<Master-Minds />

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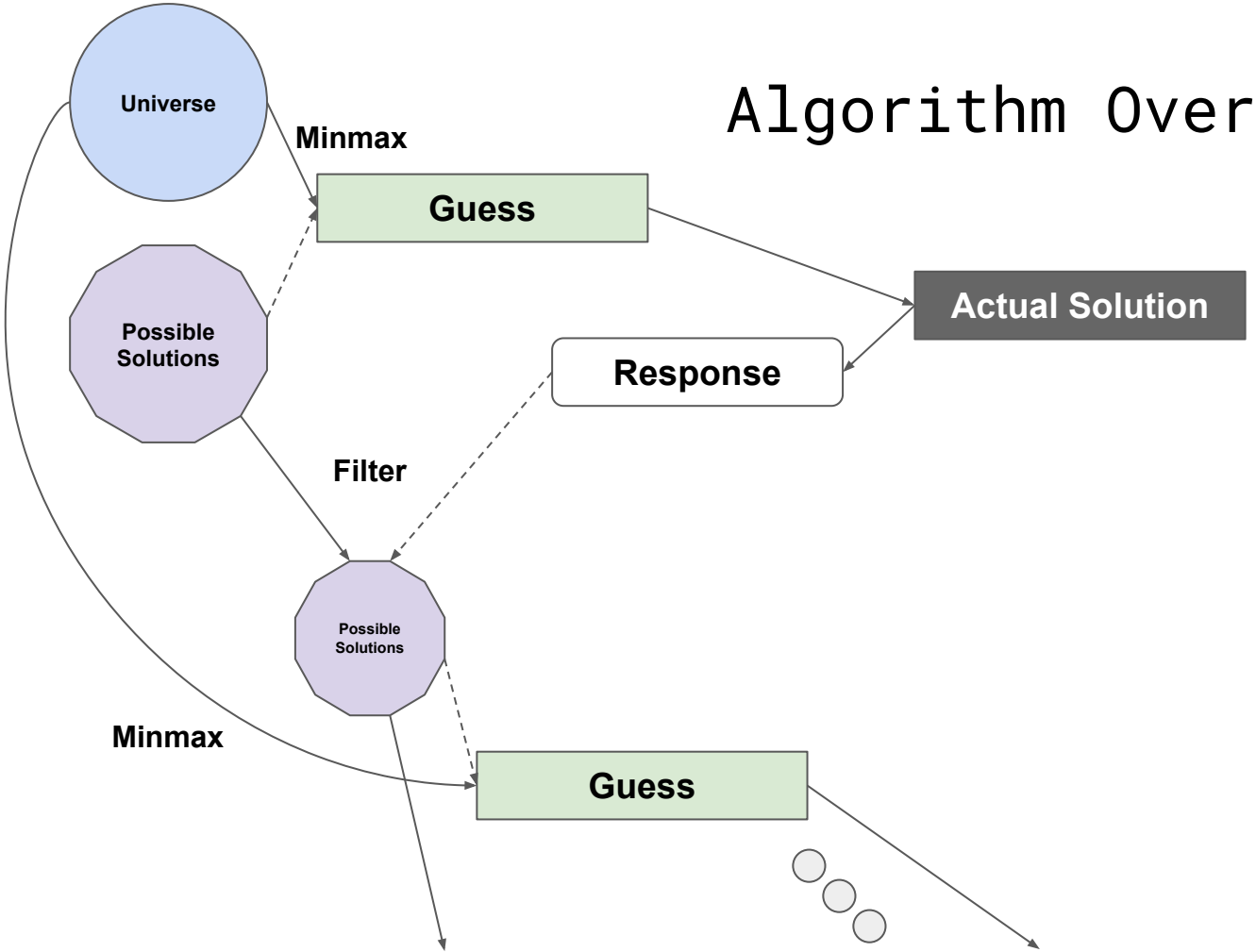
What the hack is it?

- Code: Combinations of Pegs
- Numbers of Colors = S
- Numbers of Holes = n
- S^n - 6 Colors with 4 Holes = 6^4
- Response?
  - # of Same Order & Color = # of Black
  - # of Same Color = # of White
- Key to solve the mystery?
  - Start with a good initial guess
  - **Filter** all possible codes (How?)
  - Using **MinMax** algorithm to find the possible best worst case(What & How?)
  - Repeat until solved!

Algorithm Overview



Filter all possible codes?

- Filter all the code that are impossible to be the Correct Code
- E.g.
  - Guess: 1122; Response: BB
  - Filter 1234? True! If 1234 is the code, then it will give us BW instead of BB
  - Filter 1134? False! If 1134 is the code, it indeed give us BB

- Fun Fact: for four-holes game, it is impossible to have 3B1W

MinMax Algorithm?

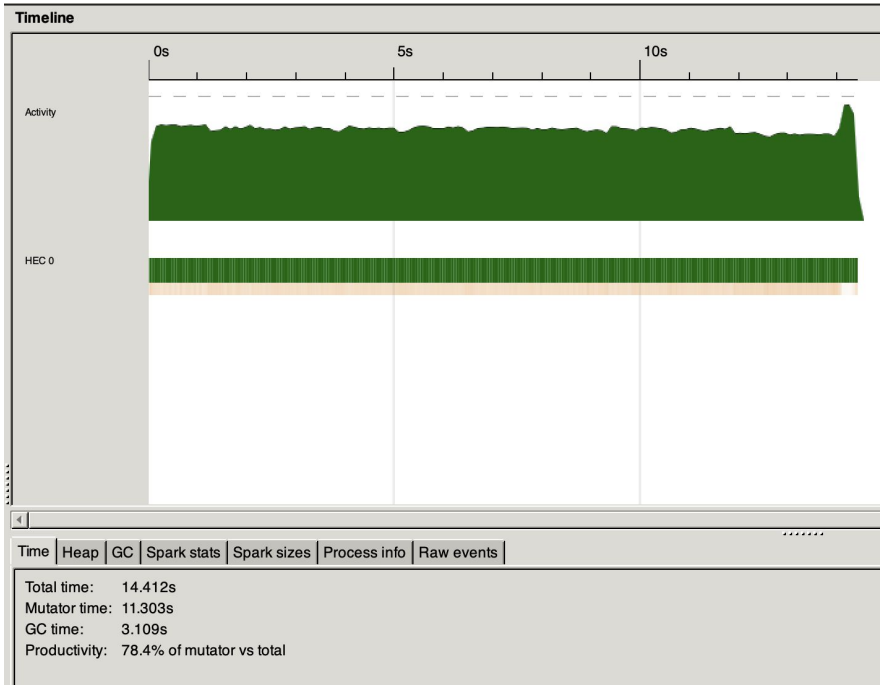
1. Consider the codes in the universe of codes for this game configuration. Call each a candidate code.
2. ***Assign each candidate code a score*** – this score is the worst-case maximum number of remaining possible solutions after this guess
3. Select as our next guess the candidate code with the lowest score. If there is a tie, prefer a code which is a possible solution. Pick the numerically lowest as a final tiebreaker.

“Assign each candidate code a score”

This score can be calculated by determining the response the candidate would get should each possible solution was the actual solution. Find which response appears most often and how many times.

1. Example 1:
    a. Remaining possible solutions: [3322, 1112, 2111]
    b. Candidate code: 1211
    c. Responses: [0B1W, 2B1W, 2B1W]
    d. Score: 2
    e. 2B1W occurs twice; if we select 1211 as our guess and the response is 2B1W, then there will be two possible solutions still (1112, 2111)
2. Example 2:
    a. Remaining possible solutions: [3322, 1112, 2111]
    b. Candidate code: 3112
    c. Responses: [2B0W, 3B0W, 2B1W]
    d. Score: 1
    e. Each response occurs only once; if we select 3112 as our guess then whatever response we receive, there will only be one possible solution — we have solved the game!

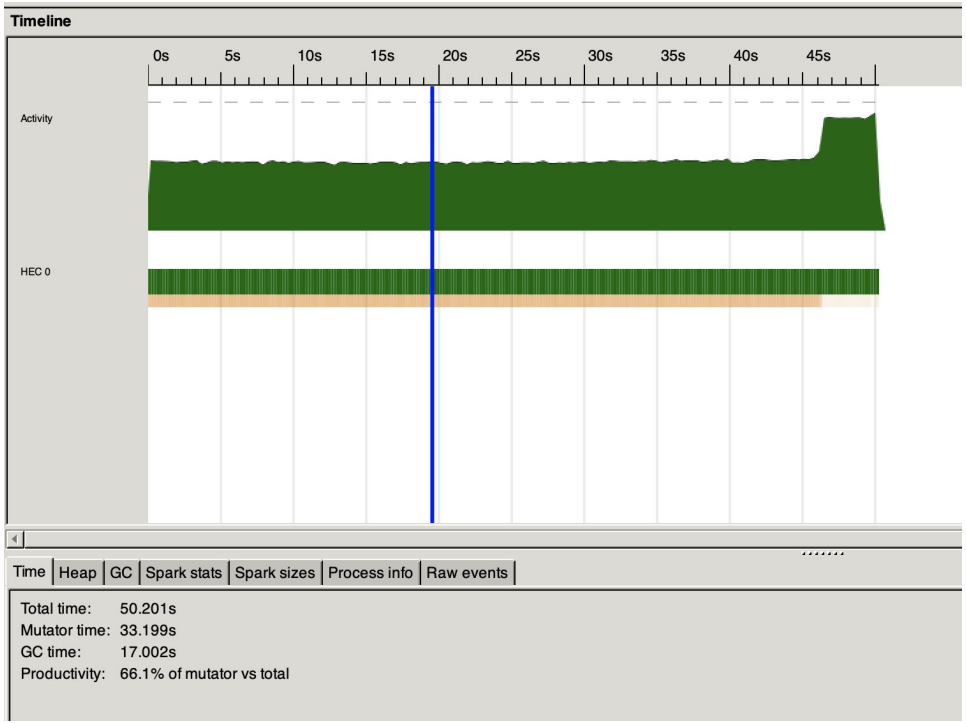
Before Parallelization (10C4H)



- Code: 2613
- Initial Guess: 1111
- 2018 mpb with 8 threads
- Compiler Options
  - threaded
  - Rtsopts
  - N8

- Nothing to surprise

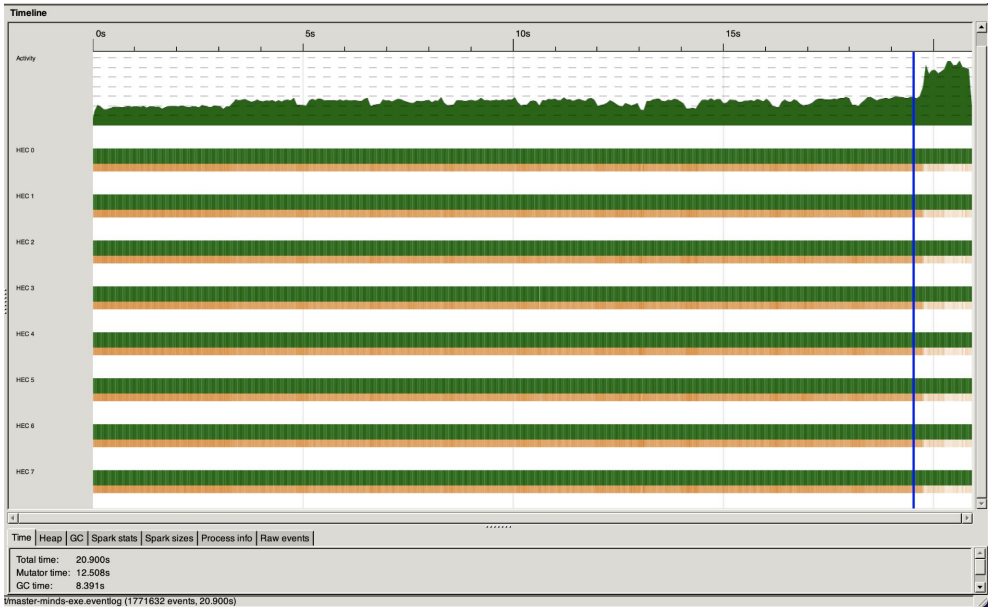
Before Parallelization (10C4H)



- Code: 8765
- Initial Guess: 1111
- 2018 mpb with 8 threads
- Compiler Options
  - threaded
  - Rtsopts
  - N8

- **Highly Depending on the Initial Guess and The Code !!**

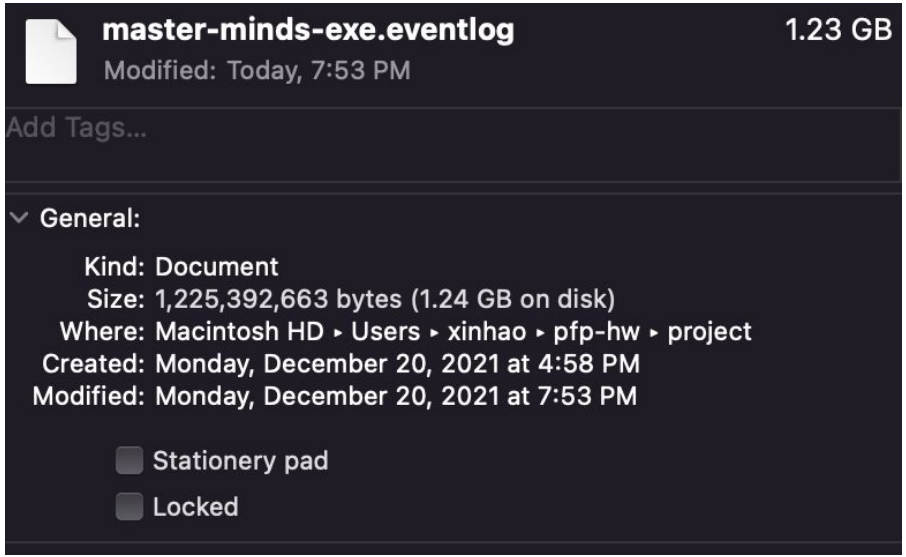
First parMap Attempt (10C4H)



- Code: 8765
- Initial Guess: 1111
- 2018 mpb with 8 threads
- Compiler Options
  - threaded
  - Rtsopts
  - N8

- **2.5X improvements**
- **Something wrong with the Huge Bump**

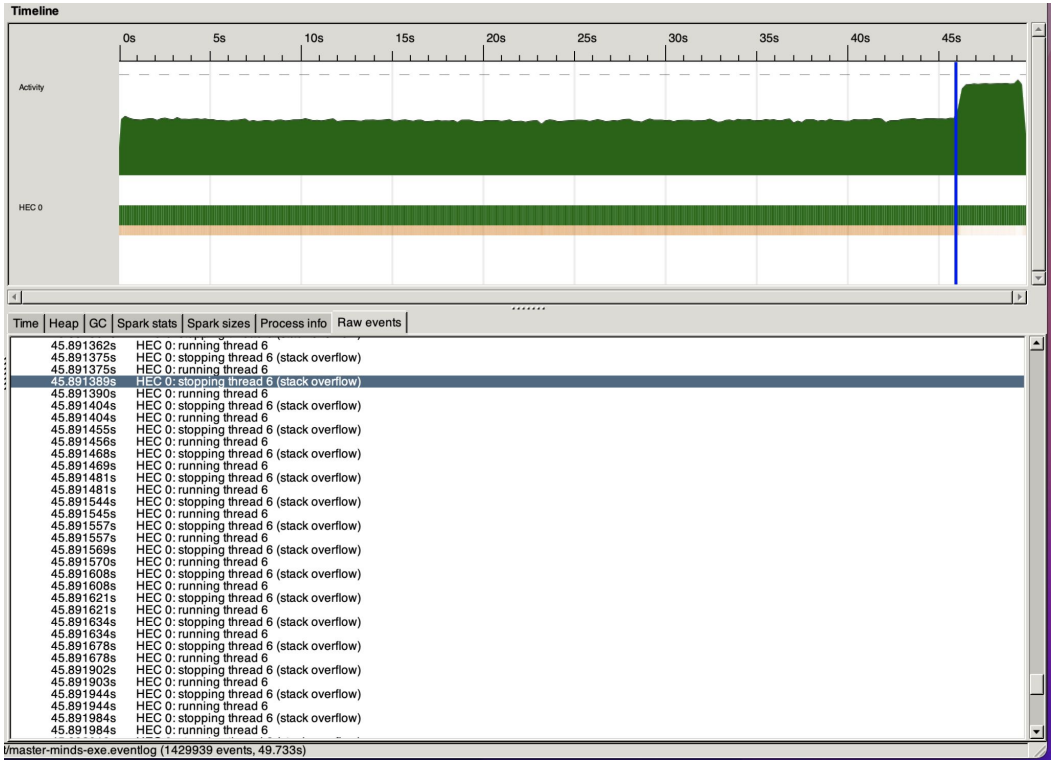
Second parMap Attempt (10C4H)



- Code: 8765
- Initial Guess: 1111
- 2018 mpb with 8 threads
- Compiler Options
  - threaded
  - Rtsopts
  - N8
- Add parMap in the inner Loop

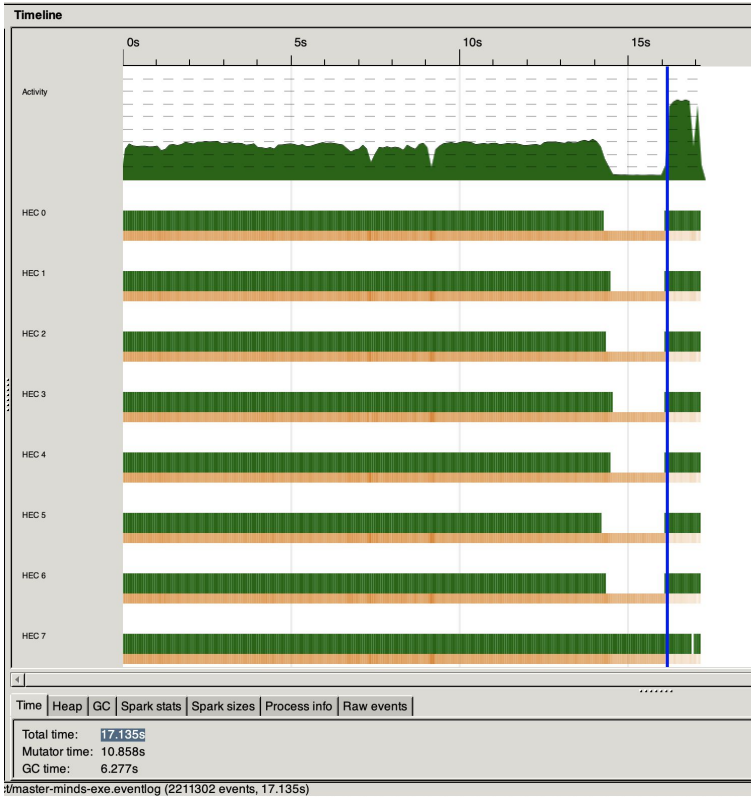
- **Much more slower**
- **Lesson Learned: Be careful of the # jobs created**

Closer Examination on the First Attempt



- Encounter Same issues in the N1
- Raw Events indicate huge numbers of stack overflow
- **Root Cause**: stack overflow make the program on and off repeatedly
- **-> Extremely Low Efficiency**

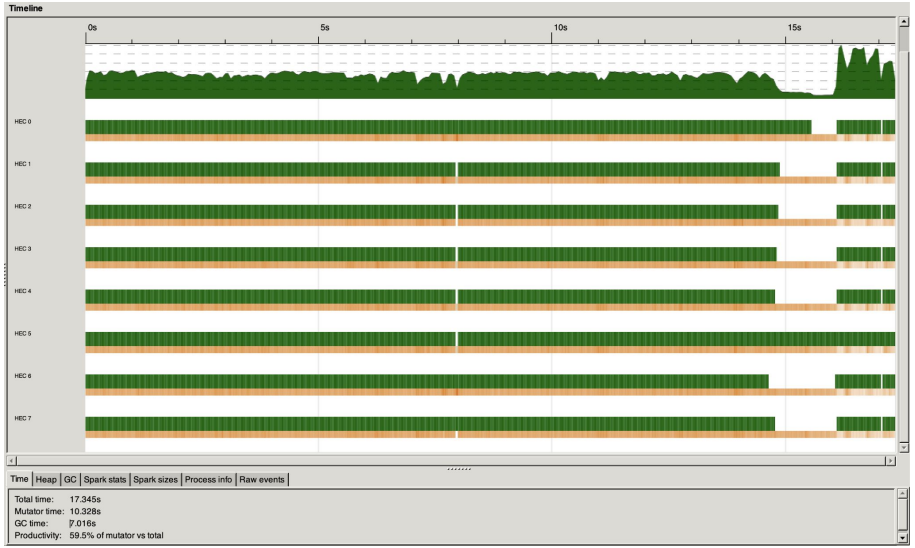
First Chunked Strategy Attempt (10C4H)



- Code: 8765
- Initial Guess: 1111
- 2018 mpb with 8 threads
- Compiler Options
  - threaded
  - Rtsopts
  - N8
- Split work into 32 chunks

- **Great Performance (15% faster than parMap attempt)**
- **Some Load Balancing Issues**

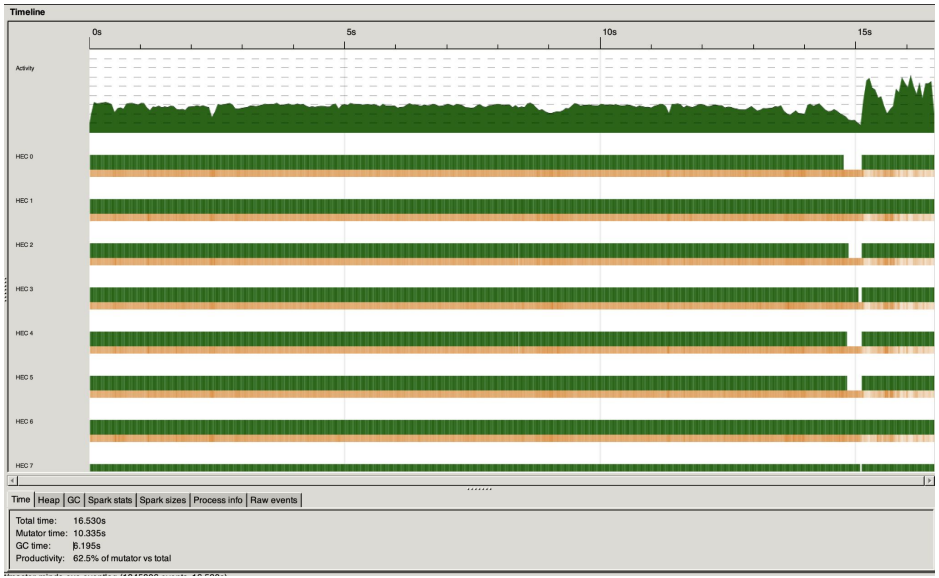
Second Chunked Strategy Attempt (10C4H)



- Code: 8765
- Initial Guess: 1111
- 2018 mpb with 8 threads
- Compiler Options
  - threaded
  - Rtsopts
  - N8
- Split work into 64 chunks

- **Great Performance (15% faster than parMap attempt)**
- **Slightly Better Load Balancing**

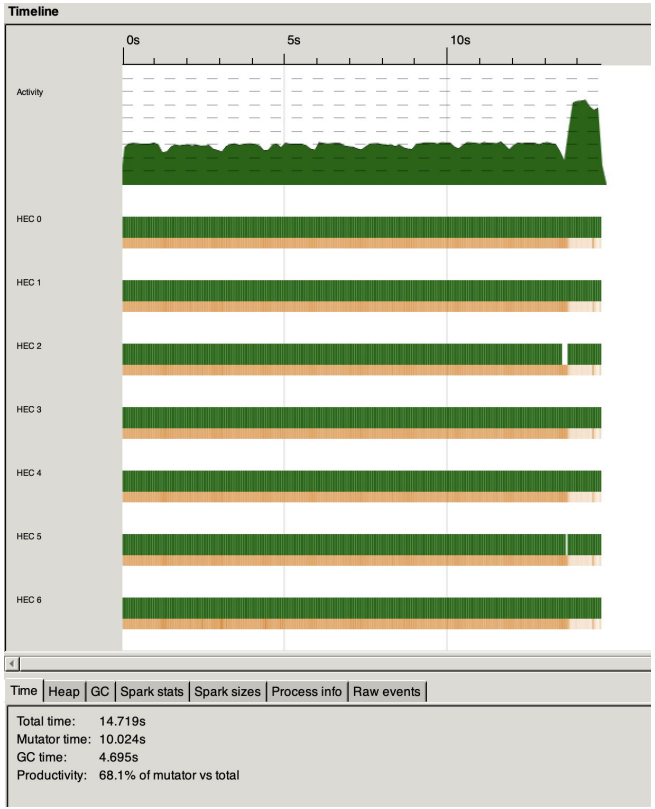
Third Chunked Strategy Attempt (10C4H)



- Code: 8765
- Initial Guess: 1111
- 2018 mpb with 8 threads
- Compiler Options
  - threaded
  - Rtsopts
  - N8
- Split work into 256 chunks

- **Much Better Load Balancing!**
- **Stack Overflow Issues Relief!!**

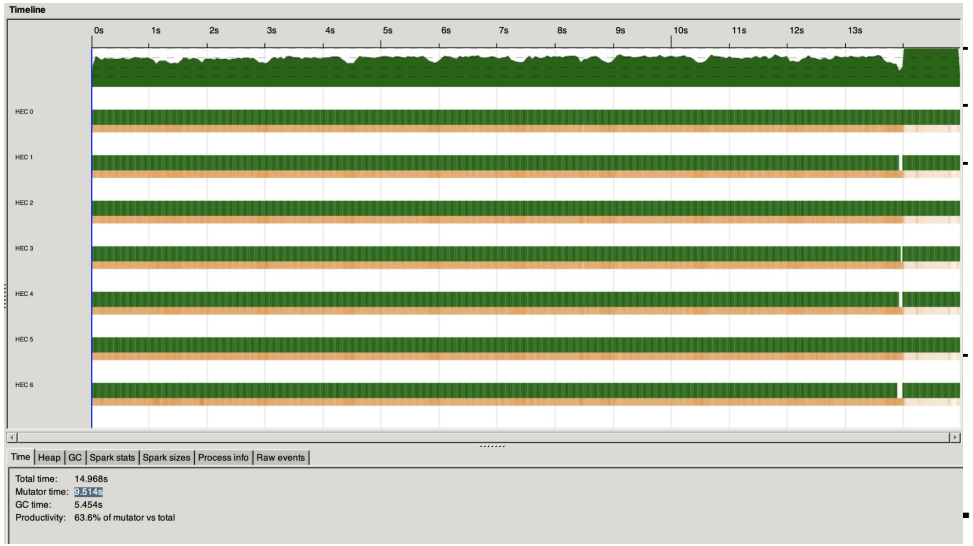
Fourth Chunked Strategy Attempt (10C4H)



- Code: 8765
- Initial Guess: 1111
- 2018 mpb with 8 threads
- Compiler Options
  - threaded
  - Rtsopts
  - N8
- Split work into 512 chunks

- **Still Getting Performance Boost**
- **Slight Worse Stack Overflow**

Fifth Chunked Strategy Attempt (10C4H)



- Code: 8765
- Initial Guess: 1111
- 2018 mpb with 8 threads
- Compiler Options
  - threaded
  - Rtsopts
  - N8
- Split work into 1024 chunks

- **No Incentives to increase the chunks anymore**

References

The Computer as Master Mind (Donald Knuth; https://www.cs.uni.edu/~wallingf/teaching/cs3530/resources/knuth-mastermind.pdf)

Appendix A: Why search the universe?

Remaining codes: [2212, 4212, 5212, 6212]

Candidate: 4222

Responses: [2B1W, 3B0W, 2B0W, 2B0W]

Score: 2

If pick any from the possibilities set:

Responses: combination([4B0W, 3B0W, 3B0W, 3B0W])

Score: 3