GRAME - Computer Music Research Lab.
Technical Note - 01-11-07

Callback adaptation techniques

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November 2001
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Abstract

This document describes a callback adaptation technique developed for the PortAudio port on ASIO. This method handle buffers of different sizes and guarantee lowest latency added by buffer size adaptation.

1 Introduction

The callback adaptation problem was encountered whilst doing a port of the PortAudio API on ASIO API. PortAudio is a cross-platform library that provides streaming audio input and output, ASIO is a Macintosh and Windows API that provides streaming audio input and output. Both API are callback based, but may use audio buffers of different size. This document presents an algorithm developed to allow adaptation between the 2 callback systems.

2 Adapting callbacks

The system we are considering is driven by an audio native callback (the “host” callback) usually called by the hardware interrupt. The host audio callback has the following prototype :

hostCallback (void* inputBuffer, void* ouputBuffer, int frameNumber, void* userData);

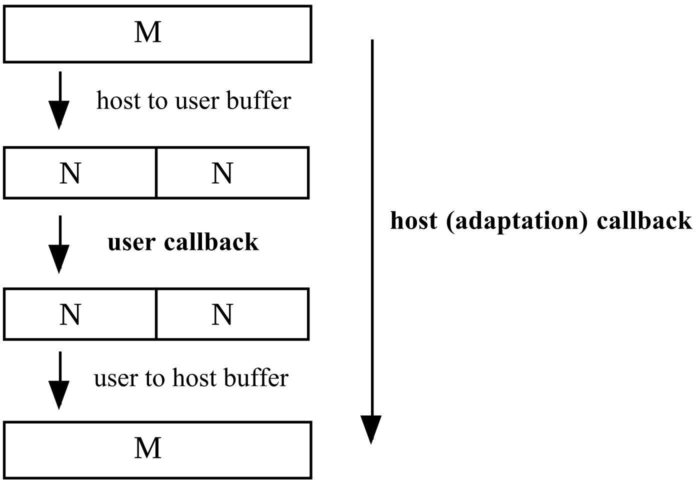
Upon return of the callback, the application has read all input data and provided all output data. InputBuffer and OutputBuffer have the same number or frames **M**.

The internal callback (the “user” callback) is implemented by the application and has the following prototype :

userCallback (void* inputBuffer, void* ouputBuffer, int frameNumber, void* userData);

where InputBuffer and OutputBuffer have the same number or frames **N**.

The user callback will be provided by the application and one need to develop the host (adaptation) callback to be given to the host audio engine. So we have two different callback and in general two different buffer sizes M and N. The running cycle is the following :



- the hardware fills the **host input buffer** of size M
- the **hostCallback** is called
- the **host input buffer** of size M is transfered to the **user input buffer** of size N
- the **userCallback** must be called to produce a **user ouput buffer** of size N
- the **user ouput buffer** of size N is transfered into the **host ouput bufffer** of size M
- the hardware uses the **host ouput buffer** of size M

Because M and N are in general different, an adpatation system must be developed. Some remaining frames will have to be kept during one cycle to be used during the next cycle. The number of user callback calls in each cycle will not be always the same.

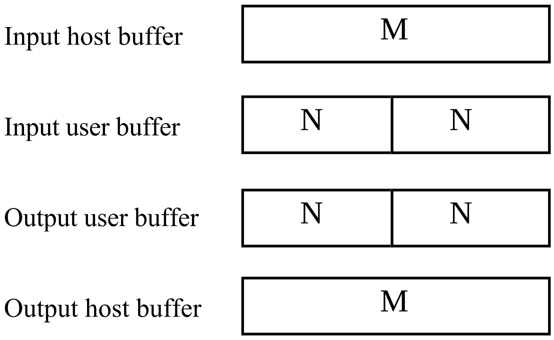
The following constraints must be respected :

- at each host callback a **full M frames** input buffer is received, this buffer must be **completely used**, a **full M frames ouput buffer must be produced.**
- the user callback must always be called with a **full N frames input buffer** and will produce a **N frames ouput buffer**.
- **latency has to be minimized** in a full-duplex case.

3 Buffer size adapdation techniques

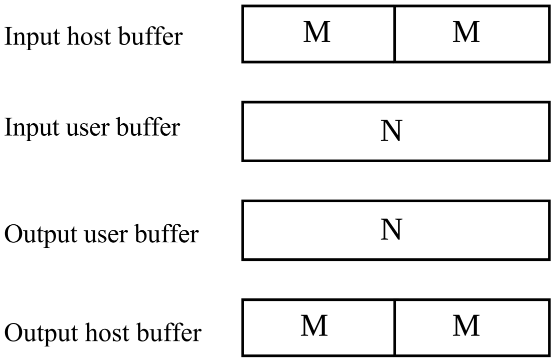
To be able to adapt the two callbacks, different cases have to be considered :

3.1 Case 1 : host buffer size multiple of user buffer size



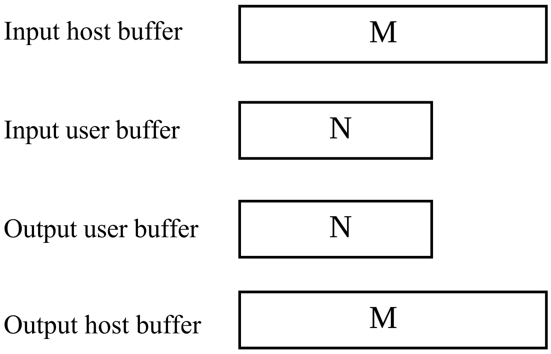
Nothing difficult here, at each host callback, an M size host buffer is received, because M is a multiple of N, M/N user callback can be called producing a complete M size host output buffer.

3.2 Case 2 : host buffer size divisor of user buffer size

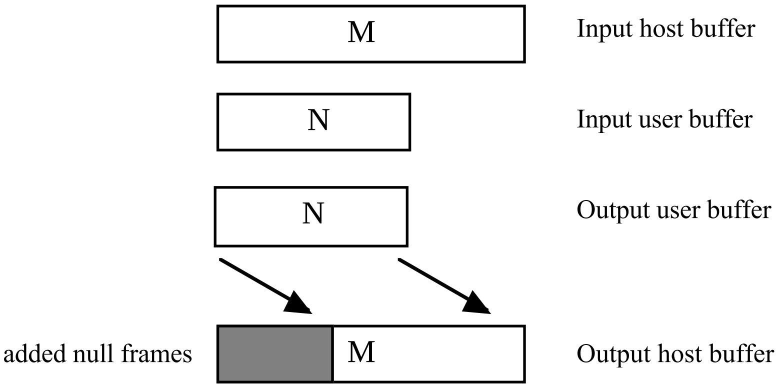


In the previous simple example where N = 2M, we have the following : at the first host callback, an M size host buffer is received, the user callback can not be called so the host input buffer content is kept. A null host output buffer is produced. At the next host callback, the user callback can be called, producing an M size ouput buffer. An host ouput buffer can be produced consuming M = N/2 frames, and so on. The ouput stream has been globally delayed by a complete M size buffer. The way of doing can be generalized for case where N= n*M.

3.3 Case 3 : host buffer size superior of user buffer size



This a more complex case when a more sophisticated buffer size adaptation system must be found. At the first host callback, a host buffer of size M is received. Because M > N, the user callback can be called consuming N frames and producing an output user buffer of N frames. But because N < M, a complete output host buffer **can not be produced directly**. The beginning of the first produced host output number must be filled with null frames, obtaining the following scheme :



Some remaining frames have to be kept during one cycle to be used during the next cycle both into the user input buffer and the user output buffer. Four values are used to describe the state of the system :

- **Host input buffer** = the number of frames available in the host input buffer
- **User input buffer** = the number of frames possibly kept in the user input buffer between two consecutive host callbacks
- **User output buffer** = the number of frames possibly kept in the user output buffer between two consecutive host callbacks
- **Host output buffer** = the number of frames written into the host ouput buffer

Let take a real example with M = 100 and N = 70. To be able to complete the first host ouput buffer we could choose **M-N = 30**, and we can display the state of the system at the beginning and the end of each host callback :

Beginning of callback 1

Host input buffer = **100** : the host input buffer is full
User input buffer = 0
User ouput buffer = 0
Host ouput buffer = 30 : added null frames for the first ouput buffer

After one adapdation cycle, the system state is the following :

End of callback 1

Host input buffer = 0 : all input frames have been used
User input buffer = 30 : remaining host input frames (remainder of 100/70)
User ouput buffer = 0
Host ouput buffer = 70 + 30 added null frames = **100** ==> the host ouput buffer is full

Beginning of callback 2 : 100 new frames are received

Host input buffer = **100**
User input buffer = 30 : frames kept from the previous cycle
User ouput buffer = 0
Host ouput buffer = 0

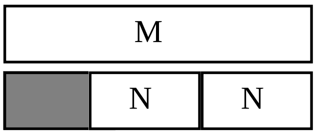
End of callback 2

Host input buffer = 0
User input buffer = 60 : remainder of (100 + 30)/70
User ouput buffer = **70**
Host ouput buffer = 0

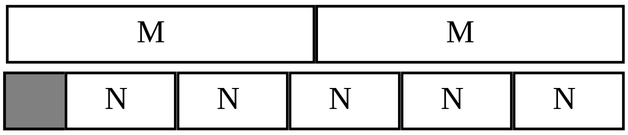
There is a problem here because a complete host ouput buffer can not be produced (because 70 <100)**.** Thus the value has to be choosen to guarantee that a **complete host ouput buffer can be produced at each cycle**. We could just add **N null frames** to start the process. But adding null frames at the beginning of the first host output buffer (that is shifting the whole ouput stream), increases the global latency.

Thus we would like to find the **smallest number of null frames** that must be put in the first output host buffer to guarantee that the audio streaming process can be done. This value can be found by doing the following reasoning :

- **At the first host callback :** M frames are received, and M/N PortAudio callback can be called. The minimum number of needed frames to complete a full M ouput buffer is **M%N** (where % gives the **remainder** of M/N).



- **At the second host callback :** the total number of received frames from the beginning is 2*M frames. The total number of user callback that can be called is (2*M)/N. The minimum number of needed frames to complete 2*M ouput buffers is (2*M)%N.



- **At the n host callback :** the total number of received frames from the beginning is n*M frames. The total number of user callback that can be called is (n*M)/N. The minimum number of needed frames to complete n*M ouput buffers is (n*M)%N.

Thus the set of all remainders of M/N, (2*M)/N....(n*M)/N can be computed. The computation must be done until the **PPCM of M and N** is reached. Indeed we can see that at **PPCM(M,N)+M** we have :

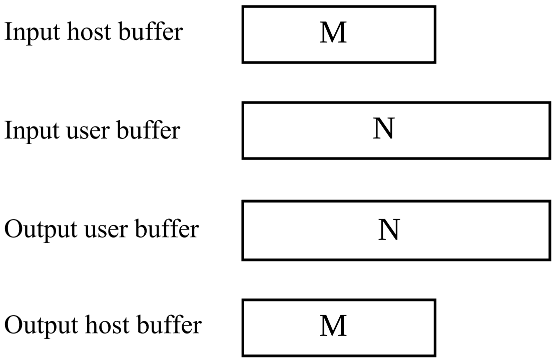
[PPCM(M,N)+M]/N = PPCM(M,N)/N + M/N = a + M/N where a is an integer value

So the remainder of **[PPCM(M,N)+M]/N** is the same of the remainder of **M/N**, thus the set of remainder values is now complete because the same cycle of values start again. Going from M, 2*M... up to the PPCM (M,N), a series of values is obtained. These values are the **minimum frame numbers** that should be added at each step to guarantee that the required number of buffer of size M can be produced.

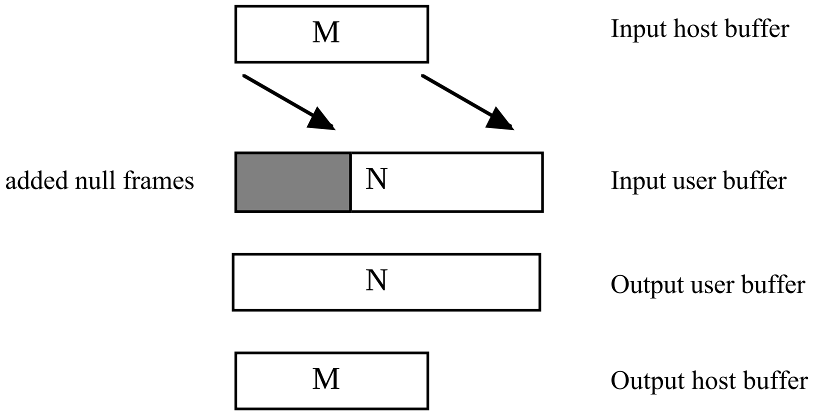
To be sure that the required number of buffers of size M can be produced at each cycle, the **maximum of this set of values** must be choosen.

- **the minimum number of frame to be added to the first host ouput buffer is the maximum of the serie (n*M)%N computed from M up to PPCM (M,N).**

3.4 Case 4 : host buffer size inferior of user buffer size



The same reasoning can be used in this case, and we can show that the previously explained algorithm can also be used to compute the needed value.



Here the null frames will be added to the **beginning of the first user input buffer**, so that the user callback can be called, and one host ouput buffer can be produced. Actually the adaptation algorithm can be used in the four different cases, where cases 1 and 2 are the more simple ones.

3.5 Performances

The used method guarantee that the latency added by buffer size adaptation is the smallest. It gives a pratical way to know the right value to be used, even if the gain in latency is usually small. Actually in the case when the host buffer size M is greater to the user buffer size N, and depending of the values M and N, the gain in latency can be up to N/2. Indeed the buffer size adaptation algorithm gives N-1 in the worst case and N/2 in the best case.

4 Implementation

The following implementation uses a **CallbackAdaptor** data structure that contains several variables needed during each adaptation cycle.

// Utilities for buffer size alignment computation

```
int PGCD (int a, int b) {return (b == 0) ? a : PGCD (b,a%b);}
int PPCM (int a, int b) {return (a*b) / PGCD (a,b);}
```

// Takes the size of host buffer and user buffer : returns the number of frames needed for buffer alignment

```
int CalcFrameShift (int M, int N)
{
        int res = 0;
        for (int i = M; i < PPCM (M,N) ; i+=M) { res = max (res, i%N); }
        return res;
}
```

// Type for the audio callbacks

```
typedef int (audioCallback)
       (void *inputBuffer, void *outputBuffer, int framesPerBuffer, void* userData);
```

// Data structure for callback adaptation

```
typedef struct {

       float* userInputBuffer;
       float* userOutputBuffer;

       // Offset in host input buffer
       int hostInputBufferOffset;
       // Offset in host ouput buffer
       int hostOutputBufferOffset;
       // Offset in user input buffer
       int userInputBufferOffset;
       // Offset in user ouput buffer
       int userOutputBufferOffset;

       int hostBufferSize;
       int userBufferSize;
       audioCallback* userCallback;

}CallbackAdaptor;
```

// Function to be provided to handle transfer of samples between host and user buffers

```
void CopyUser2Host (float* input, float* ouput, int frames)
{
       /* To be completed */
       printf ("CopyUser2Host : %d\n",frames);
}
```

// Function to be provided to handle transfer of samples between user and host buffers

```
void CopyHost2User (float* input, float* ouput, int frames)
{
       /* To be completed */
       printf ("CopyHost2User : %d\n",frames);
}
```

// Allocates a new CallbackAdaptor :

```
CallbackAdaptor*  MakeCallbackAdaptor (int M, int N, audioCallback* callback)
{
       CallbackAdaptor* adaptor = (CallbackAdaptor*)malloc (sizeof(CallbackAdaptor));

       // Allocation of user buffers
       adaptor->userInputBuffer = (float*)malloc(N*sizeof(float));
       adaptor->userOutputBuffer = (float*)malloc(N*sizeof(float));
```

```
        adaptor->userCallback = callback;
        adaptor->hostBufferSize = M;
        adaptor->userBufferSize = N;
        return adaptor;
}
```

// Computes the shift value used for the first ouput buffer : this value is used to initialize the write offset in the user input buffer or the host ouput buffer depending of M and N

```
void  InitCallbackAdaptor (CallbackAdaptor* adaptor)
{
        int frameShift = CalcFrameShift(adaptor->hostBufferSize,adaptor->userBufferSize);

        if (adaptor->userBufferSize <= adaptor->hostBufferSize) {
                adaptor->hostInputBufferOffset = 0;                             // empty
                adaptor->hostOutputBufferOffset = frameShift;
                adaptor->userInputBufferOffset = 0;                             // empty
                adaptor->userOutputBufferOffset = adaptor->userBufferSize;      // empty
        }else {
                adaptor->hostInputBufferOffset = 0;                             // empty
                adaptor->hostOutputBufferOffset = 0;                            // empty
                adaptor->userInputBufferOffset = frameShift;
                adaptor->userOutputBufferOffset = adaptor->userBufferSize;      // empty
        }
}
```

// Delete a CallbackAdaptor

```
void DeleteCallbackAdaptor (CallbackAdaptor* adaptor)
{
        if (adaptor->userInputBuffer) free (adaptor->userInputBuffer);
        if (adaptor->userOutputBuffer) free (adaptor->userOutputBuffer);
        free(adaptor);
}
```

// Internal function used by HostCallback

```
void OutputUser2Host(CallbackAdaptor* adaptor, float* hostOuputBuffer, int framesNumber)
{
    if (framesNumber > 0) {

        CopyUser2Host(adaptor->userOutputBuffer, hostOuputBuffer, framesNumber);

        adaptor->hostOutputBufferOffset += framesNumber;
        adaptor->userOutputBufferOffset += framesNumber;
    }
}
```

// Callback adpatation : does the host to user buffer transfer. Call of the the user callback, user to host buffer transfer

```
void HostCallback
        (void* InputBuffer, void* OuputBuffer, int framesPerBuffer, void* userData)
{
        float* hostInputBuffer = (float*) InputBuffer;
        float* hostOuputBuffer = (float*) OuputBuffer;

        CallbackAdaptor* adaptor = (CallbackAdaptor*)userData;

        // number of frames available into the host input buffer
        long framesInputHostBuffer = framesPerBuffer;
        // number of frames needed to complete the user input buffer
        long framesInputUserBuffer;
        // number of frames needed to complete the host output buffer
        long framesOutputHostBuffer;
        // number of frames available into the user output buffer
        long framesOuputUserBuffer;
        long tmp;

        /* Fill host output with remaining frames in user output */
        framesOutputHostBuffer = framesPerBuffer - adaptor->hostOutputBufferOffset;
        framesOuputUserBuffer = adaptor->userBufferSize - adaptor->userOutputBufferOffset;
        tmp = min(framesOutputHostBuffer, framesOuputUserBuffer);
        framesOutputHostBuffer -= tmp;
        OutputUser2Host(adaptor,hostOuputBuffer, tmp);

        /* Available frames in hostInputBuffer */
        while (framesInputHostBuffer > 0) {

          /* Number of frames needed to complete an user input buffer */
         framesInputUserBuffer = adaptor->userBufferSize - adaptor->userInputBufferOffset;

         if (framesInputHostBuffer >= framesInputUserBuffer) {

            CopyHost2User (hostInputBuffer, adaptor->userInputBuffer, framesInputUserBuffer);

              /* Call user callback */
             adaptor->userCallback(adaptor->userInputBuffer, adaptor->userOutputBuffer,
                                            adaptor-userBufferSize, NULL);

              /* Full user ouput buffer : write offset */
            adaptor->userOutputBufferOffset = 0;

              /* Empty user input buffer : read offset */
            adaptor->userInputBufferOffset = 0;

            tmp = min (adaptor->userBufferSize,framesOutputHostBuffer);
             OutputUser2Host(adaptor, hostOuputBuffer, tmp);

            framesOutputHostBuffer -= tmp;
            framesInputHostBuffer -= framesInputUserBuffer;
            adaptor->hostInputBufferOffset += framesInputUserBuffer;

         }else {

             CopyHost2User (hostInputBuffer, adaptor->userInputBuffer,framesInputHostBuffer);

            adaptor->userInputBufferOffset += framesInputHostBuffer;
            adaptor->hostInputBufferOffset += framesInputHostBuffer;

            framesInputHostBuffer = 0;
         }
    }
}

// The following functions are used to simulate a real system :

// To "simulate" the hardware interrupt :  the host input buffer has been filled, it is now full
void ReadInputHostBuffer(CallbackAdaptor* adaptor)
{
        adaptor->hostInputBufferOffset = 0; // full host input buffer;
}
```

// To “simulate” the hardware interrupt : the host ouput buffer has been used, it is now empty

```
void WriteOutputHostBuffer(CallbackAdaptor* adaptor)
{
	adaptor->hostOutputBufferOffset = 0; // empty host output buffer;
}
```

// Prints the state of the CallbackAdaptor structure

```
void PrintCallbackAdaptorState(CallbackAdaptor* adaptor)
{
	printf ("Adaptor : hostInputBufferOffset %ld \n", adaptor->hostInputBufferOffset);
	printf ("Adaptor : hostOuputBufferOffset %ld \n", adaptor->hostOutputBufferOffset);
	printf ("Adaptor : userInputBufferOffset %ld \n", adaptor->userInputBufferOffset);
	printf ("Adaptor : userOuputBufferOffset %ld \n", adaptor->userOutputBufferOffset);
}
```

// The user callback

```
int  UserCallback
	(void *inputBuffer, void *outputBuffer,int  framesPerBuffer, void* userData)
 {
	printf ("UserCallback : framesPerBuffer %d \n",framesPerBuffer);
 }
```

// General simuation function

```
void Simulate (int M, int N)
{
	int i,n = PPCM(M,N)/M+1;
	CallbackAdaptor* adaptor = MakeCallbackAdaptor(M, N, UserCallback);
	InitCallbackAdaptor(adaptor);

	// Allocation of host buffers
	float*  hostInputBuffer = (float* )malloc(M*sizeof(float));
	float*  hostOutputBuffer = (float* )malloc(M*sizeof(float));

	printf ("\n------------------------------------------- \n");
	printf ("Simulation of Callback adaptor [%d,%d]\n", M, N);

	for (i = 0; i< n ; i++) {
		printf ("----------------- \n");
		printf ("Callback %d \n",i);
		printf ("----------------- \n");
		ReadInputHostBuffer(adaptor);
		PrintCallbackAdaptorState(adaptor);
		HostCallback(hostInputBuffer,hostOutputBuffer,M,adaptor);
		PrintCallbackAdaptorState(adaptor);
		WriteOutputHostBuffer(adaptor);
	}

	DeleteCallbackAdaptor(adaptor);

	free(hostInputBuffer);
	free(hostOutputBuffer);
}

int  main ()
{
	printf ("\n---------------------------\n");
	printf ("Simulation of Callback adaptor\n");
	Simulate(2016,512);
	Simulate(128,250);
	printf ("End of simulation \n");
}
```

5 Conclusion

A callback adaptation technique has been presented. It allows to use two callbacks that use buffers of different sizes, and guarantee the lowest latency added by buffer size adaptation. This technique has been successfully used for the port of the PortAudio API on ASIO described in [Letz 2001].

References

[ASIO 97-99] Asio 2.0 Audio Streaming Input Ouput Developement kit. Steinberg (c) 1997-1999 Steinberg Soft - und harware GmbH.

[Bencina, Burk 2001] Ross bencina, Phil Burk “PortAudio : an Open Source Cross Platform Audio API” Proceedings of the International Computer Music Conference 2001, International Computer Music Association, San Francisco.

[Letz 2001] Stephane Letz “Porting PortAudio API on ASIO” GRAME - Computer Music Research Lab. Technical Note - 01-11-06