</tr>
<tr>
<td>00-04</td>
<td>1863</td>
<td>956</td>
<td>907</td>
</tr>
<tr>
<td>05-09</td>
<td>1843</td>
<td>944</td>
<td>899</td>
</tr>
<tr>
<td>10-14</td>
<td>1822</td>
<td>934</td>
<td>888</td>
</tr>
<tr>
<td>15-19</td>
<td>1862</td>
<td>954</td>
<td>908</td>
</tr>
<tr>
<td>20-24</td>
<td>2002</td>
<td>1018</td>
<td>985</td>
</tr>
<tr>
<td>25-29</td>
<td>2378</td>
<td>1188</td>
<td>1190</td>
</tr>
<tr>
<td>30-34</td>
<td>2368</td>
<td>1176</td>
<td>1191</td>
</tr>
<tr>
<td>35-39</td>
<td>2174</td>
<td>1077</td>
<td>1096</td>
</tr>
<tr>
<td>40-44</td>
<td>1977</td>
<td>985</td>
<td>991</td>
</tr>
<tr>
<td>45-49</td>
<td>1549</td>
<td>775</td>
<td>774</td>
</tr>
<tr>
<td>50-54</td>
<td>1278</td>
<td>636</td>
<td>642</td>
</tr>
<tr>
<td>55-59</td>
<td>1213</td>
<td>600</td>
<td>613</td>
</tr>
<tr>
<td>60-64</td>
<td>1157</td>
<td>557</td>
<td>600</td>
</tr>
<tr>
<td>65-69</td>
<td>1045</td>
<td>477</td>
<td>568</td>
</tr>
<tr>
<td>70-74</td>
<td>776</td>
<td>337</td>
<td>440</td>
</tr>
<tr>
<td>75-79</td>
<td>597</td>
<td>245</td>
<td>353</td>
</tr>
<tr>
<td>80+</td>
<td>634</td>
<td>218</td>
<td>416</td>
</tr>
</tbody>
</table>

endformat
# Midyear Population, by Age and Sex: 2000 (Population in thousands)
# not currently used by the International Population module

year = 2000

<table>
<thead>
<tr>
<th>AGE</th>
<th>TOTAL</th>
<th>MALE</th>
<th>FEMALE</th>
</tr>
</thead>
<tbody>
<tr>
<td>00-04</td>
<td>1757</td>
<td>903</td>
<td>854</td>
</tr>
<tr>
<td>05-09</td>
<td>1865</td>
<td>958</td>
<td>907</td>
</tr>
<tr>
<td>10-14</td>
<td>1938</td>
<td>994</td>
<td>944</td>
</tr>
<tr>
<td>15-19</td>
<td>1936</td>
<td>990</td>
<td>946</td>
</tr>
<tr>
<td>20-24</td>
<td>1955</td>
<td>994</td>
<td>960</td>
</tr>
<tr>
<td>25-29</td>
<td>2032</td>
<td>1028</td>
<td>1004</td>
</tr>
<tr>
<td>30-34</td>
<td>2160</td>
<td>1088</td>
<td>1072</td>
</tr>
<tr>
<td>35-39</td>
<td>2479</td>
<td>1233</td>
<td>1246</td>
</tr>
<tr>
<td>40-44</td>
<td>2414</td>
<td>1194</td>
<td>1220</td>
</tr>
<tr>
<td>45-49</td>
<td>2184</td>
<td>1075</td>
<td>1109</td>
</tr>
<tr>
<td>50-54</td>
<td>1964</td>
<td>967</td>
<td>997</td>
</tr>
<tr>
<td>55-59</td>
<td>1530</td>
<td>749</td>
<td>781</td>
</tr>
<tr>
<td>60-64</td>
<td>1243</td>
<td>599</td>
<td>644</td>
</tr>
<tr>
<td>65-69</td>
<td>1129</td>
<td>535</td>
<td>595</td>
</tr>
<tr>
<td>70-74</td>
<td>996</td>
<td>450</td>
<td>546</td>
</tr>
<tr>
<td>75-79</td>
<td>799</td>
<td>331</td>
<td>468</td>
</tr>
<tr>
<td>80+</td>
<td>922</td>
<td>316</td>
<td>606</td>
</tr>
</tbody>
</table>

# Source: U.S. Bureau of the Census, International Data Base.
# For more information contact Ms. Lucy Litz of the Center for
# International Research, Bureau of the Census on 301/763-4811.
# Live births by sex, and age of mother.
# The births year must exist in the Midyear Population Estimates table
births_year= 1987

<table>
<thead>
<tr>
<th>AGE</th>
<th>TOTAL</th>
<th>MALE</th>
<th>FEMALE</th>
</tr>
</thead>
<tbody>
<tr>
<td>-15</td>
<td>210</td>
<td>123</td>
<td>87</td>
</tr>
<tr>
<td>15-19</td>
<td>21452</td>
<td>11076</td>
<td>10376</td>
</tr>
<tr>
<td>20-24</td>
<td>92915</td>
<td>47503</td>
<td>45412</td>
</tr>
<tr>
<td>25-29</td>
<td>143563</td>
<td>73542</td>
<td>70021</td>
</tr>
<tr>
<td>30-34</td>
<td>81431</td>
<td>41587</td>
<td>39844</td>
</tr>
<tr>
<td>35-39</td>
<td>22419</td>
<td>11607</td>
<td>10812</td>
</tr>
<tr>
<td>40-44</td>
<td>2538</td>
<td>1313</td>
<td>1225</td>
</tr>
<tr>
<td>45-49</td>
<td>86</td>
<td>42</td>
<td>44</td>
</tr>
<tr>
<td>50+</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>TOTAL</td>
<td>86503</td>
<td>44285</td>
<td>42218</td>
</tr>
</tbody>
</table>

# Source: TABLE 10, 1989 DEMOGRAPHIC YEAR BOOK.
# Deaths by age and sex.
# The deaths year must exist in the Midyear Population Estimates table
# deaths_year = 1987

format
    age total_deaths m_deaths f_deaths
tamrof

<table>
<thead>
<tr>
<th>AGE</th>
<th>TOTAL</th>
<th>MALE</th>
<th>FEMALE</th>
</tr>
</thead>
<tbody>
<tr>
<td>-01</td>
<td>2706</td>
<td>1587</td>
<td>1119</td>
</tr>
<tr>
<td>01-04</td>
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# Source: TABLE 19, 1989 DEMOGRAPHIC YEAR BOOK.