Computing Science (CMPUT) 455

Search, Knowledge, and Simulations

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455 Today - Lecture 6

Today's Topics:

- Go rules revisited - more details
- Profiling Python 3 code
- Improving the performance of our Go code

Coursework and Uploads

- Quiz 3 due tonight
- Assignment 1
  - Assignment 1 was due yesterday
  - Feedback from TA via email by end of today
  - Late/second submission deadline Wednesday 11:55pm
    - 20% deduction
    - Second submission *allowed for any reason*
  - Your team's last submission counts for marking
- Activities Lecture 6
  - profiling/optimization exercises

Go Rules Revisited

Go Rules Revisited

- Goal: tidy up some loose ends regarding rules
- Popular variations in rule sets
- Scoring at end of game
- Full repetition rules

Go Rules So Far

- Introduced basic rules
- Showed examples of how to score at the end
- Implemented legal moves and reasonable policy for when to pass at the end in `Go1`
- Position repetition: implemented only simple ko

Versions of Go Rules

- There are many different versions of Go rules
- All agree on how to handle the vast majority of situations
- Differences in details related to:
  - What is a legal move?
  - When does the game end?
  - How to score the game at the end?
  - How to resolve different opinions about scoring?

Popular Go Rules

- Chinese, Japanese and Korean rules
- Ing, AGA (American Go Association), New Zealand, Tromp-Taylor rules
- Most of these again have different versions and revisions

Main Differences (1): End of Game

- When exactly is the game over?
  - Two or three passes
  - We use two

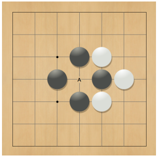
Main Differences (2): Scoring

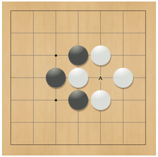
- How to score at the end?
    - Area scoring: count own stones plus surrounded empty points
    - Territory scoring: count surrounded points plus captured stones (and prisoners)
    - All rules: add komi to score
    - We use area scoring
    - Easier to implement and play correctly at the end
    - In territory scoring, playing inside your surrounded areas costs points

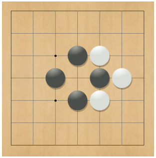
Main Differences (3): Which Moves are Legal?

- Differences regarding suicide and repetition
- Most rules forbid suicide (we do too)
  - Exceptions: e.g. Tromp-Taylor rules
- Repetition: basic ko vs full board repetition
  - Our programs only recognize basic ko

Review: Repetition Rules - Basic Ko

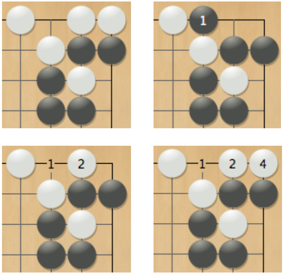






- From top to middle picture: White can capture one black stone by playing A
- From middle to bottom picture: Now if Black captures back one white stone...
- The position would repeat, infinite loop
- This is called a (basic) ko.
- Go rules forbid such repetition

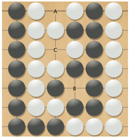
Repetition - Longer Loop

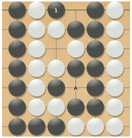


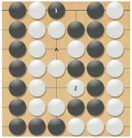
A four move loop in Go. Black passes on move 3.

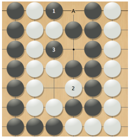
- Example of a longer repetition loop
- This really happens in games between weaker Go programs
- If White tries to play move 4 in the corner, it repeats the position from four moves ago
- If both continue like this, infinite loop
- `Go1` does not recognize or prevent such repetition

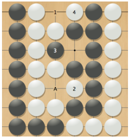
Repetition - Triple Ko

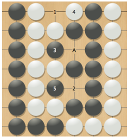


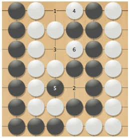












A triple ko leading to a six move long loop in Go.

Full Board Repetition

- Many rule versions forbid that the same board position is repeated in a game
- In the examples, the last, loop-closing move is illegal
- Such rules are often called *superko* rules
- They handle complex loops and situations with multiple active ko

Positional vs Situational Superko

- Superko idea: do not repeat the same board position
- What exactly is “the same”?
- Two main answers:
- Positional superko (PSK)
  - Ignore whose turn it is, only compare board
- Situational superko (SSK)
  - Compare whose turn it is as well as board
- Even more details: how do pass moves affect the repetition ban?

Detecting Superko Repetition

- Simplest but slowest:
  - Compare against all previous positions
  - Much too slow in practice
- One solution: use hashing to detect potential repetition
- Simple, effective trick (not complete solution):
  check if a move has ever been played before
- No details now, some later in search chapter

Profiling and Code Optimization

Profiling and Code Optimization

- Our `Go0` and `Go1` Python sample codes are very slow
- They were written for simplicity, not speed
- This is usually a good first approach - see quotes next slide
- Optimization is very important in search, but it can wait a bit
- We can optimize *if* and when we need it
- First, look where the time is spent
- Profiling is an easy way to check this

Go Code Now vs Then

- Note: these slides reflect my real experience from a few years ago
- At that time, we used an earlier version of our code base
- Some details are different now
- The “big picture” and the main messages are still valid

Some Famous Quotes

Fred Brooks, The Mythical Man-Month (1975)

> *The management question, therefore, is not whether to build a pilot system and throw it away. You will do that. [...]*
> *Hence plan to throw one away; you will, anyhow.*

Don Knuth, Structured Programming with go to Statements (1974)

> *We should forget about small efficiencies,*
> *say about 97% of the time:*
> *premature optimization is the root of all evil.*

Limits of Optimization

- There is often an (approximate) 80-20 rule:
  80% of the improvement can come
  from 20% of the code
- With search, it can be even higher
- However, Amdahl's law limits the amount of speedup

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Example

- Assume a program spends 80% of its time in one function
- We manage to speed this function up 100x
- Question: How much is the overall speedup?

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Example

- Assume a program spends 80% of its time in one function
- We manage to speed this function up 100x
- Question: How much is the overall speedup?
    - Less than 5x

Amdahl's Law

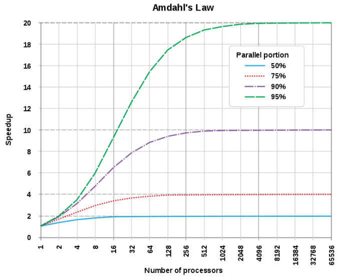

Image source:

`https://en.wikipedia.org/wiki/`

`Amdahl's_law`

- Amdahl's Law (1967)
- How does speeding up one part of program speed up the whole?
- Often used for parallel programming
- Main idea: the parts of the program that are not optimized limit the overall speedup

Amdahl's Law - Formula

- p = percentage of program that is speeded up
- s = speedup for that part
- Runtime before optimization: 1
- Runtime after optimization: $(1-p)+p/s$
- Speedup limit for the whole program:
  - limit = $\frac{\text{runtime before}}{\text{runtime after}} = \frac{1}{(1-p)+p/s}$
- Simplified version: assume s very large, then p/s is very small, ignore ...
  - limit $\approx \frac{1}{1-p}$

Amdahl's Law - Example Revisited

- 80% of program speeded up, so $p = 0.8$
- $s = 100$ speedup for the optimized function
- Speedup limit for the whole program:
  - limit = $\frac{1}{(1-p)+p/s} = \frac{1}{(1-0.8)+0.8/100} \approx 4.81$
- Simplified version:
  - limit $\approx \frac{1}{1-p} = 5$

Profiling

- Define a test that runs your program with a typical workload
- Run it with a special program called profiler
- Profiler tells you details of the program execution
- Profilers can be on the function level or instruction level
- How often was piece of code executed?
- How long did it take?
- Possibly, lower level details such as cache misses

Simple Profiling in Python with `cProfile` - Code

See code `profile_Go1.py` in directory `go0and1`

```
import cProfile
from Go1 import Go1
...
def play_moves():
    """
    play 100 random games of 100 moves each
    for profiling.
    """
    ...
cProfile.run("play_moves()")
```

Simple Profiling in Python

- See code `profile_Go1.py`
- Try it out with
- `./profile_Go1.py > profile.txt`
- `sort -k 2 -r profile.txt`
- This sorts by total time per function
- Try other options for `-k` to sort by other criteria
- Example: `sort -k 1 -r profile.txt`

Ways of Profiling in Python

- `cProfile` is a built-in module, no need to install anything
- Downside: overhead of profiling is also measured
- More advanced profilers are available for download:
  - `Profilehooks`
  - `pycallgraph`

  See profiling on our Python language page

Speeding Up `Go1`

- `Go1` is slow
- For search and simulation, speed is very important
- How to improve the code?
- Both low-level optimizations and better algorithms help
- Case study: a series of improvements to `Go1`
  - Result: `Go2` - same algorithm as `Go1` but faster

An Iterative Optimization Procedure

- First, pick a test to measure the speed
- Here: play 100 games on 7×7 board
- Repeat:
  - Run test games with profiler
  - Identify the most expensive functions
  - Try to improve them by optimization or better algorithms

Profiling `Go1`

- Profile with `cProfile`
- Total time: 6.2 seconds
- Worst 5 individual functions listed below (all in `board.py`)

Calls	Time	Name
561025	1.960	neighbors_of_color
2287541	0.680	get_color
610480	0.679	_neighbors
43441	0.662	_block_of
18268	0.405	play_move

Profiling `Go1`

- Also look at cumulative time
- Function itself plus other functions it calls
- Sort by column 4:
  `sort -k 4 -r profile.txt`
- Some interesting functions listed below
  (all in `board.py`)

Calls	Cumulative Time	Name
10974	4.429	is_legal
25584	3.566	_detect_and_process_capture
43441	3.368	_block_of
561025	3.351	neighbors_of_color
43441	1.359	_has_liberty

Strategies for Optimization

- Best: avoid calling a function
- Second best: speed up a function, avoid unneeded computation
- Here: detecting captures is most expensive

Read the Code

- Start by reading the expensive code carefully
- Can we avoid unneeded computation?
- Here: read `_has_liberty`, `neighbors_of_color`

```
def _has_liberty(self, block):
    for stone in where1d(block):
        empty_nbs = self.neighbors_of_color(
                        stone, EMPTY)
        if empty_nbs:
            return True
    return False
```

Read the Code

```
def neighbors_of_color(self, point, color):
    nbc = []
    for nb in self._neighbors(point):
        if self.get_color(nb) == color:
            nbc.append(nb)
    return nbc
```

- We do not need to compute the whole list
- Stop if we find one liberty
- `neighbors_of_color` is still used in other places
- Add a function that is optimized for our task

New Version

```
def find_neighbor_of_color(self, point, color):
    for nb in self._neighbors(point):
        if self.get_color(nb) == color:
            return nb
    return None

def _has_liberty(self, block):
    for stone in where1d(block):
        if self.find_neighbor_of_color(stone, EMPTY
            return True
    return False
```

Profiling Again

- Total time reduced from 6.2 to 6 seconds
- Reduction in `_has_liberty` by calling cheaper `find_neighbor_of_color` instead of `neighbors_of_color`
- Nice improvement for a little work, but not a huge win
- Can we avoid the many floodfills altogether?
- We do the floodfill for each neighbor of a stone
- We only need to know "does block have at least one liberty"?
- Can we check that more effectively?

Optimizing Floodfill

- We can store such a liberty for each stone `s`
- In the code: `liberty_of[s]`
- Check capture: just check if board at location `liberty_of[s]` is still empty
- If yes, no floodfill is needed (why?)
- If no, we just played there
  - Do floodfill to try to find a *different* liberty for `s`
  - If success: update `liberty_of[s]`
  - If fail: yes it is a capture

Result, and More Floodfill Optimization

- Total time reduced from 6 to 4.4 seconds
- Success!
- Next: try to reduce calls to expensive floodfill functions
- Idea: instead of always computing a block:
- First check the 4 neighbors of the stone if there is a liberty there
- Result: Total time reduced from 4.4 to 3.7 seconds
- Cost: more complex code, adds special case

Profiling Again

Calls	Time	Name
66323	0.669	find_neighbor_of_color
18645	0.396	play_move
32369	0.367	_is_surrounded
264389	0.321	_neighbors
147455	0.294	neighbors_of_color
828018	0.257	get_color

Profiling Again

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Optimizing Neighbors, First Try

```
def _neighbors(self, point):
    return [point-1, point+1,
            point-self.NS, point+self.NS]
```

- Called often: compute list of neighbors of a point
- Each call creates a new list
- Some neighbors are off the board (state `BORDER`), causing more tests in code
- Precompute a `neighbors` array for each point
- Include only on-board neighbors
- Result: EPIC FAIL, runtime over 11 seconds
- Why? board is copied and neighbors array recomputed over 11000 times

Optimizing is_legal

```
def is_legal(self, point, color):
    board_copy = self.copy()
    legal = board_copy.play_move(point, color)
    return legal
```

- This function is the reason for FAIL with previous optimization
- Slow: copy the board, then try to play the candidate move to see if it is legal
- Solution: Implement `is_legal` without `play_move`
- Success! Total time reduced from 4.4 to 2.5 seconds
- Cost: increased code complexity, some redundancy in `is_legal` and `play_move`

Details

Calls	Time	Name
51038	0.528	find_neighbor_of_color
75984	0.288	neighbors_of_color
21163	0.227	_is_surrounded
166427	0.207	_neighbors
495786	0.181	get_color
7418	0.145	play_move
{prev: 18645	0.396	play_move}

- `play_move` calls: less than half as many
- Many other function calls also significantly reduced

Optimizing Neighbors, Second Try

- Now we are no longer copying the board at each legal move check
- Now the neighbors optimization works beautifully
- Result: Total time reduced from 2.5 to 2 seconds
- Success!
- There are more opportunities to optimize but Martin stopped here

Summary (1)

- Discussed profiling and optimization
- Some concrete case studies
- Overall about 3x faster now, from 6 to 2 seconds on test
- Strategies:
  - Save computation
  - Precompute
  - Compute data incrementally when there are only small changes
  - Catch and handle frequent simple cases early

Summary (2)

- Very few optimizations are win-win. The speed often comes at the cost of code complexity
- Remember Knuth:
  premature optimization is the root of all evil