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## Bachelor Thesis

# MicroPsi and Minecraft

A Popular Video Game as a Simulation Environment for a Cognitive  
Architecture

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Ich versichere hiermit eidesstattlich, dass ich die vorliegende Arbeit selbstständig angefertigt, alle Zitate als solche kenntlich gemacht sowie alle benutzten Quellen und Hilfsmittel angegeben habe.

München, den 19. September 2013

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*(Unterschrift des Kandidaten)*



## Zusammenfassung

Simulationsumgebungen spielen für das Testen und Erforschen von neuen Ansätzen für künstliche Intelligenzen eine entscheidende Rolle. Da sich Computerprogramme nur mit erhöhtem technischen und finanziellen Aufwand in die physische Welt implementieren lassen, können simulierte Umgebungen schneller, günstiger und reproduzierbarere Ergebnisse liefern.

Genauso wie Innovationen auf dem Bereich der KI neue Impulse setzen können, können auch neue Ansätze für Simulationsumgebungen zu neuen Erkenntnissen führen.

Diese Arbeit präsentiert ein Schnittstelle, welche es kognitiven Architektur MicroPsi ermöglicht, Agenten in Umgebungen des populären Videospiels Minecraft zu steuern.

Minecraft bietet sich als Grundlage für eine Simulationsumgebung aufgrund der kompositionalen Semantik der Spielwelt besonders an, da das Agentensystem durch das Erforschen seiner Umwelt Wissen über die Spielwelt aufbauen und ähnliche Strukturen wieder erkennen kann. Objekte der Spielwelt sind in Minecraft keine bloßen Hindernisse sondern werden mit variablen Eigenschaften prozedural erzeugt und ähneln so eher einer realen Umgebung als andere virtuelle Welten.

Da Minecraft von Anfang an mit einem Mehrspielermodus ausgestattet wurde, lässt es sich zudem für Multiagenten-Umgebungen und so für kollaborative Agenten verwenden. Des Weiteren sind Minecraft-Lizenzen günstig zu erwerben, erhältlich für viele Plattformen und es gibt eine äußerst große und aktive Community für selbsterstellte Spiel-Inhalte und -Modifikationen.

Die Schnittstelle ermöglicht es MicroPsi, sich an einem Minecraft Server anzumelden, die Umgebung wahrzunehmen und sich fortzubewegen.

Daneben wurde eine Visualisierung der Umgebung aus Sicht des Agenten implementiert, welche als OpenGL gerenderte 3D-Ansicht live im Browser angezeigt wird.

Zum Schluss der Arbeit wird ein einfaches Experiment durchgeführt, bei welchem sich der Agent selbstständig auf ein bestimmtes Objekt zubewegen muss. Dieses Experiment wurde als Teil der Arbeit umfangreich dokumentiert.



## **Abstract**

Simulation environments play an important role for testing and researching new approaches to artificial intelligences. Because computer software can only be implemented into the physical world with increased technical and financial effort, simulated environments can deliver results faster, cheaper and more reproducible.

In the same way, innovations in AI can deliver new impulses, new approaches to simulation environments can lead to new insights.

This thesis presents an interface, which enables the cognitive architecture MicroPsi, to control agents in environments of the popular video game Minecraft.

Because of its compositional semantic, Minecraft turns out to be an interesting simulation environment, because agents can generate knowledge through exploring the environment and can recognise similar structures. Objects in Minecraft worlds are not just obstacles, but generated procedurally with varying characteristics and therefore are more similar to real environments than other virtual worlds.

Hence Minecraft contained a multi player mode from its early days, it is also suitable for multi agent environments and therefore for collaborative agents. Furthermore, Minecraft licenses are affordable and available for many platforms. Also, there is a huge and active community for player generated content and modifications.

The interface enables MicroPsi, to connect to a Minecraft server, perceive its environment and move around in it.

Additionally, a visualisation of the environment perceived by the agent has been implemented, that displays an OpenGL rendered 3D view live in the web browser.

Finally, a simple experiment is concluded, in which the agent has to move towards a specified object. This experiment is documented as a part of this thesis.



## **Danksagung**

I would like to thank Prof. Dr. Martin Wirsing for giving me the opportunity to prove my motivation in writing a my thesis about what I considered would suit me best. I thank my supervisor Joscha Bach, for giving me the opportunity to work with his creation, advising and inspiring me through the entire process. I especially thank my supervisor Annabelle Klarl, for supporting my plan without hesitation, guiding me through the process and providing valuable feedback whenever I needed it. Dominik Welland helped me with understanding and building upon the MicroPsi framework and fixed inhabitant bugs as soon as I reported them, thank you!

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# Chapter 1

## Introduction

The hunt for artificial intelligence started many years ago. Dividing the subject into the strong and the weak part means separating its goals into useful applications and those that try to learn about the nature of intelligence itself. The ultimate task of strong A.I.—recreating human intelligence—admittedly still seems to be science fiction, though.

But then again: a new generation of cognitive scientists, psychologists and computer scientists strives to implement new ideas for simulated cognition, by building cognitive architectures. Many of them do so by simulating, in one way or the other, what could be called neural node nets.

One of these architectures is MicroPsi 2. Developed by Joscha Bach and Dominik Welland, it is based on the Psi theory by Dietrich Dörner, who is a german professor for theoretical psychology. It aims at providing a solid and complete implementation of his theory of cognition and at the same time at being easily accessible, understandable and modifiable for the research and applications to come.

To test the functionality of such cognitive architectures and to figure out their capabilities and potential, we need to research their behaviour inside defined environments. As implementing AI into the physical world (as robots for example) requires building appropriate hardware and patience, computer-simulated environments therefore play an important role.

MicroPsi 2 is both: a cognitive architecture as well as a set of and an interface to simulation environments.

### 1.1 Motivation

Video games are natural applications of artificial intelligence. The quality of a game's A.I. can make all the difference in between an immersive experience and an uninspired demo of computer graphics technology. One game that especially stood out in the recent years is Minecraft. As a so called *sandbox game*, it attempts to leave the player with as few limitations as possible, for what they do and how they behave in the game world. This kind of a relatively open environment, delivers a simulated world rich of opportunities, for both human and artificial players. Building an interface in between the cognitive architecture MicroPsi 2 and the video game Minecraft is what this thesis is about.

## **1.2 Outline**

This project is fundamentally about combining existing technologies. The most important ones being MicroPsi 2, the most ambitious framework aiming to implement the ideas of the Psi theory, and Minecraft, the popular sandbox videogame.

To understand how and why they were chosen, a brief history of their creation as well as explanations of their basic ideas and relevant insights to their architecture are given in chapter two and three. Chapter two introduces the Psi theory and its implementations. We will especially focus on the particular implementation MicroPsi 2 and describe it's modules in detail. Chapter three introduces the video game Minecraft, it's protocol and related software projects. As the resulting software heavily relies on them, the protocol and the utilized open source software will get increased attention. In Chapter four the contribution of this thesis, the Minecraft world adapter for MicroPsi 2, is being described in detail. As a proof of concept, the description eventually leads to a small experiment. Chapter five summarises the findings of this thesis and gives an outlook on possible future applications.

## Chapter 2

# Artificial General Intelligence

To provide the necessary context for this thesis, this chapter will provide a brief introduction to AI and it's subdivision AIG. In particular, Psi and it's implementations are described in detail.

A widely accepted definition of the field of AI is that it is the study and design of intelligent agents, where an intelligent agent is a system that perceives its environment and takes actions that maximise its chances of success. It took many years for AI research to evolve from the early ideas of thinking machines over Deep Blue, the computer that could beat mankind's best chess players to Watson, the AI that beats the champions of Jeopardy, the game show, that is about asking the appropriate question to a given answer. There exist many applications for AI. Self-driving cars and online-shopping recommendation systems to name a few.

### 2.1 Strong AI

These examples have one thing in common. They are applications of technology that serves an immediate, or at least foreseeable purpose. For AI in scenarios of this kind, the term applied AI (or weak AI) has been coined. Strong AI, in contrast, is about researching the nature of intelligence itself. An actual (hypothetical) implementation of a strong AI would translate to building a machine, that is capable of acting like a human being—not just in a defined problem field, but in all of them. Putting it differently, weak AI considers computers to be an instrument to research cognitive processes. Strong AI considers simulated cognitive processes as actually being cognition.

Another term that is being used more recently is AIG for Artificial General Intelligence. It delimits itself from what are called narrow AI applications, which chess computers and other expert systems would be an excellent example for. AIG sets out, to develop software, that can solve and act appropriately in a wide variety of problem fields, without specialising on any particular problem whatsoever. A complete AIG system is supposed to control itself autonomously and to have it's own thoughts and feelings. This has been the original focus of the AI field, before many lost their enthusiasm about it, because it turned out to be quite difficult. Even though the advances in narrow AI contribute also to AIG, AIG is more than just a collection of those. Many different AIG projects are being worked on, with most of them being in early stages.[GP07]

Cognitive AI, in particular, can be thought of as architectures that implement findings and theories in the fields cognitive science and psychology, as well as the neuro-sciences, for the sake of proving, if the theories hold against what they promise.

Many cognitive architectures share characteristics with or directly implement artificial neural node nets.

Looking upon the field of AI from a philosophical point of view, computers seem to deliver enormous potential for learning about how minds work. At the same time, new questions arise. If we would know, how cognition worked, and if we could build machines that simulate it, would these minds be real? And what would the ethical implications be? According to Russel's and Norvig's standard reference [Rus09], one can differentiate in between two basic assumptions. The assumption, that computers are able to act *as if* they were intelligent, is called the weak AI hypothesis. Thinking that an intelligently acting machine in fact *is* performing cognition, is called strong AI hypothesis.

Trying to figure out, if machines are able to implement cognition, we often explain by enumerating things that computers can not do. They can not be kind, friendly or have a sense of humour. Neither can they tell right from wrong, fall in love or learn from experience. But what can they do? They are at least partly involved in almost every significant recent discovery in most sciences. They steer cars safer than we ever did. Where *exactly* to draw the dividing line between intelligence and machinery? [Rus09]

The most famous indicator for whether a machine is intelligent or not, is the Turing test. Decades after it's formulation, contests regarding to it are still being held—may the best conversationalist win! Many would argue, that even an algorithm that passes the Turing test, would still not be intelligent. It would trick people into thinking it was, but it would still not be conscious, aware of itself. Moreover, it would not have emotions. [Rus09]

But, would not what we believe is possible and what is not, become obsolete, once we would be able to build something, that cognition can not be denied from? As Dijkstra put it: “The question of whether machines can think... is about as relevant as the question of whether submarines can swim.”

## 2.2 Psi Theory

The Psi theory in its foundations was described by german psychologist Dietrich Dörner in his books “Bauplan für eine Seele” [?] and “Die Mechanik des Seelenwagens” [?] from 1998 and 2002. Dörner's holistic approach goes beyond classic problem solving but develops a unified model for cognition that implements motivations and emotions. He is convinced, that artificial intelligence does not have to focus on different aspects of cognition that have to be looked at separately, but that a unified theory will eventually lead to a deeper understanding of cognition itself.

It's main ideas are, that it thinks of the mind as a graph-like structure of relationships (e.g. node net) that strives to maintain homeostatic balance. Every form of representation of the agent's cognition—may it be percepts, plans or abstractions of space and objects—are represented as directed, hierachic spreading-activation networks. A Psi agent's behaviour is determined through it's motivational system, that keeps a dynamic balance in between a number of predefined physiologic, social and cognitive demands. In doing so, it establishes, pursues and abandons goals and behavioural tendencies. [Bac09]

Basic components of the theory are representation, memory, perception, drives, cognitive modulation and emotion, motivation, learning and problem solving as well as language and consciousness.

The basic element of Dörner's theory is the quad. It consists of a *gen* gate as

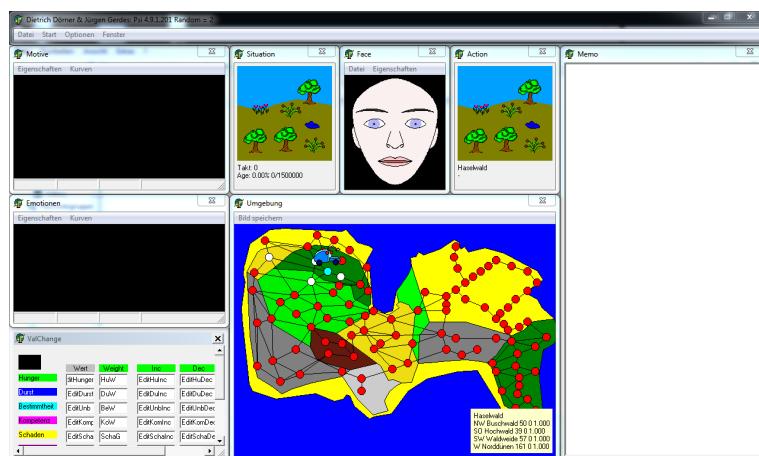
well as the four slots *por*, *ret*, *sub* and *sur* that express order and hierarchy relationships. [Bac09].

Joscha Bach adapted that theory to bring it in a contemporary form with slight modifications in [Bac09].

Even though building a conscious machine that thinks and acts like we do is still mere science-fiction, it is this kind of foundational research, that leads us to new ways of thinking about the world, that give us our most important leaps.

### 2.3 Psi Implementations

Psi has been implemented by different groups at different times. The first implementations are by Dörner and his associates themselves (see figure 2.1). They used Pascal and developed it for Windows environments. This implementation can still be downloaded and runs on Windows 7 installations, for example.



**Figure 2.1:** Dörner's Pascal Psi Implementation

There has been a 3D implementation of Dörner's island simulation called Psi3D.

The work on Dörner's team's implementation has not been continued, so Joscha Bach and his associates built new implementations of Psi.

From 2003 to 2009 they built an implementation in Java as a set of plugins for the Eclipse IDE called MicroPsi. It included a graphical editor and a 3D simulation-environment. MicroPsi provided a complex and sophisticated simulation component which contained simulated objects in three dimensional worlds—even though most experiments took place on a plane. As a pragmatic approach, different ground types of the simulation world have been stored in bitmap files similar to heightmaps. The framework offered complex administrator interfaces and appealing DirectX rendered 3D-views of the scenery as well as a more general world view which interfaced the world by providing clickable objects. Predefined simulation environments included a classic Island and a Mars world (see figure 2.2). Objects in these worlds may be generated recursively of other objects and bring their own logic. As in Dörner’s implementation, a viewer for facial expressions is included—this time as a three-dimensional simulation, too. [Bac09]

Simulated environments proved to especially serve well in terms of researching collaborative behaviour of multiple agents, in terms of mapping and exploration, image processing as well as memory and planning. Additionally, some scenarios are almost



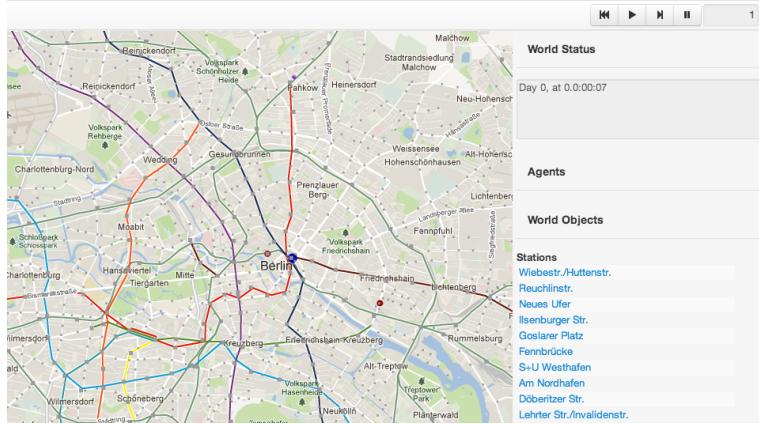
**Figure 2.2:** Screenshot of the 3D visualisation of the island and Mars worlds in MicroPsi (taken from [Bac09])

impossible to implement in the physical world, such as evolving agent populations, for example. On the other hand, downsides of simulated worlds include being limited by computing power and the programmer's specifications. [Bac09]

## 2.4 MicroPsi 2

Aiming at better understandability and to maintain platform independence, MicroPsi has been built ground up again in 2011 and 2012 using more lightweight Python code. What is remarkable about the new implementation called MicroPsi 2 (in the following MicroPsi), is that the simulation is deployed as a web application and the graphical interface is completely rendered inside a web browser using state-of-the-art internet- and webapplication-technologies. [Bac12]

Even though there have been more complex simulation environments (e.g. 3D-worlds) for previous implementations of Psi-architectures, the relatively new version of MicroPsi has only two fairly simple ones: a 2D-Island and a map of the public transportation system of Berlin (see figure 2.3). Instead of building a new 3D-world, with this project we set out for something more experimental. More on this in chapter three and four.

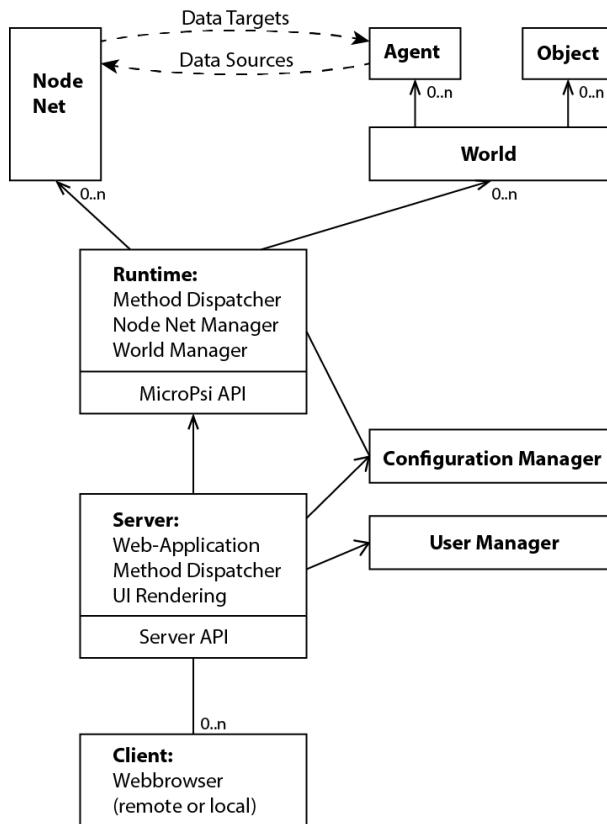


**Figure 2.3:** MicroPsi simulation environment Berlin

### 2.4.1 Module Overview

MicroPsi is written in Python with a minimum of dependencies. Therefore its modular structure is comparably easy to understand. It is illustrated in figure 2.4. First, one

can differentiate in between the **Server** module (or the web-interface) and the actual simulation **Runtime** module (also called “core”). In a regular simulation experiment setup, MicroPsi runs three threads: one for the **Server** and, invoked by the **Runtime**, one *world runner* that runs a simulation world as well as one *node net runner* that runs a node net. As these names suggest, the **Runtime** manages both the simulations environments as well as the inhabitant agents (or node net embodiments). They may by design run asynchronously. In fact, the **Runtime** works entirely independent of the **Server** and therefore may just as well be deployed for command line interaction or other GUIs. Furthermore, the **Server** contains a **UserManager** and the **Runtime** a **ConfigurationManager**. [Bac12]



**Figure 2.4:** The modular architecture of the MicroPsi framework make it easy to extend.  
(taken from [Bac12])

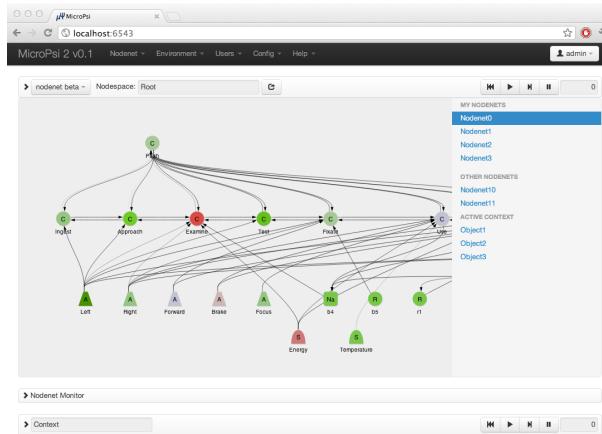
The following description is heavily based on [Bac12], where the theoretical foundations can be found in detail.

#### 2.4.2 Module Server

The **Server** renders the GUI and deploys the agent simulation as a web application. It acts as a web server for remote or local access. A client for this application may be any computer with a reasonable up-to-date web browser. Therefore simulations can be launched from anywhere without requiring any installation. It rests upon the lightweight Python web framework *Bottle*.

The web interface is naturally based on HTML as well as Javascript. The communication in between the browser and the simulation is managed via JSON remote

procedure calls. Many GUI components of Twitter's *Bootstrap* library are in use. The graphic renderings (see figure 2.5) utilise the JavaScript graphics library *PaperJS*.



**Figure 2.5:** The graphical editor is the primary interface to node nets. (taken from [Bac12])

The **Server** communicates with its users through the server API. User sessions and access rights are managed by the **UserManager**.

### 2.4.3 Module Runtime

In this setup, the **Server** starts the **Runtime**—even though it may also work independently of the **Server**. The **Runtime** component communicates with the **Server** through the MicroPsi API. It manages node nets and worlds.

### 2.4.3.1 Node Nets

A MicroPsi node net is defined as a set of states, a starting state, a network function, that defines how to advance to the next state, and a set of node types. Data sources and data targets serve nodes as input and output towards a world, where a data source is filled with data from the world and data targets are linked to agent actions in the world.

According to the Psi theory, nodes may have different types and parameters. They contain gates and slots that send and receive activation. In most cases, the activation is forwarded from a slot to a gate without further modulation.

Nevertheless, nodes may contain functions that enable the creation of new nodes and links as well as procedures for learning and planning. They may be implemented as Python code.

According to the concepts of the Psi Theory, MicroPsi defines agents as node nets or, to be more specific, hierarchical spreading activation networks. They are an "abstraction of the information processing provided by brains" [Bac12]. Agents can be placed and researched in simulation environments or physically embodied as robots.

As node nets share the relevant characteristics with neural node nets, they may enable neural learning paradigms. To store information they can form semantic networks. Furthermore, nodes may contain state machines and other operations, which make it possible to build modularised architectures.

#### 2.4.3.2 Worlds

The simulations worlds are the environments in which we can study our agent's behaviour. Worlds need to provide a world adapter which functions as the interface in between a node net and the environment. Within the world adapter data sources and data targets have to be defined carefully, to get a functional and meaningful experiment going. They represent the agent's sensory input and motoric output. Sophisticated interconnection of those enables interaction with the environment.

The kind of data the world adapter interfaces, is not specified any further, which gives developers the opportunity to experiment with classic simulation worlds as well as exotic applications (eg. stock data). At the time of the original development of the framework, the prioritised application was building a framework for knowledge representation.

#### Objects

Worlds contain objects. Objects may be anything that could be interesting for a simulation and that needs some kind of integrated logic. Light sources or collectable resources are a common example. Objects may contain a set of functions and states, but at least one function that determines how the object advances and reacts to changes while moving through a simulation cycle. A comprehensive world function calls every object function for each simulation step of the world.

#### Agents

Agents are objects that are connected to a world adapter which makes them controllable by a node net. The object that incarnates the agent is best thought of as the agents body. The function that advances the object checks for input from the node net and outputs to it.

## 2.5 Summary

This chapter provided the necessary foundations regarding AI for this Thesis. It introduced Artificial General Intelligence as a subdivision of AI research and presented it's main ideas and goals, as well as regarding foundational philosophical questions. Then, the Psi theory by Dietrich Dörner has been described briefly. An overview of implementations of the Psi theory has been given. The latest framework dedicated to the Psi theory, MicroPsi 2, has been described and it's architecture outlined. Knowing about MicroPsi 2's modules is a necessary foundation for the additions to it described in chapter 4.



# Chapter 3

## Minecraft

To understand how and why the video game Minecraft is expected to be an interesting simulation environment for artificial general intelligence, necessary background information, about what makes Minecraft different from many other games, has to be given first. To furthermore work with it, the basic elements of the game's architecture have to be described. This chapter provides a roundup of Minecraft's history and a brief explanation of the basic game mechanics. They are followed by an overview of Minecraft uses, that exceed the original game's purpose as well as an explanation, of why Minecraft is suitable as a simulation environment. Eventually, related software projects, that have been used for this thesis, are introduced and described.

### 3.1 Overview

The story of Minecraft has many interesting sides, but first and foremost it is a story of immense, unexpected success. To give an overview of it, this section delivers insights into its main ideas, as well as a general look at the developer's practices. Moreover, the game's reception is considered, as it is unusually strong. They are based on *Minecraft, beyond construction and survival* [Dun11].

#### 3.1.1 Main Ideas

When Markus (“Notch”) Persson built and released the first public version of Minecraft, it soon became clear that his creation resonated with many people. The simple concept of a world entirely build out of standard sized building blocks, which the player can create, destroy and relocate one-by-one, enabled many gamers to employ their creativity, explore the Minecraft world and test out its possibilities and boundaries.

Looking at the game for the first time, it is impossible to oversee the primitive appearance of its graphics engine. Everything in the game is made out of blocks. May it be the leaves of a tree, dirt, people or the clouds. Even the sun does not appear round, but as a cubic object. One can assume, that the obvious connotation to Lego(TM) is more than a coincidence, as it immediately gives the player a clue, about what kind of possibilities for building and creating the game might deliver.

Another interesting aspect about Minecraft is the procedural semantics the game world is generated with. Trees in Minecraft, for example, may share a similar structure that consists of a trunk and leave-covered branches spreading out fractally, but the particular characteristics of each tree are generated randomly. This makes a Minecraft world somewhat more realistic than those of many other videogames.

Minecraft strives to be the opposite of a game with a strict game-flow. Instead, it enables the player's creativity and joy of creation.

### 3.1.2 Development Process

The development process of Minecraft is very different from those of most other well-known games. Instead of building the game over months or years to finally release a (more or less) finished version to the public, Minecraft is being designed iteratively. In fact, Persson released the first version only a week after he started working on the game. Ever since, new features have been added and new versions of the game have been released frequently. Another defining aspect of Mojang's approach towards the development of Minecraft is the involvement of the game's players. Since the earliest stages, future plans have been discussed openly and many times the players' voices have been heard. Persson himself locates his approach in the field of agile software development.

### 3.1.3 Reception

The game has attracted great attention ever since its first release in 2009. Since copies of the game could be obtained commercially for the first time, different versions of the it sold more than 26 million times—with the PC version priced at about 20 Euros, for example. It should be noted, that Minecraft's development studio Mojang is a so called “indie game developer”, that is not associated with any classical game publisher, but distributes copies of their game exclusively via their own website.

Minecraft can certainly be called a world wide phenomenon. The games developers received a number of prizes for their creation - not to mention the millions of dollars that have been earned in Minecraft sales. With its huge success, Minecraft has proven clearly that it compelled to many players.

Unlike any other game, Minecraft fosters the creativity of its players. Bringing the construction component to one extreme after the other, well publicised creations include a life-size model of the USS Enterprise-D as well as a fully functional arithmetic unit. Videos of roller coaster rides through complex constructions increasingly show characteristics of an art form themselves—regarding to the amount of views on youtube, not less than other, well established formats.

## 3.2 Game Mechanics

Now knowing about the game's background, in this section we will continue with descriptions of the basic concepts of the game, that regards to our AI interface.

Before a new Minecraft game begins, it procedurally generates a three-dimensional world. The player is then dropped to a spawn point and is now facing a scenario with a minimal game interface, lacking any kind of instruction or advise about what to do next. Soon, the procedural generated world drives most players to explore the highest mountains and deepest caverns. As the player collects resources and crafts items, harder to reach resources and more complex to craft items become available. [Dun11]

Although the game can be downloaded and played as a single packet of software, many scenarios of playing the game consist of running a Minecraft server software, as well as one copy of the client software for each player. It is possible to mimic the official client by implementing the reverse-engineered client-server-protocol and therefore build artificial players that way.

The structure of Minecraft worlds and the client-server-protocol are described in the following. The descriptions are based on the regarding articles of the *Minecraft Wiki* [mcw13a].

### 3.2.1 Minecraft Worlds

The most important concept in Minecraft is the block (see figure 3.1). A block is a cube which sides are, compared to the player, roughly one meter long. Every Minecraft world is built up entirely out of them, so the worlds can be thought of as a three dimensional spaces filled with voxels. [BB] There are different types (materials) of blocks and they share their single size, which converts to the basic distance unit of Minecraft.

A chunk (see figure 3.2) is a segment of the Minecraft world that is 16 blocks long, 16 blocks wide and 256 blocks high (or deep) and therefore consists of up to 65,536 blocks. [mcw13b]

"The player" (see figure 3.3) is what the playable game-character in Minecraft is called. It is usually displayed humanoid. Also, a Minecraft world has a day-night-cycle with 24 Minecraft hours converting to 14 minutes by default

The game itself has no predefined goals. Players can walk around, discover the generated world (see figure 3.4 1) and collect resources by "destroying" blocks, with the generated resources equaling the block type. They can combine different resources to "craft" items. For example, a player can destroy the blocks that represent a tree (see figure 3.4 2). The gained "wood" resource could then be used to craft a wooden pickaxe (see figure 3.4 3), which could then be used to dig into the ground more effectively (see figure 3.4 4) to then "mine" more rare resources, like iron or gold.

There exist different game modes. The original "survival" mode adds monsters that attack the player at night. What solutions to survive the player comes up with (eg. building shelter or fighting the monsters) is left up to him or her.

In "creative" mode, the player is not being attacked by monsters, has the ability to fly and instant access to unlimited resources.

The mode of a Minecraft world does not effect the functionality of this project.

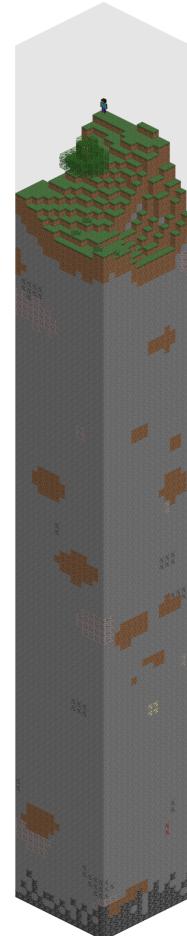
### 3.2.2 The Client Server Protocol

Minecraft's Client-Server-Protocol is not publicly documented by the developers themselves. However, the modding-community gathered full knowledge and understanding of its structure (probably by using reverse engineering techniques). The protocol is based on packets.

Packets are either "server to client", "client to server" or "two-way" and begin with a "Packet ID" byte. The structure of the packet's payload depends on it's Packet ID.



**Figure 3.1:**  
A "Grass" Block [ima13]



**Figure 3.2:**  
A Chunk [ima13]



**Figure 3.4:** Minecraft Basic Mechanics (CC-BY-3.0 Mojang AB)

To give an example of one of the easier packets, the "Client Position"-Packet is fairly straight-forward (see figure 3.1). It is exclusively send from clients to servers and starts with it's Packet ID (as every packet does), followed by the X- and Y-coordinates as doubles, the stance value as a double, which is used to modify the player's bounding box, another double for the Z-coordinate and eventually a boolean that describes if the player is on the ground or not. [pro13]

Field Name	Field Type	Notes
Packet ID	Byte	0x0B
X	double	Absolute position
Y	double	Absolute position
Stance	double	Used to modify the players bounding box
Z	double	Absolute position
On Ground	boolean	Derived from packet 0x0A

**Table 3.1:** Structure of the packet "Player Position (0x0B)" [pro13]

Knowledge of this data structure is already sufficient to move around in the Minecraft world. To go forward, one has to figure out the players current position, calculate the absolute coordinates of the destination of the movement in regard of it and send a Client Position packet with these coordinates via a TCP socket to the server. If the destination is not more than 100 blocks away from the origin of the movement, the server accepts the movement. In the official Minecraft client, a player's movement from one point to the other is rendered with a walking animation.

Other than movement, packet structures are defined



**Figure 3.3:** "The Player" [ima13]

for every aspect of the game. May it be the initial hand-shake, the creation or destruction of blocks or activities of other player- or non-player-characters.

This protocol is what a custom Minecraft client needs to speak.

### 3.3 Minecraft as a Gaming Platform

With more and more applications that move beyond the original gameplay of construction and survival, Minecraft seems to slowly shift towards being not only a game, but a gaming platform, that many other people use to implement their own ideas. Inside Minecraft worlds, players for example have built games for educational purposes. A group of students of the Miami University developed a game called Circuit Magic that is dedicated to teach the player about logical circuits. The infamous Minecraft Teacher, who implements Minecraft in primary school classes, is another good example. Following in his footsteps, “Massively Minecraft” is a community of teachers who share their thoughts and experiences with doing the same. Just as well, games have been developed for the purpose of artistic expression. Chain World, the game that tried to simulate religion, is an interesting bit. Not only do players implement their engagement inside Minecraft. The internet is full of Minecraft content, be it videos on Youtube, online tutorials or other community based knowledge resources, head-quartered at the Minecraft Wiki (<http://www.minecraftwiki.net/>). [Dun11]

As user-generated content has been an essential part in the development of Minecraft, in a process that reminds one of a self-fulfilling prophecy, more and more people explore its possibilities to experiment with new applications. As of today, Persson and Mojang seem to favour and approve new uses of their creation. [Dun11]

### 3.4 Suitability of Minecraft as a Simulation Environment

There are a number of reasons why using Minecraft as a simulation environment could be useful and lead to interesting results.

First, the game itself is easily accessible. It is developed using Java (for both the client and the server software) and therefore, up to a certain extend, platform independent. The desktop computer version is being sold for Windows, Mac OS X and Linux devices. There are official ports for Android, iOS, Xbox 360, the Raspberry Pi and a version for the upcoming gaming console Xbox One is announced. The desktop versions are priced at 19.95 euros, which makes it affordable to a large audience.

The game itself already has an enormous fanbase. It is (like most videogames) especially popular among teenagers. Minecraft being loved by so many people could benefit this project, in terms of leading to increased attention.

The game’s developer has proven many times that it acts generously towards other developers, when it comes to the creation of game modifications and content that uses or changes original Minecraft intellectual property. As mentioned before, Mojang is not restrictive towards users doing all kinds of things with their creations. This led to the availability of a fairly complete community-sourced documentation and explanation of virtually every aspect of the game—including it’s software architecture, data structures and protocols. This is useful for this project, as chances are low that they will have anything against using Minecraft for AI simulations in the foreseeable future.

The Minecraft world with it’s logic, semantic and functionalities offers possibilities for an AI to prove being able to interact with the environment—in primitive ways (e.g.

moving around), as well as with increasingly complex tasks like building, collecting resources, crafting items and interacting appropriately with both well-disposed and hostile other entities.

The semantics of the gameworld share characteristics with the real world. Moving through a Minecraft environment, one quickly realises that the game has generated different biomes (eg. forest or tundra). Also, trees, rivers, mountains and ore veins are neither hard-coded, nor appear completely randomly, but are generated procedurally and their structure appears to be (somewhat) fractal.

Using Minecraft as a simulation environment will give Psi agents possibilities to show off, what kind of sophisticated behaviour they are capable of.

## 3.5 Related Projects

Minecraft's success inspired many other projects, including artificial players and a number of Minecraft-like games in a wide variety of programming languages and environments.

### 3.5.1 Minecraft Bots

There exist many projects, that could be considered Minecraft “bots”. One has to differentiate in between two types. On the one hand there are those, that mimic an entire client software and facilitate communication with the server on the default client software's behalf. On the other hand, there are bots which are modifications of the original client (or server) software and usually add non player characters—like animals and other non-human creatures—to the game. The code is usually injected through one of the popular “modloaders” (eg. Minecraft Forge).

One example (and probably the most advanced one), for an entire bot framework that replaces the client, is Mineflayer [git13]. It has a high-level abstraction of the environment (eg. entity knowledge and tracking) and is written in JavaScript using node.js. However, it has not been used for this project, because a Python implementation was aimed for.

Opposed to Mineflayer, an example for “game modification” bots are the “Cubebots”—fan-made non-player characters that aim to help Minecraft players with mundane tasks [mcf13].

#### 3.5.1.1 Spock by Nick Gamberini

Developed by Nick Gamberini, Spock is an open-source bot framework (and as such also a Minecraft client) written in Python. It has been chosen to become an essential part of this project for two reasons: being written in Python it painlessly integrates in the existing MicroPsi code and the absence of dependencies (with one exception) leave the code understandable and easy to deploy.

#### 3.5.1.2 Protocol Implementation in Spock

The Minecraft protocol implementation in Spock is straightforward (see listing 3.5). The necessary data structures are stored separately and can be accessed globally.

These structures are used to parse each packet appropriately (see listing 3.6).

```

1 names = {
2     0x00: "Keep Alive",
3     0x01: "Login Request",
4     0x02: "Handshake",
5     0x03: "Chat Message",
6     ...
7
8 structs = {
9     #Keep-alive
10    0x00: ("int", "value"),
11    #Login request
12    0x01: (
13        ("int", "entity_id"),
14        ("string", "level_type"),
15        ("byte", "game_mode"),
16        ("byte", "dimension"),
17        ("byte", "difficulty"),
18        ("byte", "not_used"),
19        ("ubyte", "max_players")),
20    ...

```

**Figure 3.5:** data structures for the packet IDs and structures

```

1 def decode(self, bbuff):
2     #Ident
3     self.ident = datautils.unpack(bbuff, 'ubyte')
4
5     #Payload
6     for dtype, name in mcdata.structs[self.ident][self.direction]:
7         self.data[name] = datautils.unpack(bbuff, dtype)

```

**Figure 3.6:** function for decoding packets

### 3.5.2 Minecraft Clones

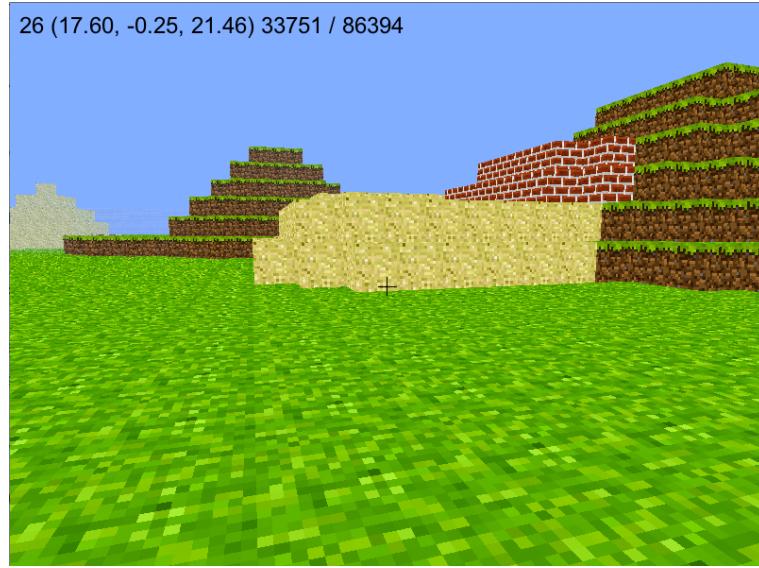
Other interesting projects include Skycraft [sky13], a Minecraft-like browser-game based on WebGL.

A particular project, that has the same name as the original game that inspired it, is **Minecraft** by Michael Fogleman (see figure 3.7). It is a simple Minecraft clone in under 600 lines of Python and gained some popularity on reddit [fog13a] and Hacker News [fog13b].

It is comparably easy to understand and modify and has been used for the visualisation component of this project. It is based on the Python multimedia library Pyglet [pyg13].

## 3.6 Summary

An overview of Minecraft, its history and architecture as well as other software and periphery have been presented in this chapter. Minecraft is a complex, yet easily accessible virtual world. It is in constant development and new features are added regularly. It has a massive fanbase and a huge community around all kinds of game-modifications. The most important concepts of Minecraft for this thesis are blocks, chunks and also the client-server-protocol. They will all be used in the next chapter.



**Figure 3.7:** *Minecraft* by Michael Fogleman

As a basis for the implementation of the Minecraft interface for MicroPsi, the bot framework **Spock** by Nick Gamberini has been chosen to extend MicroPsi. Furthermore, **Minecraft** by Michael Fogleman has been chosen to serve as a foundation for the visualisation component. The implementations will be presented in detail in the next chapter.

## Chapter 4

# Minecraft as a MicroPsi 2 World

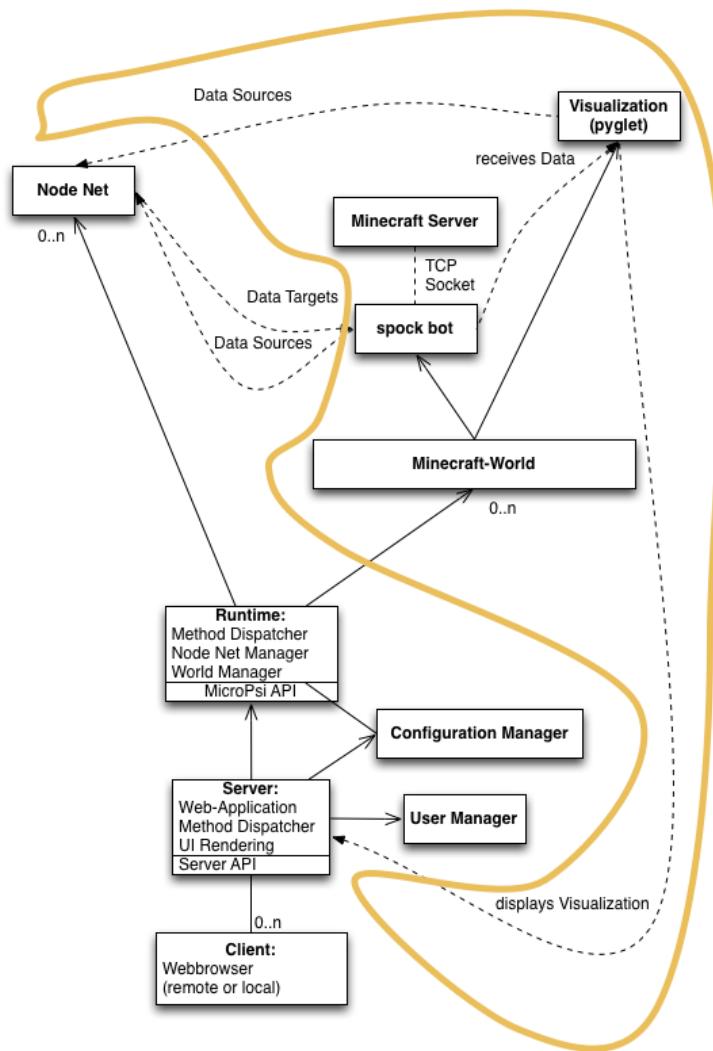
The objective of this project is to build and test an interface in between MicroPsi and Minecraft, so that a Minecraft world can be used as a simulation environment for experiments within the MicroPsi framework, which will act as an artificial player. Since there exist open source projects that perform many of the tasks required for this goal, **Spock**, the Python Minecraft bot framework by Nick Gamberini, and **Minecraft**, the Python Minecraft Clone by Michael Fogleman, have been chosen as a foundation. To make the new simulation environment monitorable, the latter has been used to implement a visualisation of the Minecraft world in the web interface. The following section gives an overview of the implemented modules.

### 4.1 Overview

The modular architecture of MicroPsi allows it to add new simulation environments (or worlds, as they are called in MicroPsi) fairly easily. To communicate with a MicroPsi node net, a world needs an interface, which is called *world adapter*. The *world adapter* has to define *data sources* and *targets*. It fills the sources with data from the world and writes the targets to the world. The node net does the opposite: it reads from the sources and writes into the targets. This enables a feedback loop in between the world and the node net. Furthermore, the *world adapter* provides a step function, that advances the world and is called by the MicroPsi world runner frequently.

Looking at the Minecraft side, communication with a Minecraft Server typically requires a constant flow of data packets going in and out. Most third party clients, including Bots, facilitate their own event loops. To add a Minecraft world to MicroPsi, the demands of both sides have to be met.

The contributions of this project are divided into the three modules `minecraftWorldadapter`, `minecraftClient` and `minecraftVisualisation`. The resulting architecture is displayed in figure 4.1. The `minecraftClient` manages the communication with the Minecraft server, provides convenient functions and data structures for sending and responding to packets and stores and constantly updates a simple representation of the environment data it receives from the server. The `minecraftVisualisation` module generates 3D-Images that display the current state of the Minecraft environment, based on the data it receives from the `minecraftClient`. What ties it all together is the `minecraftWorldadapter`. It provides a step function that advances both the `minecraftClient` and the `minecraftVisualisation` and is called itself by the world runner of the MicroPsi framework. Furthermore it defines and updates the *data sources* and *targets*.



**Figure 4.1:** The new architecture of MicroPsi with the Minecraft interface. New modules are framed orange.

The `minecraftVisualisation` module can be exchanged or cut off completely very easily, as no other modules depend on it. Instead of the visualisation, a placeholder image can be displayed in the webinterface, which does not effect the functionality of simulation. The `minecraftVisualisation` module itself depends on the data structures of the `minecraftClient` though. This means, exchanging the `minecraftClient` would require adjustments of the `minecraftVisualisation`, to still function as intended. The same holds for the *data sources* and *targets* in the `minecraftWorldadapter`.

## 4.2 Using Spock as the `minecraftClient`

As mentioned before, the purpose of the `minecraftClient` is to manage the communication with the Minecraft Server and to provide a representation of the agent's environment.

The calculation of the simulation environment, does not take place in MicroPsi itself, but on a regular Minecraft Server. Instead, Spock is integrated into MicroPsi and rep-

resents the simulation world towards it. Spock (in the following the `minecraftClient`) communicates with the Minecraft server via the client-server-protocol and provides data that can be used as *data sources* for the world adapter and translates the data from the *data targets* to actions in the simulation environment. That way, to MicroPsi it looks like the `minecraftClient` is the simulation environment itself, where in fact it's the interface to the game world server.

The original event loop of the bot framework had to be dissolved and rebuilt as an `advanceClient` function that is called as a part of the world adapter's step function. The event-loop and -handling of Spock had to be slightly modified to work with MicroPsi. It should be noted, that the frequency, with which the framework steps the bot, has to be at least chosen high enough (about 10/s), so that Spock is able to send the necessary keep-alive-signals, to not get kicked from the server.

For every iteration of the event loop, the `minecraftClient` reads incoming data from the socket, dispatches the read packages appropriately and eventually checks the MicroPsi *data targets* to perform an action — if necessary (see figure 4.2). Note, that the described event loop of the original Spock is not a loop anymore but each iteration is invoked as a part of the world adapters step function.

Eventually, useful data sources had to be picked and a system of data targets and their translation to actions had to be implemented. In most cases, performing actions means to let spock send a specific set of packets to the Minecraft server.

#### 4.2.1 Overview of the `minecraftClient`

The `minecraftClient` is heavily based on Spock, that has been developed as an educational project. The scope of this project was to build a pure Python Minecraft bot framework without dependencies. This has been achieved with one minor exception: if one would like to connect the bot to an official Minecraft online server.

The `minecraftClient` runs as a part of the world runner thread. It consists of several classes.

The main class, `minecraftClient`, holds references to instances of the classes `BoundBuffer`, `World` and `Packet`. Furthermore basic data structures are stored as `cflags`, `mcdata`.

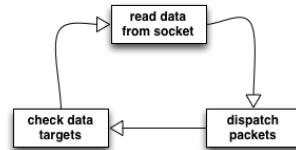
The class `BoundBuffer` is an implementation of a buffer that matches the particular needs of sending and receiving Minecraft packets.

The class `World` holds the internal representation of the gameworld. It brings functions and data structures and classes itself to represent chunks and to obtain information about which block sits where. In its heart, it manages a dictionary, that stores chunks as binary data.

The class `Packet` represents a Minecraft packet and brings functions to encode and decode a packet (read from a `BoundBuffer`) to get to its payload or to be able to send it to the Server.

The file `packethandlers.py` provides a class for each packet that the client is supposed to deal with by default. The following listing gives an example.

The dictionary `cflags` provides the Socket codes. The file `mcdata.py` provides dictionaries for the datatypes, blocktype codes, packet names and structures of packets of



**Figure 4.2:** The `minecraftClient`'s event loop

```

1 #Chunk Data - Update client World state
2 @phandle(0x33)
3 class handle33(BaseHandle):
4     @classmethod
5     def ToClient(self, client, packet):
6         client.world.unpack_column(packet)

```

**Figure 4.3:** Handling a Chunk Data packet

the Minecraft protocol.

In the file nbt.py several classes for dealing with the NBT file format exist.

The file timer.py contains the classes EventTimer, TickTimer and ThreadedTimer which provide Timing.

The client sets up a socket to the server, starts off with a handshake and then facilitates packet based communication with the server.

#### 4.2.2 Extensions to the `minecraftClient`

It was aimed for to extend the original client in a way, that it would fit in nicely as a simulation world for MicroPsi.

A reference to the new class PsiDispatcher has been added to the `minecraftClient`. It's purpose is to check the World adapters data targets frequently and invoke appropriate actions, if necessary. The following figure gives a simplified view of the resulting architecture. The PsiDispatcher is called as a part of the `advanceClient` function. It checks each available data target and if necessary invokes an appropriate action (eg. sending a packet). Listing 4.4 is an example for the data targets, that indicates that the agent is supposed to move one block towards the direction if the x-axis.

```

1 #check for MicroPsi input
2 if self.client.move_x > 0:
3     self.client.push(Packet(ident = 0x0B, data = {
4         'x': (self.client.position['x'] - 1),
5         'y': self.client.position['y'],
6         'z': self.client.position['z'],
7         'on_ground': False,
8         'stance': self.client.position['y'] + 0.11
9     }))

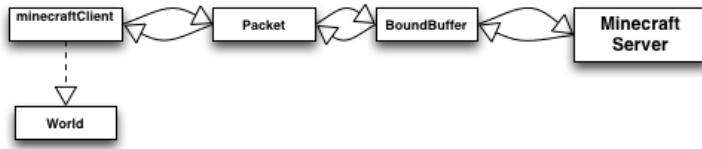
```

**Figure 4.4:** dispatching the events regarding to the move x data target

The event loop has been replaced by the function `advanceClient` that is called for every simulation step. For example, one iteration could mean receiving and storing new block data from the Minecraft Server, sending default responses to the received packets, checking the MicroPsi data targets for moving and if necessary send a "Player Position" packet to the Minecraft server.

### 4.3 Module `minecraftVisualisation`

That being said, the other important part of this project is the visualisation component. It contains classes that provide an interface to the OpenGL context that is the



**Figure 4.5:** An overview of the most import classes of the `minecraftClient` in respect to the communication with a Minecraft Server

visualisation. This sections gives an overview about what datasources the visualisation uses and how it could be replaced or extended. Inside the world adapter's step function, the visualisation module is called to generate a 3D model of the Minecraft world and the agent within. There are two main reasons for this. The first reason is, that the agent's behaviour within the simulation environment is supposed to be visually monitored from the MicroPsi web interface — in a both effective and pleasurable manor. The second reason is, that the image data is supposed to be processed by the node net as a data source itself in the future.

The module `minecraftVisualisation` consists of two classes. The class `Window` inherits from `pyglet.window.Window` and therefore initialises the OpenGL context. For every call of the `advanceVisualisation` function it updates the 3D model according to the world representation inside the `minecraftClient` and renders it. A `.png` snapshot of the frame buffer is generated and displayed in the web interface.

The class `Model` is also called as a part of the `advanceVisualisation` function. It contains functions for adding and removing blocks from the OpenGL canvas. The textures for the blocks are loaded from PNG images and stored as `pyglet.graphics.TextureGroups` and are assigned to vertices when needed.

The visualisation component reads from Spock's internal gameworld representation to generate the 3D model. This means, that from pure Minecraft world data a 3D-visualisation has to be generated from within the MicroPsi Python code. It should contain a perspective that gives a good overview over the bots environment to forward to the web interface, as well as the agent's first person perspective, to function as a data source in the future.

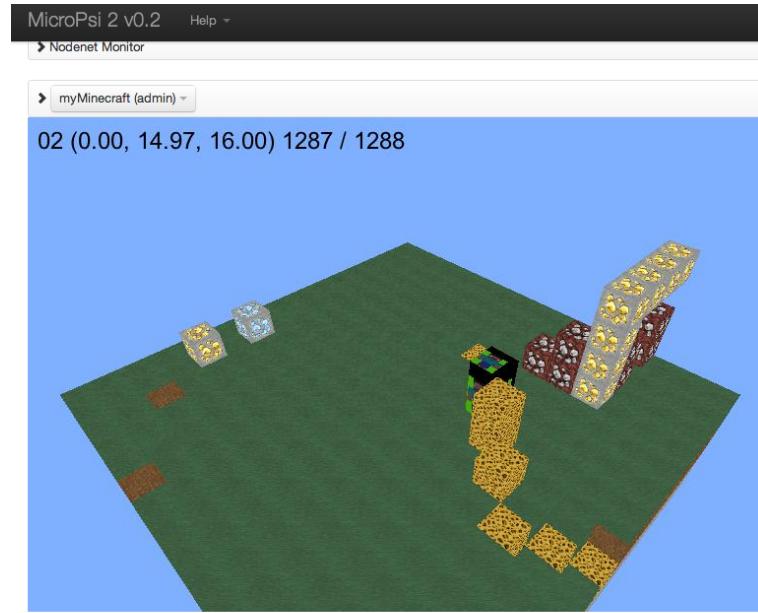
The visualisation is in it's core based on "Minecraft" by Michael Fogleman.

Specifically, the representation of the chunk, the agent is located in, is fetched and for each solid cube in this chunk, a corresponding cube is rendered within the visualisation using Pyglet's OpenGL abstraction (see figure 4.6). Each block gets textures according to it's type. The implemented format for the textures is compatible to the widely available Minecraft texture packs. That way, the visualisation's look can be changed completely within seconds. The resulting images are exported as JPEG files. Then, they are displayed in the web interface. A refresh rate of six or more images per second creates the impression of a video stream.

Similar to spock, "Minecraft" by Michael Fogleman implements it's own event-loop and -handling. Again, the event loop had to be disassembled and rebuilt as a part of the world adapter's step function, which advances the visualisation with every step.

## 4.4 Module `minecraftWorld`

The world adapter contains two classes. The class `MinecraftWorld` inherits from the `MicroPsi` class `world` and provides the assets for the webinterface, an `init` function and



**Figure 4.6:** An Image generated by the visualisation component

the step function. The class `Braitencraft` is the name of the actual `Worldadapter`. In it, the `data sources` and `targets` are defined as dictionaries and an update function advances the life of the client.

**Data Targets and sources** As a proof of concept, datasources have been defined, that symbolize sensors that detect if a block of diamond in the current section is either before, behind, left or right of the client. The data targets are filled as a part of the world adapter update function as follows:

On the other hand, data targets have been defined for walking moving forwards, backwards, left and right.

## 4.5 Case Study

To explain the usage of this implementation, we conclude an example in the following. The agent placed in the Minecraft world shall consist of four sensors, that point to the positive and negative x- and y-axis. These sensors detect, if a diamond ore block has been placed in the current chunk in the direction they are pointing. The agent furthermore consists of 4 actuators, that represent moving towards each of the same four directions. Next, the sensors get connected to the according actuators, which will lead to an agent being attracted towards a placed diamond block.

To conclude the experiment, a chunk in a Minecraft world is set up that way, that a chunk contains a plane without other obstacles that the agent might move on as well as a diamond block that is placed in its center.

Then, the agent is placed in one of the chunks corners. We furthermore define that the activation of the sensors equals the distance to the diamond block in the regarding direction. It is filled through searching the entire section, as listing 4.7 displays.

In every step of the world, the client will check the datatargets and therefore move

```

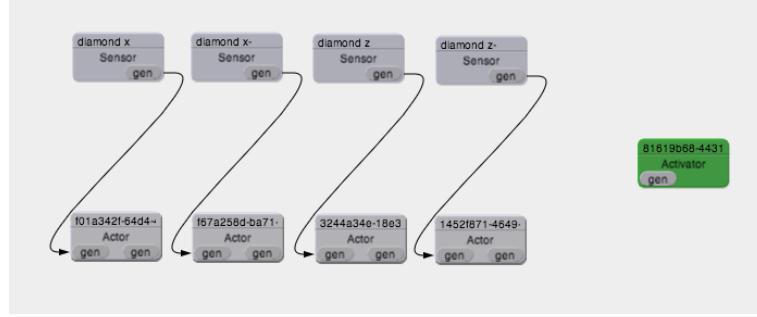
1 x_chunk = self.world.minecraftClient.position['x'] / 16
2 z_chunk = self.world.minecraftClient.position['z'] / 16
3 bot_block = (self.world.minecraftClient.position['x'], ld.minecraftClient.position['y'], s
4 current_column = self.world.minecraftClient.world.columns[(x_chunk, z_chunk)]
5
6 for y in range(0, 16):
7     current_section = current_column.chunks[int((bot_block[1] + y - 10 / 2) / 16)]
8     if current_section != None:
9         for x in range(0, 16):
10            for z in range(0, 16):
11                current_block = current_section['block_data'].get(x, _block[1] + y - 10 / 2)
12                if current_block == 56:
13                    diamond_coords = (x + x_chunk * 16, y, z + z_chunk * 16)
14                    self.datasources['diamond_offset_x'] = bot_block[0] - coords[0] - 3
15                    self.datasources['diamond_offset_z'] = bot_block[2] - coords[2] - 3
16                    self.datasources['diamond_offset_x_'] = ((bot_block[0] - coords[0]) * 16) + x + x_chunk * 16
17                    self.datasources['diamond_offset_z_'] = ((bot_block[2] - coords[2]) * 16) + z + z_chunk * 16

```

**Figure 4.7:** dispatching the events regarding to the move x data target

towards the diamond. Once it get's to a distance to the diamond below a threshold, the sensors will stop sending activation and the agent will stop moving towards it. Note, that if the node net runner and the world runner run asynchronously, there might be a delay in the shift of behaviour of the agent. Hence, it is advised, to run them synchronously or at least with a timing similar to each other.

In the node net editor, we set up the corresponding node net, as seen in figure 4.8. Now, the world writes the activation from the sensors to the actuators in every iteration of the step function.



**Figure 4.8:** A node net setup for a Diamond-finding experiment

If we start a simulation like this, the nodes of the sensors that point to the diamond light up green and their activation is forwarded to the actors. The bot moves towards the diamond until it is closer than the threshold for the sensors to not detect the diamond anymore—for this experiment the threshold has been set to two blocks. Then it stops moving. (see figure 4.9)

#### 4.5.1 Evaluation

Now, that a proof-of-concept experiment has been concluded, the implementation can be evaluated. The experiment obviously shows, that an interface in between a Minecraft world and the MicroPsi framework has been implemented. In the experiment, the agent concludes the appropriate action, if a node net actuator node receives activation, and

stops doing so, when it stops receiving activation.

With MicroPsi node nets in the back, more complex experiments can now be thought of and implemented, that lead to more complex behaviour of the bot.

An issue that remains concerning, is that the reaction time in between changes in the node net and the according changes of the agent's behaviour seem to be to high, for differing timing of node net runner and world runner.

This issue could be solve, by making the bot step-able faster, for example by stop writing the visualisation screenshots to the disk.

## 4.6 Summary

This chapter presented the implementation of the Minecraft interface for MicroPsi, that consist of the modules `minecraftClient`, `minecraftVisualisation` and `minecraftWorld`. The `minecraftClient` facilitates the communication with the Minecraft Server, the `minecraftVisualisation` delivers an OpenGL rendered image of the environment and the `minecraftWorld` serves as the actual interface in between the `minecraftClient` and MicroPsi. Next, a case study has been performed and evaluated. A MicroPsi client hat to move towards a block of a specific type. It showed, that the interface is functional and ready for more sophisticated experiments. With the implementation of the interface and the following proof-of-concept case study, the scope of this thesis has been completed. The last chapter contains a summary and an outlook towards future applications.



**Figure 4.9:** Three screenshots with a Minecraft bot walking towards the diamond



# Chapter 5

## Conclusion

After several iterations and trying out different approaches and technologies the Interface is now functional.

The experiment with the simulated Braitenbergvehikel resulted in proofing that Minecraft is usable as a simulation environment.

This Thesis presented an implementation of an interface, that makes it possible to use servers of the video game Minecraft as a simulation environment for the cognitive artificial intelligence framework MicroPsi 2. In particular, an artificial player may no connect to a Minecraft world and be controlled by a MicroPsi node net. Because there is a wide variety of possible input data from Minecraft world and of possible actions artificial players can perform, corresponding data sources and targets may be defined freely at a defined place.

The interface is in its core based on two open source software projects. The Python Minecraft bot framework Spock serves as the client that connects to Minecraft Servers. The Python Minecraft Clone Minecraft by Michael Fogleman serves as the foundation for the visualisation component.

The implemented case study shows, that the interface as a whole functions as expected. Although, it so far servers foremost as a proof-of-concept, an there is a lot of room for improvement, with the two main flaws being speed and robustness. Speeding the simulation up would require profiling and finding the bottle necks in the data flow. Most likely, at this time one of the major bottlenecks will be, that for every iteration of the visualisation component, an image file is written to the hard drive.

The Minecraft protocol proved to be easily accesible, understandable and therefore good to work with. It set's the barrier for programming against Minecraft very low, so there might even be research projects with other scopes than AI simulation, that could probably make use of Minecraft infrastructures.

### 5.1 What's next

Possible future applications of this project include implementing data targets for every Minecraft action that one wants to experiment with. For example, these could be interacting with the environment by picking up objects, creating and destroying blocks, building, mining, interacting and fighting with other objects. Espacially, in the future, multiple agents shall interact with the same environment and collaborate with each other.



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# Inhalt der beigelegten CD

Die beigelegte CD enthält folgenden Inhalt:

- diese Masterarbeit in PDF Format,
- Videos mit Interview von Fans,
- den Source-Code der Implementierung einer Maschine zur Beantwortung der Fragen aller Fragen. Der Source-Code ist im Ordner *src* zu finden.



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