Evaluation

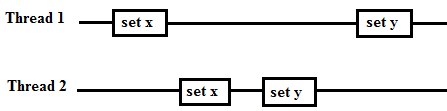
Operations in detail:

1. **Registration of clients with server:** Each client sends a message to server with a name and client type information specifying that whether it is a ghost or a pacman. The server accepts all the registration messages from each client and updates its local list of pacman and ghosts. To each client it sends an id. The server stops receiving any more registration messages when the total number of clients has reached to a particular value which is hard coded.
2. **Server broadcasts starting position of each client in one string:** The server generates a packet which contains the starting position of each client. The client on receiving the message creates an instance of Board class containing all the players in specified positions. A GUI thread is then run using Swing.invokelater() function. Now the client can see the board GUI. There is no GUI on the server side.The GUI thread continuously repaints the board. It has the logic for keep moving in the current direction.
3. **Client presses an arrow key:** When a client presses an arrow key, a message is sent to the server. This message consists of the current co-ordinate of the client on board, its current movement direction (which is static initially), and the new direction it wants to acquire (based upon the arrow key pressed). The server on receiving this message updates its local copy of client with received co-ordinates, current and new directions. It then broadcasts this information to each client, including the one with whom it received the request for new direction. Each client then updates their local copy of corresponding player and displays it in the GUI.
4. **The game over message:** As stated earlier, the server side contains a local object for each client consisting of its co-ordinates, current and new directions. This object gets updated only when a client sends a request for change in direction by pressing an arrow key. There is no logic of continuous movement on the server side. Hence in case there is a collision between ghost and client, the first one to know this would be a client itself. Also there is no information about the number of pellets eaten by the pacman on server side. Hence, in case any of these two events occur, the client sends a message to server indicating that the game is over and who wins (ghost or pacman). The server then broadcasts it to make sure that the game is over in all the clients. Each client then ends the game.

**Concurrency Issues:**

About COW client

We maintain a copy of the pacman and ghost positions on each client, which are updated by the clients GUI. When a client registers a key press event it sends a message to the server with information about its x and y coordinates, its current direction, and the direction of the key press. The server then broadcasts this information to all the clients connected to it. We have a class called ClientPosition which we use to store information about the client, i.e. its x and y coordinates along with its current direction and the next direction to move in. As the client position is updated by both the GUI and the message received from the server, it is possible that the object could end up with an invalid state. This could occur in the following scenario



As we can see, in this case it is possible for the x and y coordinates to be written from two different thread, thus ending up with an invalid client position. Similar cases were possible when the current direction of the client was not valid. Having an invalid client position would lead to errors where the pacman/ghost would make illegal moves. (The pacman board can be thought of containing 13 x 13 small squares, each the size of the pacman/ghost. The pacman/ghost changes direction only when it fits one square perfectly, thus when the pacman or ghost body is there in 2 squares, it continues to move in its current direction. An illegal move would be such that the pacman/ghost would never fit a square). To rectify this error we applied the copy on write principle by making the client position class immutable and using a wrapper class called COWClient. The GUI thread would get a copy of the client position and store the data in local variables for drawing the pacman/ghost and then write a new position at the end. The other thread updates the position using the *changeClientsState* method which would write a new client position object using the *COWClient*.*setClientPosition* method. Thus we would always have a valid state for the pacman/ghost.

As explained about the COWClient on the client side ensures that the state of a client position on board is not corrupted by the two threads updating it. There is one more place we have used synchronization. When the thread which is calling the repaint repeatedly tries to update the client’s state, it checks whether the state was already updated by the other thread (the one which is listening to server). If it is already changed, it does not change it again so that the information from server can appear in the UI.

Evaluation:

Here we would describe how we tested and changed our code from the start.

We were skeptical about what operation to put on server and what on clients. Initially we thought that the server would handle most of the operations. We coded such that the server has its own GUI for board which keeps changing its state according to keystrokes received from clients. Each change in the board was broadcasted to clients. []. The client receives a string which describes the overall state of the board and displays it in its own GUI. At this point of time, there was no continuous movement of the pacman. Hence with each key press, the player moves a fixed number of co-ordinates and becomes static. This did not comply with the traditional pacman, but we thought it would at least maintain synchronization among the clients.

The board is defined by a two dimensional array. Earlier, when a player moved, he moved by one grid in the matrix. So the movement did not look continuous. []. This implementation was easy because a particular entry in the matrix denoted the presence of a player. It was easy to update. Later on we changed it to continuous movement by making the player not a part of matrix, but a separate object consisting of co-ordinates and direction. []. This really improved the look and feel of the game and we moved on with that.

Later on, we tried to think about making the client move by itself when a key is pressed. But this seemed impossible if we kept the all the calculation on server side. The server side would have to send board state continuously and there was a possibility of huge delay and lack of synchronization among players. So, we decided to shift all the operations on the client side. The server’s only responsibility was to receive key press events from clients and broadcast to all of them. The client has the logic for updating GUI. The thread listening to the server also updates UI and that’s where we make sure that there is a consistent state for each player.

We were first implementing the code using TCP for communication between servers.[]. Later on, we shifted to UDP to reduce the lag[]. This really improved the overall performance. We were now able to play in our laptop at home reasonably well.

After all this, we faced an error which was probably the most challenging so far. We found that sometimes, the player would just go through the maze and then would keep going in a straight line and not listen to the key strokes. We had no idea why this was happening. After a lot of debugging and mutual discussion, we figured out that the reason was that the player objects on client was being updated by two threads concurrently, which sometimes lead to unpredictable behavior. This issue is discussed in detail in the section describing the concurrency related issues.

As expected, we found that the game experience is much better when it is run in Gartner lab machines on Ethernet compared to playing on wireless internet in our laptops at home. At home, we were able to play with three players (one pacman, two ghosts or two pacman and on ghost) pretty well. And in the lab, we were able to play with six players with reasonable amount of fun.