CSE 332: Data Structures and Parallelism

P3: Chess

Checkpoint 1: Tue, May 26
P3 Due Date: Wed, June 3

The purpose of this project is to compare sequential and parallel algorithms on some intractable problems. You will also learn some new graph algorithms and a bit of combinatorial game theory.

Overview

In this project, you will write several chess bots and compete against other chess bots on the CSE 332 chess server. You will implement several (graph/tree) algorithms (both sequential and parallel) and be able to see a significant difference in the quality of the bots. Unlike in previous projects, **you should feel free to use any and all Java data structures** (since you've now implemented them all yourself).

Before attempting this project, you should read the handout on the algorithms! (games.pdf)

The project is designed so that you need minimal chess knowledge, but we recommend you familiarize yourself with the basic rules just in case. We have written all of the chess-specific code (evaluator, move generation, board, GUI, etc.); all you will be responsible for is implementing the game tree searching algorithms. You may, of course, improve the board/evaluator/etc. to your liking.

The parts of this project alternate between sequential code and parallel code. For each new algorithm, you will implement the sequential version first followed by a parallel version.

Project Restrictions

- You *must* work in a group of two unless you successfully petition to work by yourself.
- You may not edit any file in the `cse332.*` packages.
- The *design and architecture* of your code are a *substantial* part of your grade.
- The Write-Up is a *substantial* part of your grade; do **not** leave it to the last minute.
- **DO NOT MIX** any of your experiment or above and beyond files with the normal code. Before changing your code for experiments or above and beyond, copy the relevant code into the corresponding package (e.g., `aboveandbeyond`, `experiments`). If your code does not compile because you did not follow these instructions, you will receive a 0 for all automated tests.

Provided Code

- `cse332.*`: You shouldn't need to look at any of the files in this package. The code in these packages sets up a GUI, a connection to the chess server, communicates with the chess server, and sets up several interfaces. You shouldn't need to understand any of this code to complete the project.
- `chess.board`: You also shouldn't need to look at any of these files. In chess, the *game position* consists of the board and some auxiliary information that these classes keep track of. We list below the only relevant methods you need to be aware of that are from the `ArrayBoard` class:

`List<Move>` **`generateMoves`**`()`
Generates a list of valid moves that the current player could make.

`void` **`applyMove`**`(Move move)`
Applies the provided move to the board changing the state of the game.

`void` **`undoMove`**`()`
Undoes the last move applied to the board.

`ArrayBoard` **`copy`**`()`
Copies the board Object in its entirety. This operation is *expensive*; you should avoid using it whenever possible.

- `chess.game`: This package contains classes related to playing a game of chess. It includes our provided evaluator (which you may edit) and a timer class which might be useful if you want to stop your bot after a certain amount of time. We list the methods you might need for these classes below.
  - `SimpleEvaluator.java`:

`int` **`infty`**`()`
Returns a number larger than any actual board evaluation to represent infinity.

`int` **`mate`**`()`
Returns the value of a board in checkmate. (Depending on the current player, this could either be very high or very low.)

`int` **`stalemate`**`()`
Returns the value of a board in a stalemate (a draw).

`int` **`eval`**`(Board board)`
Returns a number representing "how good" the provided board is. Note that the `Board` class maintains information about the current player (white or black), and `eval` will return a value *from the perspective of the current player*.

  - `SimpleTimer.java`: This class gives you a way to allow `generateMove` (the method that finds the next best move) to be time limited. You do not have to use it, but if you do, feel free to add/change methods to your liking.
- `chess.setup`:
  - `Engine.java`: This class sets up the bot that will be used with the `EasyChess` client. You can change any and all of the configuration parameters. In general, you will need to change the class of the bot, the depth, and the sequential cutoff.
- `chess.play`: This package contains classes that allow you to connect to the CSE 332 Chess Server.
  - `EasyChess.java`: This is the main client you will use to play chess using your bot on the chess server. All of the setup uses the GUI. So, just run it as a "Java Application" in Eclipse, and you're good to go.

- `CloudClient.java`: This client is for running your bot in the cloud. It automatically starts a game with the provided bot when it runs. To watch the game, log on using `EasyChess` on your computer and use the "`watch`" command.

- `chess.bots`
  - `BestMove.java`: This class will be useful when writing your bots, because you'll need to return both a move and its value. In substance, this is a lot like the `DataCount` object from p2.
  - `LazySearcher.java`: This is a very dumb searching implementation that returns the first move it finds. It's intended to show you what a working bot looks like.

A Warning

All of the parts of this project involve understanding exactly how the previous parts worked. It would be a *giant* mistake to split up the work by having one groupmate do half of the parts and the other one do the rest.

Part 1: Minimax and Parallel Minimax

In this phase, you will write two `Searchers`: `SimpleSearcher` and `ParallelSearcher`.
We *strongly recommend* that you look at `LazySearcher` before you begin to see what the structure of the bot should look like. In particular, you should `extend AbstractSearcher` and use the instance variable `ply`. If you want to use a timer, you should use the instance variable `timer`.
[**NOTE**: If you have not read the games handout yet, do so now! The algorithms described in the games handout are only partial pseudocode, they are not complete algorithms. They are meant to get you started, but you will need to think more deeply about the algorithms described there before implementing them yourself.]

(1) `SimpleSearcher`: Implementing Minimax

`SimpleSearcher` should implement the Minimax algorithm as described in the games handout. This first version should have no parallelism. While you may use a `bestMove` global variable that keeps track of the "best move so far", we recommend that you return a `BestMove` object from your `minimax` method instead. The pseudocode in the games handout does not handle the case where there are no moves quite correctly. You should handle it as follows:

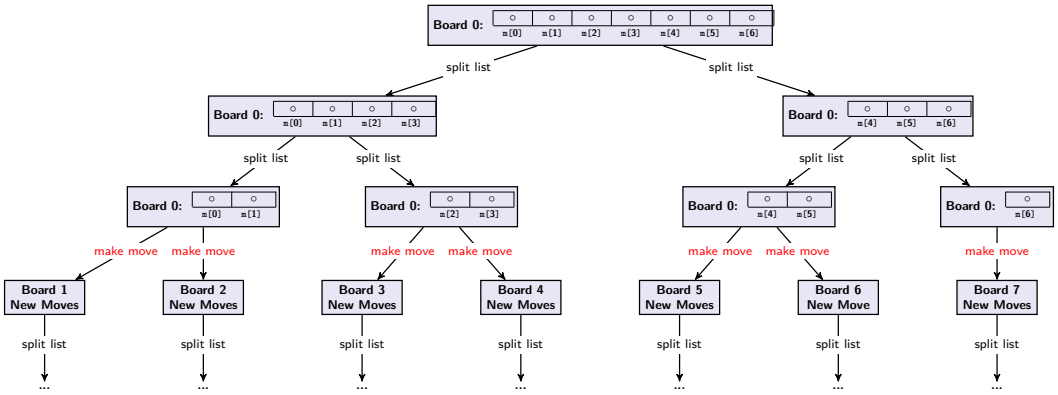
```
1 if (moves.isEmpty()) {
2    if (board.inCheck()) {
3       return -evaluator.mate() - depth;
4    } else {
5       return -evaluator.stalemate();
6    }
7 }
```

In other words, if there are no moves, it's either a stalemate or a mate. Mate is either very bad or very good, but it depends slightly on how many moves away it is.
Additionally, you may notice a call to `reportNewBestMove` in `LazySearcher`; this method is responsible for updating the "current best move" on screen, and, so, you may use it as (in)frequently as you like.

(2) `ParallelSearcher`: Implementing Parallel Minimax

`ParallelSearcher` should implement the parallel minimax algorithm as described in the games handout. This version should be parallel. This version should be able to get further down the game tree than just regular minimax. Make sure you do all the standard parallelism things: divide-and-conquer, sequential cutoff, etc. Make sure you use the `cutoff` instance variable defined in `AbstractSearcher` rather than creating your own (for the sequential cutoff); the reason is later, when you want to configure all the variables, there is a `setCutoff` method you can use to quickly edit the cutoff.

Note that you are doing parallelism *on a graph* here. In particular, you absolutely should not treat the children as a linked list by forking each thread in a loop, because that wouldn't be divide-and-conquer. Imagine that you have a `SearchTask` class that extends `RecursiveTask<BestMove<M>>`, your recursive calls should look like the following:



Once your divide-and-conquer tree gets to a certain depth with respect to `cutoff`, you should switch to a sequential algorithm. (Namely, `minimax`.) Furthermore, as above, you will be doing a divide-and-conquer algorithm; so, there will be a second cutoff, `divideCutoff`, which will tell the algorithm when to stop dividing nodes.
This bears repeating: **your code will have TWO cutoffs in it**:

- `cutoff` tells the algorithm when the number of plies remaining is small enough that the rest should be executed sequentially (Use the existing super class field for this.)
- `divideCutoff` tells the algorithm when to stop forking children via divide-and-conquer and instead fork them sequentially (Note: This does NOT mean to execute them sequentially.) (Make your own constant for this.)

Note that creating an instance of a class (e.g., `SimpleSearcher`) to run your sequential algorithm would work, but it would be prohibitively slow. Instead, note that your `minimax` method in `SimpleSearcher` is `static`; so, you can call it without instantiating a new instance every recursive call.

Part 2: Write-Up

(3) Write Up

A large portion of your grade will be based on your write-up. You will find the write-up questions here in the P3 Write-up Template. Remember to follow the instruction on the first and second page to receive full credit! The Chess Game experiments and algorithm optimization part of this project are incredibly important, and we expect you to spend an entire weeks worth of work on it.

Some of the write-up questions will ask you to design and run some experiments to compare different implementations for the Chess Game. Answering these questions will require slightly editing your algorithm to record the number of nodes you visited and producing result tables and graphs, together with relatively long answers. Do not wait until the last minute! Then, you will learn to optimize your algorithms based on sequential cutoffs as well as compare the actual run times of your four implementations after you have found the optimal settings.

Insert tables and graphs into your write-up as appropriate, and be sure to give each one a title and label the axes for the charts.

IMPORTANT: Place all your optimizing experiments code into the package experiment. Be careful not to leave any write-up related code in the normal files. To prevent losing points due to the modifications

made for the write-up experiments, you should copy all files that need to be modified for the experiments into the package experiment, and start working from there. Files in different packages can have the same name, but when editing be sure to check if you are using the correct file! If your code does not compile because you did not follow these instructions, you will receive a 0 for all automated tests. For all experimental results, we would like to see a detailed interpretation, especially when the results do not match your expectations.

Project Checkpoints

This project will have **one** checkpoints (and a final due date). A *checkpoint* is a check-in on a certain date to make sure you are making reasonable progress on the project. For each checkpoint, you (and your partner) will sign up for a 10-minute zoom meeting time slot during which you will meet with a staff member and discuss where you are on the project to ensure you are using parallelism correctly.

As long as you show up to a time-slot and you do not miss the meeting, the checkpoint will not affect your grade in any way.

Checkpoint 1: (1), (2) **Tue, May 26**
P3 Due Date: (3) Write-up **Wed, June 3**

Above and Beyond

For Above and Beyond, you can write two substantially more interesting `Searchers`: `AlphaBetaSearcher` and `JamboreeSearcher` and use them to beat bots. These `Searchers` should `extend AbstractSearcher` and use the `ply` and `cutoff` variables like in the previous part. Debugging these implementations will be substantially more time consuming than the previous ones.

`AlphaBetaSearcher`: Implementing Alpha-Beta Pruning

When starting to implement this `Searcher`, it will help to copy over your `SimpleSearcher` code and edit it directly. The hardest part of this particular implementation is understanding exactly how the algorithm works. We recommend you look very carefully at the diagrams in the games handout. Feel free to look up other explanations of the algorithm on the internet or in Weiss 10.5.2 (p. 495). This video is really helpful when learning alpha-beta for the first time.

`JamboreeSearcher`: Implementing Parallel Alpha-Beta Pruning

This searcher combines ideas from all the previous ones. It is parallel in a similar way to `ParallelSearcher`, but it uses Alpha-Beta Pruning as a base, sequential algorithm. You should probably start by copying in the `alphabeta` code from the previous implementation.

For better or worse, combining the "complicated algorithm" with the "complicated parallelism" leads to a host of new concerns/issues. We list things you will almost certainly run into here for your convenience:

- As with `ParallelSearcher`, you will need to use divide-and-conquer which means looping through the nodes when you are supposed to be parallelizing is not acceptable.
- In the sequential algorithms, you never had to *copy* the board, because only one thread needed it. In `ParallelSearcher`, you *always* needed to copy the board, because every thread needed one. Here, you get a weird in-between. You will often need to copy the board, but you should *always do it in the child, rather than the parent*. The reasoning is that if you copy in a parent thread, all of its children are waiting on the copy, but if you do it in the child, all the children can get started earlier. Note that you should avoid copying as much as possible, because it is the most expensive piece of the algorithm.
- All your recursive calls should be to `jamboree`–not `minimax`, not `parallelMinimax`–in particular, it's tempting to make the "parallel part of the recursion" be a call to your ParallelSearcher and the

"sequential part" a call to your `minimax`. This will lead to significantly worse performance and is **not** the `jamboree algorithm`.

- A good implementation of this algorithm will get to depth 6.

The games handout says "Evaluate x of the moves sequentially to get reasonable alpha/beta values" in the % sequential portion. This does not mean you should be calling AlphaBeta in % sequential. "Evaluate sequentially" means "try the first % sequential moves, one after the other, updating alpha after each one", as contrasted with "try all of the moves at the same time, with the same alpha value", which is what you do for the remaining moves.

Minimax, ParallelMinimax, AlphaBeta, and Jamboree all return the same answer (modulo tie-breaking), so whenever we want to solve the "evaluate a board using a search to a given depth" problem, we should just use whichever one of those is fastest. This fastest searcher is almost always Jamboree, but when we're below the depth cutoff inside our Jamboree, there are already a lot of threads buzzing around (and there isn't that much stuff to search in the remaining levels), so AlphaBeta is actually the faster choice in that specific situation, which is why we have the depth cutoff to begin with.

Your % sequential portion should only be hit above the depth cutoff, so you should only be constructing Jamboree tasks in the % sequential. Even if the newly created tasks end up being at the depth cutoff, they'll just hand off work to AlphaBeta immediately.

You can verify experimentally that this is the correct approach by testing both of them (it's just a one-line change). On my machine, calling alphaBeta from % sequential consistently takes around 10s for depth4, vs 5s for depth4 if I compute Jamboree tasks instead. Similarly, you can also check what happens if you ignore the sequential depth cutoff and continue calling Jamboree down to depth 0 (it causes a similar slowdown).

Playing Against Bots On The Chess Server

To play against the chess bots, you will connect to the CSE 332 Chess Server using the `EasyChess` client. We recommend playing games with your bots on the server relatively frequently, because it is a fun and interesting way to debug your code. Additionally, you can use the server to compete with other students' bots.

Commands

Command	Description
`help`	Displays a help message with all of these commands listed.
`match <name>`	Challenges `name` to a match. If `name` is one of our bots, the match will start immediately. Otherwise, the server will wait for an `accept` command.
`accept #<game>`	Accepts a challenge from another player. Once you accept, the game will start immediately.
`watch #<game>`	Allows you to watch a game currently being played. To get a list of valid games, use the `games` command.
`who`	Lists all the players currently on the chess server.
`games`	Lists all of the games currently being played
`scores <bot>`	Lists the results of the last ten games with `bot`.

The Bots

Bot Name	Description
`calculon`	You should be able to beat this bot with your `AlphaBetaSearcher`.
`clamps`	You should be able to beat this bot with a well-tuned `JamboreeSearcher`.
`flexo`	This bot is more difficult to beat than `clamps`, and you will need to go above and beyond to beat it.
`bender`	This bot is substantially more difficult to beat than `flexo`, and you will need to go significantly above and beyond to beat it.

Playing On The Server

- To have your bot play on the server, edit `Engine.java` to use the bot and parameters of your choice and then run `EasyChess`.
- You will need to log in with your teamname and password you received in your original project confirmation email from `rea@cs` referencing your gitlab repo. Your account may log in more than once, but the server will start adding numbers (e.g., `husky`, `husky1`, etc.). Additionally, your account may only play one game at a time.
- Your password is in an email you received after setting up the project (sent by rea@cs).

Using Your Algorithms to Beat Clamps, Flexo, and Bender Bots

We have designed `clamps` so that you should be able to beat him with just `JamboreeSearcher` if you have reasonable cutoffs and enough parallelism. You will probably need to increase `ply`. We will take the *very last ten games you play*, count a loss as 0, a draw as 0.5, and a win as 1; your above and beyond score on this part of the project will be the sum of these scores. **Notice that if you play 30 games against `clamps`, only the last ten you run will count.**

Beating `flexo` and `bender` will involve a substantial amount of work improving your bot. If you manage to beat `flexo` 5 times out of your last 10 games, that would be substantial. If you manage to beat `bender`, 2 times out of your last 10 games, that would be significantly substantial. Anything that goes toward these goals counts as Above and Beyond! Have fun!

Jamboree Optimization Resources

- Use "Iterative Deepening". Alpha-beta is effectively a suped-up DFS over the game graph. Because move ordering is important (as discussed below), it is often worth it to first try 1-ply, then start over and try 2-ply, etc. Keep in mind that the bulk of the graph is always at the later plys; so, this strategy doesn't redo a ton of work. Furthermore, you can use your "current guess" from the lower plys to maybe avoid large chunks of the later ones.
- Use "Move Ordering". Alpha-beta and Jamboree are very sensitive to the order that you actually look at the moves in. There are several heuristics (heuristics, because they don't always work) that often result in better ordering. Key words to look up include: "killer move heuristic", "MVV-LVA", "History Heuristic" and others: https://www.chessprogramming.org/Move_Ordering
- Use a "Transposition Table". As you explore the chess graph, you will run into the same positions many times. We solved this problem in DFS by keeping track of the nodes we'd already seen. A "transposition table" is a fancy data structure for games that does exactly this. The idea is that the number of nodes you are visiting is very large; so, instead of keeping track of everything, we keep track of the most recent nodes we've seen in a hash table. Note that we have implemented something called "Zobrist Hashing" for you to make this easier. Using this idea results in a significant speed-up. For more detail on transposition tables, check the internet.
- This article and StackOverflow post are also great resources for optimizing `JamboreeSearcher`.

Using Tokens and playing bots

You are welcome to keep playing the bots until 11:59pm on Fri, June 12 even without using a token. If you would like to update your writeup or your code in the repo then you will need to use a token. We will use whatever your score on the server is at 11:59pm Fri, June 12 both for beating clamps and any above and beyond.