Procedural Content Generation

2016-06-30

OOB

- Trajectory update
  - Meta: Game AI vs Academic, Graphs + Search
  - Physical Acts: Movement, Steering
  - Decide: FSMs, Plans, D&B Trees, RBS, BBs, Fuzzy
  - Model, Learn and Generate
- HW6 due 7/11
- Capstones, Capstones, Capstones!

Questions

1. How can we describe decision making?
2. What do the algorithms we’ve seen share?
3. What are the dimensions we tend to assess?
4. FSMs/Btrees: ____ :: Planning : _____
5. For the 2nd blank, we need m_____s.
6. When is reactive appropriate? Deliberative?
7. What is the ‘hot-potato’ passed around (KE)?
8. H______ have helped in most approaches.
9. Which approach should you use?

Questions

1. What are the 2 most “complex” decision making techniques we’ve seen?
2. What are their strengths? Weaknesses?
3. What is the key (insight) to their success?
4. What is typically necessary to support this insight (hint: used in Planning + RBS)?
5. What does Planning have that (forward chaining) RBS do not?
6. When do we need a communication mechanism?

PROCEDURAL CONTENT GENERATION

Procedural Content Generation

- Use of computation instead of manual effort to produce elements of gameplay
  - Design aspects of the game
    - Save development cost
    - Save storage or main memory (“infinite games”)
  - Adapt aspects of the game (player models)
- What sorts of problems?
- What games?

History of PCG

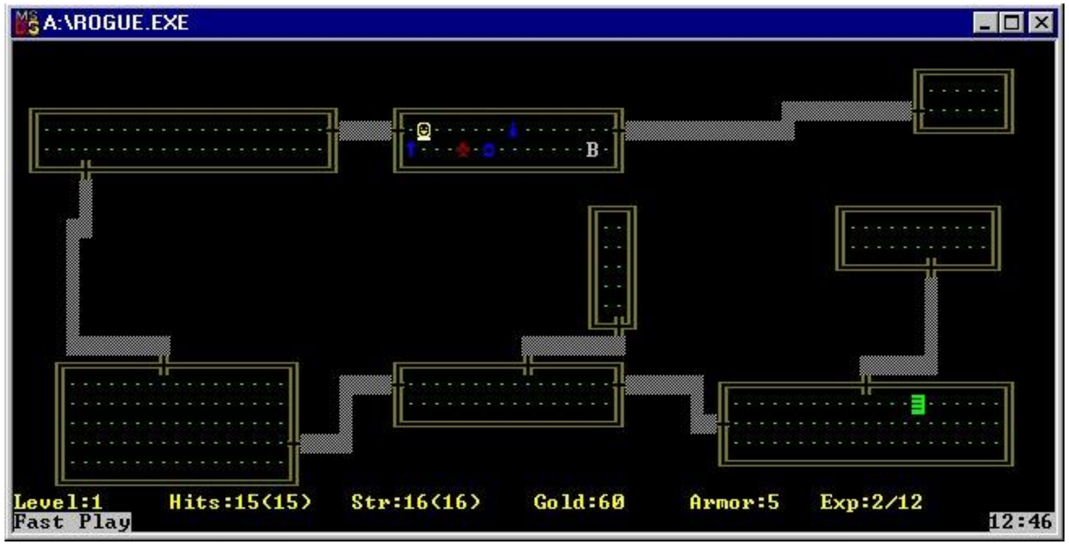
- Level generation was an early feature of games
- Games weren’t professionally developed
- Memory and storage was limited
- Processors also limited
- Tradeoff between memory/storage and processor was important
  – Random generation was the answer

The random seed

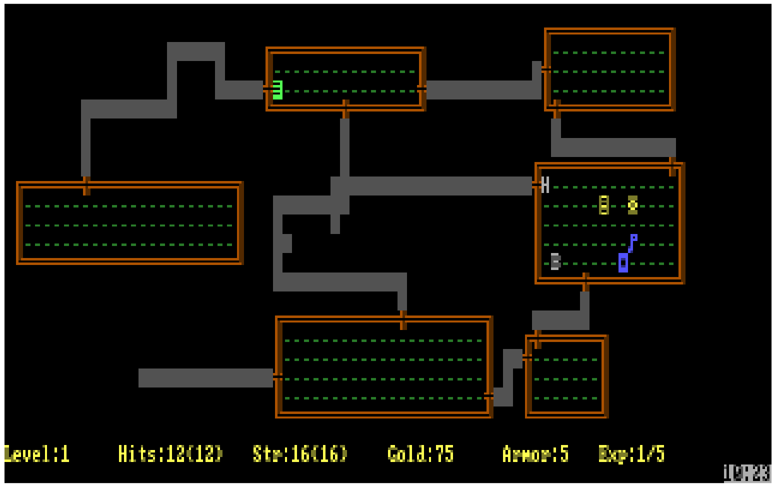
- Pseudorandom number generator
  - Algorithm creates sequence of numbers that are “sufficiently close” to random
  - Sequence is completely determined by initial value(s);
- What happens if
  - Different seed every time the game is played
  - The same seed is reused

History

- Rogue (AI Design, 1983)
  - http://www.abandonia.com/en/games/982/Rogue+-+The+Adventure+Game.html
  - Granddaddy of all rpg dungeon-crawlers
  - Unlimited replay: dungeons + monsters PCG



```
Level:1      Hits:15(15)    Str:16(16)    Gold:60      Armor:5     Exp:2/12
Fast Play                                                              12:46
```



```
Level:1    Hits:12(12)   Str:16(16)   Gold:75    Armor:5   Exp:1/5
```

History

- Elite (Acornsoft, 1984)
  - http://www.iancgbell.clara.net/elite/
  - Space trading (piracy, trade, military, etc.)
  - Original plan: 2^{48} galaxies, 256 solar systems each
  - Final: 8 galaxies
  - Planet pos., commodity prices, name/local details

History

- The Sentinel (Firebird, 1986)
  - http://www.youtube.com/watch?v=9V_pgo3vgiI
  - “The first VR game”
  - 10,000 levels
  - Pseudorandom number generators (again)
- Consolidated list:
  - http://en.wikipedia.org/wiki/Procedural_generation#Software_examples

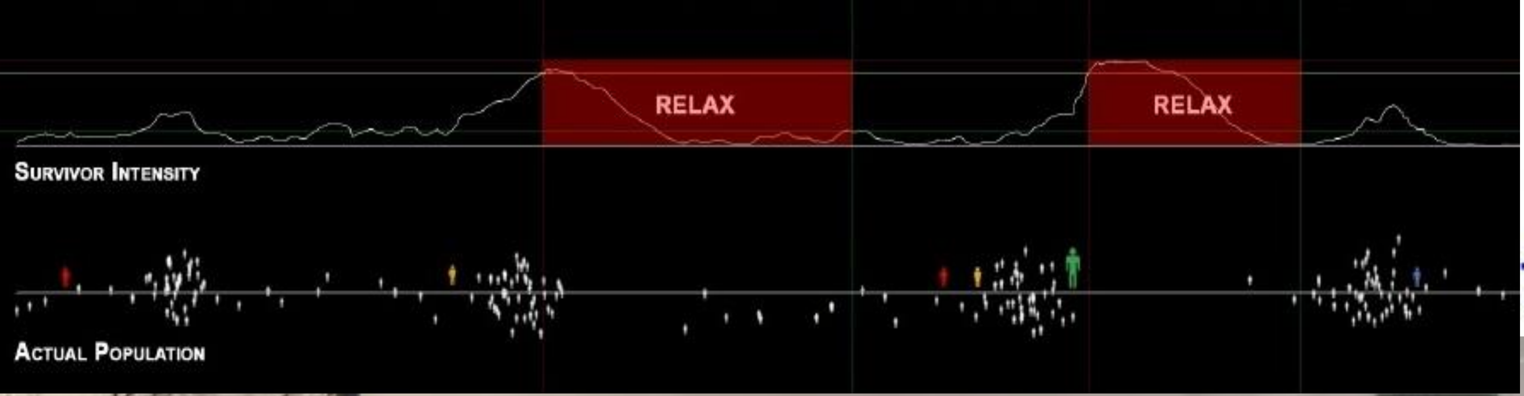
Problems, Solutions, Problems

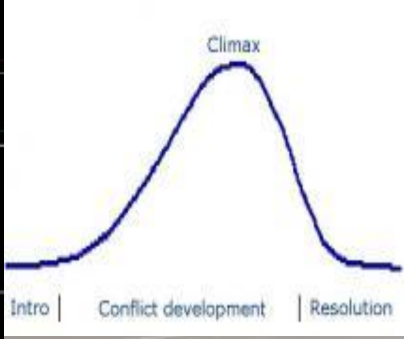
- Early
  - Not enough space
  - Artists (and art assets) cost money + space
  - Shift costs to algorithm design + CPU
- Middle
  - Can “cheat”, ok to repeat objects
  - Artists create “seeds”, algorithms combine
- Now (spiraling costs of high-quality content)
  - “behind the scenes” → trees and vegetation
  - “search-based”, “experience-driven” → Player models
  - Flow (Dynamic Difficulty Adjustment, Drama Management)

Desiderata

- Fast, Reliable, High-quality
- Novelty, Structure, Interest
- Controllable (parameterized)
  - Geometric aspects (e.g. length of track)
  - Gameplay aspects (e.g. difficulty)
  - Adapted to player(s) (e.g. preference, type, fun)
  - Designer-centric as well

See: http://www.marioai.org/levelGenerationCompetition.pdf for excellent overview





Credit: http://dankline.wordpress.com/2011/06/29/the-ai-director-of-darkspore/

Battlefish

https://dankline.wordpress.com/2011/06/29/the-ai-director-of-darkspore/

Last 2 Spikes	If Doing Well, Next is...	If Doing Poorly, Next is...
Hard, Medium	Hard	Medium
Hard, Skip	Hard	Medium
Medium, Hard	Medium	Skip
Medium, Medium	Hard	Skip
Medium, Skip	Hard	Medium
Skip, Hard	Medium	Skip
Skip, Medium	Hard	Medium

Source http://dankline.wordpress.com/2011/06/29/the-ai-director-of-darkspore/

Things we AI Directed:

1. Matchmaker
2. Level Selection
3. Spawn types
4. Spawn placement
5. Spawn amount
6. Enemy health and damage
7. Loot and DNA drops
8. Health and Power drops
9. Music

Just a Utility Targeting Function!

Source http://dankline.wordpress.com/2011/06/29/the-ai-director-of-darkspore/

Things we didn’t AI Direct, but we probably should have:

1. Damage and Crit rolls
2. Quality of Loot Drops
3. Loot Pickup Rolls
4. Elite spawns
5. Elite affixes

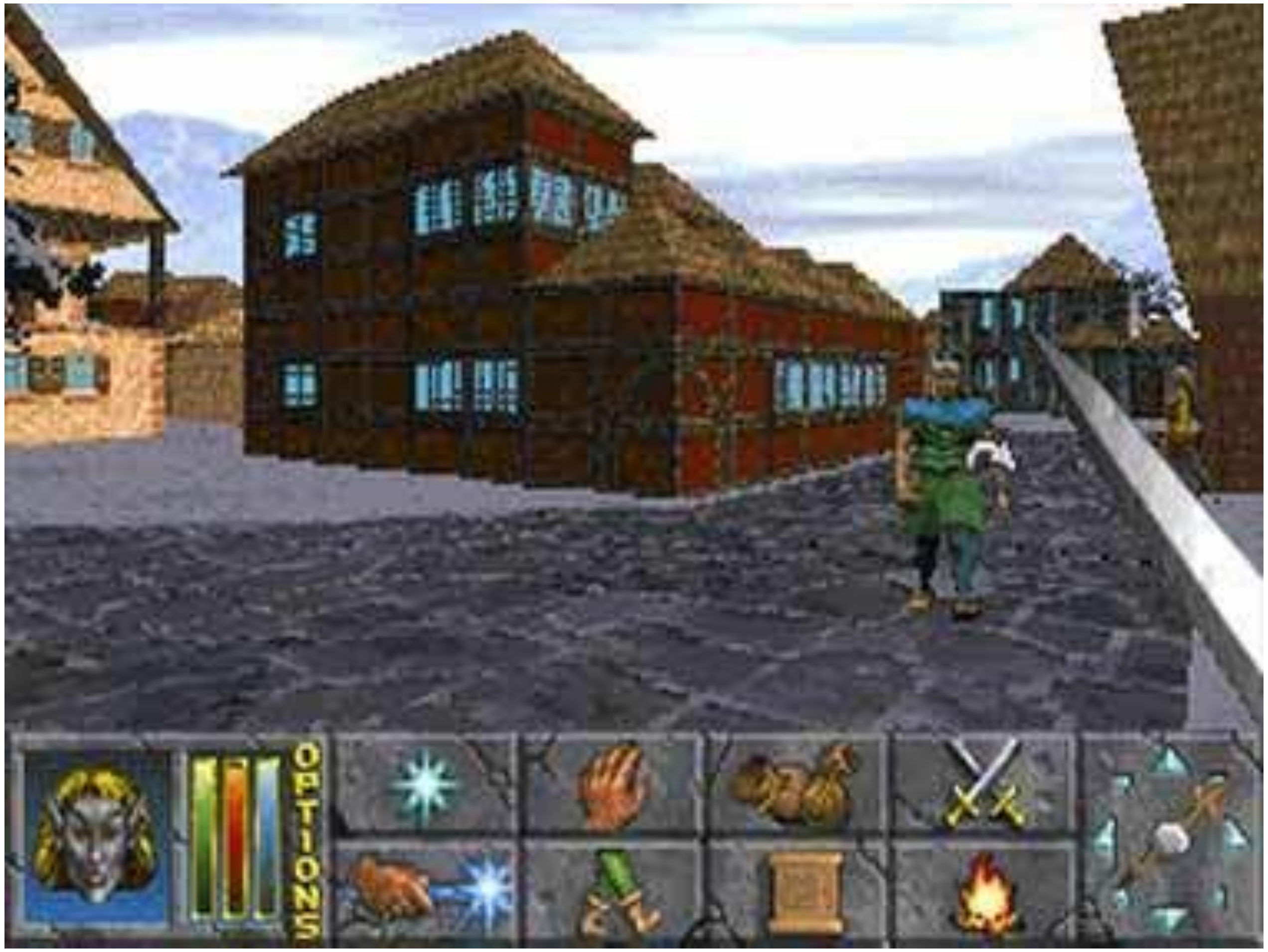
Source http://dankline.wordpress.com/2011/06/29/the-ai-director-of-darkspore/

Star Trek Online
Generates new races, new objects, star systems and planets for exploration
Players can save coordinates for a system, which becomes available for others

AIGameDev.com

From Dust: Terrain generation

Controlled Procedural Terrain Generation Using Software Agents
http://larc.unt.edu/ian/pubs/terrain.pdf



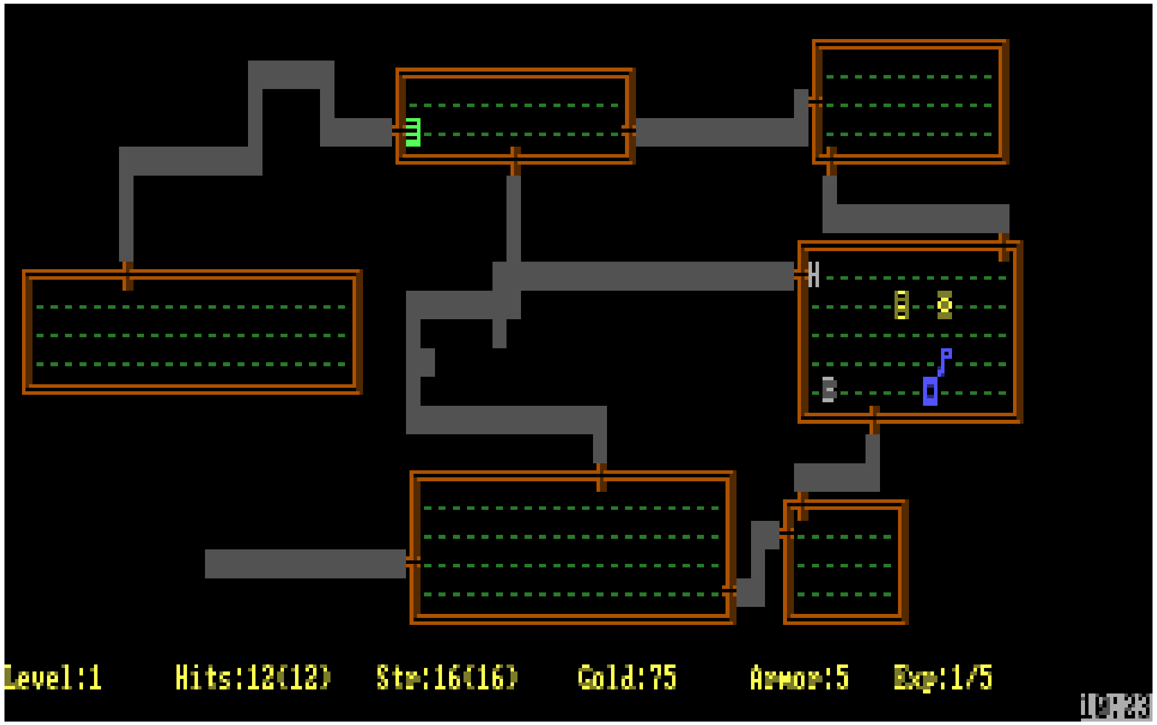
Elder Scrolls II: Daggerfall (Bethesda, 1996)
http://www.elderscrolls.com/daggerfall/
Generated terrain
15,000 towns, villages, dungeons
750,000 NPCs

Fuel (2009)
Game world is size of Connecticut
The award for largest playable area in a console game was awarded (Guinness World Record)
Wander looking or people to race

http://www.terminally-incoherent.com/blog/2011/12/16/skyrim-radiant-quest-system/
http://www.joystiq.com/2011/11/09/howard-skyrim-offers-infinite-procedurally-generated-quests/

“Roguelike” Games

- http://en.wikipedia.org/wiki/Roguelike
- Rogue
  - http://www.hexatron.com/rogue/index.html
- Moria
  - http://www-math.bgsu.edu/~grabine/moria.html
- Angband
  - http://rephial.org/play
- Diablo



Silly Platformers

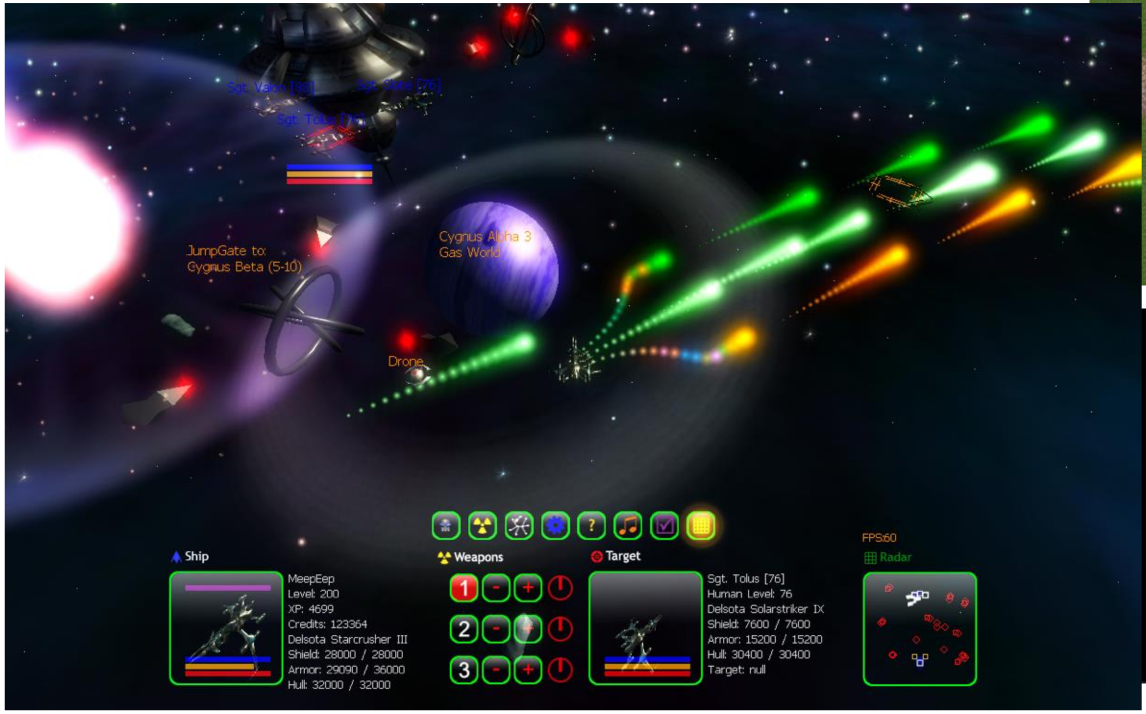
- Infinite Mario Bros
  - https://mojang.com/notch/mario/
  - http://www.flasharcade.com/action-games/infinite-mario-bros.html
- Cabalt
  - http://adamatomic.com/canabalt/
- Robot Unicorn Attack
  - http://games.adultswim.com/robot-unicorn-attack-twitchy-online-game.html

Indy Level Generators

- Spelunky
  - http://www.spelunkyworld.com/
- Dwarf Fortress
  - http://www.bay12games.com/dwarves/
- Minecraft
  - http://www.minecraft.net

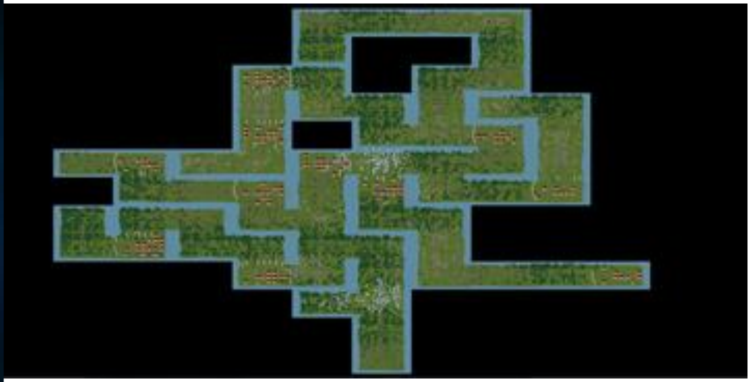
Academic labs

- Galactic Arms Race
  - http://gar.eecs.ucf.edu/
  - http://galacticarmsrace.blogspot.com/p/research.html
- Game Forge (here!)
  - https://research.cc.gatech.edu/inc/game-forge
- Challenge Tailoring + Contextualization (here!)
  - https://research.cc.gatech.edu/inc/challenge-tailoring



MeepEep
Level: 200
XP: 4699
Credits: 123364
Delsota Starcrusher III
Shield: 28000 / 28000
Armor: 29090 / 36000
Hull: 32000 / 32000

Sgt. Tolus [76]
Human Level: 76
Delsota Solarstriker IX
Shield: 7600 / 7600
Armor: 15200 / 15200
Hull: 30400 / 30400
Target: null



Game Development is Changing

- Previous model
  - Designers did design on paper
  - Designers handed over to developers
  - Developers might iterate with developers on what is possible
- Current model
  - Developers build engines
  - Developers build tools for designers
  - Designers use tools to make characters, levels, cut-scenes, etc.
  - Developers help with things the tools can't do
  - Sometimes tools are developed concurrent with design (for new features)

Take away message

- Content is king
- Content is the domain of the designer
- Sometimes new innovations in engines may drive design (e.g., Portal)

Why industry is looking at PCG

- Development cost savings
- Replayability
- Customization/adaptation
- Dynamic difficulty adjustment
  - Flow theory
    - C.f. http://en.wikipedia.org/wiki/Flow_(psychology)
    - http://jenovachen.com/flowingames/designfig.htm
    - http://en.wikipedia.org/wiki/Flow_(video_game)

Design time vs. Run time PCG

- Design time: Speed up design of static content
- Run-time: customization, dynamic adjustment

Design time PCG

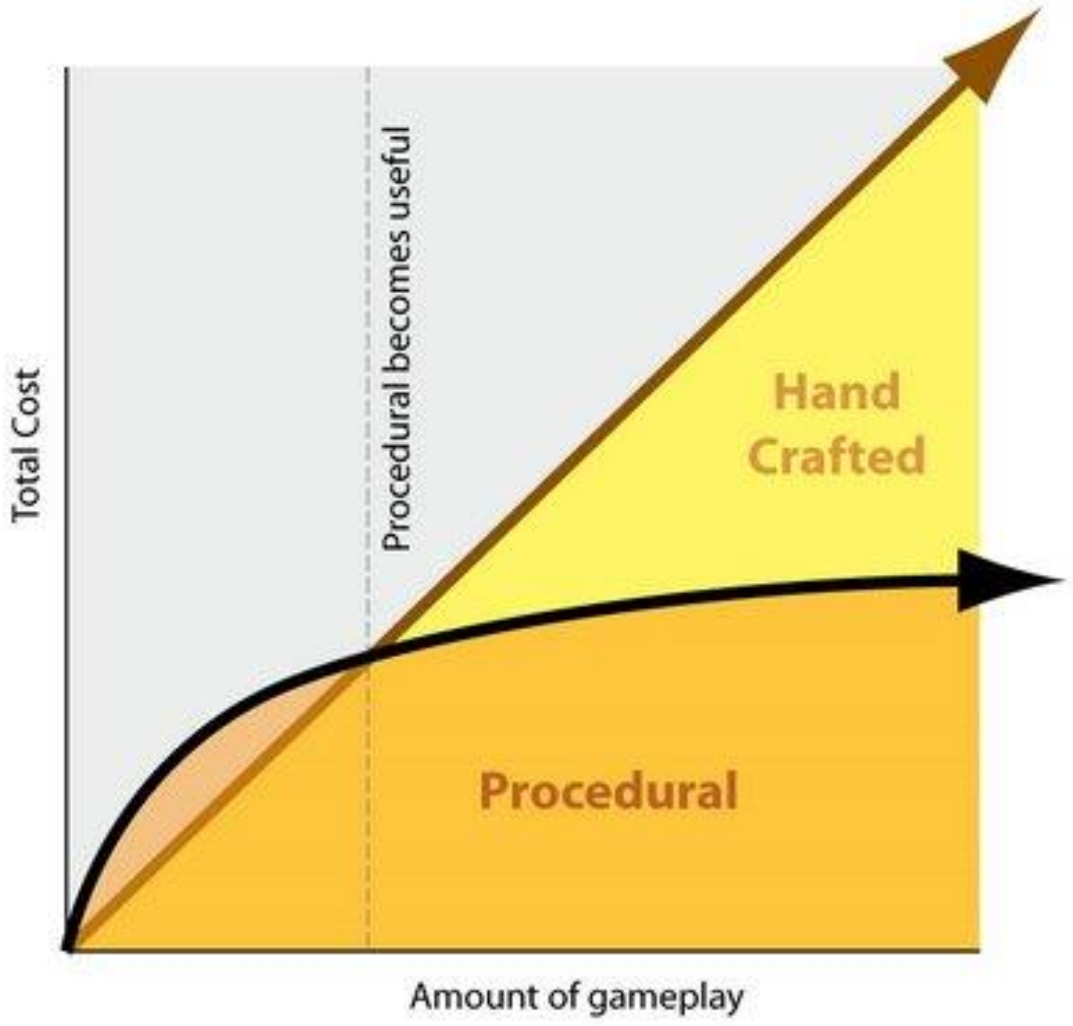
- Graphical asset construction is also consuming development time
  - # of unique objects in the world
  - Players expect non-repetitive
  - Game dev times now 100s of man-years with huge design teams
- Cost savings therefore a strong motivation
- But there are risks:
  - Procedures can do stupid things that destroy the player experience
  - Game design process exists to maximize control of design

Design time PCG

- Typically a mix of designer provided assets and procedural use of assets
  - Speedtree
  - CityEngine:
  - Terragen
    - Star Trek Nemesis
    - Golden Compass
    - TV Commercials

CityEngine: http://www.esri.com/software/cityengine/

Economies of scale



Types of content

- Throw away
- Reusable
- Handcrafted anything is expensive and hard to modify
- The more handcrafted throwaway content, the less agile development, and more time spent on things the players don’t appreciate
- PCG doesn’t have to be human-level; just “good enough”

Run time PCG

- Players are different
- Preferences for pace and playstyle
  - Moderate challenge levels
  - Help avoid getting stuck
  - Adapt to player's tastes
  - Detecting player exploits
- When to use run-time PCG
  - When decisions can only be made at run-time
  - When you just can't pre-compute due to storage/memory limits
- Optimization problem
  - What is the set of content that delivers the optimal experience to the player given individual differences?
  - Example: rubber banding

Player Modeling

- What is optimal in PCG?
- Need a player model
  - Tells you something about the player
  - Makes predictions about player
- Challenges in player modeling:
  - What do you model?
  - Where do you get the model?
  - How do you use the model?

External Inspiration Set

- Anything a priori unknown that a procedure can use to generate content
  - Music
  - Twitter feed
  - Internet traffic
- Avoid random looking!

Promises

- Instancing in-game entities (especially appearance)
- NPC histories
- Puzzles that are harder or easier
- Puzzles/levels with more than one solution
- Easing “permadeath”
- Story generation
- Pacing
- Different, multiple endings
- Meaningful choices
- Extending game lifetime

Risks

- PCG can be NP-hard for anything non-trivial
  - But you can't always make players wait
- Thorough testing of run-time PCG is impossible
  - Best you can do is statistical sampling
- Offensive material
- Bad content
- Algorithm crash
- Meaningless activities
  - Easy to create quests, but if they don't connect to the larger game, no one cares

Hard problems in PCG

- Procedures structuring player’s experience
  - Narrative
- Mental models of players
- Statistical player models
- Avoiding (dealing with) occasional catastrophic failure
- Algorithm safety
- Healing a broken level
- Social factors and full expressiveness with story/language generation
- “Deep understanding” vs. “generate & test”
- Personalized generated content
- Destiny
  - It’s easy to have infinite levels, but dungeon crawling gets boring without a sense of progression/achievement
- How do you know you are generating something interesting?

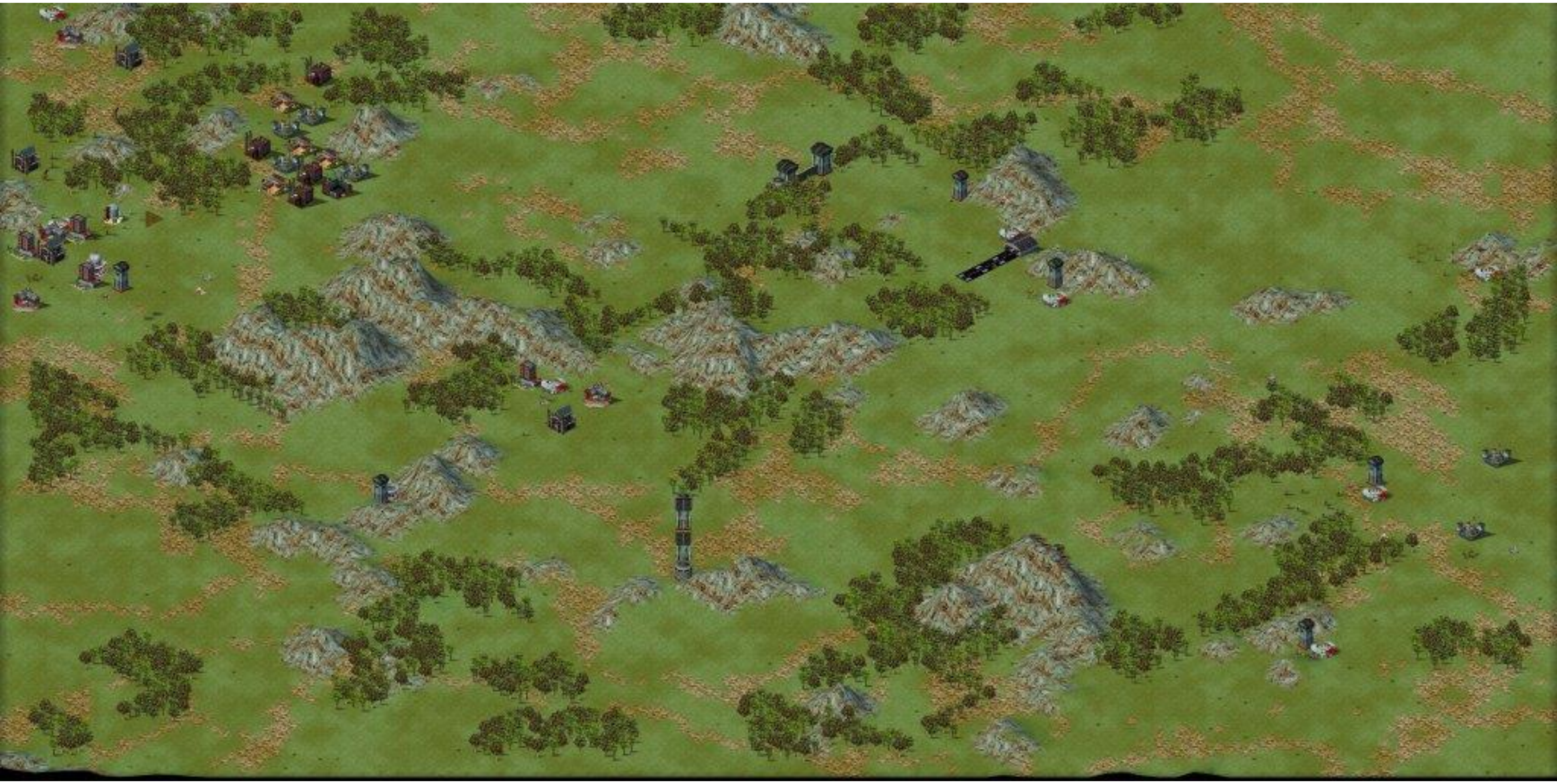
From AI Game Programming Wisdom 2 (Rabin, 2004)

CASE STUDY: EMPIRE EARTH (SHOEMAKER'S MAPMAKER)

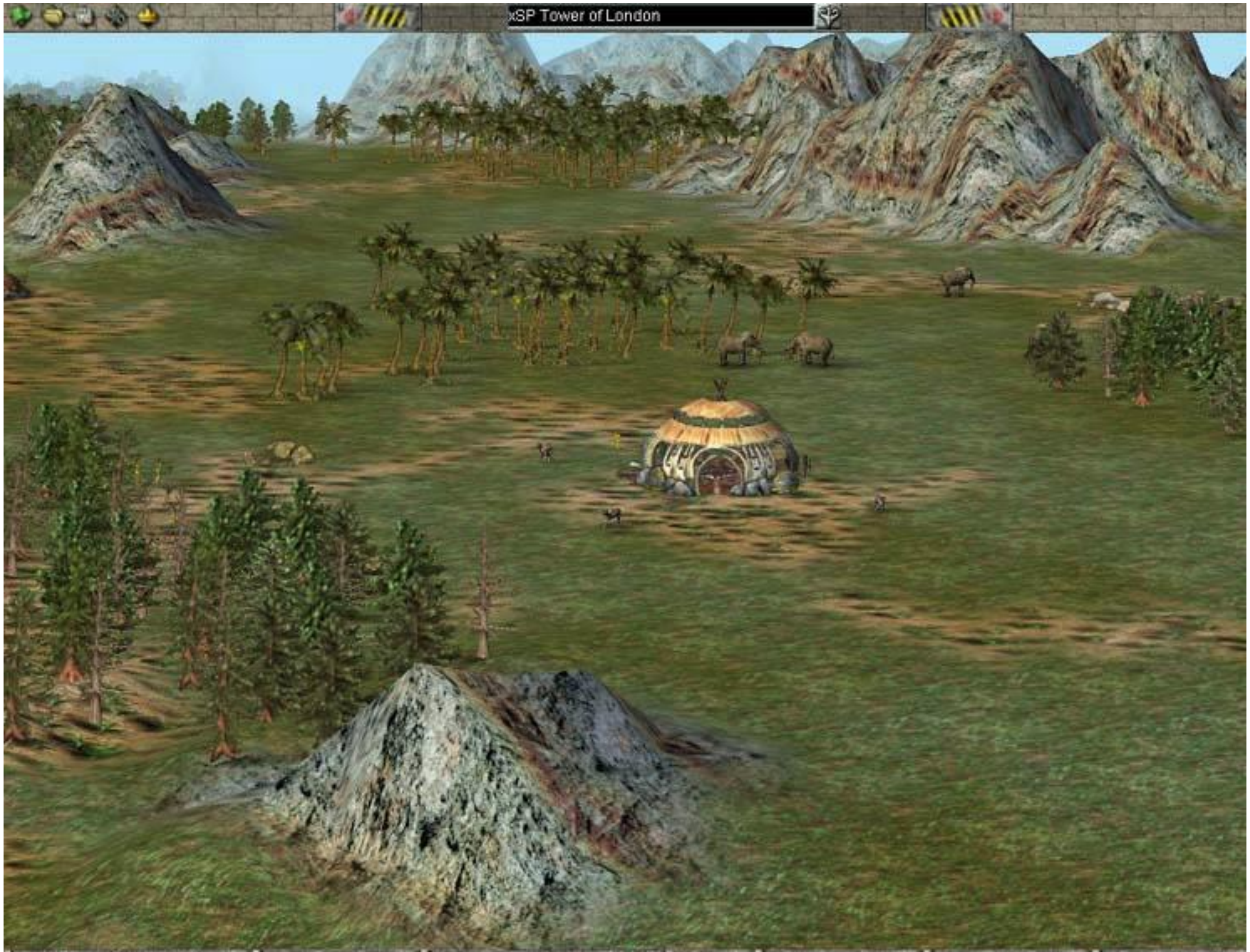
Stainless Steel Studios

- Dedicated exclusively to designing RTS games
- RT 3D game engine: TITAN 2.0
  - Windows, complete source (c++), 40+ person years
  - 3 million units sold (got cash?)
- Empire Earth
  - Released Nov 2001
  - *"… a new high-water mark for realtime strategy fans."* GameSpy's Dave Kosak
  - Same lead game designer (Rick Goodman) as AOE
- Empires: Dawn of the Modern World

Birds-Eye



Fancy 3D View



If You Were Asked…

- Make a system to generate maps
  - Tile-based
  - RTS
  - Multi-player
- What qualities should these maps have?

These Maps Must be _______?

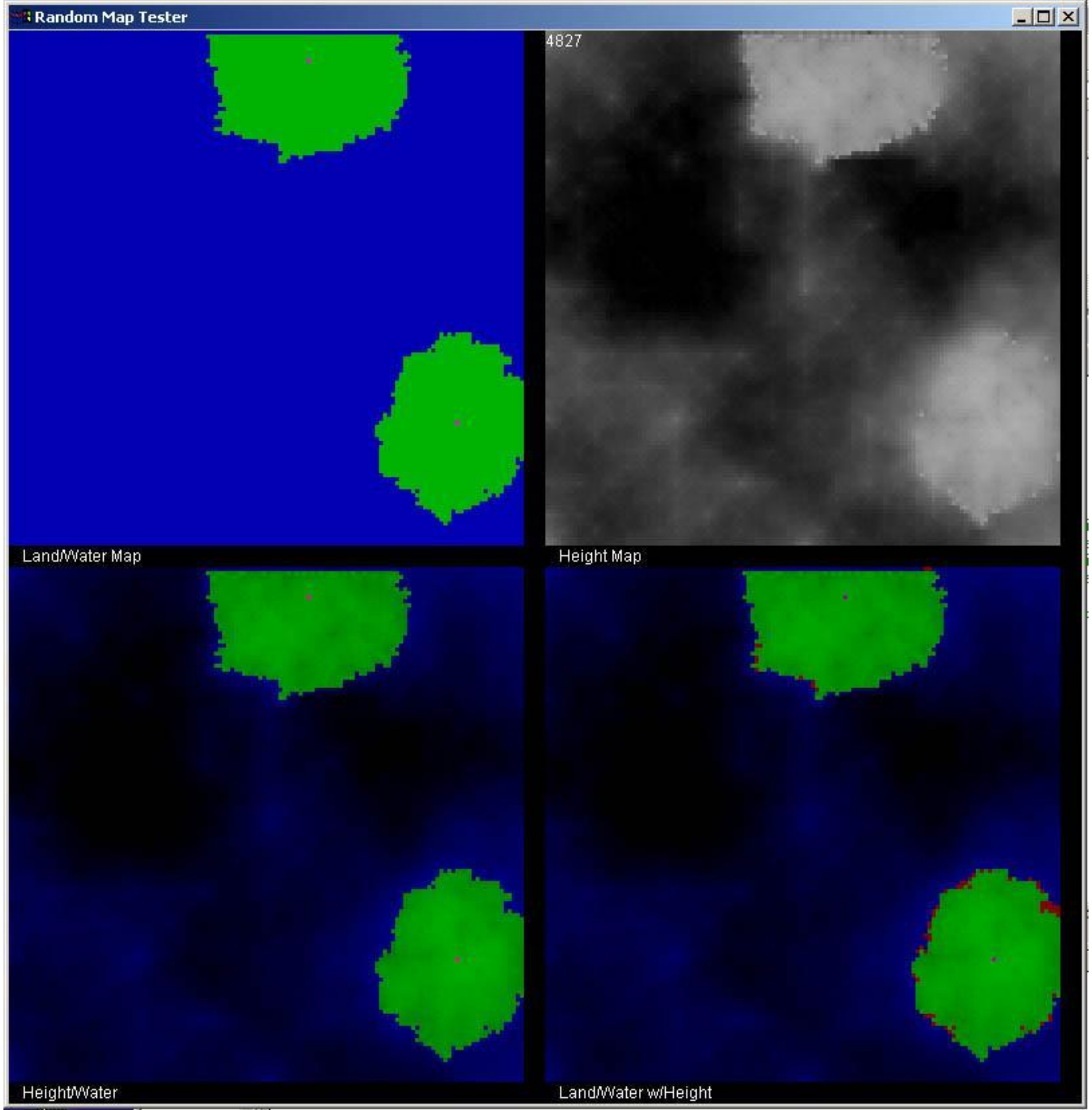
- Fair
  - Land per player
  - Resources per player
  - No strategic advantage
- Predictable
  - Similar by type
  - Allow for diff. outcomes
- Reproducible
  - Seed & type & size
  - Number of players
- Varied
  - Size
  - Type
- Relatively Quick
  - Many in-game systems not running
  - Impatient to start

Shoemaker’s Mapmaker

- 1 .dll & 50+ script files
- Different .dll can be specified
- 7 scripts for each map type
- Inputs
  - # players, # teams
  - Size
  - Climate
  - Type
  - Random # seed

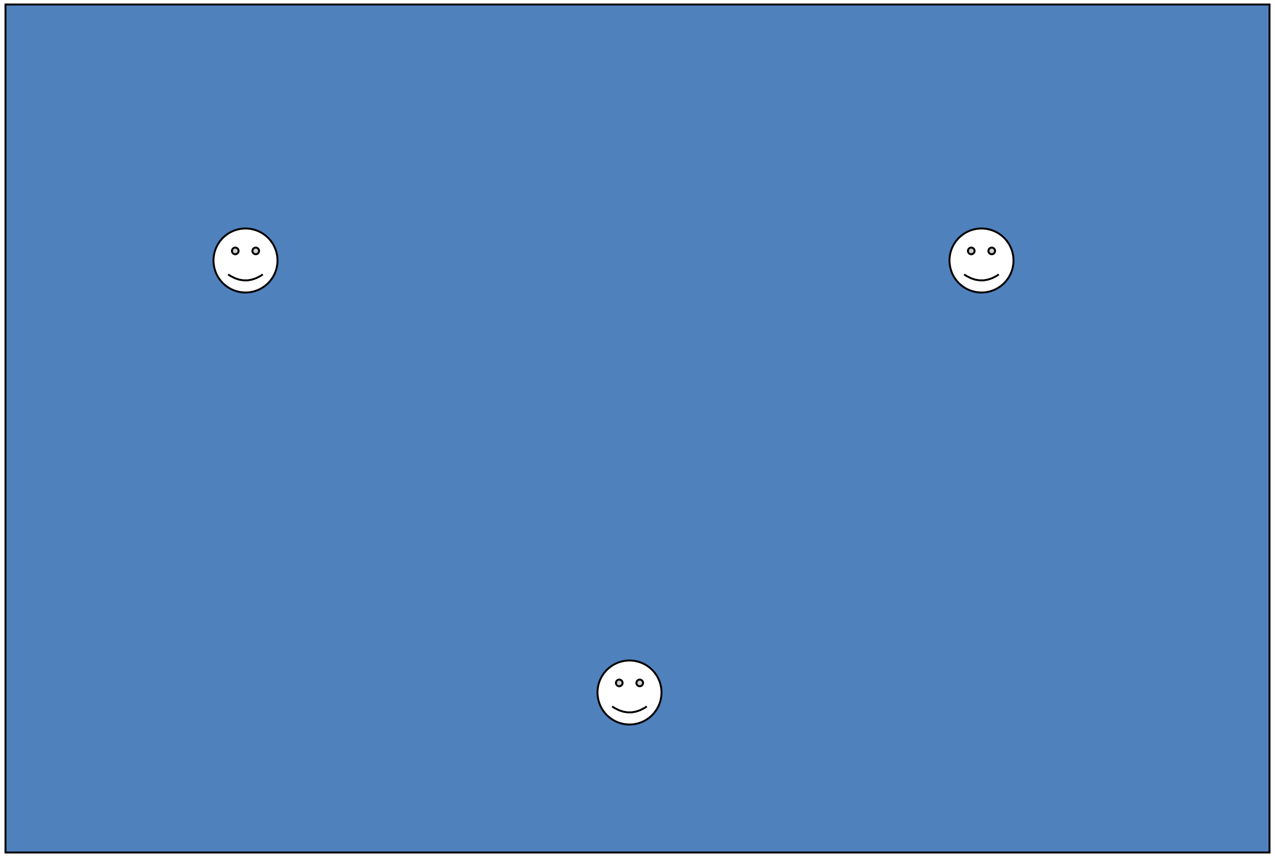
Intermediate Results

- Visualization tool created for 2D arrays
  - Land/Water
  - Height
  - Height/Water
  - Combined
- Map engine integrated late into game


Random Map Tester
4827
Land/Water Map
Height Map
Height/Water
Land/Water w/Height

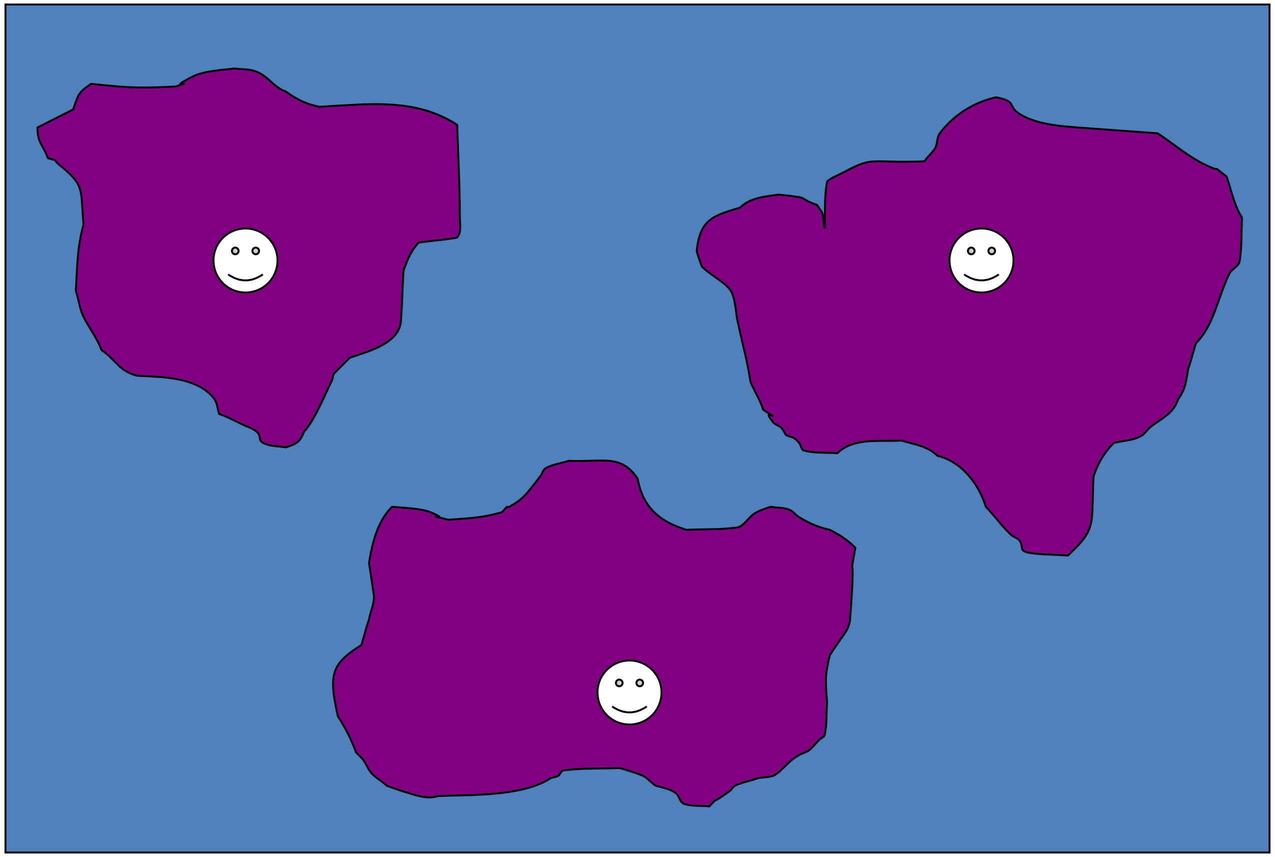
Solution Overview

- Step 1: Place players (blank map of H_2O)



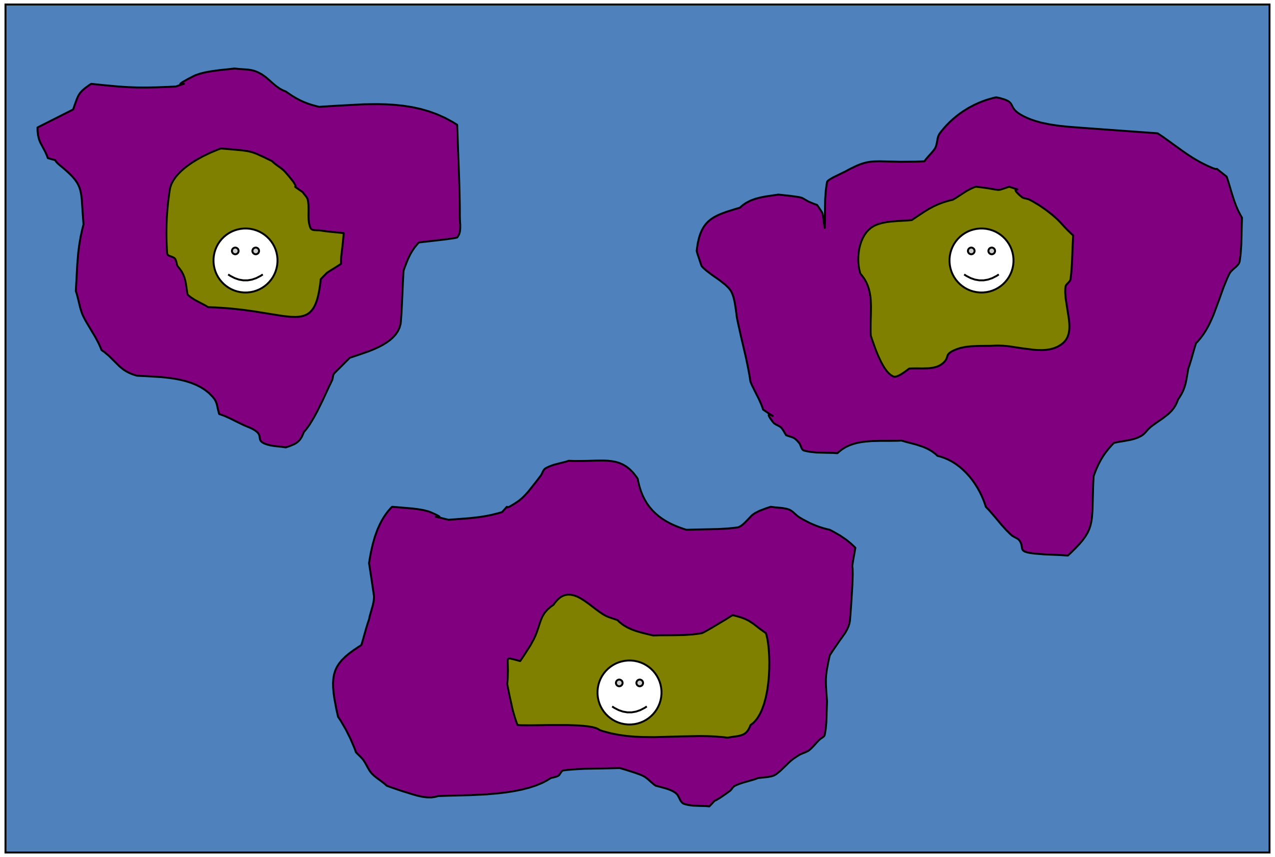
Solution Overview

- Step 2: Grow player land



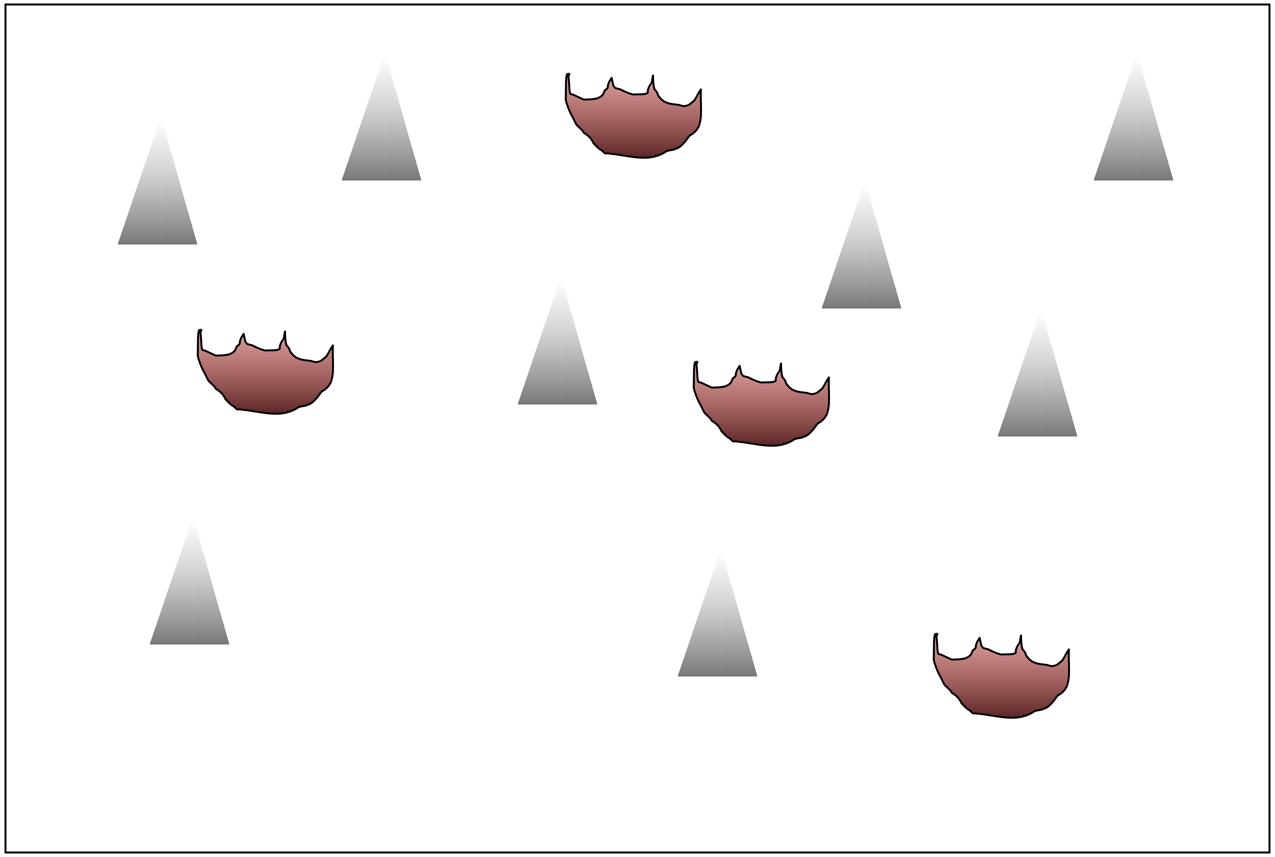
Solution Overview

- Step 3: Add flatlands to map



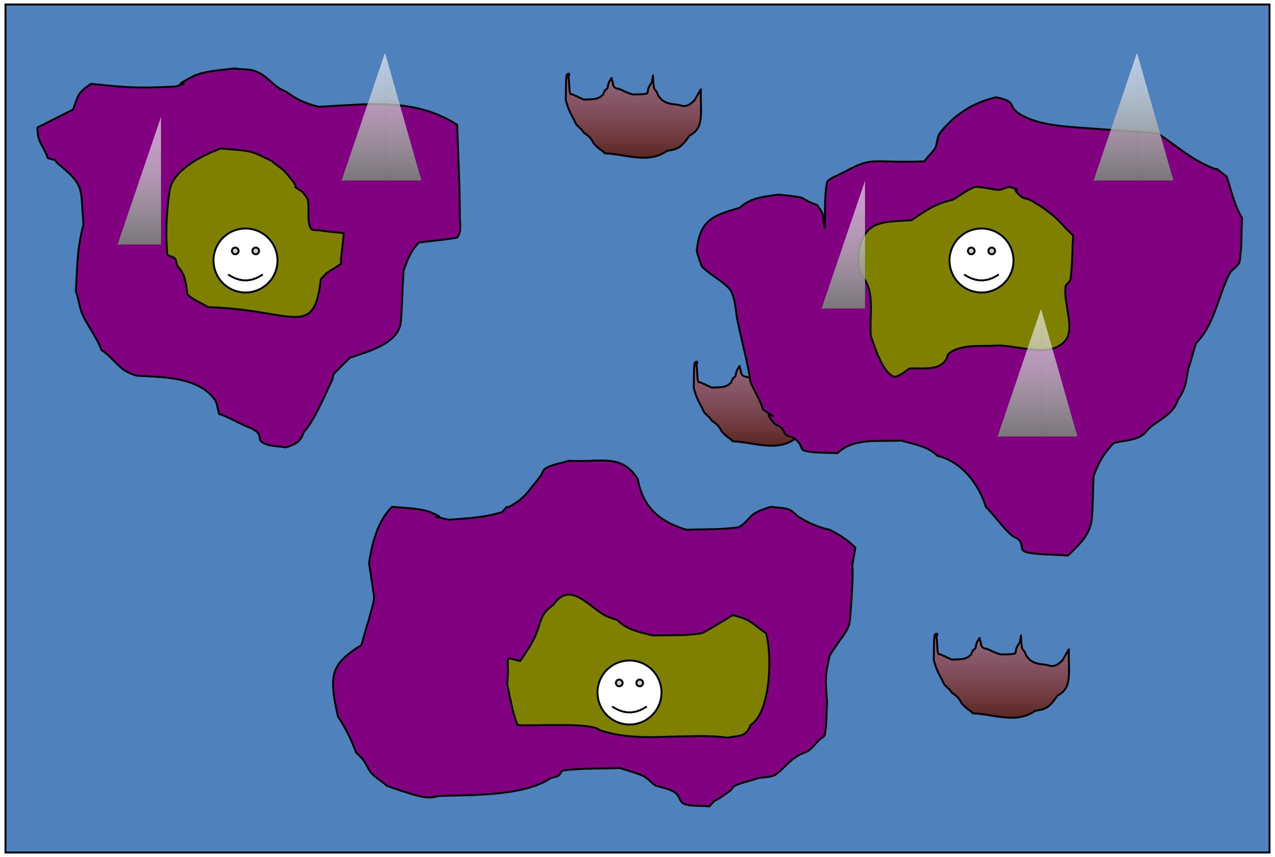
Solution Overview

- Step 4: Generate elevations map



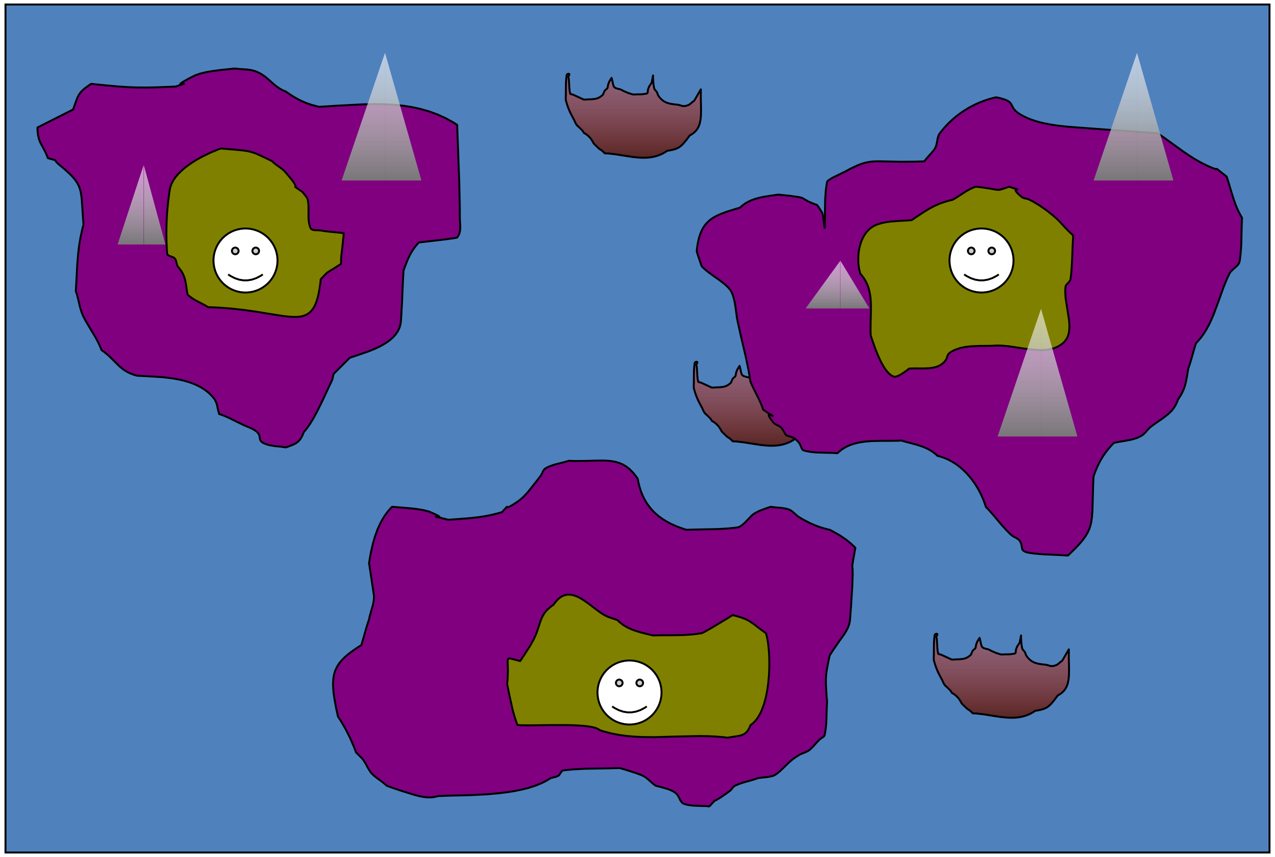
Solution Overview

- Step 5: Combine the two (obeying rules)



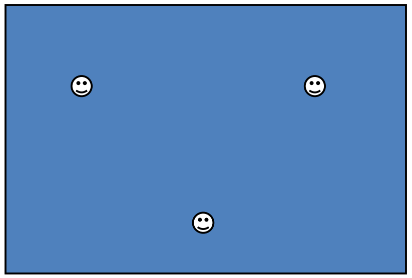
Solution Overview

- Step 6: Fix cliffs and other anomalies

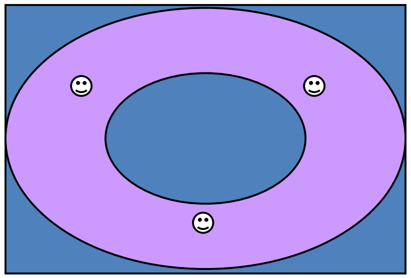


Solution Overview

- Step 7: Distribute resources to players
- Step 8: Place trees
- Step 9: Paint map with terrain textures
- Step 10: Place initial units for players
- Step 11: Place wildlife
- Steps 9 through 11 won’t be covered.



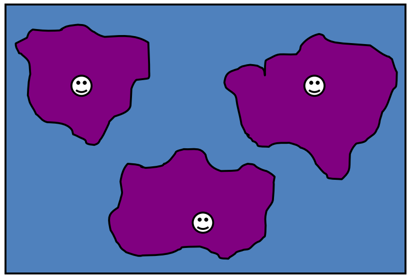
Step 1: Details



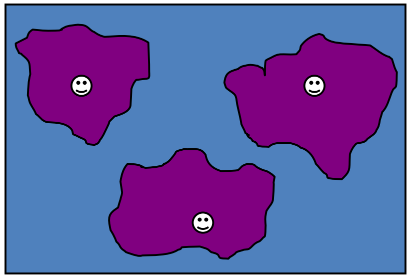
- Placement directly effects land growth
- How would you do this?
- Algorithm:
  – Inscribe one large disk onto map
  – Assign one random loc. per player w/in disk
  – Repeatedly push closest of player points apart until distribution sufficiently optimal
    - "optimal" is a map attribute
    - Specifies how evenly players must be placed

Step 1: Results

- Predictable player locations. Desirable?
  - Keeps maps balanced
  - Tunable through map attributes
- Assign player to points *after* placed. Why?
  - Teams adjacent to each other
  - Enemies somewhat symmetrically opposed
- What about colonization? “Dummy” players…
  - Placed after real players, on in/outside of disk. Why?
  - Dummies’ land grown after real players. Why?
  - Give the dummies resources too.



Step 2: Details



- Land is a resource in RTS games!
  - Allocate fairly
  - Must appear “natural”
- Clumps, modifiable script attributes
  - clumpSize
  - clumpNumber
  - Chaos level
- World starts as H_2O
- What’s a clump?

Step 2: Clumps

- Grow until
  - size == clumpsize
    - Create new clump some dist away at random, chaotic angle
  - Can’t grow any larger
    - Make new clump of *limited* size
- Continue until number == clumpNumber
- Two growth methods, step & completion

Step Clump Growth

- 1st tile is players starting location
- Choose one *valid* random edge per iteration

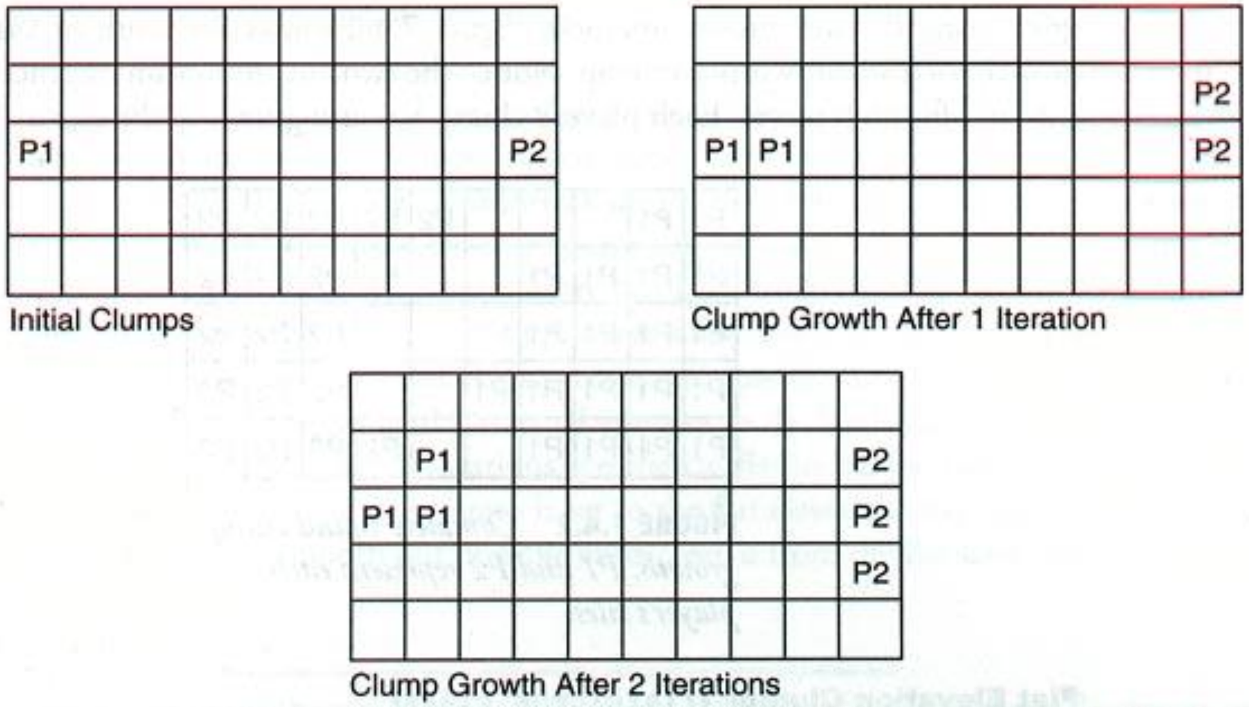
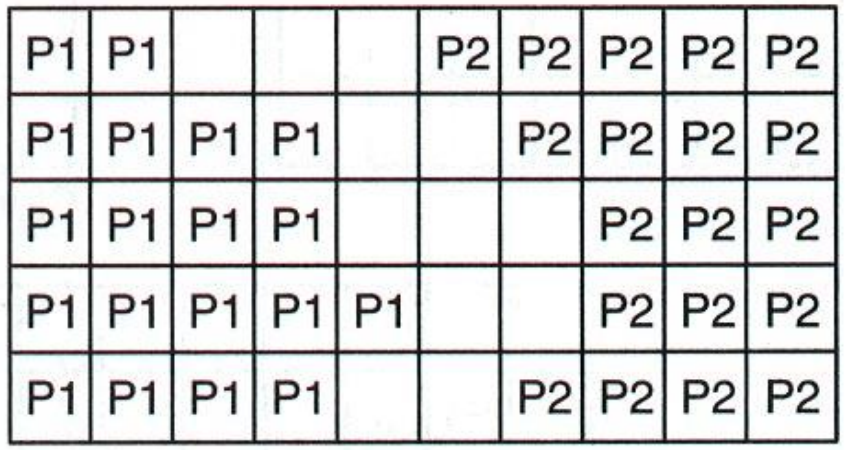

P1
P2
Initial Clumps
P2
P1 P1
P2
Clump Growth After 1 Iteration
P1
P2
P1 P1
P2
P2
Clump Growth After 2 Iterations

FIGURE 7.4.1 *Clump growth using the step method. P1 and P2 represent each player's tiles.*

Valid Clumps

- Different types have different rules
  - Don’t take owned land
  - Don’t make peninsulas
- Island Clumps:

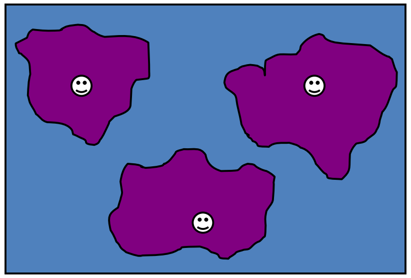


P1	P1				P2	P2	P2	P2	P2
P1	P1	P1	P1			P2	P2	P2	P2
P1	P1	P1	P1				P2	P2	P2
P1	P1	P1	P1	P1			P2	P2	P2
P1	P1	P1	P1			P2	P2	P2	P2

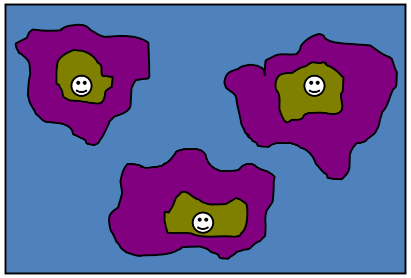
FIGURE 7.4.2 *Complete island clump growth. P1 and P2 represent each player’s tiles.*

Step Clump Discussion

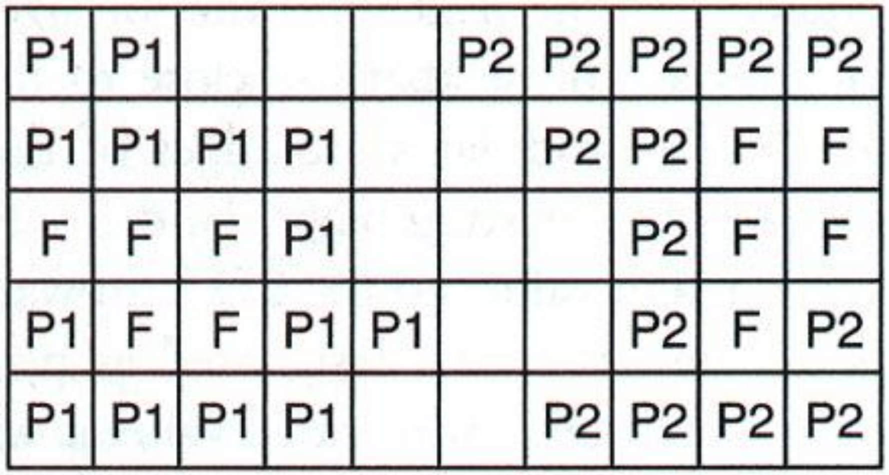
- Why is stepwise growth desirable?
  - Fair
    - each player has equal chance to grow
  - Preventative
    - Hinders one’s land “surrounding” another’s
    - Avoids “starvation”
  - Opportune
    - Makes good on the importance of placing players!
    - Remember the dummies!



Completion Clumps

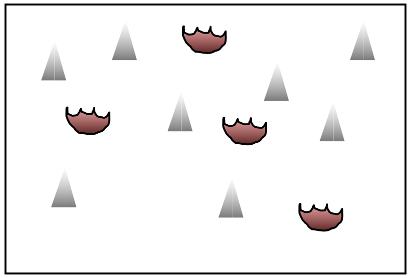


- Why bother, steps are awesome?!
- How about step 3?

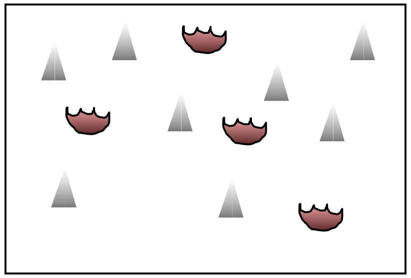


P1	P1				P2	P2	P2	P2	P2
P1	P1	P1	P1			P2	P2	F	F
F	F	F	P1				P2	F	F
P1	F	F	P1	P1			P2	F	P2
P1	P1	P1	P1			P2	P2	P2	P2

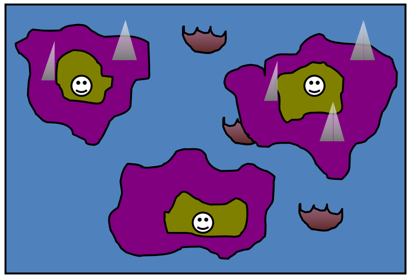
FIGURE 7.4.3 *Complete flat clump growth. P1 and P2 represent each player's tiles. F represents a flat tile.*



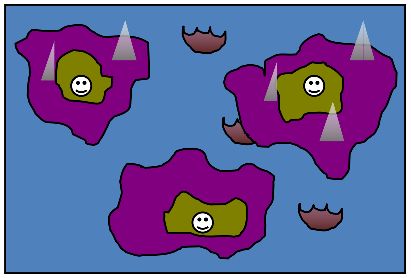
Step 4: Details



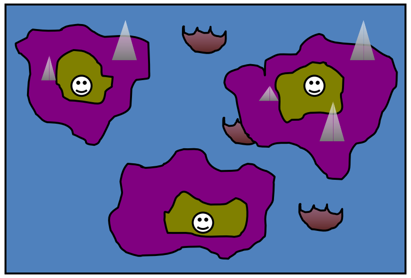
- 2D height map array
- Fractals (esp. diamond sq.)
  - Quick & easy
  - Realistic looking elevation
- Once again, map attributes
  - Min, max, initial elevation
- What about “noise”?
  - Filter used to smooth out jagged artifacts



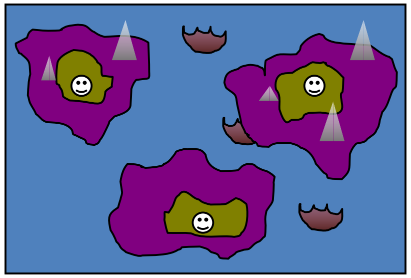
Step 5: Details



- Remember "obeying rules"?
- Algorithm:
  - if(landNH2O[i][j] == FLAT) ignore heightMap
  - if(landNH2O[i][j] == LAND &&
    height[i][j] == WATER)
    - Raise value in height[i][j] to preserve natural look
  - if(landNH20[i][j] == WATER &&
    height[i][j] == LAND)
    - Lower height[i][j] to landNH2O[i][j] level
- Why not negate in the last two cases?



Step 6: Details



- We’ve got anomalies again!
- Wouldn’t negating have worked?
- Re-apply filter

Step 7: Resource Allocation

- Each player gets same amt. of each w.r.t. other players
- Randomly placed within rings centered on players' starting locs.
- Validation
  - Some resources can't be placed on terrain features
  - Resources restricted in min. distance to other resources
  - Resources restricted in min. dist to start loc
- Once again, map attributes
  - Amount of each resource
  - Size of ring

Step 8: Place trees

- Plentiful; Restrict pathfinding
- Can the clump class be re-used?
- Map attributes
  - Number forests/player
  - Size of forests
  - Number of clumps/forest
- Some areas of map marked as forest free
- Player-owned land does not restrict growth

Scripts

- Language to manipulate map attribs
- Basic text parser and data structures
- Things like:
  - #resources per player
  - Max altitude in height map
  - Player land allocation
  - Climate (terrain/forest/animal texture set)
- Small changes yield map variations

Scripts: Pros

- Allow for incremental map type devel.
  - New attribs for new maps
  - Add attribs to parser
  - Matching code added to map generator
  - Offload some tasks from programmers to designers
  - Modability/extensibility/variety
- Next steps…
  - Island map w/teams: allow land for team-members to merge
  - Tweak elevations: island maps become canyon maps
  - Tweak clump size: island maps become river maps

Scripts: Cons

- Unfortunately:
  - One master script per type of random map
  - One script per size of type of map
  - In each script, subsections for each qty. of players (# berries? # gold?)
- You can imagine:
  - Scripts can become hard to manage
  - Manuals needed to explain types & attribs
  - Additional tools to edit attribs across files
  - Designers are not programmers
    - Programmers must create map “templates”
    - Designers simply “tweak”

Buyer Beware!

- Can’t explicitly place particular terrain features
  - “super-tile” design approach
  - Fairer/more visually appealing
- Designers are not programmers
- Chokepoints are possible & unfair
- Resource placement can still yield advantages