Being Lazy

Peter Marks and Ben Moseley

Goals

- Understand the functional paradigm, lazy evaluation and Monadic IO
- Learn some key Haskell idioms and style tips
- Experience software development in Haskell

Not…

- Haskell tutorial
- Demo of maths functions
- Sales pitch… though we are passionate

Overview

- Introduction
- Code scenarios
- Issues and pitfalls

- Break

- Live coding
- Wrap up

The power of Haskell

- Purity
- Type system
- Laziness

- Rich syntax
- Sophisticated optimizer
- Extensible

- Extensive abstract libraries

Barriers to learning Haskell

- Purity
- Type system
- Laziness

- Rich syntax
- Sophisticated optimizer
- Extensible

- Extensive abstract libraries

Haskell

A lazily evaluated, pure functional language

Lazy evaluation

```
max(x + 5, y + 5)

(x + 5) * (y + 5)
```

(Not Haskell)

Lazy evaluation

```
(x != 0) && (y / x > 0)
```

(Not Haskell)

Lazy evaluation

```
foo x z = if x /= 0
             then (z > 0)
             else False
```

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foo x (y `div` x)
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Lazy evaluation

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foo x (y `div` x)
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```
foo x (div y x)
```

Lazy evaluation

Can define your own control structures:

```
bool :: a -> a -> Bool -> a
bool t _ True  = t
bool _ f False = f
```

...replaces some uses of macros

```
contents <- bool
               readFile
               (throwError . ("Can't read:"++))
               isAdministrator file
```

Lazy evaluation

```
[42, 27, head [], 3]
```

Lazy evaluation

```
[42, 27, head [], 3] !! 3
```

Lazy evaluation

```
[42, 27, head [], 3] !! 3
```

```
allSame xs = all (== head xs) xs
```

Lazy evaluation

```
doubling a =
  a : doubling (a * 2)

take 9 $ doubling 3

[3,6,12,24,48,96,192,384,
768]
```

Code scenarios

Opportunities to be lazy

Names and numbers

Given a list of names print each one with its index in the list.

Q: How would you do this imperatively?
Q: How would you do this functionally?

Names and numbers

```
names = ["Fred","Jim","Bob"]

report ns = rep 1 ns
  where
    rep _ [] = []
    rep i (n:ns) = (printf "Name %d is %s." i n) :
                   (rep (i+1) ns)
```

Infinite data structure

```
names = ["Fred","Jim","Bob"]

zipWith (printf "Name %d is %s.")
  [1..length names]
  names
```

```
["Name 1 is Fred.", "Name 2 is Jim.", "Name 3 is
  Bob."]
```

Infinite data structure

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zipWith (printf "Name %d is %s.")
   [1..length names]
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["Name 1 is Fred.", "Name 2 is Jim.", "Name 3 is
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zipWith (printf "Name %d is %s.") [1..] names
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Infinite data structure

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```

```
["Name 1 is Fred.", "Name 2 is Jim.", "Name 3 is
  Bob."]
```

```
zipWith (printf "Name %d is %s.") [1..] names
```

Q: Why is using an infinite list better?

Top 50

Find the top 50 elements of a 50000 list.

Q: What is the obvious way to do this?
Q: Would there be any issues with that approach?

Avoid unnecessary work

```
qsort []     = []
qsort (x:xs) = qsort (filter (> x) xs) ++
               [x] ++
               qsort (filter (<= x) xs)
```

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top50 = take 50 . qsort
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top50 = take 50 . qsort

vals <- take 50000 . randoms <$> newStdGen
```

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qsort vals -- Takes 0.50s in GHCi
```

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               [x] ++
               qsort (filter (<= x) xs)

top50 = take 50 . qsort

vals <- take 50000 . randoms <$> newStdGen

qsort vals -- Takes 0.50s in GHCi
top50 vals -- Takes 0.14s in GHCi
```

Recursive definitions

- Recursive function:

```
len xs = case xs of
           [] -> 0
           _  -> 1 + len (tail xs)
```

Recursive definitions

- Cyclic values:

```
ones         = 1 : ones
```

Recursive definitions

- Cyclic values:

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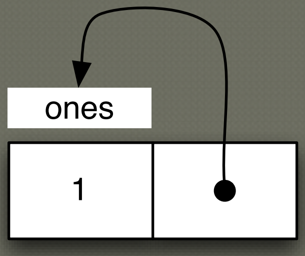

Recursive definitions

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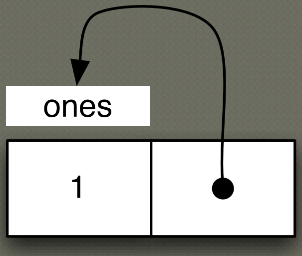
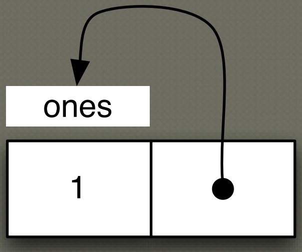


```
ones       = 1 : ones

alternates = 1 : 0 : alternates
```

Recursive definitions

- Cyclic values:



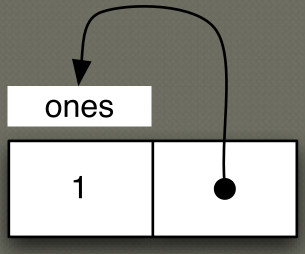
```
ones        = 1 : ones

alternates = 1 : 0 : alternates

months = "Jan" : "Feb" : "Mar" : "Apr"
       : "May" : "Jun" : "Jul" : "Aug"
       : "Sep" : "Oct" : "Nov" : "Dec"
       :  months
```

Recursive definitions

- Cyclic values:



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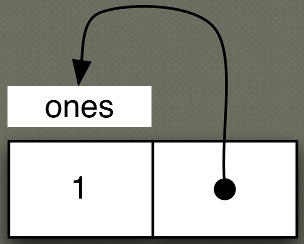
nMonthsAfter m n =
  dropWhile (/=m) months !! n
```

Recursive definitions

- Cyclic values:



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months = "Jan" : "Feb" : "Mar" : "Apr"
       : "May" : "Jun" : "Jul" : "Aug"
       : "Sep" : "Oct" : "Nov" : "Dec"
       :  months

nMonthsAfter m n =
  dropWhile (/=m) months !! n

nMonthsAfter "May" 25 ----> "Jun"
```

Tom and Jerry

Define two types:
– Cat has a name and a victim (Mouse).
– Mouse has a name and a tormentor (Cat).

Create instances:
– Cat: Tom whose victim is Jerry.
– Mouse: Jerry whose tormentor is Tom.

Q: How would you do this imperatively?
Q: Could laziness help?

Cyclic graph

```
data Cat = Cat {
        cname  :: String
        victim :: Mouse
      }
      deriving Show

data Mouse = Mouse {
        mname     :: String
        tormentor :: Cat
      }
      deriving Show
```

Cyclic graph

```
data Cat = Cat {
          cname  :: String
          victim :: Mouse
        }
        deriving Show

data Mouse = Mouse {
          mname     :: String
          tormentor :: Cat
        }
        deriving Show

tom   = Cat   {cname = "Tom",   victim    = jerry}
jerry = Mouse {mname = "Jerry", tormentor = tom}
```

Powers of 2

Define an infinite list of the powers of 2 using a cyclic definition

Q: How would you do this?

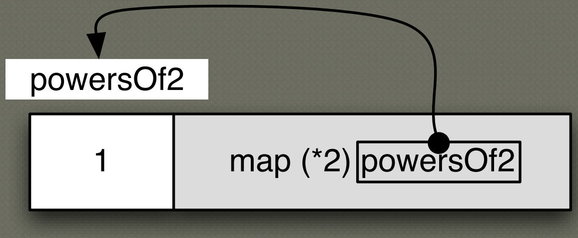
Cyclic definition

```
powersOf2 = 1 : map (* 2) powersOf2
```

```
[1,2,4,8,16,32,64,128,256,512,1024,20
48,4096,8192,16384,32768,65536,131072
,262144,524288...
```

Cyclic definition

```
powersOf2 = 1 : map (* 2) powersOf2
```



Cyclic definition

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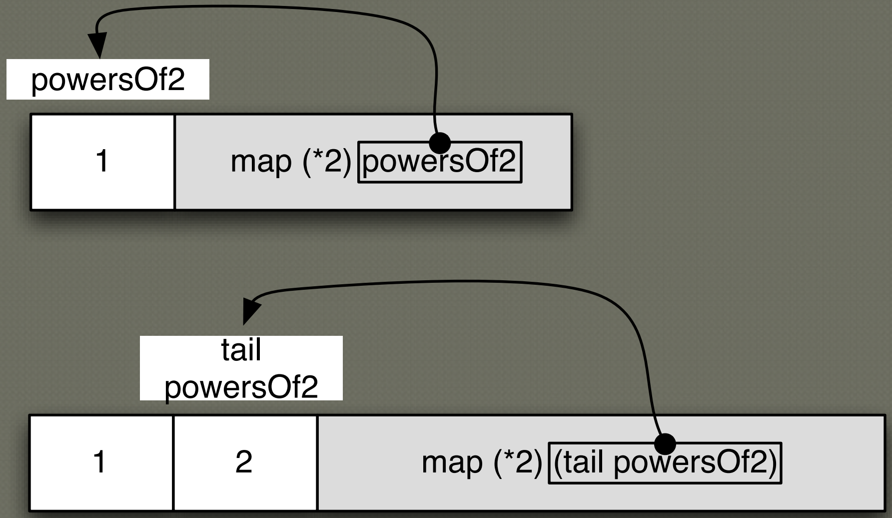
```



Cyclic definition

```
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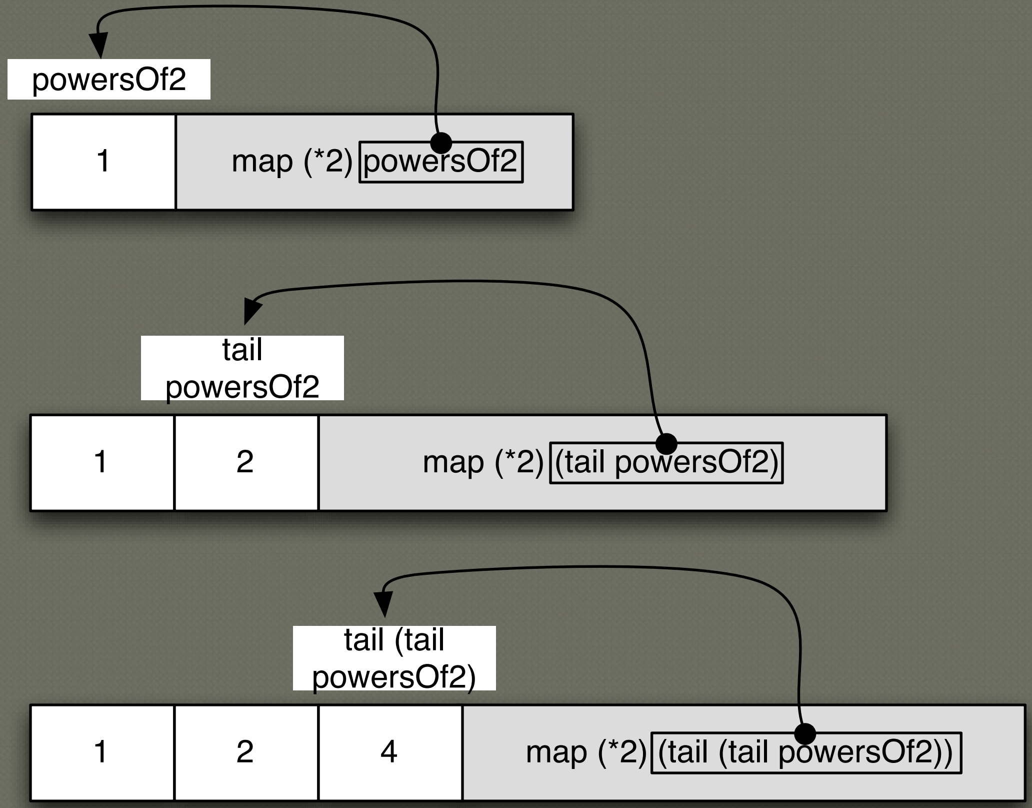
```



Memoization

Fibonnaci numbers are:

```
[1,1,2,3,5,8,13,21,34,55,89,14
 4,233,377,610,987,1597,2584,4
 181,6765...
```

Q: How would find the ‘nth’ one?

Memoization

Q: How would you do this in Haskell?

```
fib 0 = 1
fib 1 = 1
fib n = fib (n-1) + fib (n-2)
```

Memoization

Q: How would you do this in Haskell?

```
fib 0 = 1
fib 1 = 1
fib n = fib (n-1) + fib (n-2)
```

fib 30 takes about 4.3s
fib 40 will probably take about an hour...

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fib 0 = 1
fib 1 = 1
fib n = fib (n-1) + fib (n-2)
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fib 30 takes about 4.3s
fib 40 will probably take about an hour...

```
fib' n = fibs !! n
  where
    fibs = 1 : 1 : zipWith (+) fibs (tail fibs)
```

Memoization

Q: How would you do this in Haskell?

```
fib 0 = 1
fib 1 = 1
fib n = fib (n-1) + fib (n-2)
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fib 30 takes about 4.3s
fib 40 will probably take about an hour...

```
fib' n = fibs !! n
  where
    fibs = 1 : 1 : zipWith (+) fibs (tail fibs)
```

...fib’ 4000 takes 0.01s according to GHCi:

```
645748844909481735313769490153695956444139006401513427084075775981772103
590340889144494778072872417437607415237838188974992270097421831524820190
627635507987437042751068564702163075936230573885067767672020696704775060
888952943005092911660239478668417638539538139822817039366653699227090953
080068213995247807210499558291914070299436220877792964591740126101486595
203811704525911413319493360805771417086457836066360819419152173551158109
939739457834939838445927496726613615480616157565958189443176199220973699
176769740582063418920881445493379744229521401326215683407010162734227278
277627261530663030930529820517574447424280331075224194662196557804131017
595052316172225782924860810023912187851892996757577669202694023487336446
627257747177409240688283001864394259217610825454631646288077026537526196
161573244340403420573366832792840985908015O1
```

Reverse lines

Read lines from a large file, reverse the characters of each line and write the result to a new file.

Q: How would you do this imperatively?

IO loop

```
main = do
  i <- openFile "input"  ReadMode
  o <- openFile "output" WriteMode
  untilM_ (hIsEOF i) $ do
    l <- hGetLine i
    hPutStrLn o (reverse l)
  hClose i
  hClose o
```

IO loop

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  i <- openFile "input"  ReadMode
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  untilM_ (hIsEOF i) $ do
    l <- hGetLine i
    hPutStrLn o (reverse l)
  hClose i
  hClose o
```

Q: How could you do it more elegantly?

Lazy IO

```
main = do
  i <- readFile  "input"
  let o = unlines . map reverse . lines $ i
  writeFile "output" o
```

Code is simpler...

Lazy IO

```
main = do
  i <- readFile  "input"
  let o = unlines . map reverse . lines $ i
  writeFile "output" o
```

Code is simpler... and still scalable.

Lazy IO

```
main = do
  i <- readFile  "input"
  let o = unlines . map reverse . lines $ i
  writeFile "output" o
```

Code is simpler... and still scalable.

```
main = interact
          (unlines . map reverse . lines)
```

...if just want stdin / stdout, the above is even simpler

Pitfalls

- Debugging
- Lazy IO gotchas – eg file handles
- Performance
  - Harder to understand / predict
  - Benchmarking
  - Performance cost to creating thunks
  - Space Leaks
  - Too much laziness
  - Too little laziness

Pitfalls

```
foldl (+) 0 [1..100000]
5000050000
       8,216,376 bytes copied during GC
       1,706,916 bytes maximum residency (4 sample(s))
  %GC time      64.3%  (61.7% elapsed)
```

Pitfalls

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foldl (+) 0 [1..100000]
5000050000
       8,216,376 bytes copied during GC
       1,706,916 bytes maximum residency (4 sample(s))
  %GC time      64.3%  (61.7% elapsed)


foldl' (+) 0 [1..100000]
5000050000
           4,180 bytes copied during GC
           3,732 bytes maximum residency (1 sample(s))
  %GC time       2.2%  (2.8% elapsed)
```

Pitfalls

`foldl (+) 0 [1..100000]`
```
5000050000
       8,216,376 bytes copied during GC
       1,706,916 bytes maximum residency (4 sample(s))
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```

`foldl' (+) 0 [1..100000]`
```
5000050000
           4,180 bytes copied during GC
           3,732 bytes maximum residency (1 sample(s))
  %GC time        2.2%  (2.8% elapsed)
```

`foldl (+) 0 [1..100000]` **-O2** *(this is strictness analysis)*
```
5000050000
           4,152 bytes copied during GC
           3,716 bytes maximum residency (1 sample(s))
  %GC time        2.3%  (3.1% elapsed)
```

Pitfalls

- `f = ("Report\n"++) . unlines . map show`

Pitfalls

- `f = (“Report\n”++) . unlines . map show`

- `if length xs >= 0 then f (tail xs) else f xs`

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- `if not (null xs) then f (tail xs) else f xs`

Pitfalls

- `f = (“Report\n”++) . unlines . map show`
- `if length xs >= 0 then f (tail xs) else f xs`
- `if not (null xs) then f (tail xs) else f xs`
- `f (if not (null xs) then tail xs else xs)`

Break

Live coding

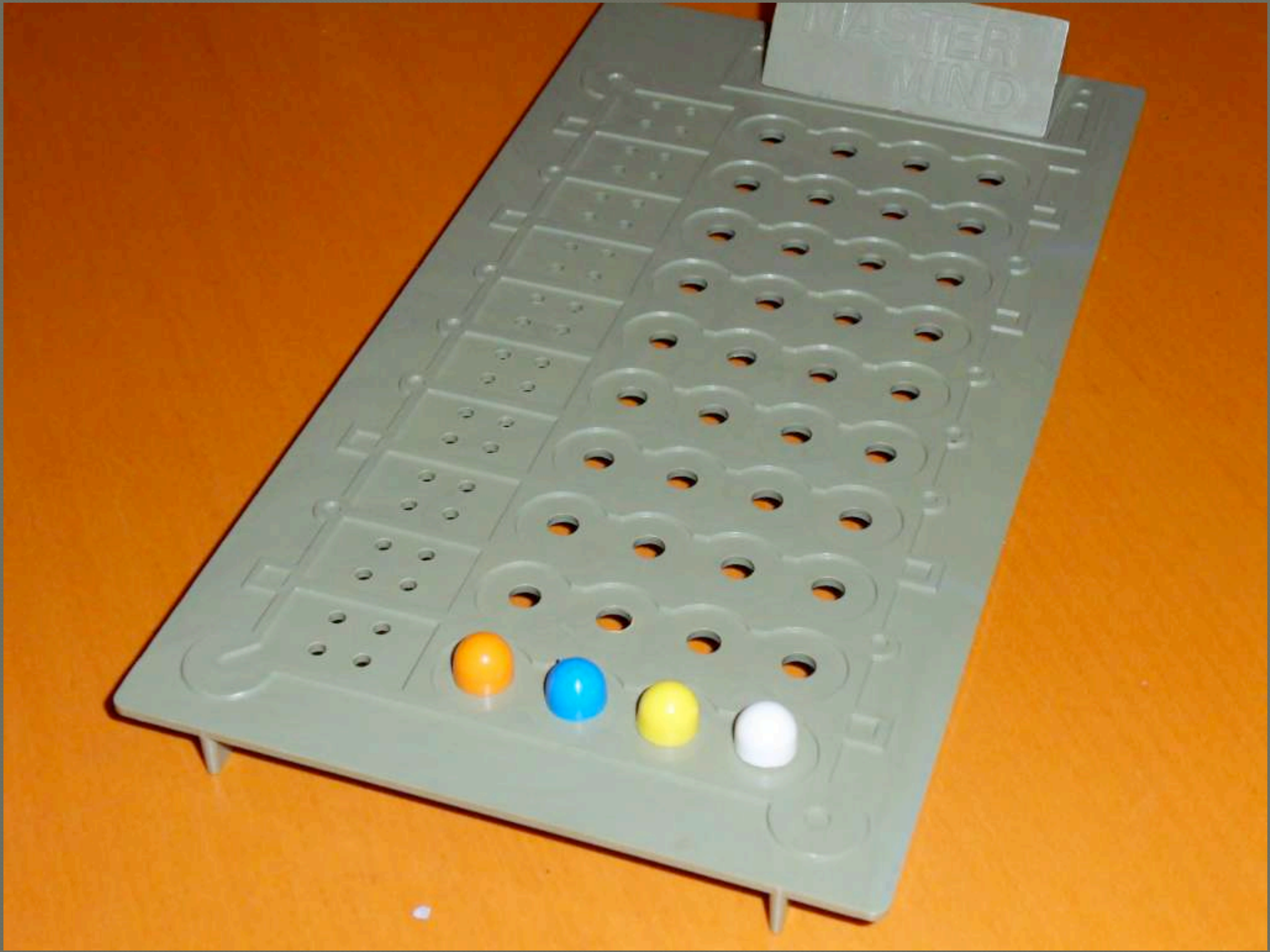
A larger example of laziness

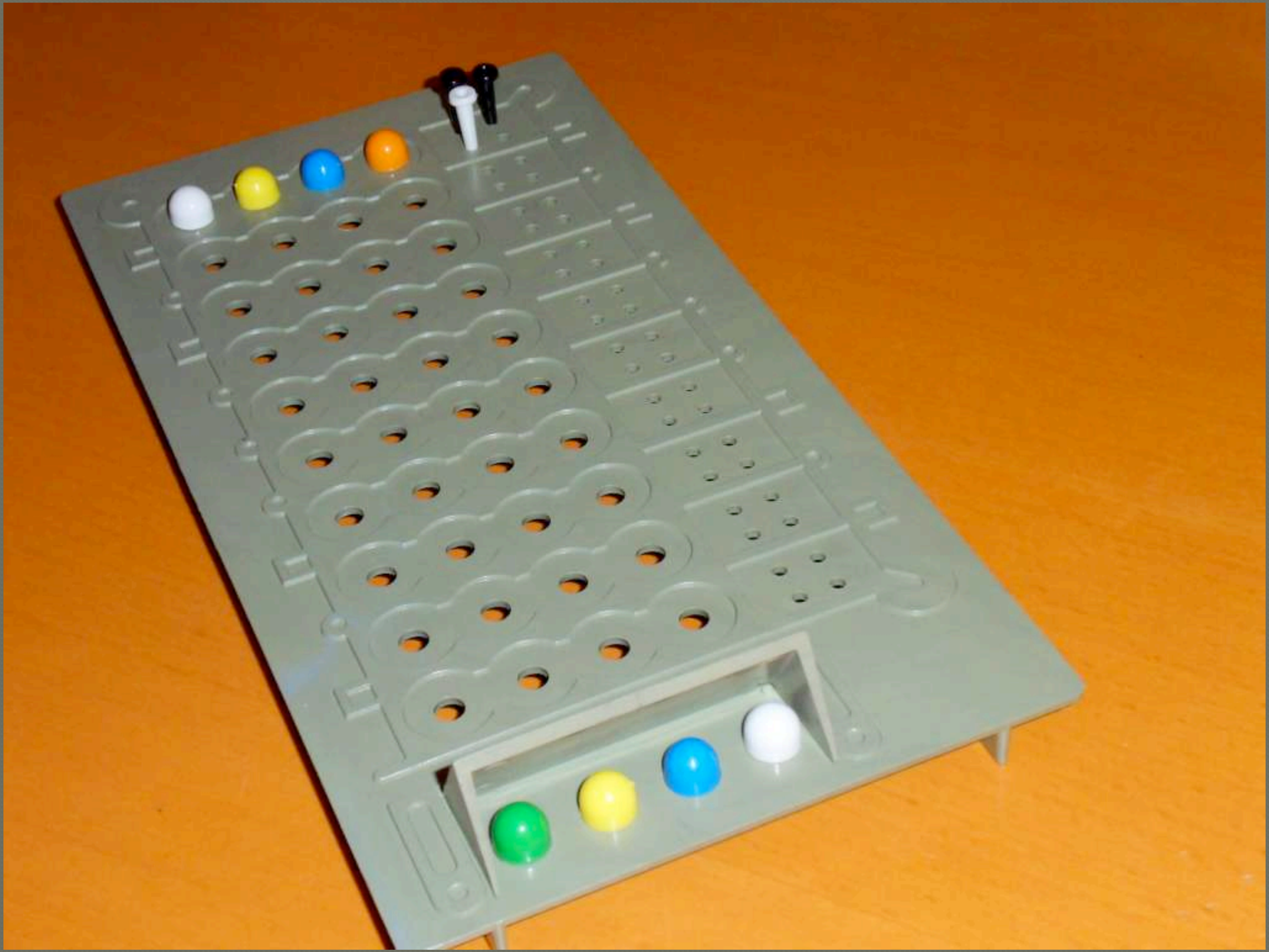
Mastermind

- Player 1 chooses a secret sequence of 4 tokens from a pool of 6 (no repeats).
- Player 2 makes a guess.
- Player 1 scores the guess indicating:
  - How many are the correct token in the correct position
  - How many are the correct token in the wrong position
- Play continues until the secret is guessed or player 2 gives up.


MASTER MIND
A GAME OF CUNNING AND LOGIC FOR TWO PLAYERS
BREAK THE HIDDEN CODE


STER MIND


MASTER
MIND

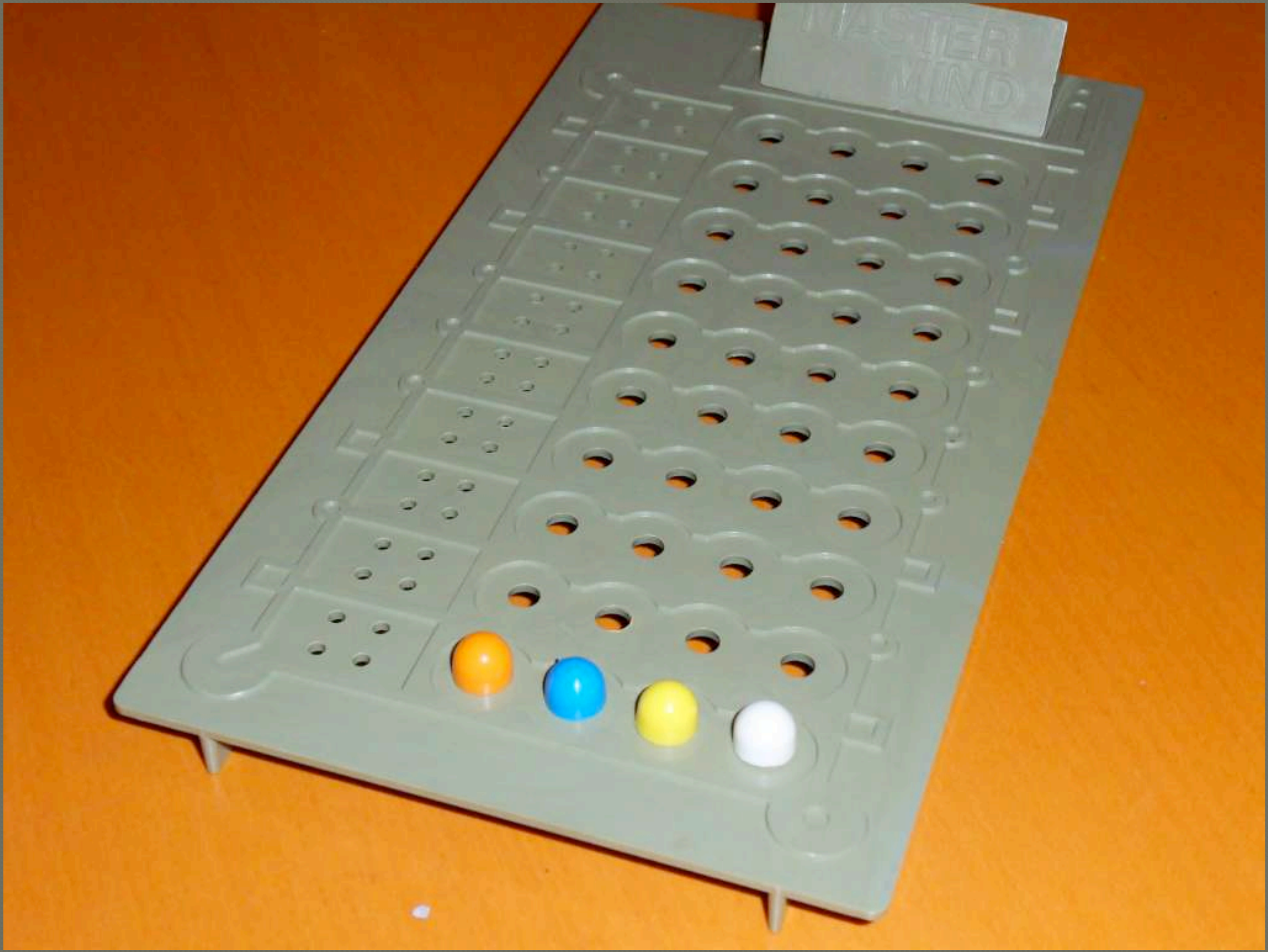



MASTER MIND


MASTER
MIND

MASTER MIND

Lets Code!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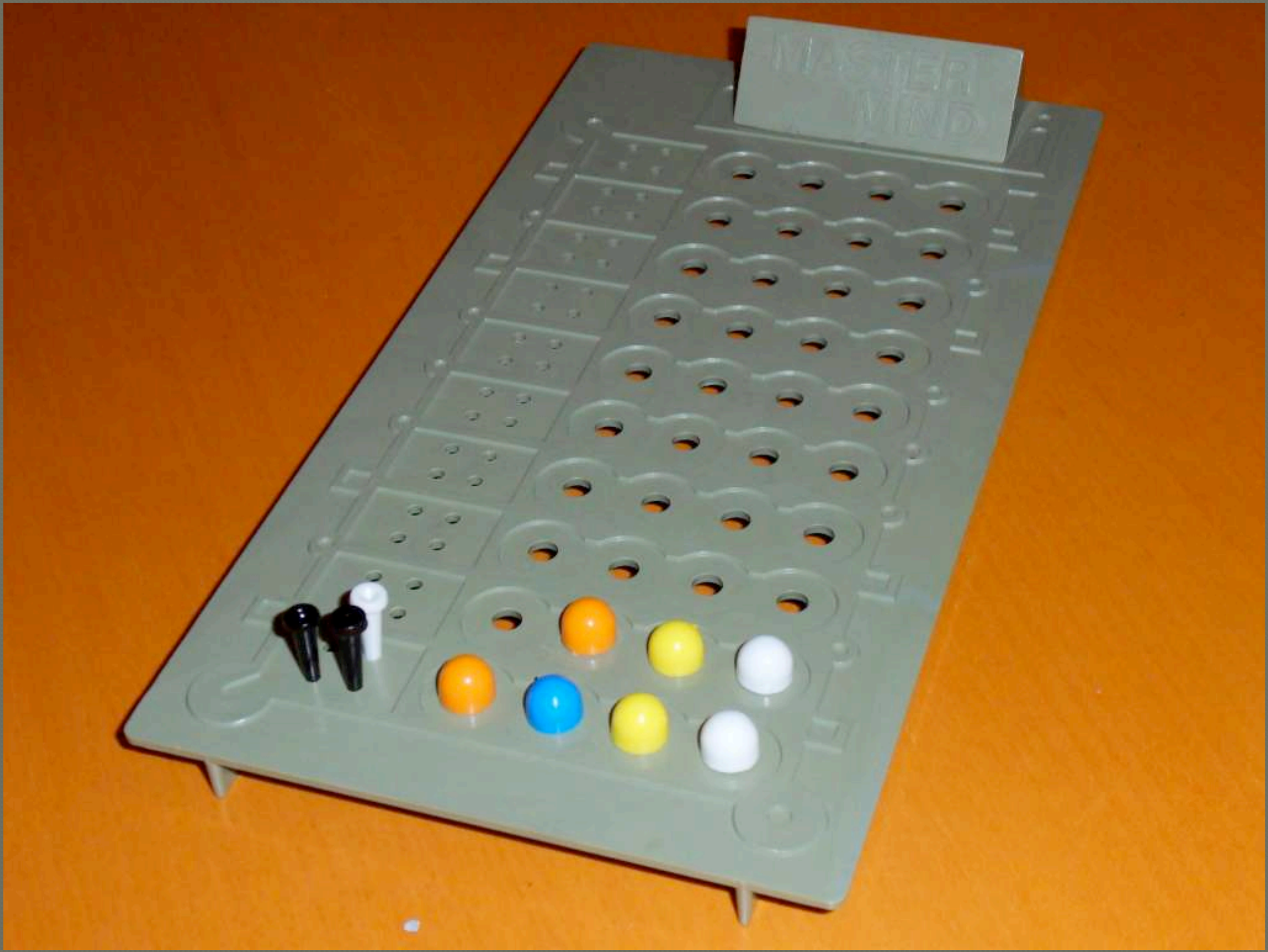
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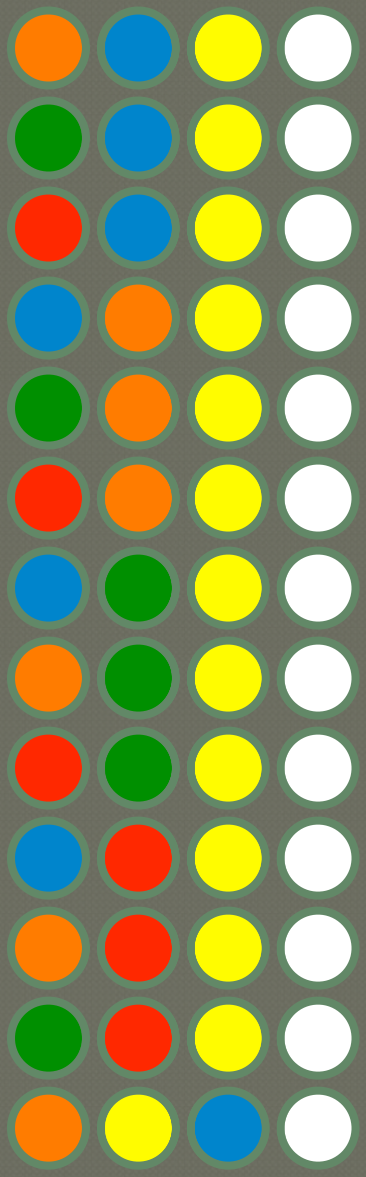
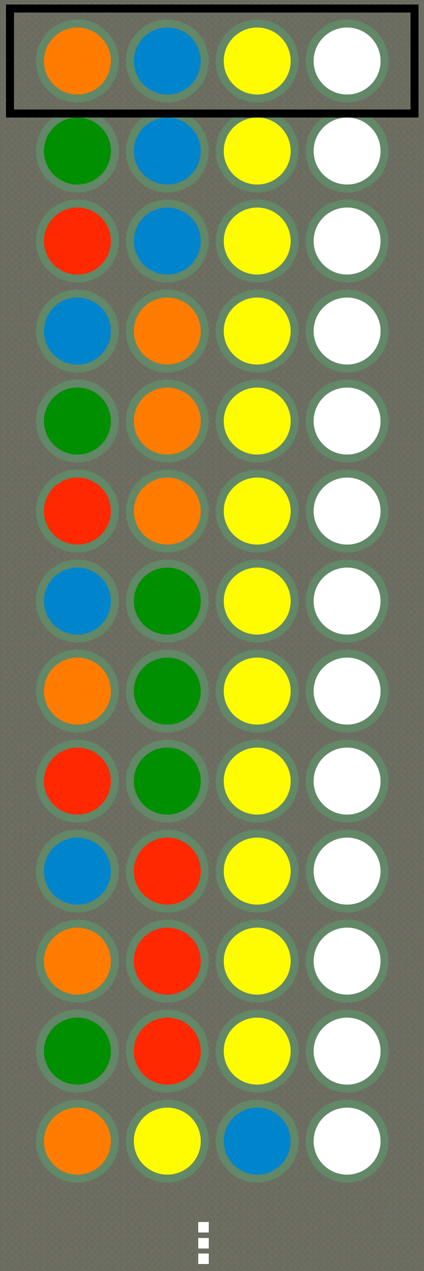
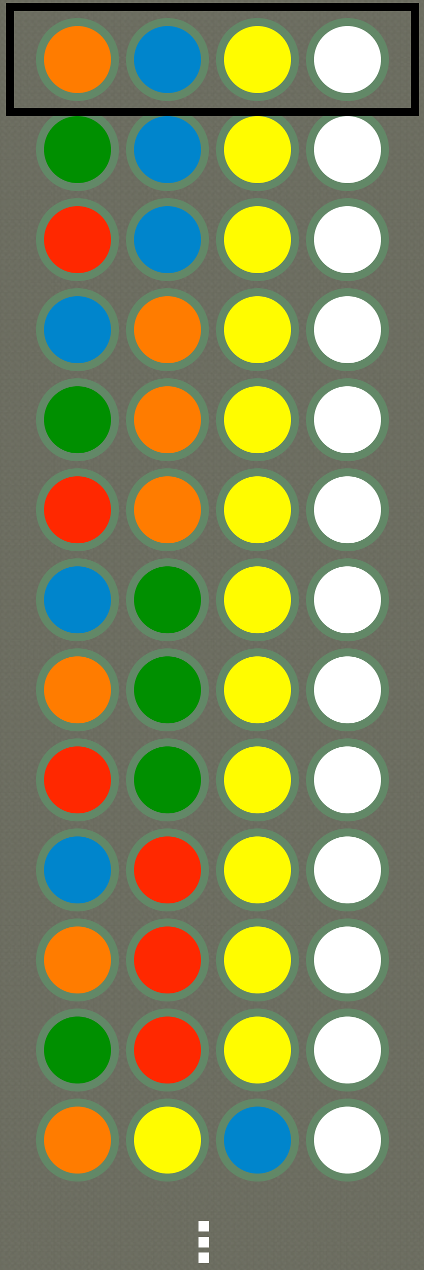
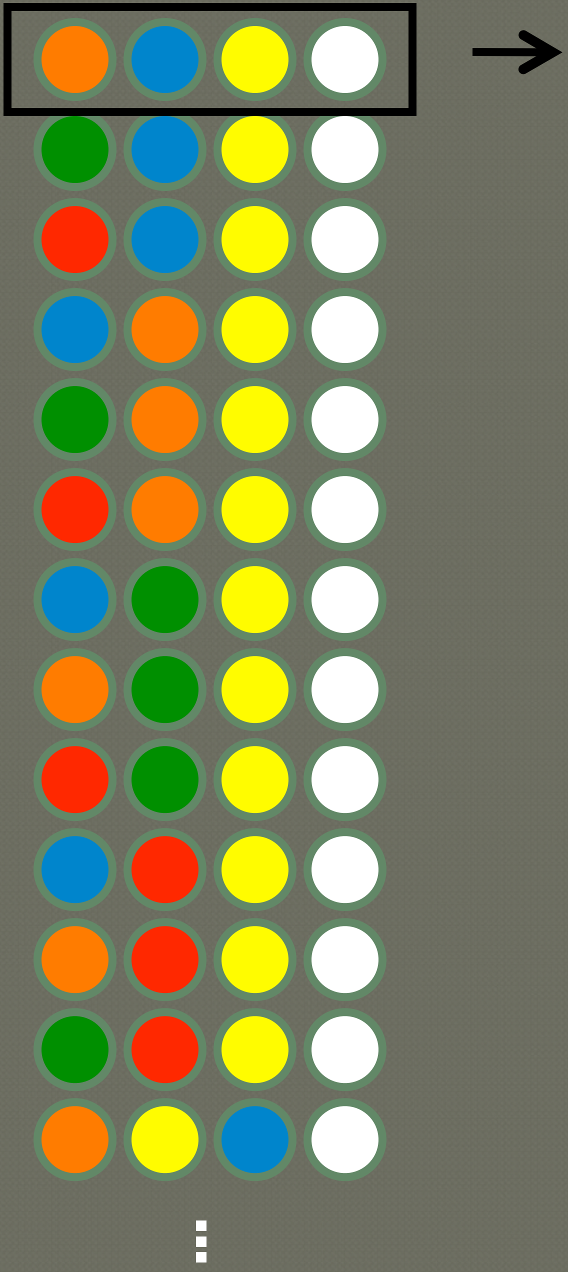


⋮





→ 2 1



2 1
3 0
3 0
2 2
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2 1
2 1
3 0
2 0
2 1
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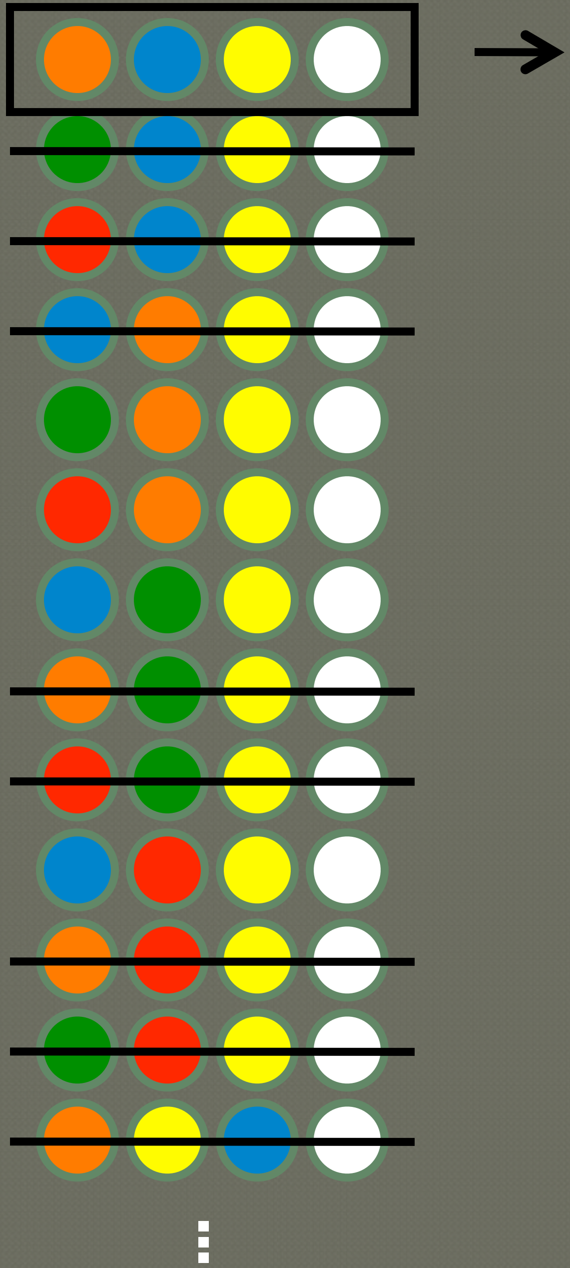
2 0
2 2



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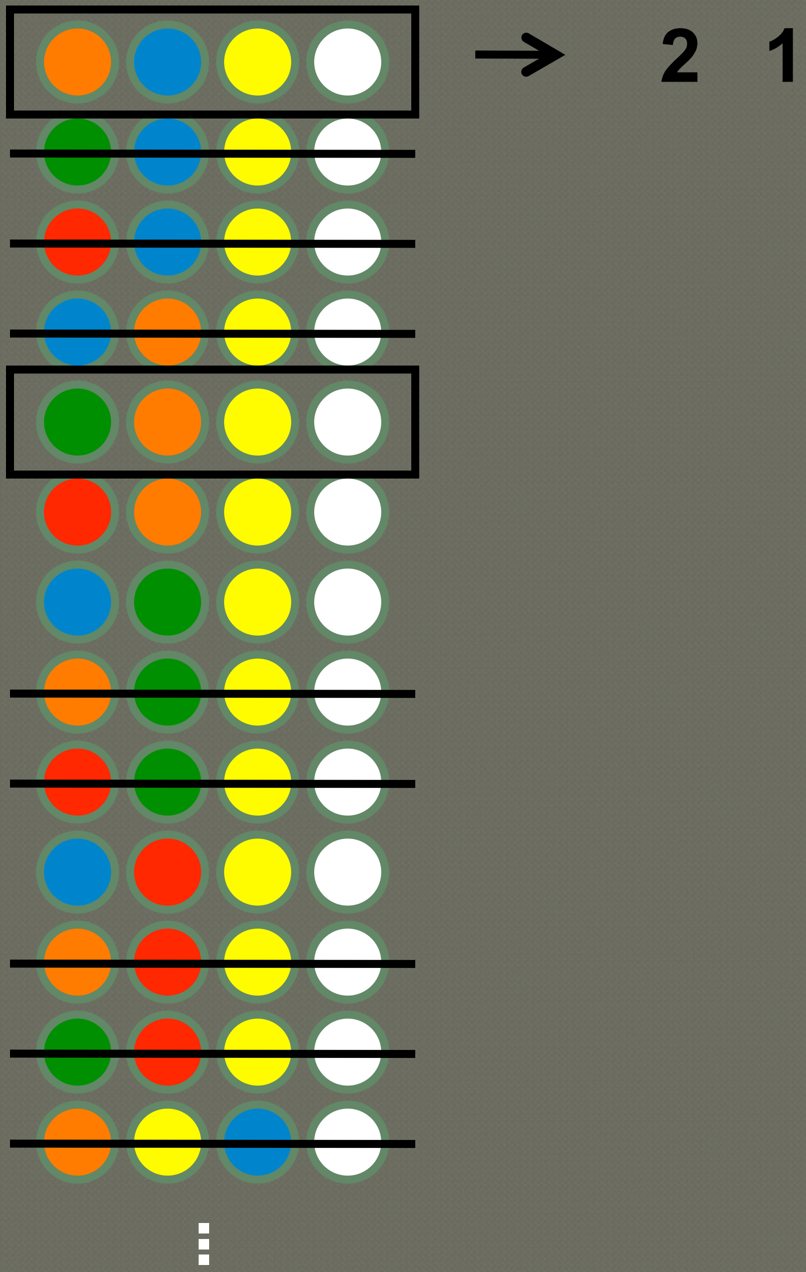
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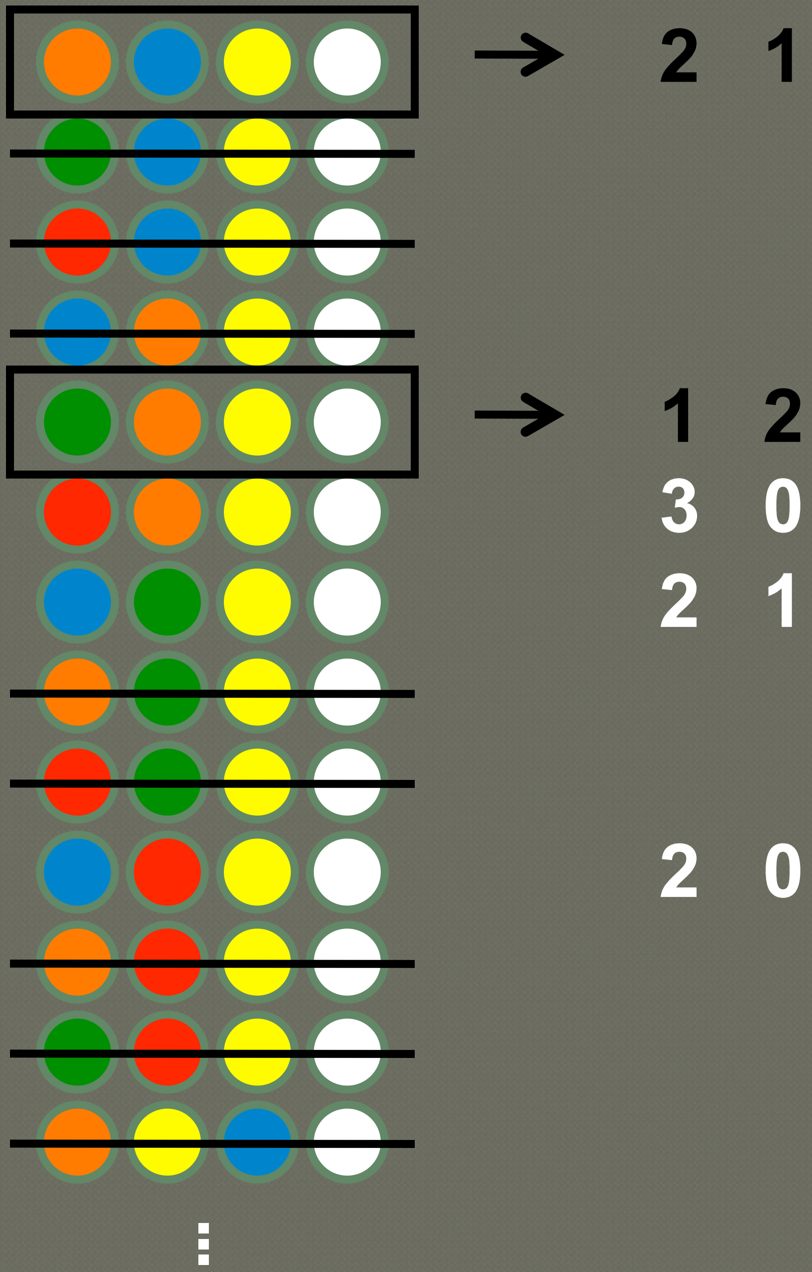


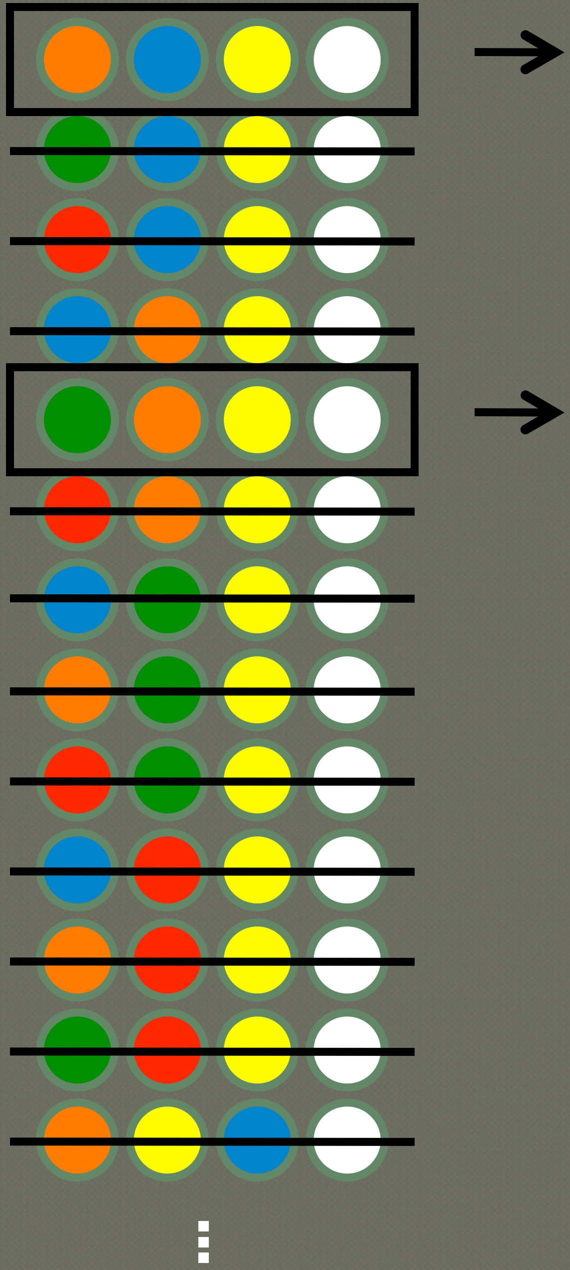
2 1

1 2

3 0

2 1

2 0



2 1

1 2
3 0
2 1

2 0

More Coding

Review

- Lazy evaluation
- Infinite structures
- Avoiding unnecessary work
- Cyclic definitions
- Memoization
- Lazy IO
- Circular programming