



Building Bigger Worlds Feasibly and Intently

By reducing cognitive load in Mixed-Initiative Wave Function Collapse

Shaad Alaka, Rafael Bidarra

Delft University of Technology

Main topics of the talk

- Mixed-Initiative Procedural Content Generation
- Reducing Cognitive Load while maintaining control
- Adaptation of Wave Function Collapse to achieve the above
- Evaluation of this adaptation



Why do we use Procedural Content Generation (PCG)?

Virtual worlds are becoming literal worlds...



What is cognitive load?

What is cognitive load?

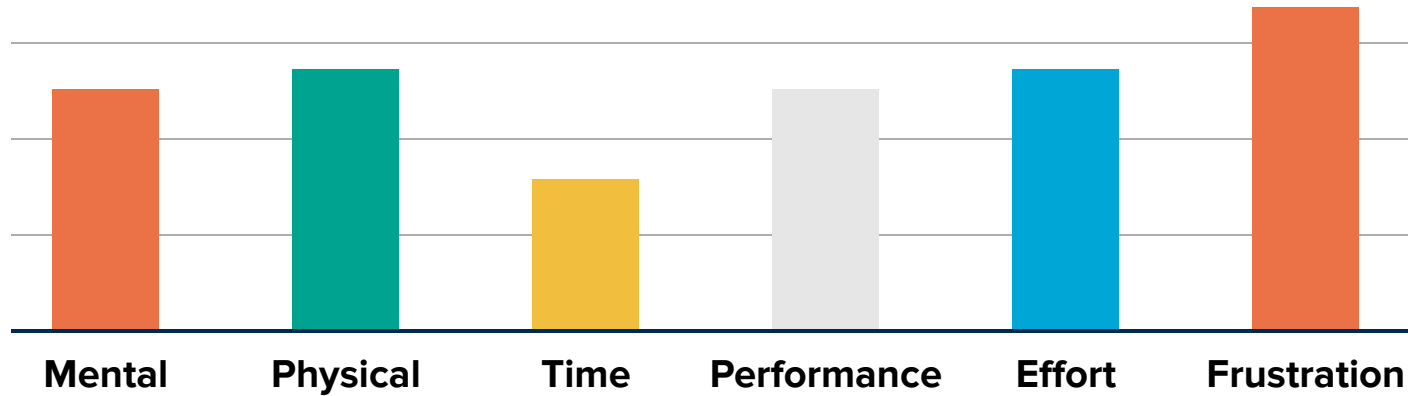
“the relative demand imposed by a particular task, in terms of mental resources required”



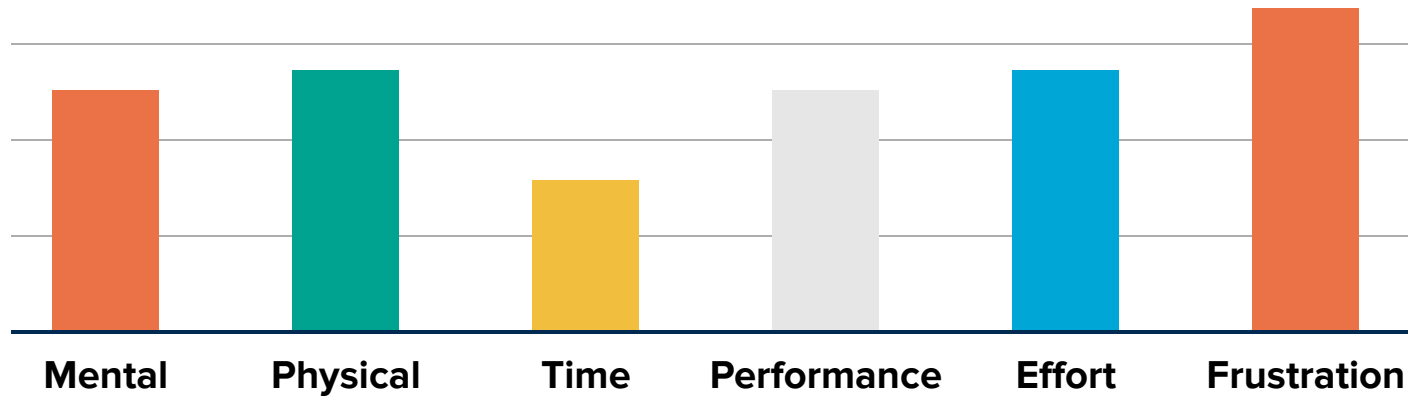
Reducing cognitive load of a task?

- You can work faster
- You can be more creative, if task permits
- You can be more intentful in achieving your goal
- Etc...

NASA TLX



NASA TLX



NOTE: These are often correlated...

Why do we use PCG?

Why do we use PCG?

To offload cognitive load imposed by content generation to machines



Virtual Worlds

Full-on PCG

- Completely orthogonal to incorporating designer intent
- Push [GENERATE] button and... hope?
- It's the “trivial solution”
- Real-time / dynamic PCG



Image: Screenshot from Minecraft

Exposing some parameters for control

- Algorithm is in charge, designer can influence it
- Algorithm offloads cognitive load to designer
- Cognitive load affected through Performance and Frustration

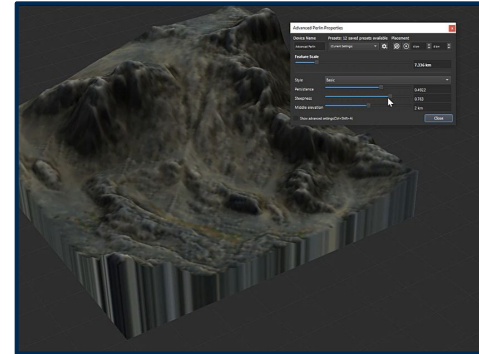
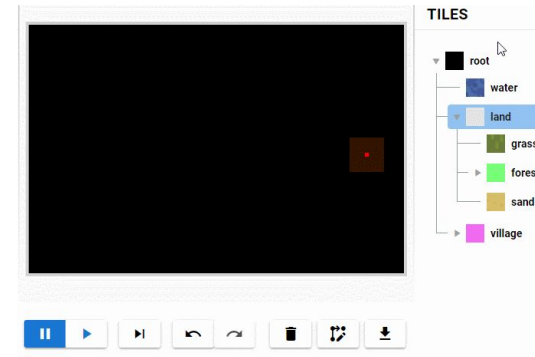


Image: World Machine erosion modelling

Mixed-Initiative PCG (MI-PCG)

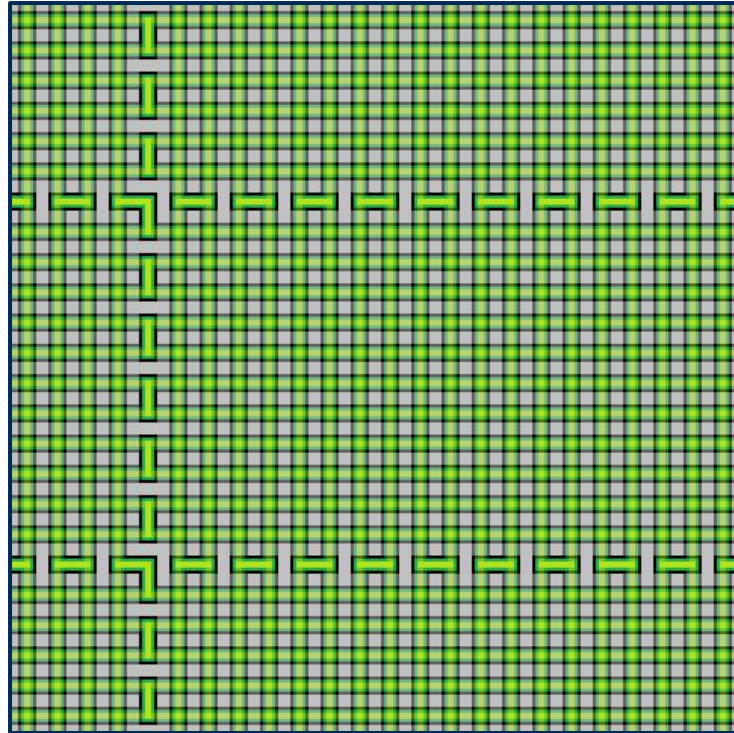
- Ideally, designer is in charge, algorithm helps
- Opposite: designer offloads cognitive load to algorithm
- Effort can be reduced → Impacts other metrics
- Frustration determined by how much algorithm interferes



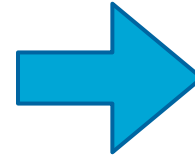
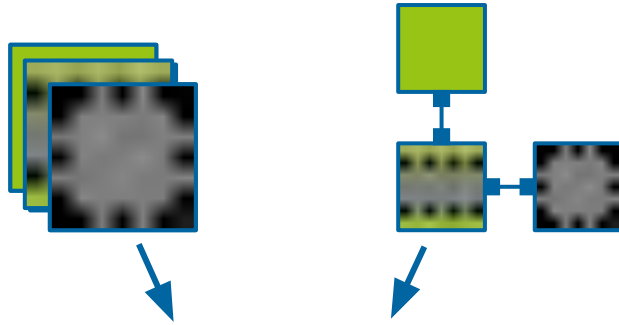
GIF: HSWFC control flow demonstration

Wave Function Collapse (WFC)

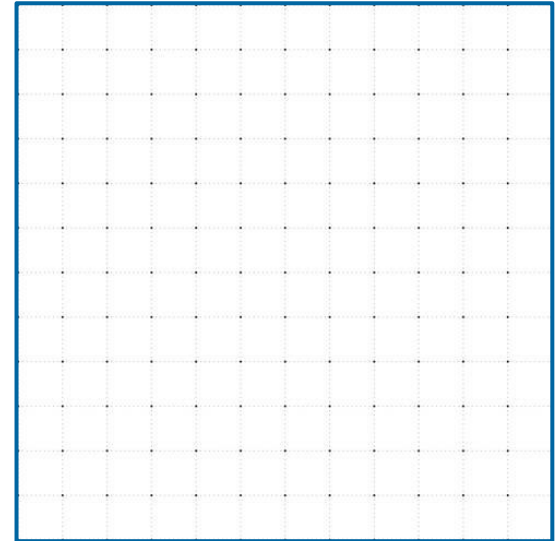
The core problem of using it directly for MI-PCG



Wave Function Collapse



Empty Grid



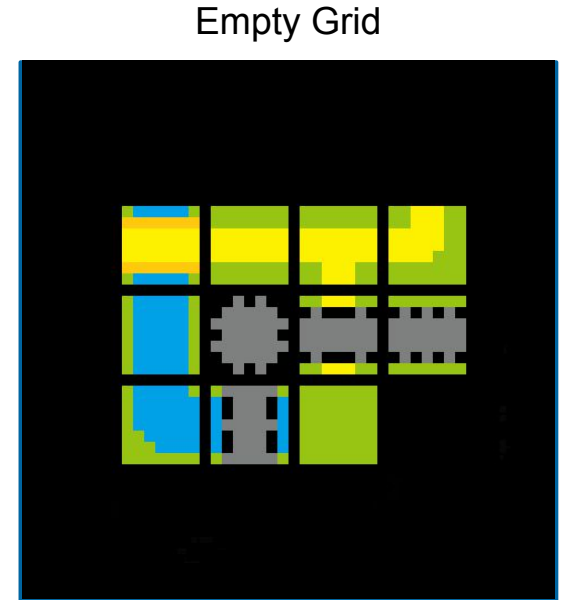
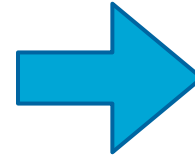
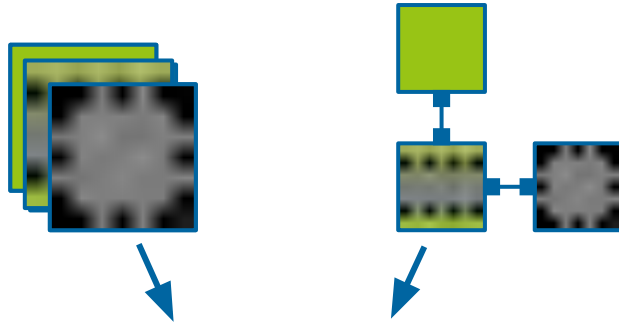
Superposition

Algorithm 1 Basic WFC algorithm

```

initialize algorithm (building tile and constraint tables)
repeat
    Choose next cell to collapse
    Choose which tile to collapse it into
    Collapse and propagate constraints
until Every grid cell is collapsed or a conflict occurred
  
```

Wave Function Collapse



Superposition

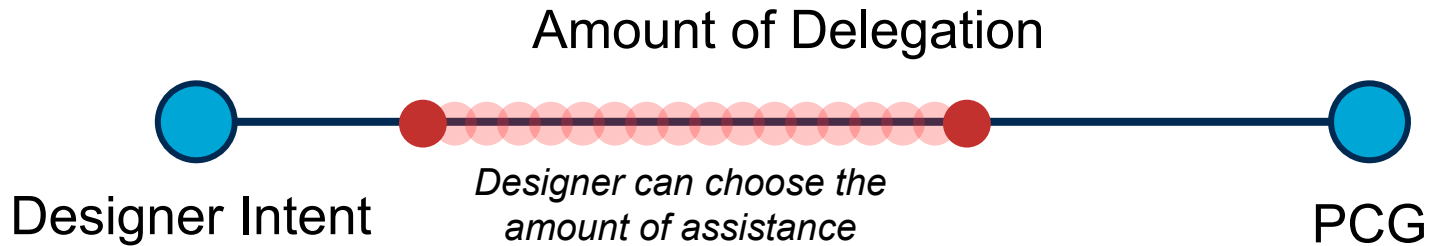
Algorithm 1 Basic WFC algorithm

```

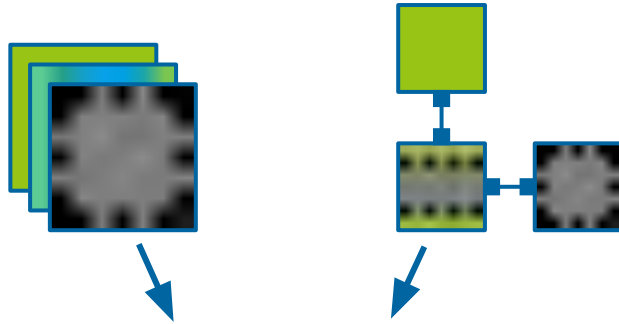
initialize algorithm (building tile and constraint tables)
repeat
    Choose next cell to collapse
    Choose which tile to collapse it into
    Collapse and propagate constraints
until Every grid cell is collapsed or a conflict occurred
  
```

Why MI-PCG with WFC?

- Core idea → Offload tile fitting process to machine
- Intuitive hooks for designer control → “Paint on canvas”
- Designer and machine work in same “space”



Wave Function Collapse



Algorithm 1 Basic WFC algorithm

initialize algorithm (building tile and constraint tables)

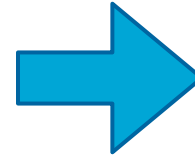
repeat

Choose next cell to collapse

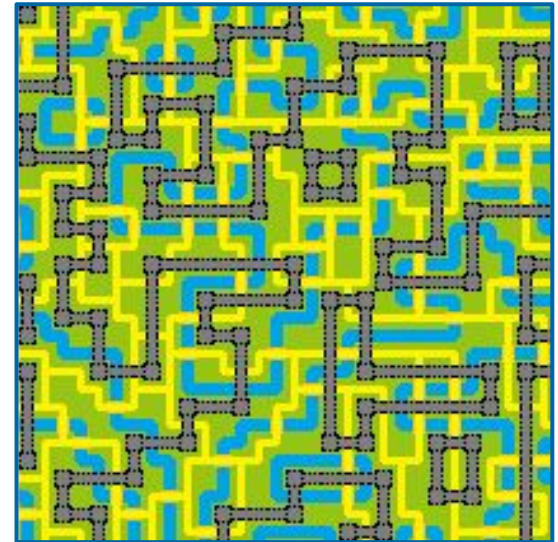
Choose which tile to collapse it into

Collapse and propagate constraints

until Every grid cell is collapsed or a conflict occurred



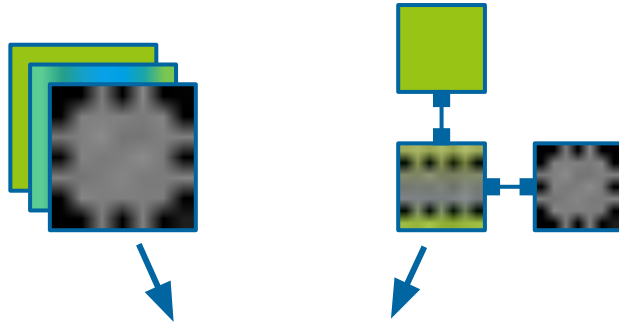
Fully Collapsed Grid



Choosing the cell to collapse



Wave Function Collapse



Algorithm 1 Basic WFC algorithm

initialize algorithm (building tile and constraint tables)

repeat

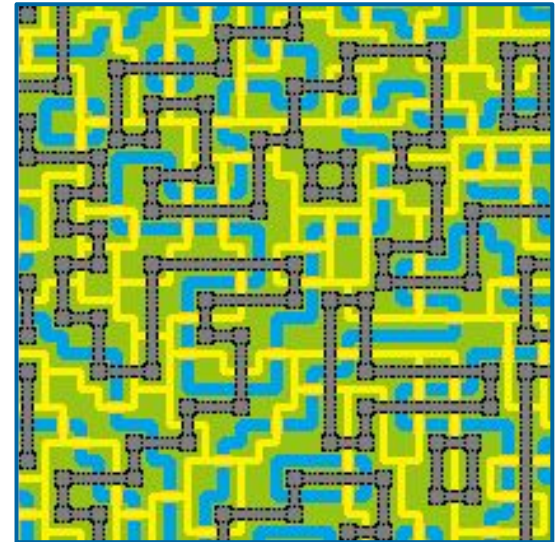
Choose next cell to collapse

Choose which tile to collapse it into

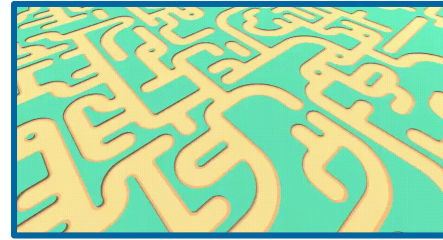
Collapse and propagate constraints

until Every grid cell is collapsed or a conflict occurred

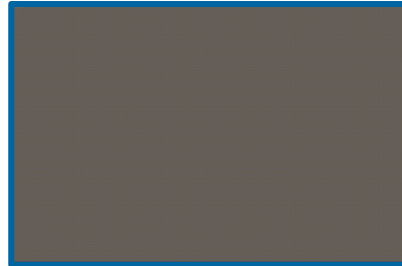
Fully Collapsed Grid



By Maxim Gumin



By BorisTheBrave

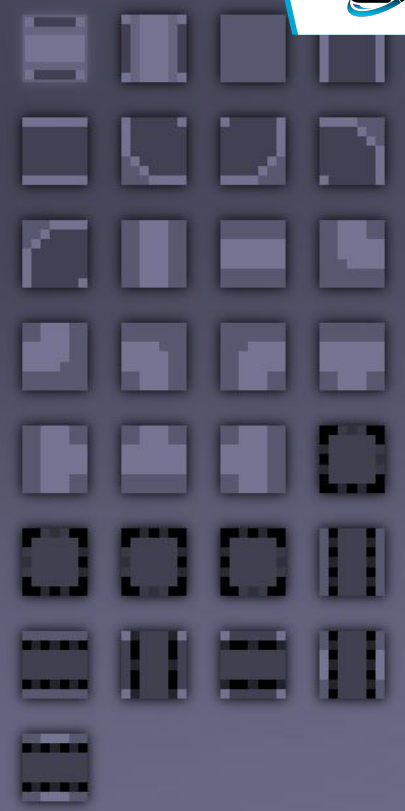
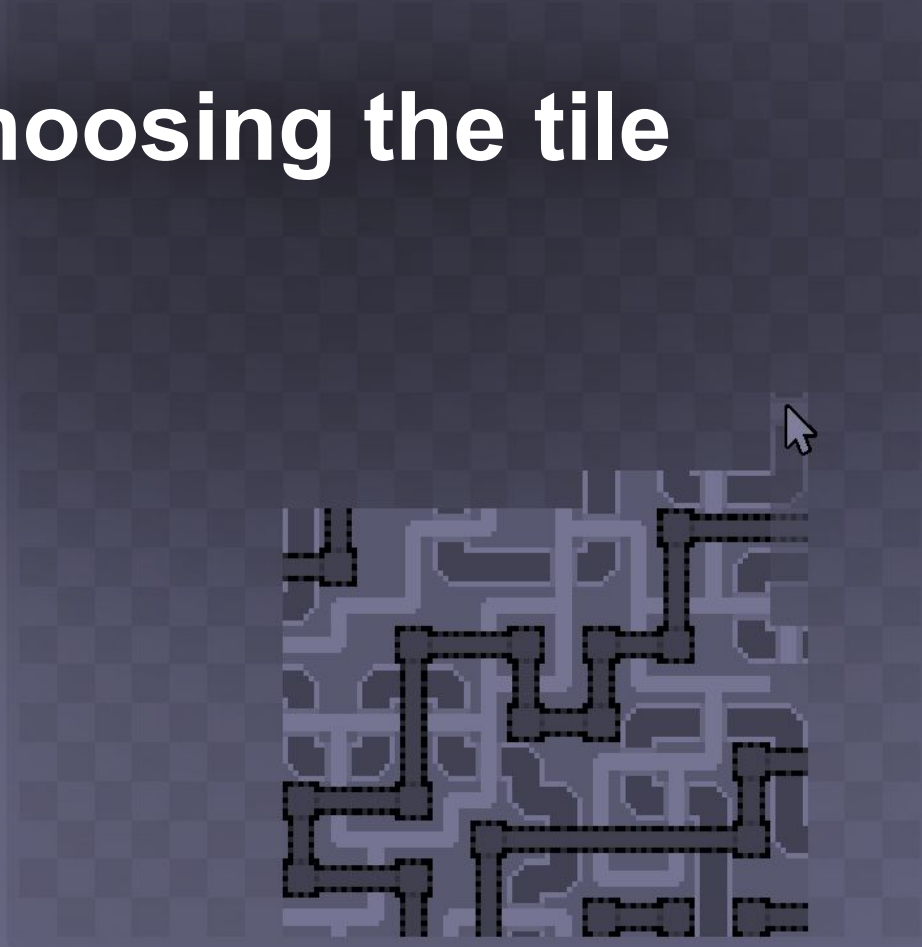


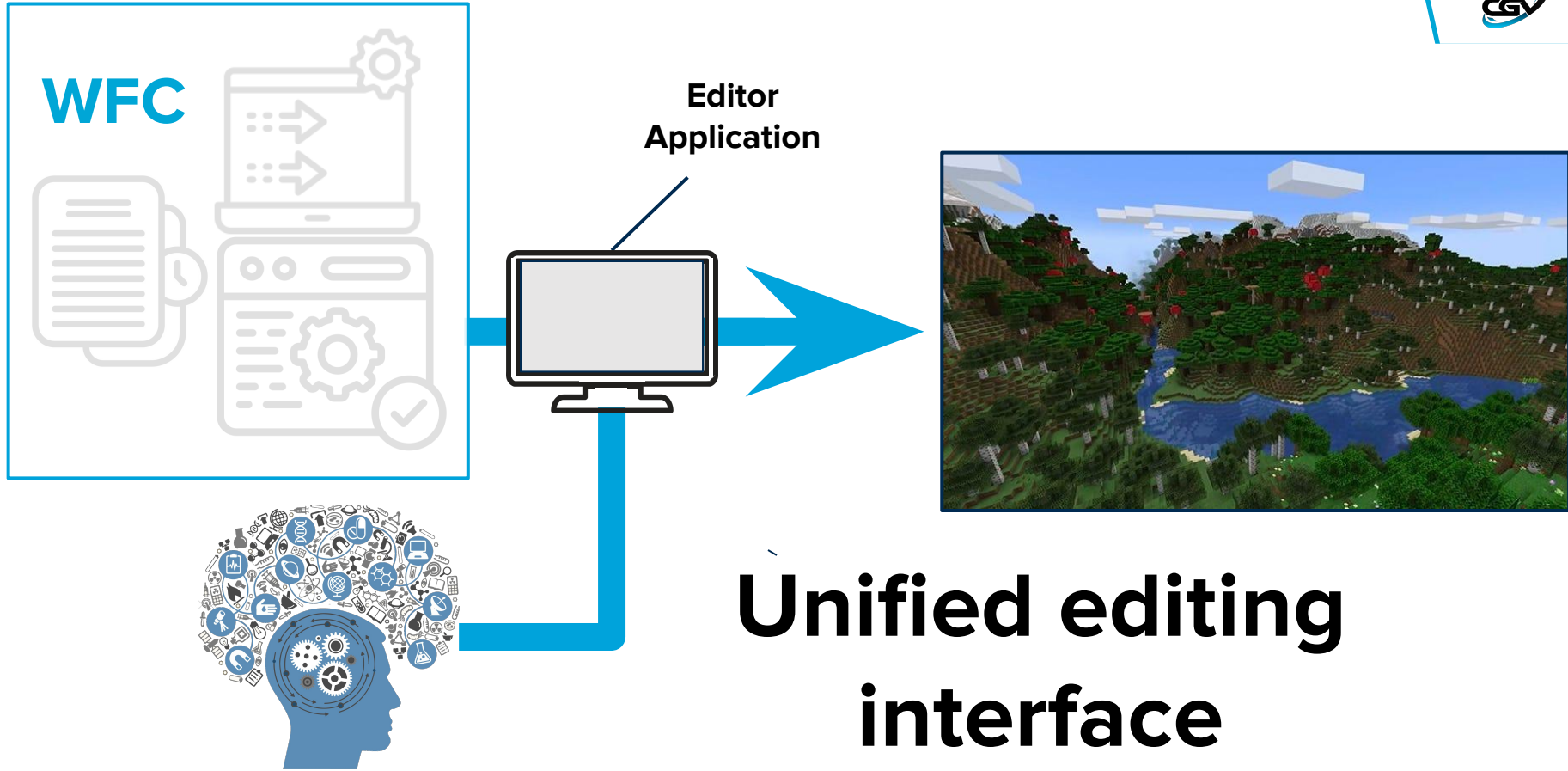


Also choosing the tile



Selected Tool Options:





Unified editing interface

**Find a piece of road with grass to the left-bottom,
with up-right turn to place onto the existing
horizontal road piece...**

Selected Tool Options:

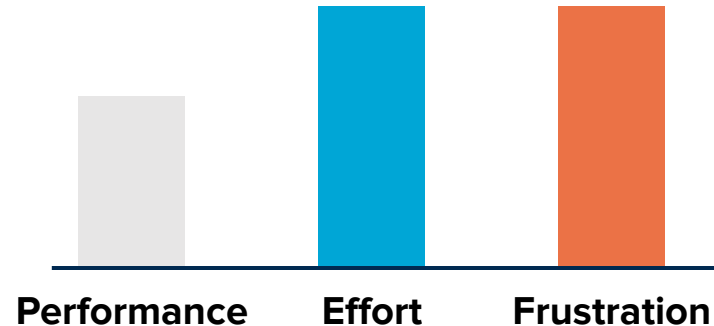


Two problems with WFC in mixed-initiative setting

1. Tiles are detailed and complex - you have to be exact
2. You have to think about fitting the tile to the existing environment

Cognitive Load!

Constraints should help the designers, not hinder them!



Find a piece of road with grass to the left-bottom, with up-right turn to place onto the existing horizontal road piece...

Selected Tool Options:

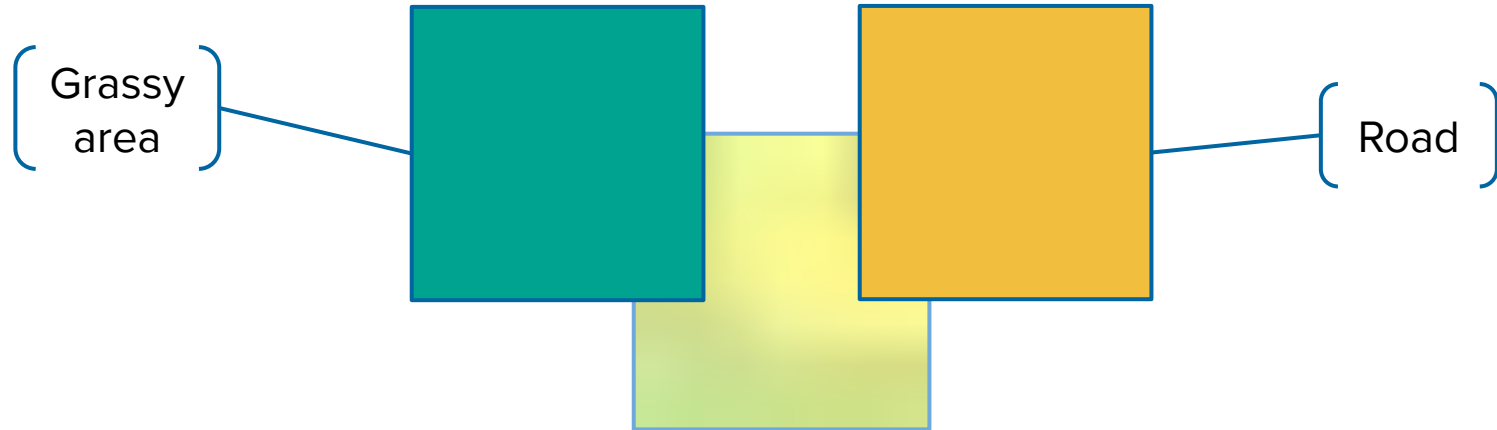


VS...

Place road.

Let the designer paint with
semantic abstractions!

Meta-tiles



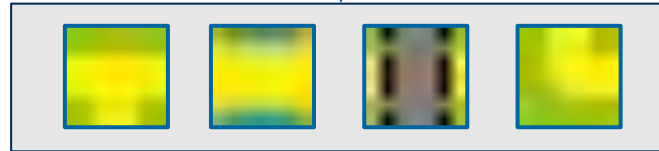
Proxy for a superposition state

Superposition of a subset of the tiles in the input...

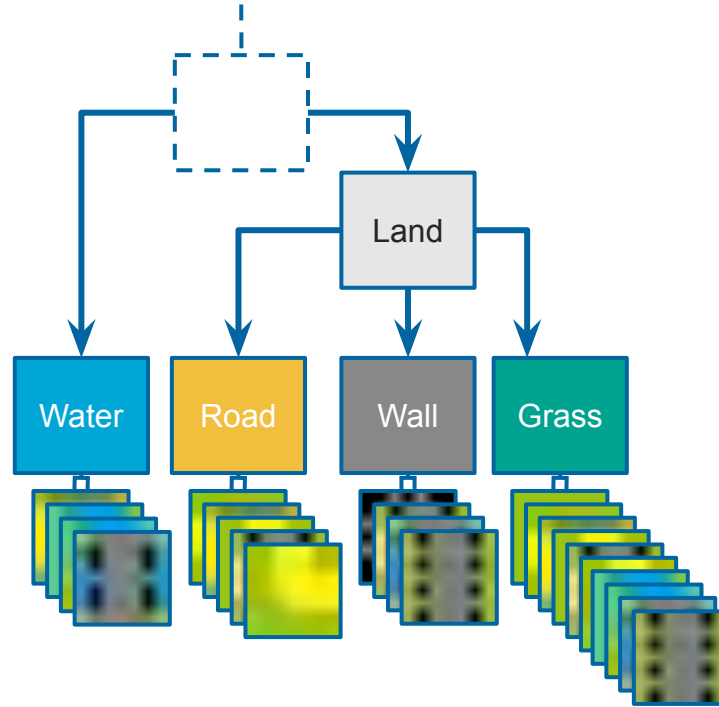


i.e. has the potential to become any of these tiles

Looser constraints!



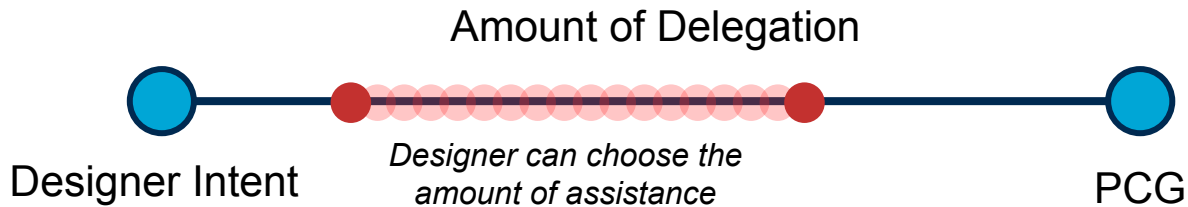
Hierarchical Semantic Wave Function Collapse



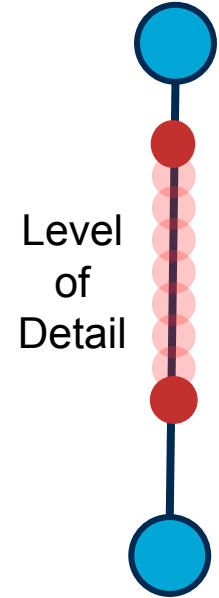
HSWFC



- Adds granularity in *level of detail*
- Offloads constraint solving back to the algorithm
 - Hypothesis: reduces cognitive load?
- This gives more avenues to express designer intent
 - Sketching, not just painting!



Empty Cell / Root



Stock WFC Tile



← *Scan for HSWFC web editor (works on mobile)*

DEMO

WFC vs HSWFC comparison

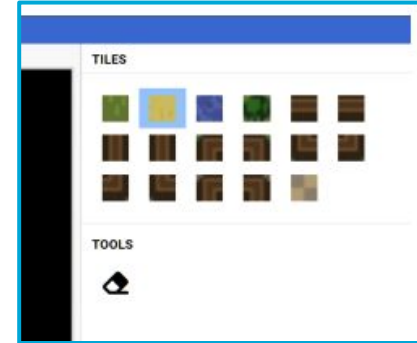
Evaluation

Is HSWFC really “better”?

Evaluation - User study setup

- Blind A/B test
 - **Group WFC:** Stock WFC editor
 - **Group HSWFC:** HSWFC Editor

- Requirements task given to user:
 - *Complex enough to use full HSWFC toolset*
 - *Not too long → maximize participation*
 - *Leave open for interpretation*



Evaluation - User study setup

- User gets role of environment designer for top-down roleplaying game.
- World has some requirements, coming from the gameplay designer and the lore guru.
- Have a second task where users can explore the editor a bit - make variations of first task.

[T1] Creating a game world



You are the environment designer of Dragon Bane, a top-down role-playing game where the player character may traverse the world to find and complete quests in search of eternal fame and glory. You have been asked by your producer to create environment concepts for one of the outdoor areas of the game, with the deadline being today.

In this game, the player cannot pass through water, can get quests and gear in towns, and the quests often take place in the forests and the wilds. Areas in the game, such as the one you will design, are connected to each other at their borders.

The gameplay designer and the lore wizard did have some more specific requirements for this particular area though:

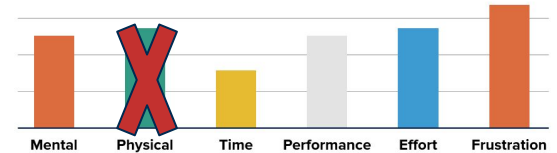
- There should be two villages that are clearly separated
- One of the villages should be surrounded by forest as far as possible
- One of the villages should have a considerably larger house in the center of it with an interesting shape
- There should be an additional but very dense forest somewhere in the area
- The villages should be connected via a sandy path
- Both villages should be adjacent to some body of water

Besides these minimum requirements (which can be interpreted fairly loosely), they trust that you will be able to fill up the rest of the environment with interesting features, as long as the points above are not violated. You can use the description given earlier to do this in a way that makes sense for the game.

Evaluation - Measuring cognitive load

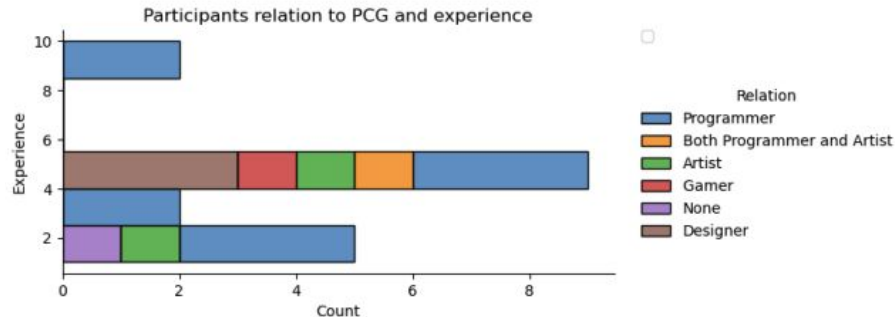
- Use NASA TLX (minus physical) on a 7-point likert scale to measure cognitive load from the first task
- Ask users to upload results, for studying adherence to task and task performance
- After the second task, ask some (HS)WFC-specific questions to gauge user experience

NASA TLX



Evaluation Results - Demography

- 18 participants total, 9 per group
- Mostly programmers, though also some designers; even spread between groups WFC and HSWFC
- Mostly male, between 20-50 years old

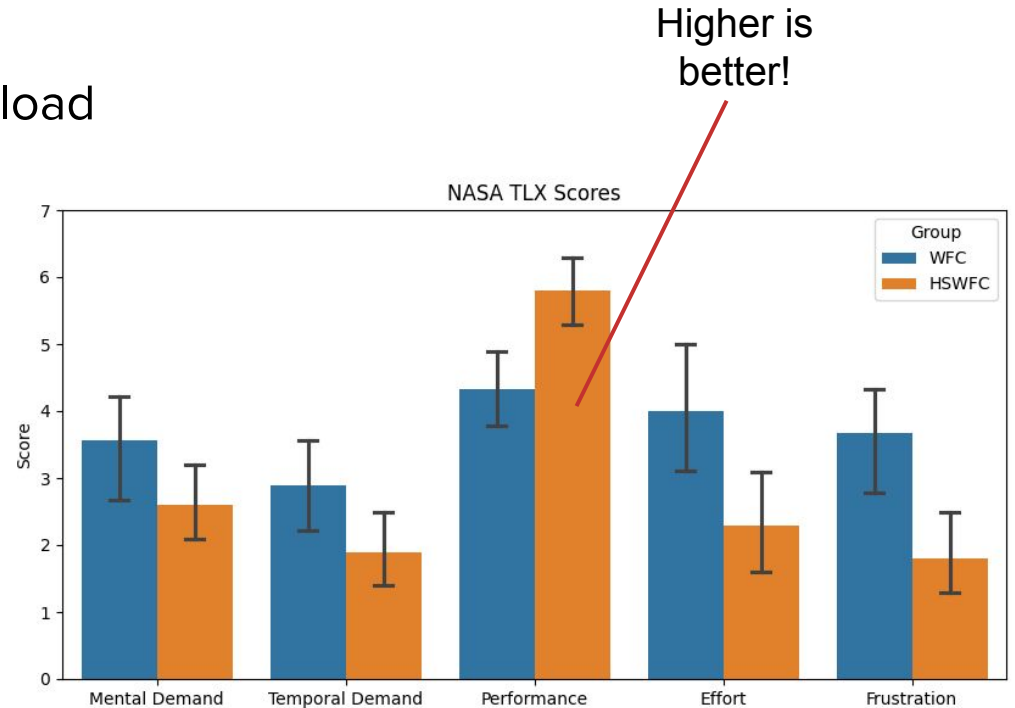


Evaluation Results - NASA TLX

- Significant reduction in cognitive load in at least 3 metrics:

- Performance (higher is better)
- Effort
- Frustration

Rubric	t(16) statistic	p value	Significant
Mental Demand	2.08514	0.05343	Doubt
Temporal Demand	2.01246	0.06132	Doubt
Performance	-4.00000	0.00103	Yes
Effort	2.60412	0.01918	Yes
Frustration	3.45218	0.00328	Yes

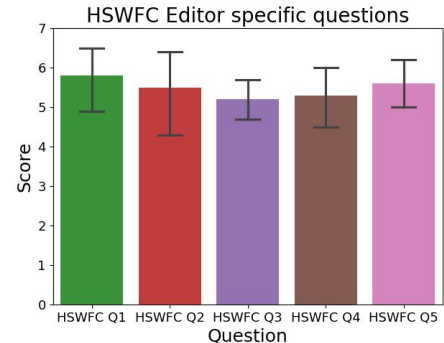
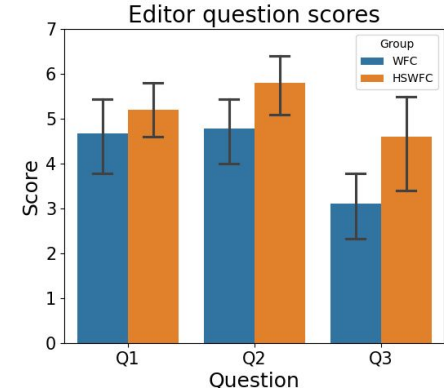


Evaluation Results - Other Questions

- Almost-significant differences in WFC-specific question at least for Q3, still rather low score
- Hierarchy considered intuitive, HSWFC-Q2 was divisive

ID	Question
Q1	I felt that the editor was able to capture my intent
Q1	I felt like I had the freedom to tweak things easily
Q3	I understood why certain tiles could not be placed in certain locations

HSWFC Q1	I found using the hierarchy for selecting a tile to paint with to be intuitive
HSWFC Q2	Using a single situation-dependent brush for painting and erasing felt intuitive
HSWFC Q3	Painting with meta tiles gave me the results I expected
HSWFC Q4	Adjusting the meta-tile probabilities had the results I expected
HSWFC Q5	I found using the regeneration tool useful for creating variations of my design



Evaluation Results - Outputs

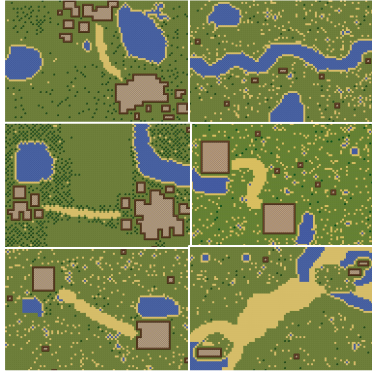


Stock WFC



HSWFC

Evaluation Results - Outputs



Stock WFC

- Simpler villages
- Less detail in forest



HSWFC

- Rivers and bridges
- More interesting structures (smiley, multiple bridges)

Evaluation Results - Open feedback

- Too little feedback
- Snapshotting considered useful in both groups
- Trees (\mathbf{T}_{TREE}) very problematic for group A
- Using \mathbf{T}_{ROOT} as eraser not very intuitive

Evaluation Findings

- HSWFC: Significantly reduced cognitive load
- HSWFC Outputs get much closer to request
- More destructive approach preferred

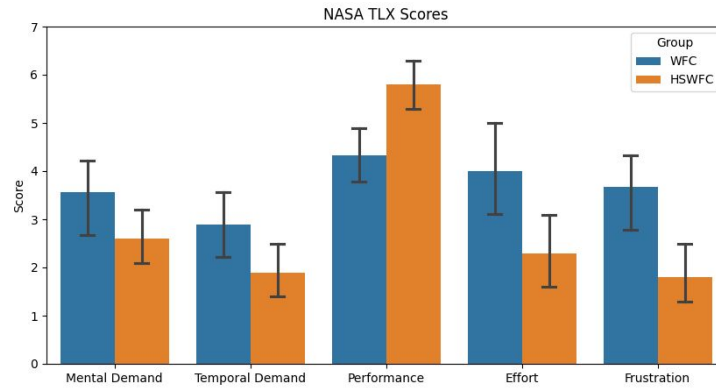
Conclusion

- HSWFC can indeed reduce cognitive load!



Future Work

- Explorer HSWFC further to reduce cognitive load even further
- Make input specification easier → facilitate adoption
- Find ideal hierarchies



Empty Cell / Root



Level of Detail



Stock WFC Tile



THANK YOU

