A small plug

It's good!

And has some puzzly stuff
Announcements

- Reminder: this is our last Wednesday lecture! (because Week 10 is a grind for everyone as is)
  - I'm sorry we never got to Grundy numbers. Go look them up, it's nice to be aware of them...
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● The puzzle hunt looks like it will take 2–3 hours. It has a nice payoff at the end, so I encourage doing the whole thing! There will also be prizes for the fastest team(s).
  ○ Final announcement of date/time tonight
Tool-assisted speedruns

- Whereas different video games have different notions of "score" (if any), time is a universal currency. How fast can we beat this video game that we like?

- ...and can we do it even faster than that? Can we shave off another second? Can we get the time below some round-number threshold like the 2 minute mark?

- What if we get computers to help us?
Interlude: Why do we care?

- Especially in the frenetic modern era, humans insist on doing everything fast

- Consider the similarity to the problem of getting from point A to point B as fast as possible during commute traffic...
  - and the "state" could be complicated, e.g., how much do you spend on bridge tolls? how much gas do you use?

- Researchers (e.g., DeepMind) use video games as test beds for AI because they are complex but not too complex
How can computers help us here?

- Execution: Perform acts of frame-perfect dexterity not (consistently) achievable by our puny, fallible human bodies
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- Planning: Find glitches and optimal routes

- Why isn't optimal routefinding easy? Just do the thing that gets you the farthest, the fastest, right?
What happened there?

- "Damage boosting": our hero took damage from a bat to get knocked back onto a platform, avoiding a long trip downstairs.

- The game state is more complicated than it may seem:
  - We only have so much health. We may be able to refill it using items, but doing that takes time!
  - A special subweapon (the watch) was needed to stop time to get the bat to arrive at the right time. Getting a subweapon takes time!
  - Subweapons consume hearts, so it matters how many hearts we have. Getting hearts takes time!
Dynamic programming interlude
Mario's extremely basic adventure
(probably like 50 bucks on Switch)
In this game, Mario has two kinds of move:

Option 1: Go forward one step
Option 2: Jump
coins are good
you want as many as possible
because Mario's life is empty
enemies do not move
(they've been doing this for 35+ years, the excitement isn't there anymore)
not OK to walk into enemies
how did you get hit, it was just standing there
OK to land on enemies because Mario is an asshole c'mon man
Greedy strategies aren't always optimal
What we should have done

3 coins
Why not just try every path?
Exponential number...
Why not just try every path?

Exponential number... so any solution that explicitly considers them all is exponential
Solving via DP

what? we can't get here... but you'll see why we need it
top row cell:
value from downleft, plus 1 if coin
bottom row cell:
max of:
1. value from upleft
2. value from left if no enemy here
top row cell: value from downleft, plus 1 if coin
bottom row cell:
max of:
1. value from upleft
2. value from left if no enemy here
top row cell:
value from downleft, plus 1 if coin
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Wait a minute...
Isn't this just the "exponential" slide again?
Wait a minute...
Isn't this just the "exponential" slide again?
No! We took **linear time**.
once we get this far, the strategy from then on doesn't depend on how we got there
def solve(length, coins, enemies):
    dp = [[0 for _ in range(2)] for __ in range(length)]
    for i in range(1, length):
        # in second index, 1 = top row, 0 = bottom row
        dp[i][1] = dp[i-1][0] + (1 if coins[i] else 0)
        dp[i][0] = max(-1 if enemies[i] else dp[i-1][0], dp[i-1][1])
    print(dp)
    print(max(dp[length-1][0], dp[length-1][1]))

solve(7, [False, True, True, False, True, False, True, True],
      [False, False, False, True, True, False, False, False])

# (base) Ians-MacBook-Air:Desktop iantullis$ python mario.py
### [[0, 0], [0, 1], [1, 1], [1, 1], [1, 2], [2, 1], [2, 3]]
# 3
More space-efficient code!

def solve(length, coins, enemies):
    prv = [0, 0]
    nxt = [0, 0]
    for i in range(1, length):
        # in second index, 1 = top row, 0 = bottom row
        nxt[1] = prv[0] + (1 if coins[i] else 0)
        nxt[0] = max(-1 if enemies[i] else prv[0], prv[1])
    prv = nxt
    print(max(nxt[0], nxt[1]))

solve(7, [False, True, True, False, True, False, True],
      [False, False, False, True, False, False, False])

# (base) Ians-MacBook-Air:Desktop iantullis$ python mario.py
# 3
Even more space-efficient code (thx Manas!)

```python
def solve(length, coins, enemies):
    curr = 0  # the column we are in
    nxt = None # the column to the right of that
    nxtnxt = None # the column to the right of THAT
    for i in range(length-1):
        if curr is not None:
            # walk
            if not enemies[i+1]:
                nxt = curr if nxt is None else max(nxt, curr)
            # or jump
            newscore = curr + (1 if coins[i+1] else 0)
            nxtnxt = newscore if nxtnxt is None else max(nxtnxt, newscore)
        # shift to next column
        curr = nxt
        nxt = nxtnxt
        nxtnxt = 0
    print(max(curr, nxt))

solve(7, [False, True, True, False, True, False, True],
     [False, False, False, True, False, False, False])  # answer 3

solve(4, [True, True, True, True],
     [False, False, False, False])  # answer 2

solve(3, [False, True, False],
     [False, False, False])  # answer 1

solve(3, [False, False, True],
     [False, True, False])  # answer 0
```

This eliminates the need for a 2D array – and now only uses 3 values – but is a little harder to understand.
Back to speedrunning

- Can do the same sort of thing with time instead of number of coins.
  - "What's the earliest time we can possibly reach this point in the level?"

- What if we have other stuff like life total, number of hearts, which subweapon...
  - "What's the earliest time we can possibly reach this point in the level, with this much life, this many hearts, this subweapon..." etc. – explosion in complexity, but possible
  - Pretty much the same thing but with a multi-dimensional array of values
amazingly, there have been CS theory papers on the computational complexity of solving the damage-boosting problem...

**Theorem 2.** DAMAGE BOOSTING is FPT in $k+r$, where $k$ is the number of possible damage values and $r$ the number of chicken events. Moreover, an optimal solution can be found in time $O(2^r(2k(r+1)+r)^{2.5(2k(r+1)+r)} poly(n))$.

**Proof.** Let $C$ be the set of chicken events of $S$, and suppose $r = |C|$. We simply “guess” which of the $2^r$ subsets of $C$ to take. That is, for each subset $C' \subseteq C$, we find the maximum time gain achievable under the condition that the chicken events taken are exactly $C'$, hence the $2^r$ factor in the complexity. For the rest of the proof, assume $C = \{c_0, c_1, \ldots, c_r, c_{r+1}\}$ is a set of chicken events such that $c_i <_S c_{i+1}$ for $0 \leq i \leq r$, each of which must be taken. For notational convenience, we have added chicken $c_0 = c_{r+1} = (0,0)$, where $c_0$ (respectively $c_{r+1}$) is a chicken event that occurs before (resp. after) every event of $S$. 
Corollary 4. There exist games $G_1$, $G_2$, $G_3$, featuring doors and pressure plates, in which the avatar has to reach an exit location, such that:

(a) In $G_1$, pressure plates can only open doors, crossovers are allowed, and $G_1$ is $P$-complete.

(b) In $G_2$, no two pressure plates control the same door, and $G_2$ is $NP$-complete.

(c) In $G_3$, each door may be controlled by two pressure plates, and $G_3$ is $PSPACE$-complete.

...and on the hardness of games based on their design elements.

<table>
<thead>
<tr>
<th>Mechanics</th>
<th>Portals</th>
<th>Long Fall</th>
<th>Complexity</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>No</td>
<td>Yes</td>
<td>$P$ (§3)</td>
</tr>
<tr>
<td>Emancipation Grills, No Terminal Velocity</td>
<td>Yes</td>
<td>Yes</td>
<td>Weakly $NP$-hard (§4)</td>
</tr>
<tr>
<td>Turrets</td>
<td>No</td>
<td>Yes</td>
<td>$NP$-hard (§5)</td>
</tr>
<tr>
<td>Timed Door Buttons and Doors</td>
<td>No</td>
<td>No</td>
<td>$NP$-hard (§6)</td>
</tr>
<tr>
<td>HEP Launcher and Catcher</td>
<td>Yes</td>
<td>No</td>
<td>$NP$-hard (§7)</td>
</tr>
<tr>
<td>Cubes, Weighted Buttons, Doors</td>
<td>No</td>
<td>No</td>
<td>$PSPACE$-comp. (§8)</td>
</tr>
<tr>
<td>Lasers, Relays, Moving Platforms</td>
<td>Yes</td>
<td>No</td>
<td>$PSPACE$-comp. (§8)</td>
</tr>
<tr>
<td>Gravity Beams, Cubes, Weighted Buttons, Doors</td>
<td>No</td>
<td>No</td>
<td>$PSPACE$-comp. (§8)</td>
</tr>
</tbody>
</table>

Table 1: Summary of New Portal Complexity Results
Figure 25: Variable gadget for Zelda

Figure 26: Clause gadget for Zelda
Manipulating randomness

- In old games (and many real-life situations!), a pseudorandom number generator is used to determine random events (e.g., how many bats appear).

- Sometimes you can figure out how the pseudorandom number generator works and reverse-engineer it.
Congratulations, Mad Moham! You have recovered the Sceptre of Order from the clutches of the evil Master Villains. As a reward for saving himself and the four continents from ruin, King Maximus and his subjects reward you with a large parcel of land, a rank of nobility and a medal announcing your

Final Score: 0
Performing computation within games
Leaves drop saplings, sticks and apples

I made Minecraft in Minecraft with redstone!
Training AIs to play games

- **Nice:** write a AI that is tailored to be good at one particular game after observing humans (AlphaGo)
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- **Impressive**: write an AI that is good at playing games in general, given the rules (Alpha Zero)

- **Even more impressive**: write an AI that is good at playing games in general, *even when it has to infer the rules* (MuZero)
Modern reinforcement learning

- In contemporary games, it is not possible for an AI agent to consider and evaluate all possible moves at each state (there could be quajillions of them)

\[\text{giant disclaimer: I have not taken CS234 and am not an RL expert}\]
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- The tl;dr is that these AIs learn the "landscape" of what moves are good using deep learning
  - which is basically a bunch of linear algebra with nonlinear functions mixed in to allow for more complexity

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- With a sense of this "landscape" in mind, the AIs do variants of dynamic programming
  - and also tune the model parameters in clever ways

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intentionally gave the agent a limited camera view of the game and limited its movement speed

- got a SC pro to consult

- beat 99.8% of human players on Battle.net
A more digestible example

- **LearnFun/PlayFun** by Tom7 (suckerpinch on YouTube, watch all his stuff!!!!) for a "fun" conference in the early 2010s.
  
  - key idea: it is usually good when values in the game's memory (score, position in the level…) go up
  
  - The AI watches a human play for a little bit and then builds its own objective function ("score") based on how values in memory change
  
  - There are some subtleties (how to identify values in memory that are stored as, e.g., two 8-bit numbers)

- Learns to play (general) NES games... with varying degrees of success.
Takeaways

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- Reinforcement learning, driven by neural networks / deep learning, seems to be the best way we have to tame the combinatorial explosion of how many possible things a game agent could potentially try.
  - still a very open problem how to implement this in a general way.
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- What DeepMind and other cutting-edge researchers want is general AI / algorithmic solving, and games and puzzles are a useful stepping stone

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  - still a very open problem how to implement this in a general way

- Let's not forget that games and puzzles are fun and often mathematically beautiful. We each have only so much time on this earth! Joy should be part of our personal objective functions!
THANK YOU MARIO!

BUT OUR DEPTH/RIGOR IS IN ANOTHER CLASS!
• Theory
  ○ CS 154 (Computational Complexity), 254, 254B
  ○ CS 151 (Logic Programming), CS 157 (Logic)
  ○ CS 161 (Algorithms), CS 168 (Modern Algorithmic Toolbox)
  ○ CS 164?? someday? (expanded version of this class)
  ○ CS 250 (Error-correcting codes)
  ○ CS 269I (Incentives in CS) – game theory
  ○ Econ and MS&E have a bunch of classes on game theory

• Math
  ○ Math 61DM, 62DM, 63DM – discrete math
  ○ Math 107 (Graph Theory), 108 (Combinatorics)
  ○ Math 109/120 (Abstract Algebra), 104/113 (Linear Algebra)
  ○ Math 193 (Polya Problem Solving Seminar)
  ○ Math 231 (Math/Stats of Gambling) or anything with Persi Diaconis
- **AI**
  - CS 221 *(Intro to AI)* — has a really fun Pac-Man project
  - CS 227B *(General Game Playing)*
  - CS 229 *(Machine Learning)* — warning, eats your life, don't take it first
  - CS 230 *(Deep Learning)*, CS 234 *(Reinforcement Learning)*, CS 224R *(Deep Reinforcement Learning)*, CS 332 *(Advanced RL)*
  - CS 238 *(Decision Making Under Uncertainty)* — take this and/or 221 first?
  - lots of others, I'm sure (e.g., vision, robotics...)

- **Design** — I know nothing about these but design is important
  - CS 146 *(Intro to Game Design)*
  - CS 247G *(Design for Play)*
  - CS 377G *(Designing Serious Games)*
Please do the feedback form when it comes out

Although my time at Stanford is ending soon, even after I'm down in San Diego I may try to continue remotely teaching this class or a more rigorous variant, CS164. So your thoughts would be very helpful!

Thank you for taking this class!