
Department of Computer Science

# Artificial Intelligence
# COS314

Project 1: Game Trees

**Due: Wednesday 31 March, 13:00**

For this project you will develop a game tree algorithm to play one of two African board games: Mancala or Bao. You have to select one of these two games. However, note that the game of Mancala is much simpler than the game of Bao, with a significantly smaller number of states. Therefore, if you choose Mancala, the maximum mark that you will get is 75%.

Find below the rules for this project, and other decsions that you will have to make, with each decision having an impact on the maximum mark that you can obtain:

1. Select your game, and carefully think about the evaluation function to use. You have to describe this evaluation function, with motivations, in a pdf document. See below.
2. Decide if a minimax or alpha-beta game tree will be used. More marks will be obtained for the alpha-beta pruning algorithm.
3. The project is done by each student individually, and all code has to be written by yourself.
4. You may implement the project either in C++, C, Java, or Scala, and must run on Linux. You have to provide a Makefile, ant file, or any other alternative project script that will run on Linux. Describe in the pdf file how the project should be compiled and used.
5. Provide a GUI for your game. The GUI can be text based, or graphical. The former will earn you less marks.
6. Your game should allow for the computer to play against a human, and should also provide for two programs to play against one another, at different user defined ply depths.
7. Although this is not a programming course, you should always provide well-structured, modular, well-written and documented code.
8. Submit your project before the deadline via the online submission system as a compressed tar archive. Provide a pdf file, *project.pdf* in the root file to which your tar ball extracts, wherein you explain how the program should be compiled and used, give your name, surname and student number, and give the game you have implemented as well as the rules of the game. Also describe your evaluation function in this pdf document. State in this document if you have implemented standard minimax or alpha-beta pruning. Provide a reference in your code where this is implemented.

9. By submitting, it is assumed that you have done, and submitted your own work. If found that the work is not your own, it will not be evaluated.

The project will be evaluated using the folliwing marking scheme. Note that the mark will be scaled down to a mark out of 135 if you have selected mancala.

| **Aspect** | | **Mark** |
|---|---|---|
| The AI used: | | |
| | Minimax | 15 |
| | Alpha-Beta | 30 |
| | Evaluation Functions | 30 |
| | Any other things done? | 10 |
| | Did it work? | 50 |
| | **Sub-total** | **135** |
| GUI: | | |
| | Text-based | 5 |
| | Graphical | 20 |
| | **Sub-total** | **25** |
| Coding style: | | |
| | Modularity | 10 |
| | Documentation | 10 |
| | **Sub-total** | **20** |
| **Total:** | | **180** |

Below, find descriptions of the games.

# Option 1: The game of *Mancala*

Many Hisotrians believe that Mancala is the oldest game in the world. The word Mancala means "to transfer" in Arabic. That is exactly what you do; you transfer, or move, playing pieces from one bin to another.

There are many different variations of the game Mancala, for example, *ti, kpo, wari, azigo, igisoro, omweso, oware,* and *bao*. Some version of Mancala is played in nearly every African country. It is enjoyed by royalty and commoners, adults and children, in cities and villages of every size.

Mancala is a two player game that is played by moving stones to different pits on a board. The board consists of two rows of six pits capped on both ends with two larger pits called mancalas as illustrated in figure 1. The pits on the bottom row and the mancala on the right belong to player 0 and the pits on top row and the mancala on the left belong to player 1. The board contains 48 stones (black dots in the figure). Initially the stones are arranged with four stones per pit and the mancalas are empty as shown. The object of the game is to capture more stones than your opponent.

The following four simple rules describe the game and are written assuming you are a player:

- **Basic Movement:** Players alternate by playing the stones from any one of their pits. If it is your turn, you choose one of your pits and remove all of the stones from this pit. You play these stones by dropping them into each pit that follows the pit you chose moving in a counterclockwise direction. You drop only one stone at a time into each pit until you are holding no more stones. You also get to drop a stone in your mancala if you pass it but you do not drop one in your opponent's mancala if it is passed.
- **Capturing Stones:** If during your turn the last stone that you drop is in one of your pits and that pit is empty, you may capture all of the opponent's stones in the corresponding pit (the opponents pit opposite yours) and place them in your mancala.
- **Extra Turn:** If your last stone is dropped in your mancala, then you get an extra turn.
- **Ending the Game:** The game ends when all six bins on your opponent's bins are empty. The player with pieces still in his/her bins places the remaining pieces into his/her mancala. The winning player is the one with the most stones in his/her mancala.

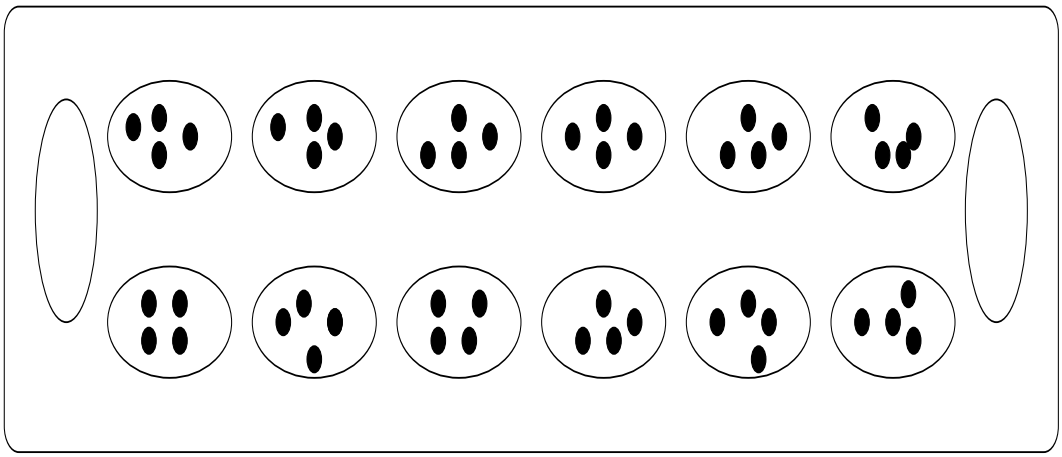

Figure 1: Initial state of Mancala board

The rules above are the Egyption rules of playing the game. You may also decide to use the Ethiopian rules, which adds to the Egyption rules that players may choose to move either to the right or to the left on each turn, and players may never start from a bowl with only one stone.

## Option 2: The game of *Bao*

The following description is from an article by Rob Nierse.

### The Rules

Frequently in Bao several rules are applied at the same time. In those situations, it is important to apply the rules in the correct order. The hierarchy of the rules is of extreme importance. In this leaflet I will present the rules in as logical an order as possible. After reading and playing the rules you can use the scheme presented below to clarify the order of application of the rules when various rules come into conflict.

### Variations in Rules

The rules presented here were collected by Alex de Voogt between 1991 and 1995. He was helped by Bao masters from Zanzibar. It is very possible that you will encouter different or additional rules to the ones presented here. These variants can be a lot of fun to play, but they are not the rules used during championship tournaments. In this article, I will only present the official rules as Alex de Voogt describes them.

### The Beginning

Diagram 1 presents a view of a Bao board as seen from above. The rectangular holes called nyumba are clearly shown. The top two rows belong to your adversary; the bottom two are yours in this article.

**diagram 1:** the Bao board seen from above (note that this image has not yet been reproduced. Instead, we present a textual version using the numeral 1 to indicate the nyumba and 0 to represent all other holes)

```
0 0 0 0 0 0 0 0
0 0 0 1 0 0 0 0
0 0 0 0 1 0 0 0
0 0 0 0 0 0 0 0
```

In diagram 2 you see the same board, with the holes replaced by numbers. A 'zero' means that there are no seeds in the hole, any other number represents that number of seeds in that hole.

**diagram 2:** schematic representation of the Bao board in the starting position

```
0 0 0 0 0 0 0 0
0 2 2 6 0 0 0 0
0 0 0 0 6 2 2 0
0 0 0 0 0 0 0 0
```

As you see, each player has ten seeds at the start. The seeds are called *kete* (plural: kete). The other 22 seeds are kept off the board and are brought into play one by one. The process of introducing the additional kete divides a Bao game into two stages. During the first stage each player brings one seed into play each turn. This is called the *Namua* stage. If you win during the namua, you win *mkononi* ('in hand') because there are still seeds left in hand to bring into play.

If there is no winner during the first stage, players keep on playing with the seeds on the board until there is a winner. This is called the *Mtaji* stage. There are no draws in Bao. Theoretically, draws are possible, however, when, for example, a move sets up an endless cycle.

In presenting the rules, I will begin by explaining namua, the first stage. After that I will present the mtaji stage.

## Goal of the Game

Before starting I would like to repeat the victory conditions of the game. In order to win you must either deplete the front row of your opponent or deprive him of all legal moves.

## Namua Stage

### Enter from the Stock

To start your move you have to look for a hole on your front row that already contains one or more seeds. Ignore the empty holes. Now select a hole with seeds that has an opposing hole that also contains one or more seeds. Ignore the occupied holes with empty opposing holes.

Take a seed from your stock and put it in the hole you have selected. Take the seeds in the opposing hole. Now you have captured these seeds.

To repeat, in order to capture seeds from the opponent you must satisfy three conditions:

- there must be one or more seeds in your own hole in the front row
- there must be one or more seeds in the opposing hole in his front row
- you put one seed from your stock into the appropriate hole in your front row

Diagram 3 shows a situation in which you can capture:

**diagram 3:**

```
0 0 0 0 0 0 0 0
1 0 1 8 1 2 0 0
0 0 0 0 7 0 2 1
0 0 0 0 0 0 0 0
```

You own the bottom two rows. You can capture by taking a seed from your stock and placing it into the hole with seven seeds. Now this hole contains eight seeds. Take the seed from the opposing hole. Now you have captured that seed. The next section describes what to do with captured seeds.

### You Must Capture If You Can

It is important to know that you have to capture if there is a possibility to do so. Let's return to diagram 3. The capture that the player executed was the only possible one. Although he had other holes with seeds, none of them had seeds in the opposite holes.

### Entering Captured Seeds

In diagram 3 you just captured a seed. In Chess or Checkers the opposing pieces are removed from play; in Bao the captured pieces (seeds) are brought back into play immediately.

Put the captured seed in the extreme left or right hole of your front row. These holes are called kichwa (literally 'head').

Let us reconsider diagram 3. If we enter the captured seed in the extreme left hole, the situation in diagram 4 arises:

**diagram 4:** entering the captured seed in the left hole

```
0 0 0 0 0 0 0 0
1 0 1 8 0 2 0 0
1 0 0 0 8 0 2 1
0 0 0 0 0 0 0 0
```

The seed is entered in the left kichwa. Because it landed in an empty hole, the move ends here.

NB: captured seed(s) are always entered in the first hole, known as the *kichwa,* never in the second or another hole.

**Entering More Than One Seed**

We have seen a situation in which we captured one seed and entered it in our front row.

Suppose we capture a hole with more than one seed, what will happen? Take all the seeds en sow them in your front row, beginning in the left or right kichwa.

Sowing means that one seed is put in the hole that lies next to the hole that received the previous seed. Always sow one seed a time and never skip a hole.

See diagram 5. Capture the three seeds opposing the hole with seven seeds.

**diagram 5:** capturing more than one seed

```
0 0 0 0 0 0 0 0
1 0 1 8 3 2 0 0
0 0 0 0 7 0 0 0
0 0 0 0 0 0 0 0
```

If you capture by placing a seed in the hole and taking the opposite seeds, then the situation in diagram 6 will occur:

**diagram 6:**

```
0 0 0 0 0 0 0 0
1 0 1 8 0 2 0 0
0 0 0 0 8 0 0 0
0 0 0 0 0 0 0 0
```

Sow the seeds you just captured, starting from the left side. The result is diagram 7:

**diagram 7:**

```
0 0 0 0 0 0 0 0
1 0 1 8 0 2 0 0
1 1 1 0 8 0 0 0
0 0 0 0 0 0 0 0
```

The last seed falls in the third hole from the left. The move then ends, because the last seed fell in an empty hole. It is also possible to enter the seeds from the right side. In that case, we end up with the siuation in diagram 8:

**diagram 8:**

```
0 0 0 0 0 0 0 0
1 0 1 8 0 2 0 0
0 0 0 0 8 1 1 1
0 0 0 0 0 0 0 0
```

The last seed falls in the third hole from the right (which is the sixth from the left).

**Kichwa and Kimbi**

Until now I presented situations were you could choose whether to enter the seeds from the left or the right. But there are situations in which you can not choose. You cannot choose if you capture seeds from the two holes on either end of the board. In that case, you must enter the captured seeds on the same side where you captured them. These two holes on the extreme left and right have special names. The outer ones we already know as kichwa. The second holes from left and right we call *kimbi*.

To make this new rule clearer, see diagram 9:

**diagram 9:**

```
0 0 0 0 0 0 0 0
4 3 1 8 0 2 5 6
1 2 0 0 8 0 3 4
0 0 0 0 0 0 0 0
```

If you capture by placing the seed from your stock in the hole with one seed, you capture four seeds. These four seeds have to be sown from the left; you are not allowed to sow them from the right. If you capture the three seeds opposing your two, you also must sow them beginning in hole one. If you capture the five seeds opposing your three, you must start sowing from hole eight (the kichwa from the right). If you capture the six seeds opposing your four, you also must enter them starting from the right side.

The result of these capture possibilities I present in diagrams 10, 11, 12 and 13. For convenience, only the front rows are shown, because there are no seeds in the back rows.

**diagram 10:** after capturing the first hole from the left

```
0 3 1 8 0 2 5 6
3 3 1 1 8 0 3 4
```

**diagram 11:** after capturing the second hole from the right

```
4 3 1 8 0 2 0 6
1 2 0 1 9 1 5 6
```

**diagram 12:** after capturing the second hole from the left

```
4 0 1 8 0 2 5 6
2 4 1 0 8 0 3 4
```

**diagram 13:** after capturing the first hole from the right

```
4 3 1 8 0 2 5 0
1 2 1 1 9 1 4 6
```

**Capturing with Captured Seeds**

Yes, the above title is true: if you capture seeds, they immediately change sides and can capture even more opposing seeds!

In diagrams 10 through 13, the last seed ends in an empty hole, ending the move. In some situations the last seed to be sown falls in a hole already containing seeds. If this happens you can capture the seeds in the opposing hole. Of course, this can only happen if there are seeds in the opposing hole. If there are none, then take all the seeds from this last hole and sow them again, sowing in the same direction.

NB: If you captured a kichwa or kimbi, the direction of sowing can change according to the kichwa and kimbi rule presented above.

Remember that you always keep on sowing or capturing. Your turn can only end when your last seed falls in an empty hole.

**Multiple Captures**

By capturing with captured seeds, multiple captures are possible. To explain this multiple capturing, see diagram 14. Enter a seed in the hole that contains two seeds and capture the opposing three.

**diagram 14:**

```
0 0 0 0 0 0 0 0
0 3 4 8 0 2 5 6
0 2 1 0 8 0 3 4
0 0 0 0 0 0 0 0
```

Because it is a kimbi hole, you must start sowing from the left kichwa.

You capture the three opposing seeds. Because it is a left sided kimbi hole, you start sowing on the left side. The last of the three seeds ends in the third hole. This hole already contains one seed, so you capture the four seeds of your opponent. Take these then and start sowing from the left. You have to start on the left, because you were already sowing in that direction. The last of those seeds falls in the fourth hole. Because the fourth was empty, the move ends.

**diagram 15:** result of capturing the second hole in diagram 14

```
0 0 0 0 0 0 0 0
0 0 0 8 0 2 5 6
2 5 3 1 8 0 3 4
0 0 0 0 0 0 0 0
```

Now, go back to diagram 14 and capture the right side kichwa. After completing all sowing you will get the postion in diagram 16 as a result.

**diagram 16:** result of capturing the eight hole from the left in diagram 14

```
0 0 0 0 0 0 0 0
0 3 0 8 0 2 5 0
1 3 3 2 0 2 5 7
1 1 1 1 1 1 0 0
```

**To Keep on Sowing**

In some situations the last seed won't fall in an occupied hole having seeds in the opposite hole. Take a look at diagram 17.

**diagram 17:**

```
0 0 0 0 0 0 0 0
1 0 0 7 0 0 0 2
0 2 3 2 0 2 5 0
0 0 0 0 0 0 0 0
```

You capture the seven seeds from your opponent. If you start sowing from the left, you will end with your last seed in the seventh hole. It is not empty, so your move doesn't end, but there's nothing to capture either. In that case take all of the seeds from that hole (there are now six) and start sowing again, not changing direction and starting with the very next hole. In this case you will end up in the back row, the fourth hole from the left. You can see this result in diagram 18.

**diagram 18:** result of capturing the seven seeds, starting from the left

```
0 0 0 0 0 0 0 0
1 0 0 0 0 0 0 2
1 3 4 4 1 3 0 1
0 0 0 1 1 1 1 1
```

If you capture the seven seeds and start sowing from the right, you will eventually end up in the back row, the third hole from the left.

**To Sow Around the Corner**

In the situations above there were more seeds to sow than there were holes. In that case, you keep on sowing in the back row. It is even possible to return to the front row, again, if you have enough seeds!

**No Capturing = Takasa**

In some situations, you can not start a move by capturing opposing seeds. Take a look at the starting positions (diagram 2) and you will know what I mean.

Moves where you cannot start with a capture we call *takasa.*

If you can't start with a capture, just put a seed in one of your holes with one or more seeds, take all seeds and start sowing them. Keep on sowing until your last seed encounters an empty hole. During the move, no captures are allowed! This is because you didn't start with a capture.

Rules of the House, Nyumba

The *nyumba* (Swahili for 'house') is the hole marked with a rectangle. This is always the fifth hole from the left on the front row.

The nyumba ceases to be a nyumba as soon as the seeds it contains are sown. After that it is an ordinary hole just as all other holes.

The nyumba has some special rules that add flavor to the game. These rules concern, amongst others, keeping on sowing and emptying the nyumba in takasa situations. These special rules do not apply if you have fewer than six seeds in your nyumba.

**To Stop Sowing**

In the above paragraph 'To Keep on Sowing' I told you that you have to continue sowing if your last seed falls in an occupied hole with a hole opposite with no seeds. The nyumba is an exception to this rules. If the last seed falls in the nyumba and the opposing hole is empty, the player may end his turn if he wishes. The opponent then starts his move. See diagram 19.

**diagram 19:** capture the four seeds and start sowing from the right

```
0 0 0 0 0 0 0 0
0 1 2 10 4 4 0 0
2 1 0 0 12 0 0 0
0 0 0 0 0 0 0 0
```

You take the four seeds opposing your nyumba (the nyumba is underlined) and start sowing from the right. Now your last seed falls in the nyumba. According to the rules, you may either start sowing the seeds or you may stop. If you continue sowing, you will end up capturing no other seeds. So, in this case, you decide to stop and wait for better chances in later turns.

**Why Stopping?**

As I already said, sometimes it is advantageous to wait for better times. If you sow the seeds from your nyumba at the right time, the result can be devestating.

For example, take a look at diagram 20.

**diagram 20:** the opponents turn: he must capture the seed

```
0 0 0 0 0 0 0 0
0 1 2 16 0 0 2 0
2 1 0 0 14 0 0 1
0 0 0 0 0 0 0 0
```

Your opponent has no choice: he has to capture the seed and put it in his right side kichwa, thus ending his turn since it was empty. The result is to be seen in diagram 21:

**diagram 21:** end of your opponents turn. Now you must capture

```
0 0 0 0 0 0 0 0
1 2 2 16 0 0 2 0
2 0 0 0 14 0 0 1
0 0 0 0 0 0 0 0
```

Now you capture the seed opposing your two seeds. You enter the seed in you left side kichwa. This captured seed is automatically your last seed. The hole is not empty and since now there is nothing left to capture, so you take the four seeds and start sowing them ending in the nyumba. If you decide to sow the seeds fom your nyumba you will capture all other seeds from your opponents front row. We call this Bao Hamna: clearance of the front row. You win!

Sowing the seeds from your nyumba at the right time is very tricky to do. It is like a climax and is one of the focal points of the Bao game.

**A Takasa Situation with Only Your Nyumba Remaining**

This is the second special rule concerning the nyumba. Take a look at diagram 22. In this situation you cannot make a capture.

**diagram 22:** only the nyumba left in a takasa situation

```
0 0 0 0 0 0 0 0
0 1 2 9 0 2 0 0
0 0 0 0 9 0 0 0
0 0 0 0 0 0 0 0
```

If the nyumba is the only hole left and you can't capture, place a seed in your nyumba then take out two seeds and sow them to the left or to the right.

**Always remember that these special rules do not apply if there are less than six seeds in your nyumba.**

**Summary of the Most Important and Frequently Used Rules**

- you have to capture if you can
- entering captured seeds must be done in the front row from the first hole from the left or right
- you have no choice whether to start from the left or right when:
- you captured a kichwa or kimbi hole
- you have already sown in a direction
- if the last seed ends in an occupied hole, capture the opposing seeds
- if there is nothing in the opposing hole, take the seeds from you holeand sow them in the same direction
- your move ends when your last seed falls in an empty hole.

## Mtaji Stage

The mtaji stage begins when the namua stage ends. That means that you start the mtaji stage when all seeds in the stocks have been brought into play. The mtaji stage is not very different from the namua stage.

**Capture**

In the mtaji stage you must capture if you can. Because no more seeds can be brought into play, you must take a hole that, after sowing the contents of it, ends with the last seed falling in a hole having a hole with seeds opposing it. The opposing hole is called mtaji (plural: mitaji).

So we can conclude:

- sow seeds from a hole (that may be a hole from the front or back row)
- the last seed from that hole must end in a hole in the front row having one or more seeds
- there must be one or more seeds in the opposing hole (mtaji)
- the seeds in the mtaji are captured
- playing singletons (holes with only one seed in it) is not allowed
- if there is no mtaji, you play takasa (which will be explained later)

In diagram 23 you have two possible mitaji. You can play your three seeds to the right and capture five, or you can play your nine seeds to the right (sowing around the corner) and capture six.

**diagram 23:**

```
0 0 0 0 0 0 0 0
0 0 0 0 5 6 0 0
0 3 0 0 4 1 0 0
0 9 0 0 0 0 0 0
```

**Takasa**

In the mtaji stage it is not uncommon to have situations in which no captures are possible. This can be because there are no occupied holes with occupied holes on the opposite side (mtaji), or because there are no holes that when sown would end opposite mtaji.

These situations are called takasa. In that case, a player must take a hole from the front row and sow it to the left or right. During the move captures are not allowed, just as in the namua stage.

If there are no occupied holes in the front row, you may sow a hole from the back row.

Take notice: you may never start by sowing a singleton hole.

If there is a hole that is the only mtaji left for your opponent (mtaji moja), than this hole may not be sown in a takasa situation. In diagram 24 your opponent has a takasa situation. This means that he must sow his five or six seeds. Because you have only one mtaji left (the hole with four seeds), he may not sow his five seeds. So your opponent must sow his six seeds to the left or the right.

**diagram 24:**

```
0 0 0 0 0 0 0 0
0 0 0 0 5 6 0 0
0 3 0 0 4 1 0 0
0 7 0 0 0 0 0 0
```