BPX Format

https://github.com/BlockProject3D/

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Abstract

This document describes the BPX format, providing an optimized, flexible and DRM [12] free storage designed for various multimedia content types commonly used in 3D applications.

1 Introduction

When developing a 3D game engine often comes the problem of dealing with game modifications (mods). For example one might consider how easy would it be for the end player to add custom assets, change existing assets; would the end player need to agree against certain complex licences or if it is even legally allowed to modify the content of certain asset files.
Here the term asset refers to various type of file loaded by the game for a specific game world or for the entire game. These resources can be multimedia files, scripts, configurations and other formats the game engine would use.
This format provides an alternative to existing asset formats geared towards the development of highly moddable (modify the game; add new assets, remove existing assets, change existing assets) and cross platform 3D games. The benefits are:

- Open source with a permissive licence.
  Redistribute source code, allow improvements of the format by others.
- DRM [12] free.
  Avoid licensing problems and restrictions. DRM stands for Digital Rights Management and is used to control how the user is allowed to interact with certain multimedia content. In moddable game DRM usually restricts the user from modifying existing assets.
- Flexible.
  Designed for providing support for moddability. The nature of container allows support for all kind of multimedia resources used in a typical real-time 3D application.
- Optimized for 3D APIs such as OpenGL [4], DirectX [8], Vulkan [5]
  Certain types of BPX uses some assumptions on the input data in order to reduce pre-process time when loading assets in a typical real time rendering engine.
- Cross platform.
  Can store data for compatibility over multiple platforms within a single file due to its nature of containers.

2 History

The BPX format also refered to BlockProject Extended is a remake of an old format designed for the first version of the BlockProject 3D engine as an attempt to allow moddability, that means change the behaviour of a game while it's running and in this case change also any multimedia asset including scenes, shaders, models and even textures...
This has proved to be a difficult task due to licensing issues, restrictions imposed by existing frameworks and restrictions imposed by certain formats.
As a result a custom asset format has been developed for initially a very limited set of type of assets in order to solve the issue.
This format is an evolution geared towards re-usability and performance.

3 Comparison against mainstream formats

Below is a non-exhaustive table showing the differences between the idea of BPX and existing mainstream formats:

Name	Open	DRM	Flexible	Optimized	Compat.
FBX	No	No	No	Yes	Partial
Unreal	No	Yes	Yes	Yes	Partial
Unity	No	Yes	Partial	Yes	Partial
OBJ	Yes	No	No	No	Yes

- FBX: It is possible to save files as Text based FBX however no open documentations exists for the format. The binary FBX requires the use of a closed source library FBX supports Windows without issues however getting the SDK to work on different platforms might be an issue.
  FBX is designed to support 3D models.
- The source code of Unreal can be accessed if you are agree to certain licences which prohibits the redistribution of the editor source code in the game preventing the use of Unreal's format as a base to support modding. Unreal does also not provide easy installations under Linux.
  Unreal is also using a unified format for all assets of the game. It has support for modding however the modder is required to agree to licences and to download the full SDK.
- Unity although it has better support for Linux it might still be a bit tricky in certain combinations of distribution/system.
  Unity is also using a unified format for all assets of the game but the game engine does not allow load of arbitrary custom assets. The asset format used by unity is also closed and does not permit modification by the player of the game like Unreal.
- OBJ is a text based 3D model format. The format has no support for skeletal based models/animations and has poor support for materials.

4 General

The format is based on the idea of a container with a reusable main header that can be extended for the different applications.
The following assumptions are used:

- A byte is assumed to be 8 bits.
- The sizes are expressed in bits in the entire document.
- The byte order in a BPX file should be **little endian** to match most of current hardware/software architectures, and then avoid a pre-processing step when loading the file.
- A transformation is stored in terms of float to match most current rendering APIs.
- The coordinate system used for this format is assumed to be left handed with the Z axis to be pointing upward.

Description of the coordinate system:

$$Right = \begin{pmatrix} 1 \\ 0 \\ 0 \end{pmatrix} Forward = \begin{pmatrix} 0 \\ 1 \\ 0 \end{pmatrix} Up = \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix} \tag{1}$$

The TypeExt section available in certain BPX types describes what fields to expect in the 128 bits of extension located in the BPX Main Header.
If the TypeExt field isn't used by a specific BPX type then this field should be set to 0.

5 Padding rules

All data structures exposed in this format specification are padded to comply with major C/C++ compilers: Visual C++, GCC and Clang.

6 Floating points

All floating points in this format are stored in IEEE 754 format [6].

7 Hashing function

Some types of BPX requires hashing for some strings. The string hash function to apply is defined by:

$$h_X(0) = 5381 \tag{2}$$

$$h_X(n+1) = \left(\left(h_X(n) \times 2^5\right) + h_X(n)\right) + X_{n+1} \tag{3}$$

where X is a row vector containing the raw bytes of the string.

8 BPX Main Header

The BPX Main Header describes general information about the container and the contained data.
This section is **not compressable**.
Below is a table describing the different fields to be expected in the header:

Name	Type	Size	Notes
Signature	String	24	File signature; always "BPX"
Type	Unsigned	8	Type of BPX
Chksum	Unsigned	32	Checksum
FileSize	Unsigned	64	Size of file after compression
SectionNum	Unsigned	32	Number of sections
Version	Unsigned	32	Version of BPX format
TypeExt	Unspecified	128	Extension space for various BPX types

<table>
<tr><td>0</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>9</td><td>10</td><td>11</td><td>12</td><td>13</td><td>14</td><td>15</td><td>16</td><td>17</td><td>18</td><td>19</td><td>20</td><td>21</td><td>22</td><td>23</td><td>24</td><td>25</td><td>26</td><td>27</td><td>28</td><td>29</td><td>30</td><td>31</td><td>32</td><td>33</td><td>34</td><td>35</td><td>36</td><td>37</td><td>38</td><td>39</td><td>40</td><td>41</td><td>42</td><td>43</td><td>44</td><td>45</td><td>46</td><td>47</td><td>48</td><td>49</td><td>50</td><td>51</td><td>52</td><td>53</td><td>54</td><td>55</td><td>56</td><td>57</td><td>58</td><td>59</td><td>60</td><td>61</td><td>62</td><td>63</td></tr>
<tr><td colspan="24">Signature</td><td colspan="8">Type</td><td colspan="32">Chksum</td></tr>
<tr><td colspan="64">FileSize</td></tr>
<tr><td colspan="32">SectionNum</td><td colspan="32">Version</td></tr>
<tr><td colspan="64">TypeExt</td></tr>
<tr><td colspan="64">TypeExt</td></tr>
</table>

8.1 Signature

Three characters to describe the file when open in a text/hex editor

8.2 Type

The type of BPX. This is used to describe what type of sections to expect in the file.
Currently only the following are supported:

- 'T' for Texture
- 'M' for Model
- 'S' for Shader
- 'C' for Scene
- 'P' for Package

Here the characters between single quotes are to interpreted as their byte representation in ASCII encoding.

8.3 Version

Version of BPX, currently 2 values are supported:

- a value of 1 refers to the initial release of this document implemented in SDK 1.0 and 2.0.
- a value of 2 refers to this current revision of the format and is available in SDK 3.0.

8.4 SectionNum

Number of sections in the file.

8.5 Chksum

Checksum of BPX main header and section header table. Compute this value by adding all bytes of data in unsigned format. Consider the value of this field to be **0** in order to correctly compute the checksum.
All fields of all section headers in the section header table and of the above header must be filled before computing this checksum otherwise the purpose of this checksum would be defeated.

8.6 FileSize

The file size field corresponds to the total size of the file including the size of this header in bytes after compression. This can be used as an additional security over the integrity of the file. It can also be used to check the remaining number of bytes in a network based streaming application.
Currently, the implementation is **not required to implement this field**. In case an implementation does not implement this field, it should be set to **0**.

8.7 TypeExt

The TypeExt field provides 128 bits of extension for different kind of BPX avoiding having to store or load additional sections in order to get usefull general information about a specific file reducing load time and memory complexity.
All unused space in this field should be to **0**.

9 BPX Section Header Table

The BPX Section Header Table is an array of data structures describing important information for each section present in the file. It is located after the BPX Main Header.
The size of this array is determined by the SectionNum field in the BPX Main Header. The array is expected to be contiguous.
Certain types of BPX expects to be able to index sections in this table using positions. For that reason, the array is expected to be 1-indexed to allow for a value of 0 to represent a null or non-existent section.
This section is **not compressable**.

9.1 BPX Section Header

Below is a table describing the feilds to expect in a BPX Section Header:

Name	Type	Size	Notes
Pointer	Unsigned	64	Offset in bytes from the beginning of the file
CSize	Unsigned	32	Size in bytes of section (compressed)
USize	Unsigned	32	Size in bytes of section (uncompressed)
Chksum	Unsigned	32	Checksum
Type	Unsigned	8	Type of Section
Flags	Unsigned	8	Flags for the current section
Reserved	Unspecified	16	Blank, always 0

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63

<table>
<tr><td colspan="8">Pointer</td></tr>
<tr><td colspan="4">CSize</td><td colspan="4">USize</td></tr>
<tr><td colspan="4">Chksum</td><td>Type</td><td>Flags</td><td colspan="2">Reserved</td></tr>
</table>

9.1.1 Pointer

Position in bytes in the file where the content for a given section should be found.

9.1.2 CSize

Size in bytes of the content after compression for a given section excluding Section Header.

9.1.3 USize

Size in bytes of the content before compression for a given section excluding Section Header.

9.1.4 Chksum

Checksum of uncompressed data, refer to the Check type of flags in the flags sub-section (9.1.6) to know how to interpret and generate this field. If no checksum flag is specified, the checksum is ignored.

9.1.5 Type

An integer to represent the type of section.

9.1.6 Flags

Bit mask based flags (or flags together). Currently the only supported flags are:

Name	Value	Notes
CompressedZlib	0x1	Indicates the section is compressed using the zlib [7] algorithm
CompressedXZ	0x2	Indicates the section is compressed using the XZ [10] algorithm
CheckCrc32	0x4	Indicates the section checksum is computed using Crc32 algorithm
CheckWeak	0x8	Indicates the section checksum is computed with the weak variant as used in the BPX Main Header

10 Standard Sections

Additionally any BPX type may use any of the following standard sections specification. The count and usage requirements of such a section is still defined by the type of BPX. The type byte for this section is generally 0xFF (255).

10.1 String section

A BPX may contain string section(s). As string section is a standardized way to store c-like strings in a BPX.

10.1.1 Encoding

The character encoding of strings in this section must be UTF-8.

10.1.2 Structure

The section is just a contiguous block of null-byte terminated UTF-8 encoded strings.
Reading a string is done by taking it's offset in the corresponding string section and start reading characters until a null byte is found.
Writing a string is done by taking the UTF-8 encoded bytes of this string and writing the bytes followed by a null byte at the end of the section.

10.2 Structured Data Section

The BPX Structured Data format, also called BPXSD, borrows various concepts from JSON. Any Structured Data section begins by an Object (see 10.2.4). The type byte for this section is generally 0xFE (254).
NOTE: This format is not exclusive to BPX: it may be used in other applications like network protocols.

10.2.1 Type codes

Each property property is encoded with a Type byte also called type code. Below is a table listing all type codes:

Type Code	Type Name
0	NULL
1	Boolean
2	Uint8
3	Uint16
4	Uint32
5	Uint64
6	Int8
7	Int16
8	Int32
9	Int64
10	Float
11	Double
12	String
13	Array
14	Object

10.2.2 Native types

Below is a table showing encoding of native types. Native types are considerered fixed-size value types.

Type Name	Value size (bits)	Notes
NULL	0	A null value
Boolean	8	A boolean value false (0), true (1)
Uint8	8	8 bit unsigned integer
Uint16	16	16 bit unsigned integer
Uint32	32	32 bit unsigned integer
Uint64	64	64 bit unsigned integer
Int8	8	8 bit signed integer
Int16	16	16 bit signed integer
Int32	32	32 bit signed integer
Int64	64	64 bit signed integer
Float	32	32 bit floating point number
Double	64	64 bit floating point number

For simplicity booleans are encoded as 8 bit bytes.

10.2.3 Strings

Strings are encoded as a UTF-8 null-terminated contiguous block of bytes.

10.2.4 Objects

An object is encoded as a contiguous list of properties each defined by a key-value pair. The first byte to read of an object gives the number of properties in this object. The encoding of a property is as follows:

Name	Type	Size	Notes
Name	Unsigned	64	Hash of property name
Type	Unsigned	8	Type of the property value
Value	Unsigned	Depends on Type	Value of the property

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63

0–63	Name
0–7	Type

10.2.5 Debugging

As stated in the previous sub-section, the BPXSD Object stores hashes of the property names which means the original name is lost. To mitigate this issue, a BPXSD Object may contain a property, accessed by $Hash("\_\_debug\_\_")$, which stores debugging symbols. This property always points to an array of strings. In order to display property name the implementation is responsible for finding in this debug symbol array the property name string such as $Hash(V_i) = P$ where V is the array of debug symbols (i representing the index in that array) and P the property hash that the implementation whishes to know the original name for.

10.2.6 Arrays

An array is encoded as a contiguous list of values. The first byte to read of an array gives the number of values in this array.

Name	Type	Size	Notes
Type	Unsigned	8	Type of the value
Value	Unsigned	Depends on Type	Value

11 BPX Type: Texture ('T')

11.1 Overview

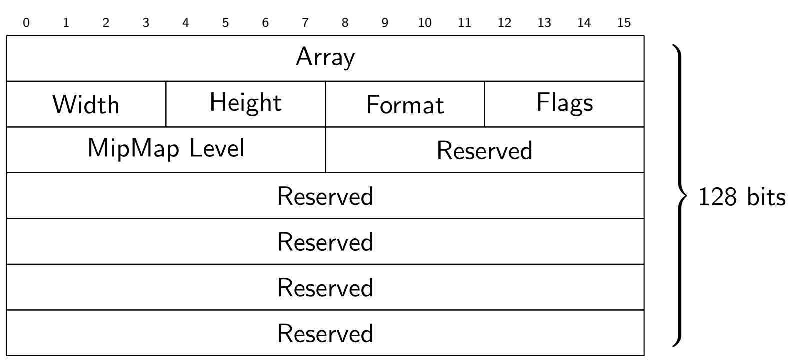
The Texture BPX is using 'T' as the type byte of BPX Main Header. This type provides optimized and efficient texture storage for 3D rendering APIs.
Below is a table describing the different sections to be expected in a BPXT:

Name	Type	Required	Single Time
PixelArray	1	Yes	Yes

11.2 TypeExt

Contains information about the texture encoding.

Name	Type	Size	Notes
Array	Unsigned	16	Size of texture array
Width	Unsigned	4	Texture width
Height	Unsigned	4	Texture height
Format	Unsigned	4	Texture format
Flags	Unsigned	4	Flags
MipMap Level	Unsigned	8	Number of mip maps
Reserved	Unspecified	72	Blank, always 0



11.2.1 Width

The expected width of all pixel arrays in power of two form (2^{k+1}px where k is the stored number).

11.2.2 Height

The expected height of all pixel arrays in power of two form (2^{k+1}px where k is the stored number).

11.3 Analysis on texture size storage

Certain redering APIs requires that the textures are aligned to a specific implementation defined number of pixels per row. This number also called stride is usualy 8 or a power of two greater than 8.
By assuming any BPX encoded texture is encoded with power of twos instead of their actual resolution in pixels, we can eliminate the need, in the cases where the implementation uses power of two strides, to run a padding

alignment before presenting the texture to this implementation. Also this allows to reduce the field size for storing texture size: instead of using 32 bits or 64 bits we can store a texture size in 8 bits and keep relatively large texture sizes, **optimizing both storage space and application load speed**. Indeed the maximum texture size in each direction allowed by BPX would be $2^{15+1} = 2^{16} = 65536$. Most rendering API implementation do not support such large texture sizes.
From there one might say that we should then use less than 8 bits. However using less than 8 bits for storing the entire size vector would conflict with hardware indexing as most hardware only indexes 8 bits bytes.

11.3.1 Format

Available formats:

Name	Value	Notes
RGB	0x1	Standard 8 bits 3 channel RGB format
RGBA	0x2	8 bits 4 channel RGB with transparency level
GreyScale	0x3	Single 8 bits channel representing grey scale level
Float	0x4	Single channel 32 bits float texture

11.3.2 Flags

Bit mask based flags (or flags together). Currently the only supported flags are:

Name	Value	Notes
Array	0x1	Indicates the texture should be interpreted as a texture array
Compressed	0x2	Indicates the texture should be GPU compressed on load
CubeMap	0x4	Indicates the texture should be interpreted as a CubeMap

11.3.3 MipMap Level

Number of mip maps [2] to auto generate when loading this texture.

11.3.4 Array

Number of textures for creating a texture array. If this value is 0 consider this is not a texture array.
Ignore this value if neither of Array or CubeMap flags are set.

11.4 PixelArray

Texture data array encoded as described by texture format.
If the *Array* value in the header is greater than 0 then a series of *Array* count texture data arrays are saved one after the other encoded with respect to the texture format described by the header.
In case the CubeMap flag is set the *Array* field in the header should be 6 and this section should contain 6 texture data arrays.

12 BPX Type: Model ('M')

12.1 Overview

The Model BPX is using 'M' as the type byte of BPX Main Header. This type provides optimized and efficient mesh storage for 3D rendering APIs.
Below is a table describing the different sections to be expected in a BPXM:

Name	Type	Required	Single Time
VertexArray	2	Yes	No
IndexArray	3	No	No
BoneArray	4	No	Yes
FrameArray	5	No	Yes
AnimationArray	6	No	Yes
Strings	255	No	Yes

12.2 TypeExt

Contains general information about the 3D model file.

Name	Type	Size	Notes
VertexFormatHash	Unsigned	64	Hash of vertex format
Reserved	Unsigned	64	Blank, always 0

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
VertexFormatHash
VertexFormatHash
Reserved
Reserved

$\Big\}$ 128 bits

12.2.1 VertexFormatHash

Hash of vertex format asset virtual path corresponding to the vertex structure that this shader expects as input.

12.2.2 VertexFormat

The actual definition of the vertex format is specified as a separate asset, left to the implementation for flexibility.

12.3 VertexArray

This section contains a header followed by an array of vertex data structure. The size of each vertex structure should be equal to the field VertexSize in the VertexFormat section.
The header data structure is described in the following table:

Name	Type	Size	Notes
MaterialHash	Unsigned	64	Hash of material
VertexCount	Unsigned	32	Total number of vertices
IndexArray	Unsigned	32	Index array section index
Reserved	Unsigned	32	Blank, always 0

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63

MaterialHash	
VertexCount	IndexArray

12.3.1 MaterialHash

Hash of material asset virtual path to apply by default to this vertex array.

12.3.2 VertexCount

The amount of vertex structures to read after this header.
We remind that all modern hardware support triangles as primitives, so the vertex count should be a multiple of 3

12.3.3 IndexArray

This field is an index in the section header table to an IndexArray that should be used alongside this VertexArray.
A value of 0 means that no IndexArray is associated to that VertexArray.

12.3.4 Total array size

The total size in bytes of the vertex array to use as pre-allocation buffer size when loading this model can be calculated as follows:

$$SA = S \times V \tag{4}$$

where SA is the total size of the vertex array, S the size of a single vertex structure as given in the VertexFormat asset and V the number of vertices in the array given by the VertexCount field.
To avoid storing an additional 64 bits field in the header of the VertexArray section this size SA is left to be calculated by the implementing application.

12.4 IndexArray

The index array section allows to ommit certain vertices and figure out these vertices at runtime. Instead of writing all vertices for a given model requiring more space to store them, we only store unique vertices, and duplicates are just resolved by matching a vertex index from this section to an actual vertex structure, **this allows to save storage space and RAM**.
This section contains a header describing the amount of indices to be found in the array, and an array of 32 bits unsigned integer each representing the index of a vertex in a given vertex array.
Below is a table describing the data structure to expect as header for an IndexArray section:

Name	Type	Size	Notes
IndexCount	Unsigned	32	Total number of indices

12.4.1 IndexCount

The number of indices expected to be read from the array below this header.

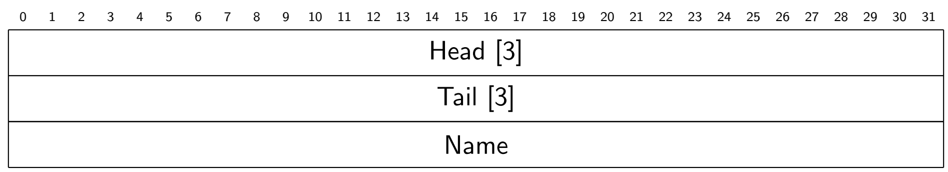
12.5 BoneArray

This section contains a header followed by an array of data structures representing each bone in a skeletal mesh. Below is a description of the header to find before bone data in this section:

Name	Type	Size	Notes
BoneCount	Unsigned	16	Total number of bones

Each bone in the array following the header is represented by the following data structure:

Name	Type	Size	Notes
Head	3D float vector	96	Initial position of bone head
Tail	3D float vector	96	Initial position of bone tail
Name	Unsigned	32	Pointer in the Strings section



12.5.1 BoneCount

Number of bones to expect in the bone array following the header. This number should belong to the interval $[1, 1024]$.

12.6 Analysis on theoretical bone limit

We can give an estimation that human skeleton can be up to 400 bones. Of course most models do not include as many bones to reduce GPU/CPU load.

- OpenGL, Vulkan and Metal maximum UBO/function constants storage size available to a shader is usualy 64Kb or 65536 bytes
- On the official MSDN page [9] for DirectX the maximum constant buffer size available to a shader is $4096constants \times 4 \times 32bits = 4096constants \times 16bytes = 65536bytes$

UBO, function constants and constant buffer refers to means of variable synchronisation between CPU accessible memory and GPU accessible memory. Vulkan is a special case as it actually supports faster memory called Push Constants, however these constants usually maxes at 256-512 bytes which is impracticable for storing bone transforms. Push constants are typically used to exchange important transformation matrices such as model, view or projection. The size of a transformation matrix in 3D space using homogeneous coordinate system [3] is $32bits(float) \times 4 \times 4(4 \times 4matrix) = 16 \times 32bits = 512bits = 64bytes$.
So assuming the lowest size for storing bones in VRAM for GPU processing is 65536 we can theoretically store up to 1024 matrices assuming each bone matrix represents 3D space transformations in homogeneous coordinate system ($\frac{65536}{64} = 1024$).
Which means in order to **keep compatibility** with as many platforms/rendering apis as possible also taking into account byte indexing, we should store the bone count as a 16 bits integer.

12.6.1 Head

Initial head position for that specific bone.

12.6.2 Tail

Initial tail position for that specific bone.

12.6.3 Name

Bone name as a pointer to a null terminated string in the strings section.

12.7 FrameArray

This section contains a header followed by an array of data structures each representing the new transform for a combination of a bone and frame.
The array should be organized as the following diagram describes:

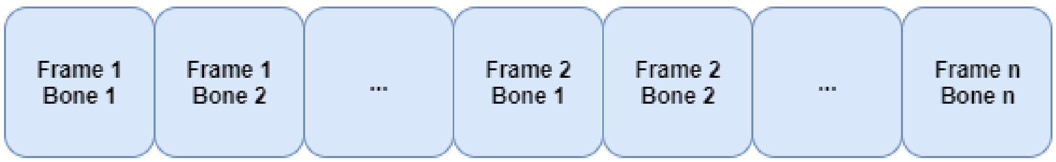


Figure 1: Diagram for organizing frame array

A single animation in a 3D model is usualy a set of actions. For example consider the following set of actions on a 3D human based model:

- move left leg
- move right leg
- move left arm
- move right arm

This set of actions could be grouped together in one animation named walking or running.
We call total animation time, the total time needed to express all animations for a single 3D model.

12.7.1 Design decision

The majority of mainstream formats represents animated models using key frames, that is storing only determinant changes in the model and interpolating intermediate frames at runtime (either when loading the file or while rendering). In BPX type M each frame is stored in the file to allow for any interpolation method, that is the interpolation if there's any is defined by the exporter of that model. The engine runtime does not have to provide any interpolation function for BPX type M.
This change grants the **flexibility** of using any interpolation functions even user defined.

12.7.2 Analysis on theoretical required storage size

We assume the total size required to store the full FrameArray is given by the following formula:

$$F \times B \times B_s \tag{5}$$

where F is the total amount of frames, B the number of bone updates per frame and B_s is the size of a single bone update structure.
We previously indicated that a bone update is determined by a transformation matrix in homogeneous coordinate space [3], that means it is exactly $512 bits$ or $64 bytes$.
Of course in a real application, it is very unlikely to have every frame in the timeline requiring update on every bone.

Worst case scenario
We assume the total animation time won't exceed 4 minutes.
We showed earlier that the theoretical maximum bone limit is 1024.
For the frame rate we choose 60, that means each second 60 frames in this FrameArray have to be rendered.
The total amount of frames to store is $60 \times 4 \times 60 = 14400 frames$.
The total size required to save a model assuming each frame requires dependency over exactly all bones is $14400 \times 1024 \times 512 = 7549747200 bits = 943718400 bytes$. That is approximately $944Mb$.

Average case scenario
Of course having 1024 bones in one model is unlikely to happen. This is why we want to have an average estimation on the size required to store the FrameArray section.
On average, the amount of bones per animated model won't exceed 50 bones.
On average, each frame will update at most 10 bones.
On average, the frame rate of a 3D model animation will be $30FPS$.
On average, the total animation time won't exceed 2 minutes.
The total amount of frames to store is $30 \times 2 \times 60 = 3600 frames$.
The total size required to save the FrameArray of a model assuming each frame requires dependency over exactly all bones is $3600 \times 10 \times 512 = 18432000 bits = 2304000 bytes$. That is approximately $2Mb$.

In conclusion the FrameArray section **should be compressed** to reduce the storage space consumed by a single model asset on disk. When loading the model in RAM one might consider adding some compression or supporting a lower limit than 1024 bones.

12.7.3 Bone transform

Each bone transformation in the FrameArray section is represented by the following structure:

Name	Type	Size	Notes
Rotation	4D float vector	128	Target bone rotation as a quaternion
Position	3D float vector	96	Target bone position
Scale	3D float vector	96	Target bone scale
BoneId	Unsigned	32	Index of affected bone

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
Rotation [4]
Position [3]
Scale [3]
BoneId

12.8 Strings

The strings section contains a list of null-terminated strings to be referenced by start offset from other sections (see 10.1).

13 BPX Type: Shader Package ('S')

13.1 Overview

The Shader Package BPX is using 'S' as the type byte of BPX Main Header. This type provides optimized and cross API/platform storage for rendering code intended to be executed on the GPU [11].
Below is a table describing the different sections to be expected in a BPXS:

Name	Type	Required	Single Time
Shader	1	Yes	No
Assembly	2	Yes	No
Bindings	3	Yes	No
MaterialConstants	4	Yes	Yes
Strings	255	Yes	Yes

At least one assembly section is required to be saved in the file.

13.1.1 Design decisions

The shader type has been designed to store different versions of a single shader but conpiled against different rendering APIs.
For this reason, each rendering API should load the shaders composing the program by referring to it's Assembly section.
The assembly section also contains required information when loading a shader program.
In order to account for cases where it is not possible to provide version for each rendering API of a given shader, the shader program BPX contains a bit mask field to indicate compatibility or incompatibility against a given rendering API.
For example a shader compiled under Linux won't have DirectX shader byte code, it can store the source code HLSL (High Level Shading Language is Microsoft's shading language for DirectX) however not all DirectX enabled systems can compile shaders on the fly.
In conclusion, for **better compatibility** it is recommended to build shaders under Windows, for the **best compatibility** a Mac will be needed in order to build shaders for MSL (Metal Shading Language is Apple's shading language for Metal API).

13.2 TypeExt

Contains information about the shader package.

Name	Type	Size	Notes
VertexFormatHash64	Unsigned	64	Hash of vertex format
VertexFormatHash32	Unsigned	32	Hash of vertex format
CompatibilityFlags	Unsigned	8	Flags
NumConstants	Unsigned	8	Number of constants
Reserved	Unspecified	16	Blank, always 0

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31

VertexFormatHash64		
VertexFormatHash64		
VertexFormatHash32		
CompatibilityFlags	NumConstants	Reserved

128 bits

13.2.1 VertexFormatHash64

64 bits hash of vertex format asset virtual path corresponding to the vertex structure that this shader expects as input.

13.2.2 VertexFormatHash32

32 bits hash of vertex format asset virtual path corresponding to the vertex structure that this shader expects as input.

13.2.3 CompatibilityFlags

Bit mask based flags (or flags together). These flags are used to check if a given shader program can be used with the current configuration of hardware/driver/rendering implementation. By default packages compiled from BPSL will be compatible with OpenGL 3.0 and greater; DirectX 11 and 12 will be supported if the compiling machine has Windows and the DirectX SDK (the DirectX SDK is not available on Linux/Mac/etc).
Currently the only supported flags are:

Name	Value	Notes
DirectX	0x1	Indicates compatibility with DirectX [8]
OpenGL	0x2	Indicates compatibility with OpenGL [4]
Vulkan	0x4	Indicates compatibility with Vulkan [5]
Metal	0x8	Indicates compatibility with Metal [1]

13.2.4 NumConstants

Number of constant description structures in the MaterialConstants section.

13.3 Shader

Contains shader data for a single rendering API...
A shader package can contain multiple shaders.

13.4 Assembly

Contains the shader list, order and other linking information for use by a rendering API. Below is a table describing the data structure to expect in this section:

Name	Type	Size	Notes
Driver	Unsigned	8	Target driver of this assenbly
Reserved	Unspecified	24	Blank, always 0
MinVersion	Unsigned	32	Minimum supported version
VertexShaderId	Unsigned	32	Vertex shader section index
DomainShaderId	Unsigned	32	Domain shader section index
HullShaderId	Unsigned	32	Hull shader section index
GeometryShaderId	Unsigned	32	Geometry shader section index
PixelShaderId	Unsigned	32	Pixel shader section index
Bindings	Unsigned	32	Number of bindings
BindingsId	Unsigned	32	Bindings section id

0–7	8–31
Driver	Reserved
MinVersion	
VertexShaderId	
HullShaderId	
DomainShaderId	
GeometryShaderId	
PixelShaderId	
Bindings	
BindingsId	

All indexes are given as positions in the Section Header Table.

13.4.1 Driver

The target rendering API for this assembly. List of possible values:

Name	Value
OpenGL	0
DirectX	1
Vulkan	2
Metal	3

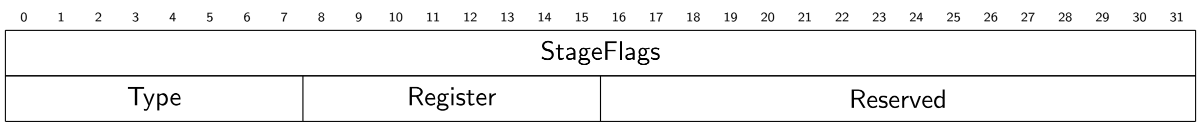
13.4.2 MinVersion

The minimum supported version for this shader. This value is dependent over the target rendering API supported by the assembly. Refer to the rendering API implementation for information on how the minimum version is encoded.

13.5 Bindings

The bindings section stores information about what bindings are used in this shader assembly for a particular rendering API.
This section stores an array of binding structures. A binding structure is defined by:

Name	Type	Size	Notes
StageFlags	Signed	32	Stage flags
Type	Unsigned	8	Type of binding
Register	Unsigned	8	Register number
Reserved	Unspecified	16	Blank, always 0



13.5.1 StageFlags

Describes to what stage this binding is acceptable. These flags are bit mask that can be or'ed together in order to map to multiple stages. Below is a table to list the different available flags:

Name	Value	Notes
LockVertexStage	0x1	Indicates binding locks to vertex shader
LockHullStage	0x2	Indicates binding locks to hull shader
LockDomainStage	0x4	Indicates binding locks to domain shader
LockGeometryStage	0x8	Indicates binding locks to geometry shader
LockPixelStage	0x10	Indicates binding locks to pixel shader

13.5.2 Type

The type of binding. Currently there are only 4 types of binding:

Name	Value
Texture	0
Sampler	1
ConstantBuffer	2
FixedConstantBuffer	3

13.6 MaterialConstants

The Material structure expected by this shader. Like for the binding section, this section is also a contiguous array of constant description structures. A constant description structure is defined as follows:

Name	Type	Size	Notes
Name	Unsigned	32	Name of constant
Type	Unsigned	8	Type of constant
Reserved	Unspecified	24	Blank, always 0

<table>
<tr><td>0</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>9</td><td>10</td><td>11</td><td>12</td><td>13</td><td>14</td><td>15</td><td>16</td><td>17</td><td>18</td><td>19</td><td>20</td><td>21</td><td>22</td><td>23</td><td>24</td><td>25</td><td>26</td><td>27</td><td>28</td><td>29</td><td>30</td><td>31</td></tr>
<tr><td colspan="32">Name</td></tr>
<tr><td colspan="8">Type</td><td colspan="24">Reserved</td></tr>
</table>

13.6.1 Name

The name of the constant as an offset pointer in the string section.

13.7 Type

The type of constant. Below is an exhaustive table of all accepted types:

Name	Value
Float	0
VectorFloat2	1
VectorFloat3	2
VectorFloat4	3
Integer	4
VectorInteger2	5
VectorInteger3	6
VectorInteger4	7
Unsigned	8
VectorUnsigned2	9
VectorUnsigned3	10
VectorUnsigned4	11
Boolean	12
VectorBoolean2	13
VectorBoolean3	14
VectorBoolean4	15
ColorRGB	16
ColorRGBA	17
Double	18
VectorDouble2	19
VectorDouble3	20
VectorDouble4	21

13.8 Strings

The strings section contains a list of null-terminated strings to be referenced by start offset from other sections (see 10.1).

14 BPX Type: Package ('P')

14.1 Overview

The Package BPX is using 'P' as the type byte of BPX Main Header. This type provides asset packages using the BPX format.
Below is a table describing the different sections to be expected in a BPXP:

Name	Type	Required	Single Time
Data	1	Yes	No
ObjectTable	2	Yes	Yes
Metadata	254	No	Yes
Strings	255	Yes	Yes

NOTE: The order of Data sections MUST be contiguous. An object is allowed to be divided in multiple sections, however an object header MUST NOT be divided.

Revision 2 (SDK $\geq$ 3.0)

- A Data section is not allowed to store object headers anymore, the ObjectTable section is here to store all object headers.
- An additional required ObjectTable section MUST only be generated in a BPX rev 2 or later.
- All data of a given object must be stored in a contiguous set of Data sections.

14.2 TypeExt

Contains general information about the Package.

Name	Type	Size	Notes
Architecture	Unsigned	8	Target architecture
Platform	Unsigned	8	Target platform
Generator	Unsigned	16	Generator ID
Reserved	Unsigned	96	Blank, always 0

0–7	8–15	16–31
Architecture	Platform	Generator
Reserved		
Reserved		
Reserved		

128 bits

14.2.1 Architecture

8 bits of architecture stored as an enumeration. The current allowed values are:

Name	Value
x86_64	0
aarch64	1
x86	2
armv7hl	3
any	4

14.2.2 Platform

8 bits of platform stored as an enumeration. The current allowed values are:

Name	Value
Linux	0
MacOS	1
Windows	2
Android	3
Any	4

14.2.3 Generator

16 bits of generator identification stored as 2 ASCII characters. The current known values are:

ASCII string	Notes
"PK"	Generated by FPKG
"BP"	Generated by BlockProject 3D Engine
"BD"	Generated by BPX debug tools

The generator identification is only useful to know the expected structure of the optional Metadata section.

14.3 Data

The Data section is used to store one or more objects. Each object begins by an object header which is defined as:

Name	Type	Size	Notes
Size	Unsigned	64	File size
Path	Unsigned	32	Pointer in the Strings section

14.3.1 Size

The total size of the object to read. When extracting an object which size is greater than the remaining bytes in the section just continue reading from next section as if the next section was simply a continuation of the current one.

14.3.2 Path

The path as a pointer to a null terminated string in the strings section. Used to identify relative extraction location and/or the virtual path of the asset in a rendering application.

Revision 2 (SDK $\geq$ 3.0)

No object header is to be written inside a Data section anymore. However a Data section can still be used to store multiple objects.

14.4 FileTable

The FileTable section stores an array of object headers where each object header points to an actual Data section where the start of the object is expected.
An object header is represented by the following structure:

Name	Type	Size	Notes
Size	Unsigned	64	Object size
Path	Unsigned	32	Pointer in the Strings section
Start	Unsigned	32	Index of the starting data section
Offset	Unsigned	32	Offset relative to the start of the data section

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63

Size	
Path	Start

14.4.1 Size

The total size of the object to read. When extracting an object which size is greater than the remaining bytes in the section just continue reading from next section as if the next section was simply a continuation of the current one.
It is expected to store as many objects as possible in one section in order to enable efficient data compression in case many small objects are packed.
When attempting to store a large object consider storing it in it's own section to avoid segmentation when reading the object.

14.4.2 Path

The path as a pointer to a null terminated string in the strings section. Used to identify relative extraction location and/or the virtual path of the asset in a rendering application.

14.4.3 Start

The index of the section to start reading the content of the object. In order to not over-read, refer to the size of the object as given in the object header.

14.5 Strings

The strings section contains a list of null-terminated strings to be referenced by start offset from other sections (see 10.1).

14.6 Metadata

The metadata section contains generator specific information about the package. It is encoded as a Structured Data Section (see 10.2).

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