

Benchmarks for Pathfinding in 3D Voxel Space

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SoCS 2018



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Warframe



Warframe





Overview

- Data Set Origins
- In-Game Usage
- Problem Set Creation
- Open Research Questions

Data Set Origins

CAN'T STOP THE SIGNAL —

Valve leaks Steam game player counts; we have the numbers

Valve plugged the hole, but important data has already escaped.

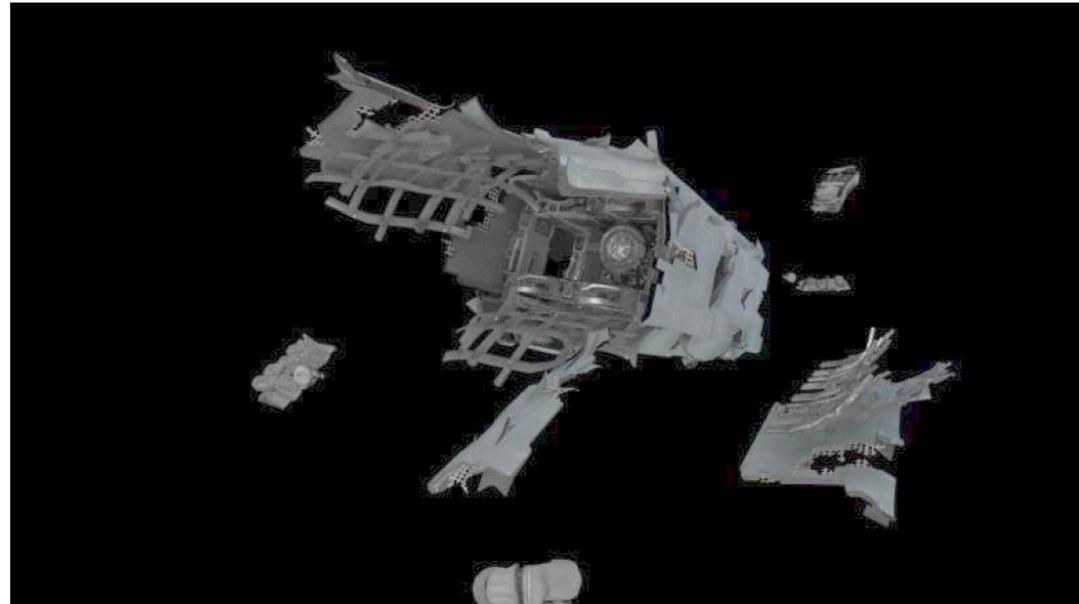
KYLE ORLAND - 7/6/2018, 1:38 PM



| | TITLE | PLAYER ESTIMATE |
|----|----------------------------------|------------------------|
| 1 | Team Fortress 2 | 50,191,347 |
| 2 | Counter-Strike: Global Offensive | 46,305,966 |
| 3 | PLAYERUNKNOWN'S BATTLEGROUNDS | 36,604,134 |
| 4 | Unturned | 27,381,399 |
| 5 | Left 4 Dead 2 | 23,143,723 |
| 6 | PAYDAY 2 | 18,643,807 |
| 7 | Garry's Mod | 18,576,379 |
| 8 | Warframe | 16,332,217 |
| 9 | Counter-Strike: Source | 15,001,876 |
| 10 | Paladins | 14,371,946 |

Warframe

- Many game types
- Archwing space combat
 - Released November, 2014
- Procedurally generated debris fields
- Prefabricated objects
- Up to 2km × 2km × 2km
 - 1m or 2m resolution







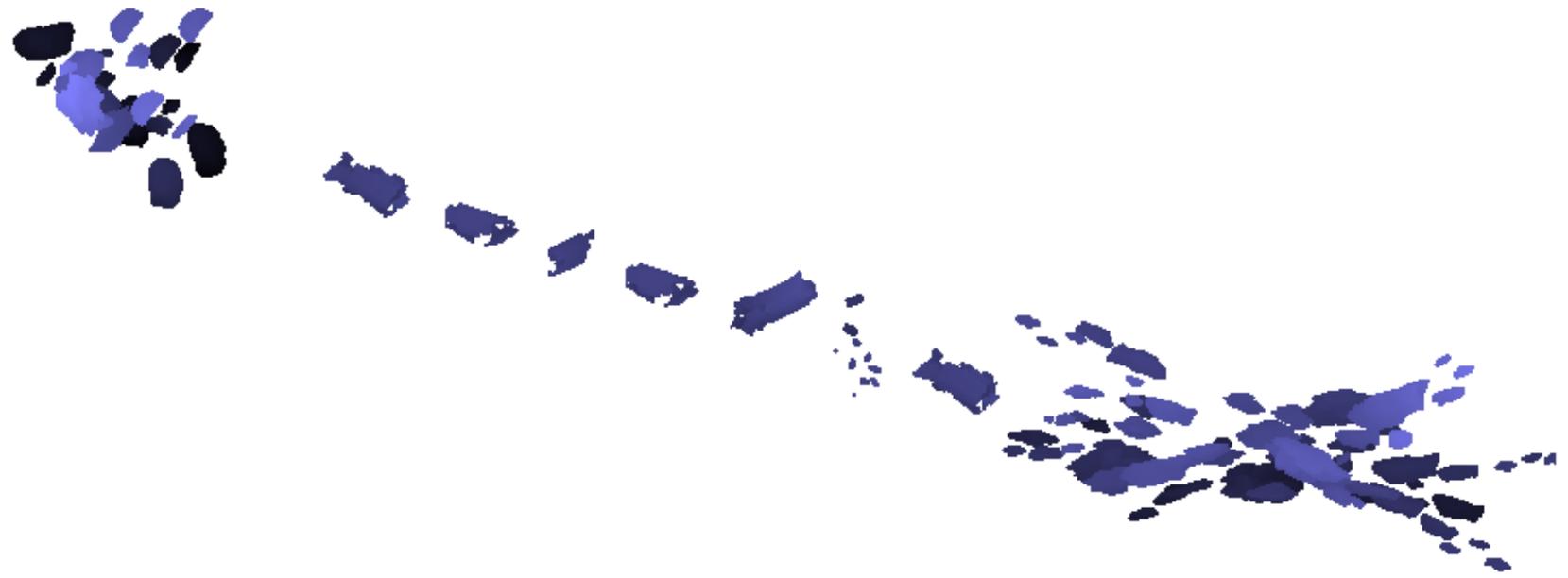






Speed requirements

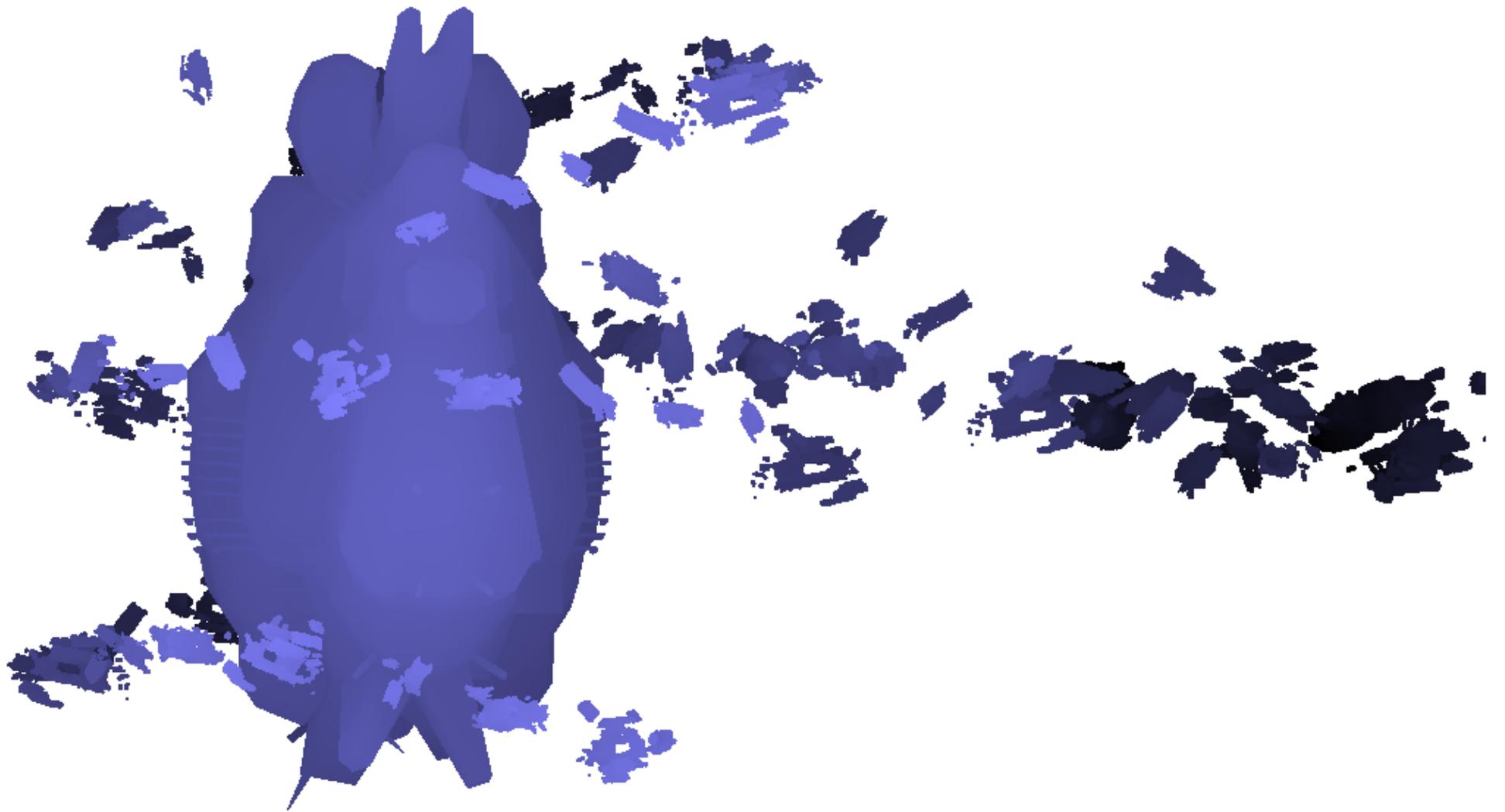
- Paths need to be found as fast as possible, with target ideal times of less than 1ms
 - Worst case of 100ms
- Hardware requirements:
 - Similar to an XBOX ONE
 - 8GB Ram with a 8 Core 1.75 GHz CPU











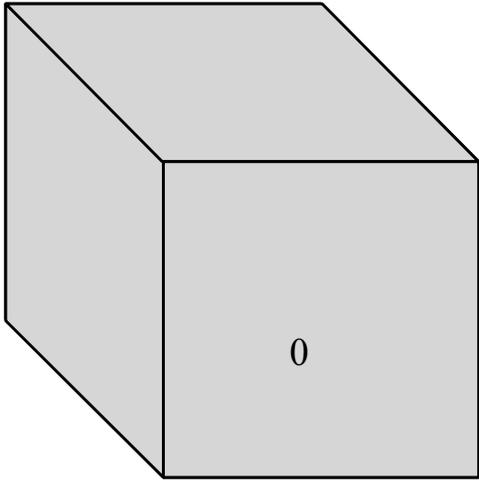
In-Game Usage



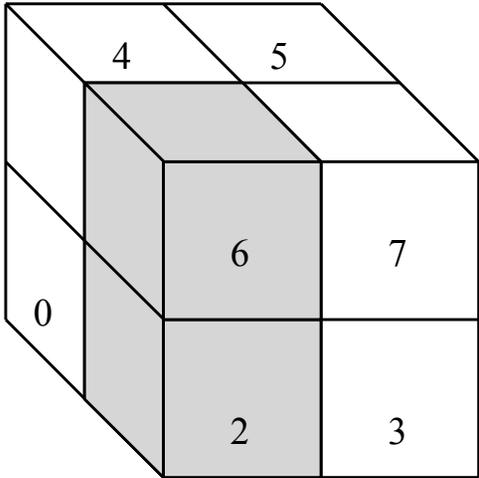
In game usage

- How is the data stored?
- How does pathfinding take place?
- How does the AI plan?

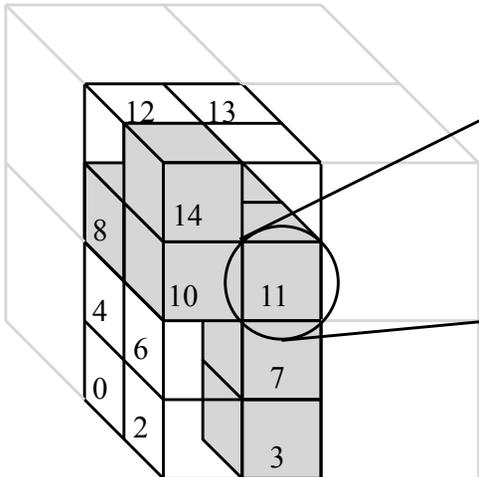
Layer 2



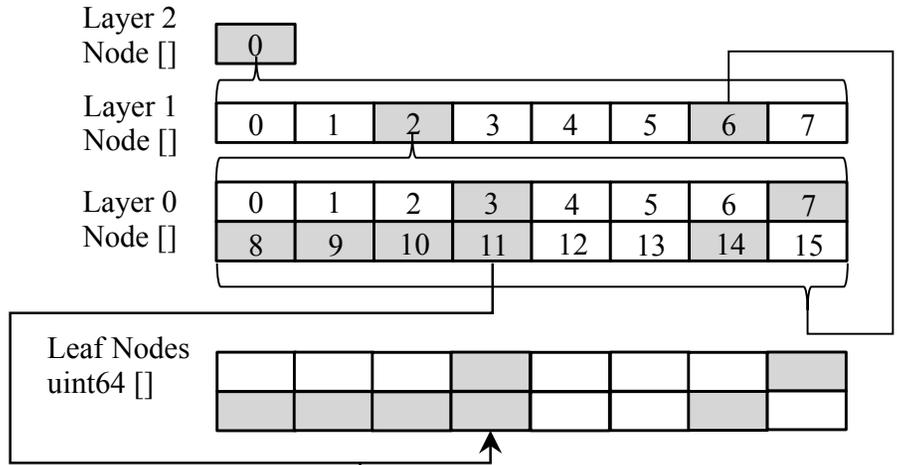
Layer 1



Layer 0

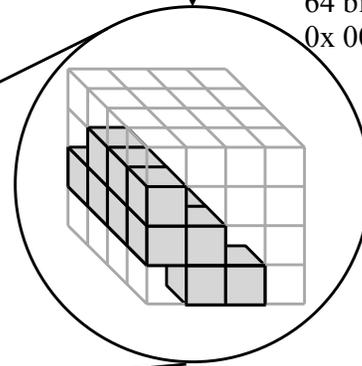


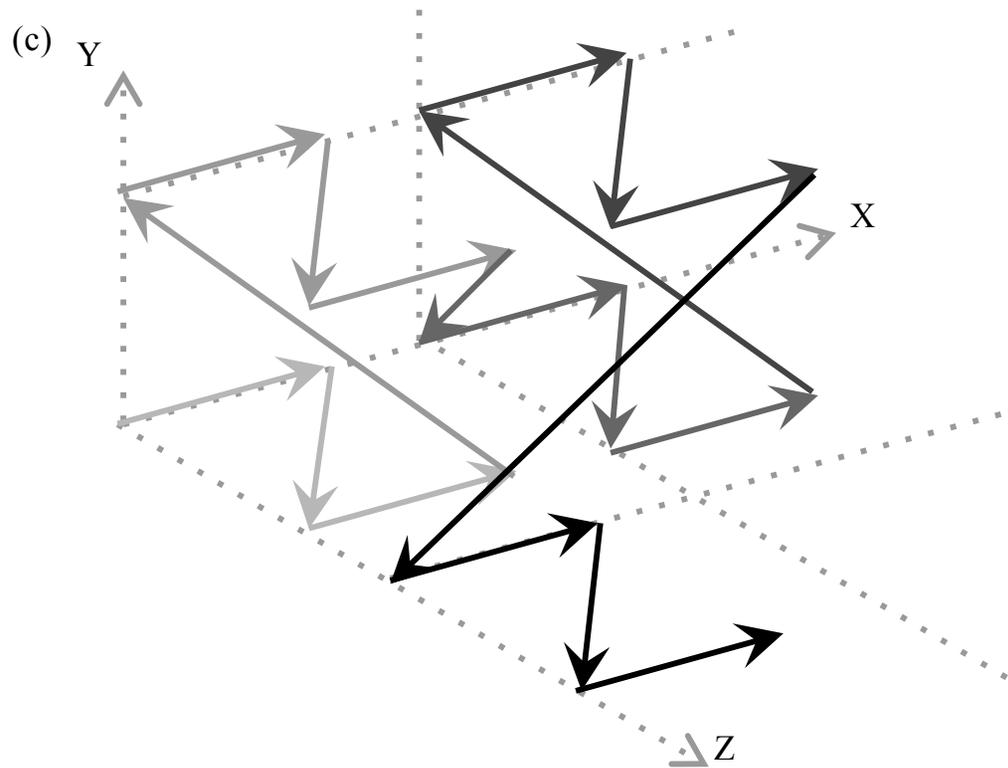
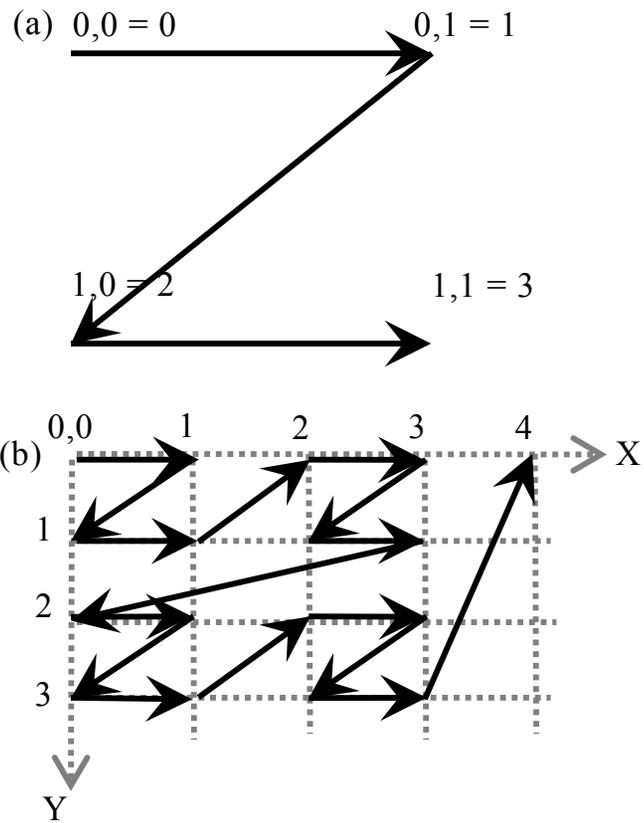
Layout of Octree nodes in memory.



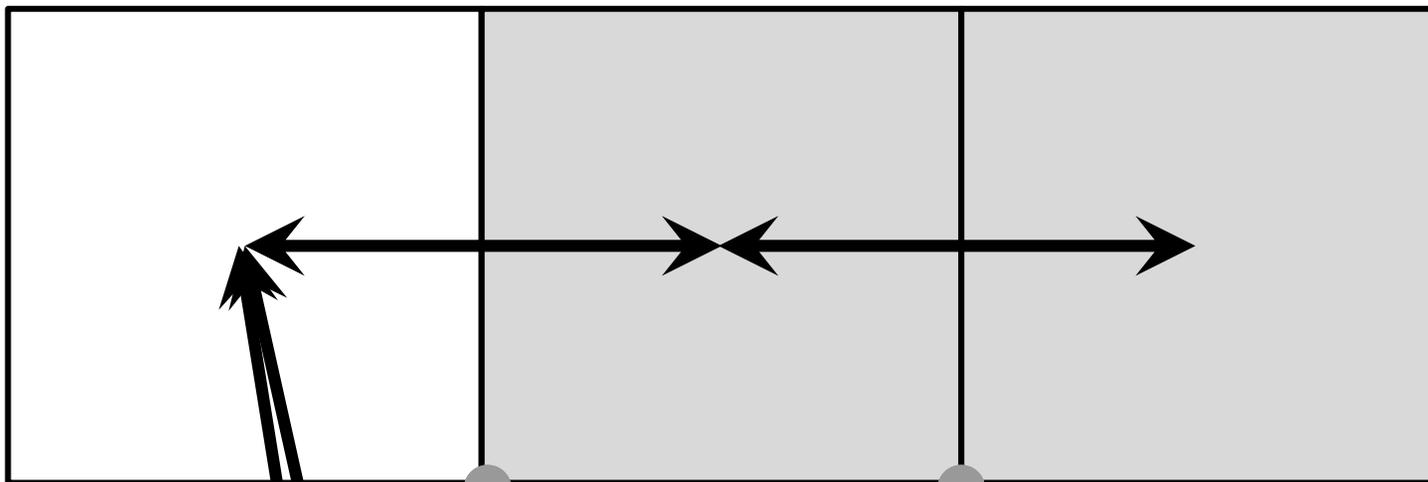
-  Node with children, contains collision geometry.
-  Node without children, contains only empty space.

Example Leaf Node contains a 4x4x4 voxel grid mapped to a 64 bit integer:
0x 0000 8880 CCCC 6000

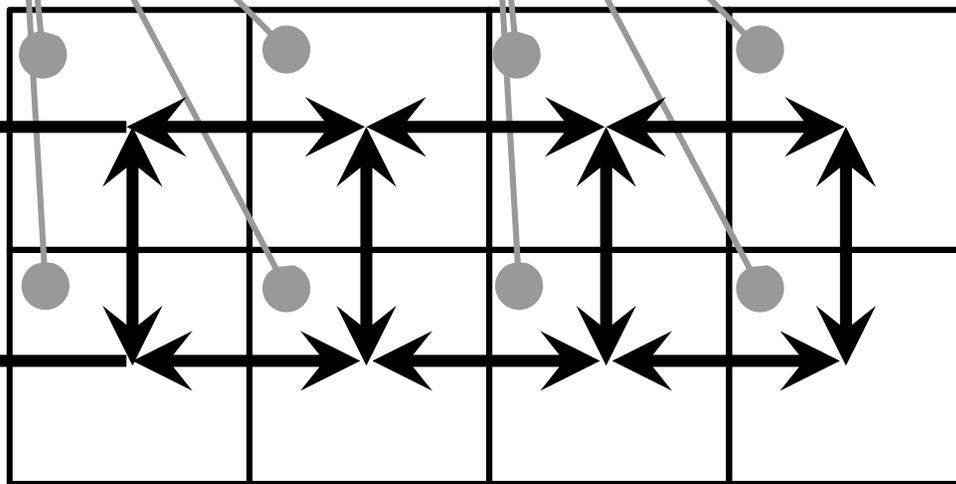




Morton / z-order curve



Layer 2



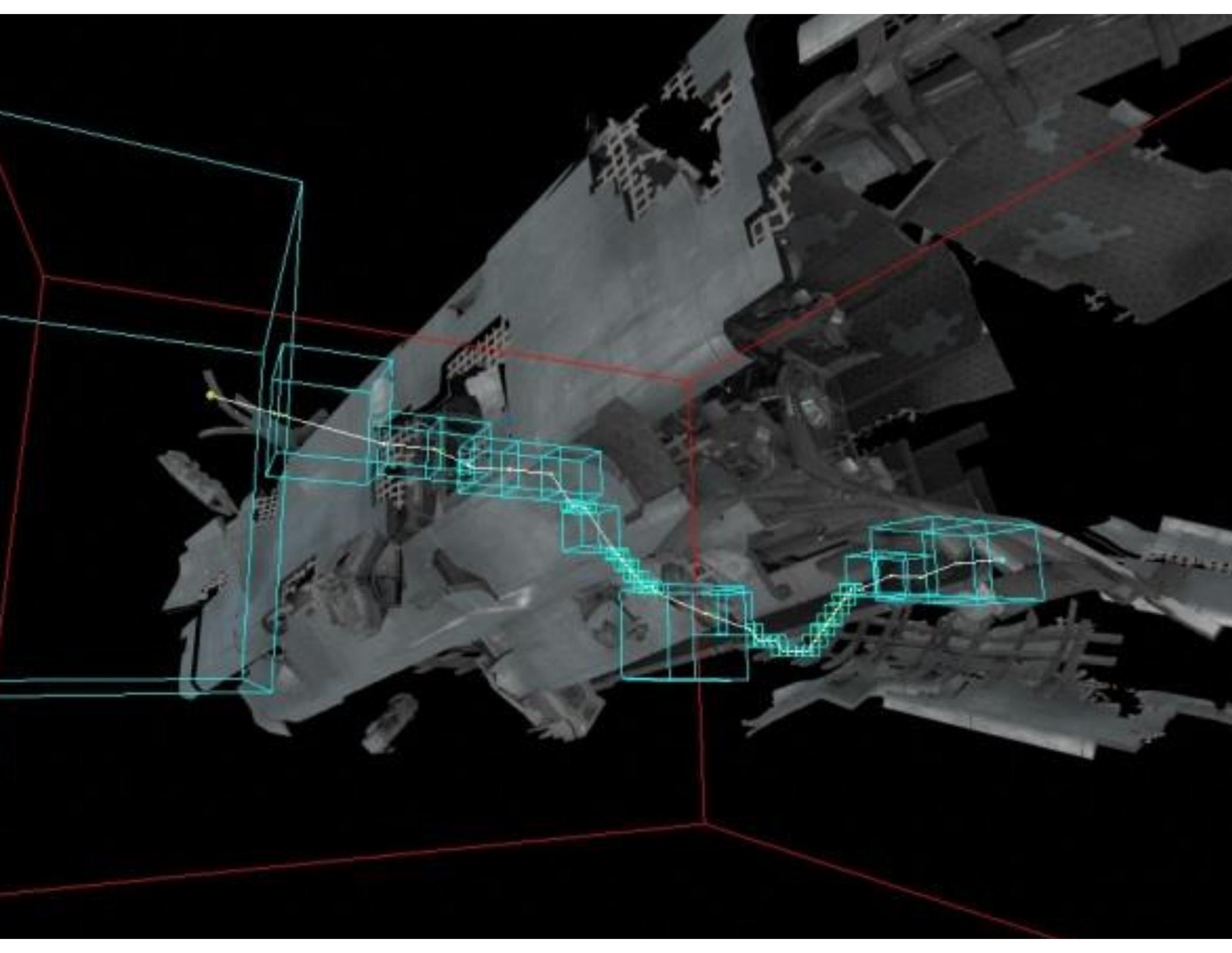
Layer 1



Links between neighboring nodes



Links between parent and child nodes





Details

- See Game AI Pro 3 (article)
- GDC Vault (video/slides)
 - <https://www.gdcvault.com/play/1022016/Getting-off-the-NavMesh-Navigating>
 - <https://www.gdcvault.com/play/1022017/Getting-off-the-NavMesh-Navigating>



Game AI NPC Behavior

- Typically between 4-20 active enemies in the game
 - Fly in formations before engaging player
 - Choose locations to move in range from player
 - Paths and target destinations updated 2x per second
 - Human players expected to be in constant motion

Problem Set Creation



Problem Definition

- Many possible problem definitions
 - Any-angle
 - Hierarchical
 - Uniform voxel grid
 - Visibility graph
 - etc



Uniform Voxel Grid

- Simplest representation (eg no research required)
- Voxel heuristic
 - Extension of octile distance
 - $h_{\text{voxel}} = (\sqrt{3} - \sqrt{2})d_{\text{min}} + (\sqrt{2} - 1)d_{\text{mid}} + d_{\text{max}}$
- 26-connected graph
- Can only move diagonally if all relevant cardinal angles are free



Problem Sets

- Wanted interesting test problem
 - Random problems are mostly trivial
 - Data is sparse
- Find all empty voxels within 5 voxels of an obstacle
- Repeat:
 - Random select start/goal
 - Discard if no solution or perfect heuristic

Data

Maps

```
voxel 896 390 255
74 80 63
74 81 63
74 82 63
75 80 63
75 81 63
75 82 62
75 82 63
76 79 63
76 80 62
76 80 63
76 81 62
76 81 63
76 82 62
76 82 63
77 80 63
77 81 62
77 81 63
77 82 62
77 82 63
```

Benchmarks

```
version 1
A1.3dmap
303 171 130 125 81 159 224.88200598 1.002
523 228 135 749 302 153 262.46925033 1.000
71 92 142 777 261 98 790.08330712 1.000
632 275 144 215 135 135 478.43622033 1.001
82 101 76 742 281 151 759.27115000 1.001
105 105 197 740 289 101 742.45972183 1.001
593 211 133 122 130 153 513.39332481 1.005
141 110 100 78 100 58 88.26430440 1.056
666 273 153 610 213 126 92.36335155 1.006
114 111 85 760 262 113 718.90979237 1.002
635 296 166 446 190 124 246.54493085 1.001
105 111 202 129 100 150 66.11949795 1.010
458 199 114 51 77 180 479.97541442 1.003
56 60 177 767 291 144 818.00038906 1.001
69 80 97 239 154 144 217.44728957 1.009
708 273 120 115 106 115 665.41970533 1.002
633 269 110 649 288 106 28.17011496 1.047
116 84 91 88 109 151 80.91163619 1.017
```

Open Research Questions



Existing Research

- Optimal Paths
 - NP Hard (Canny & Reif, 1987)
- Any-angle paths
 - Field D* (Carsten et al, 2006)
 - Theta* (Nash et al, 2010)
- Abstraction
 - (Wardhana et al, 2013)



Questions

- Best* representation
- Application of 2D techniques
- Any-angle and other approximation techniques
- Online planning problem
 - Moving Target Search
- New approaches?



Data

- <https://movingai.com/benchmarks/>
- <https://movingai.com/benchmarks/voxels.html>
- <https://movingai.com/benchmarks/warframe/>

[Download all maps \(40M\)](#)

[Download all scenarios \(7.5M\)](#)

| Preview (static) | Preview (Click for larger view) | Map | Dimensions | # states | Scenario |
|---------------------|------------------------------------|------------------------------------|-------------|------------|-------------------------|
| | | A1.3dmap (264K) | 896x390x255 | 88,983,963 | A1.scen |
| | | A2.3dmap | 896x390x255 | 88,984,281 | A2.scen |