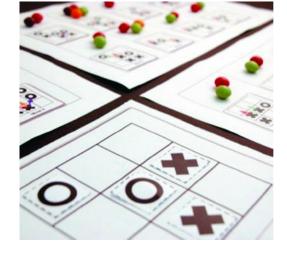


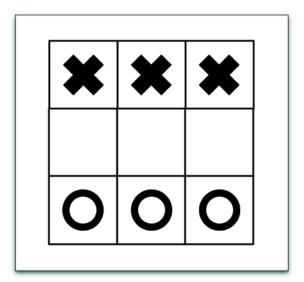
One of the most exciting branches of computer science is called *machine learning*. Machine learning aims to find ways for computers to solve complex problems by learning for themselves. For instance, a computer can use trial and error when it is learning how to play games and win by learning from its mistakes.



Here we'll look at hexapawn, a simple game you can play against your friends first. Then we'll describe how to build a computer that can play hexapawn, using only a few sheets of paper and packets of sweets. Even better, the sweet computer will learn by itself, and you'll soon find it impossible to beat!

HEXAPAWN

To play a hexapawn game, print the playing board (a 3 x 3 grid) and pieces (Xs and Os) shown on page 6, then cut out the pieces and set up the board with the Xs lined along the top row and the Os along the bottom row (as shown below). One player takes Os, the other Xs.









The rules are similar to a mini game of chess – using only pawns. A piece can move forward one square only if that square is empty. You can take an opponent's piece if it is in a diagonally neighbouring square – just like a pawn attack in chess. The players take turns to move their pieces, starting with O.

There are three ways of winning at hexapawn.

- 1. You get one of your pieces on to the back row on your opponent's side.
- 2. You take all of the other player's pieces.
- 3. You've played the game so that it is impossible for your opponent to make a move (i.e. you have blocked all of their pieces).

That's all there is to it! Play a few games against your friends to get used to hexapawn. Can you work out a good winning strategy? Which moves tend to work well? Which end up with you losing?

Now you can build a computer that can play hexapawn, using only sweets. Soon, this sweet computer will play so well that you will not be able to beat it!

HEXAPAWN COMPUTER

To build your own hexapawn computer, you will need:

- a hexapawn board and pieces (found on page 6)
- a colour printout of the hexapawn sweet computer
- a few packs of coloured sweets (red, orange, green and blue are best).

(This hexapawn sweet computer is based on a design produced by *Computer Science for Fun* www.cs4fn.org)

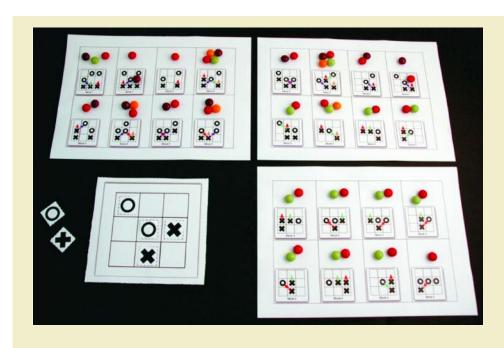
What to do

Take the packs of sweets and the colour print out of the hexapawn sweet computer. Each of the boxes in the hexapawn computer shows a different arrangement of the pieces during a hexapawn game. The coloured arrows show all the different possible moves that the computer can play from these game positions. For each box on the hexapawn computer sheets (24 in total) put a coloured sweet in the blank space at the top of the box corresponding to each of the different arrows in the board picture. So, for example, on the first box you would put one blue, one green and one red sweet into the



space above the drawing of the board. If you don't have the right coloured sweets just use different colours for the arrows and make sure you know which is which. Lay these out carefully for all the different coloured arrows for each of the boxes on the hexapawn computer sheets. Now your sweet computer is set up and ready to start!

- Set up the hexapawn pieces on the board.
- You play as Os, so you get to go first. Play your opening move.
- Now it's the sweet computer's turn. Look at the computer sheets and find the one
 that shows the same board layout (the move number is written below the board
 pictures). The board pictures also work for the mirror image of the position you
 can see. So, for example, the first box on the sweet computer would be correct if
 you had moved the right-hand O, as well as the left-hand O shown in the diagram.
- When you have found the right position shown on the sweet computer, close your
 eyes and pick a sweet from that box. Put it on top of the board picture so that you
 remember which one you picked. The colour of the sweet corresponds to one of
 the arrows on the board picture. This is the move the sweet computer has chosen
 to make, so make that move for the Xs on the hexapawn board.
- Now it's your turn again, so play your best move!





- Continue like this, finding the correct board position picture every time it's the computer's turn, picking a random sweet and playing that coloured move. If you cannot find the board position drawn in any of the boxes (make sure you've checked carefully) this means the sweet computer resigns and you win! But if you reach a position where you can't move, or the computer takes all your pieces, or gets one of its own pieces on to your back row, then the computer wins!
- If you lost, move all the coloured sweets back above their board picture, reset the hexapawn board and play again. But see if you can win this time.
- If you won, take the coloured sweet off the computer board picture that made it play its last move. You get to eat this sweet for winning. Now put all the other coloured sweets back where they came from in the gap above the board pictures and play another game. See if you can win again playing different moves...
- Keep playing hexapawn against the sweet computer, removing (and eating) the coloured sweet that caused it to play its last losing move. What do you notice about the sweet computer over time? Why do you think it begins to win more games against you? How is this computer, made of just three sheets of paper and a pile of sweets, able to keep beating you?

How the computer game works

The sweet computer will play pretty badly at first. This is no surprise – it's playing random moves every time you close your eyes and pick a coloured sweet by chance. But, as it plays more games and you get to gobble more of the sweets, the computer steadily improves until it beats you every time. The computer has learned how to play hexapawn and now never plays a bad move. How has this worked?

Every time the computer plays a losing move you eat the corresponding sweet, which means that it will never play that move again (because you won't be able to pick that colour next game). Over time, you remove more of the computer's losing moves, until eventually it plays the best move every time and can never lose.



The different moves that can be played from the start and all the moves that can be played from each of those positions, and so on, spread out like a great big tree. Deciding which move to make each time the board position changes is like tracing through this tree of possible moves. Some of the twigs at the end of this decision tree result in the computer losing and some in it winning. Whenever you eat the coloured sweets you remove the losing moves; over time the decision tree gets cut back more and more so eventually only the winning branches survive. The sweet computer has learned how to beat you every time.

Chess computers use the same strategy of pruning a decision tree and sometimes even manage to beat Grandmasters (the best human chess players in the world). Chess, however, has a much bigger board than hexapawn and 32 pieces that move in different ways, so the decision tree for all possible games of chess is enormous. In fact, the total number of different possible games of chess is more than all the particles in the Universe. This number is so large that probably no computer will ever be able to work out how to play chess perfectly.

During the early stages of a game, even the best chess computers can only look a few moves ahead, exploring the decision tree in front of them a little bit then calculating which move gives them the best chance of winning. People often can't look as many moves ahead as a fast computer, but they can play chess from experience and use their intuition. Humans are very good at seeing patterns and adapting general strategies and so are able to beat even very powerful computers.

The game of draughts (also called checkers) is much simpler than chess, so computers have already worked out every possible move and can play draughts perfectly. No human can beat such a draughts-playing computer program! But don't worry, humans are far better than computers at lots of things, just watch the Christmas Lectures to find out what!



HEXAPAWN BOARD AND PIECES
SWEET COMPUTER (FOLLOWING PAGES)

