Designing a Program and Subroutines

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Note: Subroutines are commonly called, depending on the programming language, modules, subprograms, methods, and functions.

Top-down design (sometimes called stepwise refinement) is used to break down an algorithm into subroutines.

Top-Down Design Process:

- The overall task of the program is broken down into a series of subtasks.
- Each of the subtasks is examined to determine whether it can be further broken down into more subtasks. This step is repeated until no more subtasks can be identified.
- Once all of the subtasks have been identified, they are written in code.

Three main tools for designing a program and its subroutines:

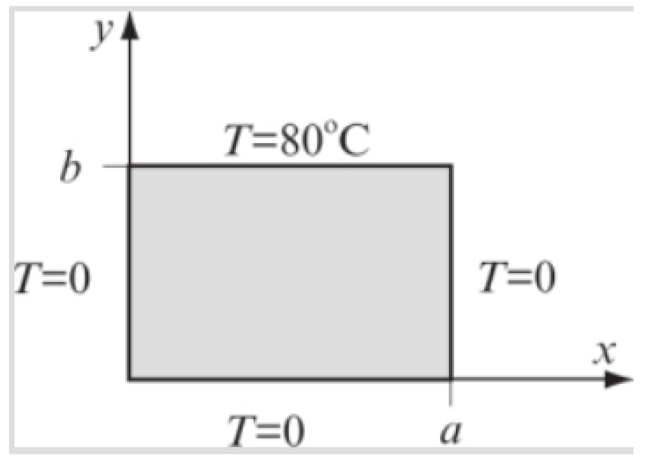
1. **Hierarchy Chart** – or a structure chart, a top-level visual representation of the main program and the relationships between subroutines.
2. **Flowcharts** – a diagram that graphically depicts the steps that take place in a program.
3. **Pseudocode** – or "fake code" is an informal language that has no syntax rules, it is a "mock-up" program. Each statement in the pseudocode represents an operation that can be performed in any high-level language.

Source: Gaddis, T., *Programming Logic and Design* (New Jersey: Pearson, 2013) pp. 79 – 112.

Top-Down Design
Program: 3D Surface Plot of Heat Conduction in a Square Plate

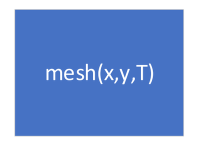
Overall Task:
Create a 3D surface plot of heat conduction in a square plate, given initial conditions as shown in the figure below.

Steps that must be taken to perform the task:
1. Calculate the temperature distribution across the plate by solving the two-dimensional heat equation. Use the Fourier series equation shown below.
2. Plot the results from the two-dimensional heat equation.



$$T(x,y) = \frac{4T_1}{\pi}\sum_{n=1}^{\infty}\frac{\sin\left[(2n-1)\frac{\pi x}{a}\right]}{(2n-1)}\frac{\sinh\left[(2n-1)\frac{xy}{a}\right]}{\sinh\left[(2n-1)\frac{\pi b}{a}\right]}$$

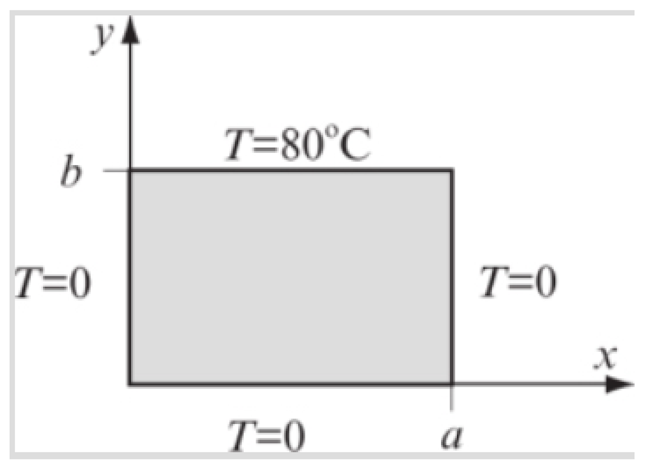
1. Hierarchy Chart

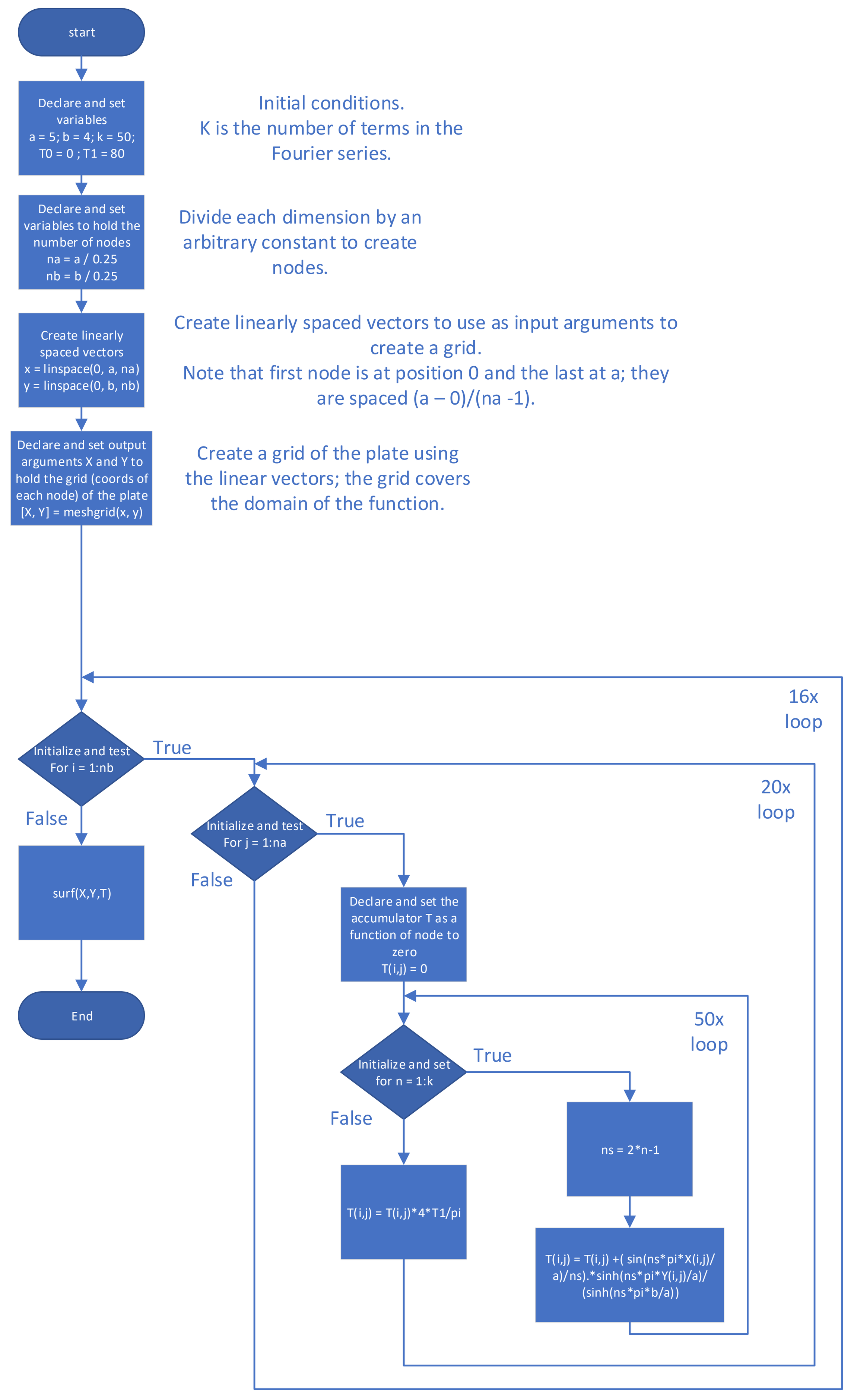


Main Program
(Input x-y coordinates and Temperature, Output surface)

Note: Hierarchy charts does not show the steps that are taken inside a subroutine; they do not reveal any details about how subroutines work.

2. Flowchart





Initial conditions.
K is the number of terms in the Fourier series.

Divide each dimension by an arbitrary constant to create nodes.

Create linearly spaced vectors to use as input arguments to create a grid.
Note that first node is at position 0 and the last at a; they are spaced (a – 0)/(na -1).

Create a grid of the plate using the linear vectors; the grid covers the domain of the function.

There are three nested for loop shown here. Why have nested loops in the first place? Think of a clock display – the program has three for loops nested together, because each 'outer' loop is dependent on the 'inner' loop. Refer to Gaddis, p. 215.

The surf function creates a three-dimensional surface plot. The function plots the values in matrix Z as heights above a grid in the x-y plane defined by X and Y. The function also uses Z for the color data, so color is proportional to height.

Note that the counter variables i and j are used in the body of the loop – in the accumulator variable, T(i,j), as part of the calculation.

Total loop iterations = 50*20*16 = 16,000 loop iterations

$$T(x,y) = \frac{4T_1}{\pi}\sum_{n=1}^{\infty}\frac{\sin\left[(2n-1)\frac{\pi x}{a}\right]}{(2n-1)}\frac{\sinh\left[(2n-1)\frac{xy}{a}\right]}{\sinh\left[(2n-1)\frac{\pi b}{a}\right]}$$

NOTE: There is a typo in the 2D heat equation shown above, the numerator of the second fraction should have pi*y ... not x*y

3. Pseudocode

```
% Start
% Declare and set
% Global variables
a = 5; b = 4; k = 50; T0 = 0; T1 = 80; % k is the number of terms in the Fourier series.

% Declare and set variables to hold number of nodes
na = a / 0.25 % 0.25 is an arbitrary constant
nb = b / 0.25

% Declare and set, create linearly spaced vectors
x = linspace(0, a, na) ; % linear vector starting at element 0 (the first node is here), and the last element is a, the spacing between nodes is determined by (a – 0)/(na – 1)

% Declare and set, output arguments X and Y to hold the coordinates of the 2D grid, the grid covers the domain of the function
[X, Y] = meshgrid(x, y)

% For loop; this loop will iterate for every node in the 'b' dimension (y), a total of 16 times. Note that since this loop has the least number of iterations it is placed in outer position – that is, the ones that follow are nested.
for i = 1:nb
      for j = 1:na
            T(i, j) = 0; % Declare and set the accumulator T to zero; the counter variables i and j will be used in pairs in the body of the loop
                        % to store the Temperature result at the corresponding coordinate.
            for n = 1:k
                  ns = 2*n-1 ; % Declare and set variable
                  T(i, j) = T(i, j) + (sin(ns * pi * X(i, j) / a) / ns) .* (sinh(ns * pi * Y(i, j) / a) / (sinh(ns * pi * b / a));
            end
            T(i, j) = T(i, j) * 4 * T1 / pi      % This is part of the Fourier 2D heat equation that is not part of the Fourier series (summation)
      end
end

surf(X, Y, T)     % Create a surface plot

End program
```