

# Unity Heat Map Plug-in

Game Engines E2013  
*IT-University of Copenhagen*

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**2D-platformer Project Report**

**Wireframe Renderer Project Report**

**Pathfinding Project Report**



## 1 Introduction

This report is the result of the final project in the Game Engines E2013 (MGAE-E2013) course at the IT-University of Copenhagen, autumn 2013.

The aim of this project was to create a Unity<sup>1</sup> plug-in that allows the user to track events in their game and generate a heat map based on this event data.

On this project I collaborated with Jacob Claudius Grooss (jcgr@itu.dk) on writing the plug-in and testing the performance.

The GitHub repository can be found at <https://github.com/esfdk/GameEnginesE2013/>.

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<sup>1</sup><http://unity3d.com/>



## 2 Project Overview

In most video games, there are many things happening during gameplay. All these things can be viewed as data points (game metrics) useful to developers when it comes to understand their game and how players play the game. Examples of interesting game metrics could be, but is certainly not limited to; player positions during gameplay, where entities died (and how they died), where certain things happened and how long play sessions lasted. These game metrics can be used for finding the right balance, finding bottlenecks in the game and figure out what players find interesting about a game.

Game metrics often consist of many data points and displaying all these data points in a easily understood format is very important. Many game metrics can easily be shown in a table or diagram (such as total play time, favourite weapon or game progress rate), because these are just numbers and do not need a more detailed visual context to be understood.

However, some game metrics are not easily understood without a visual context. Tables and diagrams are good for showing how many times an event happened, but are not well suited for showing details about *where* events happened. This is where heat maps come in.

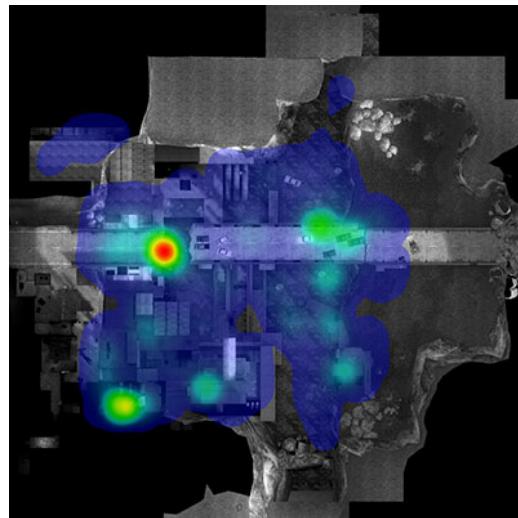


Figure 1: A heat map representing deaths in a level in Half-Life 2

Heat maps are overlays on a level that show how often an event happened at a particular spot. The overlay consists of a semi-transparent object where different parts of the object are painted with different colours. Often the colours range from either dark blue to bright yellow to dark red or from dark blue to dark purple. The further the colour is toward dark blue, the less often an event has happened there. Conversely, the further the colour is toward the dark red/purple, the more often an event has happened there.

Figure **Figure 1<sup>2</sup>** on page 2 displays where players died in a level in Half-Life 2: Episode 2. This

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<sup>2</sup>Source: <http://www.pentadact.com/2007-11-15-episode-two-death-maps/>

can indicate more than one thing; the area might be too hard, players may have missed "the trick" or the area may just be as difficult as intended. In any of these cases, the heat map provides information useful to the developer. If the area is not supposed to be difficult, then an argument could be made for making it easier. If it was supposed to be difficult, then the developers can focus on other parts of the game.

## 2.1 Goal of the project

Having recently been introduced to Unity for another project (making a game called Hiraeth), Jacob Grooss and I were both interested in doing a plug-in for the engine as our final project. While we did alpha and beta testing on Hiraeth, we felt we lacked information about which part of the game world the player(s) explored. We decided to explore heat mapping plug-ins and only found one: Game Analytics<sup>3</sup> (GA). While the GA plug-in seemed very powerful, we had a lot of trouble actually getting it to work due to problems with their servers. Because of this, we decided to make our own simple heat mapping plug-in.

In Unity all game objects can contain scripts. Scripts must either inherit from MonoBehaviour (most commonly used) or Editor. Any script inheriting from MonoBehaviour can override different event functions (such as OnDestroy, Start, OnMouseDown, etc.) and the Update function. The Update function is called once for every frame. This makes for a quite consistent API in Unity.

The goal of the project was to create a simple plug-in capable of tracking position data at certain intervals (breadcrumbs) and the positions of events when they happen using the consistent API of Unity.

### 2.1.1 Plug-in features

Because of the elements described in the goal of the project, we decided on four required features for the plug-in:

- **Track anything** - Any kind of event or object should be trackable through the plug-in.
- **Track heat map on per event basis** - The plug-in should be able to generate heat maps based on specific objects and/or events (not just all objects and events).
- **Track anything** - The plug-in should not require too much time and effort to set-up for use.
- **Stand-alone** - The plug-in should not require an internet connection and/or other software/systems besides Unity.

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<sup>3</sup><http://www.gameanalytics.com/>

### 3 How To Use

The heat mapping plug-in consists of two parts: tracking objects and generating the heat map.

To access the plug-in, the custom package must be imported. The package consists of 4 folders. *Scripts/HM\_Tracker* and *Prefabs/HM\_HeatMap* are the elements used by the developer to track events and visualise heat maps. The rest of the files are used internally in the plug-in.

#### 3.1 Tracking game objects

To track a game object, the *HM\_Tracker* script must be attached to the object. Attaching the *HM\_Tracker* to an object allows the user to change the tracking interval, save interval and toggle which of the default events that are tracked.

By default, the tracker can record the position of the game object when the following events happen: Breadcrumb (object position at intervals), Awake, onDestroy, OnTriggerEnter and OnMouseDown.

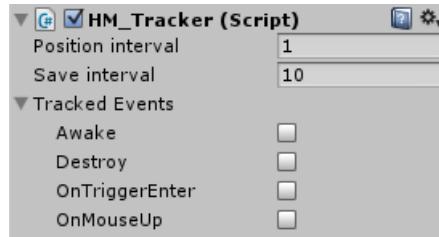


Figure 2: The tracker options.

The OnMouseDown event is only tracked on every call to Update on the game object. Assuming 30 calls to update per second (30 fps), the tracker will register a maximum of 30 mouse up events per second.

The tracking interval determines the minimum interval between every breadcrumb in seconds. This value cannot be less than one second<sup>4</sup>.

The save interval is the minimum time between the positions being saved to file<sup>5</sup>. If a game uses a lot of memory, a lower save interval would mean less memory is used, but would also mean that the hard drive is accessed more often.

The tracked data is saved in a file named "HeatMapData DATE TIME.xml" in a folder called "HeatMapData". Tracked data for individual game objects are saved with the file name "HeatMap-DataNameOfGameObject.xml" in folder "HeatMapData/DATE TIME/".

Because we track individual game objects in this manner, the names of tracked game objects must be unique. While this issue can be dealt with by the user of the plug-in, this could certainly be an element to improve in a future version of the plug-in.

<sup>4</sup>If the value was lower, it could become a memory hog and take too long to save event info.

<sup>5</sup>Like the tracking interval, this value cannot be less than 1. We felt that saving event information more often than breadcrumbs can be tracked did not make sense.

### 3.1.1 Custom events

There are two ways to track custom events.

The first way is to create a separate script that calls the AddEvent method of the *HM\_Tracker* component on the game object whenever the event happens. This is how we designed custom events to be tracked.

The second way is to modify the *HM\_Tracker* script, so that the event is tracked from inside the script itself.

## 3.2 Generating the heat map

A copy of the *Heatmapping/Prefab/HM\_HeatMap* prefab should be part of the unity scene hierarchy. The prefab has a script attached that allows for generating heat map visuals. The *Heat Marker* variable of the script should not be changed.



Figure 3: The options for generating heat map. Left picture is without any data selected, the right is with data selected.

*Heat Marker Scale* determines the scale of the sphere surrounding a tracked event. *Allowed Distance* determines how far away two positions can be from each other before they count as increased density.

*Session Data* lets the user choose from different datasets in the "HeatMapData" folder. Currently, it is only possible to load data files from the "HeatMapData" folder.

Once a data file has been loaded, lists of the objects tracked in the file and their events appear in the editor. Selecting a specific object and/or event type will only instantiate heat markers for those objects/events in the scene.

Clicking the *Generate Heatmap* button instantiates heat markers based on the selected data file and the game object / event choices. After the objects are instantiated, the density of the objects are calculated and the colours of the heat markers are set based on their density relative to the highest density.

The *Clear Heatmap Markers* button destroys all objects in the scene with the tag "HeatMarker".

### 3.2.1 Loading data from more files

Currently the only way to load data from more than one file is to load (and generate) the heat map data one file at a time. This is highly inconvenient, if there are large data sets (as there often is with heat map data. I discuss possible solutions to this problem in section 6.2 on page 12).



## 4 Overview of the Plug-in

The plug-in consists of eight scripts (six behaviour scripts, two editor scripts), two prefabs and one external plug-in (consisting of two scripts).

### 4.1 Folder structure

The plug-in contains four folders:

- **Editor** contains custom editor menus for the two of the scripts in the plug-in.
- **Plugins** contains two scripts from an external plug-in.
- **Prefabs** contains two prefab objects used in the plug-in.
- **Scripts** contains the scripts for the main logic of the plug-in.

### 4.2 Prefabs

The plug-in uses two prefabs to render heat maps. The *HM\_HeatMarker* is used for marking event positions and the density/heat of these positions in the heat map. The *HM\_HeatMap* is essentially an empty game object with the *HM\_GenerateHeatMap* script attached.

### 4.3 HM\_Tracker

This script is attached to objects to track (see section 3.1). By default, it tracks the position of the object at different intervals (breadcrumbs) and can be set up to track other events.

The tracker script keeps track of both how often to track breadcrumbs and how often to save tracked events to file. Between every save, the tracker keeps a list of all occurred events. This list is reset on every save to reduce the risk of out of memory problems.

Every tracker script also contains its own individual writer used to generate the XML files used for the data sets.

### 4.4 HM\_HeatMarkerScript

*HM\_HeatMarkerScript* contains the logic for calculating the density of a heat marker based on the heat markers around it. Calculating the density of a heat marker is  $O(n)$  where  $n$  is equal to the amount of heat markers in the scene.

### 4.5 HM\_GenerateHeatMap

*HM\_GenerateHeatMap* is in charge of generating the heat markers for the heat map. It does this in four steps:

#### 4.5.1 Load Session Data

When the Generate Heat Map button in the editor is clicked, the script loads the specified XML data file.

#### 4.5.2 Instantiate Heat Markers

After the data set has been loaded, the script scans through the data set and instantiates heat markers based on the options selected in the editor (game object(s) and event type(s)) and sets their parent to the object containing the *HM\_GenerateHeatMap* script (usually the *HM\_HeatMap* prefab).

#### 4.5.3 Calculate Density

After instantiating the heat markers, the script makes every heat marker calculate their density and figures out the highest density. This runs in  $O(n^2)$  because every heat marker must check every other heat marker to calculate the density. Due to this complexity, generation of heat markers may take a very long time on large data sets.

#### 4.5.4 Set Color

Once the density of all heat markers has been determined, the script calculates the relative density of every heat marker and generates a colour based on this relative density. This operation runs in  $O(n)$  time.

### 4.6 HM\_ControlObjectScript

The *HM\_ControlObjectScript* makes sure that only one data folder is created for each tracked game session. Additionally, it ensures that the separate data files for each tracked game object is collected into one data file at the end of the game session. At the start of the game session, a dummy object containing this script is automatically instantiated.

### 4.7 HM\_Event & HM\_EventTypes

*HM\_Event* represents an event in the game and contains the logic for how to print itself in an XML-document. *HM\_EventTypes* is a helper class that contains the names of the standard event types used in the plug-in.

### 4.8 Editor scripts

The two editor scripts change the appearance of the *HM\_GenerateHeatMap* and *HM\_Tracker* by adding drop-down lists to select data files, toggle options for tracked events and buttons for generating and clearing the heat map.

### 4.9 External plug-in

The external plug-in is only used for a smooth colour transition on based on the density. The plug-in is called ColorX<sup>6</sup>.

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<sup>6</sup>Source: ColourX package <http://wiki.unity3d.com/index.php/Colorx>

## 5 Test

We tested our plug-in on three different games. An example top-down shooter game called Angry Bots<sup>7</sup>, an example 2D-platformer game<sup>8</sup> and a first person exploratory game called Hiraeth<sup>9</sup> we made for a different course. We tested these three types of games to see how our heat map plug-in worked on different types of games.

In addition to testing the three different game types, we also tested the performance of our plug-in. The test was performed on a laptop with 8GB memory, Nvidia Geforce GTX 765M graphics card and Intel Core i7 processor (2.4 GHz) on the Hiraeth game.

### 5.1 Tested games

#### 5.1.1 Hiraeth

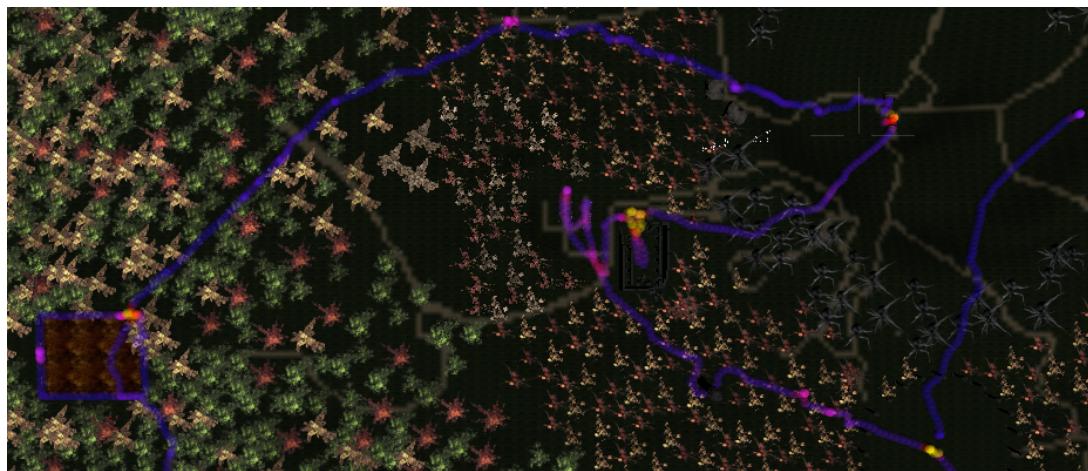


Figure 4: A heat map generated in Hiraeth.

Hiraeth features a relatively large square terrain with different height levels. The game was made for the Game Design E2013 course at IT-University of Copenhagen. The plug-in worked as intended. **Figure 4** shows an example heat map generated in the game.

#### 5.1.2 Angry Bots

The Angry Bots game is a top-down shooter where the player moves around and shoots robots. When we tested, we successfully registered breadcrumb events and custom death events for the player game object. When we generated the heat map, the heat markers were very hard to see due to the transparency (see figure **Figure 5** on page 10). The screenshot on the left has some purple orbs that are very hard to see - those are the heat markers. Giving the developer control over the transparency of the heat marker material could be an improvement for cases like this.

<sup>7</sup>Source: <https://www.assetstore.unity3d.com/#/content/12175>

<sup>8</sup>Source: <https://www.assetstore.unity3d.com/#/content/11228>

<sup>9</sup><https://github.com/esfdk/DarkForest>



*Figure 5: Angry Bots heat map with different levels of transparency.*

### 5.1.3 Example 2D-platformer

Tracking the player object worked as expected in the 2D-platformer game, but the rendering of the heat map did not. When we render the heat map, we use a transparent shader to render the 3D-spheres. The 2D-platformer does not support the use of the standard transparent shader of Unity, which means that the objects are not rendered.

## 5.2 Performance test

We tested the performance of our plug-in on our own Hiraeth game. This game is the one we had collected most data on, so we decided we could better evaluate the results when testing with this game.

### 5.2.1 Tracking/saving event data

We tested how much the tracking of events impacted the performance of our game by playing with no objects being tracked and with different amounts of objects being tracked.

### Results

Test number	Elements tracked	Impact
1	0	N/A
2	10	No noticeable impact
3	20	No noticeable impact
4	70	No noticeable impact
5	150	No noticeable impact

As shown by the table, even with 150 objects tracked at a time (far more than what we would assume is necessary for most games), we could see no impact on the performance of the game. I conclude from these results that the saving/tracking of event data does not need to be improved from a performance perspective.

### 5.2.2 Generating the heat map

To test the performance of the heat map generation, we timed the process using .NET DateTime. We tested this by loading the data set generated by tracking 70 objects in the scene. This data set contained 3224 event entries.

#### Results

Test number	Events loaded	Time in seconds
1	3224	37.081
2	3224	35.106
3	6448	61.844
4	6448	86.323
5	9672	169.625
6	9672	129.206
7	12896	238.759
8	12896	218.894
9	16120	311.298
10	16120	325.748
11	19344	443.752
12	22568	581.286

As suspected (and discussed briefly in section 4.5.3) large amounts of data slow down the heat map generation process significantly. 22568 events correspond to 6.26 hours of gameplay if breadcrumbs are tracked every second. This is a lot of a single tester, but if 30 people are tested, 6.26 hours of gameplay does not seem like a lot of time.



## 6 Issues

In this section I describe the various issues with the implementation of our plug-in.

### 6.1 Heat map generation performance

Because of the  $O(n^2)$  operational complexity of the density calculation, the performance of the heat map generation is very poor on large data sets. While this does not make the plug-in non-functional, it makes it very cumbersome to use as intended.

This could possibly be solved by doing large bins (bins being areas in the game world) and then only checking the heat markers in the bins that are within the allowed range of the positon that is currently having its density calculated.

### 6.2 Loading data from more files

Currently the plug-in is only able to load one data set at a time. This causes a problem combined with the previous point. In our tests, loading data from just the single session of 3324 data points took 35 seconds. If data had to be loaded from many different files, such as from playtest sessions, the process would take an extremely long time.

A possible solution could be to make a seperate file combiner, so that loading would only need to happen once per generation of heat mapping.

### 6.3 Unique game object names

As I mention in section 3.1, the names of tracked game objects must be unique. If they are not, an input/output exception occurs and data is not properly recorded.

To fix this, I would suggest adding a check to see if there are other objects with the same name being tracked. If there is, create a new file with the same name except with a number at the end. Because the render check for all events in a node with a specific name, it does not matter if the objects with the same name end up in different XML nodes when combined on game close.

### 6.4 Lack of Unity 2D-tool support

With Unity 4.3 came highly improved support for 2D-platformer games<sup>10</sup>. As mentioned in section 5.1.3, our plug-in is not very compatible with the 2D tools provided by Unity. Although the positions were tracked, we were not able to render the semi-transparent heat markers used to render the heat map. A possible solution to this problem could be to make the heat markers completely solid.

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<sup>10</sup>Source: <http://blogs.unity3d.com/2013/08/28/unity-native-2d-tools/>



## 7 Conclusion

The goal of the project was to create a Unity plug-in that was capable of tracking events and rendering a heat map. Based on the results of our testing, I conclude that the plug-in lives up to the requirements we set for the project.

The plug-in is capable of tracking any kind of event on chosen game objects by either using the default events or creating custom events based on the needs of the developer. When generating a heat map, the user is able to select which game object and which event types to generate heat markers for.

As seen in the screenshots from the Hiraeth and Angry Bots games in section 5, the quality of the heat map visuals are not stellar, but I believe they are of an acceptable quality. As mentioned in the Test section, an improvement on this could be to give the user more control over the colours, the transparency and the object shape.

There are issues with the plug-in, as described in section 6 and the focus should be on remedying these problems if more work were to be done on the project.

### 7.1 Future Work

In addition to the points I describe in section 6, I would consider implementing an option to generate a binned heat map instead of the 3D spherical version we used for this project. Additionally I would implement a method to reduce the amount of elements in the scene when generating the heat map.

**Binned heatmap** A binned heat map is when the heat markers in the world are predetermined. Every tracked position that falls inside an area (e.g. a 1x1 square) increases the density of that square by 1.

A binned heat map would take less time to generate than our 3D-spherical version. The 3D-spherical version runs at  $O(n^2)$  and the binned heat map would be  $O(n+m)$ , where  $n=number\ of\ tracked\ events$  and  $n = number\ of\ bins$ .

Binned heat maps are generally viewed in a top-down 2D-perspective. This makes them quite good for games / levels that do not have multiple floors. Figure **Figure 6<sup>11</sup>** on page 14 is an example of a binned heat map.

**Reducing number of objects in the scene** The current implementation of our heat map plug-in generates one *HeatMarker* per tracked event that is loaded. This means that if there is a lot of data, there will be very many game objects in the scene. This can slow down the Unity engine (if not cause Out of Memory exceptions), which can be problematic.

I would suggest implementing the following method for combining tracked events: If two or more event positions are within allowed range, combine them to one game object and calculate the middle of their positions and use this for the new position.

This would not work in all cases, but it could potentially lead to a very high reduction of the amount of unnecessary objects in the scene.

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<sup>11</sup>Source: Game Engines E2013 course Power Point slides: 13\_metrics\_final.ppt

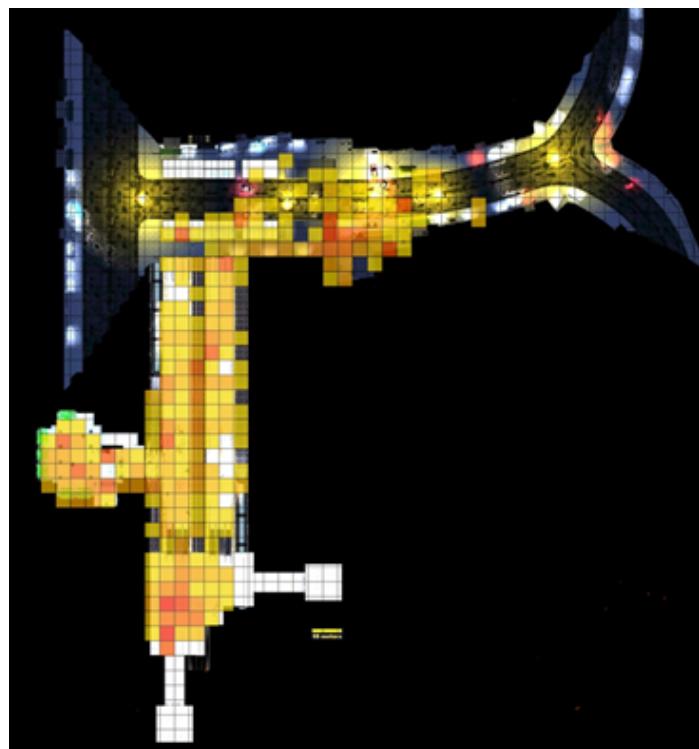


Figure 6: An example of a binned heat map.

# 2D-platformer

Game Engines E2013

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September 27, 2013

## 1 Introduction

This report is the result of a project to implement a simple 2D-platformer game engine for the Game Engines, E2013 course at IT-University of Copenhagen.

The required features of the engine were:

- Side scrolling
- 2D platformer physics (walking, jumping, falling)
- Collision detection (e.g. between player and enemy)
- Sprite animations based on state (walking vs. standing)
- Architecture based on game loop and events

In addition to the required features of the engine, I have implemented animation of walking for the player and enemies.

My implementation supports a game consisting of a single level. The y-position of the camera is fixed, so while the engine supports "tall" levels, the camera will not show the player or anything outside the "standard" level height.

The engine supports 1 texture for "solid" game tiles, 1 texture for goal tile(s) and up to 6 different types of enemies (two example enemies are included).

The engine uses a variable time step, so the speed of the game can vary depending on hardware. I discuss this in more detail in section 3.1 on page 2.

The game engine is implemented in C++ for Windows using the SDL 2.0 framework<sup>1</sup>.

I have worked with Jacob Grooss (jcgr@itu.dk) on parts of this project (mainly the design, but also parts of the implementation).

## 2 How To Use

Most of the changeable values for the game are placed in the *EngineSettings* header. These settings include game name, window size, controls, player/tile textures names, player speed, game gravity and the maximum possible number of enemies in the game<sup>2</sup>.

### 2.1 Making levels

Currently the engine loads the "Level0.txt" file in the "levels" folder as the level for the game. First two lines describes the height and length of the level, respectively. The rest of the document describes the layout of the level.

The "levels" folder included with the example game contains an example of the formatting for the level files.

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<sup>1</sup><http://www.libsdl.org/hg.php> - SDL\_image and SDL\_ttf libraries were also used.

<sup>2</sup>These settings could be defined in a text file and loaded at runtime instead of being defined at compile time.

## 2.2 Adding new enemies

Adding additional enemies to the game (engine) requires inheriting from the *Enemy* class and overriding the constructor, *updateTexture* and *move* functions. In addition, the *loadEnemies()* function in *game* must have an if-clause added to include the new enemy type. *enemyTypes.h* is used to define the different values for the enemy types<sup>3</sup>. The engine currently supports up to 6 different enemy types.

My example game contains two enemies. A Demon that runs horizontally in the level and a Copter that flies vertically in the level.

## 3 Overview of the Engine

The general architecture of the engine is based on the *Game* class. It contains the game loop, a list of enemies, the player and the level. The *Game* class is also responsible for figuring out what to draw on the screen.

The *Map* class is responsible for keeping track of the map layout and loading the map. The *Enemy* and *Player* classes are responsible for keeping track of their own position and animation as well as moving their position.

The *Window*<sup>4</sup> class is responsible for actually creating a window and drawing the textures.

### 3.1 Variable time step

I have not implemented a fixed time step in my engine. This means the game speed heavily depends on the performance of the hardware the engine is run on. Very limited processing power would significantly slow down the games made on the engine and provide a very different experience compared to using the engine on a powerful machine. The problem with a fixed time step is that on a slow computer, the fixed time step could give the experience of "frame skips", where parts of the game is skipped.

Implementing a fixed time step would require keeping track of a global variable to keep track of time since last frame and then multiplying the speed of the game characters by this value for every game loop. If a game loop finishes before the time to next frame is finished, then just wait until this time has passed.

### 3.2 Extending the engine

In this section I discuss ways to expand the functionality of the engine.

**More levels** To support more than one level, the *Game* class would need to be changed. Instead of quitting the game on completing a level, a different map should be loaded, new memory allocated for the list of monsters and a new player object created.

**Controls** Changing the control scheme is simply changing the values in the *EngineSettings* header. Expanding the control scheme would require a change to the main game loop, so that the new controls would be registered.

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<sup>3</sup>This could be moved to the *enemy* header file instead

<sup>4</sup>Source: <https://github.com/Twinklebear/TwinklebearDev-Lessons/blob/master/Lesson8/src/window.cpp>

**More tile/enemy types** The current map format only supports 10 tile types. To allow for more varied levels, the format would need to be changed to support more integer. A possible format could be "01,01,02" to indicate [solidTile], [solidTile], [goalTile] instead of just 112.

**Events** Implementing custom events to the engine could be done by expanding the number of *SDL\_Events* in the *HelperClass* header and then expanding the main game loop to check for these custom events.

**Collectibles** If the map format was expanded, the game could support collectible items (e.g. power-ups) by having the collectibles be a tile type and throwing a custom event upon player collision with the tile.

## 4 Conclusion

The engine successfully implements the required features of the project. There is support for side-scrolling, standard 2D-platformer physics collision detection, sprite animation and is based on a game loop and events (for win/loss conditions).

The main problems of the game engine is the lack of a fixed time step and the support of only a single level. Additionally, the game engine uses a very poor map loading algorithm and level file format making for very limited variety in levels and enemies.

### 4.1 Future work

As I mentioned in section 3.2, there are a few ways to improve/extend the game engine. In this section I discuss the two I would focus on if I were to improve the engine.

**Fixed time step** As discussed in section 3.1, there is some merit to using a fixed time step in a 2D-platformer game. Implementing a fixed time step would require a rewrite of the movement and updating of textures. If I were to implement it, I would implement it in such a way, that there would be support for choosing either a fixed or a variable time step.

**More levels** Changing the engine to support more than one level would make it easier for game developers to create an actual full-length game. Currently this can be done by making different game clients for each level, but this is not very desirable.

**Better level format** Using the current format to describe a level, there can only be 10 different values. Implementing a better map loading algorithm and a better level file format would be obvious points to improve. This would allow for more varied levels.

## 5 Appendix

### 5.1 Screenshots

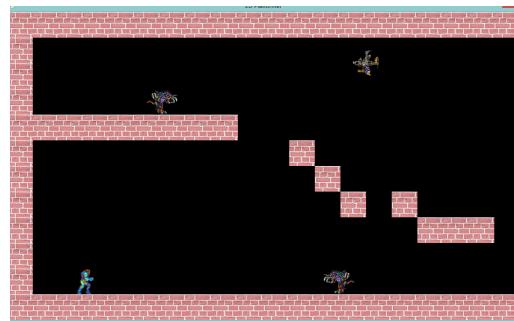


Figure 1: Screenshot of the example game: Starting position



Figure 2: Screenshot of the example game: Close to the end of the level.

### 5.2 Video

I have included a video of the demo game in action with the report.



# 3D Wireframe Renderer

## Game Engines E2013

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October 22, 2013

## 1 Introduction

This report is the result of a smaller project to implement a 3D wireframe renderer in the Game Engines, E2013 course at IT-University of Copenhagen.

The project had the following constraints: Transforms and rendering must be implemented in software without using DirectX or OpenGL functions. The use of an existing line-drawing API and an existing library for basic matrix math was allowed.

The wireframe renderer is implemented in C# (using Windows Forms) based on the transforms and pseudo-code from the "Overview of transforms used in rendering"<sup>1</sup> tutorial by Mark Nelson. The implementation of the matrix (and multiplication of matrixes) is taken from dev.bratched.com<sup>2</sup>.

I have worked closely on the design of the code for the renderer with Jacob Grooss (jcgr@itu.dk) on this project.

## 2 Features

The core of the wireframe renderer takes a list of triangles (consisting of three vertices) and renders them to a Windows Forms window according to the Near, Far, Aspect Ratio and Field of View variables for the camera.

The renderer loads a hardcoded pyramid shape of five vertices making up four triangles. The position of the camera and the point the camera is looking at are changeable using the controls described in 2.1.

### 2.1 Camera controls

Movement of the camera position and look point is done in 10-unit intervals. This interval is hardcoded and should probably be a changeable variable or a smaller value.

The controls for the camera are:

- a/s/q decrease the value of the x/y/z position of the camera, respectively.
- d/w/e increase the value of the x/y/z position of the camera, respectively.
- j/k/u decrease the value of the x/y/z position of the camera's look point, respectively.
- l/i/o increase the value of the x/y/z position of the camera's look point, respectively.

## 3 Overview of the Program

The **Vector**, **Matrix**, **Vertex** and **Triangle** are just object representations of the respective math/geometry concepts. I have implemented the wireframe renderer using the column-vector convention.

The **Camera** class represents the camera of the renderer. The constructor defines the Near, Far, Aspect Ratio and Field of View variables, but these can be changed using the properties of the

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<sup>1</sup><https://blog.itu.dk/MGAE-E2013/files/2013/09/transforms.pdf>

<sup>2</sup><http://dev.bratched.com/en/fun-with-matrix-multiplication-and-unsafe-code/>

camera. It also contains the calculations for the transformation matrices.

Currently the movement of the camera is very poorly implemented. Better camera movement would be actual rotation (instead of the look point only moving on one axis at a time) and the user being able to move the camera around with the mouse.

### 3.1 Renderer

The constructor of the **Renderer** instantiates a new camera and uses it to open a Windows Forms window. Then it gets the pyramid from the **Loader** and starts the first draw/paint.

Whenever the renderer is drawing to the screen, it first makes the camera calculate all of the transforms (more on this in section 3.2). Then it asks each triangle to update itself according to the camera (triangle then makes its three vertices update according to the camera) and then it draws the three lines making up the triangle.

I have chosen not to draw each point (only the lines), because it makes no difference to how the wireframe looks when rendered in my implementation. Each vertex could be a thicker/larger point than the line itself, but I do not believe this is necessary.

### 3.2 Math

The update function of the vertex contains most of the pseudo-code from section 4 of the overview document mentioned in section 1. I have chosen to update the screen point of the vertex at a lower level, because I believe it makes the code much cleaner.

It does come with a drawback, however. In my implementation I do not skip updating the screen point (as per "*if any of .x/.y/.z are outside the range [-1,1], skip to next vertex*"), so the figure may appear deformed if the camera is positioned in a particular way. A way around this problem could be to force calculation of the screen points if the screen point is null or (0, 0).

I have not implemented frustum culling (for the reasons stated above), but would do so if I also implemented the skipping of the vertices outside of the the range [-1, 1].

I have chosen to do an optimization when multiplying the three transforms camera transforms (*perspectiveTransform \* cameraLookTransform \* cameraLocationTransform*). I calculate the resulting matrix of this chain of transforms every time the renderer is about to draw and cache it to decrease the amount of necessary calculations on each draw. While it does not matter when there are only 20 updates to calculate<sup>3</sup>, these calculations could take a very long time to do in case there are very many vertices.

## 4 Conclusion

The wireframe renderer works to a degree that allows models to be rendered as wireframes (if they are hardcoded). Because of the problem with screen point calculations (and no clipping), rendering an entire scene is problematic with the current implementation. Navigating a scene is also rather cumbersome due to the poor camera controls. A mouse implementation would offer a large improvement.

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<sup>3</sup>Because every triangle is asked to update its vertices, even shared vertices are updated multiple times. This could be fixed by having a list of all vertices and not updating them once per triangle, but instead running through the entire list of vertices.

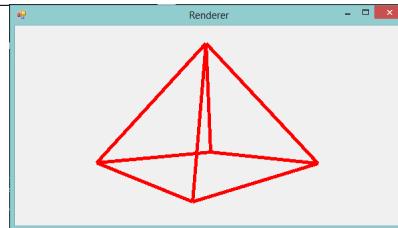


Figure 1: The starting position of the renderer.

#### 4.1 Performance

The hardcoded pyramid contains 5 vertices and 4 triangles, which limits the amount of necessary calculations per call to the *Renderer\_Paint* method. This limits the impact that can be felt from the lack of culling / clipping (even if the camera is away from the view object). To properly test the impact, there would need to be more than one object and/or more complex objects.

### 5 Future Work

My suggestions for future work done on this project would be to test performance on larger scenes, load triangles/vertices from a file, do frustum culling and to improve camera controls.

#### 5.1 Test performance

The hard-coded pyramid does not stress the renderer at all, so it is hard to know if optimizations are necessary. Using a larger wireframe (such as a ship, a person or a detailed building) would stress the renderer in a way that would show this. Hard-coding these would be fairly cumbersome, so I would suggest this is done in combination with my next suggestion.

If optimizations are necessary, I would suggest implementing frustum culling (or clipping) as mentioned in section 3.2.

#### 5.2 Load triangles/vertices from a file

In the current implementation of the renderer, it is much too cumbersome to render detailed objects as they need to be hard-coded. I suggest implementing a way to import triangles and vertices from a file, so that models made in 3D modelling software could be imported.

#### 5.3 Better camera controls

Currently the camera controls are quite limited, as they do not do rotation of the view and the position of the camera can only be moved on the x/y/z-axis. Utilizing the mouse instead of only using the keyboard would also offer a large improvement.

## 6 Appendix

### 6.1 Screenshots

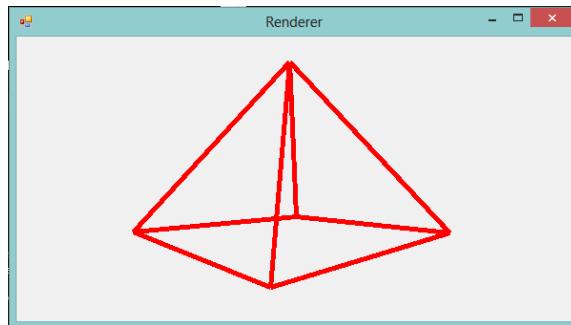


Figure 2: The starting position of the renderer.

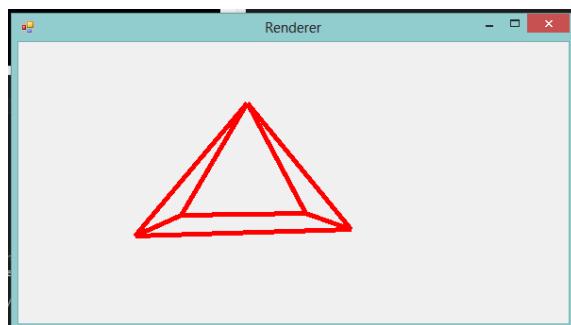


Figure 3: The camera position moved and the camera lookpoint changed.

### 6.2 Video

I have included a video of the wireframe renderer in action along with this document. Additionally I have uploaded the video to Youtube. Youtube Link: <http://youtu.be/3KjRljro1zk>



# Pathfinding

Game Engines E2013

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## 1 Introduction

This report is the result of a smaller project to implement the A-star (A\*) algorithm in a chase between two automated agents in a game world for the Game Engines, E2013 course at IT-University of Copenhagen.

The constraints of the project were: Agent A (the chasing agent) must use the A\* algorithm to calculate a path to Agent B. Agent B must escape from agent A by moving according to a finite state machine. The agents must move in a grid world where some grids are passable and others are impassable. The chase must be displayed visually.

I have implemented the project in C# based loosely on A\* pseudo code by Rajiv Eranki<sup>1</sup>. The visual representation of the chase is displayed in the console.

I have worked with Jacob Grooss (jcgr@itu.dk) on some parts of this project (drawing of the map and parts of the movement for the fleeing agent).

## 2 How To Use

Running the Pathfinding.exe opens a console window asking for size of the game world, position of the two agents and their speed. The program automatically sets approximately 10% of the terrain to be impassable. After initialisation is done, the first map is drawn. Pressing the *Enter* key continues the simulation. If agent A catches agent B (occupying the same x/y coordinates), the simulation ends.

```
Please enter map width and height in the format "x,y":  
30,30  
Please enter Agent A's values in the format "xPosition,yPosition,speed":  
2,2,2  
Please enter Agent B's values in the format "xPosition,yPosition,speed":  
20,15,1
```

Figure 1: The information input screen.

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<sup>1</sup><http://web.mit.edu/eranki/www/tutorials/search/>

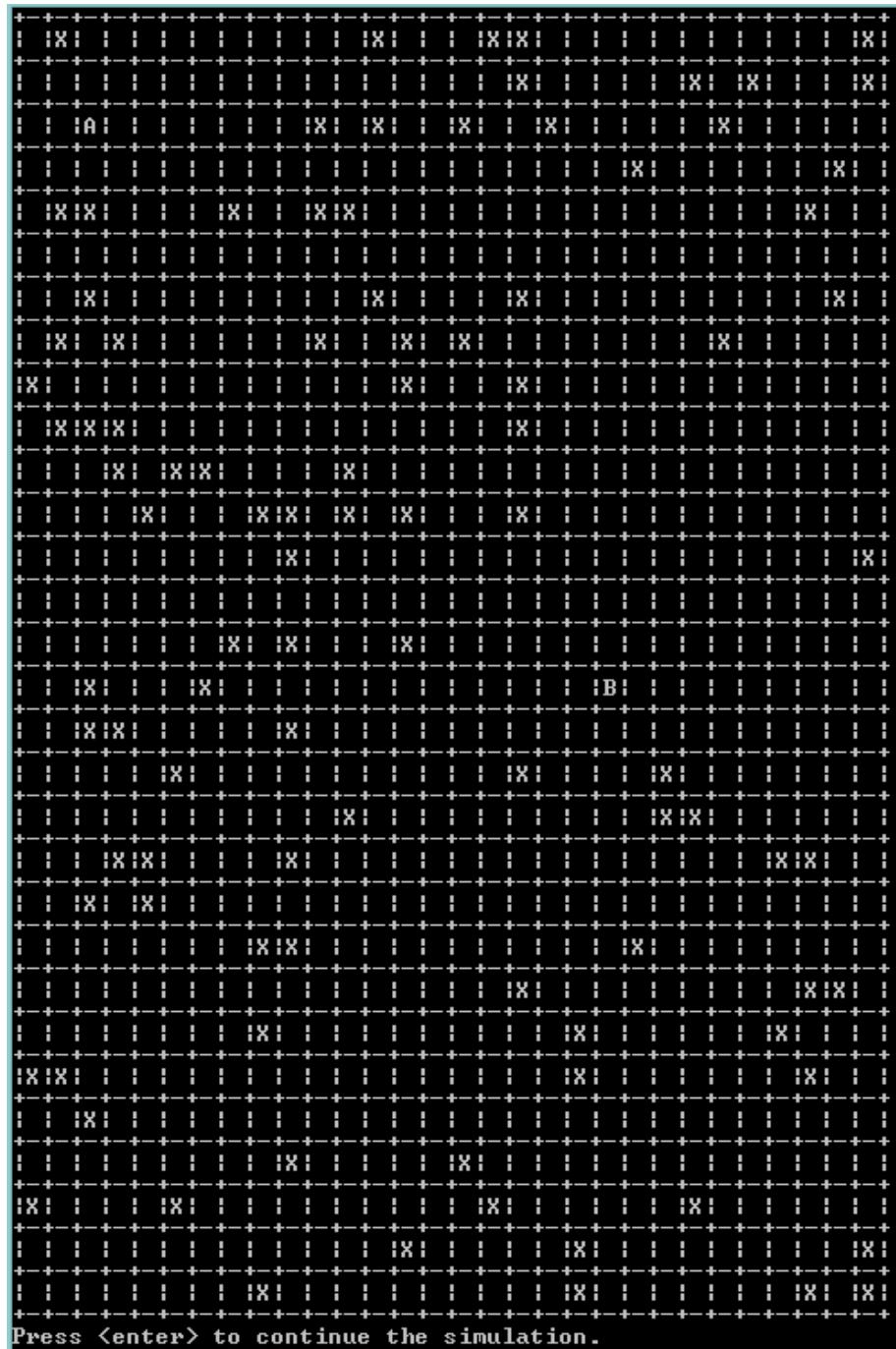


Figure 2: Starting screen based on the given information.

### 3 Overview of the Program

The game world is constructed from a two-dimensional array of **Nodes**. A **Node** contains information about its x/y location, its parent and its cost. The cost of the node is how many "movement points" agent A must spend to move into the node (cost -1 means the node is impassable). Agent B can move freely around the game world.

After initialization of the game world and the agents, the map is drawn. Then agent B and agent A move until agent A occupies the same position as agent B. If the Euclidean distance between agent A and agent B is less than twice the speed of agent A, agent B moves up to his own speed directly away from agent A. If agent B will move in the current iteration, he moves before agent A.

After agent B has moved, agent A calculates a path to agent B using the A\* algorithm. My implementation of the A\* algorithm uses the game map as the nodes (as opposed to generating new ones as neighbours/successors) and thus is not suited for two units moving simultaneously. My implementation is also a bit slow for very, very large maps as every node must have their parent reset before a run of the algorithm.

## 4 Conclusion

The project successfully implements the A\* algorithm and the chase between the two agents. There is impassable terrain for agent A and agent B only moves when he is alerted to agent As presence. The chase could be improved primarily in two different ways.

One would be to make the fleeing agent more dynamic/smarter in his movement (not just straight away) and make agent B unable to go through impassable terrain.

Second would be to make the agents move one step of their path per simulation step (instead of their entire speed). This would make the movement speeds more evident in the simulation, but it is trickier to implement.

### 4.1 Future work

Other than the improvements mentioned above, I would change my A\* implementation to be more flexible in its choice in distance calculation (instead of just Euclidean). Additionally I would rewrite the algorithms approach to nodes so that new ones are generated (making it more efficient for large map sizes).