Reverse-Engineering the Minecraft protocol

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Minecraft

- Sandbox building (and survival) game, alpha release in May 2009
- Developed by Markus Persson (Notch)
- Mojang Specifications (now Mojang AB)

Minecraft

- 7 million copies sold (10th best selling PC game)
- Written in Java

- Started reverse-engineering the protocol in October 2009 (few months after release), wrote first open-source server
- Wrote widely used API for saved game files (JNBT)

Minecraft

- Map is a giant grid of blocks
- Single- and multi-player modes
- Players can create/destroy the blocks

- Later versions added:
  - Basic physics (flowing water, explosions, etc.)
  - Monsters/fighting
  - Items (tools, food, etc.)
  - Weather, day/night cycle
  - etc.

Tools

- Packet analyzer (Wireshark)
- Java disassembler (javap, JBE)
- Java decompilers (JAD and JODE)

Obfuscation

- Debugging info removed
- JVM is fairly lenient
- Flow control obfuscation
  - new branches leading to invalid code
  - expression always or never evaluates
  - confuses decompilers
- String encryption
- Static member scrambling
- Unused code added
  - e.g. local variables never used, redundant casts
- Various optimisations

Obfuscation

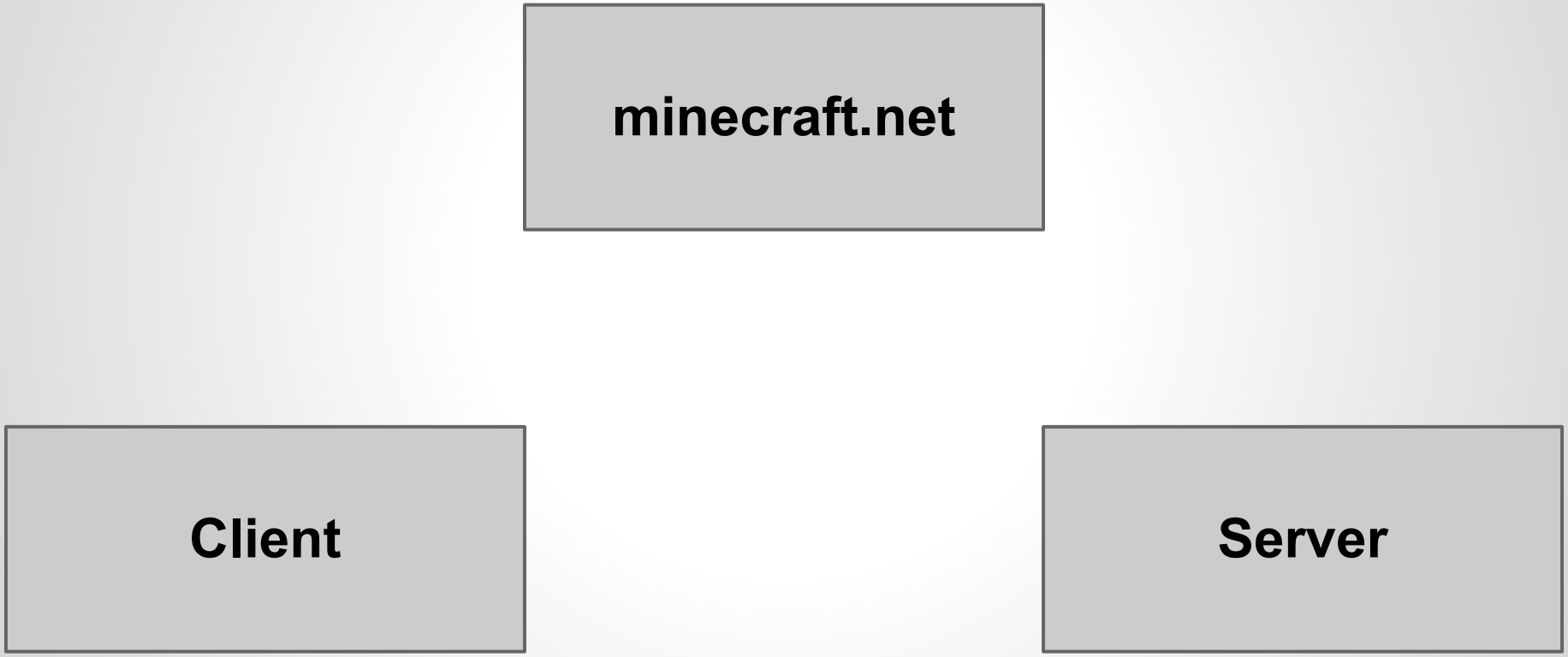
```
    JVM INSTR dup ;
    Object obj;
    obj;
    printStackTrace();
_L1:
    O = minecraftapplet;
    new com.mojang.minecraft.e(this);
    j = canvas;
    b = i1;
    c = j1;
    I = flag;
    if(canvas == null) goto _L3; else goto _L2
```

Java Serialization

- Used as part of the saved game format
- Some classes do not get renamed (for compatibility between releases)

Minecraft Classic

Authentication Protocol



Authentication Protocol

- Client and server downloadable by anyone
  - (although proprietary and obfuscated)

- minecraft.net allows secure authentication between servers/clients, without giving away passwords

Authentication Protocol

Server sends a HTTP POST request to http://minecraft.net/heartbeat.jsp every 90s

```
POST /heartbeat.jsp HTTP/1.1
Content-Type: application/x-www-form-urlencoded
Host: www.minecraft.net
Content-Length: 89

port=25565&users=0&max=64&name=Test&public=false&version=7&salt=-2421305394947607028
```

Authentication Protocol

```
if(k1 % 900 == 0) {
    MinecraftServer minecraftserver1 = this;
    Object obj;
    ((Map) (obj = new HashMap())).put("name",
minecraftserver1.d);
    ...
    ((Map) (obj)).put("port", Integer.valueOf
(minecraftserver1.s));
    ((Map) (obj)).put("salt", minecraftserver1.w);
    ((Map) (obj)).put("version", Byte.valueOf((byte)7));
    obj = a(((Map) (obj)));
    (new d(minecraftserver1, ((String) (obj)))).start();
}
```

Authentication Protocol

```
private static String a(Map map) {
    Object obj;
    obj = "";
    for(Iterator iterator = map.keySet().iterator();
iterator.hasNext();) {
        String s1 = (String)iterator.next();
        if(obj != "")
            obj = (new StringBuilder()).append(((String)
(obj))).append("&").toString();
           obj = (new StringBuilder()).append(((String)
(obj))).append(s1).append("=").append(URLEncoder.encode
(map.get(s1).toString(), "UTF-8")).toString();
    }
    return ((String) (obj));
}
```

Authentication Protocol

```
(httpurlconnection = (HttpURLConnection)((URL) (obj = new
URL("http://www.minecraft.net/heartbeat.jsp")))).
openConnection()).setRequestMethod("POST");


((DataOutputStream) (obj = new DataOutputStream
(httpurlconnection.getOutputStream()))).writeBytes(a);
((DataOutputStream) (obj)).flush();
((DataOutputStream) (obj)).close();


String s = ((BufferedReader) (obj = new BufferedReader(new
InputStreamReader(httpurlconnection.getInputStream())))).
readLine();
MinecraftServer.a.info((new StringBuilder()).append("To
connect directly to this server, surf to: ").append(s).
toString());
```

Authentication Protocol

Server receives a URL back to give to players e.g.

http://www.minecraft.net/classic/play/a9a021709992b18501618569ea317cf5

Authentication Protocol

```
<applet>
      ...
      <param name="username" value="Ancient">
      <param name="sessionid" value="
-55194254334507281l1">
      <param name="haspaid" value="true">
      <param name="server" value="127.0.0.1">
      <param name="port" value="25565">
      <param name="mppass" value="
48aa44d9cf4ea3a8ddb4a42bc65ea5a0">
</applet>
```

Server authentication code

Upon login:

```
String s1 = ((String)aobj[1]).trim();
aobj = (String)aobj[2];

if(k.k && !((String)(aobj)).equals(k.j.a
(s1))) {
    a("The name wasn't verified by
minecraft.net!");
    return;
}
```

Server authentication code

```
w = (new StringBuilder()).append("").append((new
Random()).nextLong()).toString();
j = new i(w);

public final class i {
    public i(String s) {
        a = s;
    }
    public final String a(String s) {
        this = (new StringBuilder()).append(a).append(s).
toString();
        (s = MessageDigest.getInstance("MD5")).update
(getBytes(), 0, length());
        return (new BigInteger(1, s.digest())).toString(16);
        ...
```

Authentication Protocol

mppass = md5(salt + username)

Client sends username and mppass to server
(it doesn't know the salt)

Server verifies the mppass is correct
(it knows the salt and username)

Game Protocol

```
~% netstat -nap | grep java
tcp 0 30 10.0.0.1:36333 178.79.130.214: 25565 ESTABLISHED 13262/java
~%
```

Runs on top of TCP, uses port 25565 by default

Decompiled packet encoding code

```
if(obj == Integer.TYPE) {
    a2.d.putInt(((Number)k).intValue());
}


if(obj == java/lang/String) {
    obj = ((String)k).getBytes("UTF-8");
    for(k = 0; k < 64 && k < obj.length; k++)
        a2.i[k] = obj[k];

    for(k = obj.length; k < 64; k++)
        a2.i[k] = 32;    // 32 = 0x20 = space character

    a2.d.put(a2.i);
}
```

Decompiled packet encoding code

```
if(obj == [B) {
    byte abyte0[];

    // fills unused bytes with zeros:
    if((abyte0 = (byte[])k).length < 1024)
        abyte0 = Arrays.copyOf(abyte0, 1024);

    a2.d.put(abyte0);
}
```

Decompiled packet structure code

```
static {
    b = new a(new Class[] {
        Byte.TYPE, java/lang/String, java/lang/String, Byte.TYPE
    });
    c = new a(new Class[0]);
    new a(new Class[0]);
    d = new a(new Class[] {
        Short.TYPE, [B, Byte.TYPE
    });
    e = new a(new Class[] {
        Short.TYPE, Short.TYPE, Short.TYPE
    });
    ...
```

Packet decoding code

```
byte byte0 = a2.c.get(0);
com.mojang.minecraft.net.a a4;
if((a4 = com.mojang.minecraft.net.a.a[byte0]) == null)
    throw new IOException((new StringBuilder()).append
("Bad command: ").append(byte0).toString());

if(a2.c.remaining() < a4.q + 1)
    break; /* Loop/switch isn't completed */
a2.c.get();
Object aobj[] = new Object[a4.s.length];
for(int i8 = 0; i8 < aobj.length; i8++)
    aobj[i8] = a2.a(a4.s[i8]);
```

Data types summary

integer: byte, short, int, long

floating point: IEEE 754 float and double

byte array (1024 bytes, shorter arrays padded with zeros)

string (64 bytes of UTF-8, shorter strings padded with spaces)

Game Protocol

- single byte opcode
- constant amount of data for each packet

- unusual in that it is symmetric
  - packet structures same in both directions
  - some fields unused
  - some packets unused

Wireshark dump (login packet)

```
0000    00 07 41 6e 63 69 65 6e 74 20 20 20 20 20 20 20   ..Ancient
0010    20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20
0020    20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20
0030    20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20
0040    20 20 62 36 61 62 39 62 66 38 62 65 61 34 37 34     b6ab9bf8bea474
0050    62 37 38 39 61 38 35 63 65 30 35 63 36 61 66 33   b789a85ce05c6af3
0060    35 62 20 20 20 20 20 20 20 20 20 20 20 20 20 20    5b
0070    20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20
0080    20 20 00                                          .
```

type (0=login), protocol version, username, mppass (last byte unused)

Login response

```
0000    00 07 4f 70 65 6e 43 72 61 66 74 20 20 20 20 20   ..OpenCraft
0010    20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20
0020    20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20
0030    20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20
0040    20 20 68 74 74 70 3a 2f 2f 6f 70 65 6e 63 72 61  http://opencra
0050    66 74 2e 73 66 2e 6e 65 74 2f 20 20 20 20 20 20   ft.sf.net/
0060    20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20
0070    20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20
0080    20 20 64                                         .
```

example of the symmetric structure:

player name -> server name,
mppass -> server motd,

unused byte -> user type
(0=normal, 0x64=admin)

Level data packets

```
0000    03 04 00 1f 8b 08 00 00 00 00 00 00 00 ec d1 41
0010    11 00 31 0c 03 b1 cc f5 53 58 c7 1f 55 61 ec 23
0020    12 02 ef 78 fe 99 03 00 00 00 00 00 00 00 00 00
...
0400    00 00 00 34
```

type (3=level data)

0x0400 = 1024, number of bytes

0x1f8b08 (GZIP header magic)

last byte = experimented to find it is the progress bar for map loading

Decompiled GZIP code

```
public static byte[] b(InputStream inputstream) {
    byte abyte0[];
    abyte0 = new byte[(inputstream = new DataInputStream(new
GZIPInputStream(inputstream))).readInt()];
    inputstream.readFully(abyte0);
    inputstream.close();
    return abyte0;
    inputstream;
    throw new RuntimeException(inputstream);
}
```

4 byte length
followed by 'length' bytes of data

Decompiled GZIP code

```
byte abyte0[] = com.mojang.minecraft.level.a.b(new ByteArrayInputStream
(((com.mojang.minecraft.net.c) (word4)).a.toByteArray())); // this calls
method shown on previous slide
...
Level level1;
level1.setData(word6, word7, word0, abyte0);

public void setData(int j, int i1, int j1, byte abyte0[]) {
    width = j;
    height = j1;
    depth = i1;
    blocks = abyte0;
    ...
}

blocks[(i1 * height + j1) * width + j]
```

data is the level block array!

Level data packets

```
0000    02
```

type (2=start of level data)

```
0000    04 01 00 00 40 01 00
```

type (4=end of level data)
width = 256 tiles
depth = 64 tiles
height = 256 tiles

Level data packets

```
// level start (id 2)
((com.mojang.minecraft.net.c) (word4)).c.a(((Level)
(null)));
       word4.a = new ByteArrayOutputStream();

// level data (id 3)
short word5 = ((Short)byte14[0]).shortValue();
       byte abyte1[] = (byte[])(byte[])byte14[1];
       byte byte16 = ((Byte)byte14[2]).byteValue();
       ((com.mojang.minecraft.net.c) (word4)).c.p.a
(byte16);
       ((com.mojang.minecraft.net.c) (word4)).a.write
(abyte1, 0, word5);
```

Level data packets

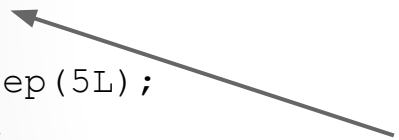
```
// level finish (id 4)
((com.mojang.minecraft.net.c) (word4)).a.close();
byte abyte0[] = com.mojang.minecraft.level.a.b(new
ByteArrayInputStream(((com.mojang.minecraft.net.c)
(word4)).a.toByteArray()));
word4.a = null;
short word6 = ((Short)byte14[0]).shortValue();
short word7 = ((Short)byte14[1]).shortValue();
short word0 = ((Short)byte14[2]).shortValue();
Level level1;
(level1 = new Level()).setNetworkMode(true);
level1.setData(word6, word7, word0, abyte0);
```

Updating other players

- 20 ticks per second
- small maps - all players notified of all other player's actions
- 128 players max
  - Negative player ids have special meanings:
  - yourself in movement packets (for teleporting)
  - set spawn position in spawn player packet
  - server 'broadcast' message in chat message packet

Server tick code

```
int i1 = 0x2faf080;  // 50,000,000 nanoseconds (0.05 seconds)
long l2 = System.nanoTime();
do {
     while(System.nanoTime() - l2 > (long)i1) {
         l2 += i1;
         ...
    }
    Thread.sleep(5L);
} while(true);
```



code for updating players, network I/O, authentication server heartbeat, saving the map to disk, etc.

Updating other players

- Add player
- Move/rotate player
- Remove player

- To save bandwidth:
  - delta-encoding position and rotation changes
  - packets for only moving, only rotating, and moving & rotating
  - absolute versions also exist (if client/server get too far out of sync), also for teleporting

Add player client code

```
if(byte1 >= 0) {
    byte14 += 128;
    word4 -= 22;
    obj4 = new NetworkPlayer(((com.mojang.minecraft.net.c) (obj2)).
c, byte1, ((String) (obj4)), i7, word4, k8, (float)(byte14 * 360) /
256F, (float)(byte15 * 360) / 256F);
    ((com.mojang.minecraft.net.c) (obj2)).f.put(Byte.valueOf
(byte1), obj4);
    ((com.mojang.minecraft.net.c) (obj2)).c.d.addEntity(((Entity)
(obj4)));
} else {
    ((com.mojang.minecraft.net.c) (obj2)).c.d.setSpawnPos(i7 / 32,
word4 / 32, k8 / 32, (byte14 * 320) / 256);
    ((com.mojang.minecraft.net.c) (obj2)).c.f.moveTo((float)i7 /
32F, (float)word4 / 32F, (float)k8 / 32F, (float)(byte14 * 360) /
256F, (float)(byte15 * 360) / 256F);
}
```

Client position packet

```
if(y.e) {
    int i4 = (int)(player.x * 32F);

    int k4 = (int)(player.y * 32F);
    int j5 = (int)(player.z * 32F);
    int j6 = (int)((player.yRot * 256F) / 360F) & 0xff;
    int k7 = (int)((player.xRot * 256F) / 360F) & 0xff;
    c1.b.a(com.mojang.minecraft.net.a.i, new Object[] {

        Integer.valueOf(-1), Integer.valueOf(i4), Integer.
valueOf(k4), Integer.valueOf(j5), Integer.valueOf(j6),
Integer.valueOf(k7)
    });
}
```

Block changes

```
if(k8 == com.mojang.minecraft.net.a.g)
      {
            if(((com.mojang.minecraft.net.c)
(word4)).c.d != null)
               ((com.mojang.minecraft.net.c)
(word4)).c.d.netSetTile(((Short)byte14[0]).
shortValue(), ((Short)byte14[1]).
shortValue(), ((Short)byte14[2]).
shortValue(), ((Byte)byte14[3]).
byteValue());
      }
```

Block changes

- Whole map compressed and sent to new clients
  - server uses lowest GZIP compression - still slow
- Solution: copy map, compress in another thread
  - but map can change while this is done
- Queue up block changes, send them all once client has the map

Chat messages

```
if(k8 == com.mojang.minecraft.net.a.n) {
    String s1 = (String)byte14[1];
    byte byte7 = ((Byte)byte14[0]).byteValue();
    short word2 = word4;
    if(byte7 < 0) {
        ((com.mojang.minecraft.net.c) (word2)).c.w.a((new
StringBuilder()).append("&e").append(s1).toString());
    } else {
        ((com.mojang.minecraft.net.c) (word2)).f.get(Byte.
valueOf(byte7));
        ((com.mojang.minecraft.net.c) (word2)).c.w.a(s1);
    }
}
```

Other packets

- Kicking a player with a reason (e.g. bans, login at another computer)
- Change user type (normal/admin) whilst they are logged in
- Other variants of movement packet
- Ping
- Remove player

Limitations of classic protocol

- Fixed sized strings/byte arrays
  - wasted bandwidth (zero/space padding)
  - limited lengths (e.g. 64 byte chat message isn't many chars, esp. with multibyte chars from non-Latin languages)
- Whole map must be sent and kept in client's memory at once
  - limited map size - realistically 1024x1024x256 is max
  - wastes bandwidth and memory

Minecraft 'SMP'

- 'Infinite' maps
  - map is split into 16x16x256 chunks
  - only chunks near you are loaded
- Fixes limitations in the protocol
  - longer strings/byte arrays possible
  - no padding - saves bandwidth
  - (as of a few weeks ago) encryption
- Many new features

Server Implementation

- OpenCraft
- Java
- Event-driven single-threaded I/O
  - (using Apache MINA library)
- Customizable with Python scripts
  - (using Jython)

- Interesting scripts made by users:
  - Wireworld
  - Capture the flag
  - Basketball
  - Zombies

Open-Source

- OpenCraft
  - 20k+ downloads
  - forked and still developed (OpenCraft ACM, CTF)
- Lightstone (~100 forks on GitHub)
- Glowstone, Spout
  - popular servers based on Lightstone, active development
- JNBT
  - library for the saved game format
  - used in many projects
    - servers
    - map editors
    - etc.

Open-Source

- Both projects had several other contributors
- Lessons learned:
  - Don't open the code up too early - contributors often shape the design of the code to suit individual patches rather than the overall system
  - Saying no to poor code (with tips for improvements) - hard, but necessary to keep good quality
  - Also saying no to unwanted features
- Forks - good and bad

Alternative approaches

hMod/Bukkit

- Bukkit API
  - consists mainly of interfaces
  - some helper code
- CraftBukkit
  - the proprietary server software
  - Bukkit developers have a tool to:
    - analyse bytecode
    - modify it (change names, add extra methods, implement their interfaces)
- Plugins

Summary

Techniques:

- Magic numbers (e.g. GZIP in Minecraft)
- Strings
- Mixture of:
  - analysis of packet dumps
  - analysis of bytecode & decompiled source code
- Guesswork!

Links

OpenCraft:
http://sourceforge.net/projects/opencraft
Lightstone (rewrite for new protocol):
http://github.com/grahamedgecombe/lightstone

Community protocol/file format documentation:
http://wiki.vg/

Slides:
http://grahamedgecombe.com/talks/minecraft.pdf