

Lecture 14

Procedural Content Generation

Lessons for Today

- Procedural content is **harder**, not easier
 - You must already know your *design patterns*
 - Controlling *difficulty* is a potential challenge
 - *Unwinnable levels* are also a challenge
- Many procedural approaches are **ad hoc**
 - Designed for specific games
 - Limited adaptability to other games
- Procedural generation is a **stretch goal**

Important Caveat

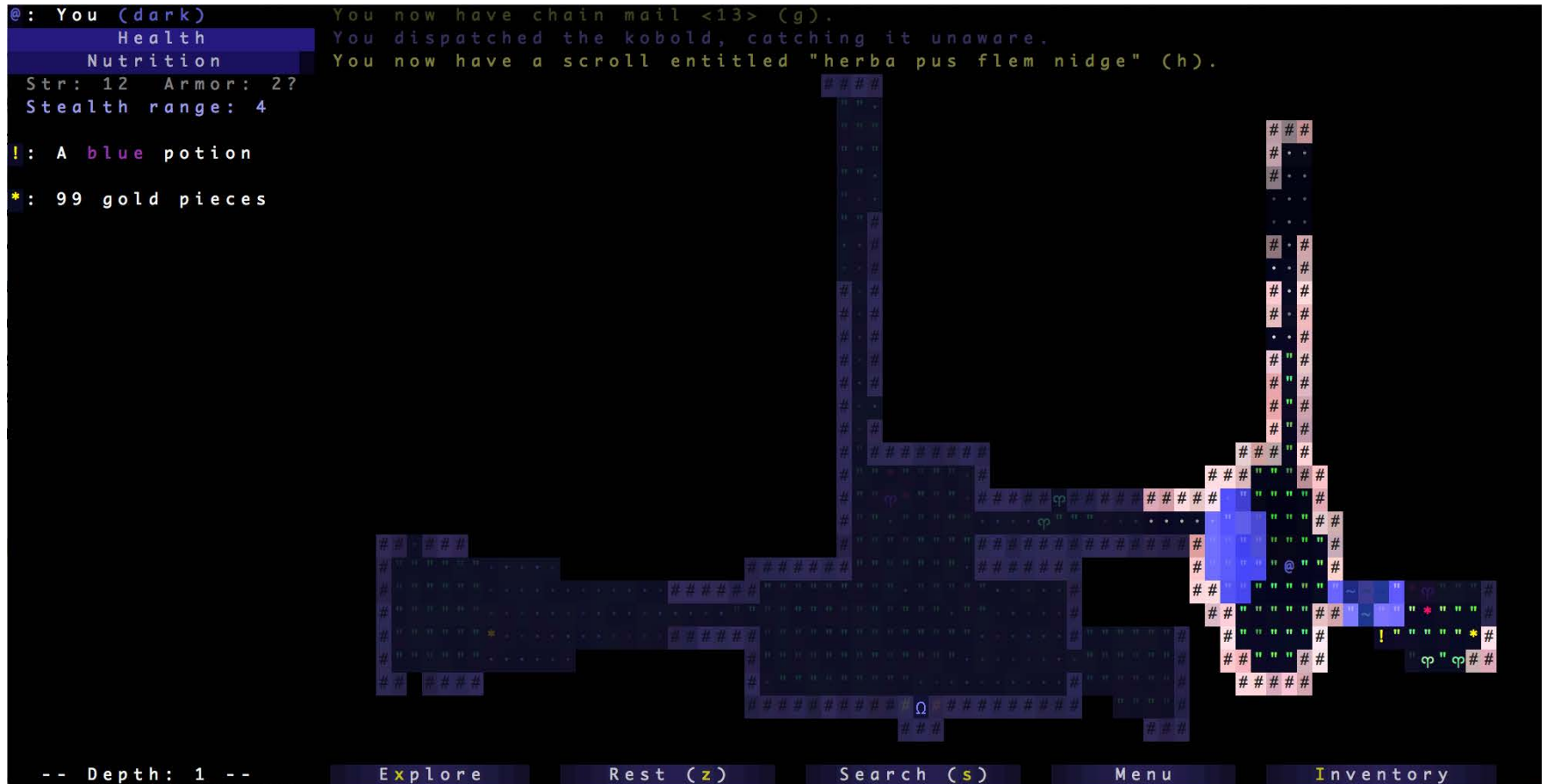
- This lecture is up to date as of **GDC 2025**
 - I attended the generative AI sessions in 2024
 - Have tried to keep up with the state-of-the-art
- But generative AI is rapidly advancing
 - New tools are produced every day
 - We know game studios have internal tech
- Have tried to be as current as I possibly can
 - Lecture includes news reports from **last week**
 - May not know more until a game uses the tech

In the Beginning, There Was *Rogue*

```
@: You (dark)           You now have chain mail <13> (g).
  Health               You dispatched the kobold, catching it unaware.
  Nutrition            You now have a scroll entitled "herba pus flem nidge" (h).
Str: 12  Armor: 2?
Stealth range: 4

!: A blue potion
*: 99 gold pieces

-- Depth: 1 --
  Explore  Rest (z)  Search (s)  Menu  Inventory
```

The image shows a terminal window of the Rogue game. The top left displays the player's name and stats: "You (dark)", Health, Nutrition, Str: 12, Armor: 2?, and Stealth range: 4. The top right shows recent actions: "You now have chain mail <13> (g).", "You dispatched the kobold, catching it unaware.", and "You now have a scroll entitled 'herba pus flem nidge' (h).". The main area is a dungeon map represented by a grid of characters like '#', '.', '@', and 'p'. The player's position is marked with '@'. The bottom of the screen features a command menu with options: "-- Depth: 1 --", "Explore", "Rest (z)", "Search (s)", "Menu", and "Inventory".

In the Beginning, There Was *Rogue*

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@: You (dark)           You now have chain mail <13> (g).
Health                 You dispatched the kobold, catching it unaware.
Nutrition              You now have a scroll entitled "herba pus flem nidge" (h).
Str: 12  Armor: 27
Stealth range: 4

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```



The screenshot shows the Rogue game interface. On the left, a character's stats are displayed: Health, Nutrition, Str: 12, Armor: 27, and Stealth range: 4. Below the stats, a list of items is shown: a blue potion and 99 gold pieces. The main area is a procedurally generated dungeon map represented by a grid of characters. The player's character is at the bottom center, surrounded by various rooms and corridors. At the bottom of the screen, there is a status bar showing the current depth (1) and several action buttons: Explore, Rest (z), Search (s), Menu, and Inventory.

Roguelike Genre

- Classic RPG style
- Procedural dungeons
- **Permadeath**

Modern Roguelikes: *Spelunky*



Modern Roguelikes: *FTL*



Modern Roguelikes: *FTL*



A Brief History of Roguelikes

- Precursors (1978)

- *Beneath Apple Manor*
- *Dungeon* (unfamous one)

- Like *Rogue*, but less famous
 - Limited content generation
-

- *Rogue* (1980)

- Multiplatform launch
-

- Immediate Copycats

- *Hack* ('82), *NetHack* ('87)
- *Moria* ('83), *Angband* ('90)

- All very close in playstyle
 - Open source development
 - Middle Earth themed
-

- *Island of Kesmai* (1985)

- *Legends of Kesmai* (1996)

- Massively (~80) multiplayer
 - But content less procedural
-

- The Modern Revival

- Relaxing RPG requirement
-

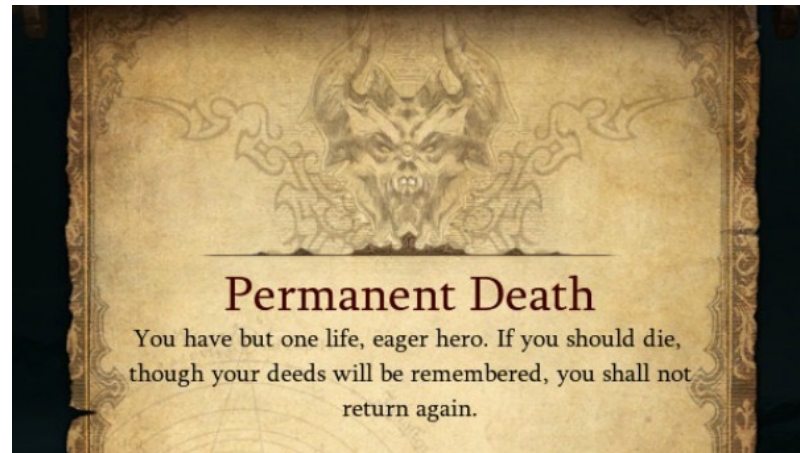
Changing Perspectives on Permadeath

Advantages

- Greater challenge
 - Used as a badge of honor
- Higher emotional stakes
 - Easy to instill fear & horror

Disadvantages

- Greater discouragement
 - Seen as a personal failure
- Missed game content
 - Cannot progress in story



Changing Perspectives on Permadeath

Advantages

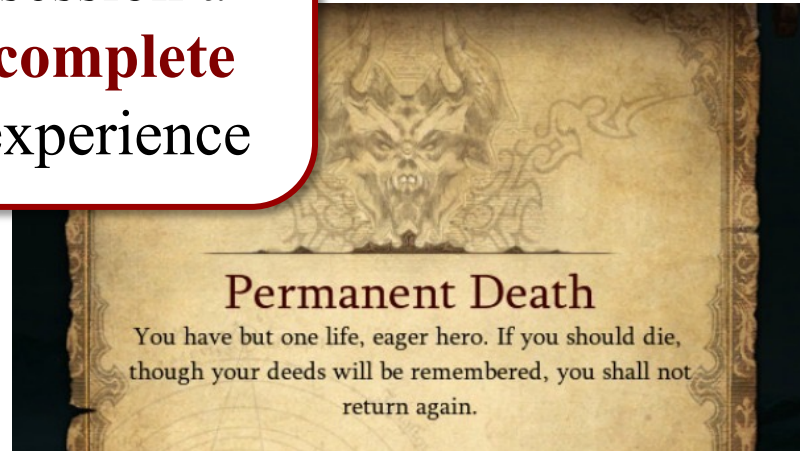
- Greater challenge
 - Used as a teaching tool
- Higher emotional investment
 - Easy to identify with the character

Make dying expected & **inevitable**

Make each session a **complete** experience

Disadvantages

- Greater discouragement
 - Seen as a personal failure
- Missed game content
 - Cannot progress in story



Changing Perspectives on Permadeath

Advantages

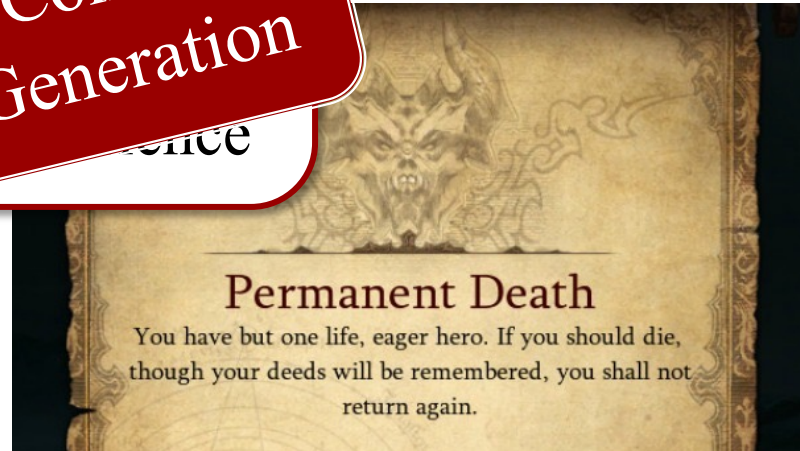
- Greater challenge
 - Used as a teaching tool
- Higher emotional investment
 - Easy to integrate

Make dying expected & **inevitable**

Content Generation

Disadvantages

- Greater discouragement
 - Seen as a personal failure
- Missed game content
 - Cannot progress in story



Aside: Rogue-lites

- Modern roguelikes do not completely reset
 - Some state carries over between play session
 - Way to reward player for simply trying
 - Call this variation a **Rogue-lite**
- Creates a sense of **meta-progression**
 - There is now the ability to “finish the game”
 - But there still replayability after the end
- **Examples**
 - Unlockable cards/items in *Slay the Spire*
 - Storyline and dialog in *Hades*

Issues with Roguelikes/lites

- Design is often **horizontal**
 - Many verbs, game elements
 - Little coupled behavior
- Each play is a **slice**
 - Access to limited elements
 - Work with what you get
- “Expensive” to create
 - Requires a lot of content
 - But historically just text
- Difficult to balance

WEAPON (Table 1)					
Dagger	COST	WGT	PROB	MATL	APPEARANCE
orcish dagger	\$4	10	12	IRON	crude dagger
dagger	4	10	30	IRON	--
silver dagger	40	12	3	SILV	--
athame	4	10	0	IRON	--
elven dagger	4	10	10	WOOD	runed dagger
Knife	COST	WGT	PROB	MATL	APPEARANCE
worm tooth	2	20	0	NONE	--
knife (shito)	4	5	20	IRON	--
stiletto	4	5	5	IRON	--
scalpel	6	5	0	METL	--
crysknife	100	20	0	MINL	--
Axe	COST	WGT	PROB	MATL	APPEARANCE
axe	8	60	40	IRON	--
battle-axe	40	120*	10	IRON	double-headed axe
Pick-axe	COST	WGT	PROB	MATL	APPEARANCE
pick-axe	50	100	tool	IRON	--
dwarvish mattock	50	120*	13	IRON	broad pick
Short sword	COST	WGT	PROB	MATL	APPEARANCE
orcish short sword	10	30	3	IRON	crude short sword

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- Each play is a **slice**
 - A
 - V
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					--
				5 IRON	--
scalpel	6	5	0	METL	--
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axe	8	60	40	IRON	--
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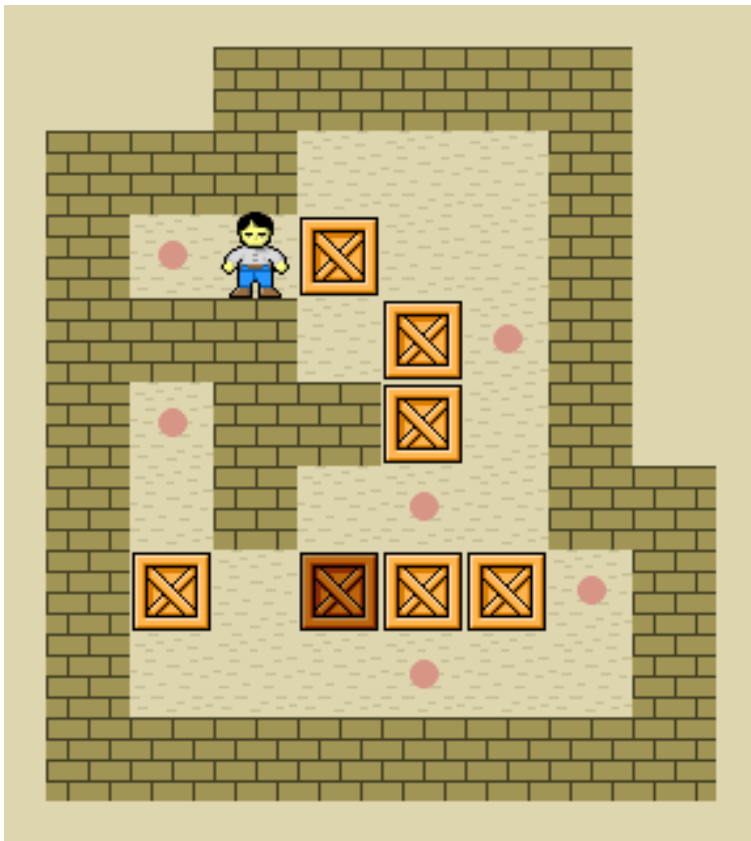
Procedural Content for Modern Games?

Can't We Use Generative AI?

- This is an application that designers **want**
 - Create custom levels for your game
 - Train an LLM on your designed levels
 - Use that to crank out even more levels
- But they **struggle** with this application
 - Related to the LLM counting problem
 - **E.g.** How many **R**'s are in “**strawberry**”?
- Even if we solve it, level design is not obsolete
 - Still need good training data/example levels
 - What makes a good level is unique to your game

Case Study: Sokoban

Graphical Interface

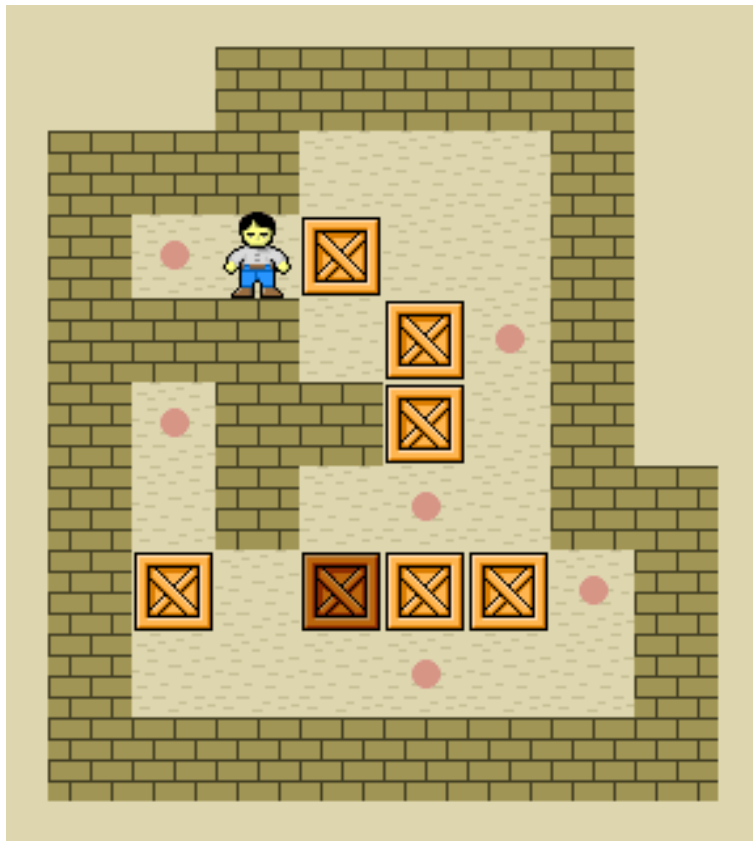


Level Representation

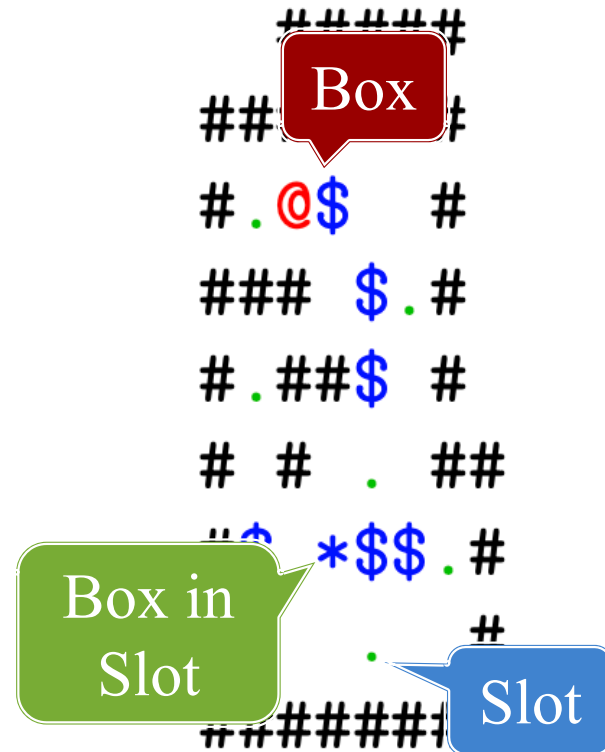
```
#####  
###   #  
# . @ $ #  
### $ . #  
# . ## $ #  
# # . ##  
#$ *$$ . #  
# . #  
#####
```

Case Study: Sokoban

Graphical Interface



Level Representation



Case Study: Sokoban

Graphical Interface



Level Representation

```
#####  
###      #  
# . @ $   #  
### $ . #  
# . ## $  #  
# # . ##  
#$ *$$ . #  
#      .  #  
#####
```

The Solvability Problem

- Levels need to be **solvable**
 - Must be possible to reach the objective
 - Unsolvable levels are treated as bugs
- PCG does not always guarantee solvability
 - Possible to generate map with no route to exit
 - Possible to generate enemy too powerful to beat
- True PCG must include **constraints**
 - Rules to limit the content generated
 - Often *algorithmic* or mathematical in nature

Sokoban Constraints

Parity

```
#####  
#           #  
# . @ $ . #  
#           #  
#           #  
#####
```

Reachability

```
#####  
# .       #  
##### #  
#       # $ #  
#           @ #  
#####
```

The Unfortunate Result

- Study by Julian Togelius et al (NYU Poly)
 - Generic Chat-GPT can recognize Sokoban text
 - But it **cannot generate a solvable level**
 - Vast majority of the time, even parity fails
- Can train on GPT with existing levels
 - A few **hundred levels** seems(?) to address parity
 - Reachability still an issue for larger levels
 - No way to tune difficulty/solution length

The Unfortunate Result

- Study by Julian Togelius et al (NYU Poly)
 - Generic Chat-GPT can recognize Sokoban text
 - But it **cannot generate a solvable level**
 - Vast majority of solutions generated fail
- Can train LLMs to generate solvable levels
 - A few levels can be generated with parity
 - Reachability still an issue for larger levels
 - No way to tune difficulty/solution length

LLMs will solve programming long before they replace this.

Verdict: Only for “Cosmetic” Content



Verdict: Only for “Cosmetic” Content



Ensuring Solvability

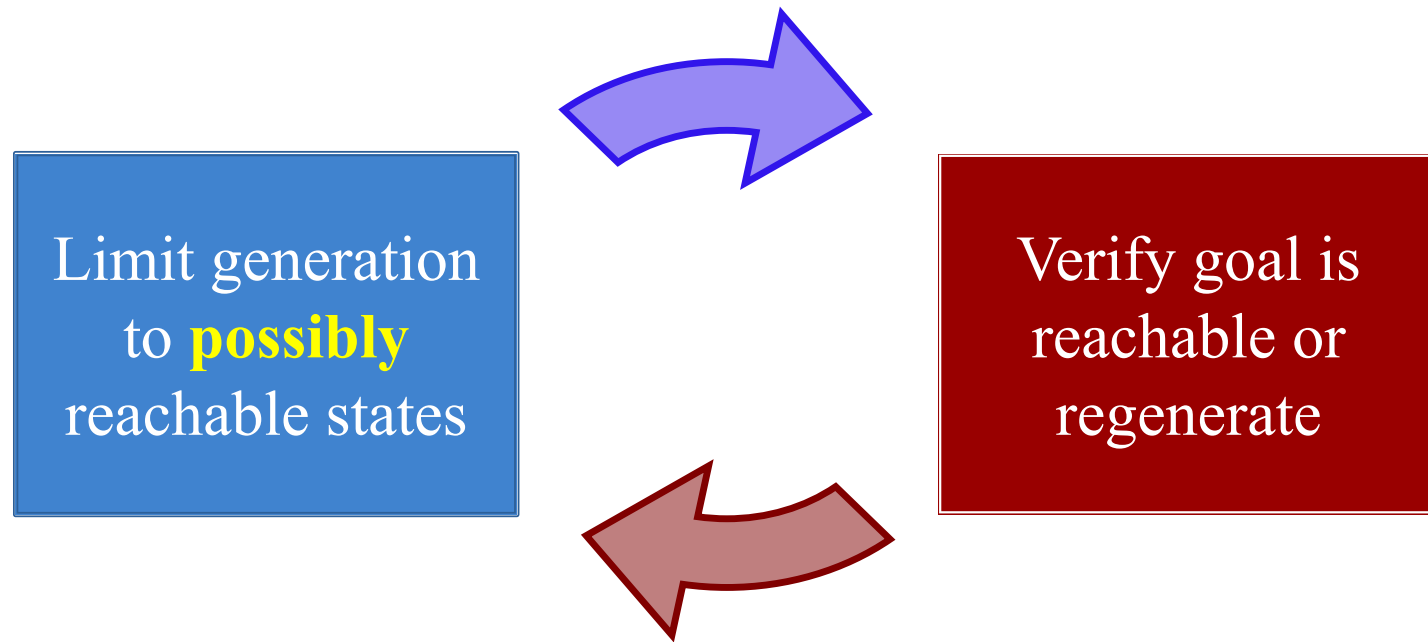
Two Options:

Limit generation
to reachable
game states

Verify goal is
reachable or
regenerate

Ensuring Solvability

Two Options:



Example: NetHack

```
-----
| $$$, #####| |
#| $$$| #+ |
#----- #| |
## #| +####-----
# #| | #| \.+.+.+.+. \.+.+.+.+. \.+.+.+.+. |
# #| < | #| .+.+.+.+.+.+.+.+.+. | #
# #----- #| .+.+.+.+.+.+.+.+.+. | #
-----# ##### #| .+.+.+.+.+.+.+.+.+. | #
| @@@@@@@@@ | # # #| .+.+.+.+.+.+.+.+.+. | #####
| @@@@@@@@@ | # ###| .+.+.+.+.+.+.+.+.+. |
| @@@@@@@@@ | # @ .+.+.+.+.+.+.+.+.+. |
| @@@@@@@@@ | #####| .+.+.+.+.+.+.+.+.+. | #####
| @@@@@@@@@ | #| \.+.+.+.+.+.+.+.+.+. | #
| @@@@@@@@@ | #----- #|
----- #####|
| | |
| | ^ |
| | |
| | |
-----
```

Izchak the Curator St:18/11 Dx:16 Co:17 In:18 Wi:18 Ch:17 Lawful
Dlv1:8 \$:94041 HP:217(234) Pw:190(195) AC:7 Exp:30

Example: NetHack

The image displays a NetHack game screen. At the top, a blue callout box labeled "Room" points to a central area containing a grid of objects including a sword, a shield, a book, and a chest. To the left, another blue callout box labeled "Room" points to a vertical stack of gold bars. The bottom of the screen shows the player's status bar: "Izchak the Curator St:18/11 Dx:16 Co:17 In:18 Wi:18 Ch:17 Lawful Dlv1:8 #:94041 HP:217(234) Pw:190(195) AC:7 Exp:30".

Example: NetHack

The image displays a NetHack game screen. At the top, a blue callout bubble labeled "Room" points to a central area containing a grid of dots and a red square representing the player character. To the left, another blue callout bubble labeled "Room" points to a vertical column of 'Q' characters. Below the central area, an orange callout bubble labeled "Hallway" points to a horizontal line of '#' characters. The bottom of the screen shows the player's status: Izchak the Curator, St:18/11, Dx:16, Co:17, In:18, Wi:18, Ch:17, Lawful, Dlv1:8, #:94041, HP:217(234), Pw:190(195), AC:7, Exp:30.

Example: NetHack

The image shows a NetHack game screen with several callouts identifying different areas:

- Room** (blue callout): Points to a large room containing a player (red square) and a monster (green 'X').
- Exit** (red callout): Points to a red door in the hallway.
- Room** (blue callout): Points to a room on the left side of the screen.
- Hallway** (orange callout): Points to the central hallway.
- Entrance** (green callout): Points to a green door in the hallway.

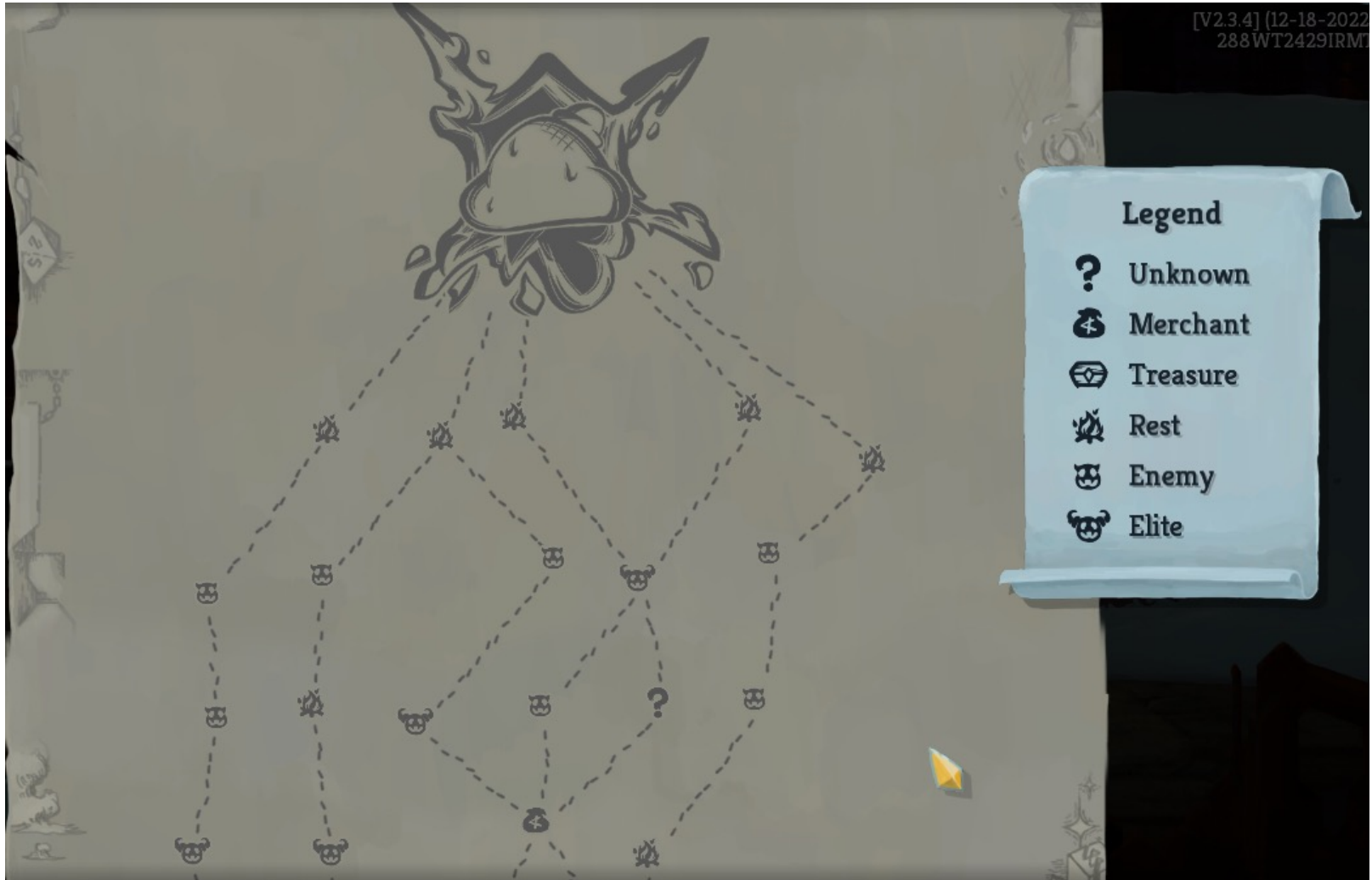
Game status at the bottom:

```
Izchak the Curator      St:18/11 Dx:16 Co:17 In:18 W:18 S:17 L:17  
Dlv1:8  #:94041 HP:217(234) Pw:190(195) AC:7 Exp:30
```

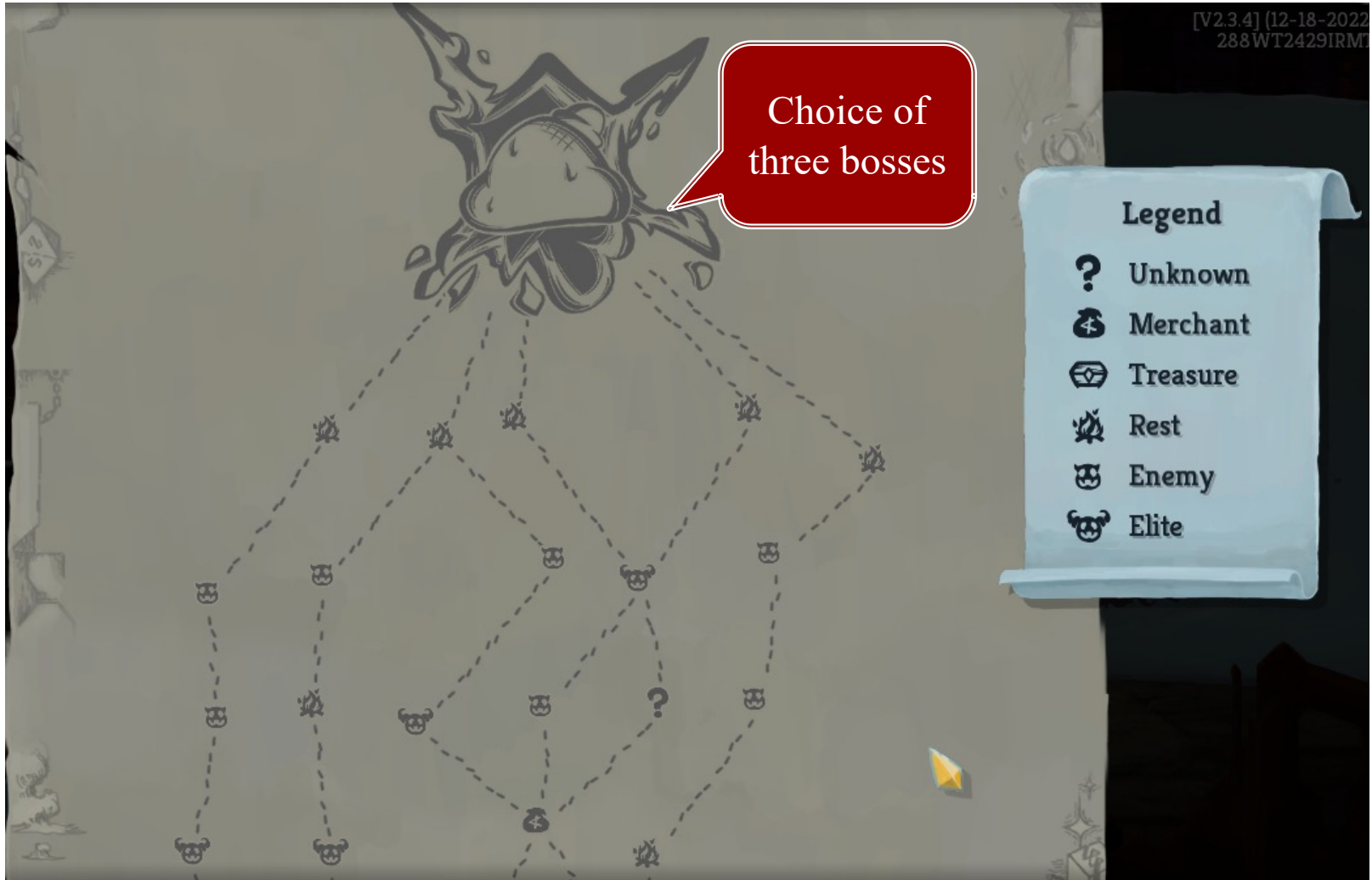

Case Study: *Slay the Spire*



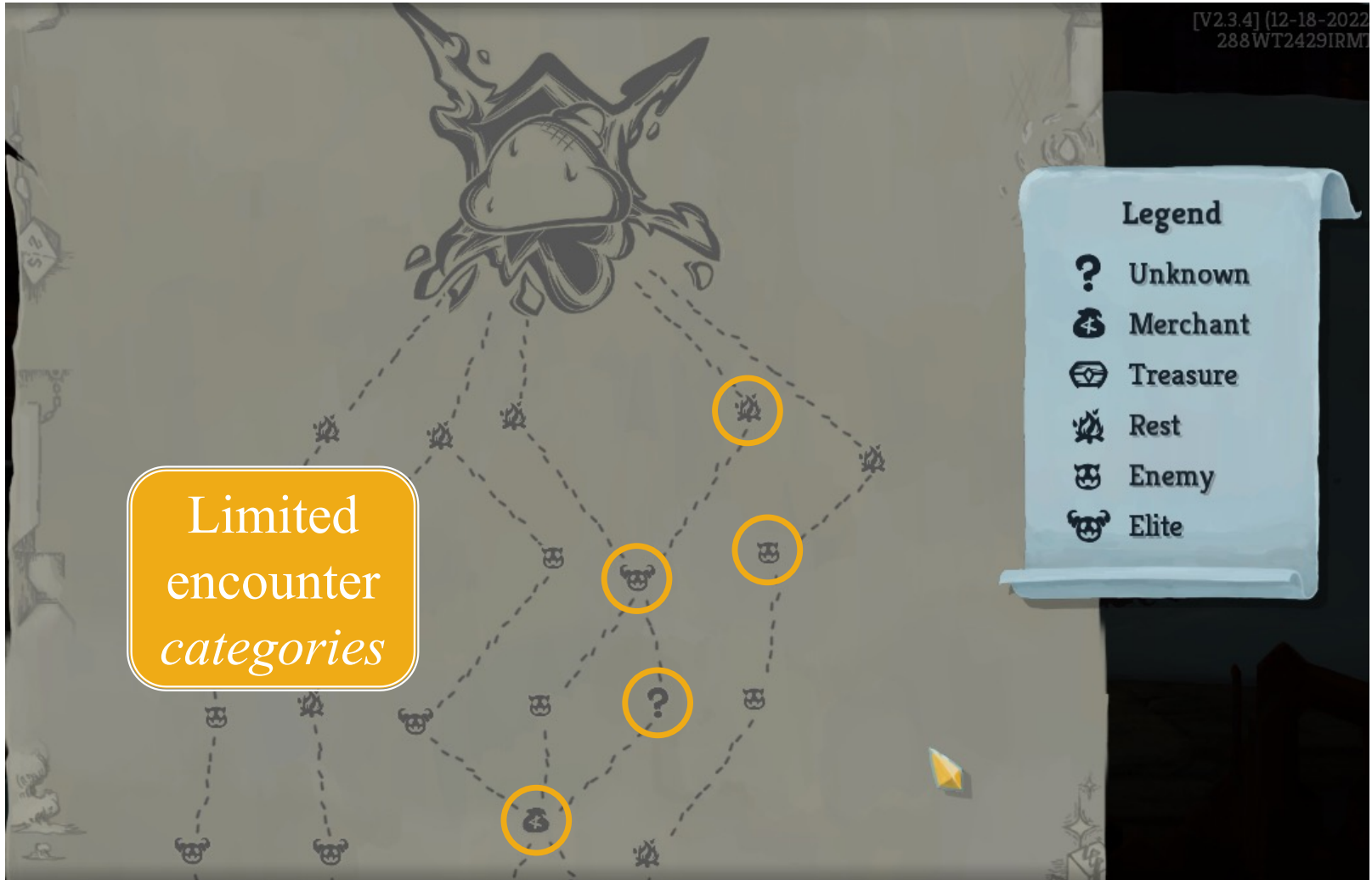
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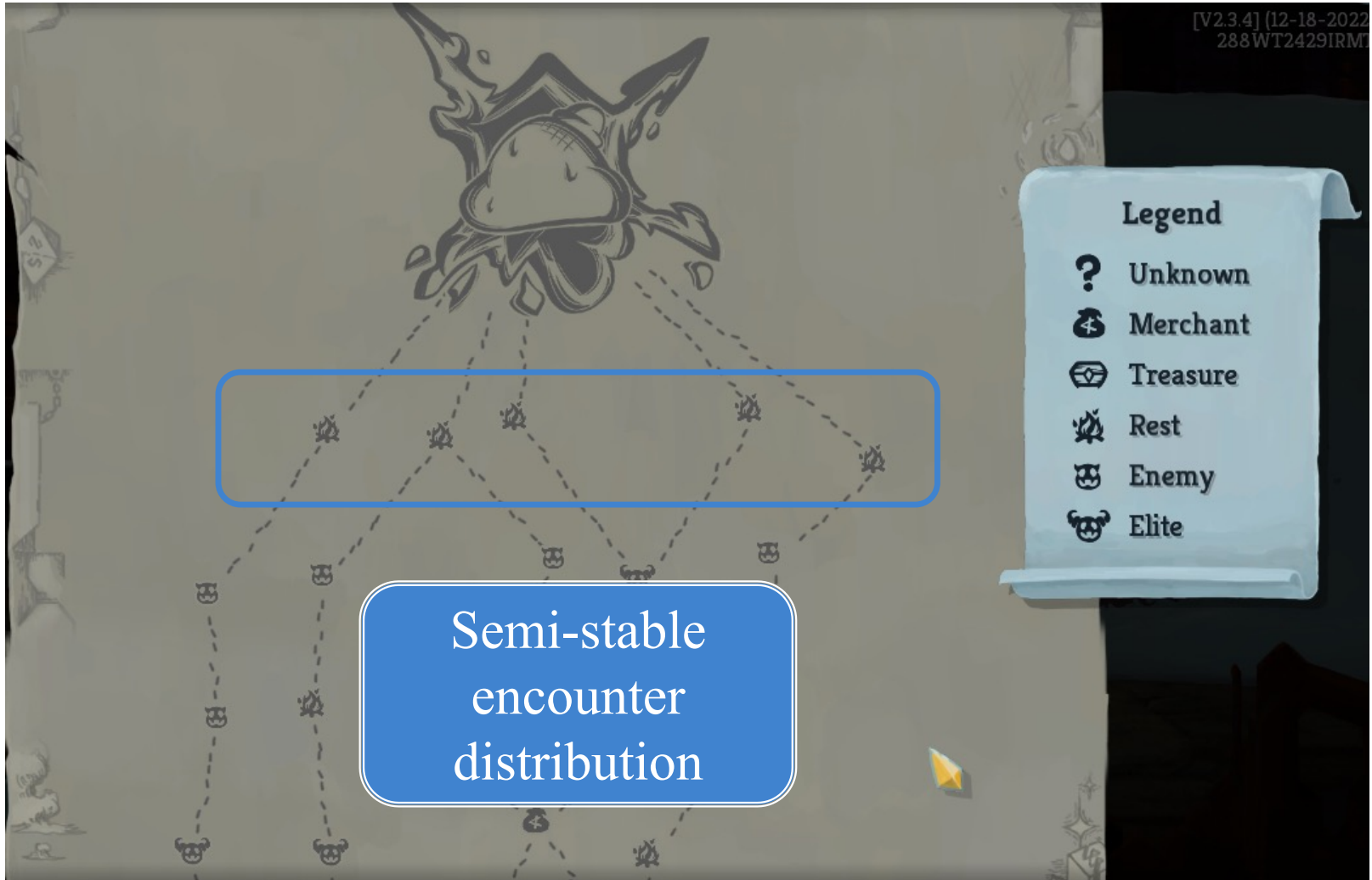
Case Study: *Slay the Spire*



Case Study: *Slay the Spire*



Case Study: *Slay the Spire*



Case Study: *Slay the Spire*



Other Considerations in *Slay the Spire*

- PCG includes card, relic and potion rewards
 - Like loot boxes, but rarity is tightly controlled
 - **Goal:** Ensure that a viable build is possible
- **Example:** Card Rewards
 - Each fight has a base rarity for each card
 - **Normal:** 3% Rare, 37% Uncommon, 60% Common
 - **Elite:** 10% Rare, 40% Uncommon, 50% Common
 - Numbers are offset by special percentage
 - Rares more likely each time a Common is rolled
 - Rolling a Rare resets the special percentage

Case Study: *Hades*



Case Study: *Hades*



Case Study: *Hades*

Choose from
exit options



Not Just Map Generation

- Tempting to think of all PCG like NetHack
 - Generate paths from entrance to exit
 - Randomly generate content in-between
 - Just make sure the content gets “harder”
- Good roguelites understand full progression
 - **Entrance** = player abilities at start of run
 - **Exit** = fight with final boss at end of run
 - Constrain the **ludic space**, not just geography
- **Recall:** Card rarity in *Slay the Spire*

Skyrim's Radiant Quest System

- Geography includes NPCs
 - Mobile, removable location
 - Dialogue is also a space
- System “randomly” chooses
 - Quest giver
 - Quest location
 - Location's challenges
 - Quest redeemer
- Randomness is limited
 - Lists appropriate to quest
 - Depends on earlier actions



- **Goals:**
 - Send to unexplored areas
 - Provide some predictability
 - Adjust challenges to level
 - Can never be missed

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Guarantees
reachability

- unexplored areas
- Provide some predictability
- Adjust challenges to level
- Can never be missed

But Sometimes a Problem



But Sometimes a Problem

Always have a fallback



Example: *Card Crawl*



Example: *Card Crawl*

Panic
Button



Grammars: A Formal Approach

• Notation

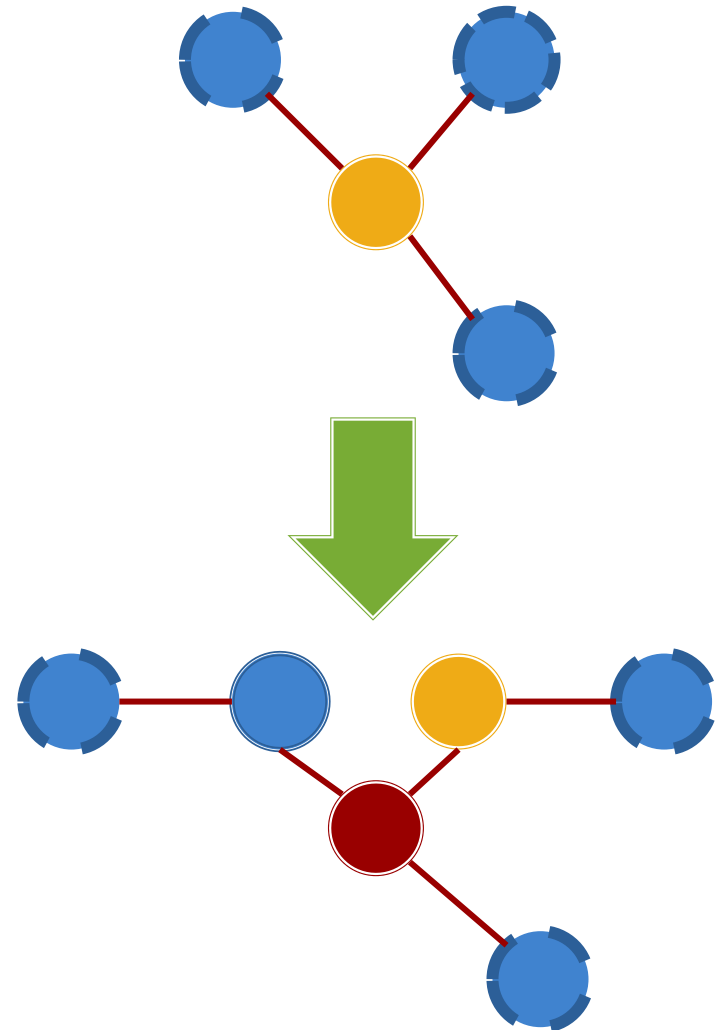
- Set \mathcal{N} of nonterminals
- Set Σ of terminal symbols
- Set \mathcal{P} of production rules
 - Have the form $A \Rightarrow B$
 - A, B are **words** of symbols
- To generate a value
 - Start with word XAY
 - Pick any rule $A \Rightarrow B$
 - Replace with XBY
 - Repeat until only terminals

Example

- $\mathcal{N} = \{S, B\}$
- $\Sigma = \{a, b, c\}$
- \mathcal{P} is the list of rules
 - $S \Rightarrow aBSc$
 - $S \Rightarrow abc$
 - $Ba \Rightarrow aB$
 - $Bb \Rightarrow bb$
- Possible **outputs**
 - $abc, aabbcc, aaabbbccc, \dots$

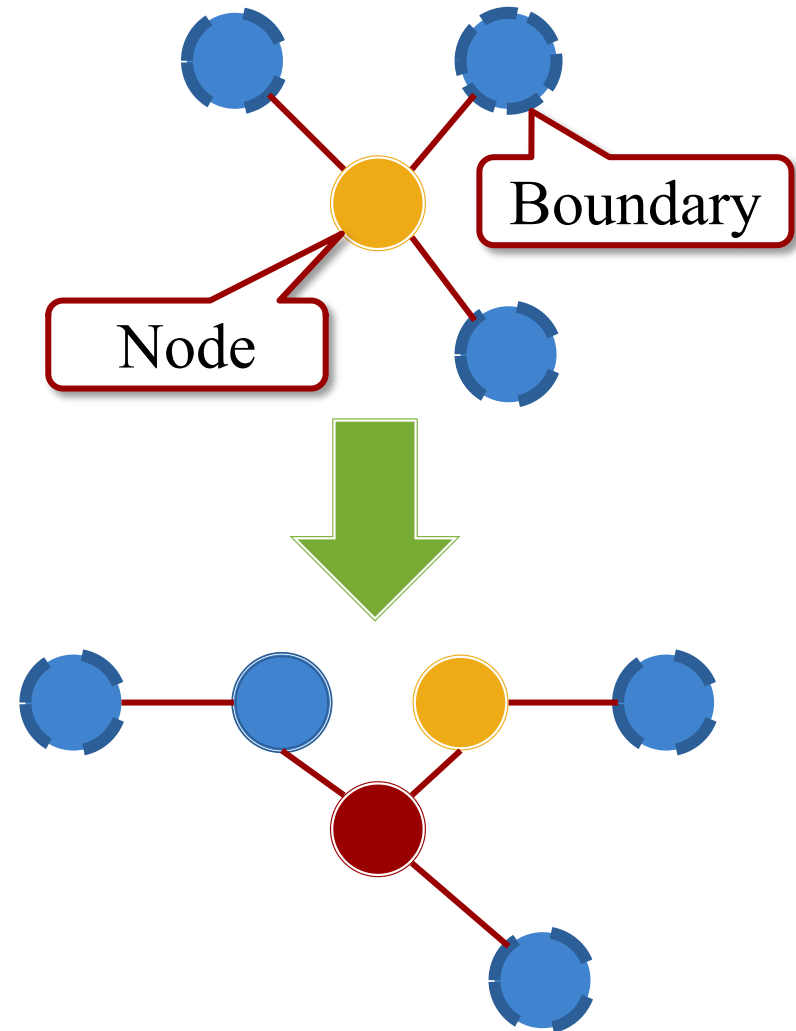
Grammars on Graphs

- Symbols are colored nodes
 - Either terminal or not
 - Edges replace word order
- Words are now graphs
 - Productions on subgraphs
 - LHS is node+boundary
 - RHS alters the node
- Output built as before
 - But rule matching harder
 - Graph equivalency



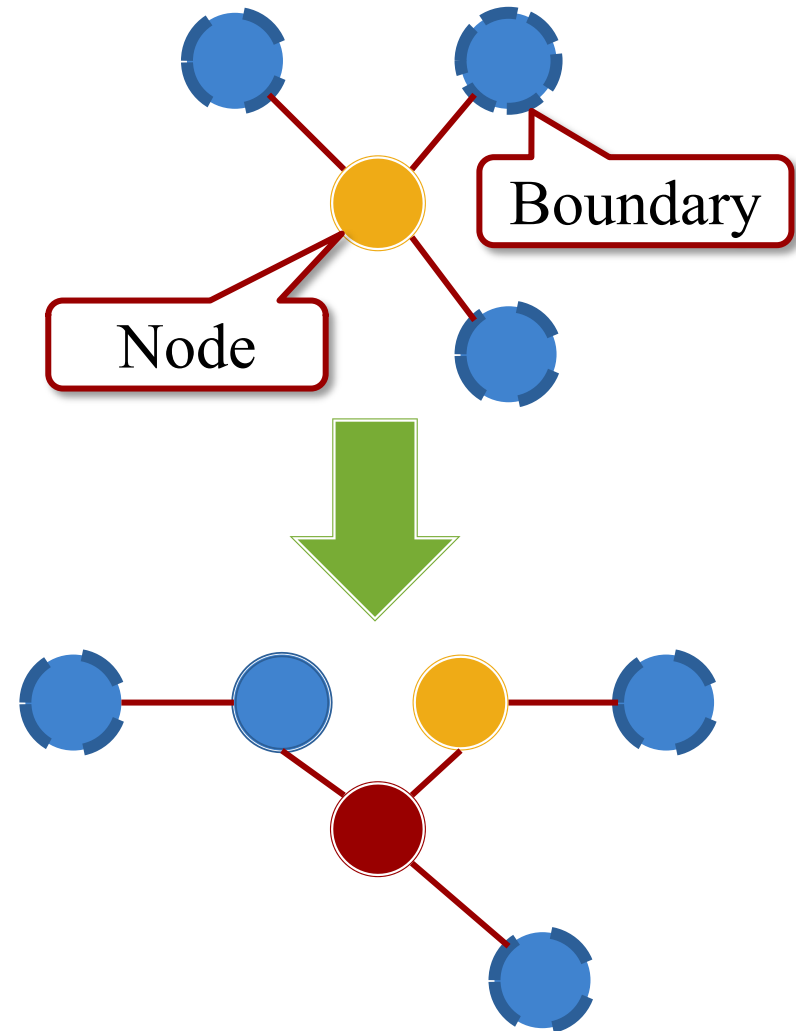
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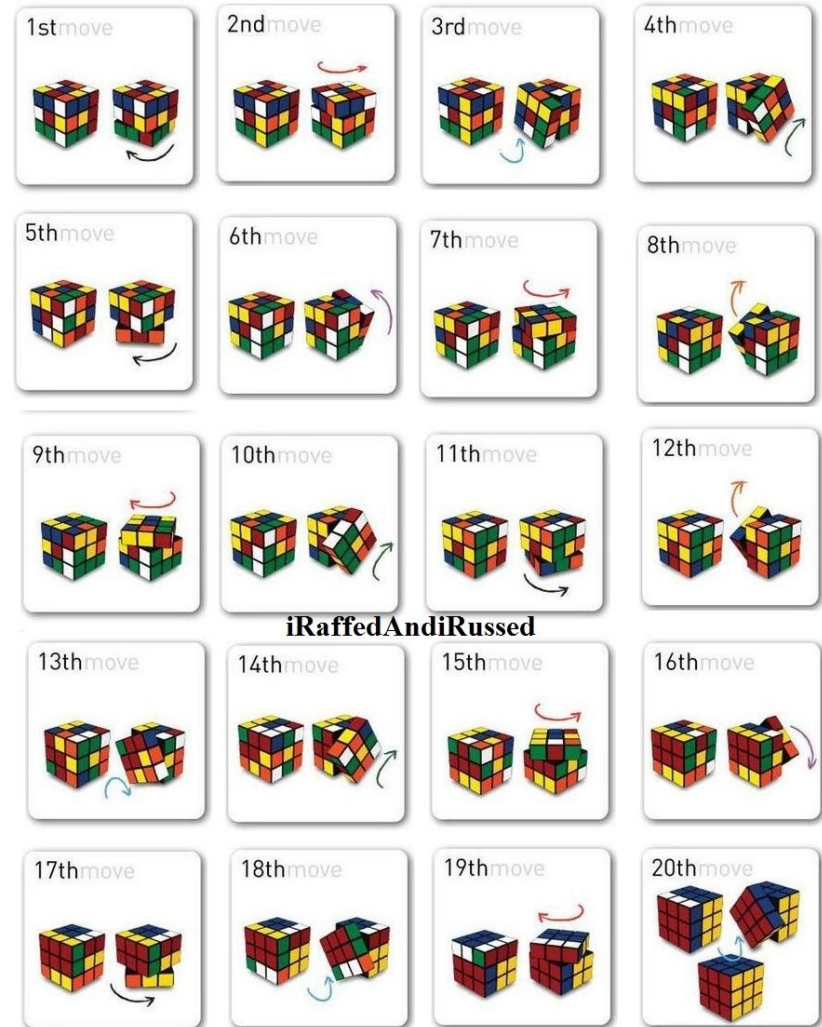
Grammars on Graphs

- Symbols are colored nodes
 - Either terminal or not
 - Edges replace word order
- Words are now graphs
 - Productions on subgraphs
- **Levels are a graph**
This alters the node
- Output built as before
 - But rule matching harder
 - Graph equivalency

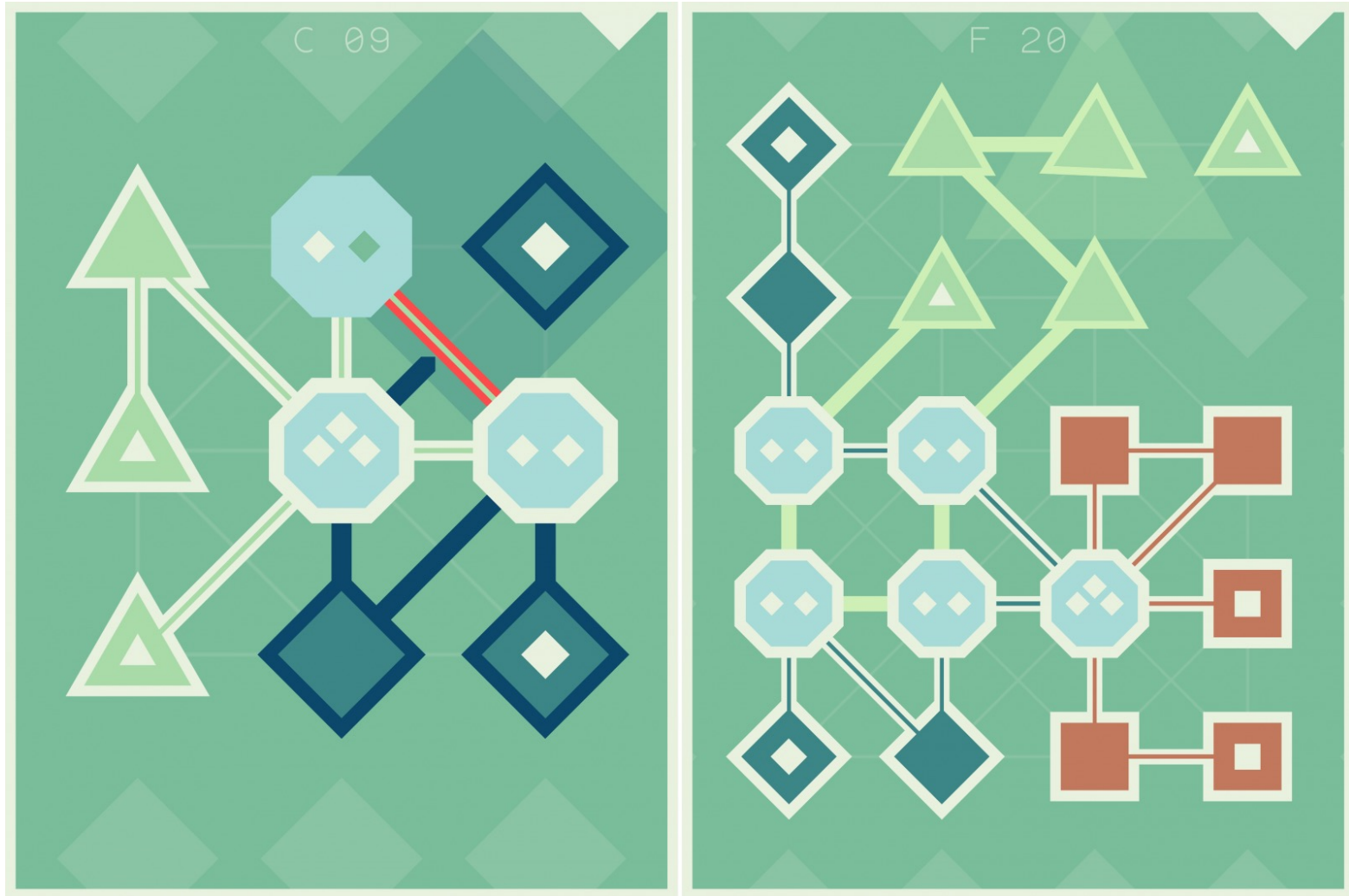


Puzzle Generation

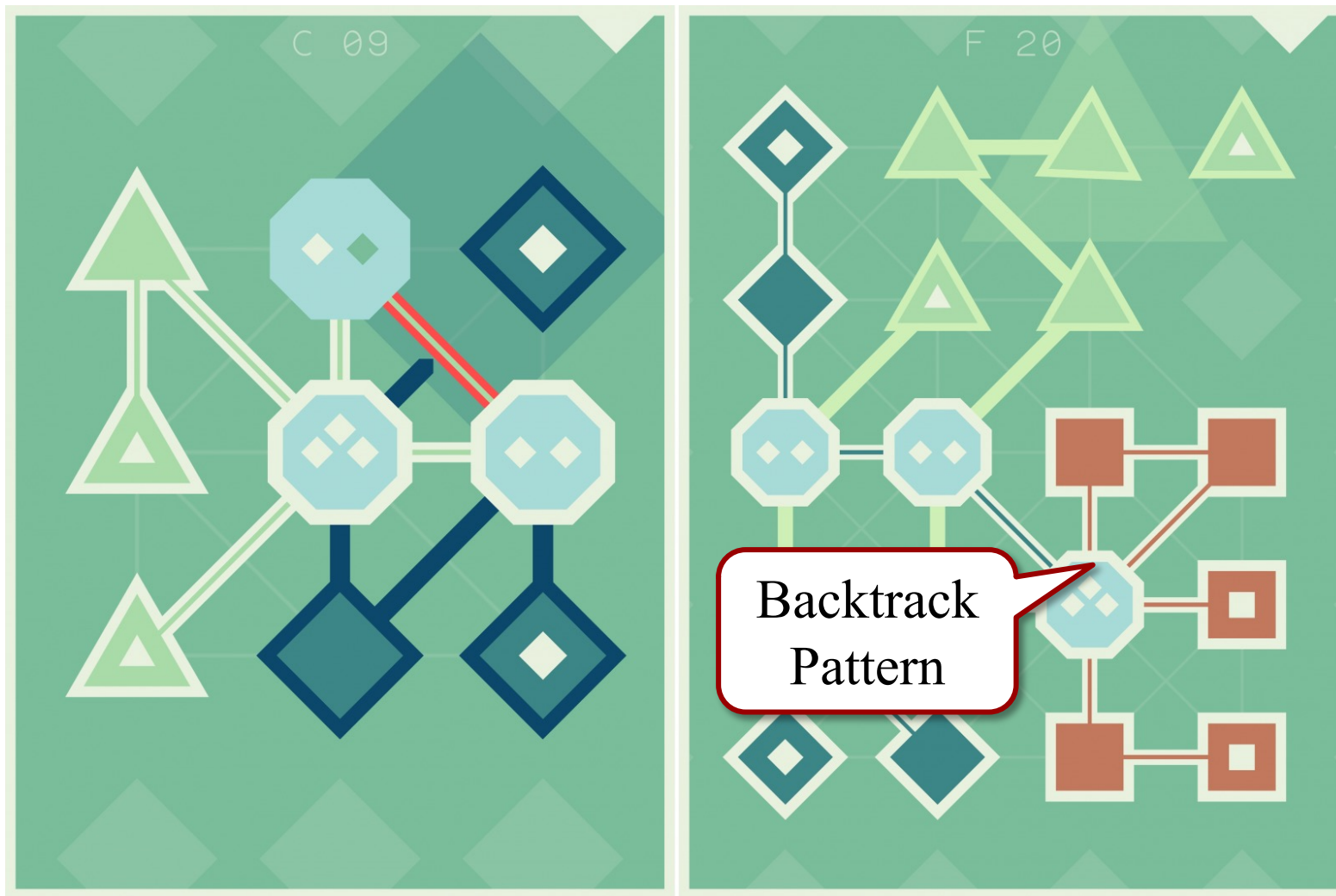
- Understand basic structure
 - Discrete actions/moves
 - Moves applied in sequence
 - **Goal:** get correct sequence
- Identify move sequences
 - Could be a loose category
 - Represent specific strategies
- Build up from sequences
 - Start from solved state
 - Invert moves (scrambling)
- Does require verification



Example: Lyne

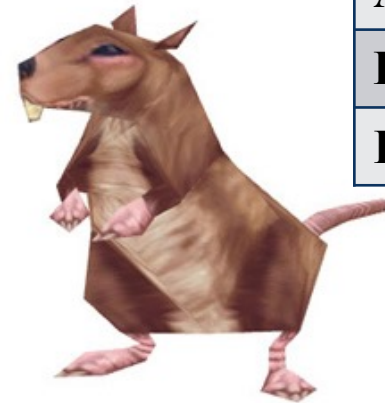


Example: Lyne



Dynamic Challenges

- Dynamic: adaptive challenges
 - Become easier or harder
 - Or are just different
- **Example:** Autoleveling
 - NPCs have statistics
 - Adjust to character level
 - Difficulty always reasonable
 - Allows true “open” world
- Not always popular
 - Can lead to design recycling
 - Sense of risk is lost



Rat: Level 1

ATK	1
DFN	0
HP	5



Rat: Level 50

ATK	30
DFN	10
HP	90

Other Types of Dynamic Challenges

- **Composite Challenges**

- Encounter is a collection of NPCs, obstacles
- Add or remove individuals from encounter

- **Dynamic NPC AI**

- NPCs have a choice of AI scripts
- Choose one that matches the player

- **Player Boosting**

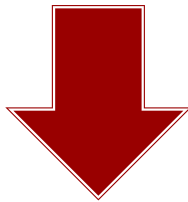
- Change result of player actions, interactions
- Modifications make challenges easier/harder

Assigning Dynamic Challenges

Player



Extract feature
vector from
play history



$(a_1, a_2, a_3, \dots, a_n)$

Challenge



Match the
challenge to
the play style



Parameterize
challenge
difficulty

$(b_1, b_2, b_3, \dots, b_k)$



Procedural Content

Assigning Dynamic Challenges

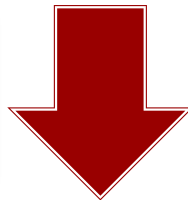
Player

Challenge



Matching Function is
hardest to balance

Extract feature
vector from
play history



Match the
challenge to
the play style



Parameterize
challenge
difficulty

$(a_1, a_2, a_3, \dots, a_n)$



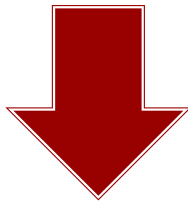
$(b_1, b_2, b_3, \dots, b_k)$

Adaptive Difficulty

Player

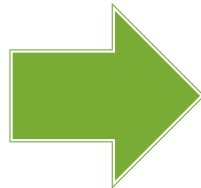


Extract feature
vector from
play history



$(a_1, a_2, a_3, \dots, a_n)$

Match via
machine
learning



Challenge



Parameterize
challenge
difficulty



$(b_1, b_2, b_3, \dots, b_k)$

Adaptive Difficulty

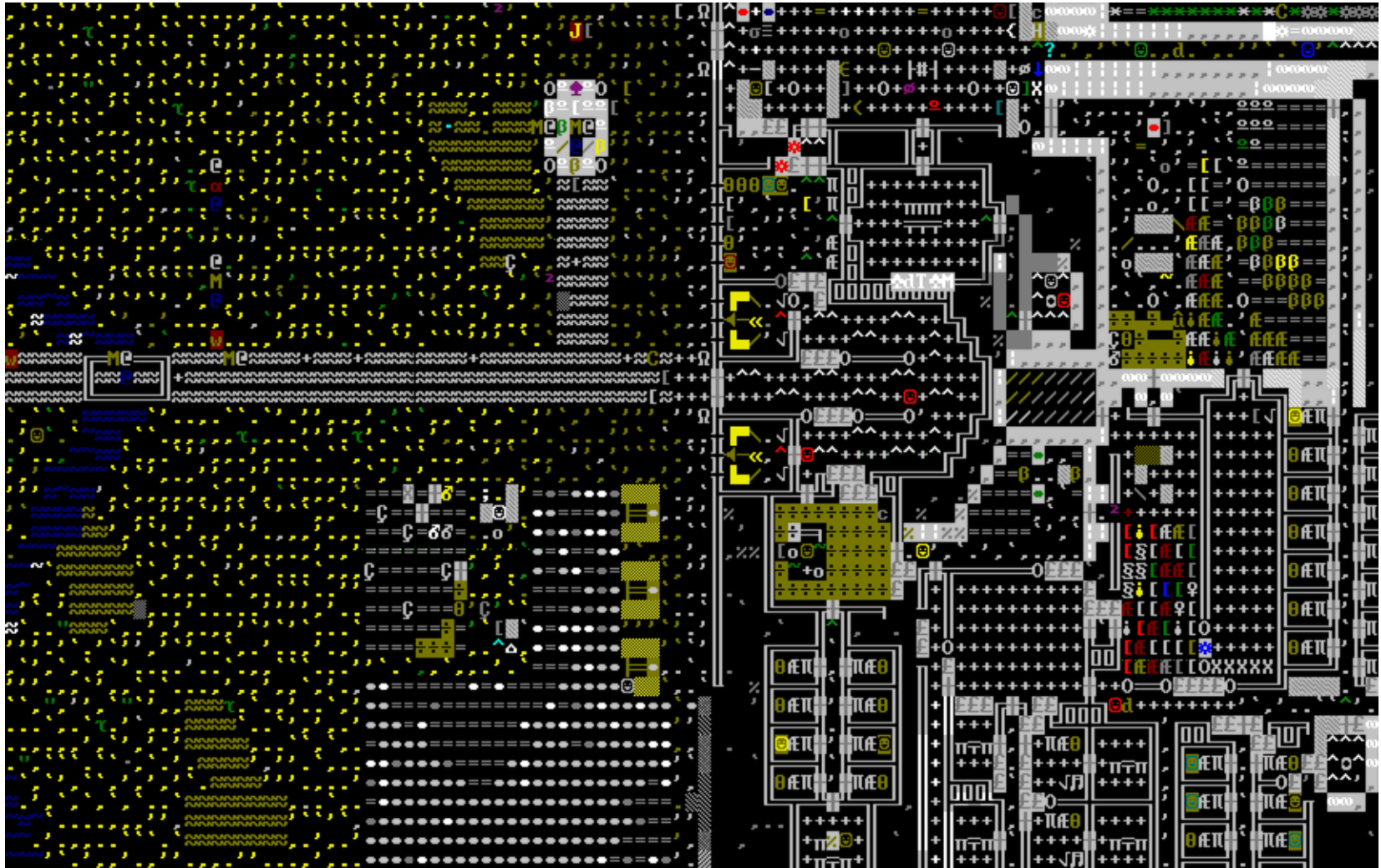
- Manually define the **gameplay model**
 - Metrics that identify player behavior
 - Parameters that define challenge behavior
 - Also metrics to evaluate player success or failure
- **Goal:** Use ML to find player-challenge match-up
 - Use playtesting/beta to get a large training set
 - Create an initial model from these results
 - Adjust in the game according to current player
- This has become popular in the industry

Story Generation

- **Narrative** is tightly crafted
 - Must have emotional arc
 - Very hard to generate
- But **backstory** is looser
 - Collection of tales/subplots
 - Combine to form a story
 - Often displayed in a codex
 - Much easier to generate
- **Idea:** Create list of subplots
 - Pick some subset at a time
 - Mix with NLG techniques



Example: Dwarf Fortress



Generative AI Has Promise Here

- Area known as **N**atural **L**anguage **G**eneration
 - **Given**: complex set of data
 - **Outcome**: commentary on that data
 - *Exactly* the problem LLMs are designed for

- **Examples**

- Sports commentary
- Party combat chatter
- Intelligent townsfolk



- Major topic of research in game studios

How Far Can We Take It?

Leaked Internal Sony Video Uses Horizon's Aloy to Show AI-Powered PlayStation Character Prototype

"This is just a glimpse of what is possible..."

A leaked internal video has revealed Sony is experimenting with AI-powered PlayStation characters.

[The Verge](#) reported on the emergence of an internal video allegedly created by PlayStation Studios' advanced technology group that uses Aloy from the Horizon games to demonstrate AI-powered game characters.

The video was subsequently pulled from YouTube following a copyright claim from Muso, an internet enforcement company The Verge said lists Sony Interactive Entertainment as a client. This suggests the video is legitimate. IGN has asked Sony for comment.

In the video, as reported by The Verge, Sony Interactive Entertainment director of software engineering, Sharwin Raghoebardajal, has a conversation with an AI-powered Aloy via voice prompts and AI-generated speech and facial animations.

Storytelling Has Constraints Too!

- Conversations in games have **purpose**
 - Start/end a quest
 - Inform us about a location/challenge
 - Define our character
 - Elicit reactions to our behavior
- We want this dialog to be **economical**
 - The NPC should not ramble
 - The information should be pertinent
 - The delivery should be dramatic
- But these are constraints LLMs can handle

Generative Storytelling

- **Hidden Door:** Founded by Hillary Mason
 - Former founder of Fast Forward Labs
 - Combining NLG and game development
- Games to support roleplaying in literary worlds
 - Interactive, but narrative-driven games
 - Targeting the fan fiction market
- Available to play, but still proof of concept
 - <https://www.hiddendoor.co>

Hidden Door

Create your **universe**.

Hidden Door is a platform for fans to roleplay in the worlds of their favorite books, movies, and TV shows.

Working directly with authors and IP holders, our Narrative AI allows us to collaboratively adapt existing works in just a few hours.

The game is a tabletop-like social adventure, with an “AI Dungeon Master” who provides controls for the rules of the world and safety.



Basic Idea: Story Templates

Combinatorial Tropes Contextualized Into Story

GDC Adventure



Pride & Prejudice & Hackers



ML/LLMs to Convert “In Universe”

Example

active threads

- Find your Lost Friend
- Hack a Device
- COMPLICATION: Curious Guard

player character

- Nyall Sektyr (they/them)
- Roguish hacker
- Petabytes of charm ins...

current location

- The MPD Datastacks
- Secure Police Databas...
- Outsourced Security

previous turn

You lean back from the console with a grin, trace successfully deployed.

You nearly fall out of your chair when a part-time security guard turns the corner and sees you. He starts to approach.

“Who are you? What are you doing here?”

```
ThreadTemplate
name="flirtatious_conversation",
display_name="Flirtatious Conversation",
objective="Win over the target's affection",
description="Engage in a conversation with romantic or seductive undertones to establish a connection.",
intro="the protagonist begins to flirt with {person}",
variables={
  "person": {"entity_type": "character", "fill_on_instantiation": True},
  "interest_level": {"incantation": "the current level of {person}'s romantic interest"},
  "specific_interest": {"incantation": "something that {person} is particularly interested in"},
},
elements=[
  {"element": "{person} consents to participating in a conversation", "required": True},
  {"element": "charm {person} with witty banter", "after": "consent"},
  {"element": "{person} is intrigued with protagonist's mention of {specific_interest}"},
  {"element": "{person} subtly indicates their {specific_interest}"},
  {"element": "receive a positive response from {person}"},
  {"element": "the conversation turns affectionate"},
],
complications=[
  "a rival intervenes and competes for person's attention",
  "person misinterprets the protagonist's intentions",
  "the conversation becomes awkward",
],
ends_when={
  "success": [
    "the protagonist successfully gains {person}'s affection",
    "the conversation ends on friendly terms",
  ],
  "failure": [
    "{target} has no interest in flirtation with the protagonist",
    "{target} becomes offended or uncomfortable",
  ],
},
}
```

player intent

I disarm the guard with some flirtatious conversation.

mediating rules

Difficulty Social Challenge
Aid: Petabytes of Charm Installed
Result: SUCCESS!

fill variables

PERSON: Security Guard
INTEREST LEVEL: Low
SPECIFIC INTEREST: Gundams

intro

You disarm the guard with a gentle smile and a compliment on their polyester uniform.

He sniffs and rubs the whiskers on his wispy chin. “Gee, thanks...”

Between your natural charisma and their lack of dedication to the job, you’ve disrupted their security protocols.



Summary

- Procedural content started with Rogue(likes)
 - Randomly generated, but reasonable-looking maps
 - Coupled with permadeath, horizontal design
- Content generation requires **constraints**
 - Unconstrained levels are not solvable
 - Current tech cannot adapt to LLMs
- **Natural Language Generation** is the hot topic
 - This is the application LLMs were designed for
 - Technology here is bleeding-edge, proof-of-concept

Summary

- Procedural content started with Rogue(likes)
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- Content
 - Unco
 - Curre
- **Natural Language Generation** is the hot topic
 - This is the application LLMs were designed for
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Procedural Content Wiki:
<http://pcg.wikidot.com>