the gamedesigninitiative
at cornell university

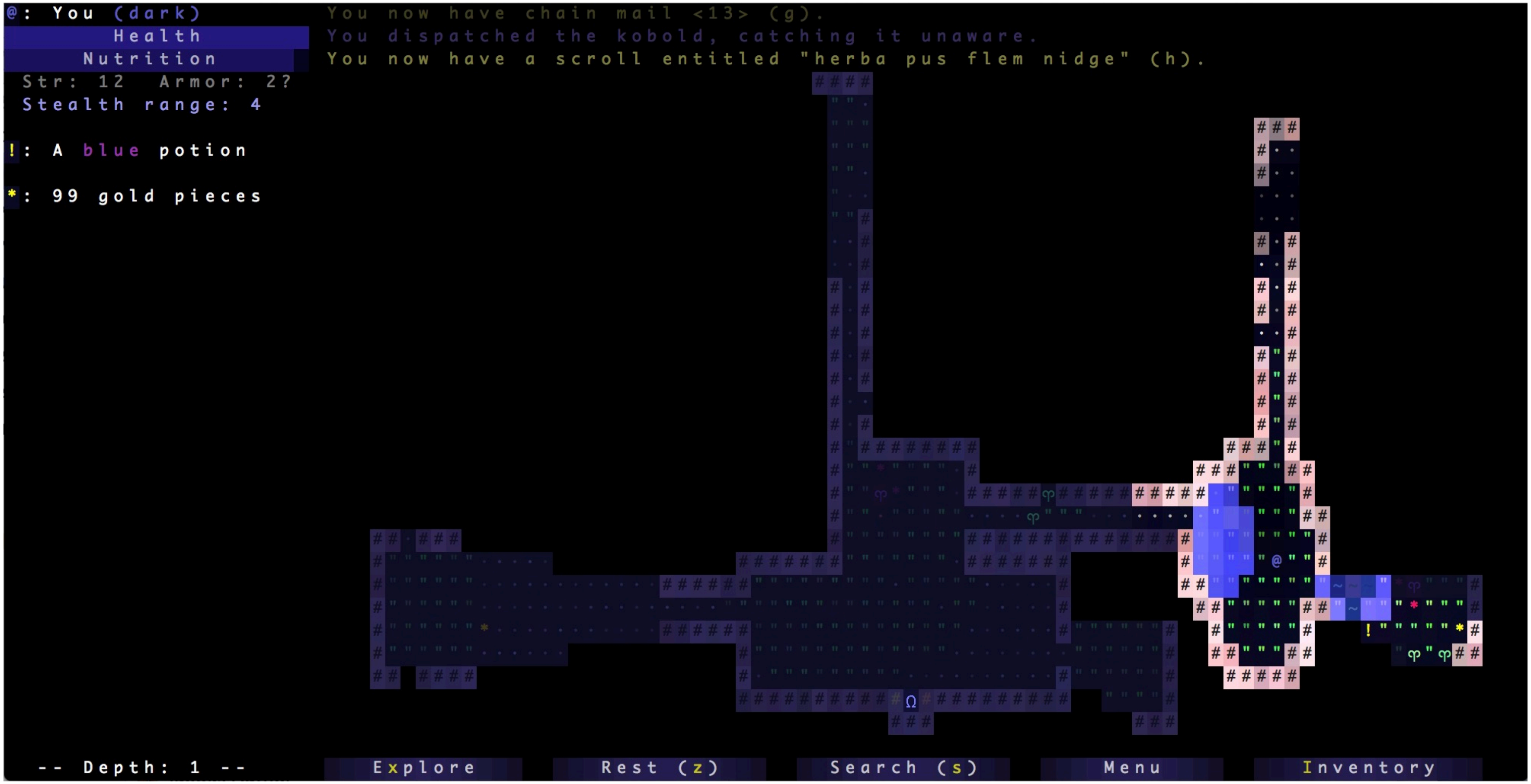
Lecture 15

Procedural Content Generation

Important 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**

In the Beginning, There Was *Rogue*



@: You (dark)

Health

Nutrition

Str: 12 Armor: 2?

Stealth range: 4

!: A blue potion

*: 99 gold pieces

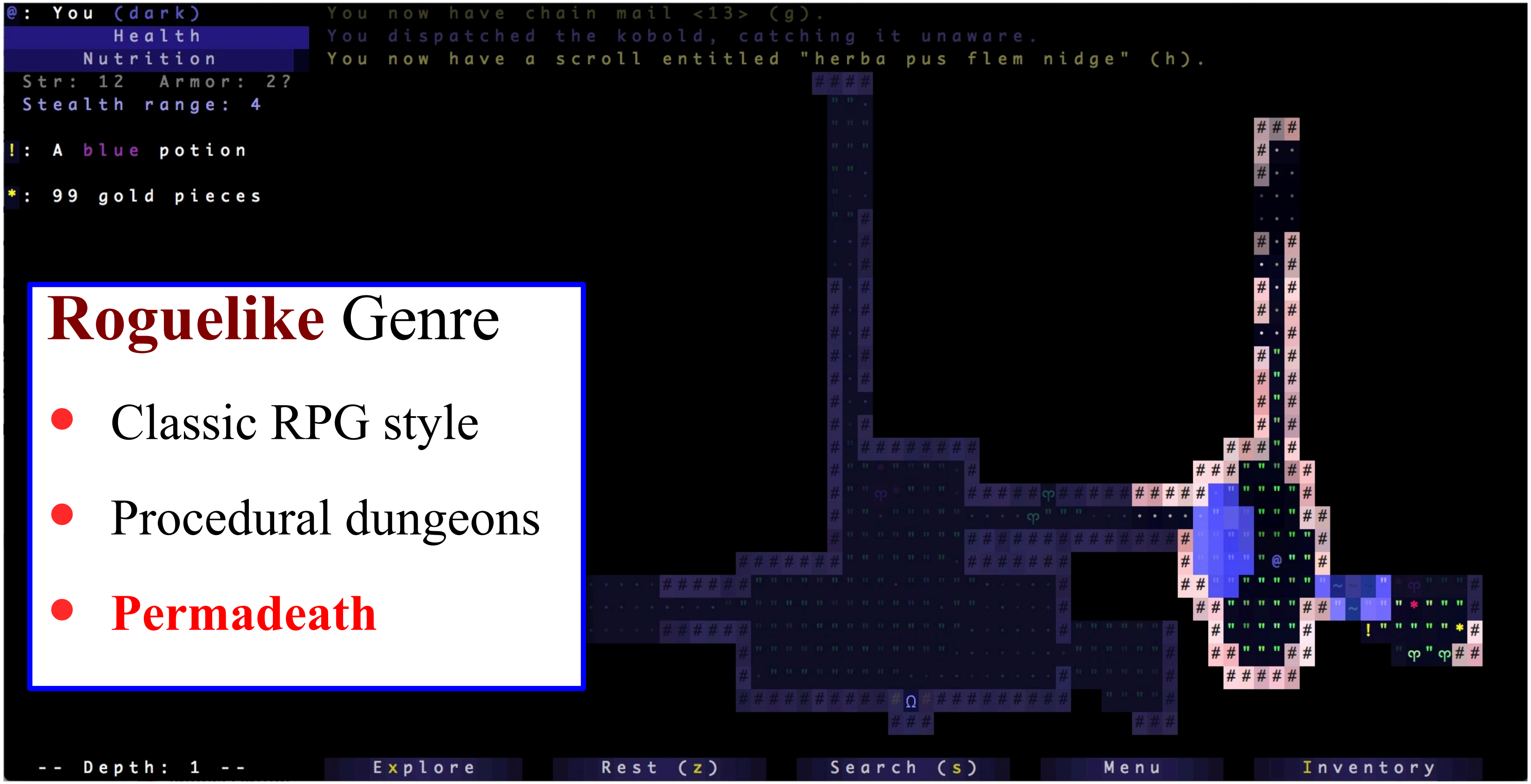
You now have chain mail <13> (g).

You dispatched the kobold, catching it unaware.

You now have a scroll entitled "herba pus flem nidge" (h).

-- Depth: 1 --

In the Beginning, There Was *Rogue*



```
@: You (dark)
      Health
    Nutrition
  Str: 12    Armor: 2?
  Stealth range: 4

!: A blue potion

*: 99 gold pieces
```

```
You now have chain mail <13> (g).
You dispatched the kobold, catching it unaware.
You now have a scroll entitled "herba pus flem nidge" (h).
```

```
-- Depth: 1 --
```

Roguelike Genre

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

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

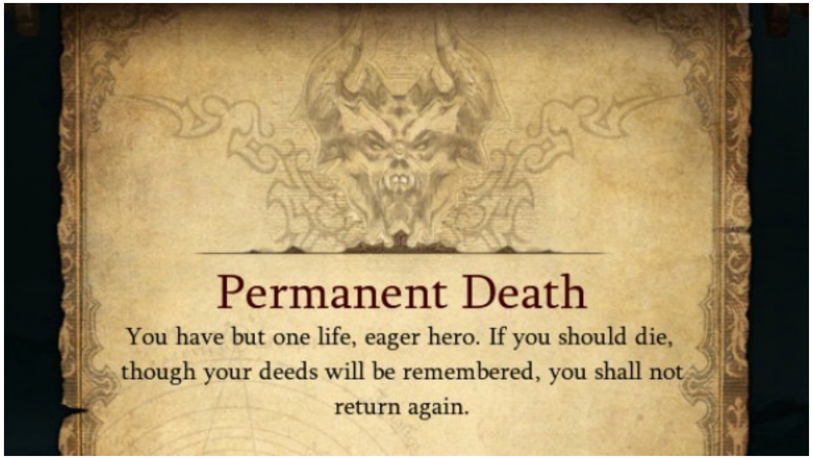
Changing Perspectives on Permadeath

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



Permanent Death

You have but one life, eager hero. If you should die, though your deeds will be remembered, you shall not return again.

Changing Perspectives on Permadeath

Advantages

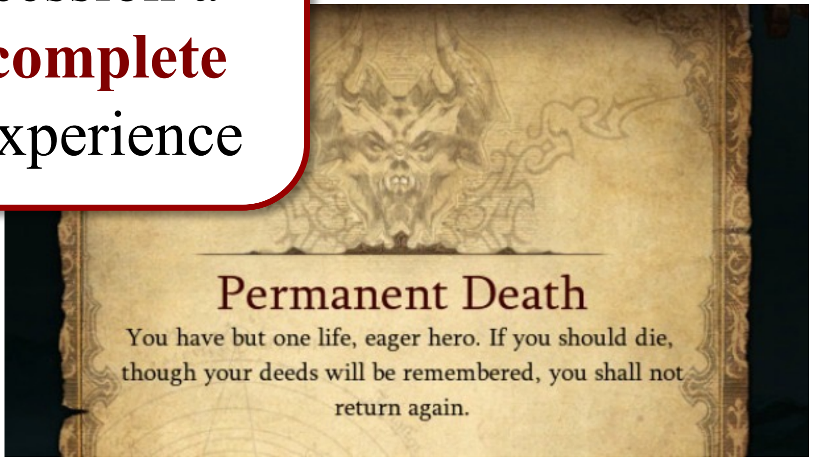
- Greater ch
  - Used as a
- Higher em
  - Easy to i

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



Permanent Death

You have but one life, eager hero. If you should die, though your deeds will be remembered, you shall not return again.

Changing Perspectives on Permadeath

Advantages

- Greater ch
  - Used as a
- Higher em
  - Easy to i

Make dying expected & **inevitable**

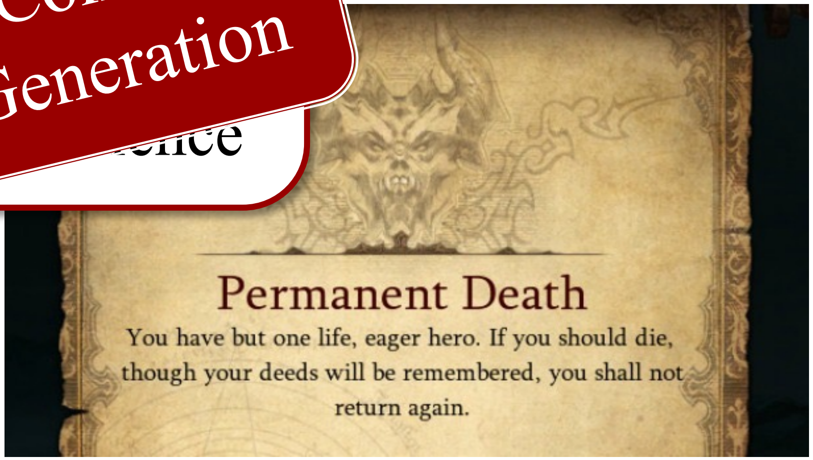
Mak

ence

Content Generation

Disadvantages

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

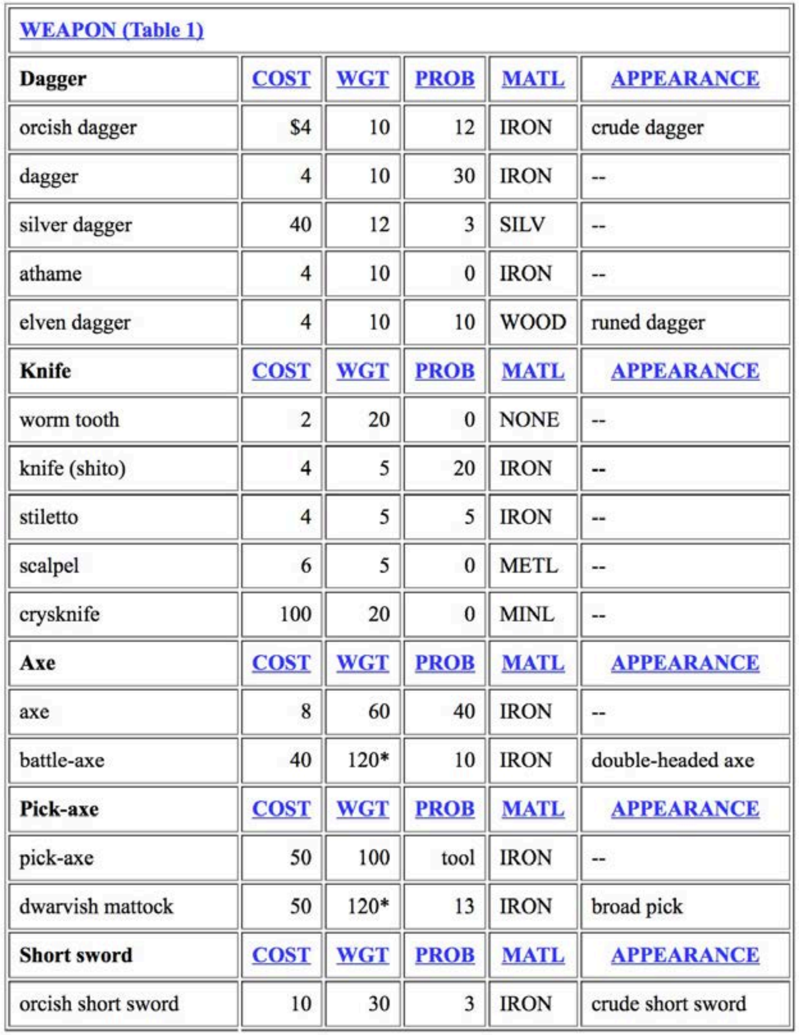


Permanent Death

You have but one life, eager hero. If you should die, though your deeds will be remembered, you shall not return again.

Issues with Roguelikes

- 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



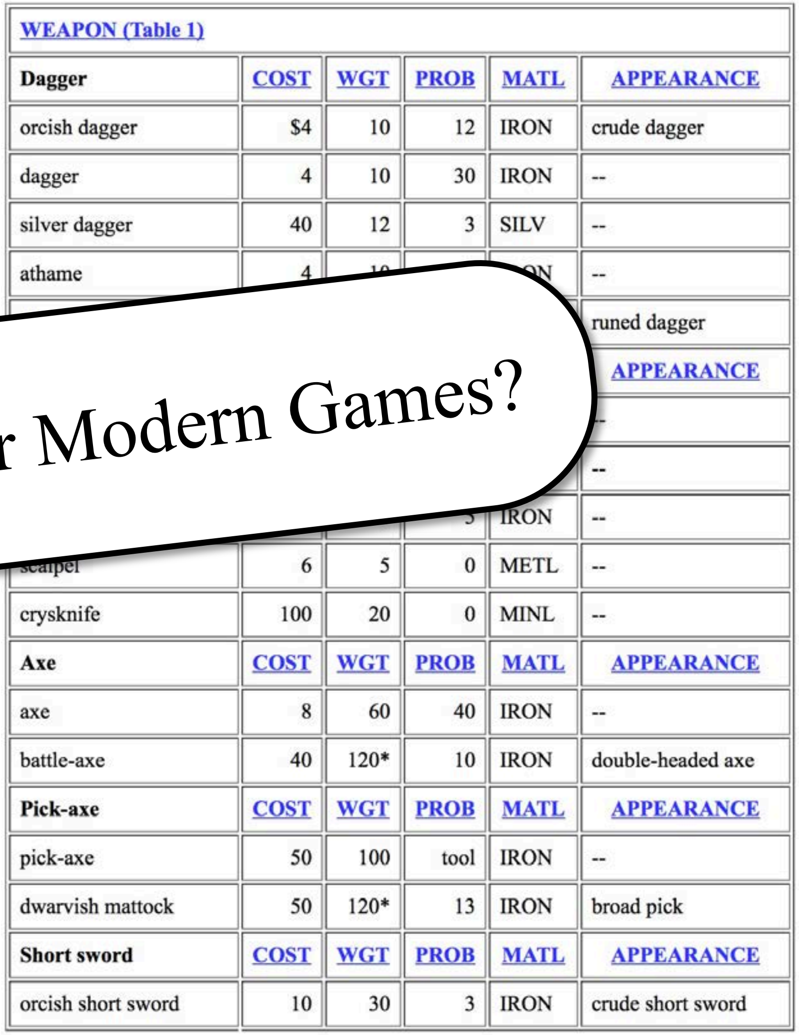
WEAPON (Table 1)

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

Issues with Roguelikes

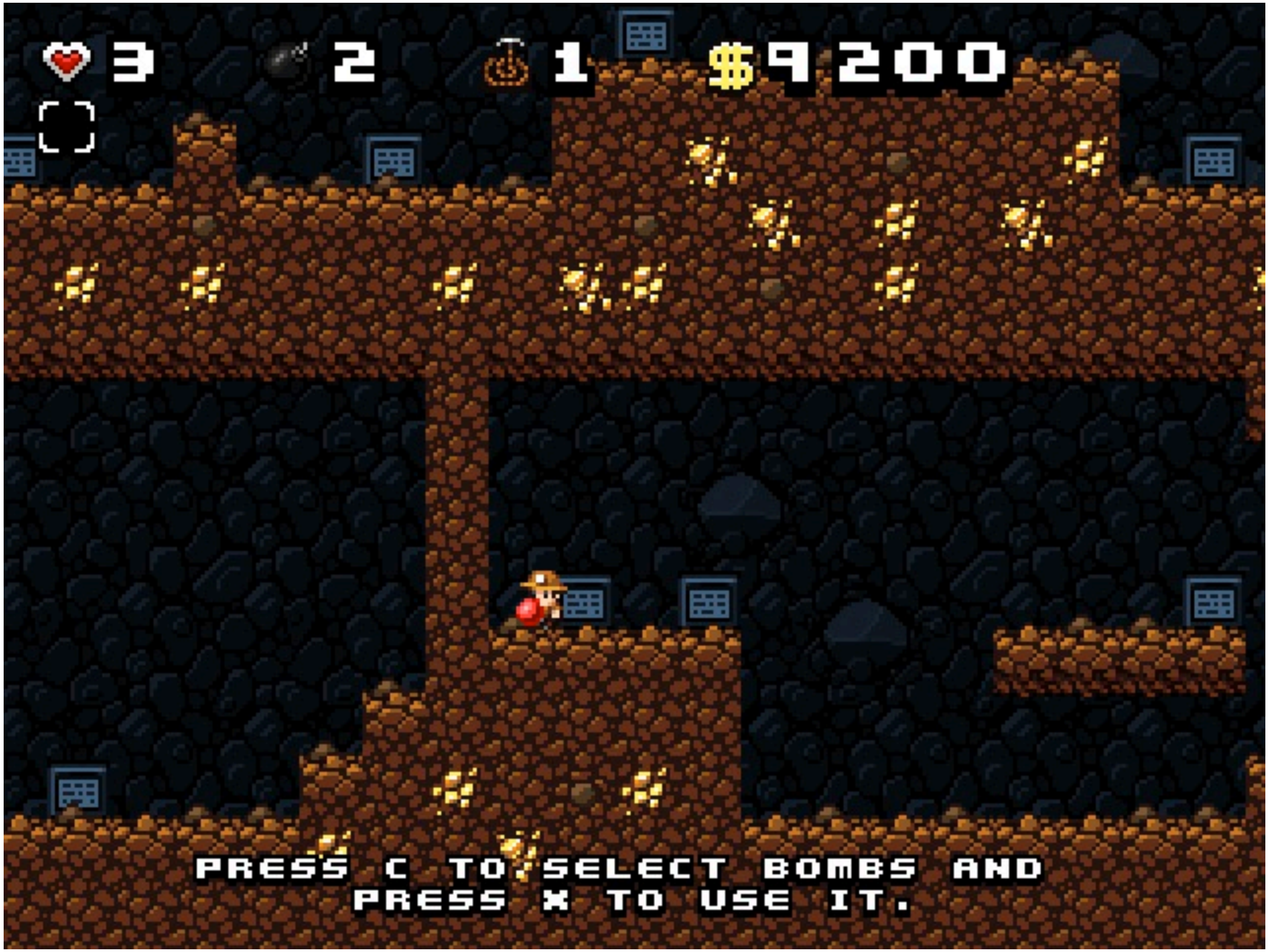
- Design is often **horizontal**
  - Many verbs, game elements
  - Little coupled behavior
- Each play is a **slice**
  - A
  - W
- “Expensive” to create
  - Requires a lot of content
  - But historically just text
- Difficult to balance

Procedural Content for Modern Games?

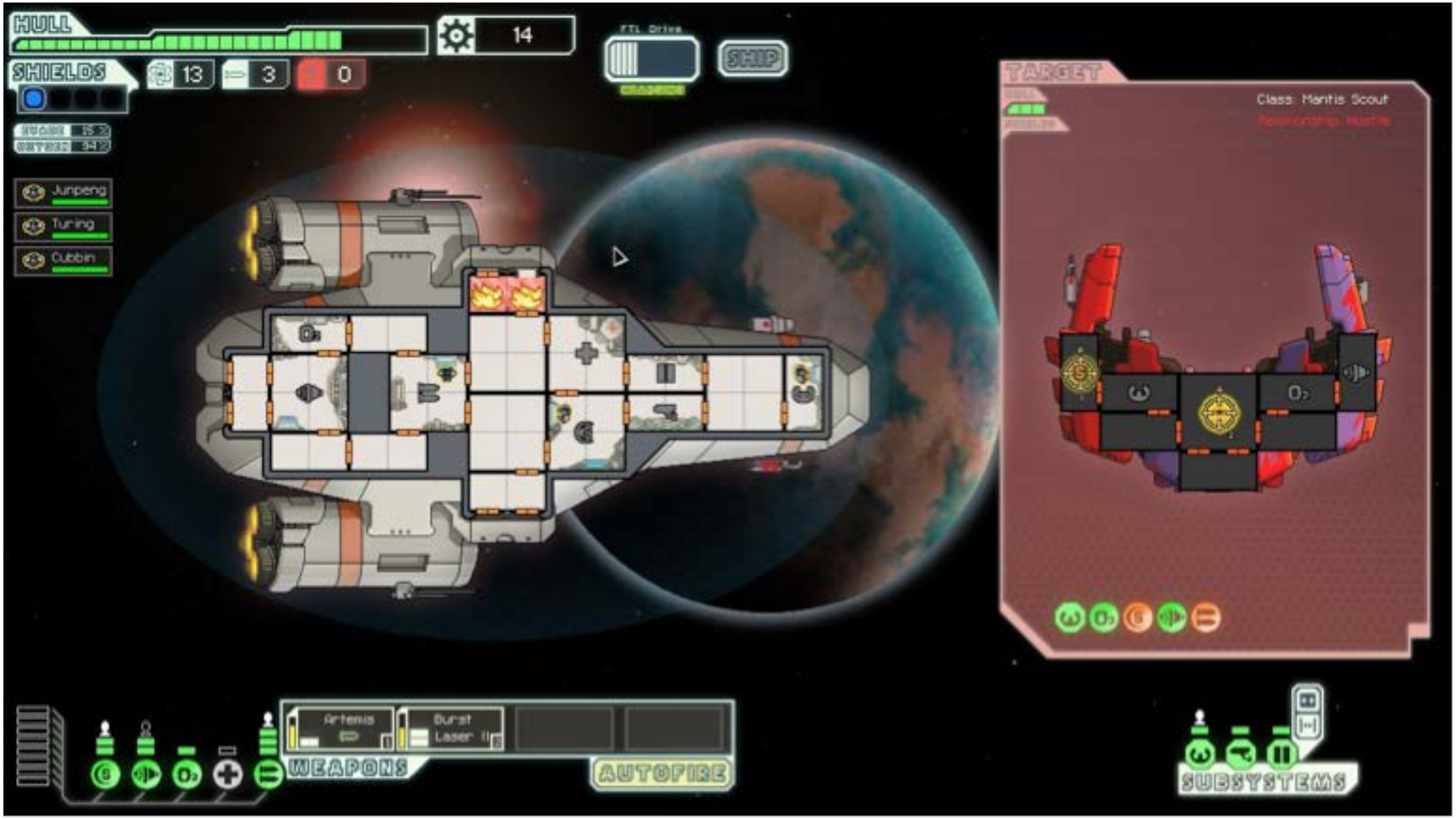


WEAPON (Table 1)					
Dagger	COST	WGT	PROB	MATL	APPEARANCE
orcish dagger	$4	10	12	IRON	crude dagger
dagger	4	10	30	IRON	--
silver dagger	40	12	3	SILV	--
athame	4	10		IRON	--
					runed dagger
					APPEARANCE
					--
					--
			5	IRON	--
scalpel	6	5	0	METL	--
crysknife	100	20	0	MINL	--
Axe	COST	WGT	PROB	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

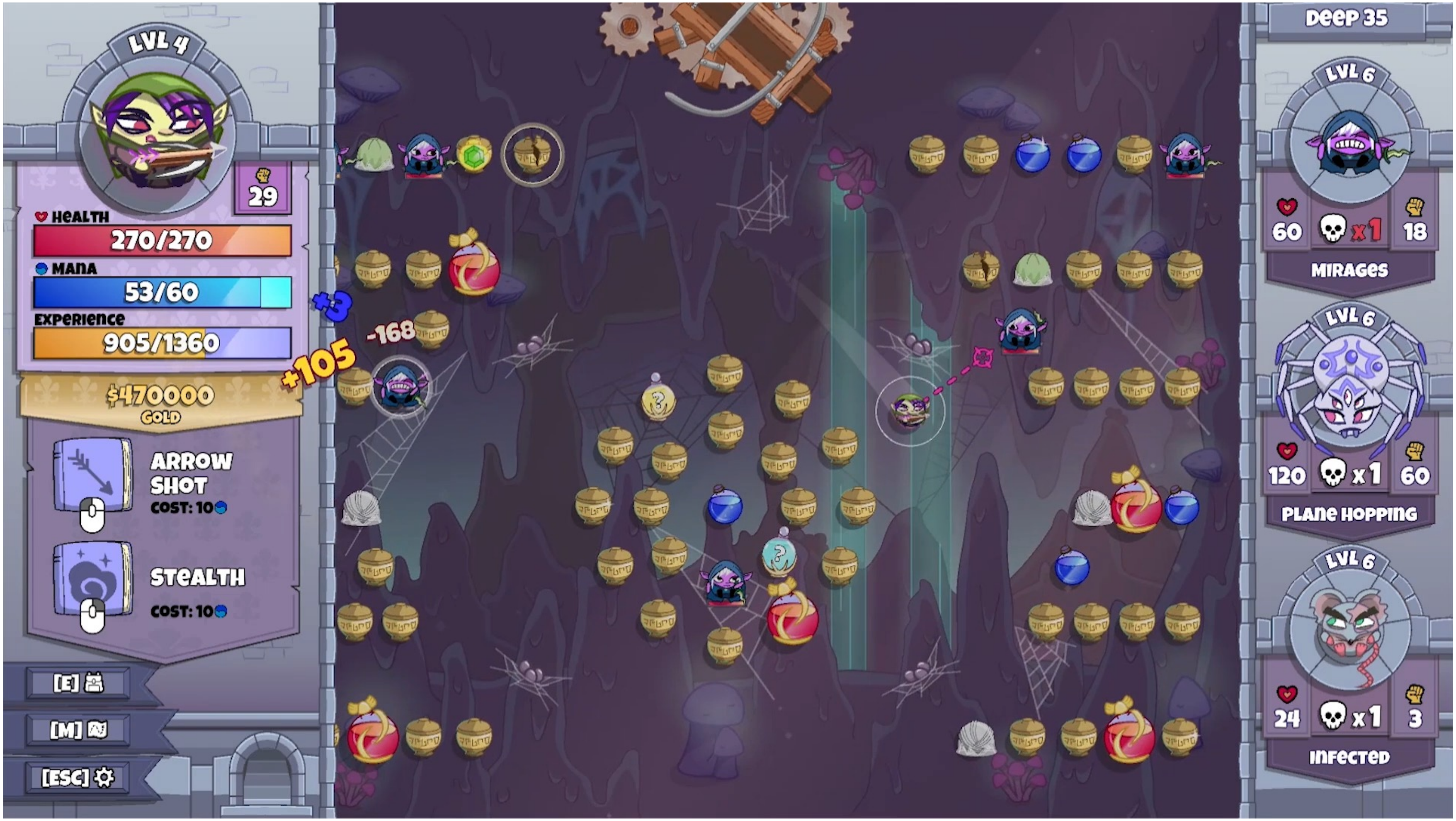
Modern Roguelikes: *Spelunky*



Modern Roguelikes: *FTL*



Modern Roguelikes: *Roundguard*



Main Types of Procedural Content

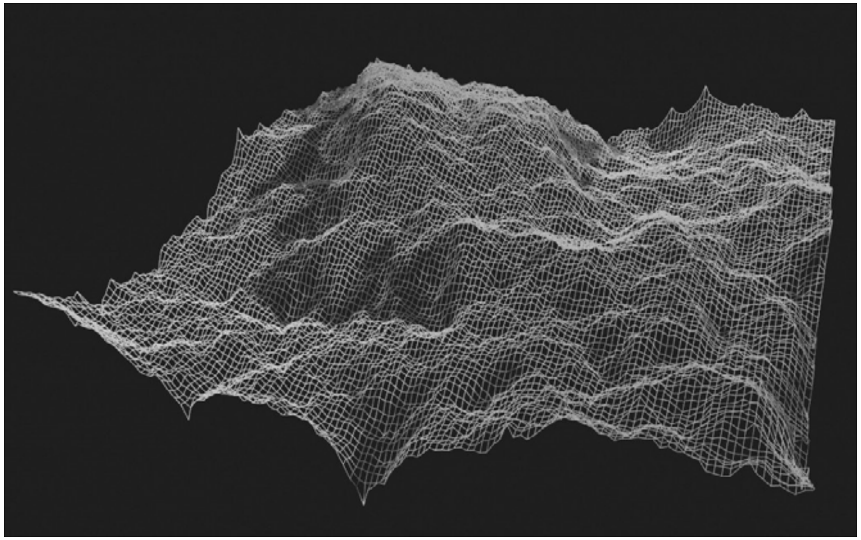
- Simulation
- World Generation
- Puzzle Generation
- Story Generation
- Dynamic Challenges
- Adaptive Difficulty

Procedural Content Wiki:

http://pcg.wikidot.com

Simulation

- Complexity appears random
- Often a physical process
  - Fires, Fluids, Weather
  - Terrain generation
  - Artificial life
- **Teleological**
  - Run the full simulation
  - Accurate; hard to control
- **Ontological**
  - Create reasonable output
  - Inaccurate; easy to control



Simulation

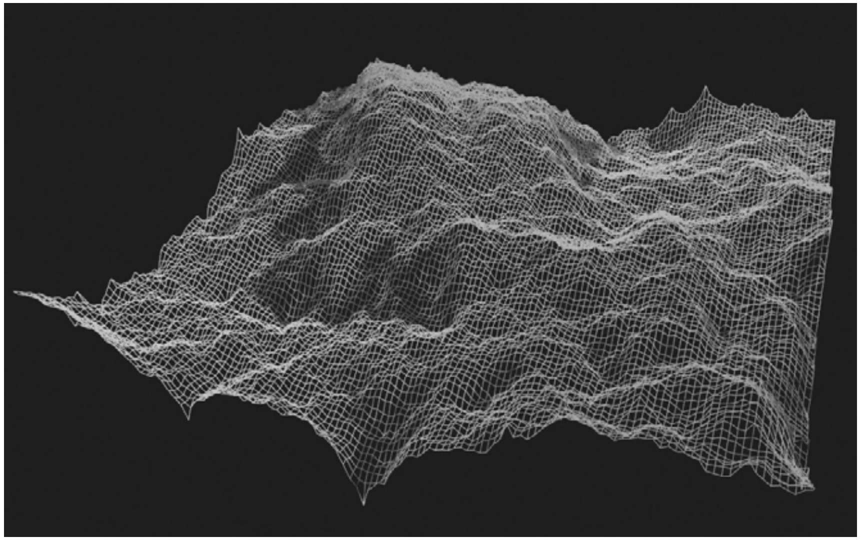
- Complexity appears random
- Often a physical process
  - Fires, Fluids, Weather
  - Terrain generation
  - Artificial life
- **Teleological**
  - P

  o control
- **Ontological**

  , easy to control

Scientific Computing

Ad Hoc Algorithms



Simulation

- Complexity appears random
- Often a physical process
  - Fires, Fluids, Weather
  - Terrain generation
  - Artificial life
- **Teleological**
  - P

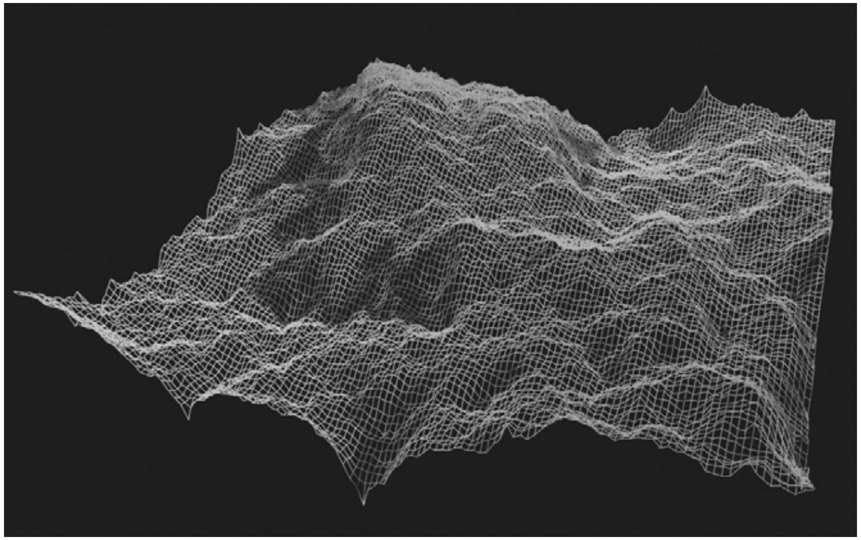
  to control

Scientific Computing

- **Ontological**

  , easy to control

Ad Hoc Algorithms

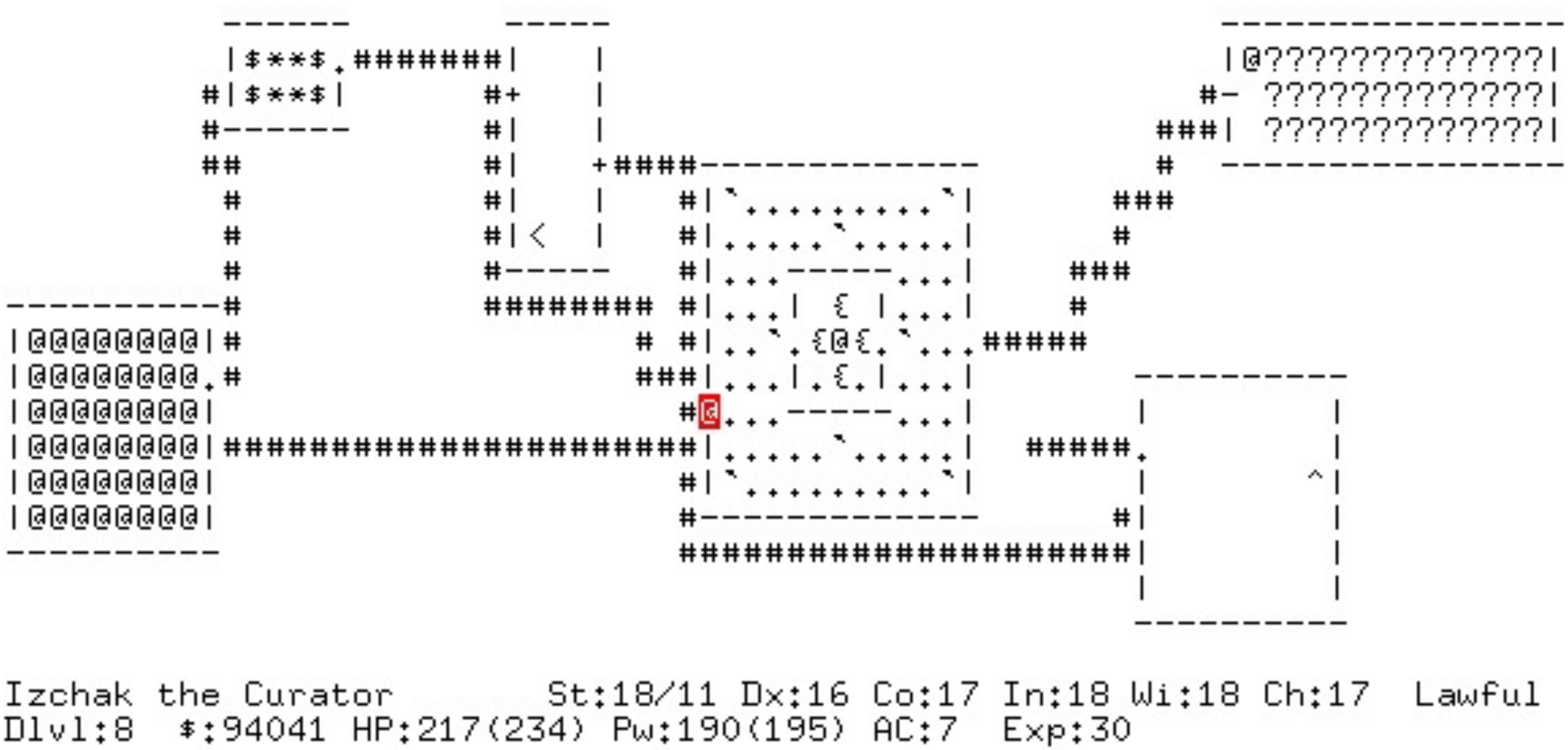


- Minimal effect on gameplay
  - Often largely aesthetic
  - Hard to control difficulty
- Lot of work for little payoff

World Generation

- Often thought of as map generation
  - But really generation of game ***geography***
  - Particularly broad category of PCG
- **Basic Format**
  - Start with basic geography building blocks
  - Include combination rules for blocks
  - Build until reach a stopping point
- Algorithms vary widely

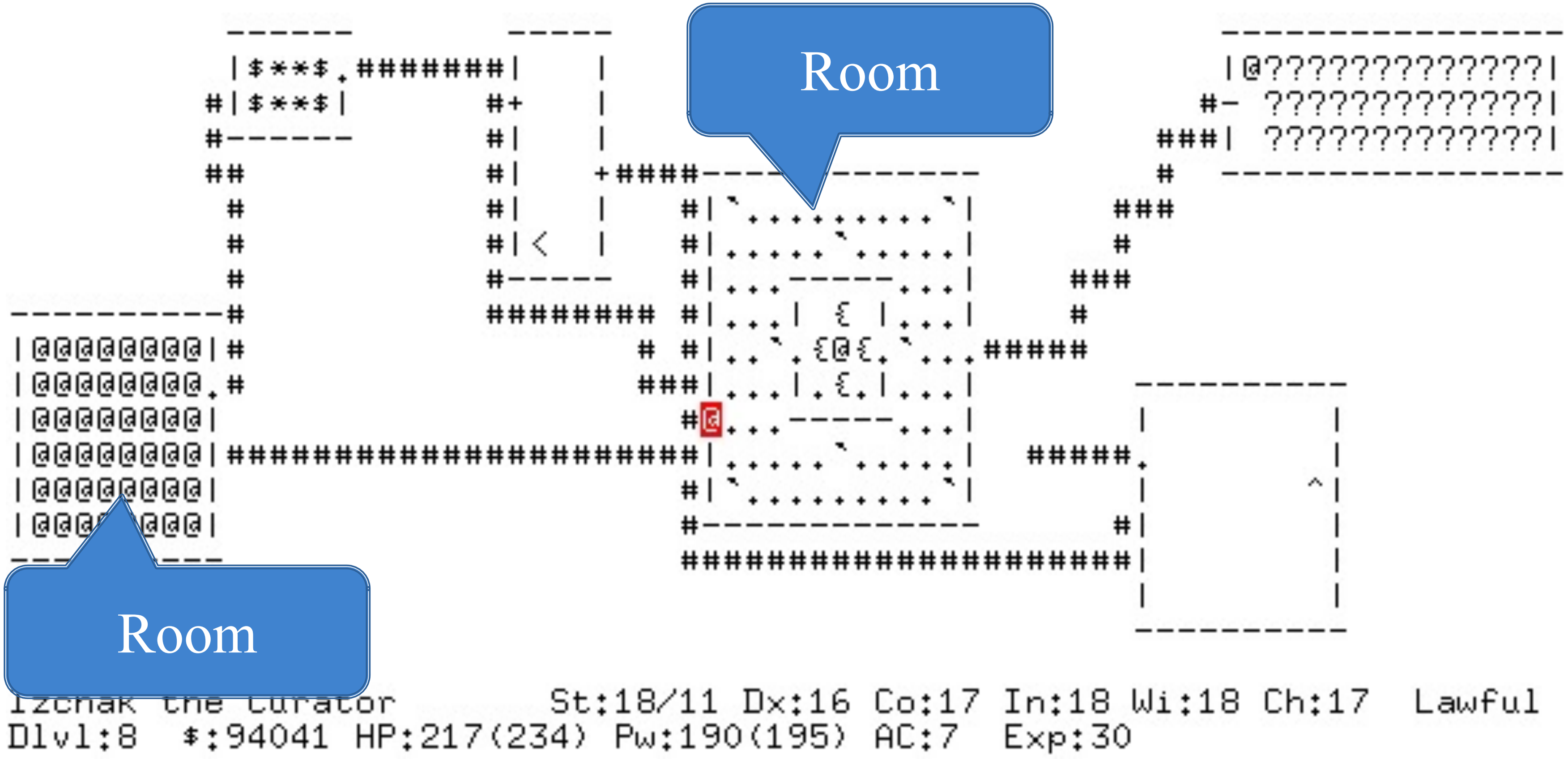
Example: NetHack



```
          ------       -----                            ----------------
          |$**$.#######|   |                            |@?????????????|
         #|$**$|      #+   |                           #- ?????????????|
         #------      #|   |                         ###| ?????????????|
         ##           #|   +####-------------        #  ----------------
          #           #|   |   #|`.........`|      ###
          #           #|<  |   #|.....`.....|      #
          #           #-----   #|...-----...|    ###
----------#           ######## #|...| { |...|    #
|@@@@@@@@|#                  # #|..`.{@{.`...#####
|@@@@@@@@.#                  ###|...|.{.|...|       ----------
|@@@@@@@@|                     #@...-----...|       |        |
|@@@@@@@@|######################|.....`.....|  #####.        |
|@@@@@@@@|                     #|`.........`|       |       ^|
|@@@@@@@@|                     #-------------      #|        |
----------                     #####################|        |
                                                    |        |
                                                    ----------

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

Example: NetHack

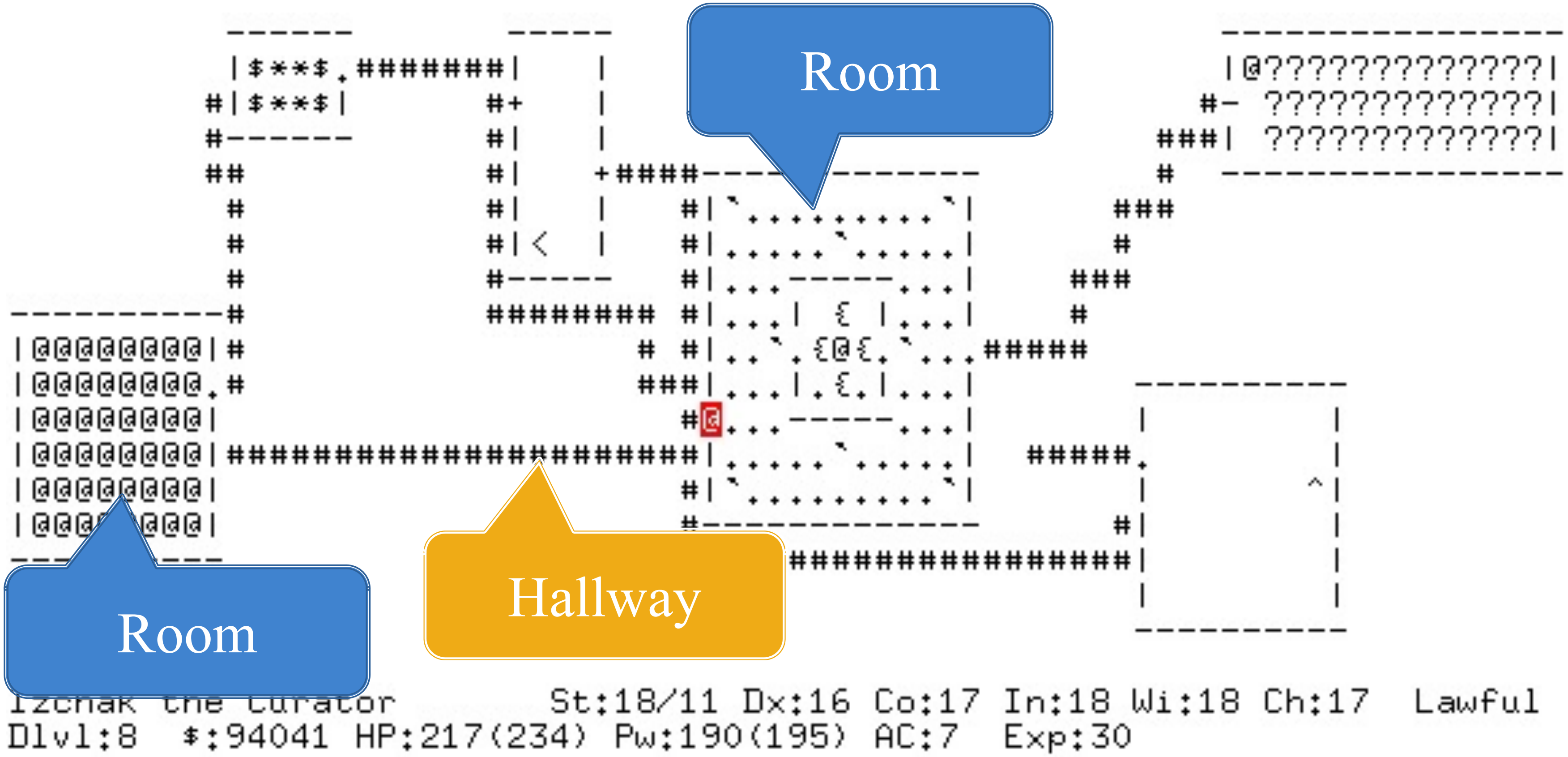


```
          ------       -----                            ----------------
          |$**$.#######|   |                            |@?????????????|
         #|$**$|      #+   |                           #- ?????????????|
         #------      #|   |                         ###| ?????????????|
         ##           #|   +####-------------        #  ----------------
          #           #|   |   #|`.........`|      ###
          #           #|<  |   #|.....`.....|      #
          #           #-----   #|...-----...|    ###
----------#           ######## #|...| { |...|    #
|@@@@@@@@|#                  # #|..`.{@{.`....#####
|@@@@@@@@.#                  ###|...|.{.|...|       ----------
|@@@@@@@@|                     #@...-----...|       |        |
|@@@@@@@@|######################|.....`.....|  #####.        |
|@@@@@@@@|                     #|`.........`|       |       ^|
|@@@@@@@@|                     #-------------      #|        |
----------                     #####################|        |
                                                    |        |
                                                    ----------
Izchak the Curator         St:18/11 Dx:16 Co:17 In:18 Wi:18 Ch:17  Lawful
Dlvl:8  $:94041 HP:217(234) Pw:190(195) AC:7  Exp:30
```

Room

Room

Example: NetHack



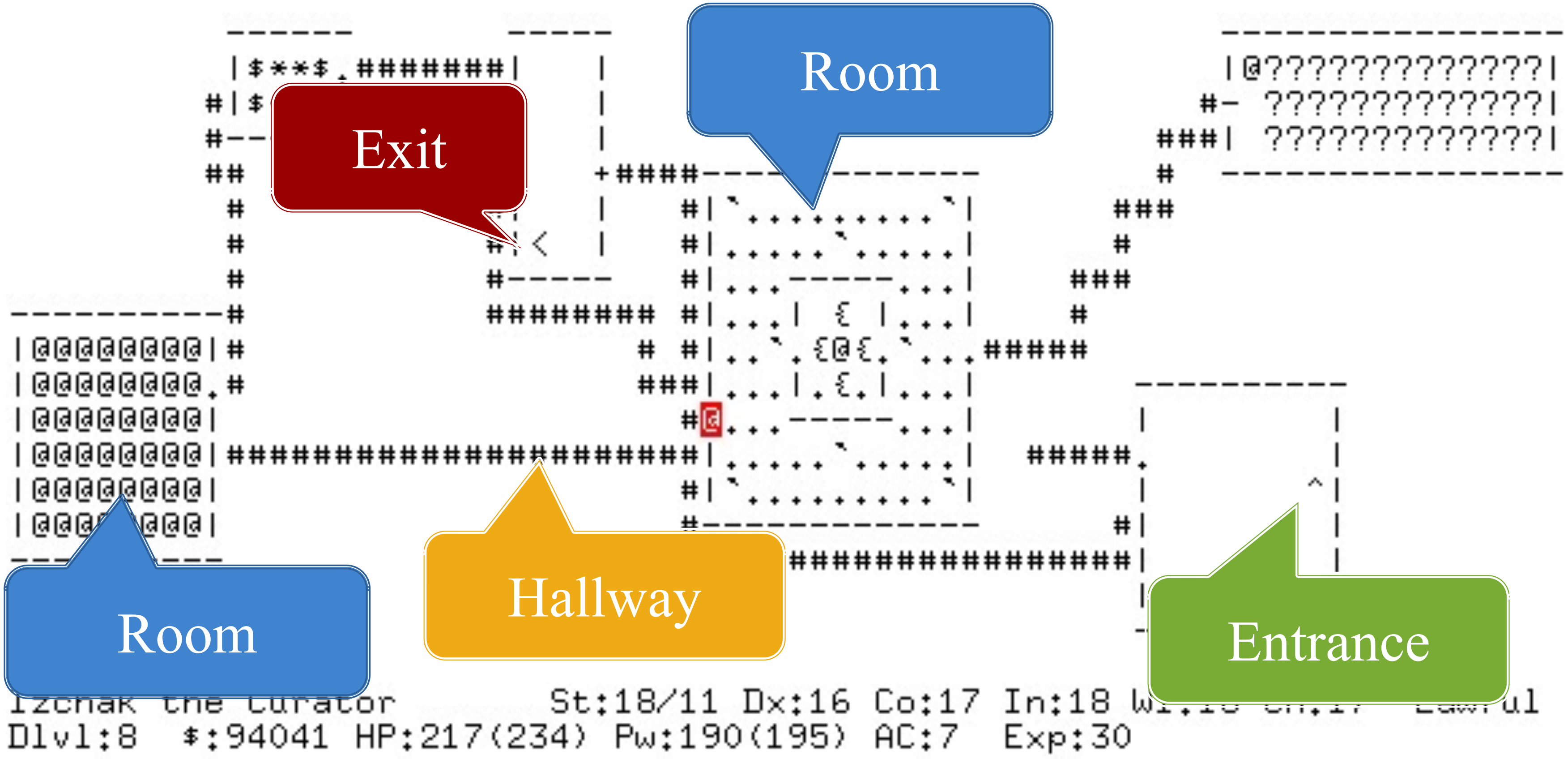
```
          ------       -----                            ----------------
          |$**$.#######|   |                            |@?????????????|
         #|$**$|      #+   |                           #- ?????????????|
         #------      #|   |                         ###| ?????????????|
         ##           #|   +####-------------        #  ----------------
          #           #|   |   #|`.........`|      ###
          #           #|<  |   #|.....`.....|      #
          #           #-----   #|...-----...|    ###
----------#           ######## #|...| { |...|    #
|@@@@@@@@|#                  # #|..`.{@{.`...#####
|@@@@@@@@.#                  ###|...|.{.|...|       ----------
|@@@@@@@@|                     #@...-----...|       |        |
|@@@@@@@@|######################|.....`.....|  #####.        |
|@@@@@@@@|                     #|`.........`|       |       ^|
|@@@@@@@@|                     #-------------      #|        |
----------                          ################|        |
                                                    |        |
                                                    ----------
Izchak the Curator          St:18/11 Dx:16 Co:17 In:18 Wi:18 Ch:17  Lawful
Dlvl:8  $:94041 HP:217(234) Pw:190(195) AC:7  Exp:30
```

Room

Room

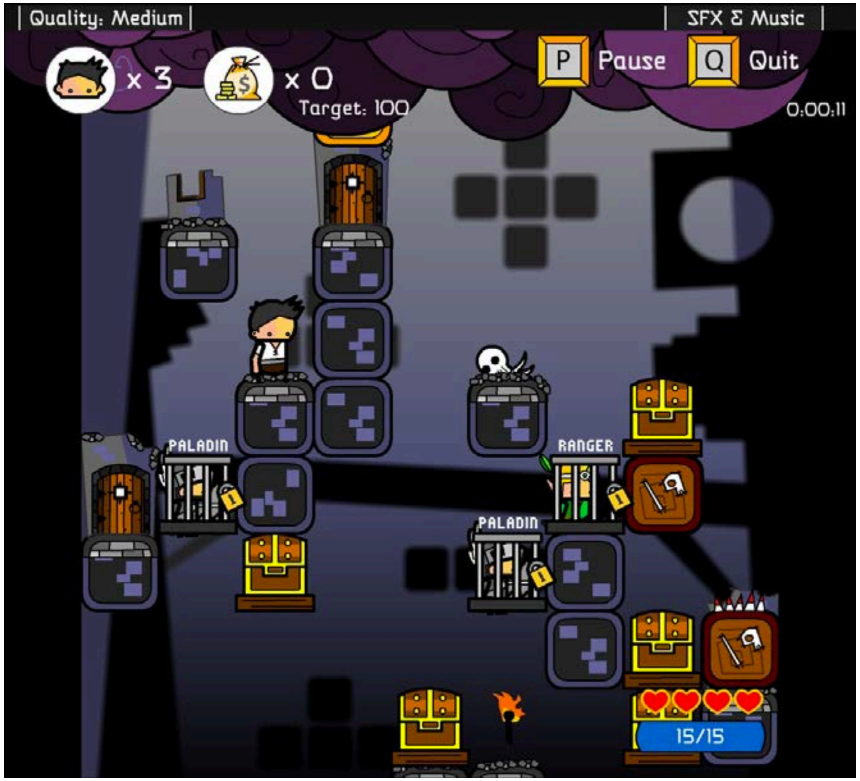
Hallway

Example: NetHack



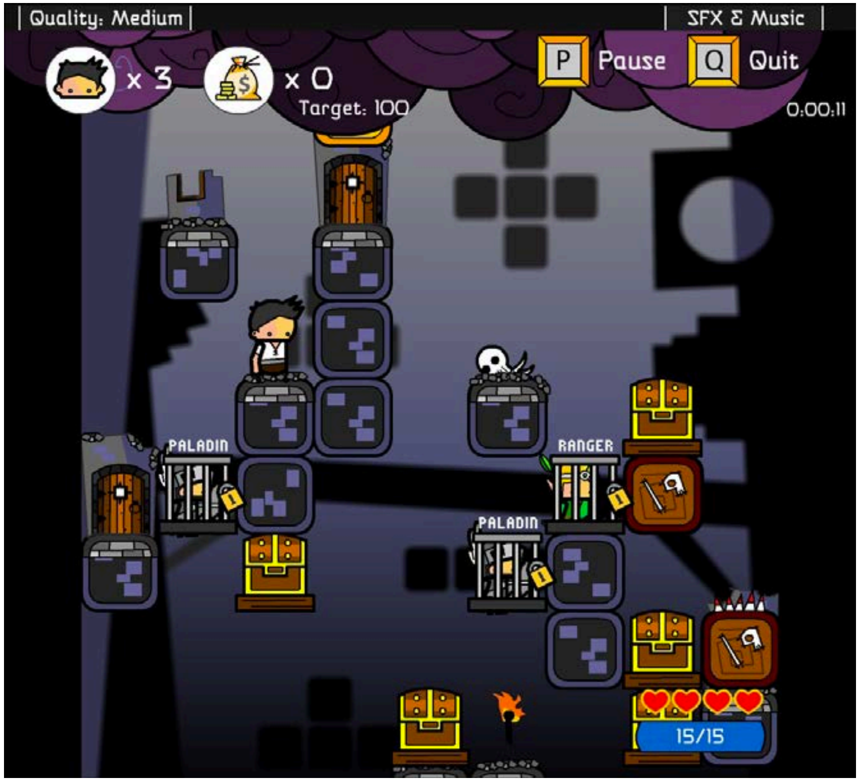
```
Izchak the Curator          St:18/11 Dx:16 Co:17 In:18 Wi            Lawful
Dlvl:8  $:94041 HP:217(234) Pw:190(195) AC:7  Exp:30
```

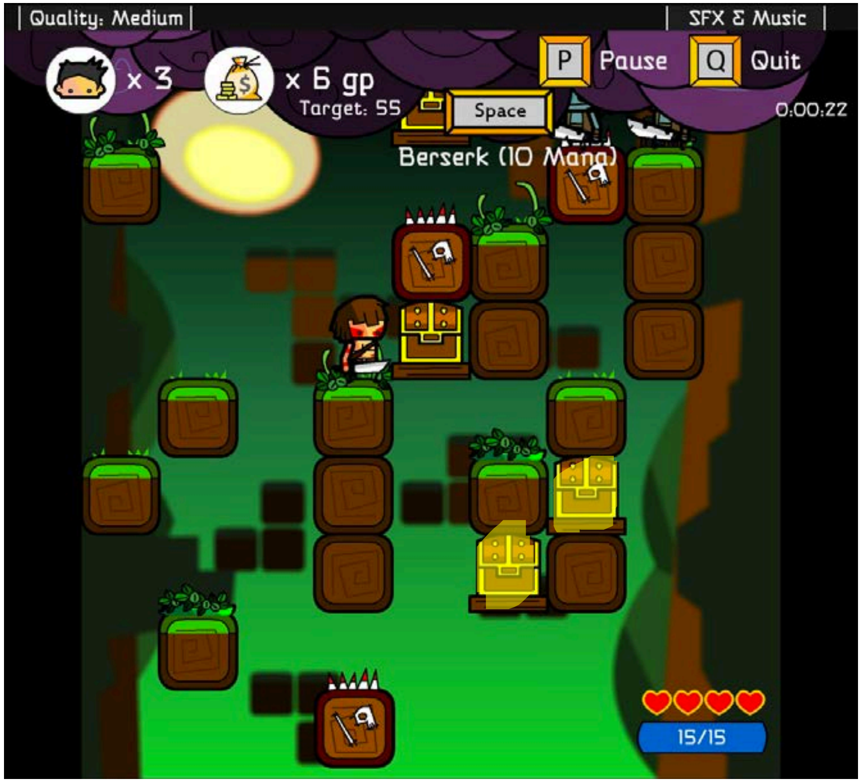
Example: *Vertical Drop Heroes*



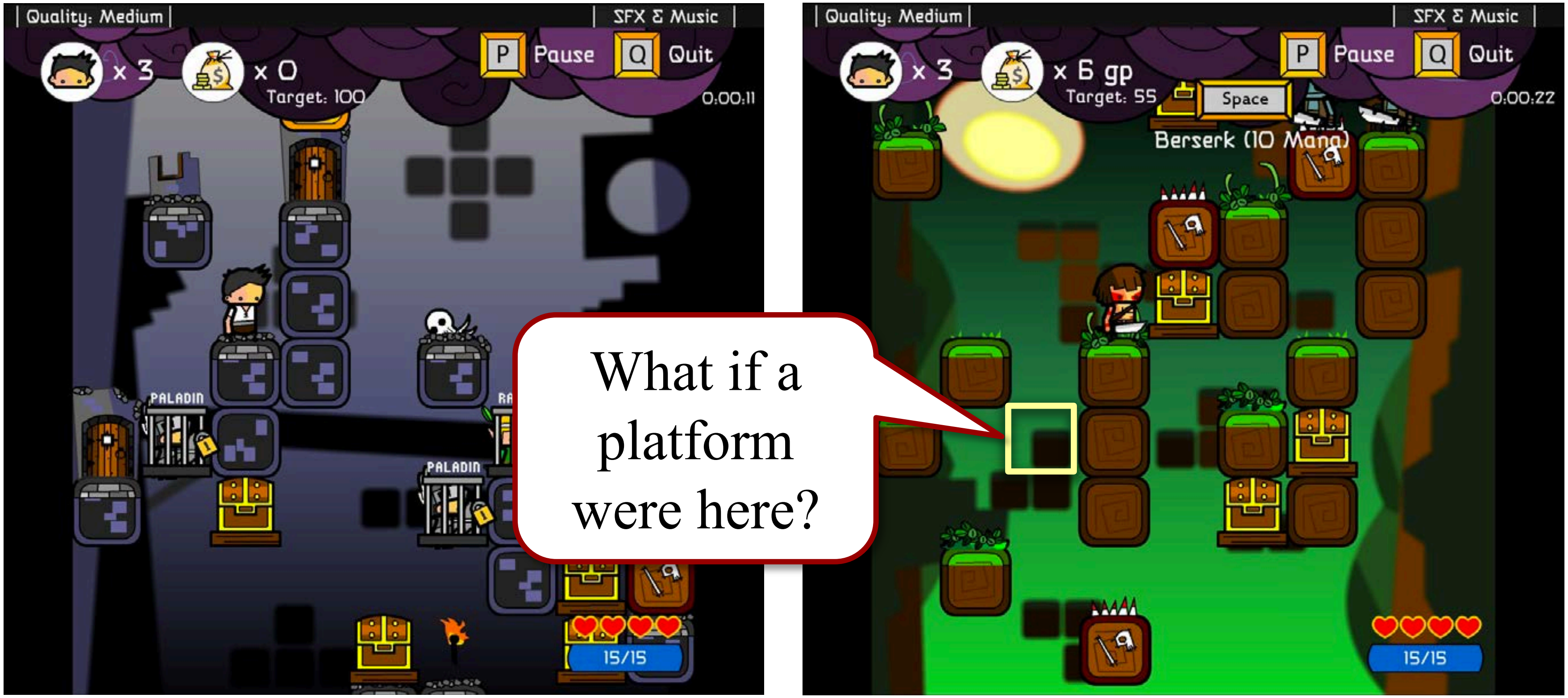
- **Movement**
  - Can move left-right
  - Down arrow to stomp/fall
  - Cannot jump at all!
- **Combat**
  - Space to fire weapon
  - Weapon depends on class
  - Free cage to switch class
- **Goal**
  - Collect treasure
  - Reach (a possible) exit

Example: *Vertical Drop Heroes*





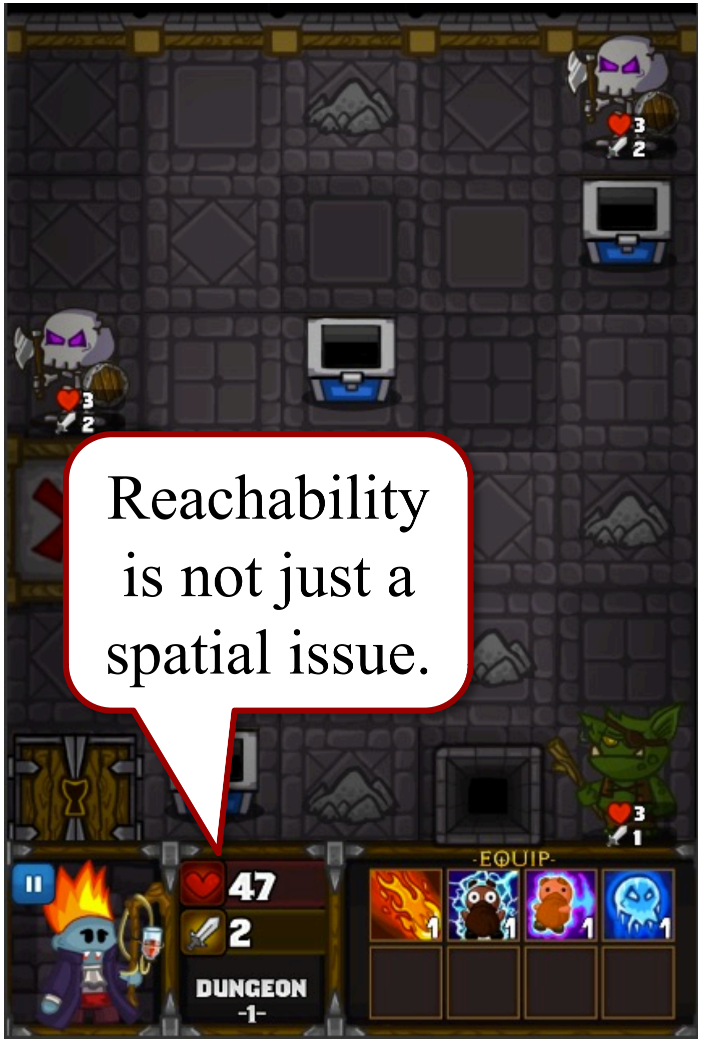
Example: *Vertical Drop Heroes*



What if a platform were here?

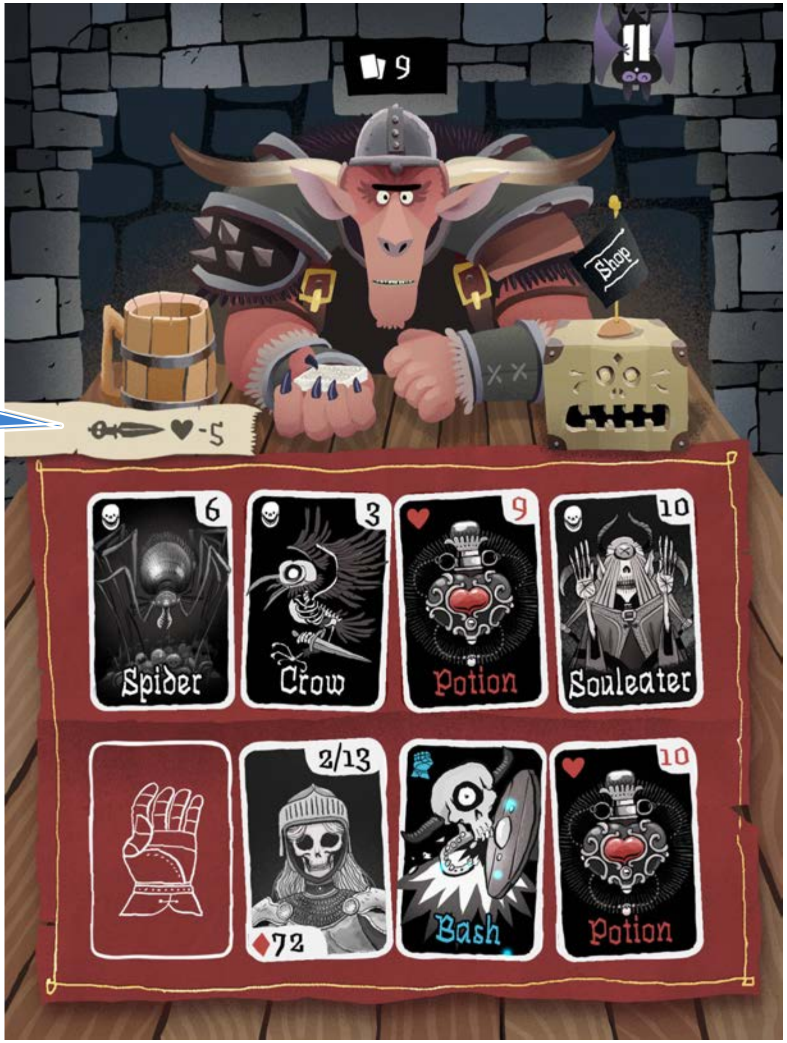
The Reachability Problem

- Levels are effectively graphs
  - Edges are player choices
  - Choices are discretized
  - Fully **connected** (why?)
- PCG might make a graph
  - with a lot of dead ends
  - with a lot of backtracking
  - that is **unconnected**
- Need to remember goal
  - Should always be reachable
  - Else, reset must be painless



Reachability is not just a spatial issue.

Example: *Card Crawl*



Panic Button

Ensuring Reachability

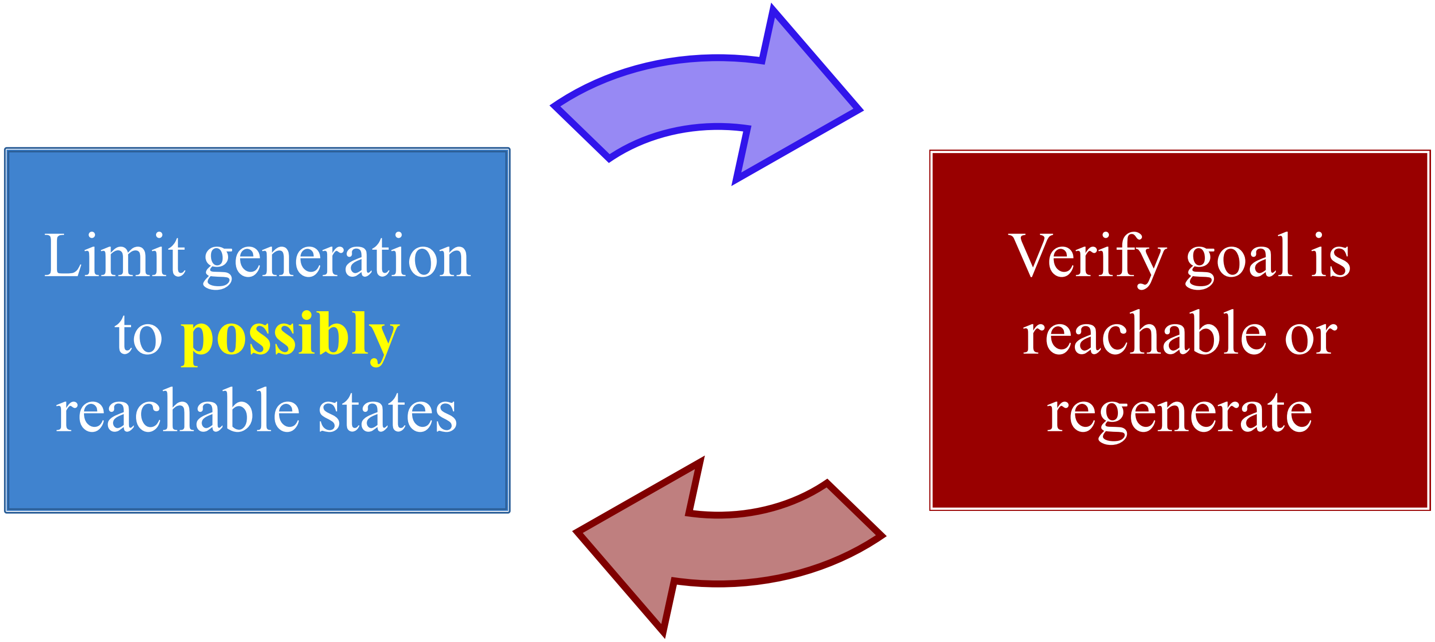
Two Options:

Limit generation to reachable game states

Verify goal is reachable or regenerate

Ensuring Reachability

Two Options:



Limit generation to **possibly** reachable states

Verify goal is reachable or regenerate

Grammars: A Formal Approach

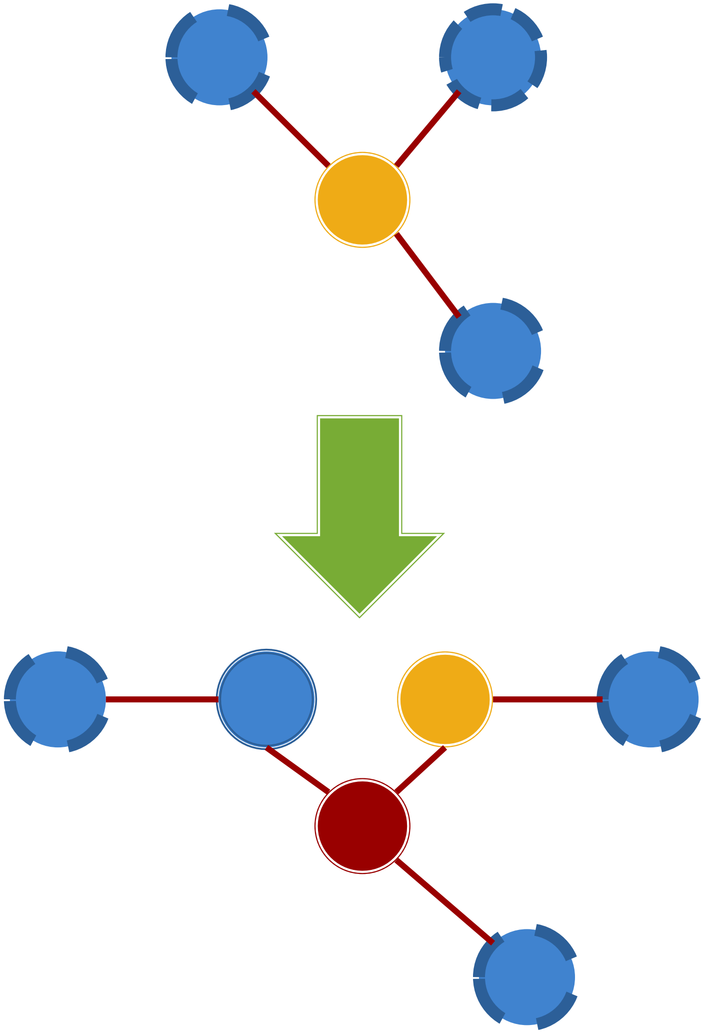
- **Notation**
  - Set $\mathcal{N}$ of nonterminals
  - Set Σ of terminal symbols
  - Set $\mathcal{P}$ of production rules
    - Have the form *A* => *B*
    - *A*, *B* are **words** of symbols
- To generate a value
  - Start with word *XAY*
  - Pick any rule *A* => *B*
  - Replace with *XBY*
  - Repeat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

Example

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

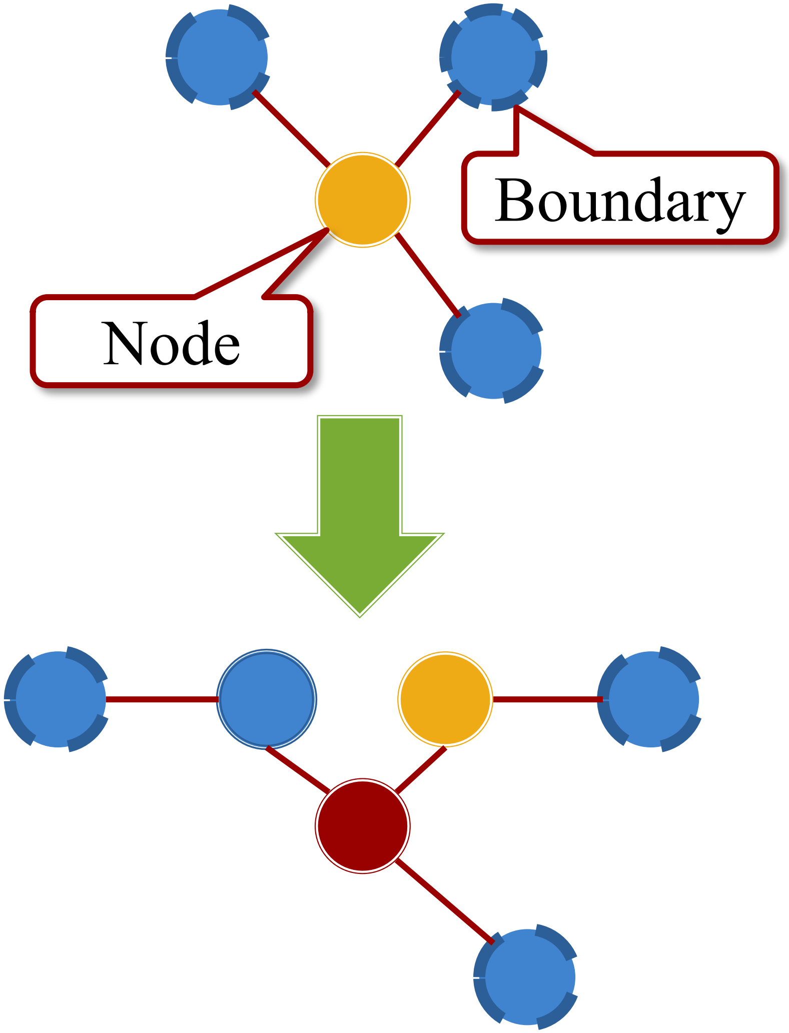
Grammars on Graphs

- 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



Grammars on Graphs

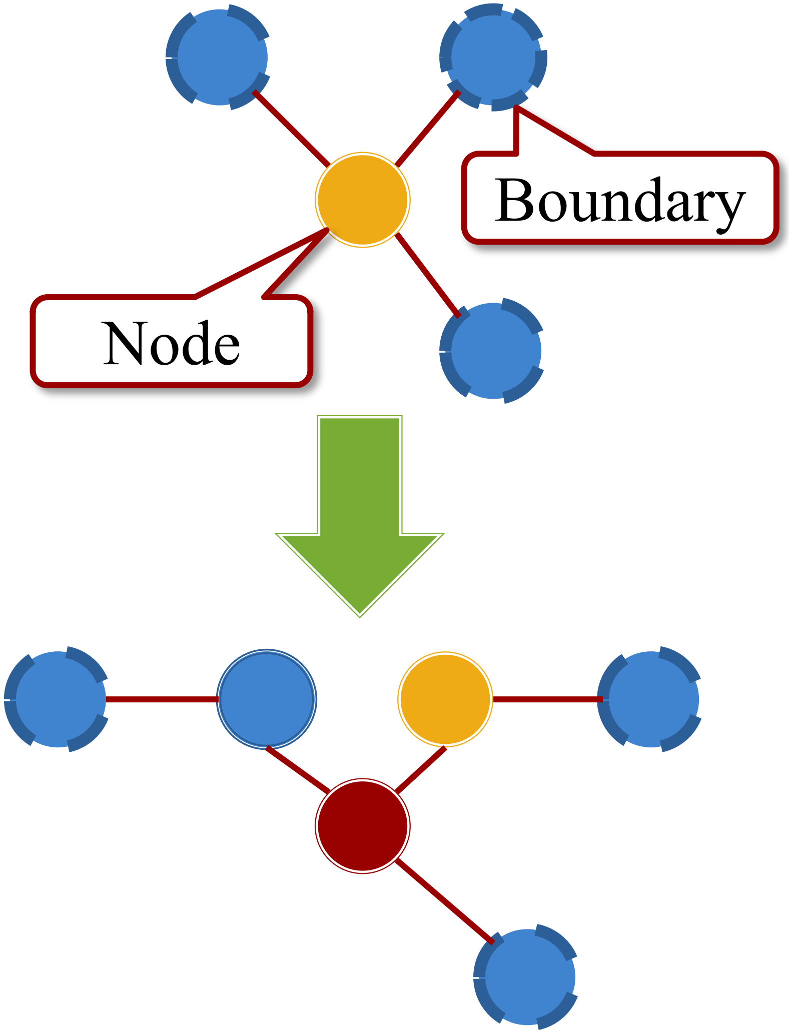
- Symbols are colored nodes
  - Either terminal or not
  - Edges replace word order
- Words are now graphs
  - Productions on subgraphs
  - LHS is node+boundary
  - RHS alters the node
- Output built as before
  - But rule matching harder
  - Graph equivalency



Grammars on Graphs

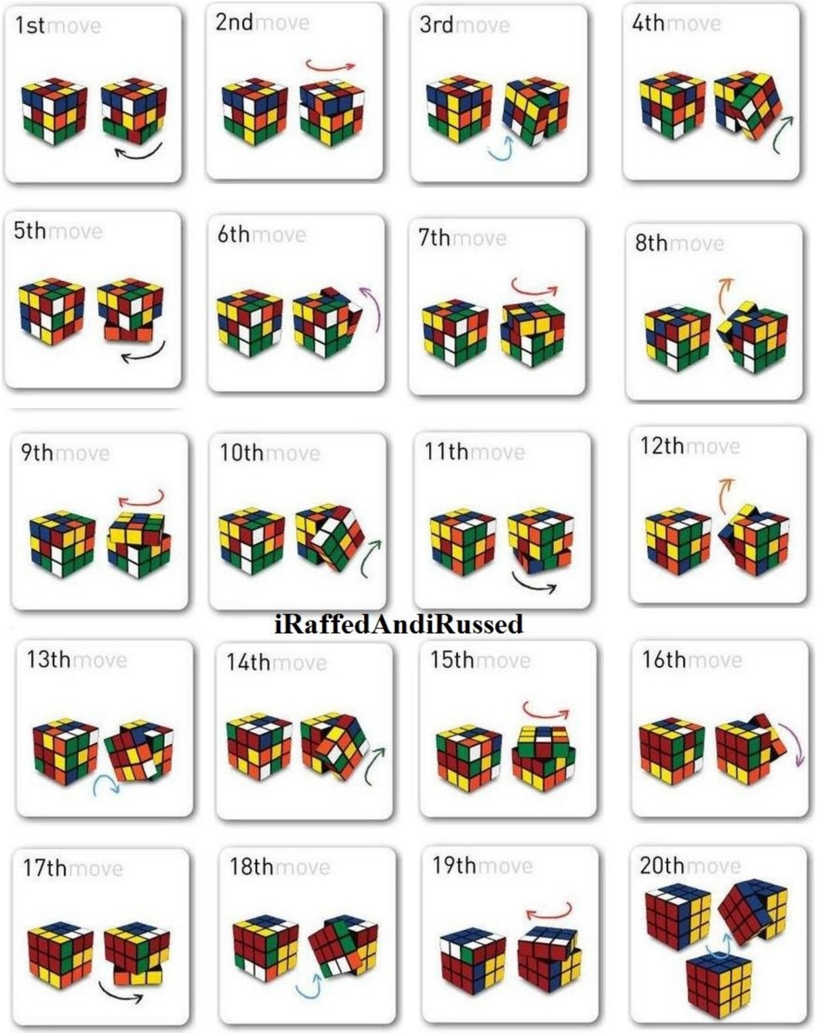
- Symbols are colored nodes
  - Either terminal or not
  - Edges replace word order
- Words are now graphs
  - Productions on subgraph
  - RHS alters the node
- Output built as before
  - But rule matching harder
  - Graph equivalency

Game Geography is a graph

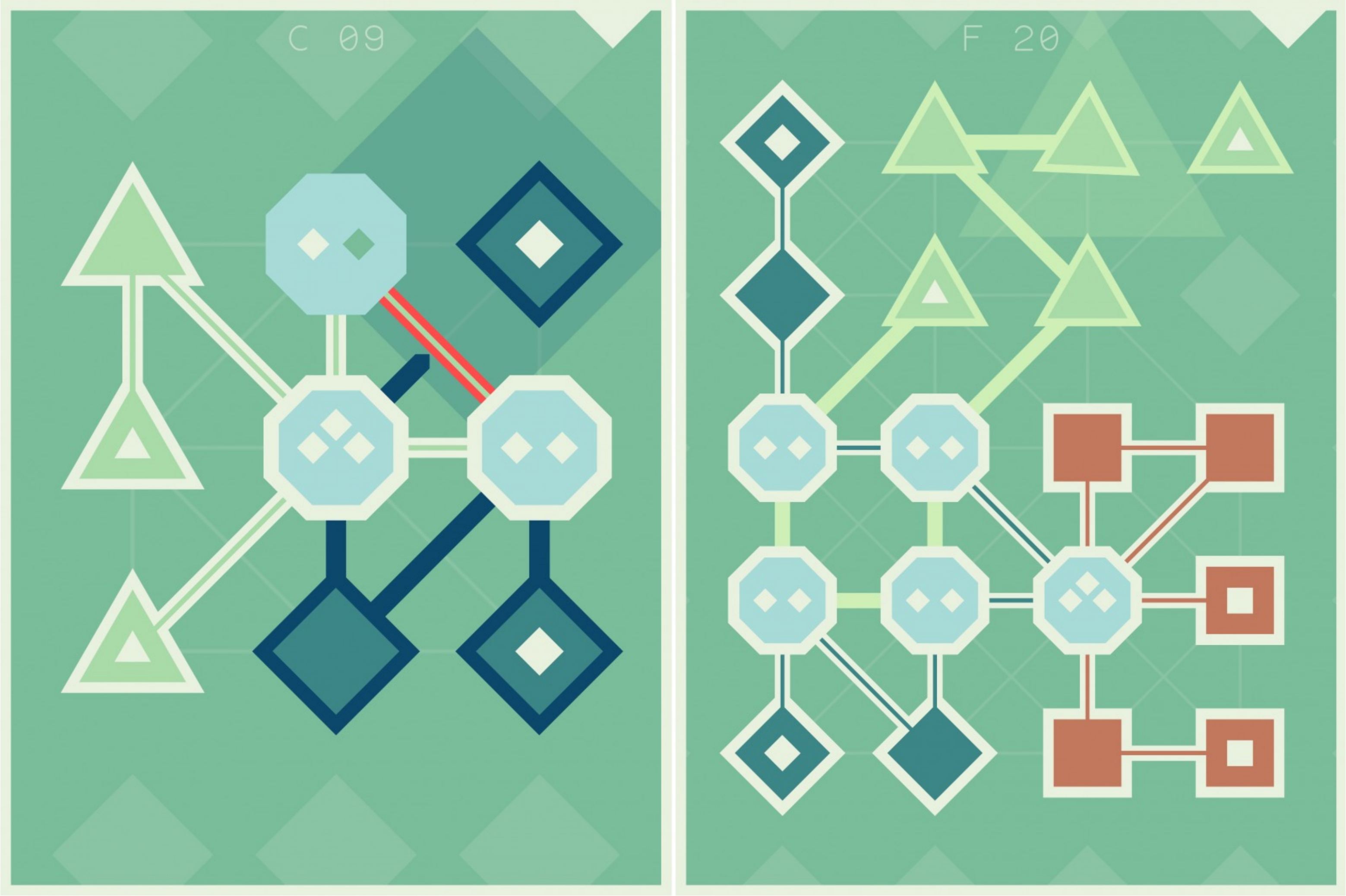


Puzzle Generation

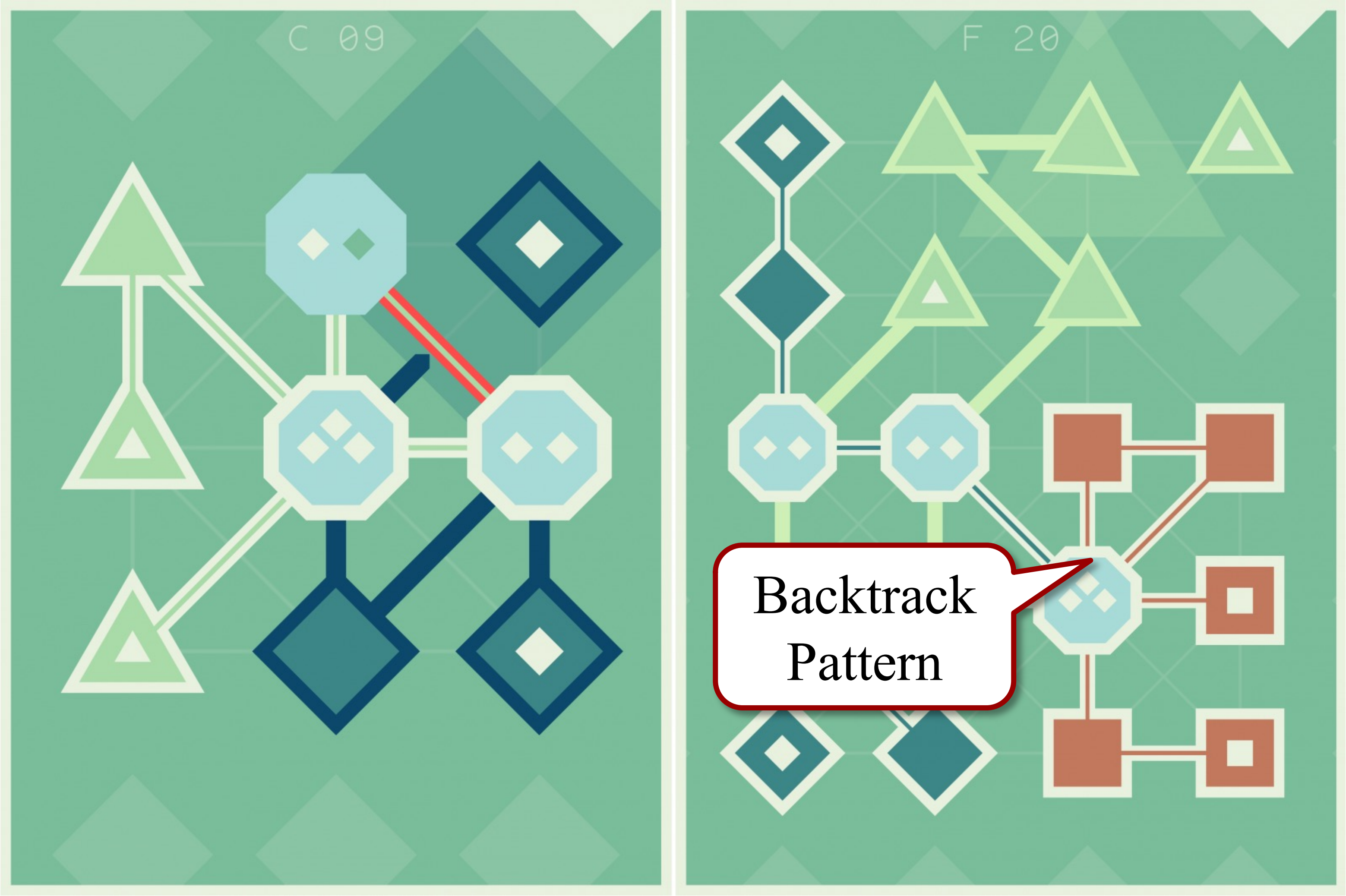
- Basic puzzle structure
  - Discrete actions/moves
  - Moves applied in sequence
  - **Goal**: get correct sequence
- Identify move sequences
  - Could be a loose category
  - Represent specific strategies
- Build up from sequences
  - Start from solved state
  - Invert moves (scrambling)
- Will require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



Example: Lyne



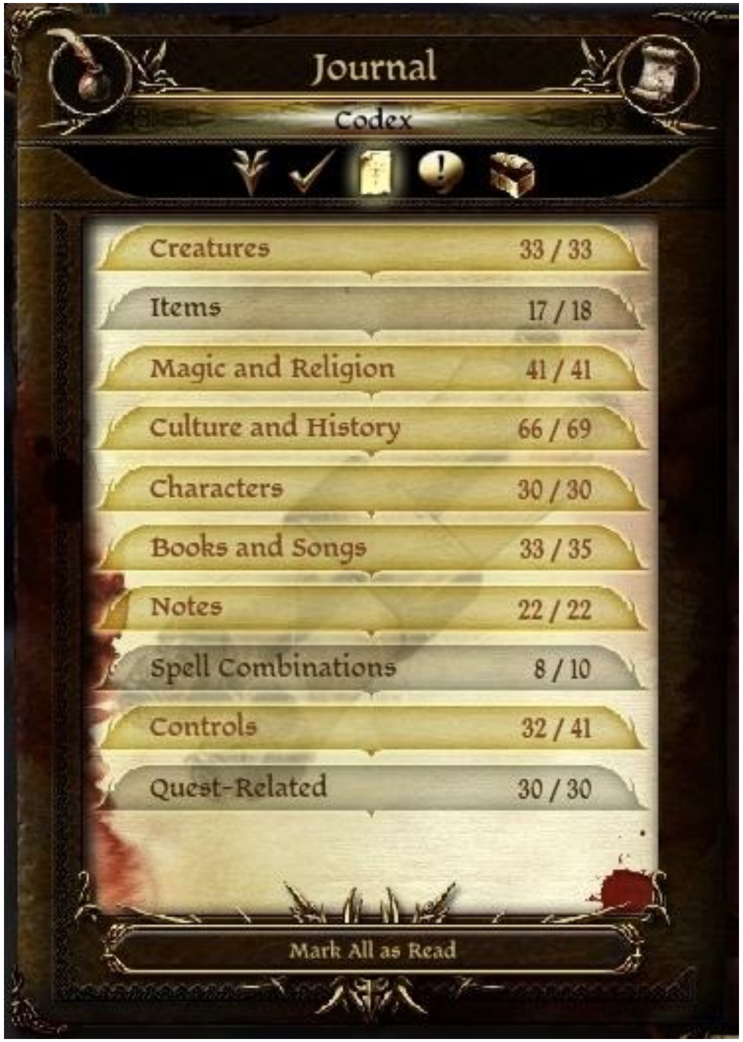
Example: Lyne



Backtrack Pattern

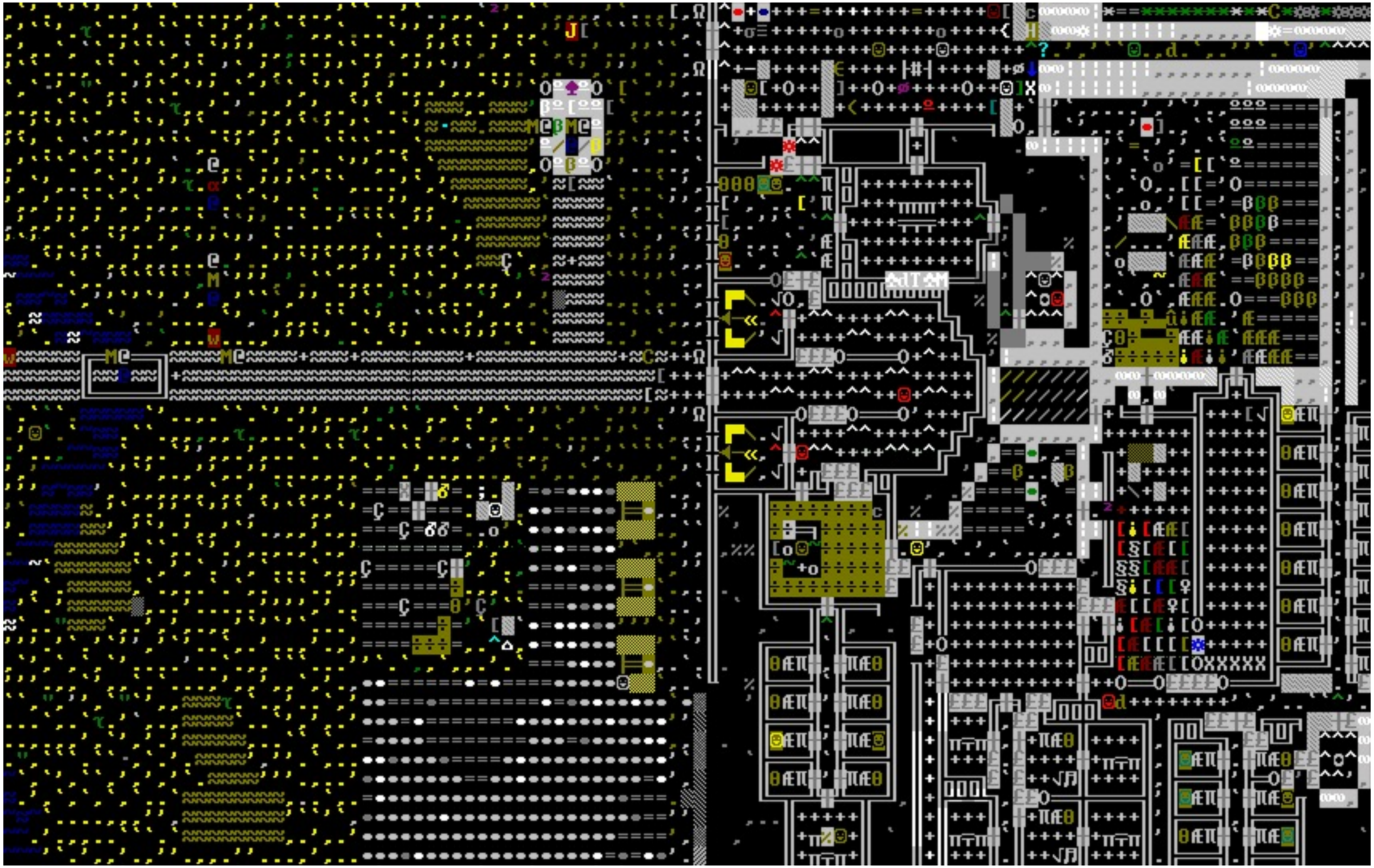
Story Generation

- **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



Creatures	33 / 33
Items	17 / 18
Magic and Religion	41 / 41
Culture and History	66 / 69
Characters	30 / 30
Books and Songs	33 / 35
Notes	22 / 22
Spell Combinations	8 / 10
Controls	32 / 41
Quest-Related	30 / 30

Example: Dwarf Fortress

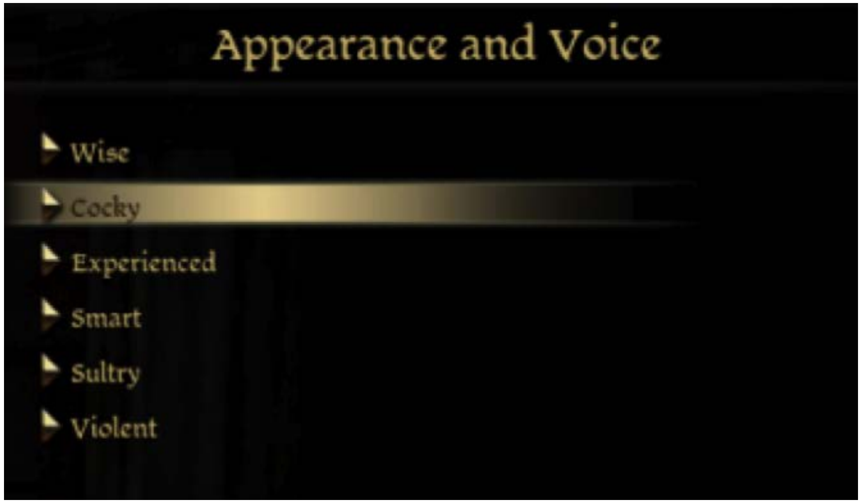


Natural Language Generation

- Function that outputs language
  - **Given**: complex set of data
  - **Outcome**: comment on data
  - Major area of CS research
- Comment requirements
  - Must be simpler than data
  - Should also be natural
- **Examples**
  - Sports commentary
  - Party combat chatter
  - Intelligent townsfolk

NLG and Story Dialogue

- Often a set of "canned" text
  - React to specific events
  - NPC picks text as appropriate
- Text is *parameterized*
  - "What do we do, <name>?"
  - "Someone killed <monster>!"
  - "That was <numb> days ago."
- Choosing text to say
  - Favor important events?
  - Favor recent events?
  - Random (pull-toy)?

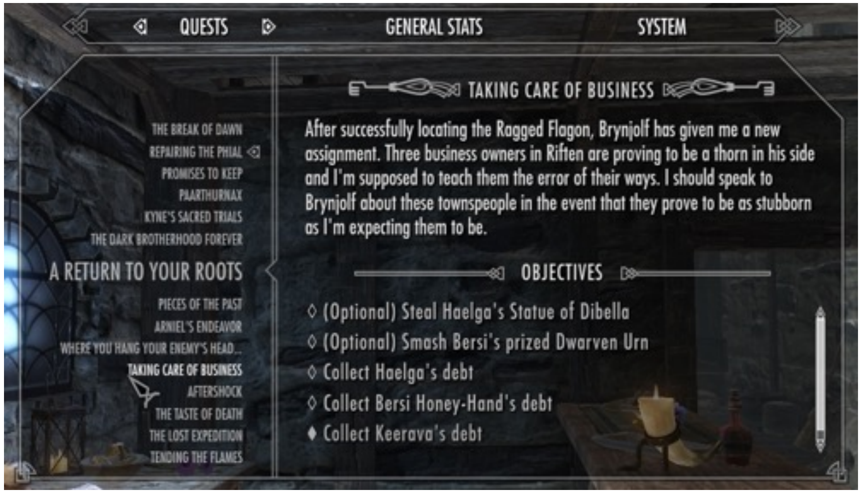


Appearance and Voice

- Wise
- Cocky
- Experienced
- Smart
- Sultry
- Violent

Skyrim's Radiant Quest System

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



TAKING CARE OF BUSINESS

After successfully locating the Ragged Flagon, Brynjolf has given me a new assignment. Three business owners in Riften are proving to be a thorn in his side and I'm supposed to teach them the error of their ways. I should speak to Brynjolf about these townspeople in the event that they prove to be as stubborn as I'm expecting them to be.

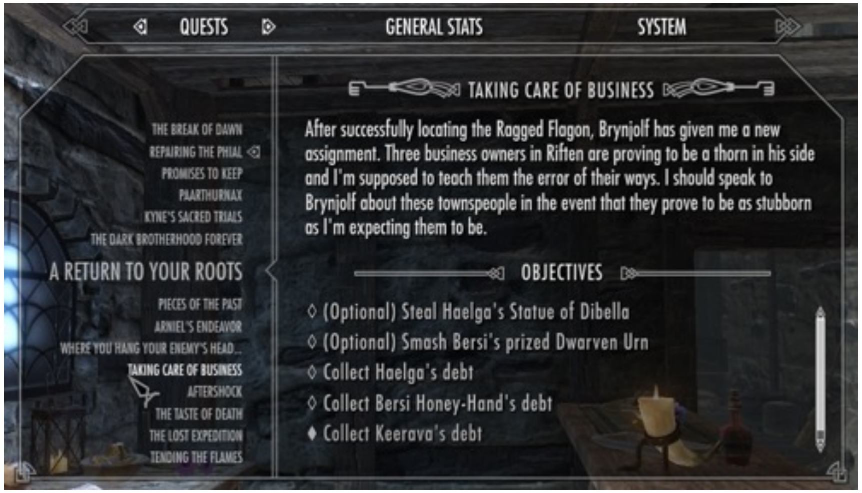
OBJECTIVES

◇ (Optional) Steal Haelga's Statue of Dibella
◇ (Optional) Smash Bersi's prized Dwarven Urn
◇ Collect Haelga's debt
◇ Collect Bersi Honey-Hand's debt
◆ Collect Keerava's debt

- Goals:
  - Send to unexplored areas
  - Adjust challenges to level
  - Can never be missed
- Largely a success

Skyrim's Radiant Quest System

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



THE BREAK OF DAWN
REPAIRING THE PHIAL
PROMISES TO KEEP
PAARTHURNAX
KYNE'S SACRED TRIALS
THE DARK BROTHERHOOD FOREVER
A RETURN TO YOUR ROOTS
PIECES OF THE PAST
ARNIEL'S ENDEAVOR
WHERE YOU HANG YOUR ENEMY'S HEAD...
TAKING CARE OF BUSINESS
AFTERSHOCK
THE TASTE OF DEATH
THE LOST EXPEDITION
TENDING THE FLAMES

TAKING CARE OF BUSINESS

After successfully locating the Ragged Flagon, Brynjolf has given me a new assignment. Three business owners in Riften are proving to be a thorn in his side and I'm supposed to teach them the error of their ways. I should speak to Brynjolf about these townspeople in the event that they prove to be as stubborn as I'm expecting them to be.

OBJECTIVES

◇ (Optional) Steal Haelga's Statue of Dibella
◇ (Optional) Smash Bersi's prized Dwarven Urn
◇ Collect Haelga's debt
◇ Collect Bersi Honey-Hand's debt
◆ Collect Keerava's debt

Guarantees reachability

unexplored areas
  - Adjust challenges to level
  - Can never be missed
- Largely a success

But Sometimes a Problem

Dynamic Challenges

- Challenges that can change
  - Become easier or harder
  - Just be 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

ATK	1
DFN	0
HP	5

Rat: Level 1

ATK	30
DFN	10
HP	90

Rat: Level 50

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

Challenge

Extract feature vector from play history

Match the challenge to the play style

Parameterize challenge difficulty

$(a_1, a_2, a_3, \ldots, a_n)$ → $(b_1, b_2, b_3, \ldots, b_k)$

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

$(a_1, a_2, a_3, \ldots, a_n)$ → $(b_1, b_2, b_3, \ldots, b_k)$

Adaptive Difficulty

Player

Challenge

Extract feature vector from play history

Match via **machine learning**

Parameterize challenge difficulty

$(a_1, a_2, a_3, \ldots, a_n)$ → $(b_1, b_2, b_3, \ldots, b_k)$

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 learning 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
- Still largely an academic exercise

Summary

- Procedural content started with Rogue(likes)
  - Tightly coupled with permadeath, horizontal design
  - Becoming fashionable once again
- Many applications to modern game design
  - World Generation
  - Puzzle Generation
  - Story Generation
  - Dynamic Challenges

Summary

- Procedural content started with Rogue(likes)
  - Tightly coupled with permadeath, horizontal design
  - Becoming fashionable once again

Procedural Content Wiki:

http://pcg.wikidot.com

- Many ign
  - Worl
  - Puzz
  - Story Generation
  - Dynamic Challenges