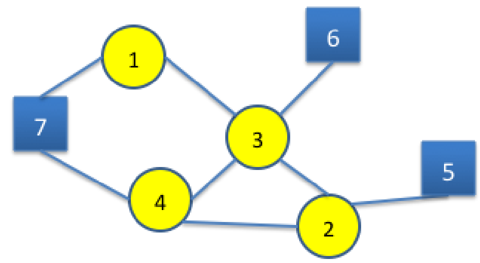
(a) (1 points) The graph on the right represents a netlist of standard cells. Circles represent N movable gates (modules) and squares represent fixed I/O pads. No weight is assumed on the edges for now. We would like to formulate the wire length minimization placement problem using quadratic optimization in the form of:



$$\text{Total cost} = \frac{1}{2}\mathbf{x}^T Q\mathbf{x} + d_x^T\mathbf{x} + \frac{1}{2}\mathbf{y}^T Q\mathbf{y} + d_y^T\mathbf{y} + \text{const}$$

where **x** and **y** are the x and y coordinate vectors of the gates, Q is an N×N matrix derived from the netlist, and the “d” vectors are derived from the fixed I/O coordinates.

Assuming that the (x,y) coordinates of I/O pads are $(x_5, y_5)=(10, 5)$, $(x_6,y_6)=(5, 8)$, $(x_7,y_7)=(0, 1)$, write the Q matrix as well as the d vectors. Show the details of your calculations.

(b) (0.6 points) Show the derivation of a set of linear equations from the quadratic equation in the previous part. Show the matrix form of the set of equations as well.

(c) (0.8 points) Solve the set of equations associated with the netlist of part (a). ONLY SOLVE THE X EQUATIONS. List the x coordinates of all the gates.

(d) (0.8 points) The wire length is represented as a quadratic function in the above formulation.

- Name two disadvantages of the quadratic wire length model:

- Suggest a heuristic that can help reduce the gap between the desired linear cost function and the quadratic function.

(e) (0.8 points) List two well-known methods for removing the overlap between gates. Comment on the (rough) time complexities of the methods.