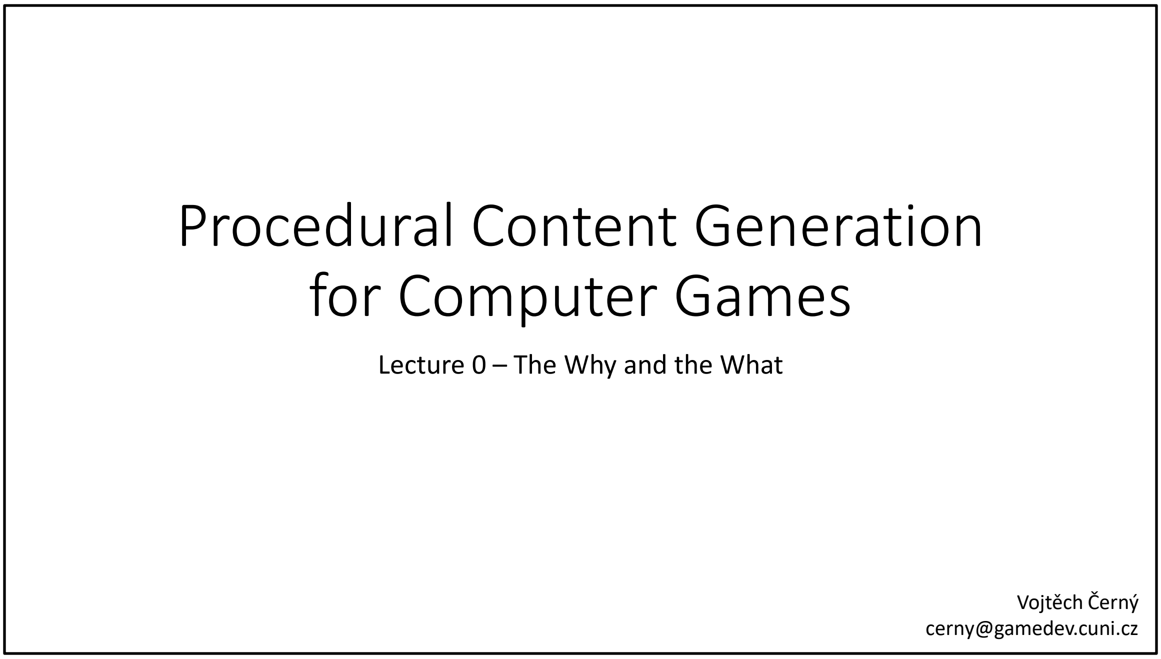
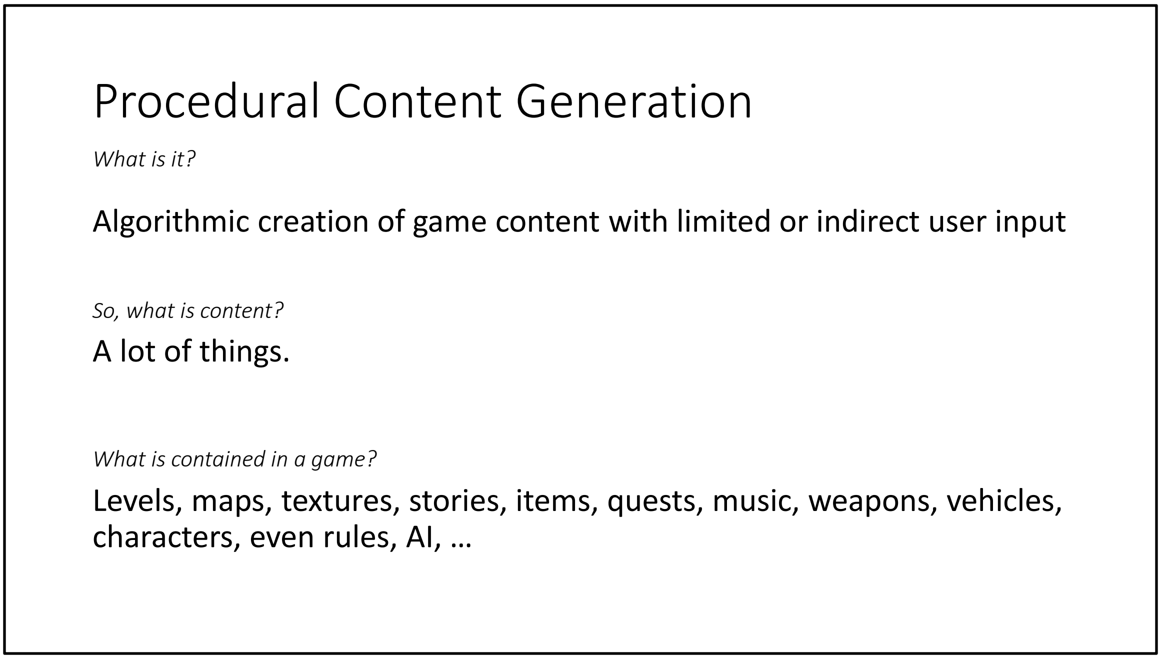


Procedural Content Generation for Computer Games

Lecture 0 – The Why and the What

Vojtěch Černý
cerny@gamedev.cuni.cz



Procedural Content Generation

What is it?

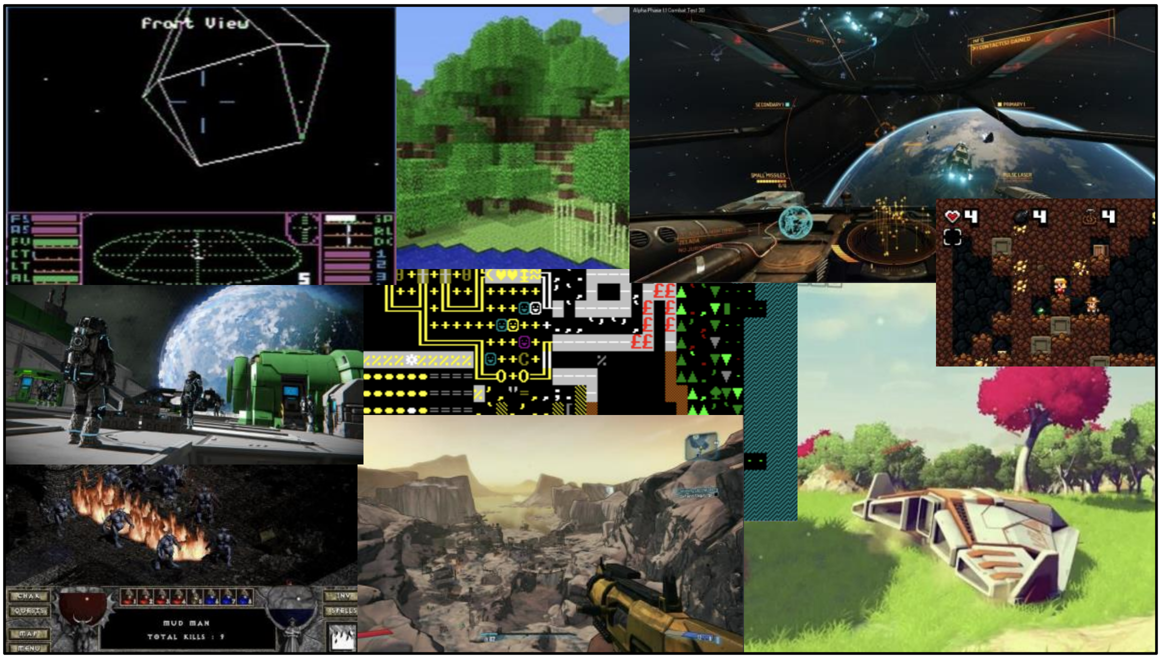
Algorithmic creation of game content with limited or indirect user input

So, what is content?

A lot of things.

What is contained in a game?

Levels, maps, textures, stories, items, quests, music, weapons, vehicles, characters, even rules, AI, …

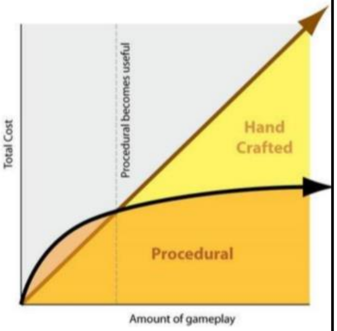


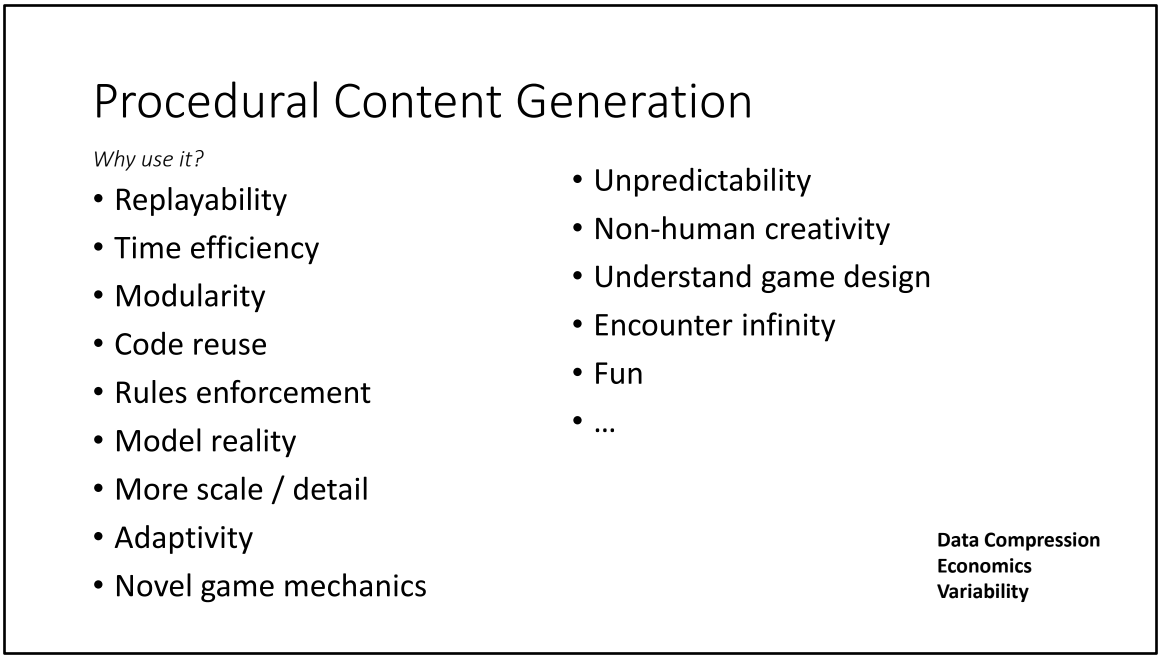
https://store.steampowered.com/app/1135960/Space_Engineers__Economy_Deluxe

Procedural Content Generation

Why use it?

- Data compression
  - More content than fits your media
- Economics
  - Cheaper to generate than design your amount of things
- Variability (beyond human)
  - Experience new stuff each time / more stuff than humans could imagine





Procedural Content Generation

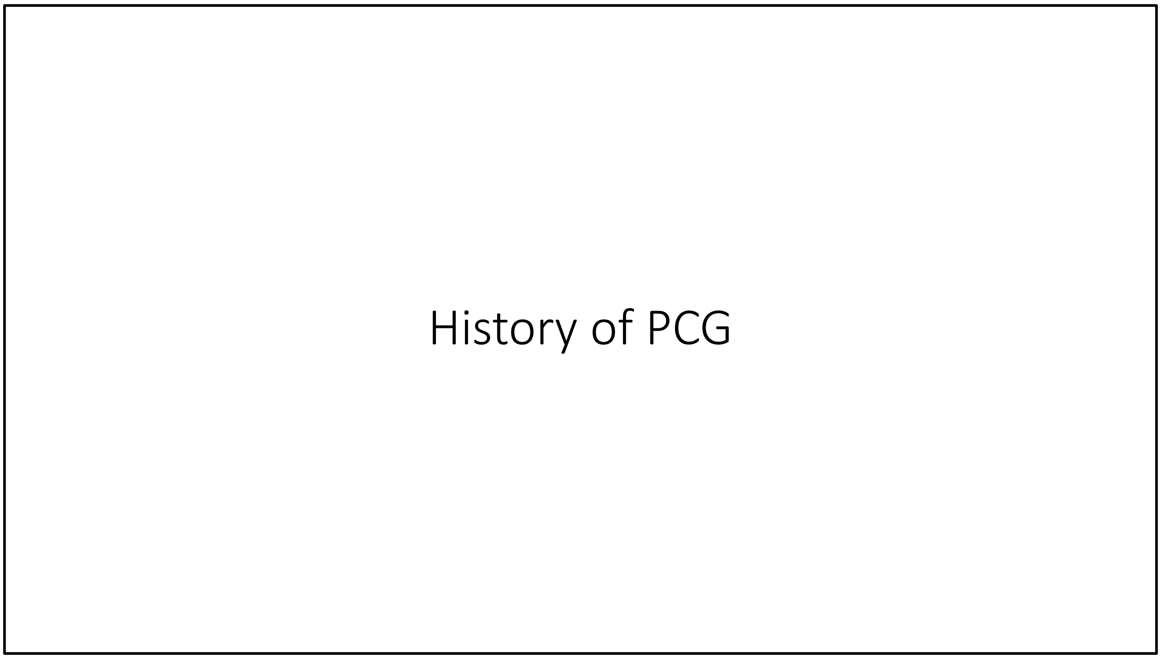
Why use it?

- Replayability
- Time efficiency
- Modularity
- Code reuse
- Rules enforcement
- Model reality
- More scale / detail
- Adaptivity
- Novel game mechanics
- Unpredictability
- Non-human creativity
- Understand game design
- Encounter infinity
- Fun
- …

Data Compression
Economics
Variability

Modularity – generate parts of content separately, and let them merge
Code Reuse – fire spreader can be turned into a disease spreader in another game

Example games that just wouldn’t work without PCG – No Man’s Sky, Diablo, Borderlands, Spelunky…



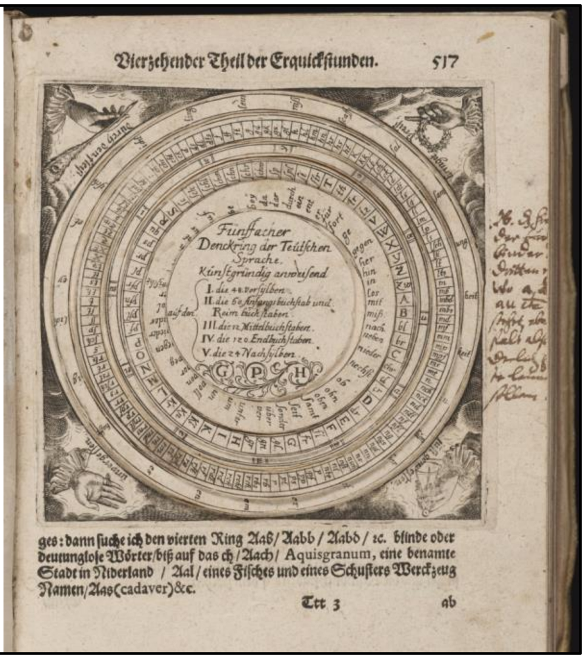
History of PCG

People usually mention two games, but we are going to start earlier.

History of PCG

- At least the 17th century
- George Philipp Harsdörffer

- Generating words by a Volvelle

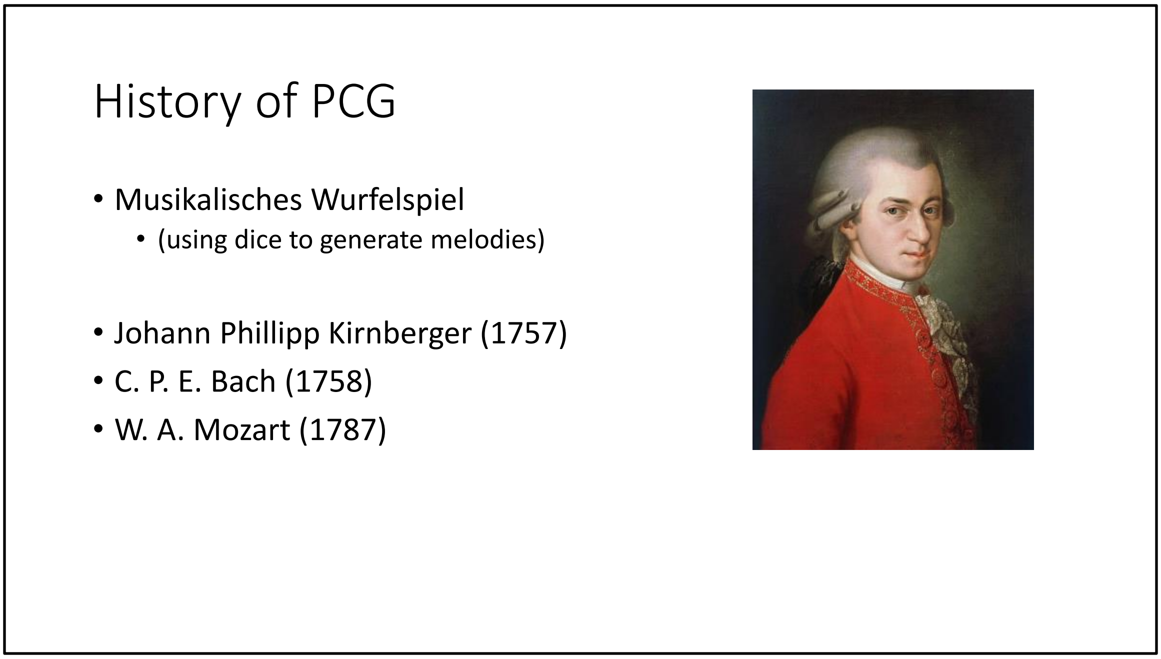


Vierzehender Theil der Erquickſtunden. 517

ges: dann ſuche ich den vierten Ring Aaß/ Aabb / Aabd / ꝛc. blinde oder deutungloſe Wörter/biß auf das ch / Aach/ Aquisgranum, eine benamte Stadt in Niderland / Aal / eines Fiſches und eines Schuſters Werckzeug Namen/Aas(cadaver)&c.

Ttt 3 ab

First PCG

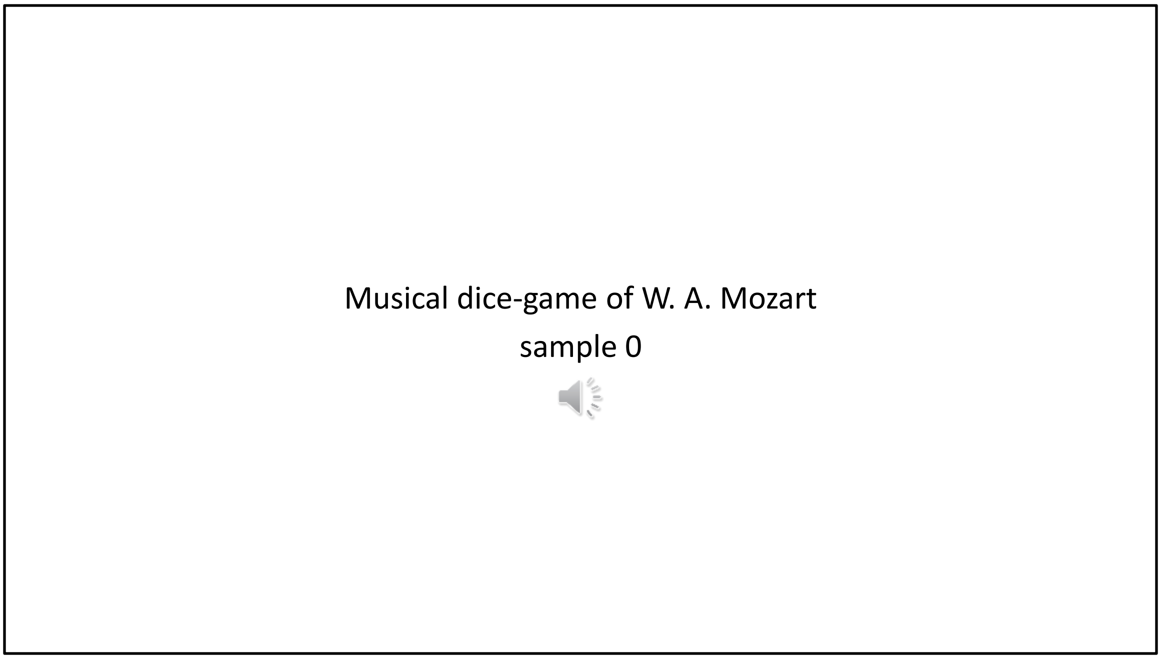


History of PCG

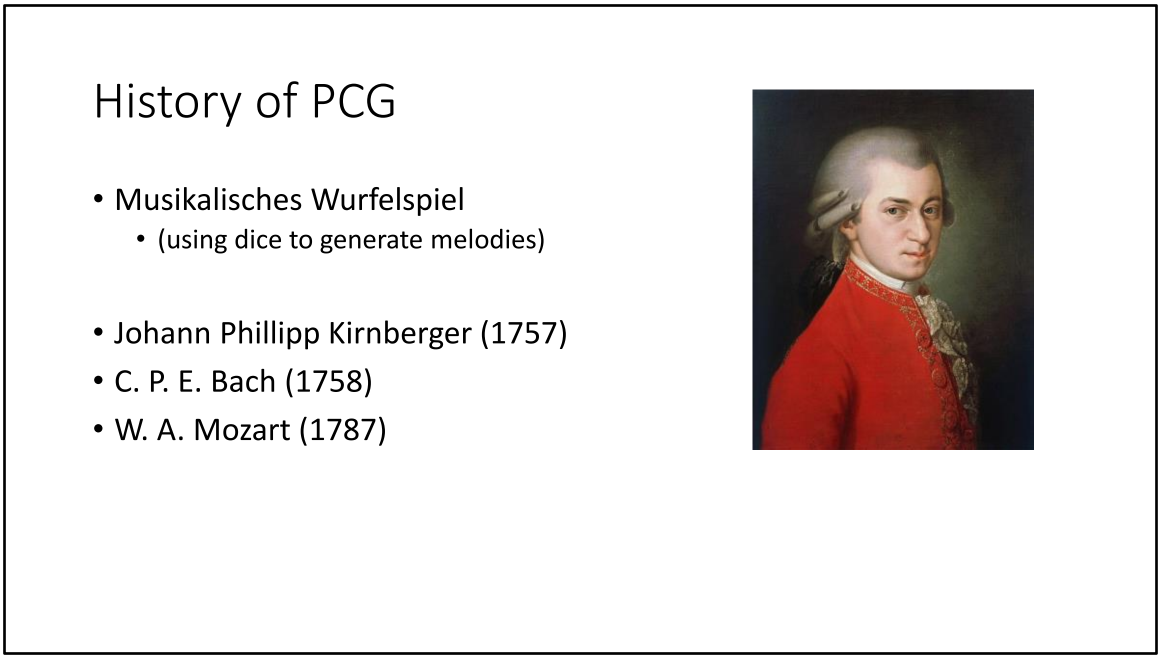
- Musikalisches Wurfelspiel
  - (using dice to generate melodies)

- Johann Phillipp Kirnberger (1757)
- C. P. E. Bach (1758)
- W. A. Mozart (1787)

https://cs.m.wikipedia.org/wiki/Soubor:Wolfgang-amadeus-mozart_1.jpg
PCG Music



Musical dice-game of W. A. Mozart
sample 0

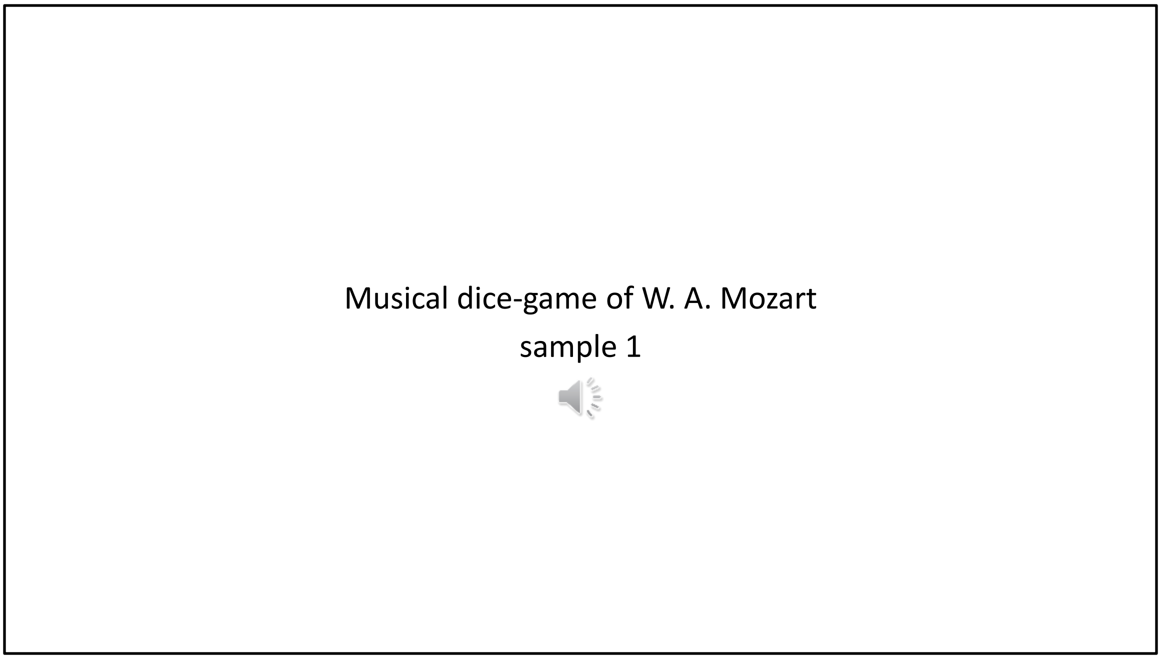


History of PCG

- Musikalisches Wurfelspiel
  - (using dice to generate melodies)

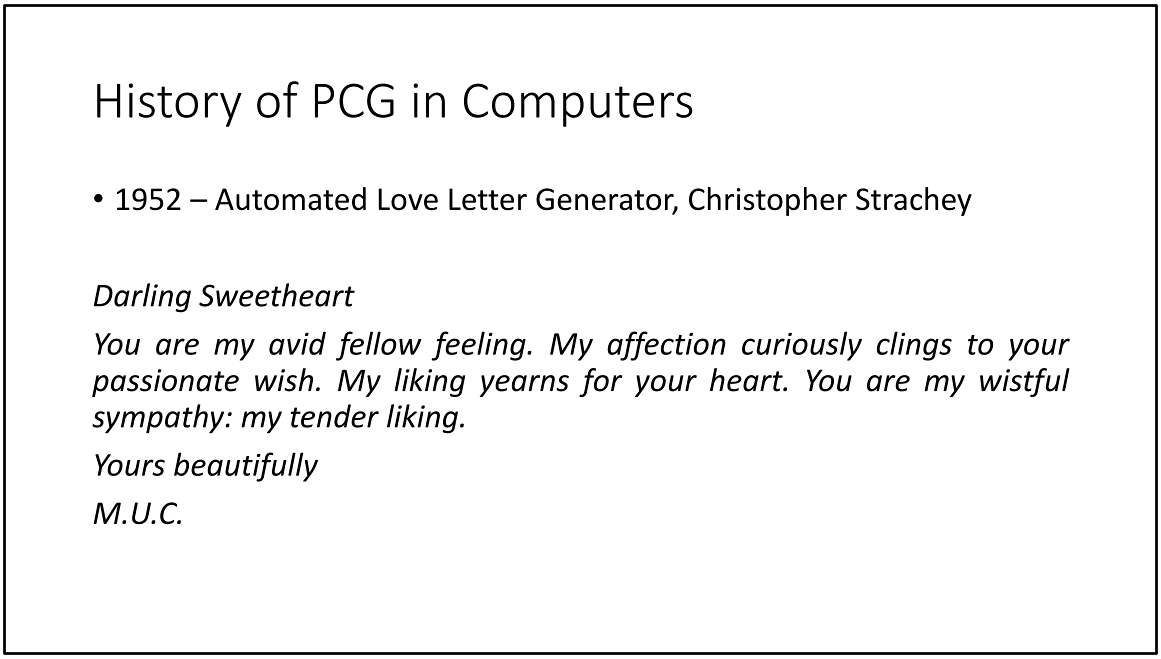
- Johann Phillipp Kirnberger (1757)
- C. P. E. Bach (1758)
- W. A. Mozart (1787)

https://cs.m.wikipedia.org/wiki/Soubor:Wolfgang-amadeus-mozart_1.jpg
PCG Music



Musical dice-game of W. A. Mozart
sample 1

🔊



History of PCG in Computers

- 1952 – Automated Love Letter Generator, Christopher Strachey

Darling Sweetheart

You are my avid fellow feeling. My affection curiously clings to your passionate wish. My liking yearns for your heart. You are my wistful sympathy: my tender liking.

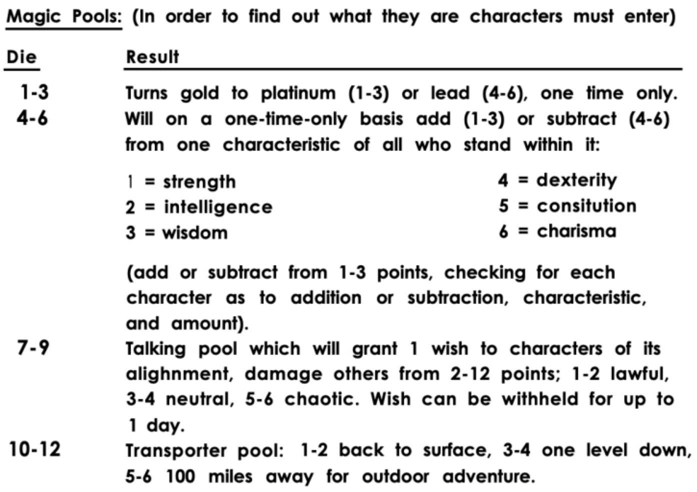
Yours beautifully

M.U.C.

(arguably) first content generation on a computer
M.U.C. – Manchester University Computer (Manchester Mark I(

History of PCG in Games

- Gary Gygax
- Solo Dungeon Adventures in The Strategic Review (1975)



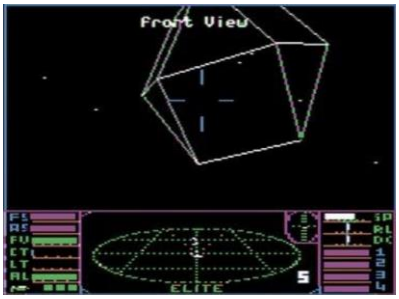
Magic Pools: (In order to find out what they are characters must enter)

Die	Result
1-3	Turns gold to platinum (1-3) or lead (4-6), one time only.
4-6	Will on a one-time-only basis add (1-3) or subtract (4-6) from one characteristic of all who stand within it: 1 = strength 2 = intelligence 3 = wisdom 4 = dexterity 5 = consitution 6 = charisma (add or subtract from 1-3 points, checking for each character as to addition or subtraction, characteristic, and amount).
7-9	Talking pool which will grant 1 wish to characters of its alighnment, damage others from 2-12 points; 1-2 lawful, 3-4 neutral, 5-6 chaotic. Wish can be withheld for up to 1 day.
10-12	Transporter pool: 1-2 back to surface, 3-4 one level down, 5-6 100 miles away for outdoor adventure.

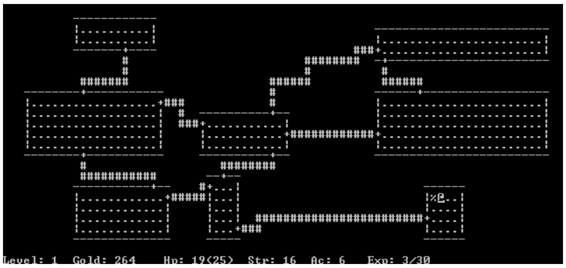
First PCG in games, maybe?
https://annarchive.com/files/Strv101.pdf

History of PCG in Computer Games

Original motivation: Data Compression



Elite (1984)

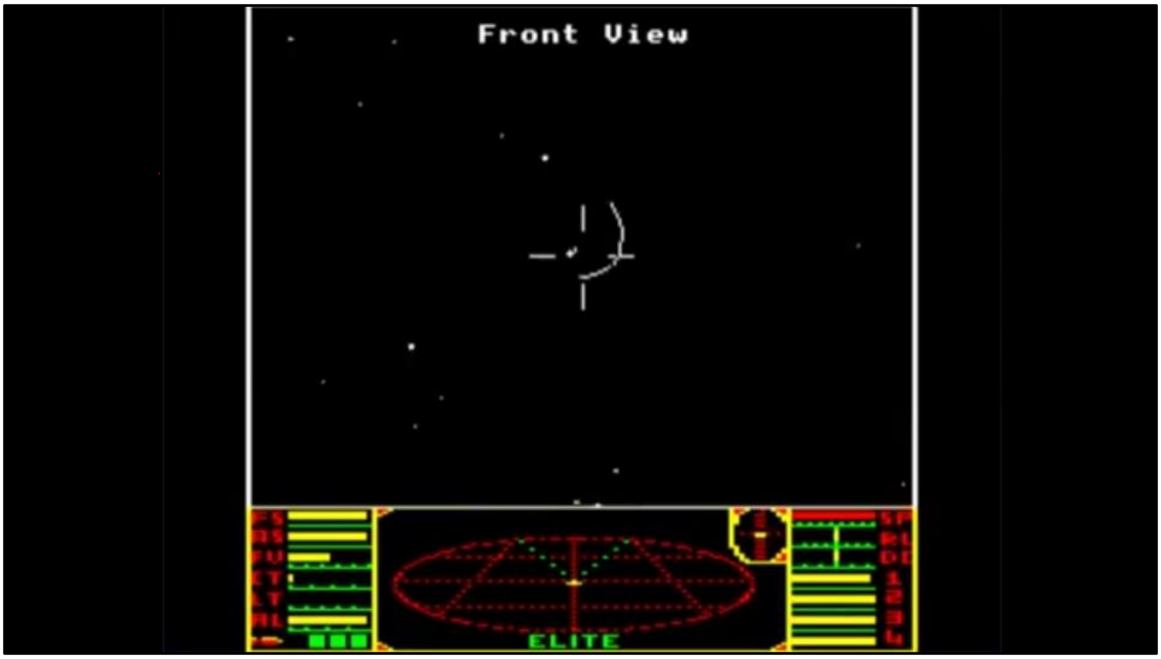


```
Level: 1  Gold: 264   Hp: 19(25)  Str: 16  Ac: 6   Exp: 3/30
```

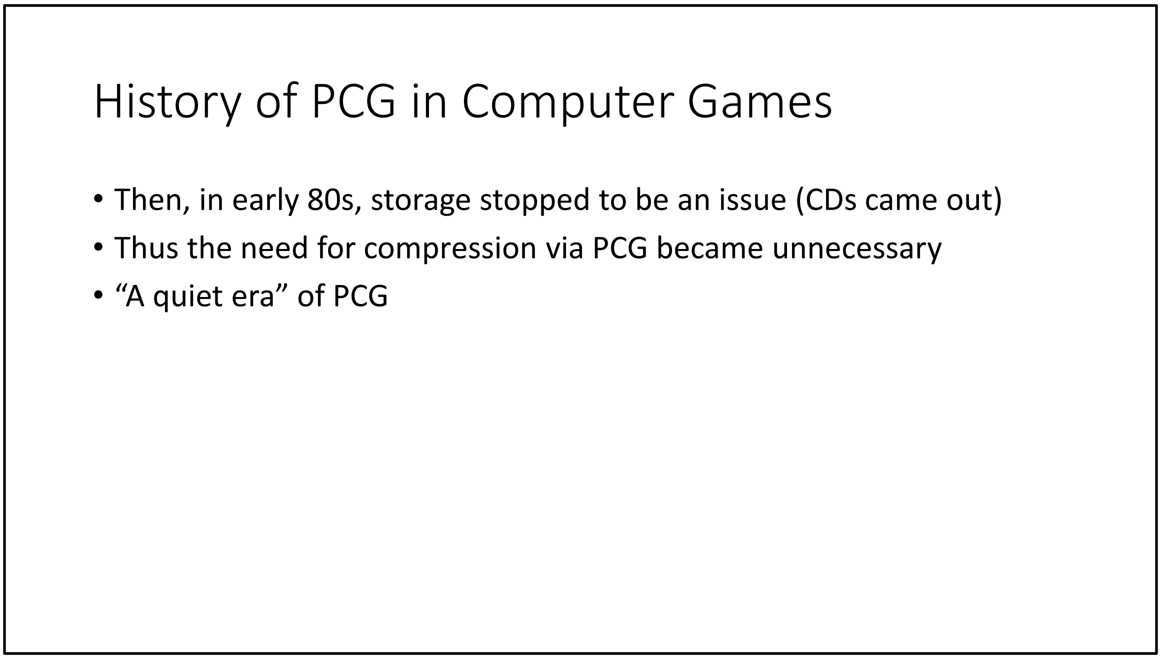
Rogue (1980)

Even earlier: *Beneath Apple Manor (1978)*

Elite – 8 galaxies with 256 planets each, BBC Micro, but got to Apple II, Commodore, ZX Spectrum, even NES, …
Rogue –UNIX (BSD 4.2), but got to Amiga, Atari, ZX Spectrum, …



Front View
ELITE



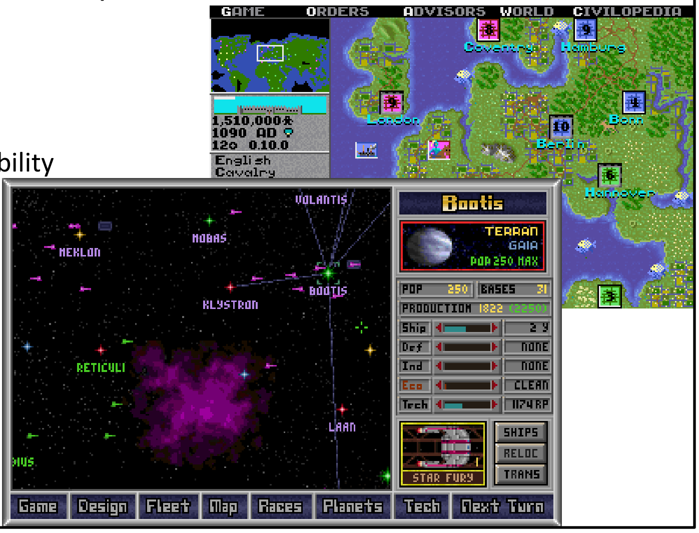
History of PCG in Computer Games

- Then, in early 80s, storage stopped to be an issue (CDs came out)
- Thus the need for compression via PCG became unnecessary
- “A quiet era” of PCG

History of PCG in Computer Games

- Early 90s
- 4X strategies come to light
  - PCG maps useful for replayability

- [Civilization](#) (1991)
- [Master of Orion](#) (1993)



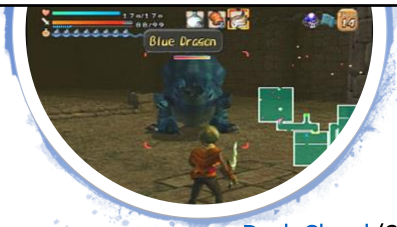
Civilization invented Tech Tree
Master of Orion coined the term 4X

History of PCG in Computer Games

- Diablo (1995)
- Started new era of rogue-likes
- Popularized:
    - Random dungeons
    - Random items

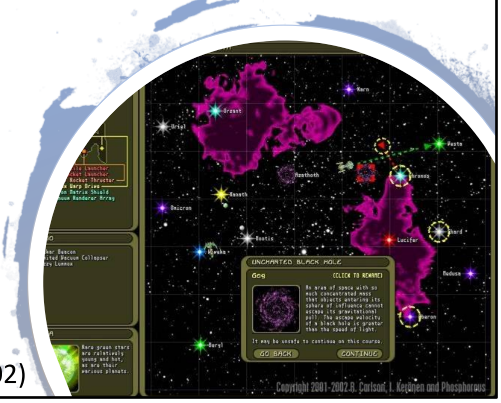
MUD MAN
TOTAL KILLS : 9

History of PCG in Computer Games



Dark Cloud (2002)

- 1996 – early 2000s
- PCG used almost only in
  - RPG games
  - Space games



UNCHARTED BLACK HOLE

Gog (CLICK TO RENAME)

An area of space with so much concentrated mass that objects entering its sphere of influence cannot escape its gravitational pull. The escape velocity of a black hole is greater than the speed of light.

It may be unsafe to continue on this course.

Copyright 2001-2002 R. Carlson, I. Keränen and Phosphorous

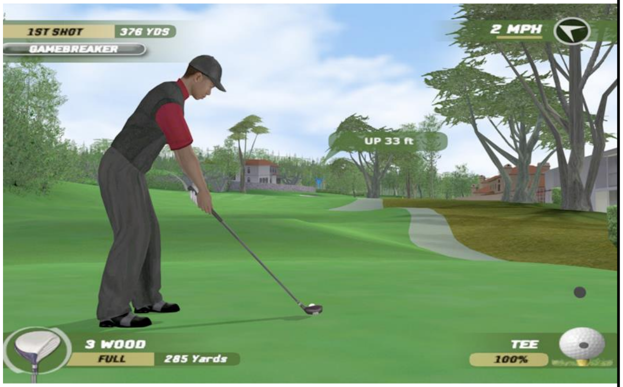
Strange Adventures in Infinite Space (2002)

https://www.freegamesutopia.com/game/strange-adventures-in-infinite-space/651/

History of PCG in Computer Games

- Commercial success of PCG tools
- SpeedTree (2002)
  - Most famous vegetation generator

speedtree



Tiger Woords PGA Tour (2006) , using SpeedTree

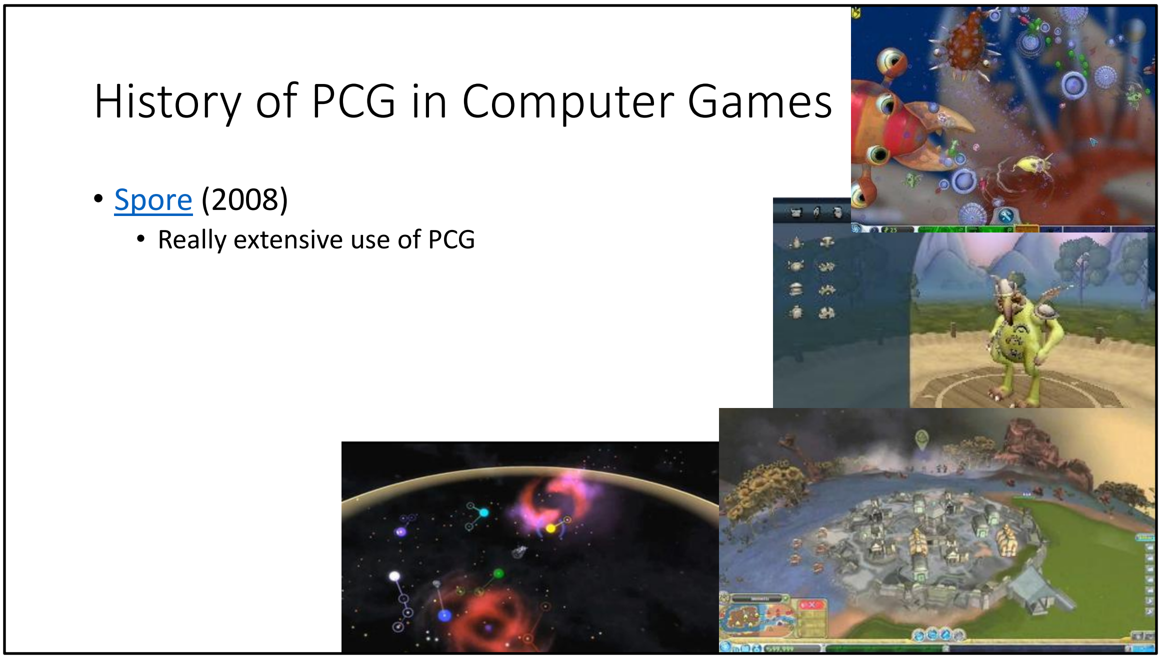
https://droidtrix.com/tiger-woods-pga-tour-06/

Since then used in many games, including GTA IV, Batman: Arkham Asylum and Battlefield 3.

History of PCG in Computer Games

Dwarf Fortress (2006)

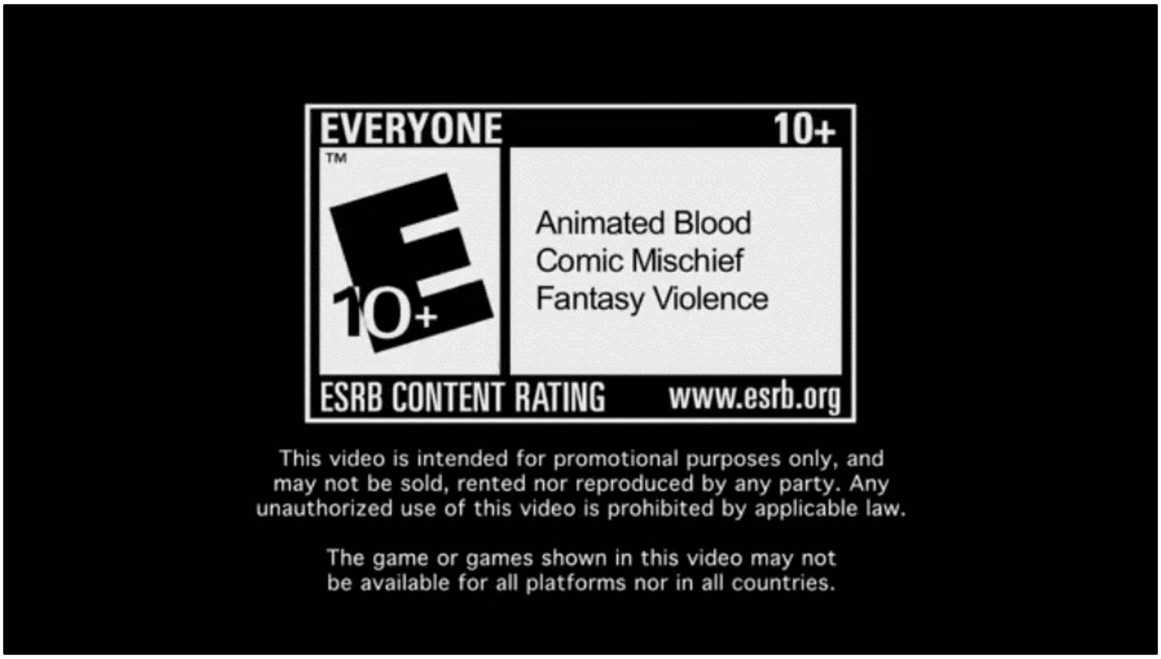
- Generates:
  - World, history, biomes, geological distribution of materials, water erosion
  - Poetry, monsters, animals, cities, …
- Mainly a dwarf-management sim, but also can be played as an RPG



History of PCG in Computer Games

- Spore (2008)
  - Really extensive use of PCG

https://en.wikipedia.org/wiki/Spore_(2008_video_game)
PCG at every step of the game.... Very notábly procedural animation
Also very specific thing that doesn‘t happen often… Semi-multiplayer – using other people‘s works to affect your game



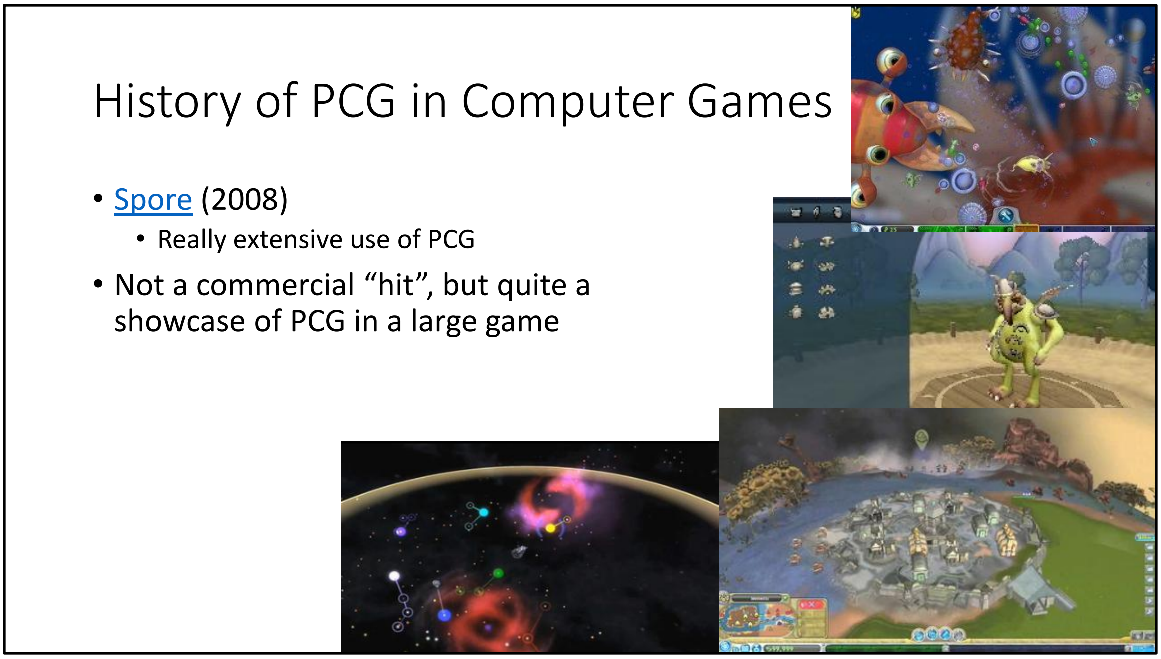
EVERYONE 10+

Animated Blood
Comic Mischief
Fantasy Violence

ESRB CONTENT RATING www.esrb.org

This video is intended for promotional purposes only, and may not be sold, rented nor reproduced by any party. Any unauthorized use of this video is prohibited by applicable law.

The game or games shown in this video may not be available for all platforms nor in all countries.



History of PCG in Computer Games

- Spore (2008)
  - Really extensive use of PCG
- Not a commercial “hit”, but quite a showcase of PCG in a large game

https://en.wikipedia.org/wiki/Spore_(2008_video_game)
PCG at every step of the game.... Very notábly procedural animation
Also very specific thing that doesn‘t happen often… Semi-multiplayer – using other people‘s works to affect your game

History of PCG in Computer Games

Minecraft (Mojang, 2011)

- Endless, editable, voxel world
- Inspired by Dwarf Fortress
- Also a platform for projects
  - Rogue-like in Minecraft

History of PCG in Computer Games

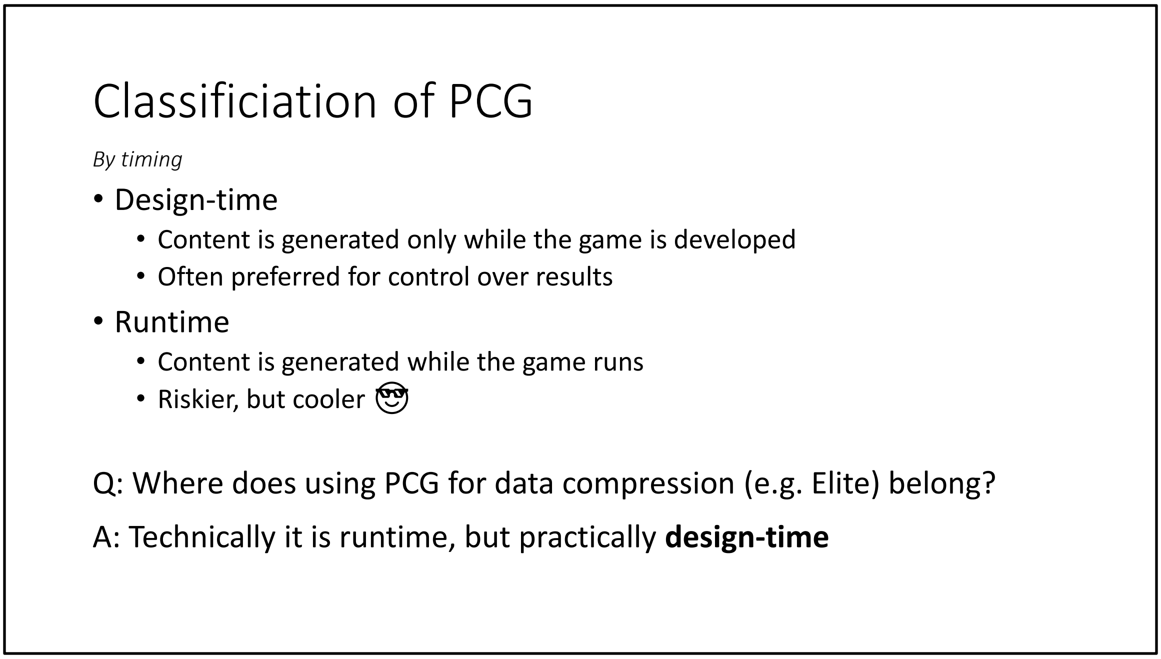
No Man’s Sky (Hello Games, 2016)

- “Every atom procedural”
- Planets with fauna, flora, aliens, …

Current state of PCG

- A large variety of experiments
- Used in pretty much every large game

Classification of PCG



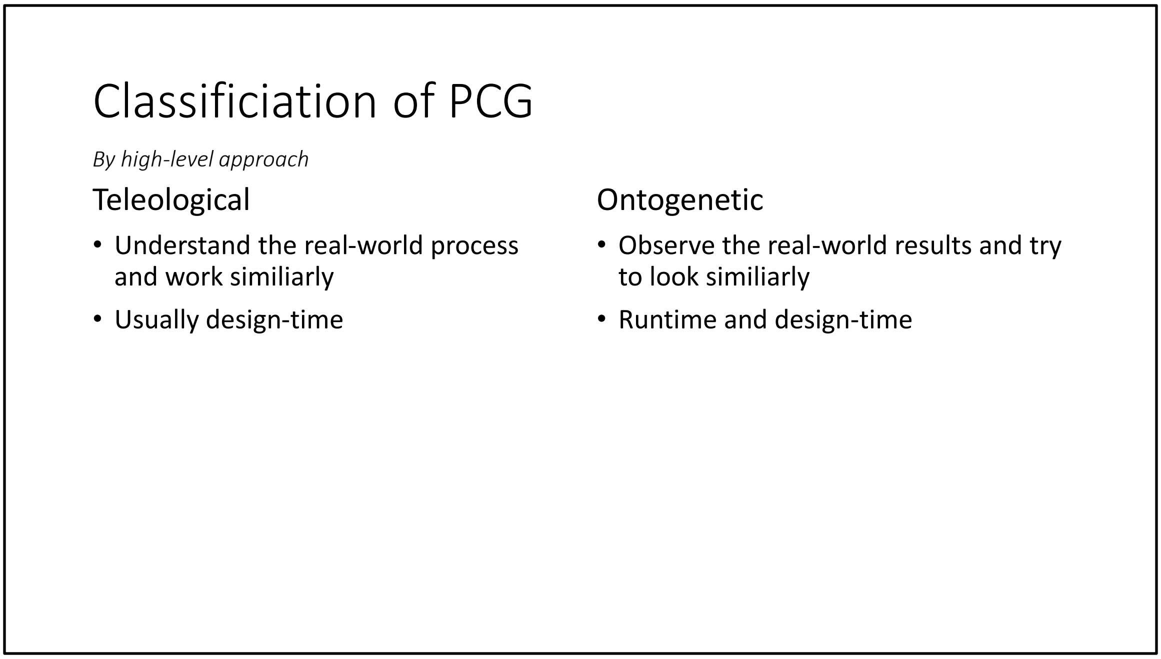
Classificiation of PCG

By timing

- Design-time
  - Content is generated only while the game is developed
  - Often preferred for control over results
- Runtime
  - Content is generated while the game runs
  - Riskier, but cooler 😎

Q: Where does using PCG for data compression (e.g. Elite) belong?

A: Technically it is runtime, but practically **design-time**



Classificiation of PCG

By high-level approach

Teleological

- Understand the real-world process and work similiarly
- Usually design-time

Ontogenetic

- Observe the real-world results and try to look similiarly
- Runtime and design-time

Classificiation of PCG

By high-level approach

Teleological

- Understand the real-world process and work similiarly
- Usually design-time

Ontogenetic

- Observe the real-world results and try to look similiarly
- Runtime and design-time

Q: Where does using PCG solely for data compression belong?

A: Ontogenetic

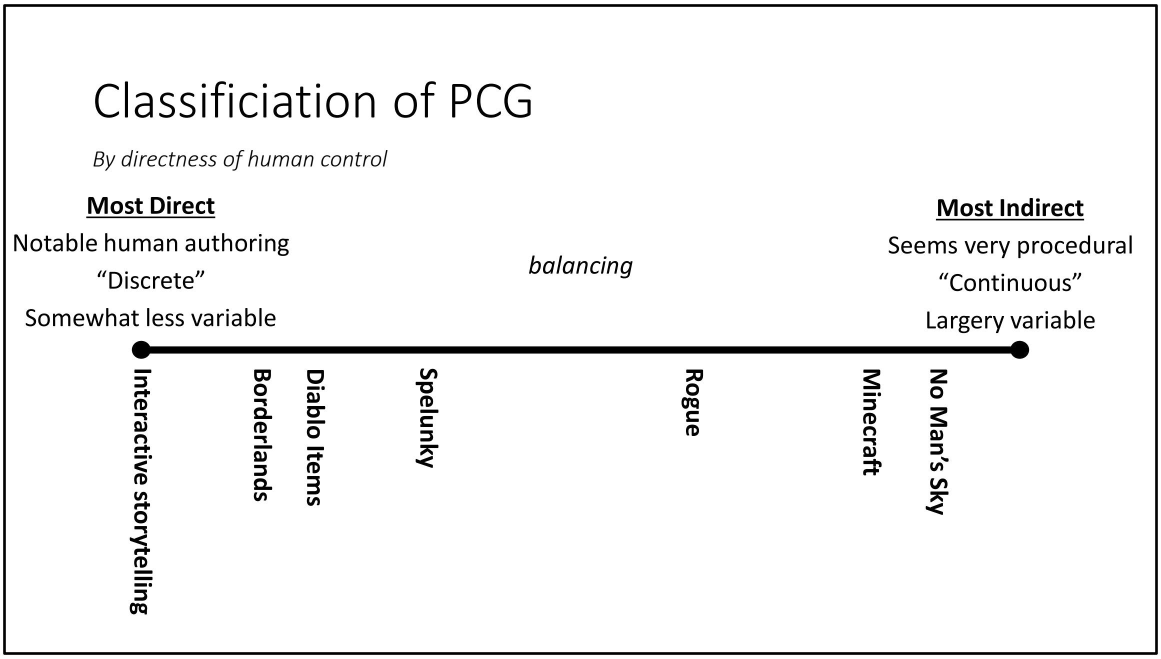
Ontogenetic methods

- Evolutionary algorithms
- Templating search
- Cellular automata
- Grammar systems (most notably L-Systems)
- Noise functions
- PCG via machine learning
- Voronoi diagrams
- …

Teleological methods

- Terrain forming
  - Fault lines, erosion, glaciers, etc.
- Fire spread
- Fluids simulation (water, lava, etc.)
- History simulation
- Fauna / flora growth and decay

Just look at Dwarf Fortress
or maybe Ultima Ratio Regum



Classificiation of PCG

By directness of human control

Most Direct

Notable human authoring

“Discrete”

Somewhat less variable

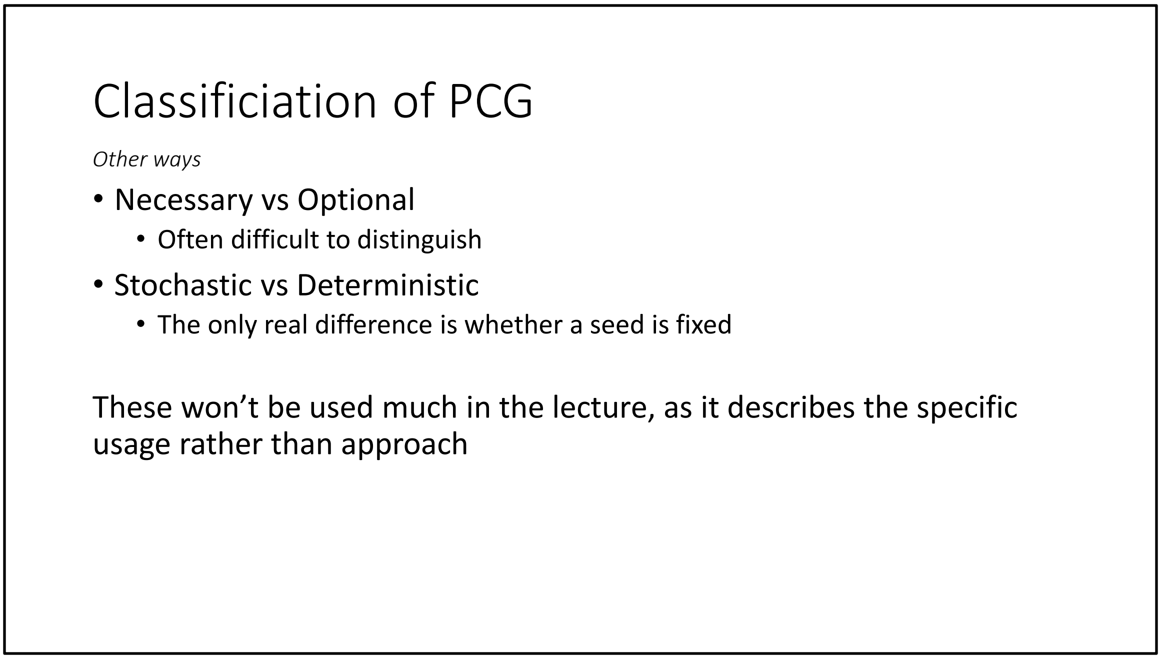
balancing

Most Indirect

Seems very procedural

“Continuous”

Largery variable



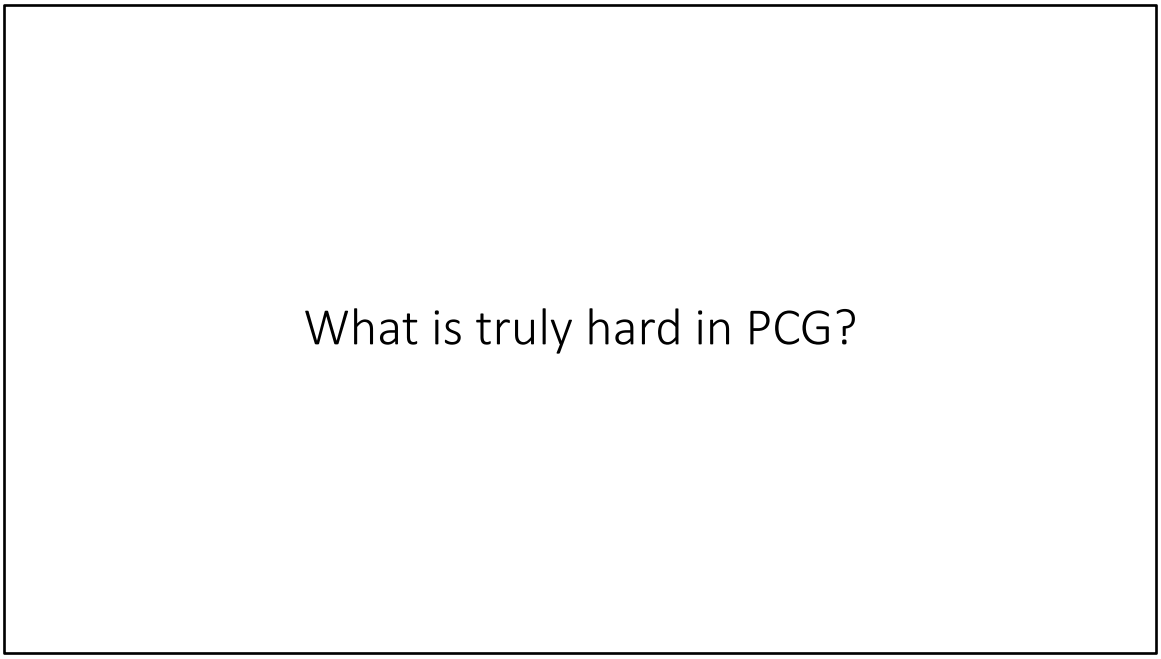
Classificiation of PCG

Other ways

- Necessary vs Optional
  - Often difficult to distinguish
- Stochastic vs Deterministic
  - The only real difference is whether a seed is fixed

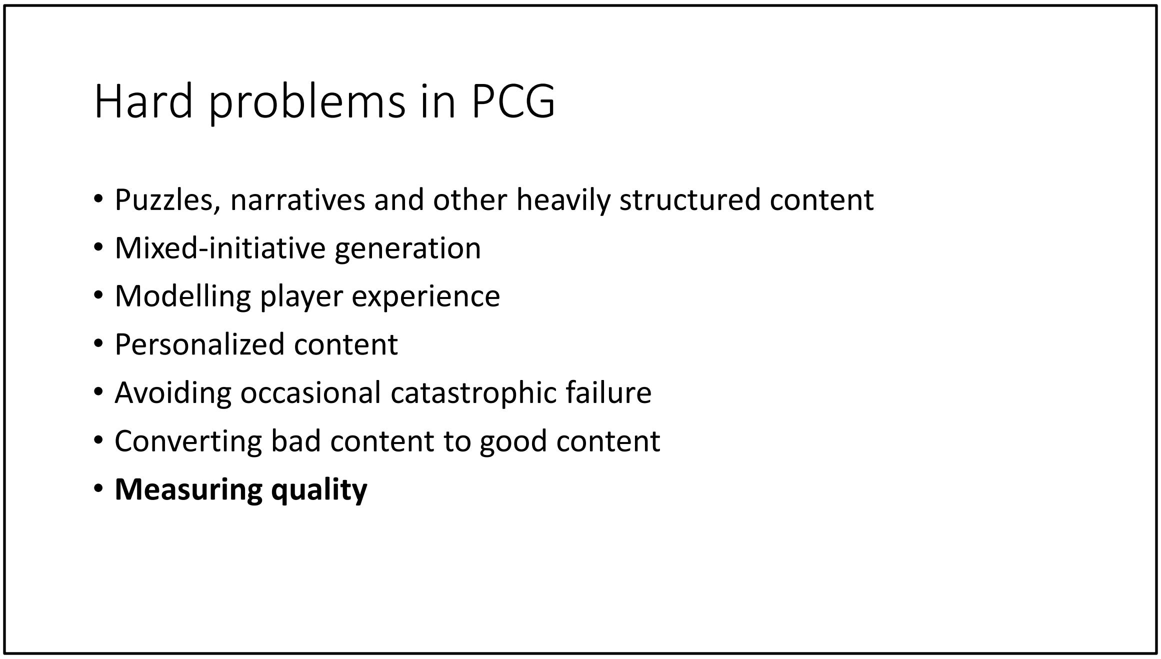
These won’t be used much in the lecture, as it describes the specific usage rather than approach

Optional – off the critical path



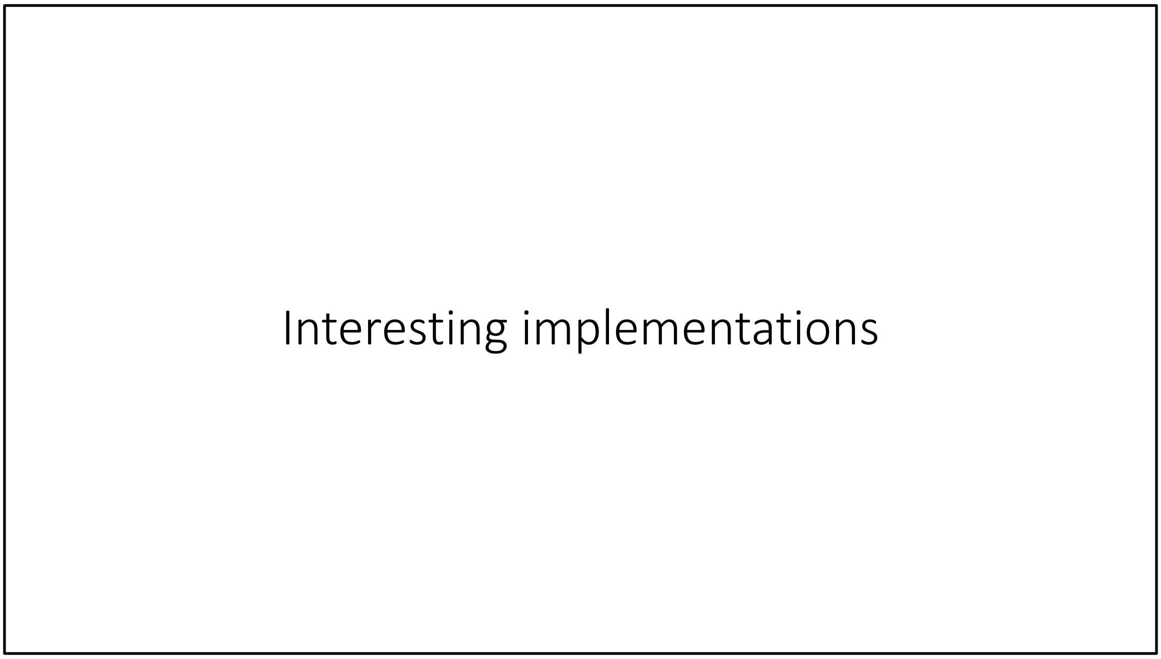
What is truly hard in PCG?

Left 4 Dead, X-Com (distributes players around worlds)



Hard problems in PCG

- Puzzles, narratives and other heavily structured content
- Mixed-initiative generation
- Modelling player experience
- Personalized content
- Avoiding occasional catastrophic failure
- Converting bad content to good content
- **Measuring quality**



Interesting implementations

Left 4 Dead, X-Com (distributes players around worlds)

Borderlands series

- Generating guns procedurally

JAKOBS
VLADOF
Sight
Barrel
Body
Accessory
Grip
Clip
Trigger
Grip
Stock
Shoulde

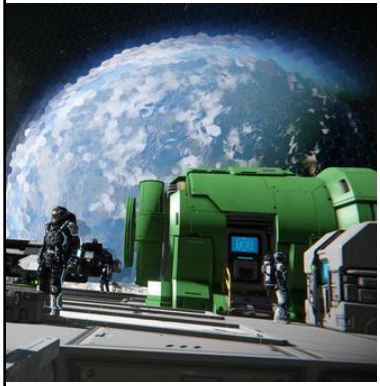
https://borderlands.fandom.com/wiki/Weapons

Yavalath & Pentalath

- Commercial boardgames designed by PCG

https://boardgamegeek.com/boardgame/33767/yavalath

Planets in space

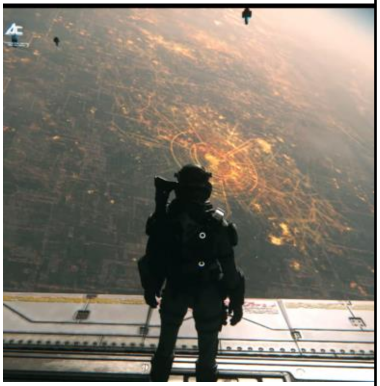


Space Engineers

10 – 60 km radius

No Man’s Sky

avg. 127 km radius



Star Citizen

upto 1000km radius

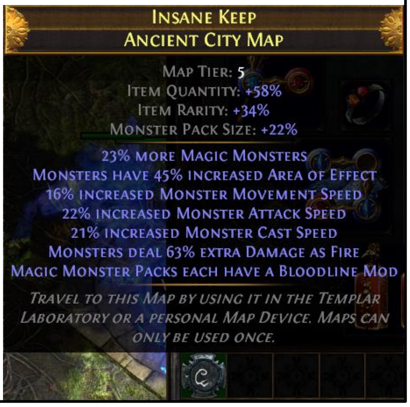
One of them is a “megacity”

Honorary mention: Kerbal Space Program

https://www.pcworld.com/article/3292660/no-mans-sky-next-review.html

Game interaction with PCG

- Path of Exile (Diabloesque RPG)
- Maps as endgame items
  - Find them
  - Upgrade them
  - Expand them into… you know, maps
  - Play them



Insane Keep
Ancient City Map

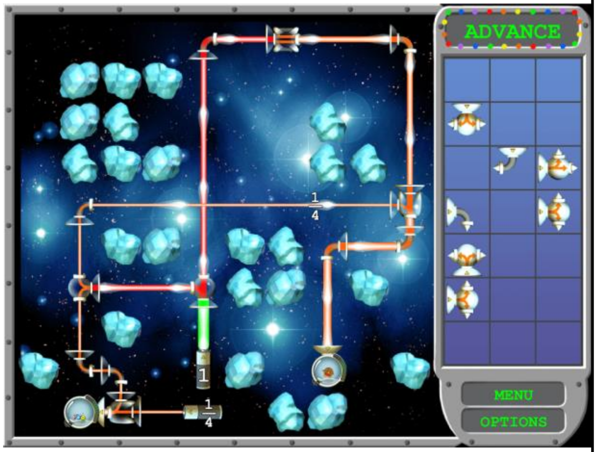
Map Tier: 5
Item Quantity: +58%
Item Rarity: +34%
Monster Pack Size: +22%

23% more Magic Monsters
Monsters have 45% increased Area of Effect
16% increased Monster Movement Speed
22% increased Monster Attack Speed
21% increased Monster Cast Speed
Monsters deal 63% extra Damage as Fire
Magic Monster Packs each have a Bloodline Mod

Travel to this Map by using it in the Templar Laboratory or a personal Map Device. Maps can only be used once.

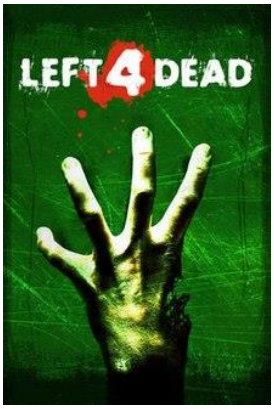
Refraction

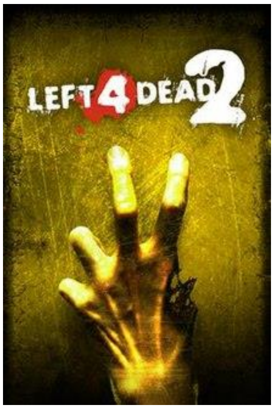
- Generates puzzle-game levels



Dynamic balance

- Left 4 Dead 2
- AI Director
  - Spawns enemies
  - Places weapons
  - Creates walls
  - Controls weather
  - …





Generating content from music

Interactive storytelling

- *borderline PCG*
- *Façade*
- Alter the story by text

Galactic Arms Race

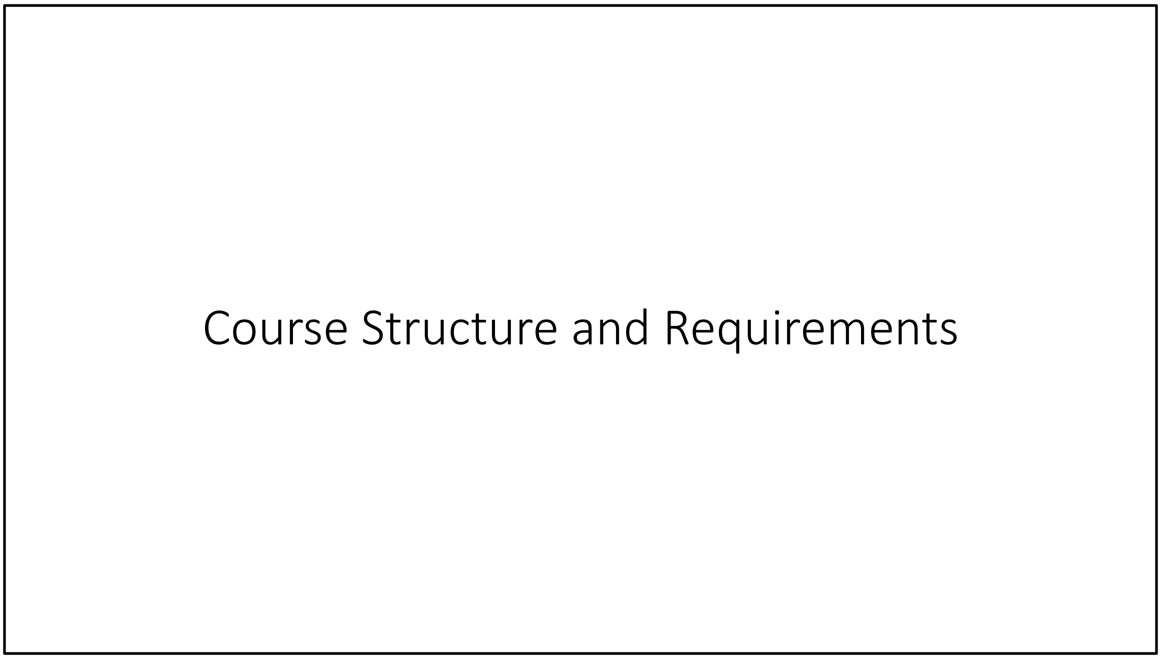
- Evolves weapons as you play
- cgNEAT
    - (neural networks)

Other games featuring Neural Networks may be Creatures, Black & White

.kkrieger

- Modern example of using PCG to compress
- A full FPS game in under 100kB
- Would require 200-300 MB if stored conventionally

https://en.wikipedia.org/wiki/.kkrieger



Course Structure and Requirements

Left 4 Dead, X-Com (distributes players around worlds)

What can you expect from the lecture?

- A “Zoo” of approaches, algorithms and contexts
  - Terrain generation, music, puzzles, dungeons etc.
- An overview of the world of procedural generation
- Trying stuff out!

- No machine learning

Computational Synthesis and Creative Systems
Noor Shaker
Julian Togelius
Mark J. Nelson
Procedural Content Generation in Games
Springer
Procedural Generation in Game Design
Edited by
Tanya X. Short • Tarn Adams
CRC Press

Resources

Noor Shaker, Julian Togelius, and Mark J. Nelson (2016). *Procedural Content Generation in Games: A Textbook and an Overview of Current Research*. Springer.
ISBN 978-3-319-42714-0.

Available online at: *pcgbook.com*

Tanya Short and Tarn Adams (2017). *Procedural Generation in Game Design*. A. K. Peters, Ltd.
ISBN 978-1-4987-9919-5.

One of them too high-level, one of them too low-level

Course Structure

- Two lectures at the start, then alternate with practicals

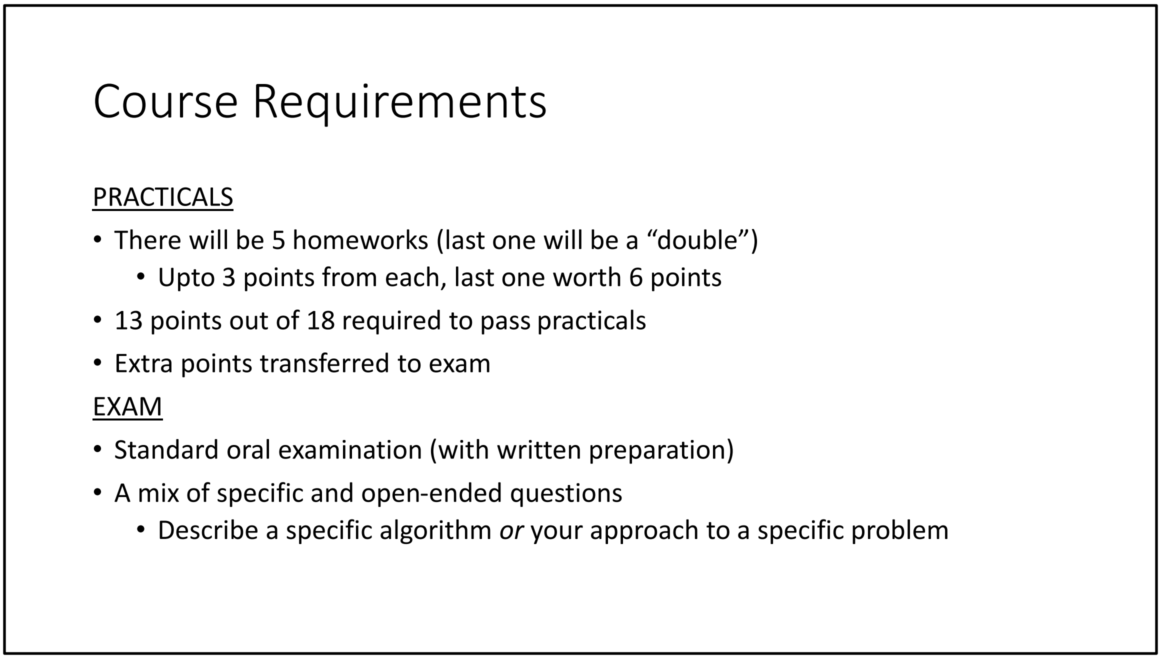
#	Type	Topic
1	Lecture	Introduction
2	Lecture	Terrain Generation
3	Practical	Terrain Generation
4	Lecture	Search-based PCG
5	Practical	Search-based PCG

⋮

- 6 lectures + 6 practicals
- Each practical will be associated with homework

Homework

- Create a PCG element (e.g. terrain, music, …)
- Multiple programming languages
  - Kotlin / Java
  - Python
  - ...
- *Homework tasks do not require complex coding, it is possible (and easy) to finish them without knowing the language beforehand*
  - *Good source learnxinyminutes.com*



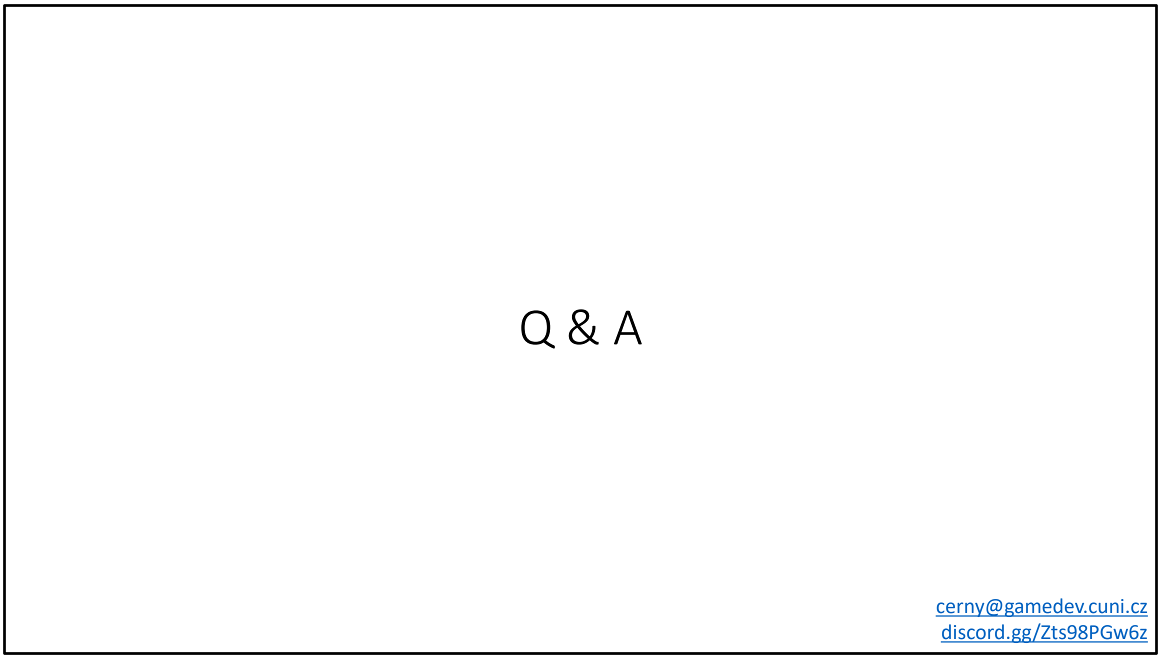
Course Requirements

PRACTICALS

- There will be 5 homeworks (last one will be a “double”)
  - Upto 3 points from each, last one worth 6 points
- 13 points out of 18 required to pass practicals
- Extra points transferred to exam

EXAM

- Standard oral examination (with written preparation)
- A mix of specific and open-ended questions
  - Describe a specific algorithm *or* your approach to a specific problem



Q & A

cerny@gamedev.cuni.cz
discord.gg/Zts98PGw6z