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2D Platformer Navigation

Documentation v.0.8

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Overview

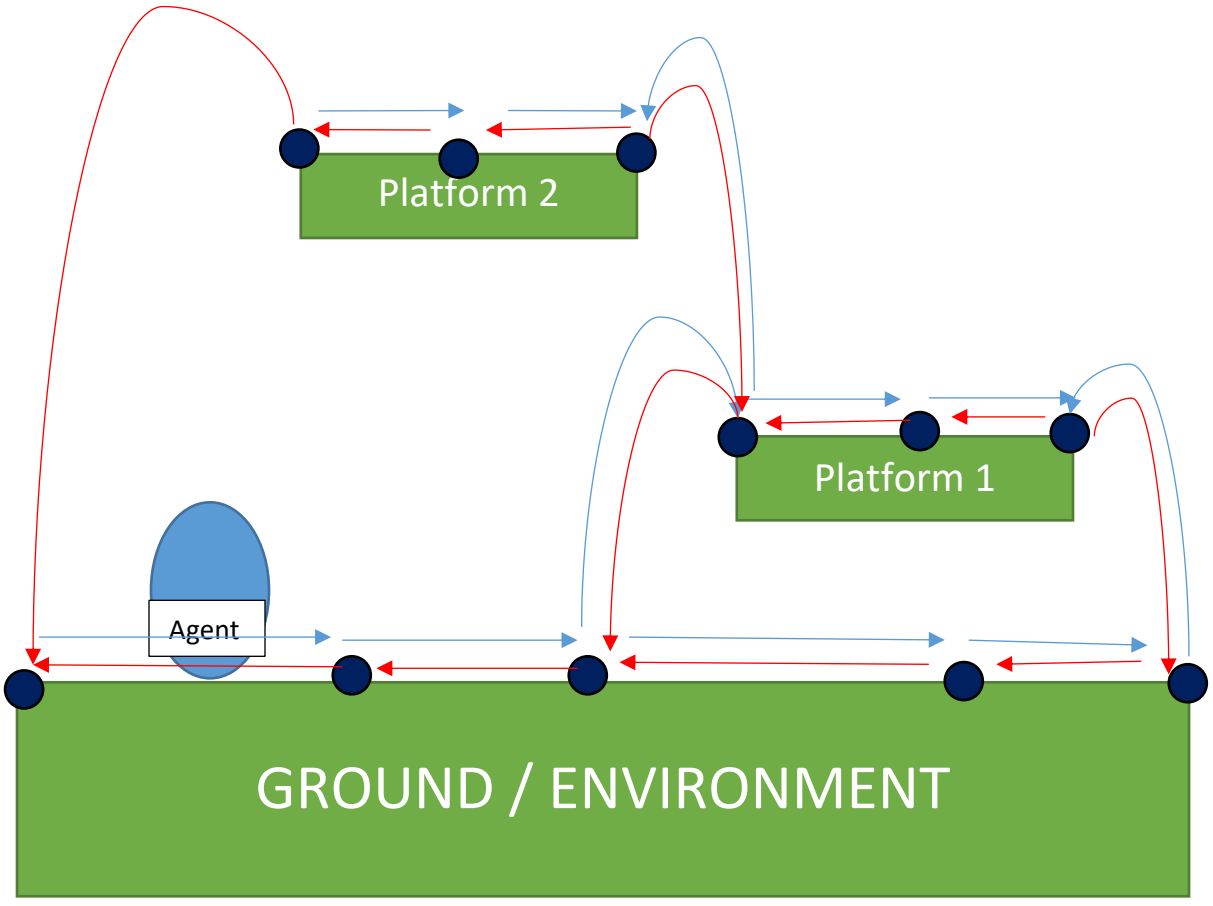
This project is a very basic implementation of a 2D pathfinding system for platformers, which could be used in 2D games.
It uses a similar approach to traditional tile-based Pathfinding, with some notable differences.
The nodes in the graph are not limited by a grid system and nodes could theoretically be “infinitely” connected by jumps, which was my main challenge when building this system.

In the example Scene, there is an actor navigating to the node closest to the mouse position.

Basic Concept

The game needs a graph of nodes and then uses Pathfinding algorithms like A* or Dijkstra to find a path in the graph.

For simplicity sake lets examine the following Image.



The Dots represent Nodes in the Graph, and the Arrows represent existing Edges. Notice how the player Agent could reach Platform 2 via Platform 1 but not from the Ground.

This very simple concept could be implemented by placing the Nodes and Edges Manually, thus very precisely controlling where and how the Agent could navigate.

This deterministic way of implementing navigation was not attractive to me as it is very simple and thus not very interesting.
It also creates a lot of work for the level designers and the Agent is not able to navigate “new level” or randomly generated levels.

My endeavour with this project was to autogenerate as much of the basic concept as possible.

Generating Nodes

Using polygon colliders (which technically includes Boxes) for the environment allows me to cut the colliders into Line, which can then be segmented, with nodes added along the way.

Take the following geometrie for instance and split it into Lines.

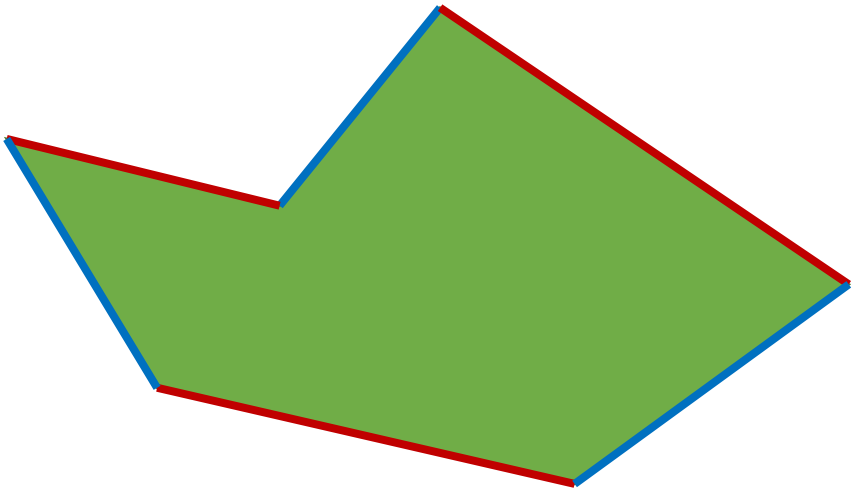


Image 1: Alternating colours red and blue for clarity).

Now “walk” along the lines and place nodes along the way.

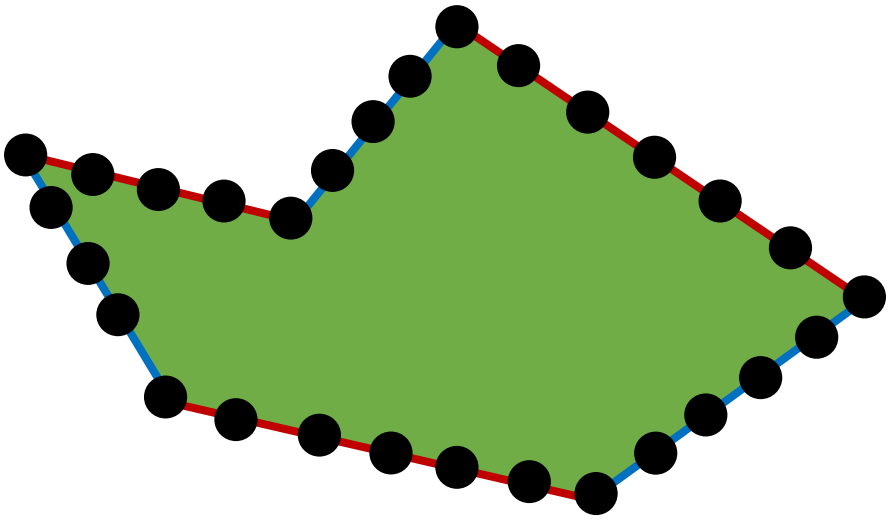


Image 2

Then evaluate every node for its eligibility.
It **a)** must be grounded and **b)** must not be inside a collider.
Both of which can be determined with a single raycast, starting slightly above the node going downward a short distance.

Image 3: For simplicity's sake only example nodes are shown. shows this process. Green nodes have been determined viable. Red ones are discarded.
Node A was discarded because it has no ground below. Node B was discarded because the ray starts inside a collider.

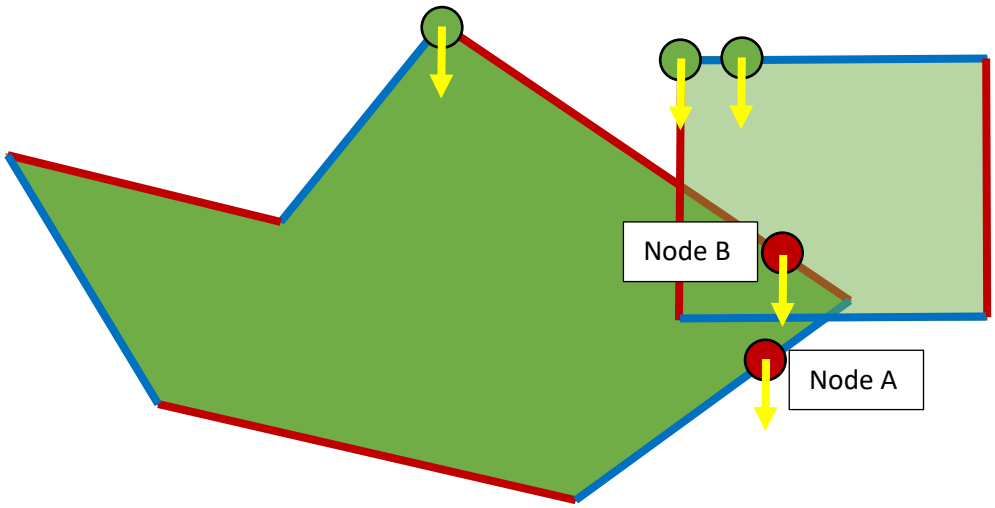


Image 3: For simplicity's sake only example nodes are shown.
Notes:

- *The ray is much shorter in practice, but again shown here for clarity.*
- *Second collider added to illustrate b).*

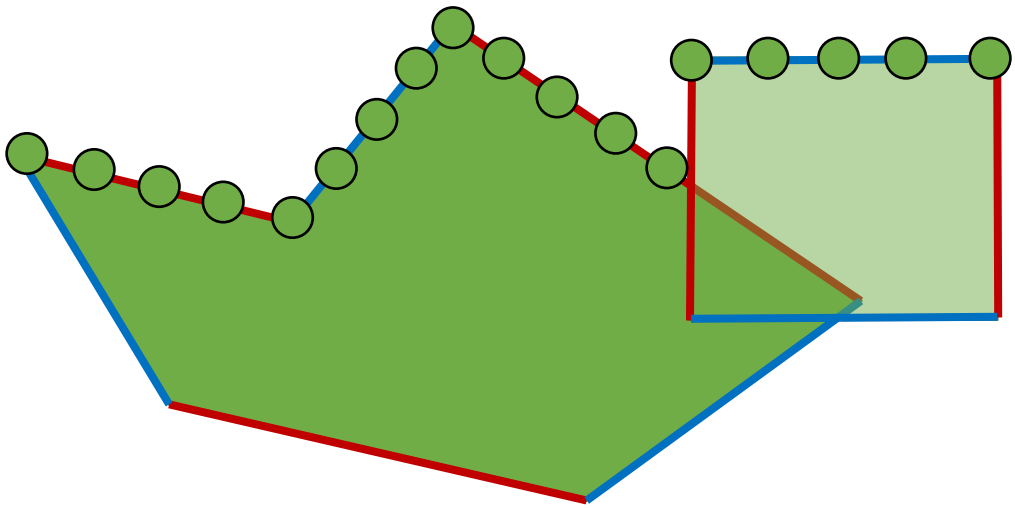


Image 4: Possible example result.

Generating Edges

Continuing with the example from generating nodes, the next step is to generate edges.
If a node exists within a certain small radius from another node, there might be an edge which is then checked.
The edge is determined not viable, when it goes through a collider.

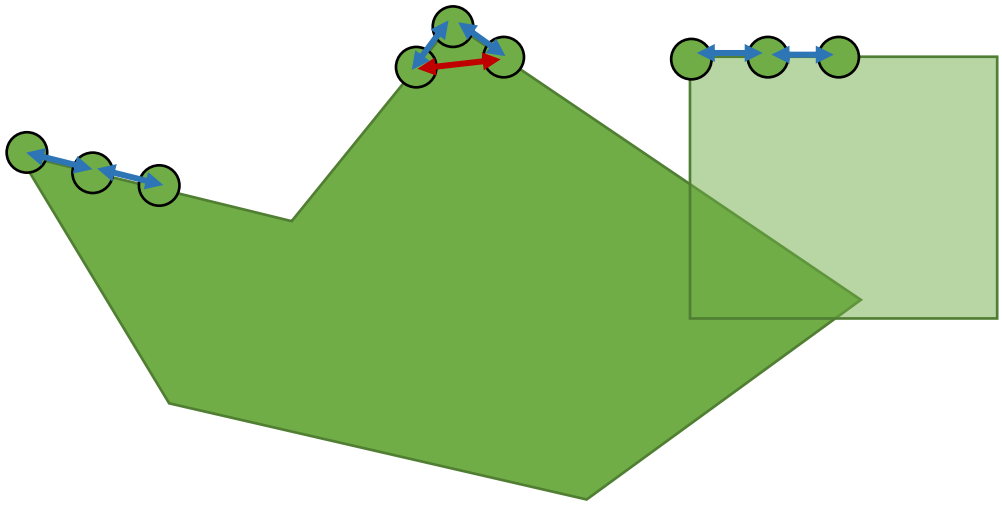


Image 5: Process of generating Edges.

After this, one basically has internally connected platforms.

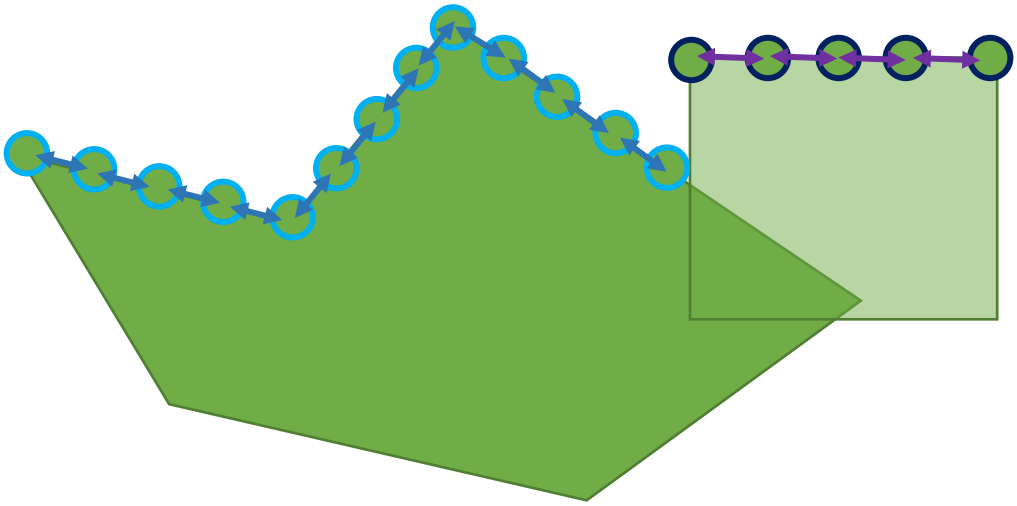


Image 6
Note: Every blue node can be reached from every blue node and every purple node from every other purple node.

After that every node which can not be reached by walking from a given node is added to a list to be tested for a possible jump.
Using *Image 6*
Note: Every blue node can be reached from every blue node and every purple node from every other purple node. as an example this would mean there might be a viable jump edge from every blue node to

every purple node, and thus will be tested for a jump.
Using the jump height and movement speed Edges can quickly be discarded when exceeding height or horizontal distances possible.

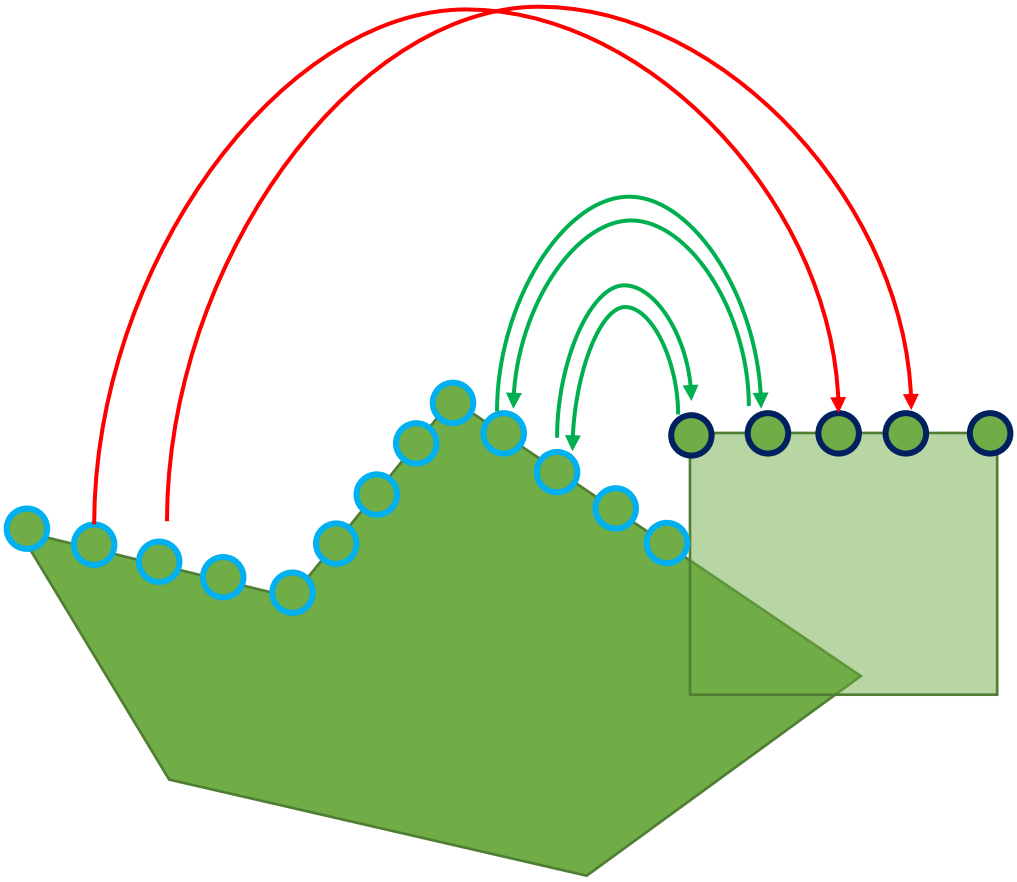


Image 7: Green Jumps determined possible, Red are not possible

After determining which jumps are theoretically possible, the jumps are checked for collisions along the jump path. (see: *Image 8: Collision check of jump edges*)

Collision boxes corresponding to the Agents Hitbox are placed along the jump path in sub steps and if a collider is hit the jump is deemed not possible and discarded.

This process is good enough to get decent results, but in practice is flawed which I will further extrapolate in Results and future outlook.

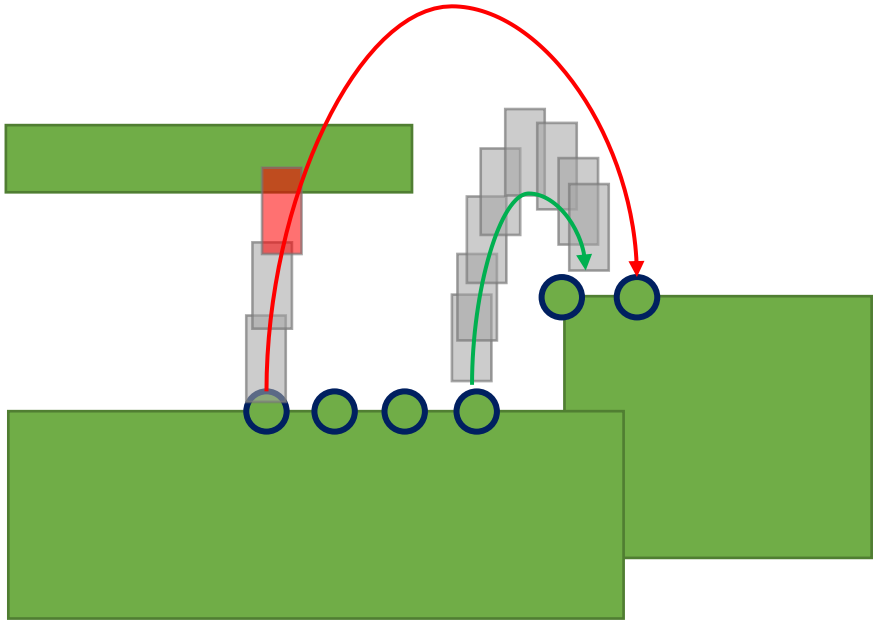


Image 8: Collision check of jump edges

Generating Path

Using the generated nodes and edges, distances from every node to every node are precomputed using Dijkstra's Algorithm and the results are stored in an *n*n matrix*, where *n* is the number of nodes, storing the distance from source to target and the relevant predecessor.

From this dataset one can easily get a path from one node to another by employing a backtracking algorithm, "walking" from the target to the source via the predecessors.

Classes and Methods

Class NavNode2D : ScriptableObject

Description

Basic class storing information of a graph node.
Needs to be a Scriptable Object, which is explained in TODO LINK .

Fields

Type	Name	Notes
int	`m_id`	ID of the Node in the Graph
Vector2	`m_position`	World position of the node
List<Edge>	`m_neighbours`	List of all neighbours stored as Edges to the neighbour

Methods

GetNeighbour

```
public Edge GetNeighbour(int _id)
```

Parameters

`_id`	ID of the neighbour to get

Description

Loops through *m_neighbours* and return the Edge where *m_destination.m_id == _id*.
Returns *null* if the Node does not have _id as a neighbour.

Class Edge

Description

Basic class storing information of an Edge.
Weight is the time it takes going from m_source to m_destination.

Fields

Type	Name	Notes
float	`m_weight`	Predecessor to reach this node
NavNode2D	`m_source`	Source/Start of the Edge
NavNode2D	`m_destination`	Destination/End of the Edge
bool	`m_isJump`	True if the Edge is a Jump. False by default
float	`m_jumpYVelocity`	The Initial Vertical Velocity when the Edge is a Jump
float	`m_jumpXVelocity`	The Horizontal Velocity when the Edge is Jump

Methods

Edge (+overloads)

```
public Edge( * )
```

Description

Constructors taking different parameters to initialize membervariables.

Class NavMeshManager : MonoBehaviour

Description

Main Class handling all the calculation of Nodes and Edges.
Has an Editor Interface Button to initiate Building the NavMesh etc.

Fields

Type	Name	Notes	Default	Scope
NavMeshData	`m_navMeshDataSORef`	Reference to scriptable Object storing the NavMeshData	0, 0	public
List<Vector2>	`m_allNodes`	List of all Positions eligible for Graph Nodes	*null*	public
List<Vector2>	`m_doubledNodes`	List of all nodes which have been determined to be doubled. Used for visualization only.	*null*	public
Queue<Edge>	`m_checkForJump`	Queue of all Edges that might be a viable Jump	*null*	private
float	`m_fPointAccuracy`	Distance used to create individual Nodes along the Edges of the Colliders Smaller Values -> More Nodes	*0.1f*	public
float	`m_fDoubleNodeDistance`	Distance of two nodes to be determined being the “same” node and prompted for deletion	*0.01f*	public
float	`M_iJumpTestSubsteps`	Number of Collisionchecks along the possible Jumppath	*20*	public
float	`m_fJumpHeight`	Max Jump Height to be used for calculation of Jump Edges	*3.0f*	public
float	`m_fmoveSpeed`	Grounded Horizontal Movement Speed	*4.0f*	public
float	`m_fjumpHorMoveSpeed`	Aerial Horizontal Movement Speed	*4.0f*	public
float	`m_fJumpStartVelocity`	Jump Velocity needed to reach m_fJumpHeight in Environment with m_gravityMagnitude	-	private
float	`m_fJumpTime`	Time to reach m_fJumpHeight in default Jump	-	private

float	`m_gravityMagnitude`	Gravity Magnitude	*10.0f*	public

Methods

RebuildNavmesh

```
public bool RebuildNavMesh()
```

Description

This Method is called when clicking on the Rebuild Navmesh Button in the Editor.
Reninitializes Lists as well as *m_fJumpStartVelocity* and *m_fJumptime*, and then calls Methods to rebuild Nodes and Edges.

Return false when *m_navMeshDataSORef* is not set and thus *null*.

Finally calls *m_navMeshDataSORef.InitNavMeshData()* and returns true.

CreateNodePositions

```
void CreateNodePositions()
```

Description

Finds all 2D Colliders and iterates through them to create possible node Positions.
Passes the sides of the Colliders to the *AddNodesAlongLine* Method.

AddNodesAlongLine

```
void AddNodesAlongLine(Vector2 _point1, Vector2 _point2)
```

Parameters

`_point1`	Starting point of the given line
`_point2`	Ending point of the given line

Description

“Walks” along the line in steps with m_fPointDistance as length and adds possible node positions every step.
The possible positions are passed to the *TryAddingNodeToList* Method.

TryAddingNodeToList

```
bool TryAddingNodeToList(Vector2 _pointToAdd)
```

Parameters

_pointToAdd	Position of possible node position to add to list

Description

Casts a small ray downwards to see if:
a) Inside collider
- or -
b) No ground below

If both of these conditions are *false* the point is added to *m_allNodes* and the method returns *true*.

ClearDoubleNodes

```
void ClearDoubleNodes()
```

Description

Checks all positions in *m_allNodes* if there is another position in *m_allNodes* with distance smaller or equal than *m_fDoubleNodeDistance*.
If so, then one of the positions is deleted and the other is added to *m_doubledNodes*.

CreateGraphNodesFromPositions

```
void CreateGraphNodesFromPositions()
```

Description

Deletes all previous Node Scriptable Objects in the *"Assests/BuiltData/Nodes"* folder.
Then creates *NavNode2D* Scriptable Objects for all the positions in *m_allNodes*.

ConstructEdges

```
void ConstructEdges()
```

Description

Iterate through all possible Edge combinations and passes the relevant Nodes to the *TryAddingEdge* Method.
If the Edge is eligible then it passes the new Edge to the *SetNodeNeighbour* Method.

Finally all nodes that are not connected to any other node are removed.

TryAddingEdge

```
Edge TryAddingEdge(NavNode2D _startNode, NavNode2D _targetNode)
```

Parameters

_startNode	Source of the Edge
_targetNode	Destination of the Edge

Description

Checks of the Distance of *_startNode* and *_targetNode* is below a given Value.
Then checks whether the given Edge would go through a collider and if so, discards it and returns null.

If the Edge is viable it is added to *m_navMeshDataSORef.m_GraphEdges_temp* *and is returned.*

CheckAllNodesForJumpEdges

```
void CheckAllNodesForJumpEdges()
```

Description

Using breadth-first search alle nodes are checked if they can currently reach every other node using *CanReachNode*.
If two nodes are currently not connected by any path, the non-existent edge is added to be checked for a possible jump

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CanReachNode

```
bool CanReachNode(NavNode2D _start, NavNode2D _target)
```

Parameters

_start	Source of the breadth-first search
_target	Destination of the breadth-first search

Description

Returns true of the breadth-first search succeeds.

SetNodeNeighbour

```
bool SetNodeNeighbour(Edge _newEdge)
```

Parameters

_newEdge	New edge to set Neighbour

Description

Checks whether the source of the current Edge already has the Neighbour given in *_newEdge*.
If not, then the Destination in *_newEdge* is set as a new Neighbour and the Method return *true*.

EvaluateJumpEdges

```
void EvaluateJumpEdges()
```

Description

Iterates through all Edges in *m_checkForJump* and passes them to *EvaluateSingleJumpEdge*.

EvaluateSingleJumpEdge

```
bool EvaluateSingleJumpEdge(Edge _edgeToCheck)
```

Parameters

_edgeToCheck	Edge to check for Jump

Description

This method looks for a possible efficient jump from *_edgeToCheck.m_source* to *_edgeToCheck.m_destination*.

If a jump is found, the Neighbours of *_edgeToCheck.m_source* are set accordingly and the method returns true.

GetClosestNodeToPosition

```
public NavNode2D GetClosestNodeToPosition(Vector2 _position)
```

Parameters

_position	Position to get the closest Node to

Description

Returns the Node in *m_navMeshDataSORef.m_GraphNodes* closest to *_position*.

CollisionCheckJump

```
bool CollisionCheckJump(Edge _edgeToCheck, float _jumpTime,
                        float _yVelocity, float _xVelocity)
```

Parameters

_edgeToCheck	Edge to check for collisions
_jumpTime	Duration of the jump
_yVelocity	Initial Vertical velocity
_xVelocity	Horizontal Velocity

Description

Substeps the jump and performs an OverlapArea at the substep position to check if overlapping with the “environment”. If so, the jump is not possible and false is returned.

Class NavAgent : MonoBehaviour

Description

Stores basic information of a simple game Tile.

Fields

Type	Name	Notes	Scope
NavNode2D	`m_currentNode`	Current Node the Agent is currently positioned regarding Navigation	public
NavNode2D	`m_closestNode`	Closest Node to the Mouse Cursor	public
int	`m_headingNodeID`	ID of the Node the Agent is currently heading towards. (ie. the next node on the current path)	public
int	`m_currentNodeID`	The ID of the current Node Mainly used for debugging reason to display in inspector	public
Edge	`m_currentEdge`	The current Edge the Agent is traveling on. (Ideally an Edge where the source is m_currentNode and the destination is a node with m_id == m_headingNodeID)	private
NavMeshManager	`m_navManagerRef`	Reference to the NavMeshManager	public
Stack<int>	`m_currentPath`	The path the Agent is currently traveling on given as a Stack<int>	private
float	`m_bufferedTime`	Container to store time buffer when actor would overshoot a node in a single frame	private
float	`m_currentMoveTime`	Current time passed moving on m_currentEdge	private
float	`m_timeToHeading`	Time from m_currentEdge.m_source to m_currentEdge.m_destination Mainly used for debugging to display in inspector	public

Methods

Update

```
void Update()
```

Description

Set the closest Node to the Mouse Cursor and then finds a path to that node and navigates towards it.

SetHeadingNodeAndAdjustPosition

```
bool SetHeadingNodeAndAdjustPosition(float _timeBuffer)
```

Parameters

`_timeBuffer`	The leftover time when arriving at node

Description

Called whenever a node was reached.
Sets the *m_headingNodeID* to the next ID in the *m_currentPath* and adjusts the position of the Actor.

Returns *false* when *m_currentPath == null*, meaning there is no Edge to currently travel on. Otherwise return *true*;

GetCurrentBufferedTime

```
float GetCurrentBufferedTime()
```

Description

Returns the current buffered time and resets the value to 0.

SetClosestMouseNode

```
void SetClosestMouseNode()
```

Description

Sets m_closestNode using the Mouse Screen Position and pasing it to the *m_navManagerRef.GetClosestNodeToPosition* method.

MoveGrounded

```
void MoveGrounded()
```

Description

Process moving along *m_currentEdge* when m_currentEdge is not a Jump.

MoveInair

```
void MoveInair()
```

Description

Process moving along *m_currentEdge* when m_currentEdge **IS** a Jump.

Class NavMeshData : Scriptable Object

Description

Data Container Storing Build Navigation Data since Data in MonoBehaviour is not persistent.
Precalculated Data makes pathfinding more efficient during runtime.

Fields

Type	Name	Notes	Default	Scope
List<NavNode2D>	`m_GraphNodes_temp`	List of all Graph Nodes	*null*	public
List<Edge>	`m_GraphEdges_temp`	List of all Edges in Graph	*null*	public
List<Edge>	`m_JumpEdges_temp`	List of all Edges, which are Jumps in Graph	*null*	public
NavNode2D[]	`m_GraphNodes`	Array of all Graph Nodes Used for efficiency	*0.1f*	public
NavDataContainer_Row[]	`m_GraphNavigationData`	Array of NavDataContainer_Row. This is basically a nxn Matrix of NavigationDataContainers, where n is number of Nodes.	*0.01f*	public
float	`M_iJumpTestSubsteps`	Number of Collisionchecks along the possible Jumppath	-	public
float	`m_gravityMagnitude`	Gravity Magnitude	-	public

Methods

InitNavMeshData

```
public void InitNavMeshData()
```

Description

Called from the *NavMeshManager* after building the Graph Nodes etc.
Builds an array of *NavNode2D* from the List of Nodes and adjusts the IDs to be the same as the index in the array. This is done for efficiency and for the benefit of random access.

BuildNavData

```
void BuildNavData()
```

Description

Loops through all nodes and perform Dijkstra's Algorithm.
Then stores results (distance / predecessor) in *m_GraphNavigationData*.

Dijkstra

```
void Dijkstra(int _sourceID)
```

Parameters

_sourceID	ID of the source node in graph

Description

Dijkstra's Algorithm.

Data stored in *m_GraphNavigationData*.

GetPathBacktracking

```
public Stack<int> GetPathBacktracking(int _sourceID, int _targetID)
```

Parameters

_sourceID	ID of the source node in graph
_targetID	ID of the target node in graph

Description

Finds and returns the fastest possible path as a *Stack<int>* from source to target by looking through *m_GraphNavigationData* in reverse.

VisualizeJumpPath

```
void VisualizeJumpPath(Edge _jumpEdge)
```

Parameters

_jumpEdge	Edge to visualize

Description

Helperfunction to visualize a given jump. Draws a line in between the substeps.

VisualizePath

```
void VisualizePath(NavNode2D _source, Stack<int> _path)
```

Parameters

_source	The source node of the path
_path	The path to visualize given as a stack of node IDs.

Description

Helperfunction to visualize a given path.

Class NavDataContainer_Row

Description

Stores basic information of a simple game Tile.

Fields

Type	Name	Notes	Scope
NavigationDataContainer[]	m_GraphNodes_temp	Array of NavDataContainers	public

Methods

NavDataContainer_Row (constructor overload)

```
public NavDataContainer_Row(int _size)
```

Parameters

_size	Size of *m_GraphNodes_temp*

Description

Constructor with the size of the *NavigationDataContainer* Array as Parameter.

Class NavigationDataContainer

Description

Stores basic information of a simple game Tile.

Fields

Type	Name	Notes	Default	Scope
float	`m_distance`	Distance to the relevant source node	*float.MaxValue*	public
int	`m_predecessorId`	Predecessor to reach this node	*-1*	public
bool	`m_visited`	Stores if the node was already visited used in Dijkstra's Algorithm	*false*	public

Methods

NavigationDataContainer (constructor overload)

```
public NavigationDataContainer(float _distance, int _predecessorId)
```

Parameters

`_distance`	Init distance to set
`_predecessorId`	Init predecessor to set

Description

Constructor to set _distance and predecessor.

Results

Shortcomings

Although the results are somewhat satisfying, the project suffered somewhat from the theoretically large scope.

I deemed certain functionality to be possible, but in the end did not implement it, since I prioritized an extensive documentation at the expense of some functionality and even then, the documentation leaves room for things to be desired.

Currently Edges are not discarded based on angle, meaning very steep Edges are viable, which can look weird depending on the geometry of the level. It would have been nice to add a setting (like *m_fMaxWalkableAngle*) for this in the *NavMeshManager*.

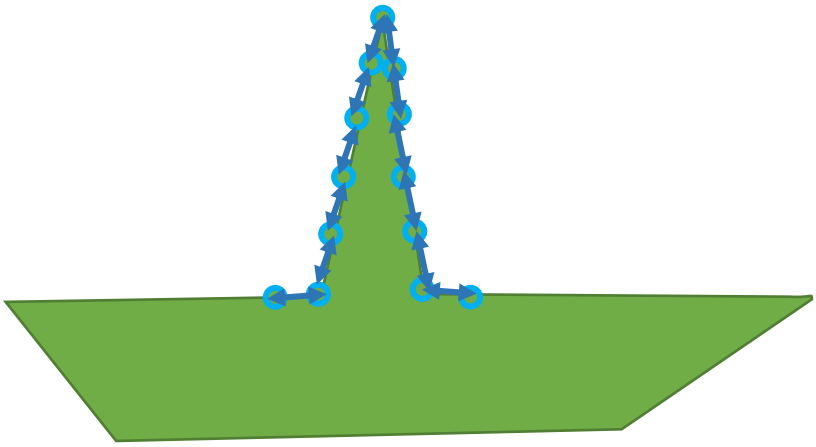

Image 9: Steep Edges are not discarded

Another problem is Nodes not being checked for collision similar to what is done for Jumping. Every Node could easily be checked for the Agents hitbox and if the hitbox does not fit, the Nodes is discarded. This could fix some edge cases where Nodes are placed in awkward positions (although currently this rarely happens if ever, since Nodes are deleted when no edges connect to it).

Also, there is currently no way of using multiple Actors regarding each other's positions as well as moving platforms or changing terrains.
Furthermore NavMeshData is always saved in the same Folder, thus making it impossible currently to have different Scenes with prebuilt NavData.

Lastly determining if a Jump is theoretically possible is a very complex topic depending on what is allowed. Things like circumventing obstacles mid-air by strafing or stopping movement mid-air to land on a certain node are very specific types of jumps, which can't be generalized easily and are thus hard to autogenerate.
On the other hand, a lot of jumps are deemed possible with the current implementation, but only a fraction of them is actually used ever in pathing creating a lot of "garbage jumps" in the form of edges, which are never used. Which again could have been streamlined and I have ideas how to do it, but I just did not find the time to do it.

Learnings and Future Outlook

In general, implementing the Dijkstra with a weird self-made node structure was insightful. One of the biggest problems were Unity's serialization rules which I discovered to be a bottleneck for my architecture.

Unity does not allow self-referencing classes to be serialized as this could lead to infinitely deep structures.
This was obviously due to my bad architecture but did not cause problems until I tried precomputing the NavData and storing it. Self-referencing might be a pattern to be avoided in general, but it was hard to take out of my Structure once I noticed the problem and linked lists use a similar architecture so I assumed it would not be a problem.
I had to compromise to avoid rewriting most of my code and found the solution to be making the NavNode2D inherit from Scriptable Object. Self-referencing and serialization work fine with Scriptable Objects, so the creation and storing of the Nodes got a little bit convoluted but solved my serialization problems. On a positive Note, this increased debuggability since the Nodes could now be inspected in the hierarchy.

The biggest topic in my opinion is determining possible jumps. Creating logic which helps to find efficient jumps is something to be further examined. One Idea I played with in my head was autogenerating high value mid-air transition nodes, to allow for a variety of new "creative" jumps. This would also require a neat way of storing more complex jumps in edges, like jumps where the Actor changes direction mid-air for example.

Concluding I would like to mention, that I briefly investigated using machine learning to create an "intelligent Actor" able to solve platformer puzzles but decided that to be way out of scope and too complex.