Understanding the Low Fragmentation Heap

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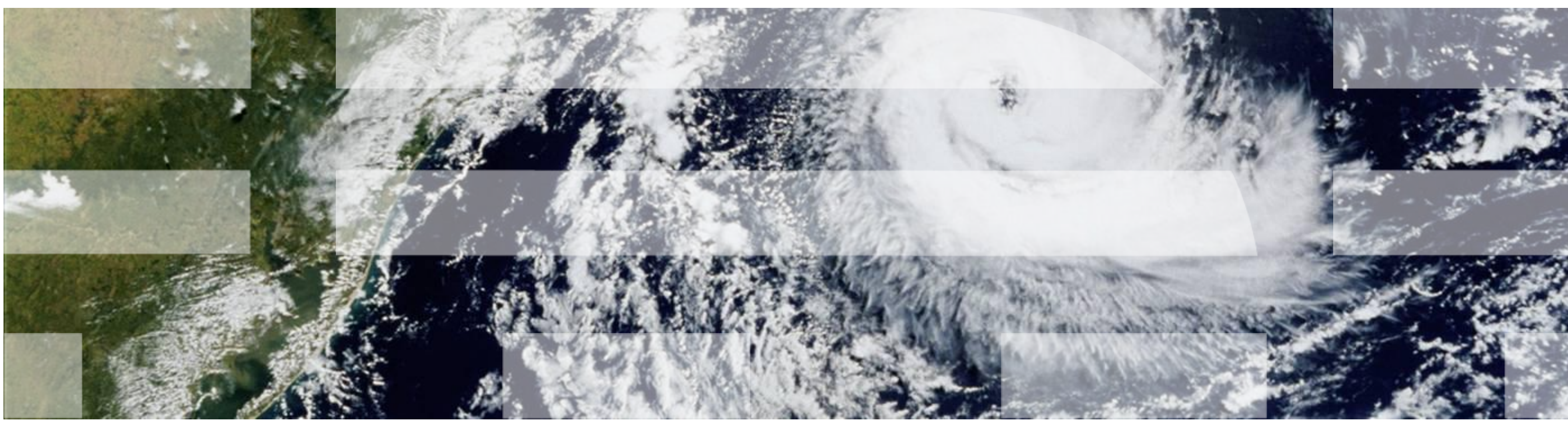
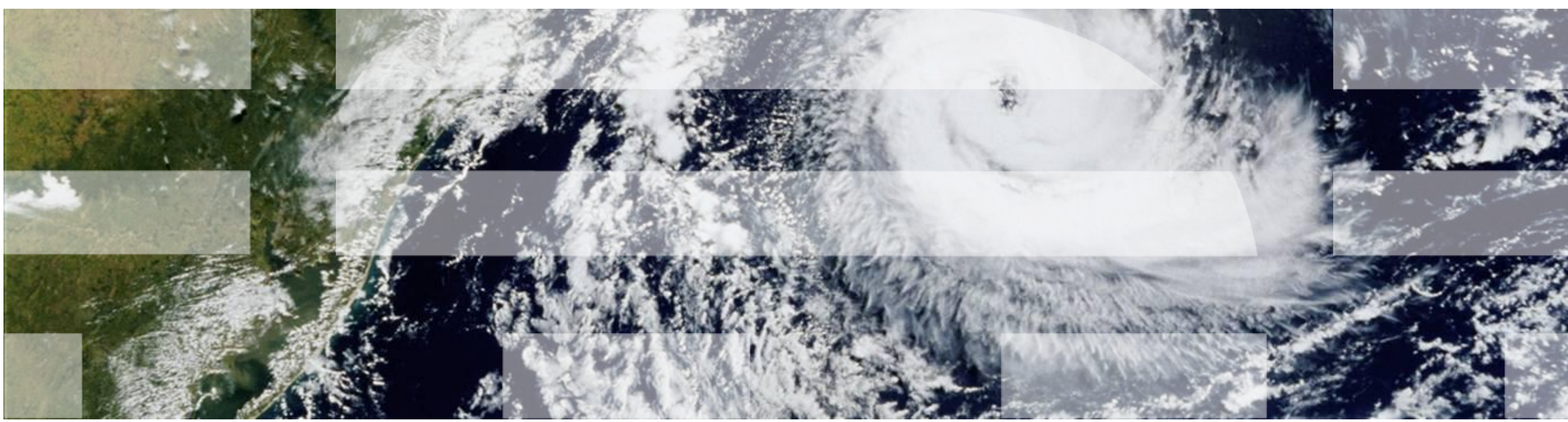


Introduction

“What. Are. You……?”



Introduction

- Much has changed since Windows XP
- Data structures have been added and altered
- Memory management is now a bit more complex
- New security measures are in place to prevent meta-data corruption
- Heap determinism is worth more than it used to be
- Meta-data corruption isn’t entirely dead

The Beer List

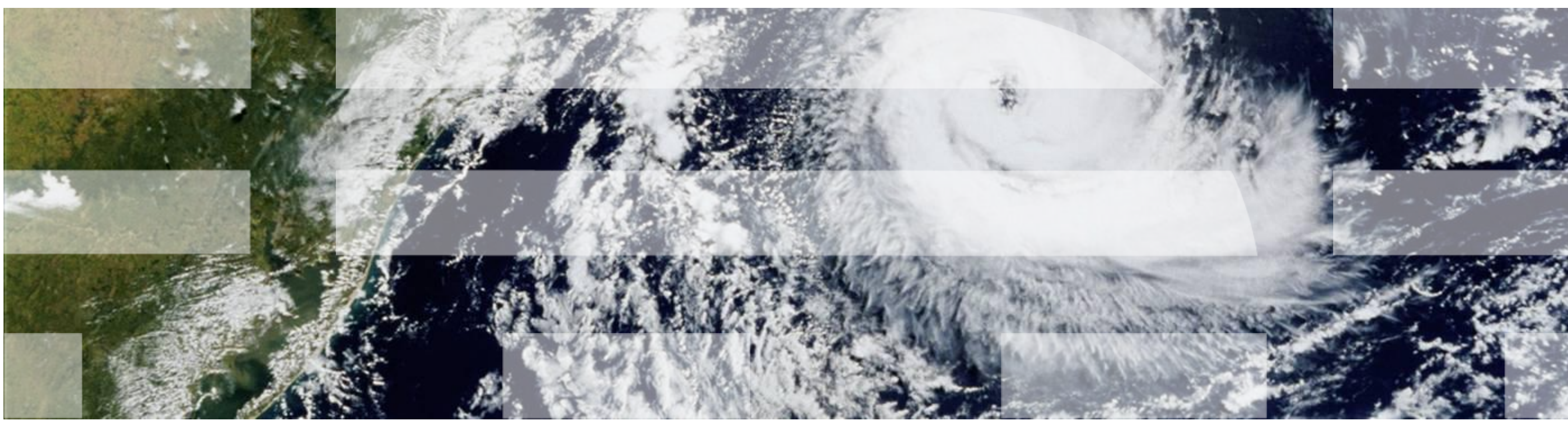
- Core data structures
  - _HEAP
  - _LFH_HEAP
  - _HEAP_LIST_LOOKUP
- Architecture
  - FreeLists
- Core Algorithms
  - Back-end allocation (RtlpAllocateHeap)
  - Front-end allocation (RtlpLowFragHeapAllocFromContext)
  - Back-end de-allocation (RtlpFreeHeap)
  - Front-end de-allocation (RtlpLowFragHeapFree)
- Tactics
  - Heap determinism
    - LFH specific heap manipulation
  - Exploitation
    - Ben Hawkes #1
    - FreeEntry Offset
    - Observations

Prerequisites

- All pseudo-code and data structures are taken from Windows 7 ntdll.dll version 6.1.7600.16385 (32-bit)
  - Yikes! I think there is a new one…
- Block/Blocks = **8-bytes**
- Chunk = contiguous piece of memory measured in **blocks** or **bytes**
- HeapBase = _HEAP pointer
- LFH = Low Fragmentation Heap
- BlocksIndex = _HEAP_LIST_LOOKUP structure
  - 1st BlocksIndex manages chunks from 8 to 1024 bytes
    - ListHint[0x7F] = Chunks >= 0x7F **blocks**
  - 2nd BlocksIndex managages chunks from 1024 bytes to 16k bytes
    - ListHint[0x77F] = Chunks >= 0x7FF **blocks**
- Bucket/HeapBucket = _HEAP_BUCKET structure used as size/offset reference
- HeapBin/UserBlocks = Actually memory the LFH uses to fulfill requests

Core Data Structures

“Ntdll changed, surprisingly I didn’t quit”



_HEAP
(HeapBase)

_HEAP
+0x04c EncodeFlagMask : Uint4B
+0x050 Encoding : _HEAP_ENTRY
+0x0b8 BlocksIndex : Ptr32 Void
+0x0c4 FreeLists : _LIST_ENTRY
+0x0d4 FrontEndHeap : Ptr32 Void
+0x0da FrontEndHeapType : UChar

- **EncodeFlagMask** – A value that is used to determine if a heap chunk **header** is encoded. This value is initially set to 0x100000 by **RtlpCreateHeapEncoding()** in **RtlCreateHeap()**.
- **Encoding** – Used in an XOR operation to encode the chunk **headers**, preventing predictable meta-data corruption.
- **BlocksIndex** – This is a **_HEAP_LIST_LOOKUP** structure that is used for a variety of purposes. Due to its importance, it will be discussed in greater detail in the next slide.
- **FreeLists** – A special linked-list that contains pointers to ALL of the free chunks for this heap. It can almost be thought of as a **heap cache**, but for chunks of every size (and no single associated bitmap).
- **FrontEndHeapType** – An integer is initially set to 0x0, and is subsequently assigned a value of 0x2, indicating the use of a **LFH**. Note: Windows 7 does not actually have support for using **Lookaside Lists**.
- **FrontEndHeap** – A pointer to the associated front-end heap. This will either be NULL or a pointer to a _LFH_HEAP structure when running under Windows 7.

_HEAP_LIST_LOOKUP

(HeapBase->BlocksIndex)

_HEAP_LIST_LOOKUP
+0x000 ExtendedLookup : Ptr32 _HEAP_LIST_LOOKUP
+0x004 ArraySize : Uint4B
+0x010 OutOfRangeItems : Uint4B
+0x014 BaseIndex : Uint4B
+0x018 ListHead : Ptr32 _LIST_ENTRY
+0x01c ListsInUseUlong : Ptr32 Uint4B
+0x020 ListHints : Ptr32 Ptr32 _LIST_ENTRY

- **ExtendedLookup** - A pointer to the next **_HEAP_LIST_LOOKUP** structure. The value is NULL if there is no **ExtendedLookup**.
- **ArraySize** – The highest **block** size that this structure will track, otherwise storing it in a *special* **ListHint**. The only two sizes that Windows 7 currently uses are **0x80** and **0x800**.
- **OutOfRangeItems** – This 4-byte value counts the number items in the *FreeList[0]-like* structure. Each **_HEAP_LIST_LOOKUP** tracks free chunks larger than **ArraySize-1** in **ListHint[ArraySize-BaseIndex-1]**.
- **BaseIndex** – Used to find the relative offset into the **ListHints** array, since each _HEAP_LIST_LOOKUP is designated for a certain size. For example, the BaseIndex for 1st BlocksIndex would be 0x0 because it manages lists for chunks from **0x0 – 0x80**, while the 2nd BlocksIndex would have a BaseIndex of **0x80**.
- **ListHead** – This points to the same location as **HeapBase->FreeLists**, which is a linked list of all the free chunks available to a heap.
- **ListsInUseUlong** – Formally known as the **FreeListInUseBitmap**, this 4-byte integer is an optimization used to determine which **ListHints** have available chunks.
- **ListHints** – Also known as **FreeLists**, these linked lists provide pointers to free chunks of memory, while also serving another purpose. If the **LFH** is enabled for a given **Bucket** size, then the **blink** of a specifically sized **ListHint/FreeList** will contain the address of a **_HEAP_BUCKET** + 1.

_LFH_BLOCK_ZONE
(HeapBase->FrontEndHeap->LocalData->CrtZone)

_LFH_BLOCK_ZONE
+0x000 ListEntry : _LIST_ENTRY
+0x008 FreePointer : Ptr32 Void
+0x00c Limit : Ptr32 Void

- **ListEntry** – A linked list of **_LFH_BLOCK_ZONE** structures.
- **FreePointer** – This will hold a pointer to memory that can be used by a **_HEAP_SUBSEGMENT**.
- **Limit** – The last **_LFH_BLOCK_ZONE** structure in the list. When this value is reached or exceeded, the **back-end** heap will be used to create more **_LFH_BLOCK_ZONE** structures.

_LFH_HEAP

(HeapBase->FrontEndHeap)

_LFH_HEAP	
+0x024 Heap	: Ptr32 Void
+0x110 Buckets	: [128] _HEAP_BUCKET
+0x310 LocalData	: [1] _HEAP_LOCAL_DATA

- **Heap** – A pointer to the parent heap of this **LFH**.
- **Buckets** – An array of 0x4 byte data structures that are used for the sole purpose of keeping track of indices and sizes. This is why the term **Bin** will be used to describe the area of memory used to fulfill request for a certain **Bucket** size.
- **LocalData** – This is a pointer to a large data structure which holds information about each **SubSegment**. See _HEAP_LOCAL_DATA for more information.

_HEAP_LOCAL_DATA
(HeapBase->FrontEndHeap->LocalData)

_HEAP_LOCAL_DATA
+0x00c LowFragHeap : Ptr32 _LFH_HEAP
+0x018 SegmentInfo : [128] _HEAP_LOCAL_SEGMENT_INFO

- **LowFragHeap** – The **Low Fragmentation heap** associated with this structure.
- **SegmentInfo** – An array of **_HEAP_LOCAL_SEGMENT_INFO** structures representing all available sizes for this **LFH**. This structure type will be discussed in later sections.

_HEAP_LOCAL_SEGMENT_INFO
(HeapBase->FrontEndHeap->LocalData->SegmentInfo[])

_HEAP_LOCAL_SEGMENT_INFO
+0x000 Hint : Ptr32 _HEAP_SUBSEGMENT
+0x004 ActiveSubsegment : Ptr32 _HEAP_SUBSEGMENT
+0x058 LocalData : Ptr32 _HEAP_LOCAL_DATA
+0x060 BucketIndex : Uint2B

- **Hint** – This **SubSegment** is only set when the **LFH** frees a chunk which it is managing. If a chunk is never freed, this value will always be **NULL**.
- **ActiveSubsegment** – The **SubSegment** used for most memory requests. While initially NULL, it is set on the **first** allocation for a specific size.
- **LocalData** – The **_HEAP_LOCAL_DATA** structure associated with this structure.
- **BucketIndex** – Each **SegmentInfo** object is related to a certain **Bucket** size (or Index).

_HEAP_SUBSEGMENT

(HeapBase->FrontEndHeap->LocalData->SegmentInfo[]->Hint,ActiveSubsegment,CachedItems)

_HEAP_SUBSEGMENT	
+0x000 LocalInfo	: Ptr32 _HEAP_LOCAL_SEGMENT_INFO
+0x004 UserBlocks	: Ptr32 _HEAP_USERDATA_HEADER
+0x008 AggregateExchg	: _INTERLOCK_SEQ
+0x016 SizeIndex	: UChar

- **LocalInfo** – The **_HEAP_LOCAL_SEGMENT_INFO** structure associated with this structure**.**
- **UserBlocks** – A **_HEAP_USERDATA_HEADER** structure coupled with this **SubSegment** which holds a large chunk of memory split into n-number of chunks.
- **AggregateExchg** – An **_INTERLOCK_SEQ** structure used to keep track of the current **Offset** and **Depth**.
- **SizeIndex** – The **_HEAP_BUCKET SizeIndex** for this **SubSegment**.

_HEAP_USERDATA_HEADER

(HeapBase->FrontEndHeap->LocalData->SegmentInfo[]->Hint,ActiveSubsegment,CachedItems->UserBlocks)

_HEAP_USERDATA_HEADER	
+0x000 SubSegment	: Ptr32 _HEAP_SUBSEGMENT
+0x004 Reserved	: Ptr32 Void
+0x008 SizeIndex	: Uint4B
+0x00c Signature	: Uint4
+0x010 User Writable Data	: XXXX

_INTERLOCK_SEQ

(HeapBase->FrontEndHeap->LocalData->SegmentInfo[]->Hint,ActiveSubsegment,CachedItems->AggregateExchg)

_INTERLOCK_SEQ
+0x000 Depth : Uint2B
+0x002 FreeEntryOffset : Uint2B
+0x000 OffsetAndDepth : Uint4B

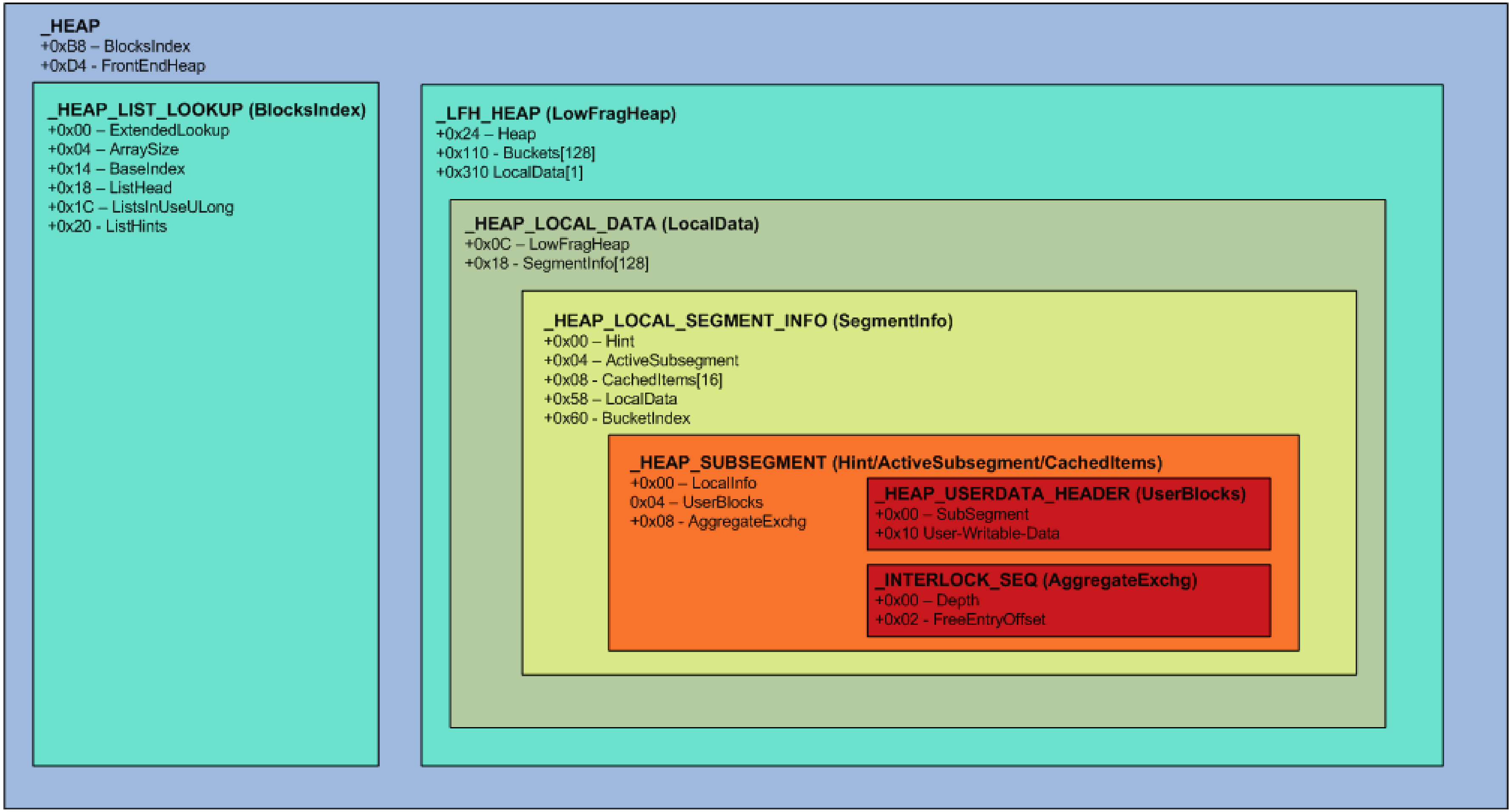
- **Depth** – A counter that keeps track of how many chunks are left in a **UserBlock**. This number is **incremented** on a free and **decremented** on an allocation. Its value is initialized to the size of **UserBlock** divided by the **HeapBucket** size.
- **FreeEntryOffset** – This 2-byte integer holds a value, when added to the address of the **_HEAP_USERDATA_HEADER**, results in a pointer to the next location for freeing or allocating memory. This value is represented in **blocks** (0x8 byte chunks) and is initialized to 0x2, as **sizeof(_HEAP_USERDATA_HEADER)** is 0x10. [0x2 * 0x8 == 0x10].
- **OffsetAndDepth** – Since both **Depth** and **FreeEntryOffset** are 2-bytes, are combined into this single 4-byte value.

_HEAP_ENTRY
(Chunk Header)

_HEAP_ENTRY
+0x000 Size : Uint2B
+0x002 Flags : UChar
+0x003 SmallTagIndex : Uchar
+0x007 UnusedBytes : Uchar

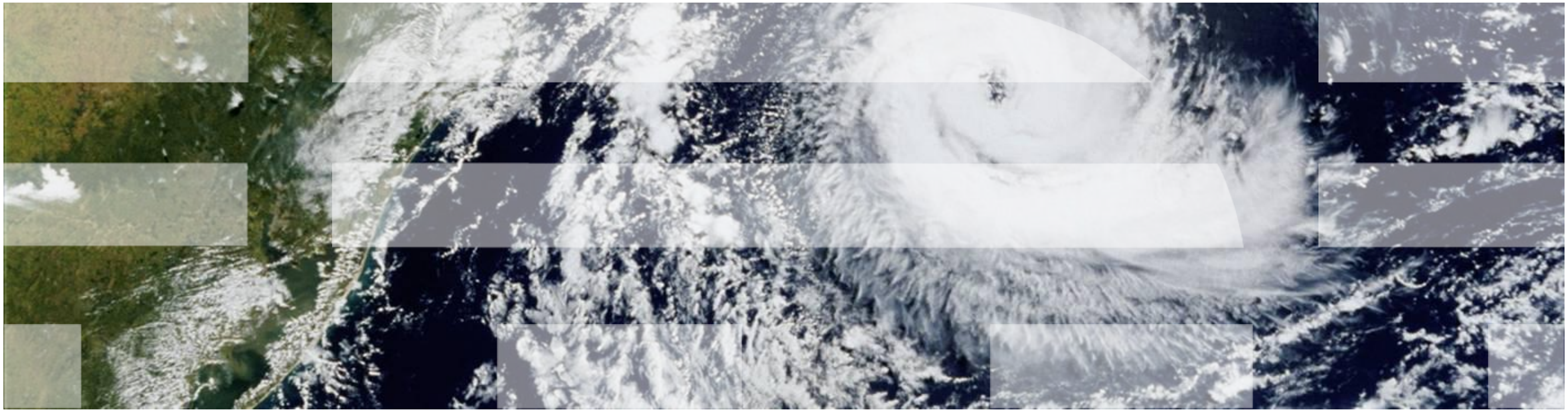
- **Size** – The size, in blocks, of the chunk. This includes the _HEAP_ENTRY itself
- **Flags** – Flags denoting the state of this heap chunk. Some examples are FREE or BUSY
- **SmallTagIndex** – This value will hold the XOR'ed checksum of the first three bytes of the _HEAP_ENTRY
- **UnusedBytes/ExtendedBlockSignature** – A value used to hold the unused bytes or a byte indicating the state of the chunk being managed by the **LFH**.

Overview


_HEAP
+0xB8 – BlocksIndex
+0xD4 - FrontEndHeap
_HEAP_LIST_LOOKUP (BlocksIndex)
+0x00 – ExtendedLookup
+0x04 – ArraySize
+0x14 – BaseIndex
+0x18 – ListHead
+0x1C – ListsInUseULong
+0x20 - ListHints
_LFH_HEAP (LowFragHeap)
+0x24 – Heap
+0x110 - Buckets[128]
+0x310 LocalData[1]
_HEAP_LOCAL_DATA (LocalData)
+0x0C – LowFragHeap
+0x18 - SegmentInfo[128]
_HEAP_LOCAL_SEGMENT_INFO (SegmentInfo)
+0x00 – Hint
+0x04 – ActiveSubsegment
+0x08 - CachedItems[16]
+0x58 – LocalData
+0x60 - BucketIndex
_HEAP_SUBSEGMENT (Hint/ActiveSubsegment/CachedItems)
+0x00 – LocalInfo
0x04 – UserBlocks
+0x08 - AggregateExchg
_HEAP_USERDATA_HEADER (UserBlocks)
+0x00 – SubSegment
+0x10 User-Writable-Data
_INTERLOCK_SEQ (AggregateExchg)
+0x00 – Depth
+0x02 - FreeEntryOffset

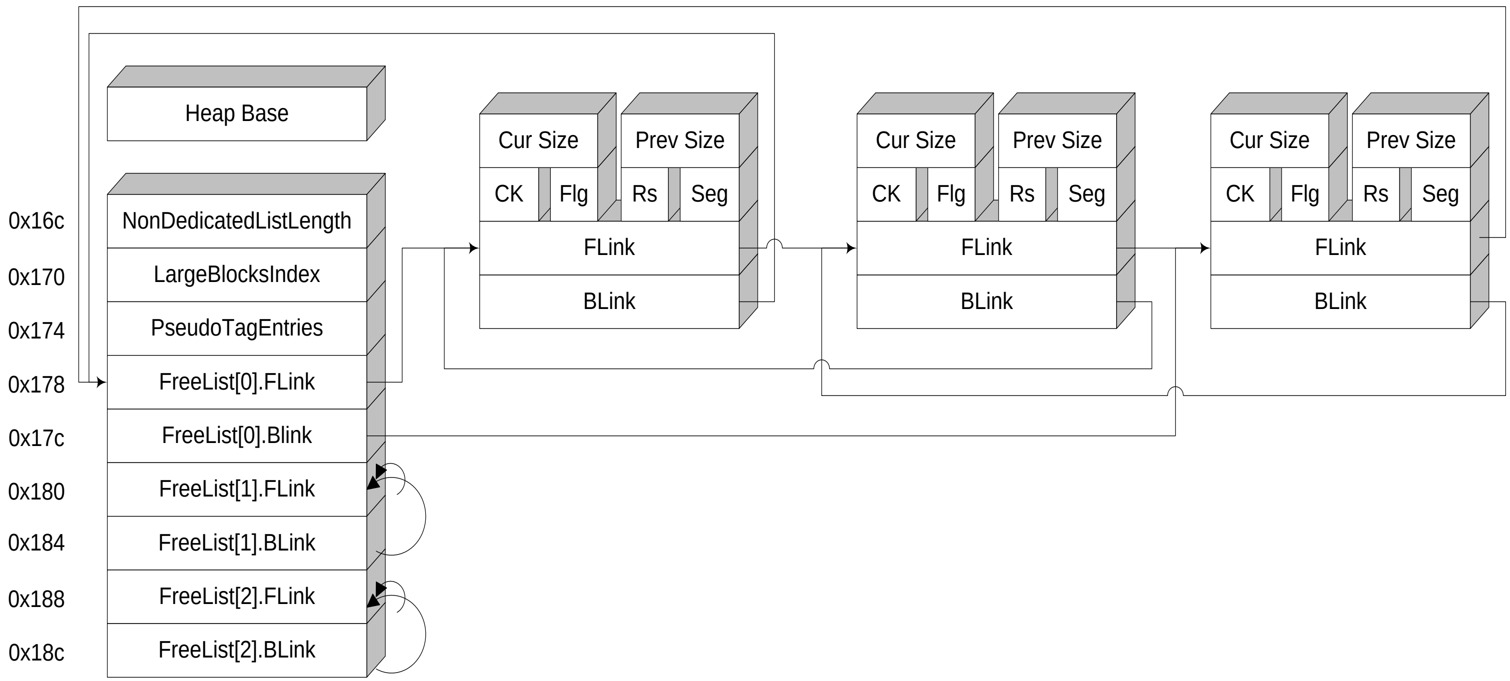
Architecture

“The winner of the BIG award is…”



WinXP FreeLists

Once upon a time there were dedicated FreeLists which were terminated with pointers to sentinel nodes. Empty lists would contain a Flink and Blink pointing to itself.



Win7 FreeLists

- The concept of **dedicated** FreeLists have gone away. **FreeList** or **ListHints** will point to a location within Heap->FreeLists.

- They Terminate by pointing to &HeapBase->FreeLists. Empty lists will be NULL or contain information used by the LFH.

- Only Heap->FreeLists initialized to have Flink/Blink pointing to itself.

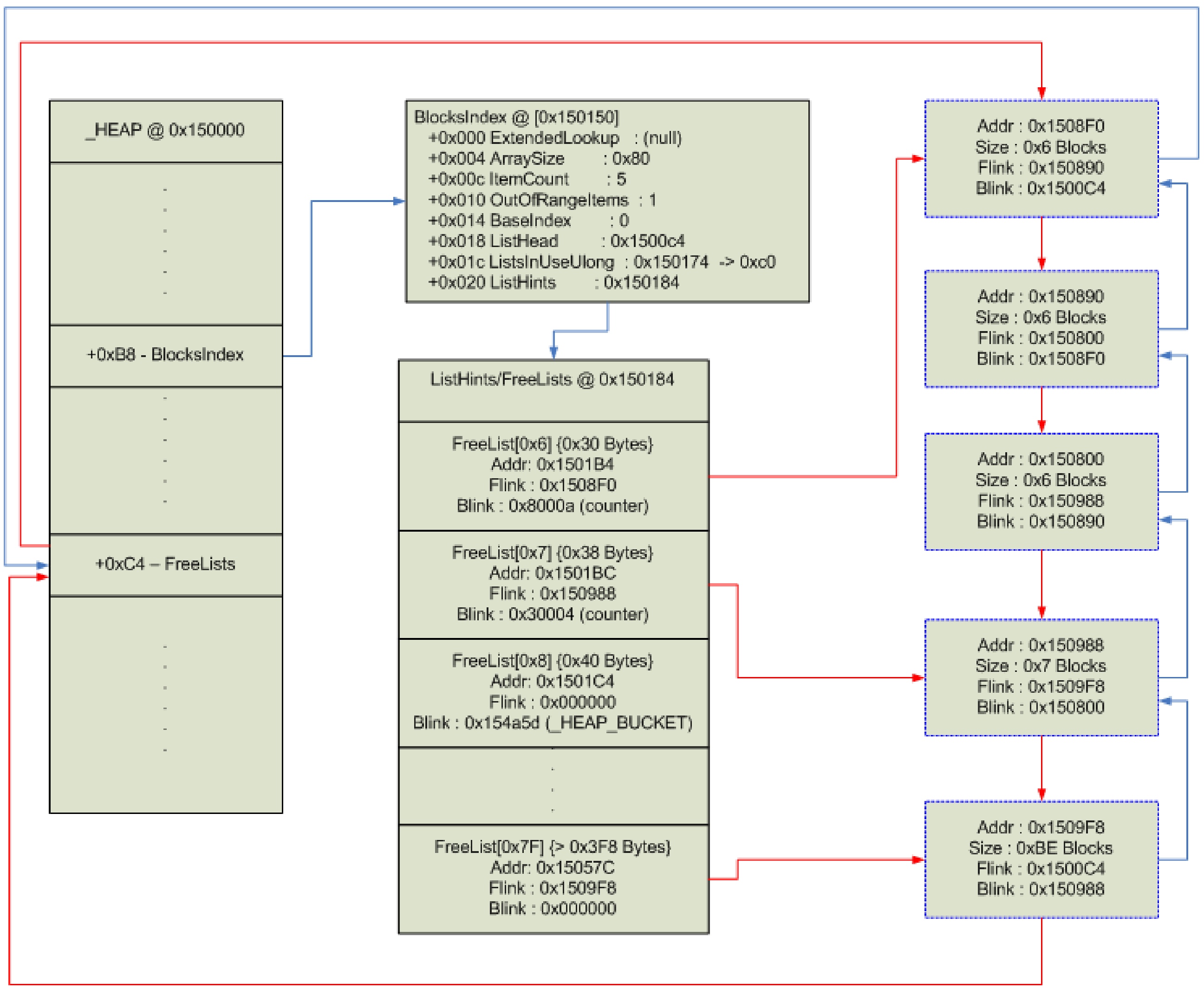
- Chunks >= ArraySize-1 will be tracked in BlocksIndex->ListHints[ArraySize-BaseIndex-1]

- If the **LFH** is enabled for a specific Bucket then the ListHint->**Blink** will contain the address of a _HEAP_BUCKET + 1. Otherwise,
ListHint->**Blink** can contain a **counter** used to enable the LFH for that specific _HEAP_BUCKET.

- LFH can manage chunks from 8-16k bytes.

- FreeLists can track 16k+ byte chunks, but will not use the LFH.

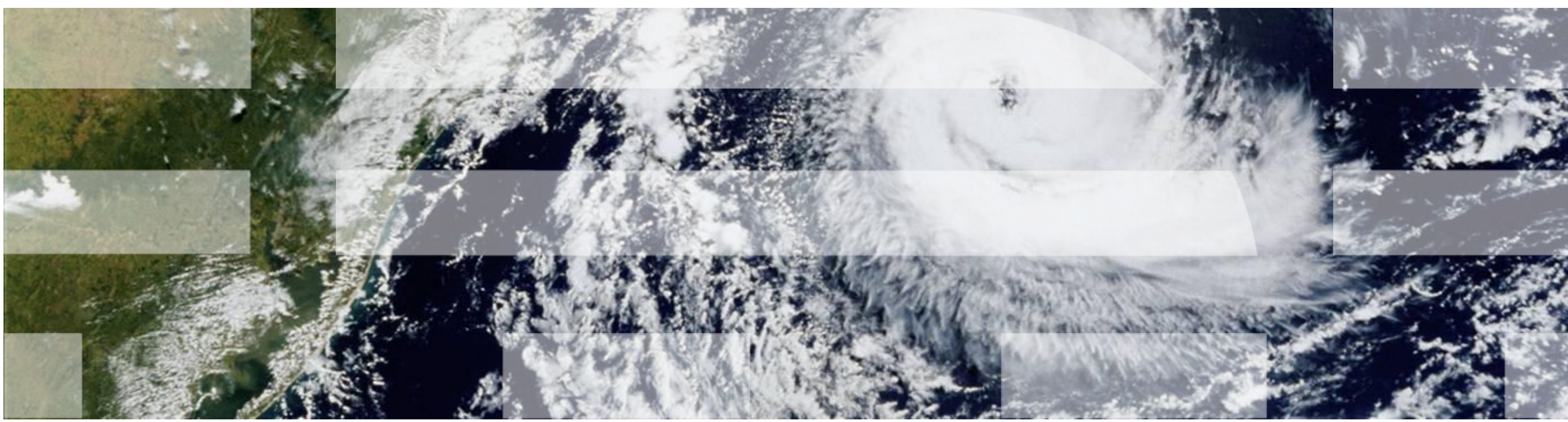
Win7 FreeLists



Circular Organization of Chunk Headers (COCHs)

Algorithms: Allocation

“@hzon Do you remember any of the stuff we did last year?”



Allocation

- **RtlAllocateHeap: Part I**
  - It will round the size to be 8-byte aligned then find the appropriate BlocksIndex structure to service this request. Using the *FreeList[0]* like structure if it cannot service the request.

```
if(Size == 0x0)
       Size = 0x1;

//ensure that this number is 8-byte aligned
int RoundSize = Round(Size);

int BlockSize = Size / 8;

//get the HeapListLookup, which determines if we should use the LFH
_HEAP_LIST_LOOKUP *BlocksIndex = (_HEAP_LIST_LOOKUP*)heap->BlocksIndex;

//loop through the HeapListLookup structures to determine which one to use
while(BlocksSize >= BlocksIndex->ArraySize)
{
       if(BlocksIndex->ExtendedLookup == NULL)
       {
              BlocksSize = BlocksIndex->ArraySize - 1;
              break;
       }

       BlocksIndex = BlocksIndex->ExtendedLookup;
}
```

* The above searching now will be referred to as: **BlocksIndexSearch()**

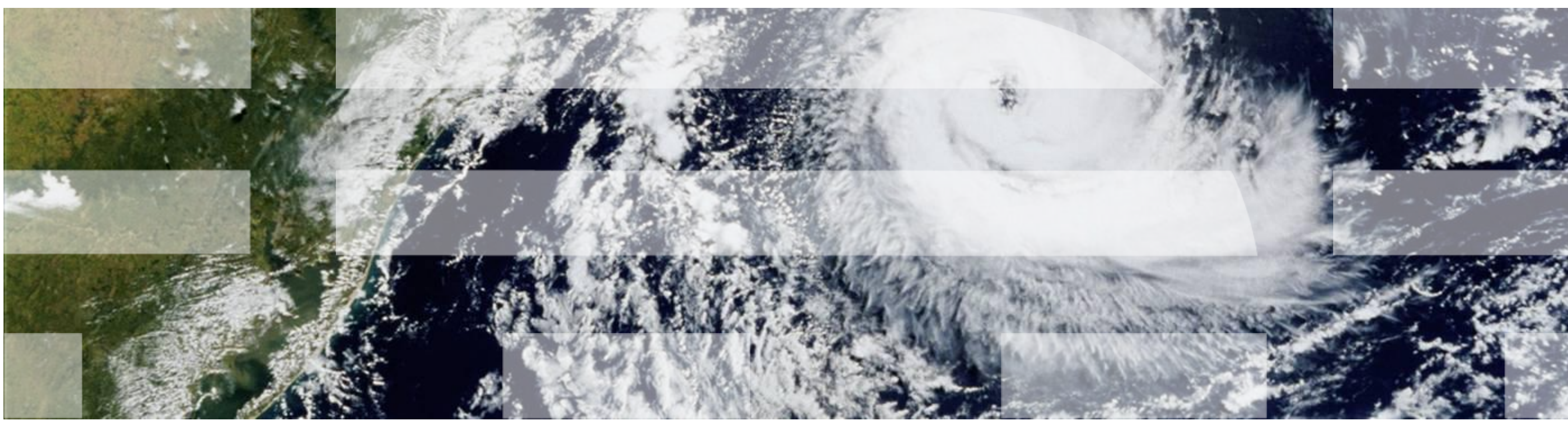
Allocation

- **RtlAllocateHeap: Part II**
  - The **ListHints** will now be queried look for an optimal entry point into the FreeLists. A check is then made to see if the **LFH** or the **Back-end** should be used.

```
//get the appropriate freelist to use based on size
int FreeListIndex = BlockSize - HeapListLookup->BaseIndex;

_LIST_ENTRY *FreeList = &HeapListLookup->ListHints[FreeListIndex];
if(FreeList)
{
	//check FreeList[index]->Blink to see if the heap bucket
	//context has been populated via RtlpGetLFHContext()
	//RtlpGetLFHContext() stores the HeapBucket
	//context + 1 in the Blink
	_HEAP_BUCKET *HeapBucket = FreeList->Blink;

	if(HeapBucket & 1)
	{
		RetChunk = RtlpLowFragHeapAllocFromContext(HeapBucket-1, aBytes);

		if(RetChunk && heap->Flags == HEAP_ZERO_MEMORY)
			memset(RetChunk, 0, RoundSize);
	}
}

//if the front-end allocator did not succeed, use the back-end
if(!RetChunk)
{
	RetChunk = RtlpAllocateHeap(heap, Flags | 2, Size, RoundSize, FreeList)
}
```

Algorithms: Allocation : Back-end

"Working in the library? Everyday day I'm Hustlin'!"



Allocation: Back-end

- **RtlpAllocateHeap: Part I**
  - The size is rounded if necessary and **RtlpPerformHeapMaintenance()** based on the **CompatibilityFlags**. This is what will actually enables the **LFH.**

```
int RoundSize = aRoundSize;

//if the FreeList isn't NULL, the rounding has already
//been preformed
if(!FreeList)
{
       RoundSize = Round(Size)RoundSize;
}

int SizeInBlocks = RoundSize / 8;

if(SizeInBlocks < 2)
{
       //RoundSize += sizeof(_HEAP_ENTRY)
       RoundSize = RoundSize + 8;
       SizeInBlocks = 2;
}

//if NOT HEAP_NO_SERIALIZE, use locking mechanisms
//LFH CANNOT be enabled if this path isn't taken
if(!(Flags & HEAP_NO_SERIALIZE))
{
       if(Heap->CompatibilityFlags & 0x60000000)
              RtlpPerformHeapMaintenance(Heap);
}
```

Allocation: Back-end

- **RtlpAllocateHeap: Part II**
  - If there is a FreeList and it doesn't hold a **_HEAP_BUCKET** update the **flags** used to enable the **LFH**. If the LFH is already enabled assign the **_HEAP_BUCKET** to the **blink**.

```
//if this freelist doesn't hold a _HEAP_BUCKET
if(FreeList != NULL && !(FreeList->Blink & 1))
{
	//increment the counter
	FreeList->Blink += 0x10002;

	//on the 0x10th time, try to get a _HEAP_BUCKET
	if(WORD)FreeList->Blink > 0x20 || FreeList->Blink > 0x10000000)
	{
		int FrontEndHeap;
		if(Heap->FrontEndHeapType == 0x2)
			FrontEndHeap = Heap->FrontEndHeap;
		else
			FrontEndHeap = NULL;

		//gets _HEAP_BUCKET in LFH->Bucket[BucketSize]
		char *LFHContext = RtlpGetLFHContext(FrontEndHeap, Size);

		//if the context isn't set AND
		//we've seen 0x10+ allocations, set the flags
		if(LFHContext == NULL)
		{
			if((WORD)FreeList->Blink > 0x20)
			{
				//RtlpPerformHeapMaintenance heuristic
				if(Heap->FrontEndHeapType == NULL)
					Heap->CompatibilityFlags |= 0x20000000;
			}
		}
		else
		{
			//save the _HEAP_BUCKET in the Blink
			FreeList->Blink = LFHContext + 1;
		}
	}
}
```

Allocation: Back-end

- **RtlpAllocateHeap: Part III**
  - If we've found a chunk in one of the **FreeLists** it can now be safely **unlinked** from the **list** and the **ListsInUseUlong** will be updated if necessary. The chunk will then be returned to the calling process.

```
//attempt to use the Flink
if(FreeList != NULL && FreeList->Flink != NULL)
{
	//saved values
	_HEAP_ENTRY *Blink = FreeList->Blink;
	_HEAP_ENTRY *Flink = FreeList->Flink;

	//get the heap chunk header by subtracting 8
	_HEAP_ENTRY *ChunkToUseHeader = Flink - 8;

	DecodeAndValidateChecksum(ChunkToUseHeader);

	//ensure safe unlinking before acquiring this chunk for use
	if(Blink->Flink != Flink->Blink || Blink->Flink != FreeList)
	{
		RtlpLogHeapFailure();
		//XXX RtlNtStatusToDosError and return
	}

	//update the bitmap if needed
	_HEAP_LIST_LOOKUP *BlocksIndex = Heap->BlocksIndex;
	if(BlocksIndex)
	{
		int FreeListOffset = GetFreeListOffset();

		//if there are more of the same size
		//don't update the bitmap
		if(!LastInList(BlockIndex, FreeListOffset)
			BlocksIndex->ListHints[FreeListOffset] = Flink->Flink;
		else
			UpdateBitmap(BlocksIndex->ListsInUseUlong); //bitwse AND
	}

	//unlink the current chunk to be allocated
	Blink->Flink = Flink;
	Flink->Blink = Blink;
}
```

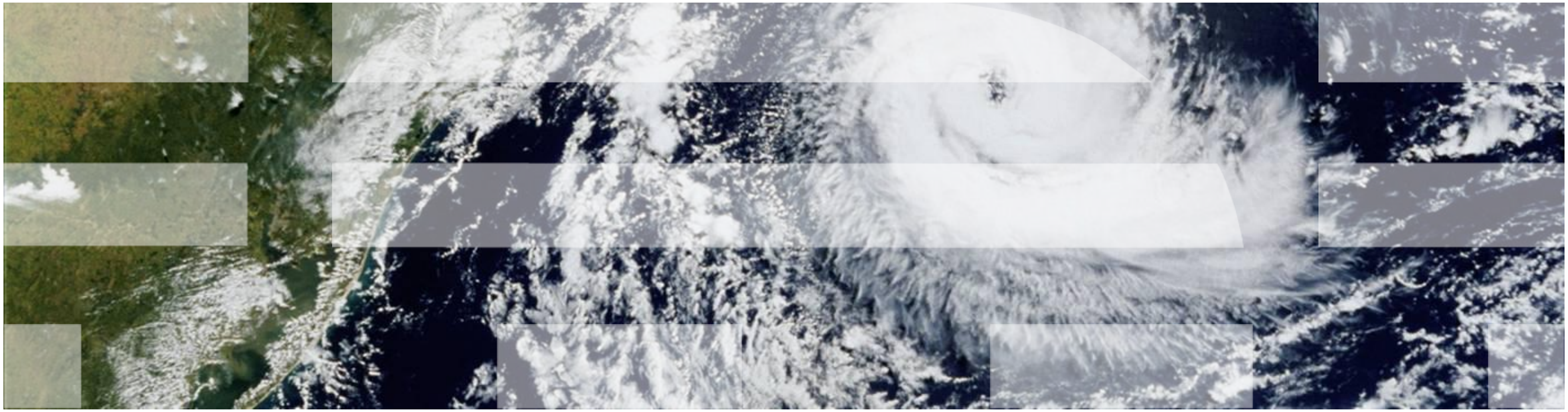
Allocation: Back-end

- **RtlpAllocateHeap: Part IV**
  - If the **ListHints** weren't successful, attempt to use the **Heap->FreeList** / **BlocksIndex->ListHead.** If successful it will return **ChunkToUse**, otherwise the heap will need to be extended via **RtlpExtendHeap()**.

```
//BI->ListHead == Heap->FreeLists
_LIST_ENTRY *HeapFreeLists = &Heap->FreeLists;
_LIST_ENTRY *ChunkToUse;
_HEAP_LIST_LOOKUP *BI = Heap->BlocksIndex;

while(1)
{
	//bail if the list is empty
	if(BI == NULL || BI->ListHead == BI->ListHead)
	{
		ChunkTouse = BI->ListHead;
		break;
	}

	_HEAP_ENTRY *BlinkHeader = DecodeHeader(BI->ListHead->Blink - 8);

	//if the requested size is too big, extend the heap
	if(SizeInBlocks > BlinkHeader->Size)
	{
		ChunkToUse = BI->ListHead;
		break;
	}

	_HEAP_ENTRY *FlinkHeader = DecodeHeader(BI->ListHead->Flink-8);

	//if the first chunk is sufficient use it
	//otherwise loop through the rest
	if(FlinkHeader->Size >= SizeInBlocks)
	{
		ChunkToUse = CurrListHead->Flink;
		break;
	}
	else
		FindChunk(BlocksIndex->ListHints, SizeInBlocks)

	//look at the next blocks index
	BI = BI->ExtendedLookup;
}
```

Algorithms: Allocation : Front-End

“Dr. Raid will take your pizza, fo sho“



Allocation: Front-end

- **RtlpLowFragHeapAllocFromConext: Part I**
  - A _HEAP_SUBSEGMENT is acquired based off the _HEAP_BUCKET passed to the function. The *Hint* SubSegment is tried first, proceeding to the *ActiveSubsegment* pending a failure. If either of these succeed in the allocation request, the chunk is returned.

```
//gets the data structures based off the SizeIndex (affinity left otu)
_LFH_HEAP *LFH = GetLFHFromBucket(HeapBucket);
_HEAP_LOCAL_DATA *HeapLocalData = LFH->LocalData[LocalDataIndex];
_HEAP_LOCAL_SEGMENT_INFO *HeapLocalSegmentInfo = HeapLocalData-
>SegmentInfo[HeapBucket->SizeIndex];

//try to use the 'Hint' SubSegment first
//otherwise this would be 'ActiveSubsegment'
_HEAP_SUBSEGMENT *SubSeg = HeapLocalSegmentInfo->Hint;
_HEAP_SUBSEGMENT *SubSeg_Saved = HeapLocalSegmentInfo->Hint;

if(SubSeg)
{
	while(1)
	{
		//get the current AggregateExchange information
		_INTERLOCK_SEQ *AggrExchg = SubSeg->AggregateExchg;
		int Offset = AggrExchg->FreeEntryOffset;
		int Depth = AggrExchg->Depth;
		int Sequence = AggrExchg->Sequence

		//attempt different subsegment if this one is invalid
		_HEAP_USERDATA_HEADER *UserBlocks = SubSeg->UserBlocks;
		if(!Depth || !UserBlocks || SubSeg->LocalInfo != HeapLocalSegmentInfo)
			break;

		int ByteOffset =  Offset * 8;
		LFHChunk = UserBlocks + ByteOffset;

		//the next offset is store in the 1st 2-bytes of the user data
		short NextOffset = UserBlocks + ByteOffset + sizeof(_HEAP_ENTRY));

		if(AtomicUpdate(AggrExchg, NextOffset, Depth--)
			return LFHChunk;
		else
			SubSeg = SubSeg_Saved;
	}
}
```

Allocation: Front-end

- **RtlpLowFragHeapAllocFromConext: Part II**
  - If a SubSegment wasn't able to fulfill the allocation, the LFH must create a new SubSegment along with an associated **UserBlock**. A **UserBlock** is the chunk of memory that holds individual chunks for a specific _HEAP_BUCKET. A certain formula is used to calculate how much memory should actually be acquired via the **back-end** allocator.

```
//assume no bucket affinity
int TotalBlocks = HeapLocalSegmentInfo->Counters->TotalBlocks;
int BucketBytesSize =  RtlpBucketBlockSizes[HeapBucket->SizeIndex];
int StartIndex = 7;
int BlockMultiplier = 5;

if(TotalBlocks < (1 << BlockMultiplier)) { TotalBlocks = 1 << BlockMultiplier; }

if(TotalBlocks > 1024) { TotalBlocks = 1024; }

//used to calculate cache index and size to allocate
int TotalBlockSize = TotalBlocks * (BucketBytesSize + sizeof(_HEAP_ENTRY)) +
sizeof(_HEAP_USERDATA_HEADER) + sizeof(_HEAP_ENTRY);

if(TotalBlockSize > 0x78000) { TotalBlockSize = 0x78000; }

//calculate the cahce index upon a cache miss, this index will determine
//the amount of memory to be allocated
if(TotalBlockSize >= 0x80)
{
       do
       {
              StartIndex++;
       }while(TotalBlockSize >> StartIndex);
}

//we will @ most, only allocate 40 pages (0x1000 bytes per page)
if((unsigned)StartIndex > 0x12)
       StartIndex = 0x12;

int UserBlockCacheIndex = StartIndex;

//allocate ((1 << UserBlockCacheIndex) / BucketBytesSize) chunks on a cache miss
void *pUserData = RtlpAllocateUserBlock(lfh, UserBlockCacheIndex, BucketByteSize + 8);
_HEAP_USERDATA_HEADER *UserData = (_HEAP_USERDATA_HEADER*)pUserData;
if(!pUserData)
       return 0;
```

Allocation: Front-end

- **RtlpLowFragHeapAllocFromConext: Part III**
  - Now that a **UserBlock** has been allocated, the LFH can acquire a **_HEAP_SUBSEGMENT**. If a SubSegment has been found it will then initialize that SubSegment along with the UserBlock; otherwise the **back-end** will have to be used to fulfill the allocation request.

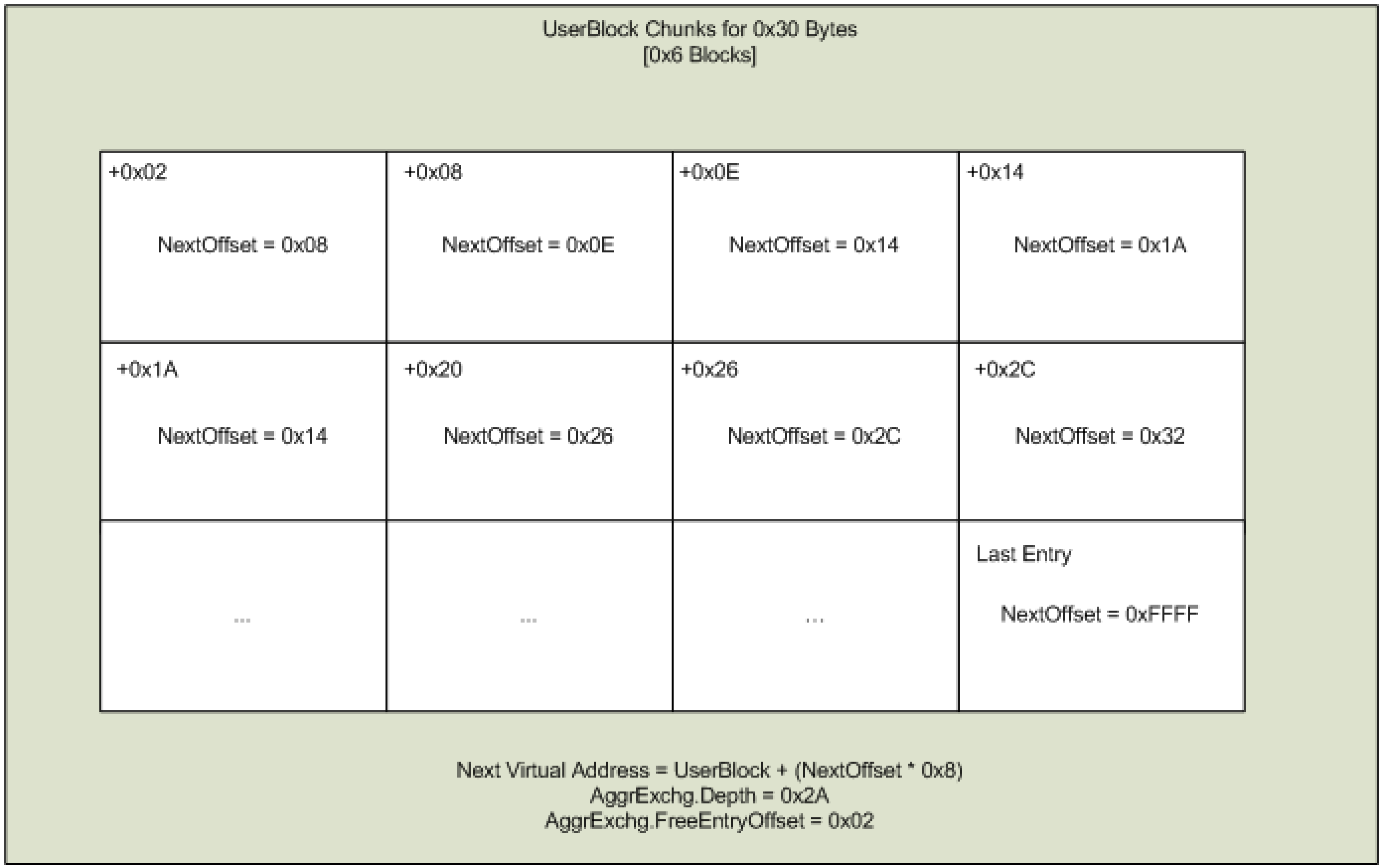
```
int UserDataBytesSize = 1 << UserData->AvailableBlocks;
if(UserDataBytesSize > 0x78000)   { UserDataBytesSize = 0x78000; }

int UserDataAllocSize = UserDataBytesSize - 8;

//Increment SegmentCreate to denote a new SubSegment created
InterlockedExchangeAdd(&LFH->SegmentCreate, 1);

_HEAP_SUBSEGMENT *NewSubSegment = NULL;
DeletedSubSegment = ExInterlockedPopEntrySList(HeapLocalData);
if (DeletedSubSegment)
       NewSubSegment = (_HEAP_SUBSEGMENT *)(DeletedSubSegment - 0x18);
else
{
       NewSubSegment = RtlpLowFragHeapAllocateFromZone(LFH, LocalDataIndex);

       if(!NewSubSegment)
              return 0;
}

//this function will setup the _HEAP_SUBEMENT structure
//and chunk out the data in 'UserData' to be of HeapBucket->SizeIndex chunks
RtlpSubSegmentInitialize(LFH,
       NewSubSegment,
       UserBlock,
       RtlpBucketBlockSizes[HeapBucket->SizeIndex],
       UserDataAllocSize,HeapBucket);

//each UserBlock starts with the same sig
UserBlock->Signature = 0xF0E0D0C0;

//now used for LFH allocation for a specific bucket size
NewSubSegment = AtomicSwap(&HeapLocalSegmentInfo->ActiveSegment, NewSubSegment);
```

Allocation: Front-end

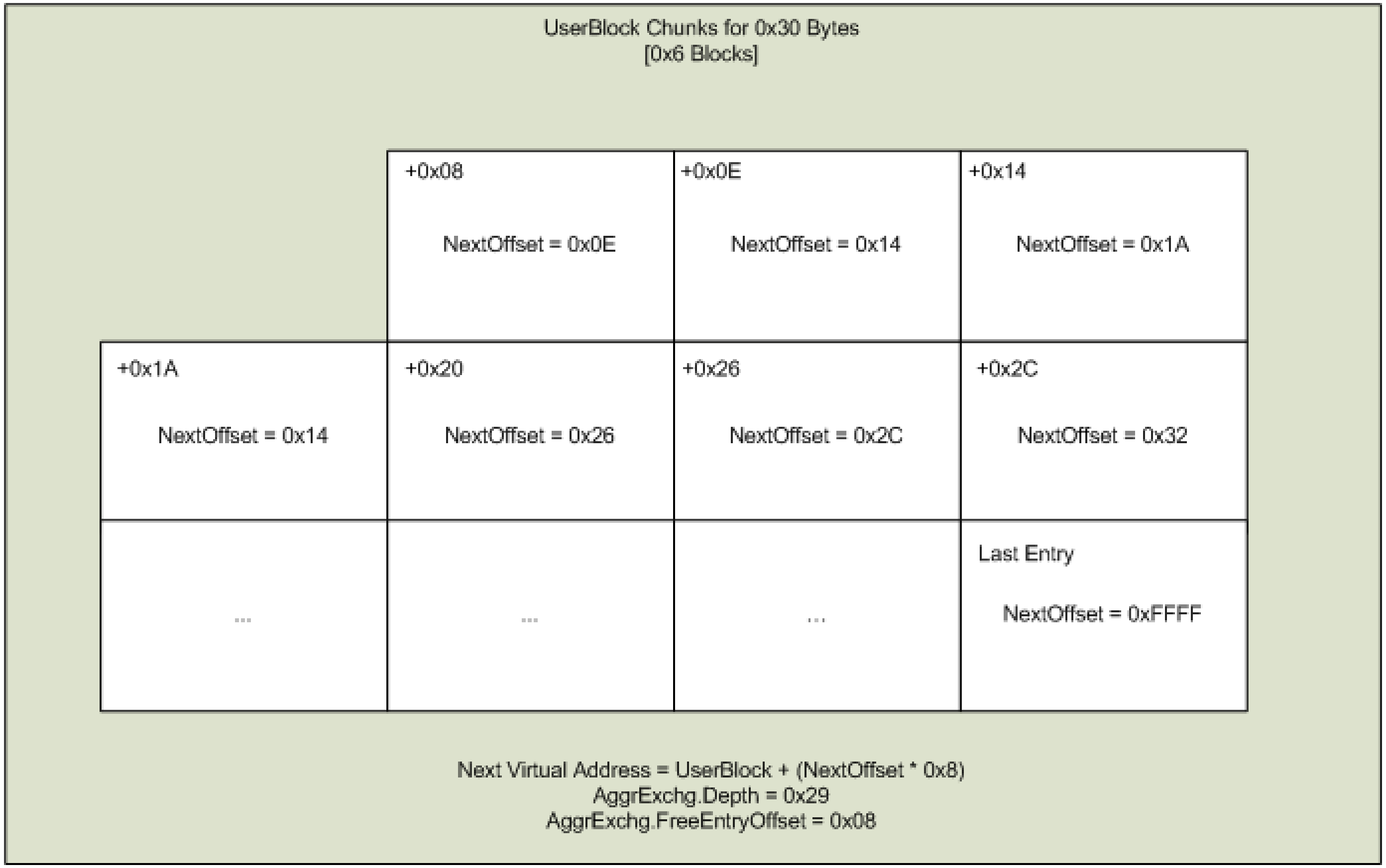
- **RtlpLowFragHeapAllocFromConext: Part IV [RtlpSubSegmentInitalize]**
  - The **UserBlock** chunk is divided into **BucketBlockSize** chunks followed by the **SubSegment** initialization. Finally, this new SubSegment is ready to be assigned to the **HeapLocalSegmentInfo->ActiveSubsegment**.

```
void *UserBlockData = UserBlock + sizeof(_HEAP_USERDATA_HEADER);
int TotalBucketByteSize = BucketByteSize + sizeof(_HEAP_ENTRY);
int BucketBlockSize = TotalBucketByteSize / 8;

//sizeof(_HEAP_USERDATA_HEADER) == 0x10
int NumberOfChunks = (UserDataAllocSize - 0x10) / TotalBucketByteSize;

//skip past the header, so we can start chunking
void *pUserData = UserBlock + sizeof(_HEAP_USERDATA_HEADER);

//assign the SubSegment
UserBlock->SubSegment = NewSubSegment;

//sizeof(_HEAP_USERDATA_HEADER) == 0x10 (2 blocks)
int SegmentOffset = 2;

_INTERLOCK_SEQ AggrExchg_New;
AggrExchg_New.FreeEntryOffset = 2;

if(NumberOfChunks)
{
        int NumberOfChunksItor = NumberOfChunks;
        do
        {
                SegmentOffset += BucketBlockSize;
                pUserData = UserBlockData;
                UserBlockData += BucketByteSize;

                //next FreeEntryOffset
                *(WORD*)(pUserData + 8) = SegmentOffset;

                //Set _HEAP_ENTRY.LFHFlags
                *(BYTE*)(pUserData + 6) = 0x0;

                //Set _HEAP_ENTRY.ExtendedBlockSignature
                *(BYTE*)(pUserData + 7) = 0x80;

                EncodeDWORD(LFH, pUserData)
        }
        while(NumberOfChunksItor--);
}

//-1 indicates last chunk in the UserBlock
*(WORD*)(pUserData + 8) = -1;

//Sets all the values for this subsegment
InitSubSegment(NewSubSegment);
```

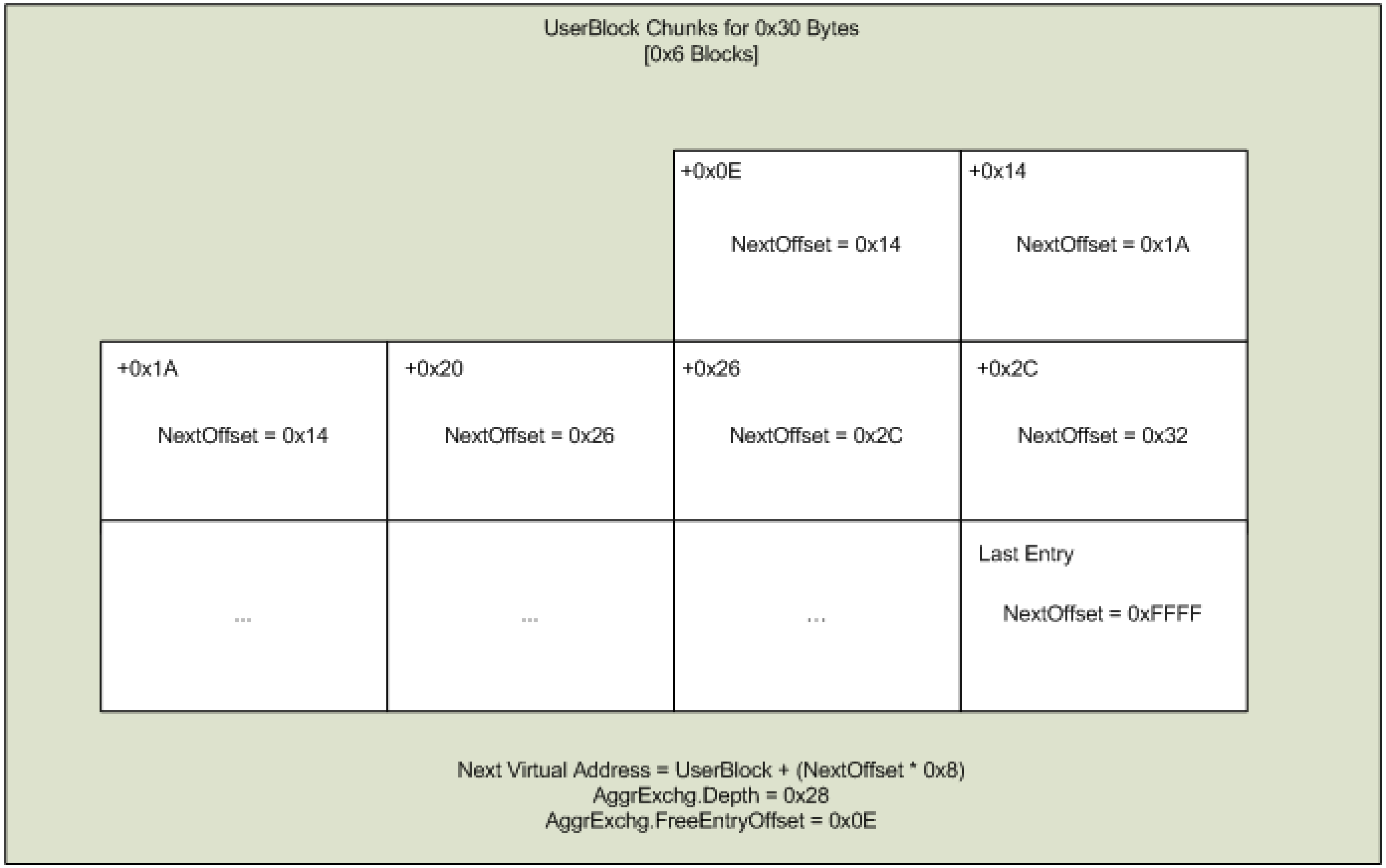
Allocation: Front-End : Example I



Allocation : Front-End : Example II

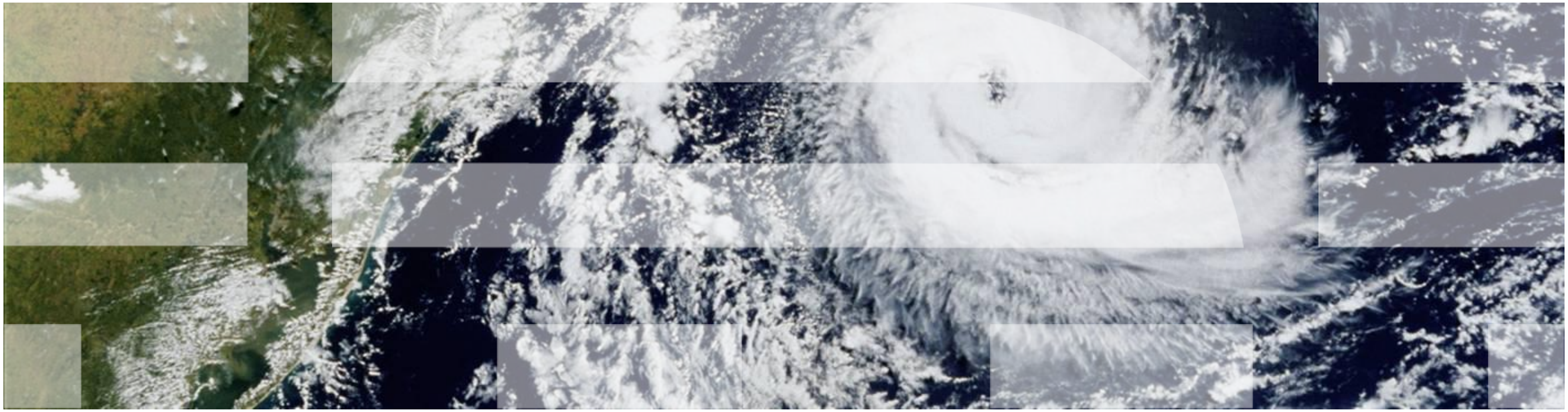


Allocation : Front-End : Example III



Algorithms: Freeing

“How can you go wrong? (re: Dogs wearing sunglasses)”



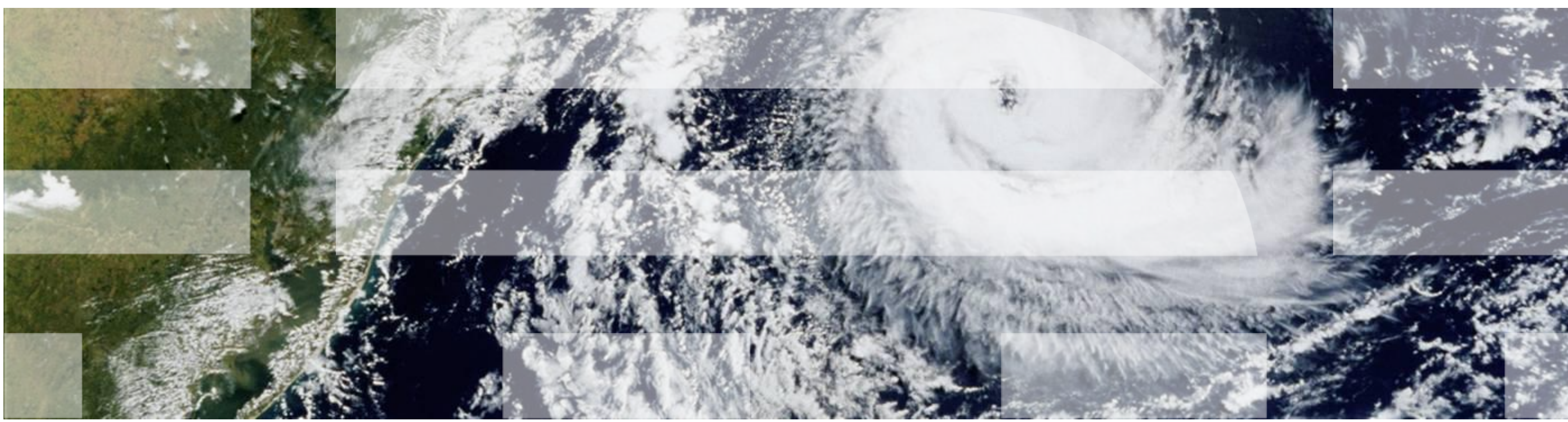
Freeing

- **RtlFreeHeap**
  - RtlFreeHeap will determine if the chunk is free-able. If so it will decide if the **LFH** or the **back-end** should be responsible for releasing the chunk.

```
ChunkHeader = NULL;

//it will not operate on NULL
if(ChunkToFree == NULL)
	return;

//ensure the chunk is 8-byte aligned
if(!(ChunkToFree & 7))
{
	//subtract the sizeof(_HEAP_ENTRY)
	ChunkHeader = ChunkToFree - 0x8;

	//use the index to find the size
	if(ChunkHeader->UnusedBytes == 0x5)
		ChunkHeader -=
			0x8 * (BYTE)ChunkToFreeHeader->SegmentOffset;
}
else
{
	RtlpLogHeapFailure();
	return;
}

//position 0x7 in the header denotes whether the chunk was allocated via
//the front-end or the back-end (non-encoded ;) )
if(ChunkHeader->UnusedBytes & 0x80)
	RtlpLowFragHeapFree(Heap, ChunkToFree);
else
	RtlpFreeHeap(Heap, Flags | 2, ChunkHeader, ChunkToFree);

return;
```

Algorithms: Freeing : Back-End

“Spencer Pratt explained this to me”



Freeing : Back-End

- **RtlpFreeHeap: Part I**
  - The back-end manager will first look for a **ListHint index** to use as an insertion point. It will then attempt to update the **counter** used in the **LFH heuristic**.

```
//returns ArraySize-1 on miss & no ExtendedLookup
_HEAP_LIST_LOOKUP *BlocksIndex = Heap->BlocksIndex;
ChunkSize = SearchBlocksIndex(BlocksIndex, ChunkHeader->Size);

//attempt to locate a FreeList
_LIST_ENTRY *ListHint = NULL;

//if the chunk can fit on a blocksindex OR
//BlocksIndex[ArraySize-BaseIndex-1] can hold the chunk
if(FitsInBlocksIndex(BlocksIndex, ChunkSize))
{
	int FreeListIndex = ChunkSize - BlocksIndex->BaseIndex;

	//acquire a dedicated freelist
	ListHint = BlocksIndex->ListHints[FreeListIndex];
}

if(ListHint != NULL)
{
	//If no _HEAP_BUCKET adjust counter
	if( !(BYTE)ListHint->Blink & 1)
	{
		if(ListHint->Blink >= 2)
			ListHint->Blink = ListHint->Blink - 2;
	}
}
```

Freeing : Back-End

- **RtlpFreeHeap: Part II**
  - The header values are set for the chunk being freed and it is **coalesced** if necessary. While the function may be called every iteration, it will only combine chunks that are adjacently **FREE**.

```
//unless the heap says otherwise, coalesce the adjacent free blocks
int ChunkSize = ChunkHeader->Size;
if( !(Heap->Flags & 0x80) )
{
       //combine the adjacent blocks
       ChunkHeader = RtlpCoalesceFreeBlocks(Heap, ChunkHeader, &ChunkSize, 0x0);
}

//reassign the ChunkSize if neccessary
ChunkSize = ChunkHeader->Size;

//XXX Decomit or Give to Virtual Memory if exceeding the Thresholds

//mark the chunk as FREE
ChunkHeader->Flags = 0x0;
ChunkHeader->UnusedBytes = 0x0;
```

Freeing : Back-End

- **RtlpFreeHeap: Part III**
  - Now the heap manager will find which **BlocksIndex** and corresponding **ListHint** will manage this chunk. It will ensure that **ListHead** isn't empty and can insert this chunk before the largest chunk residing on the list.

```
BlocksIndex = Heap->BlocksIndex;
_LIST_ENTRY *InsertList = Heap->FreeLists.Flink;

//attempt to find where to insert this item
//on the ListHead list for a particular BlocksIndex
if(BlocksIndex)
{
        int FreeListIndex = BlocksIndexSearch(BlocksIndex, ChunkSize)

        while(BlocksIndex != NULL)
        {
                //abort if the list is empty or too large to fit on this list
                _HEAP_ENTRY *ListHead = BlocksIndex-ListHead;
                if(ListHead == ListHead->Blink || ChunkSize > ListHead->Blink.Size)
                {
                        InsertList = ListHead;
                        break;
                }

                //start at the beginning of the ListHead pick the insertion point behind the 1st
                //chunk larger than the ChunkToFree
                _LIST_ENTRY *NextChunk = BlocksIndex->ListHints[FreeListIndex];
                while(NextChunk != ListHead)
                {
                        //there is actually some decoding done here
                        if(NextChunk.Size > ChunkSize)
                        {
                                InsertList = NextChunk;
                                break;
                        }
                        NextChunk = NextChunk->Flink;
                }

                //if we've found an insertion point, break
                if(InsertList != Heap->FreeLists.Flink)
                        break;

                BlocksIndex = BlocksIndex->ExtendedLookup;
        }
}
```

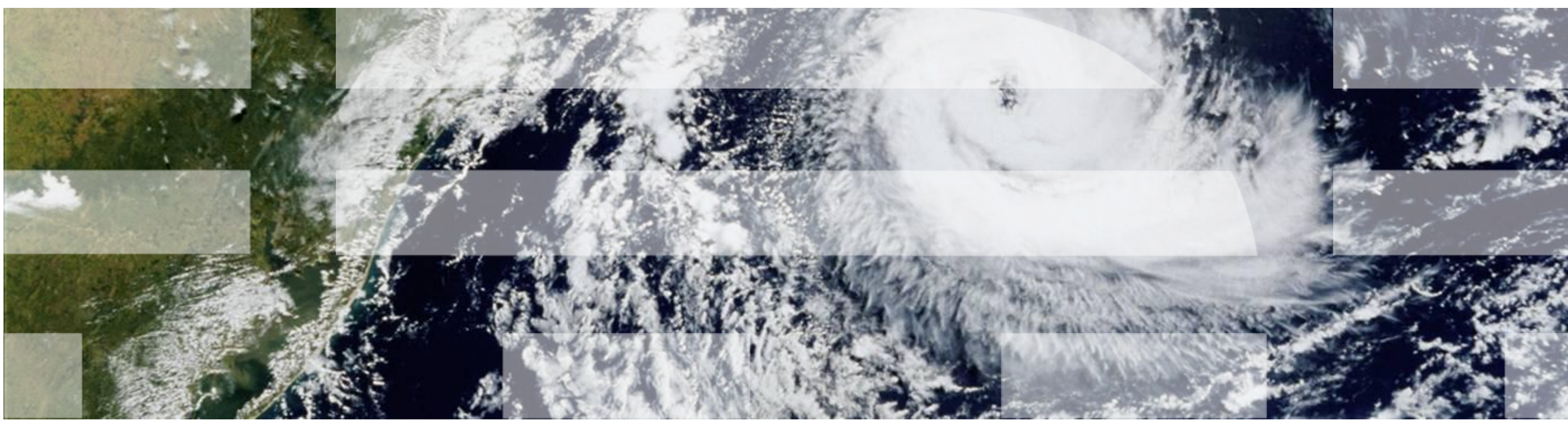
Freeing : Back-End

- **RtlpFreeHeap: Part IV**
  - Finally the chunk is **safely** linked into the list and **ListInUseUlong** is updated.

```
while(InsertList != Heap->FreeLists)
{
        if(InsertList.Size > ChunkSize)
                break;
        InsertList = InsertList->Flink;
}

//R.I.P FreeList Insertion Attack
if(InsertList->Blink->Flink == InsertList)
{
        ChunkToFree->Flink = InsertList;
        ChunkToFree->Blink = InsertList->Blink;
        InsertList->Blink->Flink = ChunkToFree;
        InsertList->Blink = ChunkToFree
}
else
{
        RtlpLogHeapFailure();
}

if(BlocksIndex)
{
        FreeListIndex = BlocksIndexSearch(BlocksIndex, ChunkSize);

        _LIST_ENTRY *FreeListToUse = BlocksIndex->ListHints[FreeListIndex];

        if(ChunkSize >= FreeListToUse.Size)
                BlocksIndex->ListHints[FreeListIndex] = ChunkToFree;

        //bitwise OR instead of previous XOR R.I.P Bitmap flipping (hi nico)
        if(!FreeListToUse)
        {
                int UlongIndex = Chunkize - BlocksIndex->BaseIndex >> 5;
                int Shifter = ChunkSize - BlocksIndex->BaseIndex & 1F;
                BlocksIndex->ListsInUseUlong[UlongIndex] |= 1 << Shifter;
        }

        EncodeHeader(ChunkHeader);
}
```

Algorithms: Freeing : Front-End

“Omar! Omar! Omar comin’!”



Freeing : Front-End

- **RtlpLowFragHeapFree: Part I**
  - The chunk **header** will be checked to see if a relocation is necessary. Then the chunk to be freed will be used to get the **SubSegment**. Flags indicating the chunk is now **FREE** are also set.

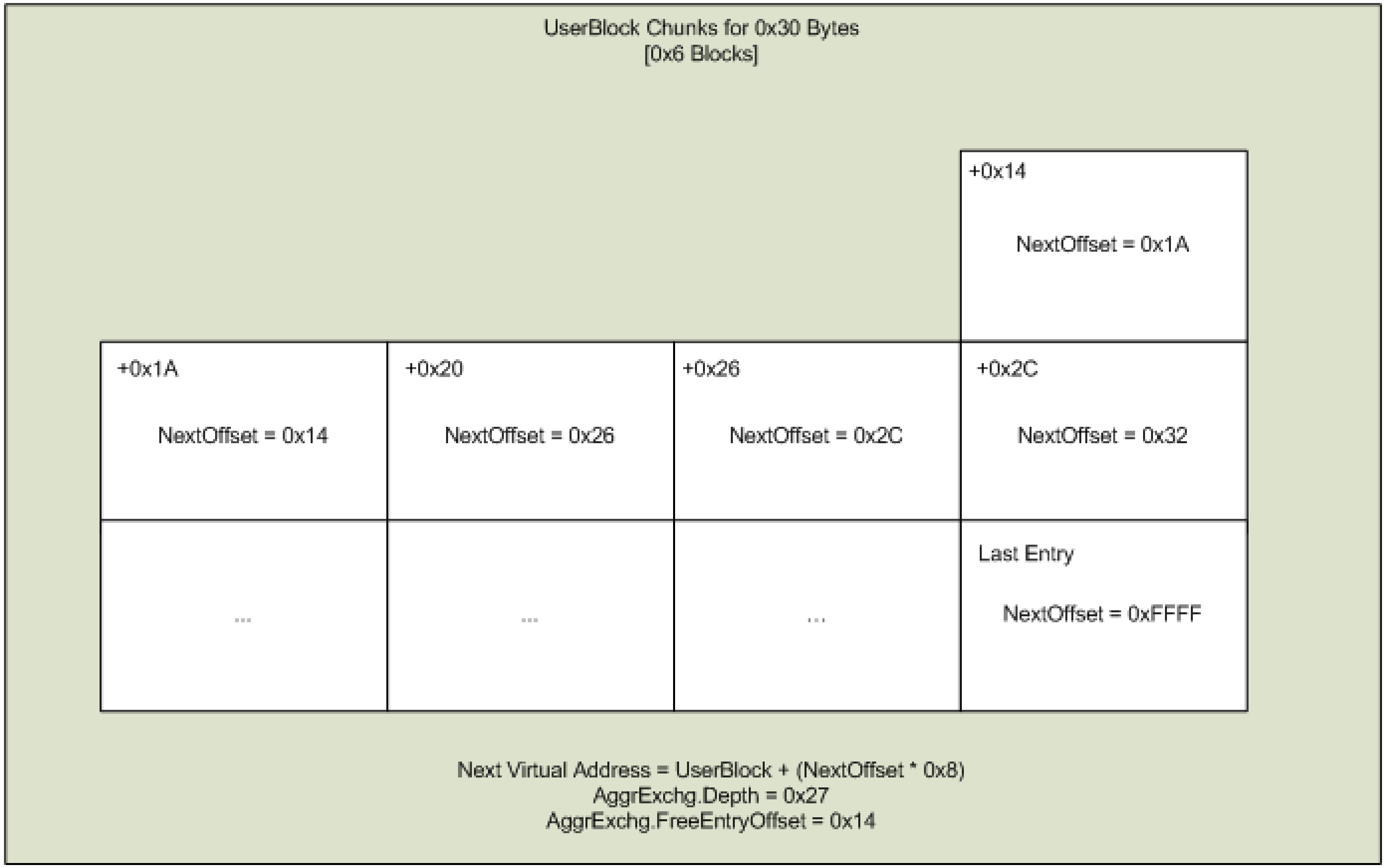
```
//hi ben hawkes :)
_HEAP_ENTRY *ChunkHeader = ChunkToFree - sizeof(_HEAP_ENTRY);
if(ChunkHeader->UnusedBytes == 0x5)
       ChunkHeader -= 8 * (BYTE)ChunkHeader->SegmentOffset;

_HEAP_ENTRY *ChunkHeader_Saved = ChunkHeader;

//gets the subsegment based from the LFHKey, Heap and ChunkHeader
_HEAP_SUBSEGMENT SubSegment = GetSubSegment(Heap, ChunkToFree);
_HEAP_USERDATA_HEADER *UserBlocks = SubSegment->UserBlocks;

//Set flags to 0x80 for LFH_FREE (offset 0x7)
ChunkHeader->UnusedBytes = 0x80;

//Set SegmentOffset or LFHFlags (offset 0x6)
ChunkHeader->SegmentOffset = 0x0;
```

Freeing : Front-End

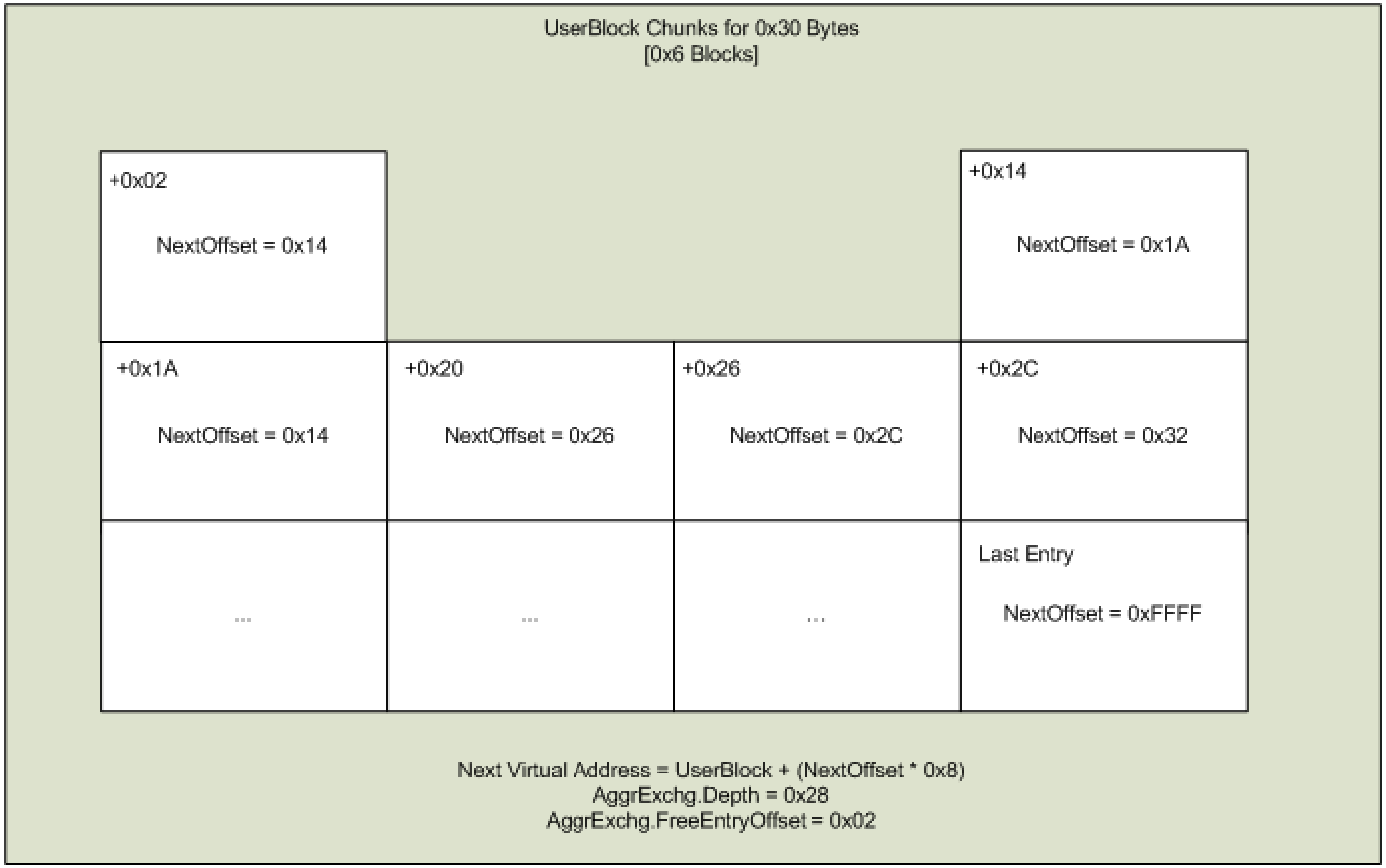
- **RtlpLowFragHeapFree: Part II**
  - The Offset and Depth can now be updated. The *NewOffset* should point to the chunk that was recently freed and the depth will be incremented by 0x1.

```
while(1)
{
	int Depth = SubSegment->AggregateExchg.Depth;
	int Offset = SubSegment->AggregateExchg.FreeEntryOffset;

	_INTERLOCK_SEQ AggrExchg_New;
	AggrExchg_New.Sequence = UpdateSeq(SubSegment->AggregateExchg);

	if(!MaintanenceNeeded(SubSegment))
	{
		//set the FreeEntry Offset ChunkToFree
		*(WORD)(ChunkHeader + 8) = Offset;

		//Get the next free chunk, based off the offset from the UserBlocks
		//add 0x1 to the depth due to freeing
		int NewOffset = Offset - ((ChunkHeader - UserBlocks) / 8);
		AggrExchg_New.FreeEntryOffset = NewOffset;
		AggrExchg_New.Depth = Depth + 1;

		//this is where Hint is set :)
		SubSegment->LocalInfo->Hint = SubSegment;
	}
	else
	{
		PerformSubSegmentMaintenance(SubSegment);
		RtlpFreeUserBlock(LFH, SubSegment->UserBlocks);
		break;
	}

	//_InterlockedCompareExchange64
	if(AtomicSwap(&SubSegment->AggregateExchg, AggrExchg_New))
		break;
	else
		ChunkHeader = ChunkHeader_Saved;
}
```

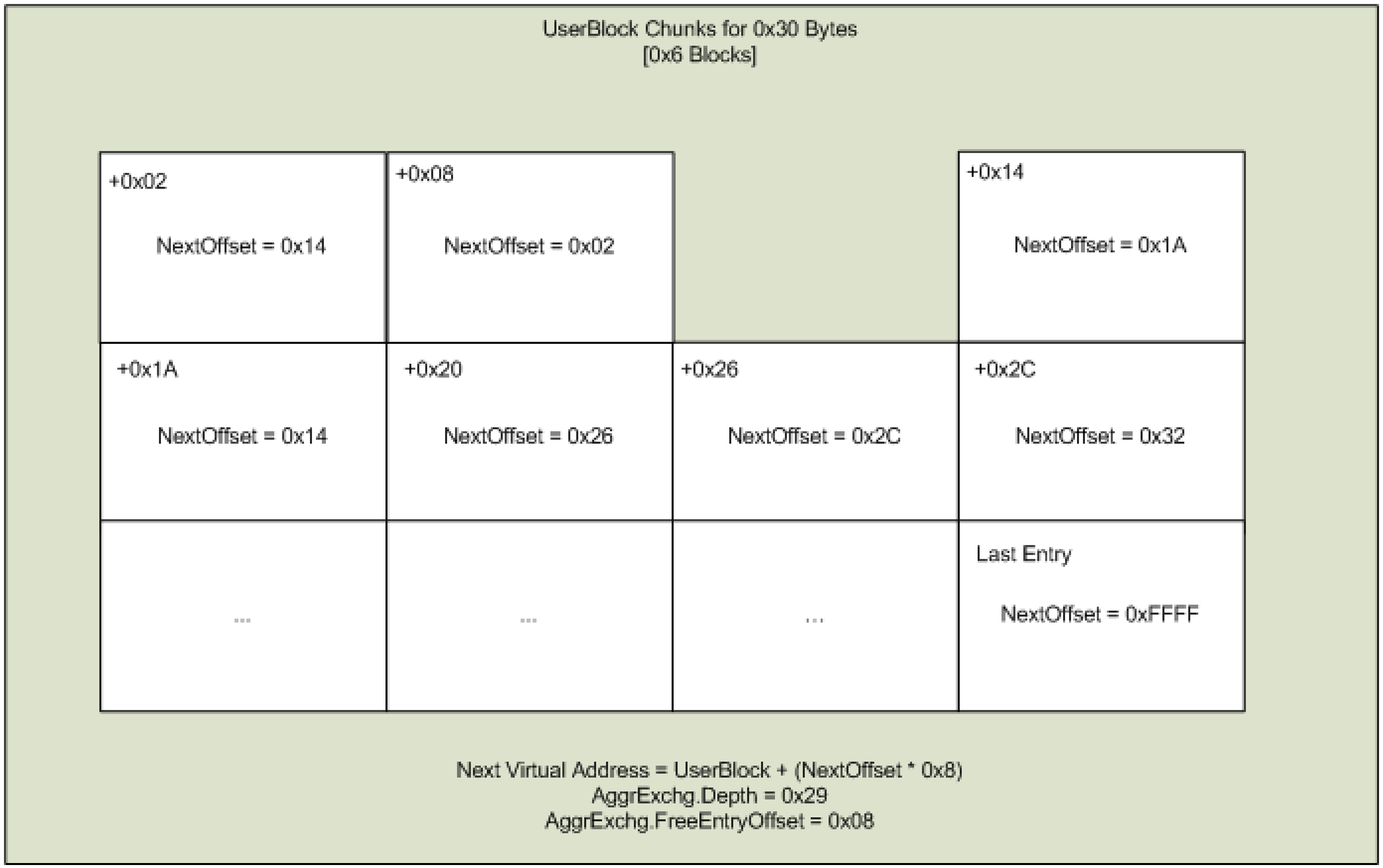
Freeing : Front-End : Example I



Freeing : Front-End : Example II

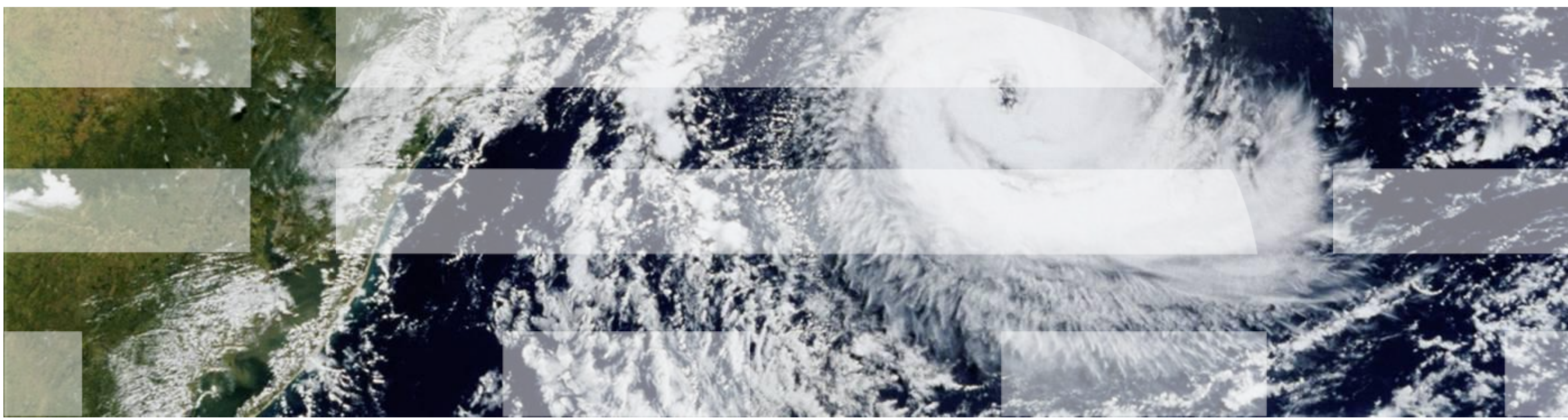


Freeing : Front-End : Example III



Security Mechanisms

“@shydemeanor I think I’m using too much code in the slides.”



Security Mechanisms : Heap Randomization

```
int RandPad = (RtlpHeapGenerateRandomValue64() & 0x1F) << 0x10;

//if maxsize + pad wraps, null out the randpad
int TotalMaxSize = MaximumSize + RandPad;
if(TotalMaxSize < MaximumSize)
{
	TotalMaxSize = MaximumSize;
	RandPad = Zero;
}

if(NtAllocateVirtualmemory(-1, &BaseAddress....))
	return 0;

heap = (_HEAP*)BaseAddress;
MaximumSize = TotalMaxSize;

//if we used a random pad, adjust the heap pointer and free the memory
if(RandPad != Zero)
{
	if(RtlpSecMemFreeVirtualMemory())
	{
		heap = (_HEAP*)RandPad + BaseAddress;
		MaximumSize = TotalSize - RandPad;
	}
}
```

- Information
  - 64k aligned
  - 5-bits of entropy
  - Used to avoid the same HeapBase on consecutive runs

- Thoughts
  - Not impossible to brute force
  - If *TotalMaxSize* wraps, there will be no RandPad
  - Hard to influence **HeapCreate()**
  - Unlikely due to **NtAllocateVirtualmemory**() failing

Security Mechanisms : Header Encoding/Decoding

```
EncodeHeader(_HEAP_ENTRY *Header, _HEAP *Heap)
{
        if(Heap->EncodeFlagMask)
        {
                Header->SmallTagIndex =
                        (BYTE)Header ^ (Byte)Header+1 ^ (Byte)Header+2;
                (DWORD)Header ^= Heap->Encoding;
        }
}
```

```
DecodeHeader(_HEAP_ENTRY *Header, _HEAP *Heap)
{
        if(Heap->EncodeFlagMask && (Header & Heap->EncodeFlagMask))
        {
                (DWORD)Header ^= Heap->Encoding;
        }
}
```

- Information
  - Size, Flags, CheckSum encoded
  - Prevents predictable overwrites w/o information leak
  - Makes header overwrites much more difficult

- Thoughts
  - NULL out **Heap->EncodeFlagMask**
    - I believe a new heap would be in order.
  - Overwrite first 4 bytes of encoded header to break *Header & Heap->EncodeFlagMask* (Only useful for items in FreeLists)
  - Attack last 4 bytes of the header

Security Mechanisms : Death of Bitmap Flipping

```
// if we unlinked from a dedicated free list and emptied it,clear the bitmap
if (reqsize < 0x80 && nextchunk == prevchunk)
{
    size = SIZE(chunk);
    BitMask = 1 << (size & 7);

    // note that this is an xor
    FreeListsInUseBitmap[size >> 3] ^= vBitMask;
}
```

```
//HeapAlloc
size = SIZE(chunk);
BitMask = 1 << (Size & 0x1F);
BlocksIndex->ListInUseUlong[Size >> 5] &= ~BitMask;

//HeapFree
size = SIZE(chunk);
BitMask = 1 << (Size & 0x1F);
BlocksIndex->ListInUseUlong[Size >> 5] |= BitMask;
```

- Information
  - XOR no longer used
  - OR for population
  - AND for exhaustion
- Thoughts
  - SOL
  - Not as important as before because FreeLists/ListHints aren't initialized to point to themselves.

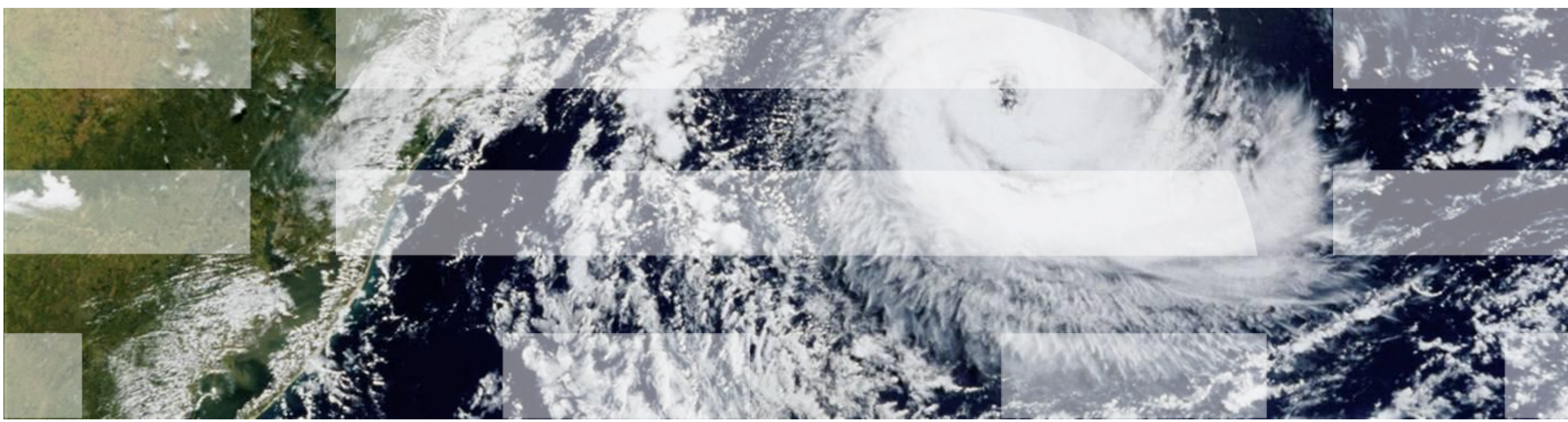
Security Mechanisms : Safe Linking

```
if(InsertList->Blink->Flink == InsertList)
{
	ChunkToFree->Flink = InsertList;
	ChunkToFree->Blink = InsertList->Blink;
	InsertList->Blink->Flink = ChunkToFree;
	InsertList->Blink = ChunkToFree
}
else
{
	RtlpLogHeapFailure();
}
if(BlocksIndex)
{
	FreeListIndex = BlocksIndexSearch(BlocksIndex, ChunkSize);
	_LIST_ENTRY *FreeListToUse = BlocksIndex->ListHints[FreeListIndex];

	//ChunkToFree.Flink/Blink are user controlled
	if(ChunkSize >= FreeListToUse.Size)
	{
		BlocksIndex->ListHints[FreeListIndex] = ChunkToFree;
	}

	.
	.
}
```

- Information
  - Prevents overwriting a FreeList->Blink, which when linking a chunk in can be overwritten to point to the chunk that was inserted before it
  - Brett Moore Attacking FreeList[0]
- Thoughts
  - Although it prevents Insertion attacks, if it doesn't terminate, the chunk will be placed in one of the **ListHints**
  - The problem is the Flink/Blink are fully controlled due to no **Linking** process
  - You still have to deal with **Safe Unlinking**, but it's a starting point.

Tactics

“You do not want to pray-after-free – Nico Waisman”



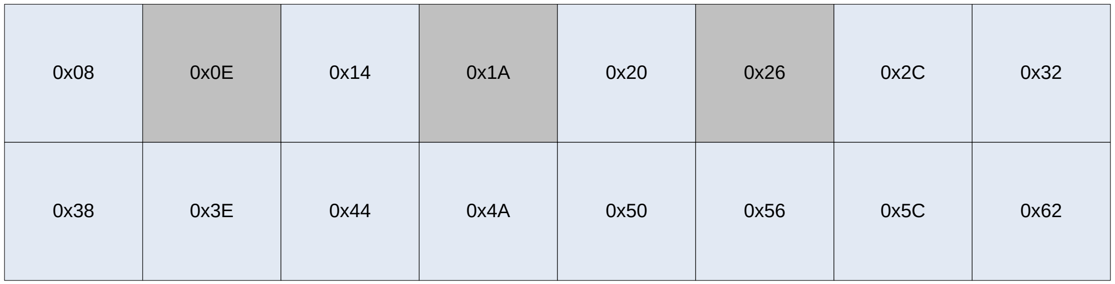
Tactics : Heap Determinism : Activating the LFH

```
//Without the LFH activated
//0x10 => Heap->CompatibilityFlags |= 0x20000000;
//0x11 => RtlpPerformHeapMaintenance(Heap);
//0x11 => FreeList->Blink = LFHContext + 1;
for(i = 0; i < 0x12; i++)
     HeapAlloc(pHeap, 0x0, SIZE);
```

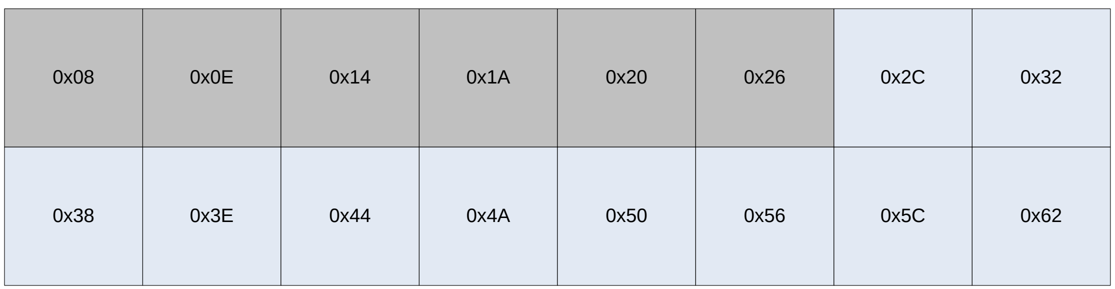
- 0x12 (18)consecutive allocations will guarantee LFH enabled for *SIZE*
  - 0x11 (17) if the _LFH_HEAP has been previously activated

Tactics : Heap Determinism : Defragmentation

Gray = BUSY
Blue = FREE



Gray = BUSY
Blue = FREE



- A game of filling the holes
- Easily done by making enough allocations to create a new **SubSegment** with associated **UserBlock**

Tactics : Heap Determinism : Adjacent Data

```
EnableLFH(SIZE);
NormalizeLFH(SIZE);

alloc1 = HeapAlloc(pHeap, 0x0, SIZE);

alloc2 = HeapAlloc(pHeap, 0x0, SIZE);
memset(alloc2, 0x42, SIZE);
*(alloc2 + SIZE-1) = '\0';

alloc3 = HeapAlloc(pHeap, 0x0, SIZE);
memset(alloc3, 0x43, SIZE);
*(alloc3 + SIZE-1) = '\0';

printf("alloc2 => %s\n", alloc2);
printf("alloc3 => %s\n", alloc3);

memset(alloc1, 0x41, SIZE * 3);

printf("Post overflow..\n");
printf("alloc2 => %s\n", alloc2);
printf("alloc3 => %s\n", alloc3);
```

```
Result:
alloc2 => BBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBB
alloc3 => CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC

Post overflow..

alloc2 => AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
           AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAACCCCCC
           CCCCCCCCC
alloc3 => AAAAAAAAAAAAAAAAAAAAAAAACCCCCCCCCCCCCCC
```

```
alloc1 = HeapAlloc(pHeap, 0x0, SIZE);
alloc2 = HeapAlloc(pHeap, 0x0, SIZE);
alloc3 = HeapAlloc(pHeap, 0x0, SIZE);

HeapFree(pHeap, 0x0, alloc2);

//overflow-able chunk just like alloc1 could reside in same position as alloc2
alloc4 = HeapAlloc(pHeap, 0x0, SIZE);

memcpy(alloc4, src, SIZE)
```

- Overwrite into adjacent chunks (requires normalization)
- Can overwrite NULL terminator (Vreugdenhil 2010)
- Ability to use data in a recently freed chunk with proper heap manipulation

Tactics : Heap Determinism : Data Seeding

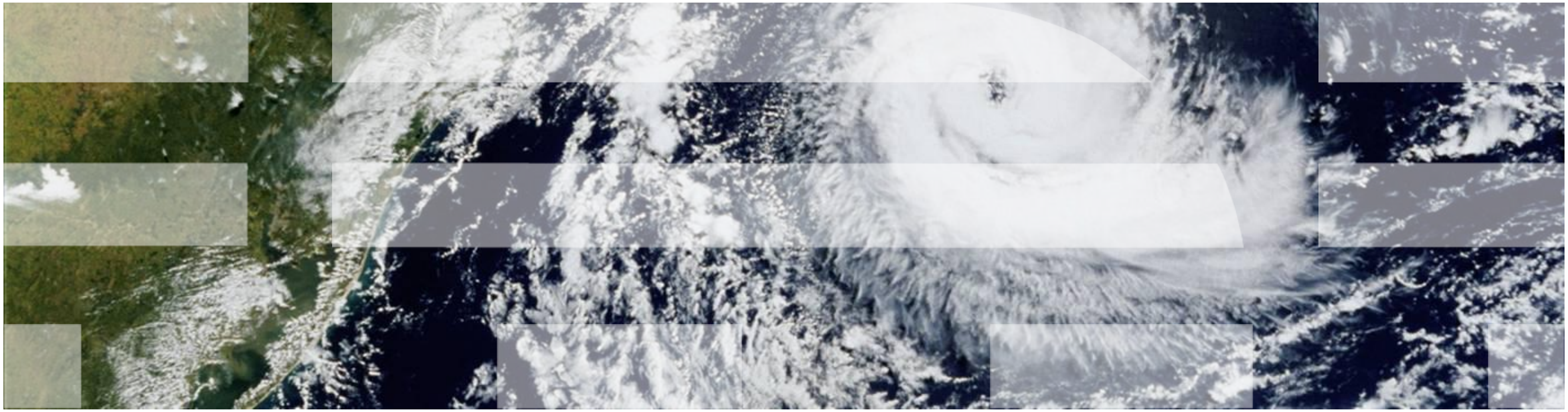
```
EnableLFH(SIZE);
NormalizeLFH(SIZE);

for(i = 0; i < 0x4; i++)
{
       allocb[i] = HeapAlloc(pHeap, 0x0, SIZE);
       memset(allocb[i], 0x41 + i, SIZE);
}

printf("Freeing all chunks!\n");
for(i = 0; i < 0x4; i++)
{
       HeapFree(pHeap, 0x0, allocb[i]);
}

printf("Allocating again\n");
for(i = 0; i < 0x4; i++)
{
       allocb[i] = HeapAlloc(pHeap, 0x0, SIZE);

}
```

```
Result:
Allocation 0x00 for 0x28 bytes => 41414141 41414141 41414141
Allocation 0x01 for 0x28 bytes => 42424242 42424242 42424242
Allocation 0x02 for 0x28 bytes => 43434343 43434343 43434343
Allocation 0x03 for 0x28 bytes => 44444444 44444444 44444444

Freeing all chunks!
Allocating again
Allocation 0x00 for 0x28 bytes => 0E004444 44444444 44444444
Allocation 0x01 for 0x28 bytes => 08004343 43434343 43434343
Allocation 0x02 for 0x28 bytes => 02004242 42424242 42424242
Allocation 0x03 for 0x28 bytes => 62004141 41414141 41414141
```

- Saved FreeEntryOffset resides in 1st 2 bytes
- Influence the LSB of vtable
- Good for use-after-free
- See Nico Wasiman's 2010 BH Presentation / Paper
- NICO Rules!

Tactics : Exploitation

“For the Busticati, By the Busticati”



Tactics : Exploitation : Ben Hawkes #1 : Part I

RtlpLowFragHeapFree() will adjust the _HEAP_ENTRY if certain flags are set.

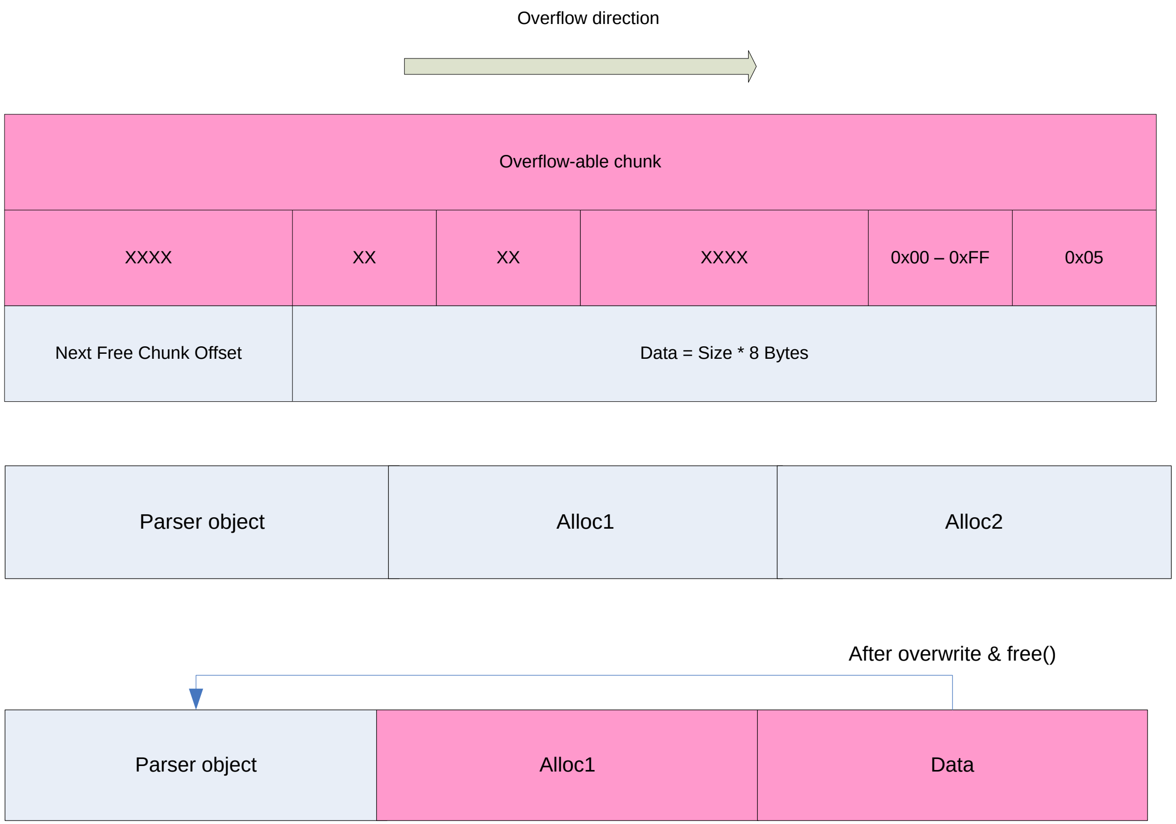
```
_HEAP_ENTRY *ChunkHeader = ChunkToFree - sizeof(_HEAP_ENTRY);
if(ChunkHeader->UnusedBytes == 0x5)
      ChunkHeader -= 8 * (BYTE)ChunkHeader->SegmentOffset;
```

0	2	3	4	6	7
Size	Flags	Checksum	Prev Size	Seg Offset	UnusedBytes
Next Free Chunk Offset	Data = Size * 8 Bytes				

If you can overflow into a chunk that will be freed, the **SegmentOffset** can be used to point to another **valid** _HEAP_ENTRY.

This could lead to controlling data that was previously allocated (Think C++ objects)

Tactics : Exploitation : Ben Hawkes #1 : Part II



Prerequisites

- Ability to allocate SIZE
- Place legitimate a chunk before a chunk to be overflowed
- Overflow at least 8-bytes
- Ability to free overwritten chunk

Methodology

1. Enable LFH
2. Normalize LFH
3. Alloc1
4. Alloc2
5. Overwrite Alloc2's header to point to an object of interest
6. Free Alloc2
7. Alloc3 (will point to the object of interest)
8. Write data

Tactics : Exploitation : FreeEntryOffset Overwrite: Part I

All code in RtlpLowFragHeapAllocFromContext() is wrapped in try/catch{} . All exceptions will return 0, letting the back-end handle the allocation.

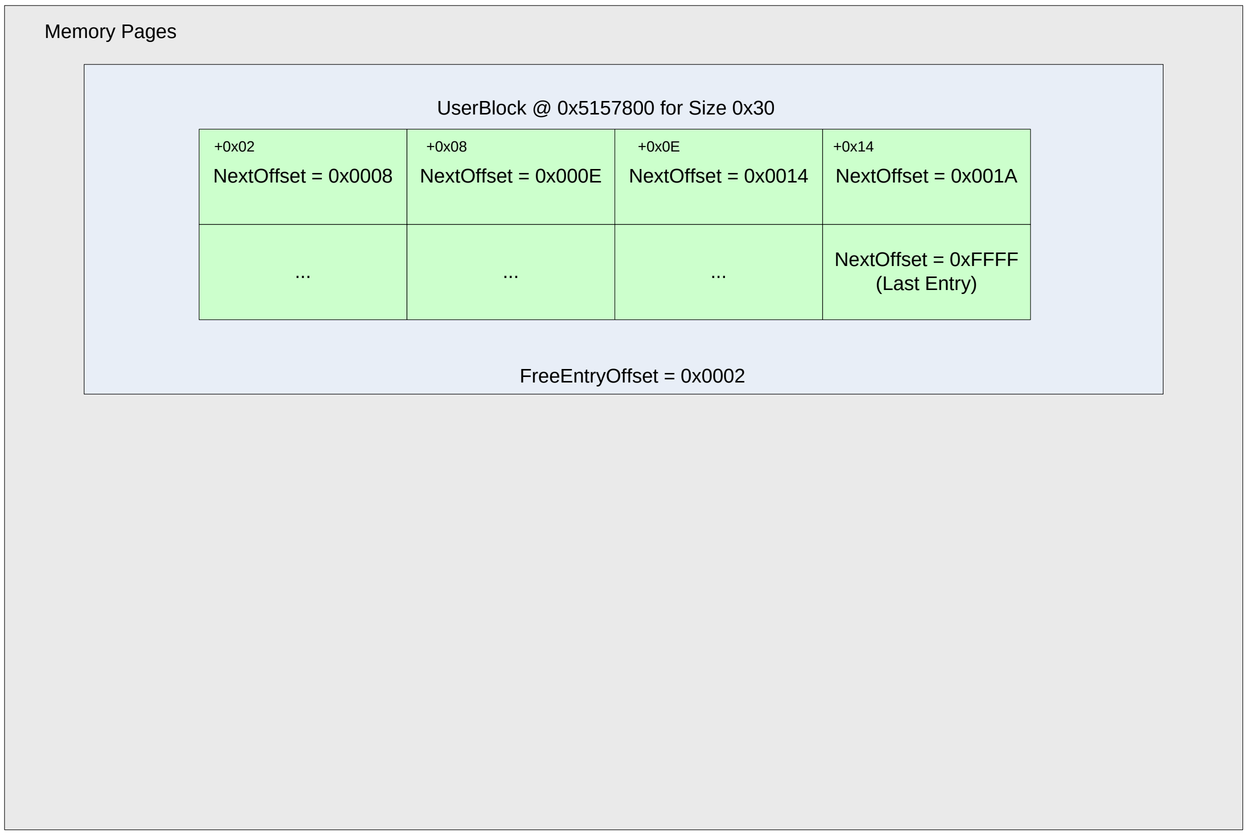
```
try
{
        //the next offset is stored in the 1st 2-bytes of userdata
        short NextOffset =
                UserBlocks + BlockOffset + sizeof(_HEAP_ENTRY));

        _INTERLOCK_SEQ AggrExchg_New;
        AggrExchg_New.Offset = NextOffset;
}
catch
{
        return 0;
}
```

As we saw, the **FreeEntryOffset** is stored in the 1st 2 bytes of user-writable data within each chunk in a **UserBlock**.

This will be used to get the address of the next **free** chunk used for allocation. What if we overflow this chunk?

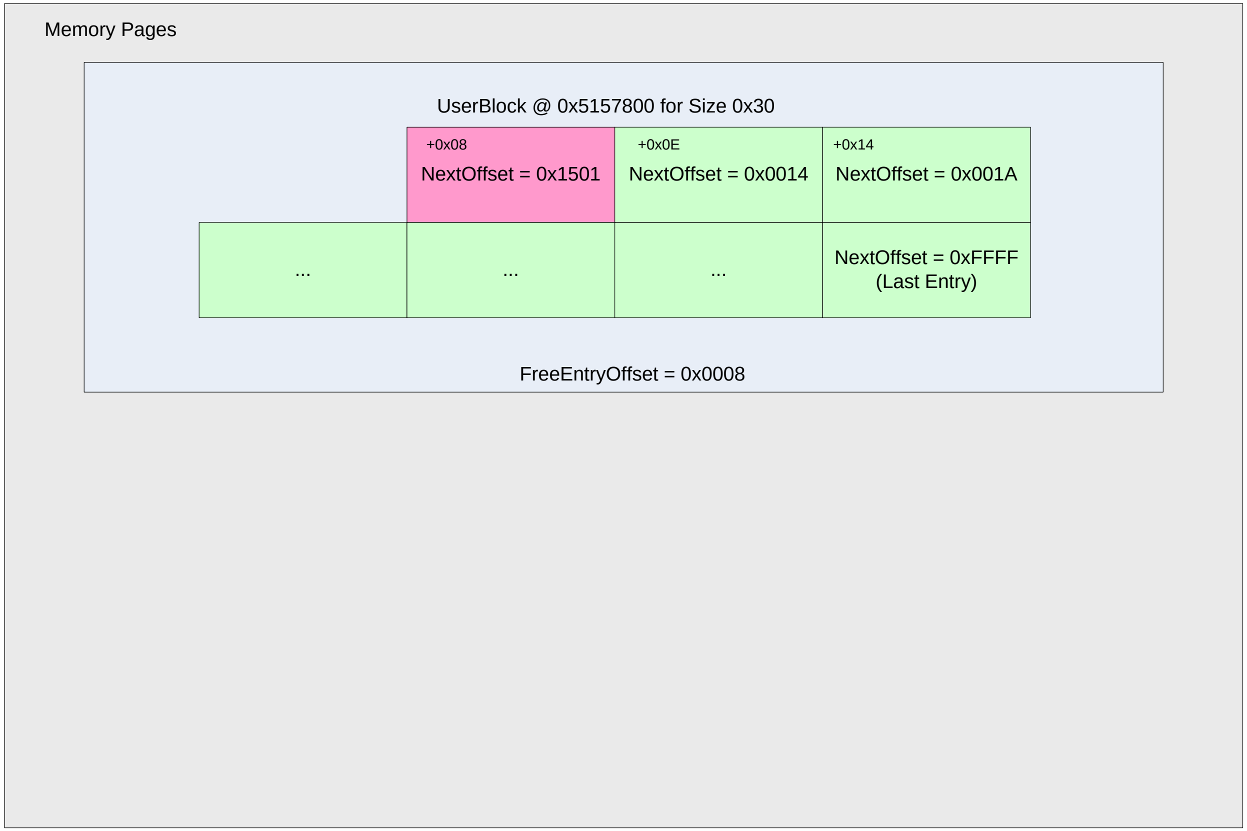
Tactics : Exploitation : FreeEntryOffset Overwrite: Part II

Assume a **full** UserBlock for 0x30 bytes (0x6 blocks). Our first allocation will update the **FreeEntryOffset** to **0x0008**. (Stored in the _INTERLOCK_SEQ.FreeEntryOffset



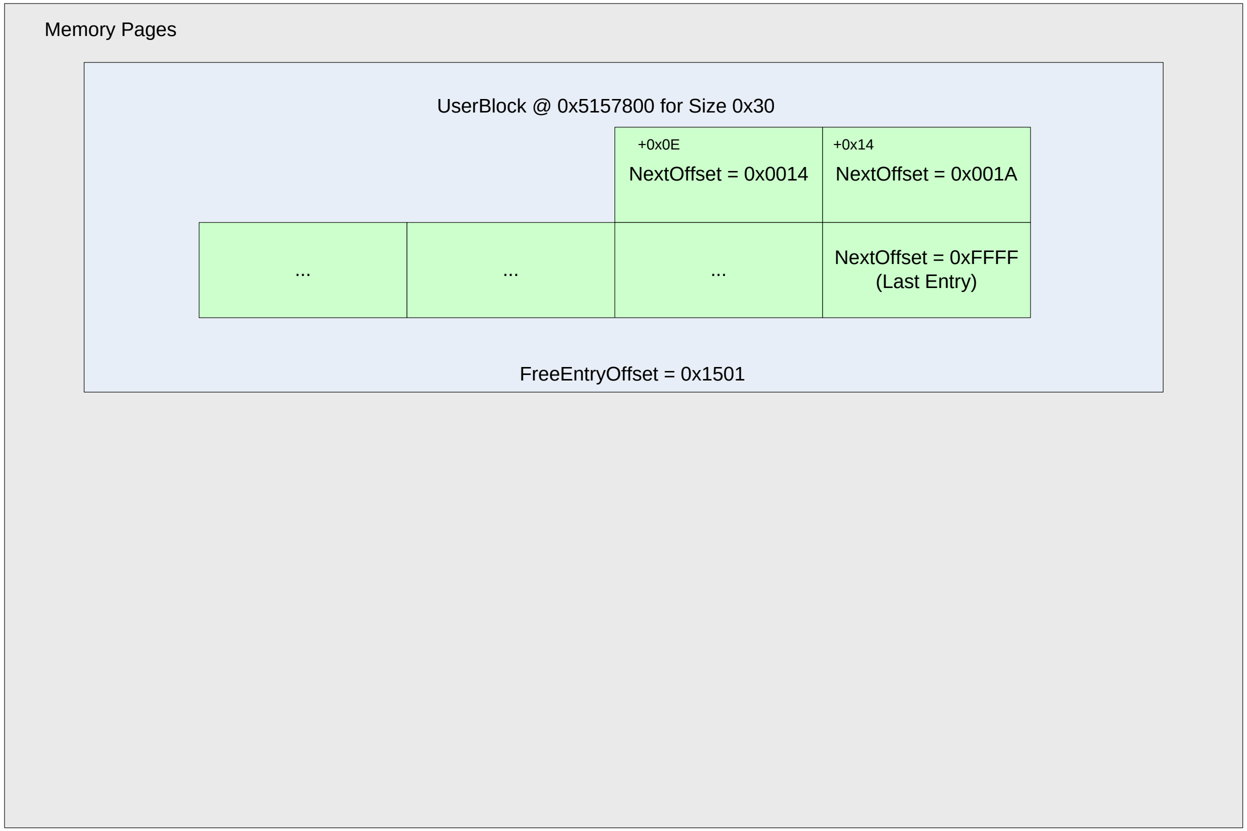
Tactics : Exploitation : FreeEntryOffset Overwrite: Part III

If an overflow of at least 0x9 bytes (0xA preferable) is made. The saved FreeEntryOffset of the adjacent chunk can be overwritten. This gives the attacker a range of 0xFFFF * 0x8 (Offsets are stored in **blocks** and converted to **byte offsets**.)



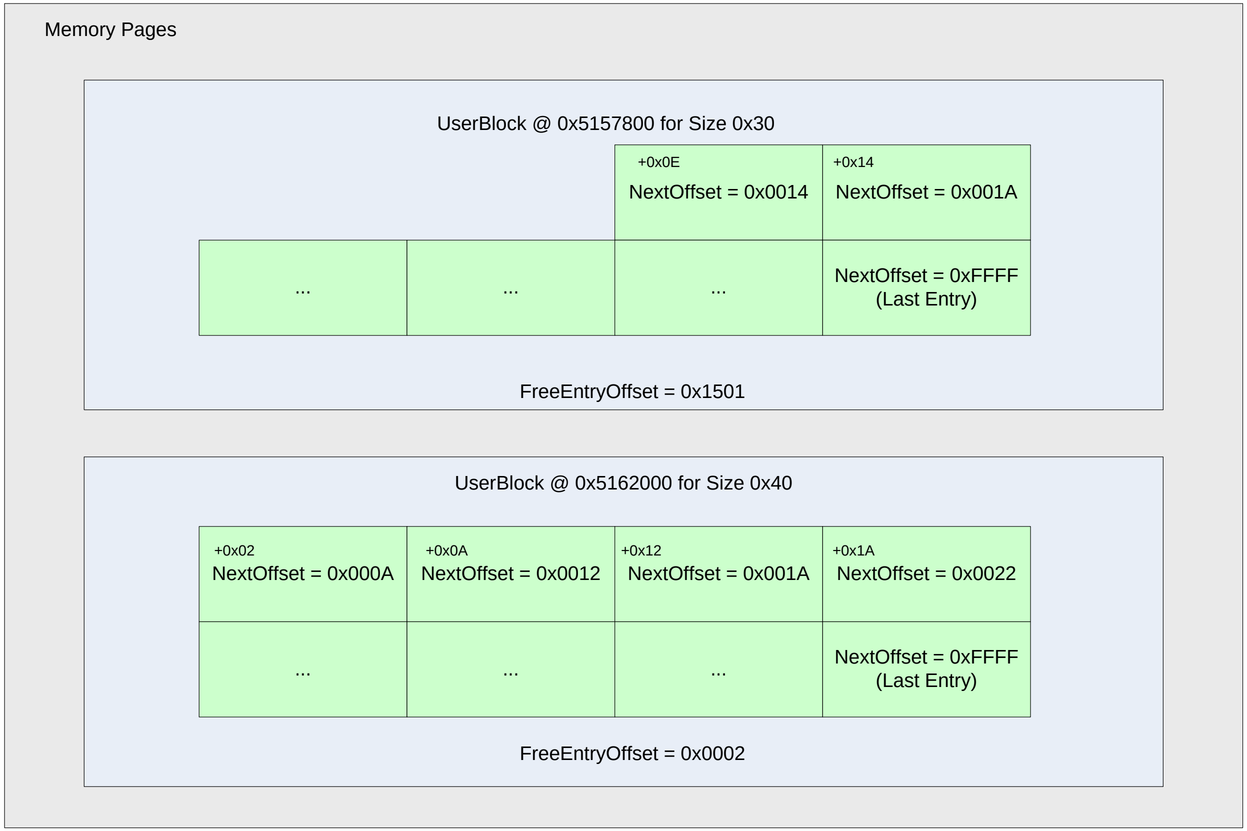
Tactics : Exploitation : FreeEntryOffset Overwrite: Part IV

An allocation for the overwritten block must be made next to store the tainted offset in the _INTERLOCK_SEQ. In this example, we will have a 0x1501 * 0x8 jump to the *next* 'free chunk'.

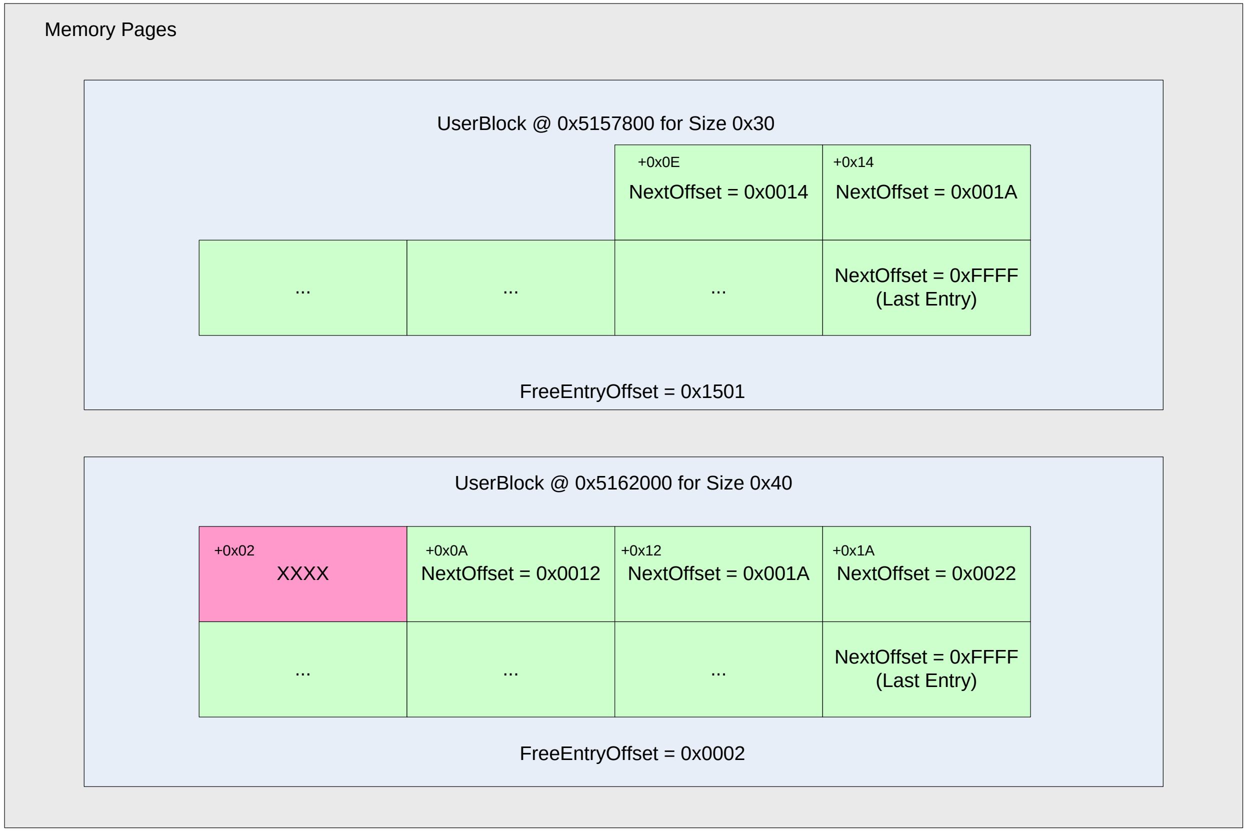


Tactics : Exploitation : FreeEntryOffset Overwrite: Part V

Since it's possible to get SubSegments adjacent to each other in memory, you can write into other forwardly adjacent memory pages (Control over allocations is required). This gives you the ability to overwrite data that is in a different _HEAP_SUBSEGMENT than the one which you are overflowing.



Tactics : Exploitation : FreeEntryOffset Overwrite: Part VI



NextChunk = UserBlock + Depth_IntoUserBlock + (FreeEntryOffset * 8)
NextChunk = 0x5157800 + 0x0E + (0x1501 * 8)
NextChunk = 0x5162016

Prerequisites

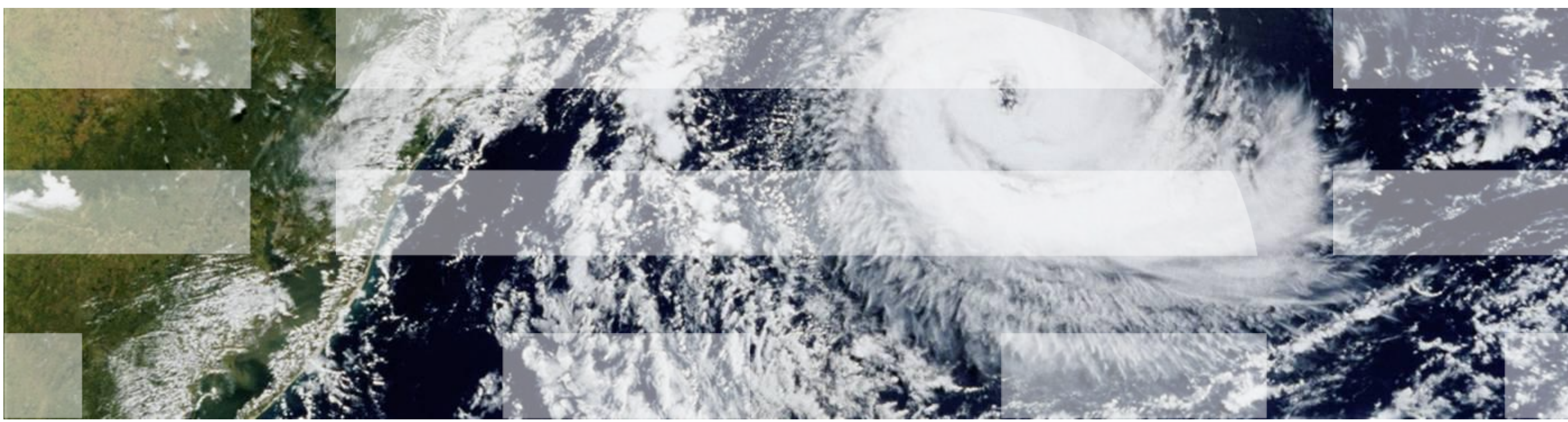
- Enabled the LFH
- Normalize the heap
- Control allocations for SIZE
- 0x9 – 0xA byte overflow into an adjacent chunk
- Adjacent chunk must be FREE
- Object to overwrite within the range (0xFFFF * 0x8 = max)

Methodology

1. Enable LFH
2. Normalize LFH
3. Alloc1
4. Overwrite into free chunk from Alloc1
5. Alloc2 (contains overwritten header)
6. Alloc3 (Uses overwritten FreeEntryOffset)
7. Write data to Alloc3 (which will be object of your choosing w/in 0xFFFF * 0x8)

Tactics : Exploitation : Observation

“Strawberry Pudding? Psst, this is a five course meal.”



Tactics : Exploitation : SubSegment Overwrite: Part I

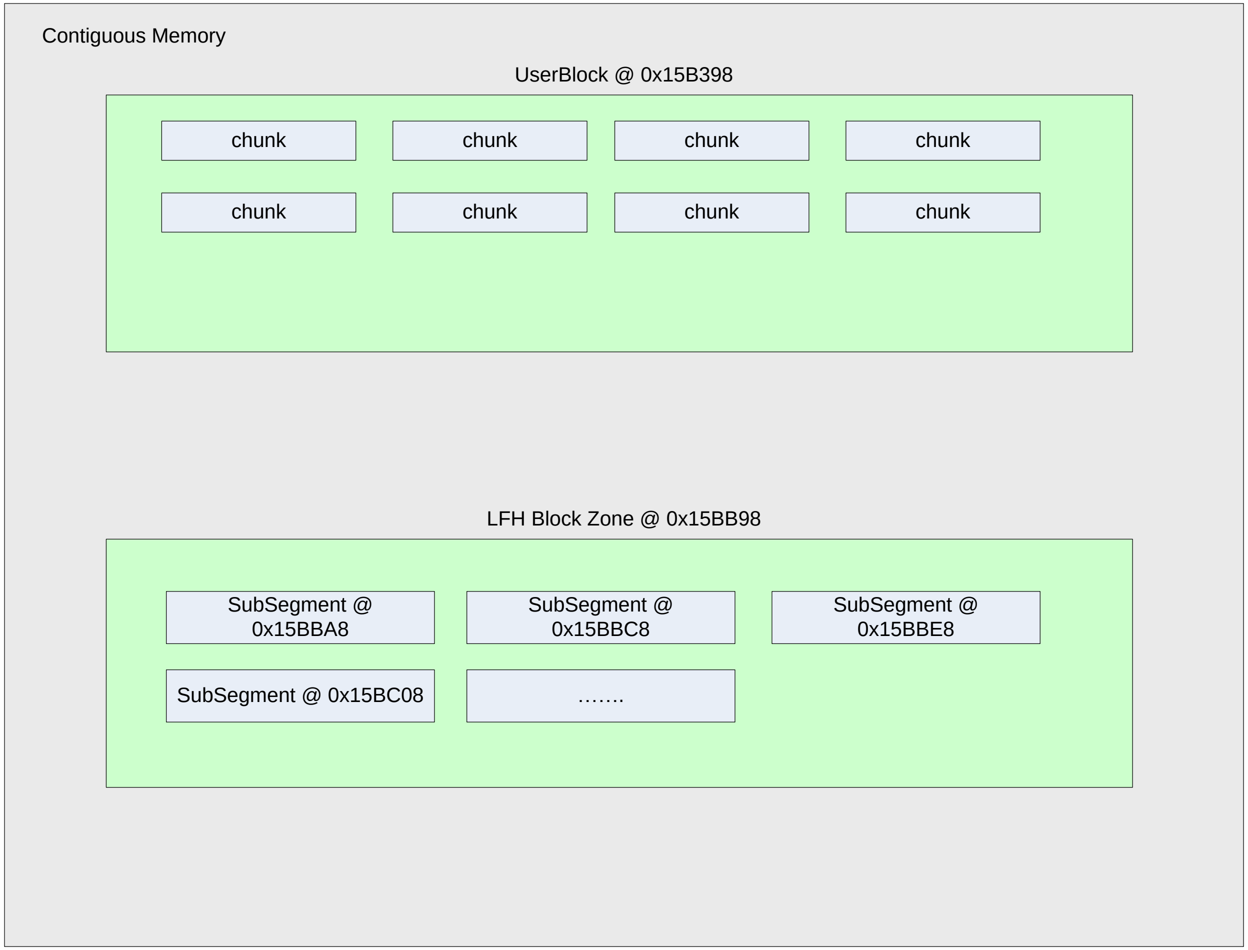
If the SubSegment can not be used, it will create a new **UserBlock** and assign it to a **new SubSegment**.

RtlpLowFragHeapAllocateFromZone will create space for new SubSegments if they have all been exhausted.

```
_HEAP_SUBSEGMENT *SubSeg = HeapLocalSegmentInfo->ActiveSubsegment;

//checks to ensure valid subsegment
_HEAP_USERDATA_HEADER *UserBlocks =
       SubSeg->UserBlocks;
if(!Depth ||
       !UserBlocks ||
       SubSeg->LocalInfo != HeapLocalSegmentInfo)
{
       Get new subsegment;
}

_HEAP_USERDATA_HEADER *UserData =
       RtlpAllocateUserBlock(lfh, UserBlockCacheIndex, BucketByteSize + 8);

_HEAP_SUBSEGMENT *NewSubSegment = RtlpLowFragHeapAllocateFromZone(LFH,
LocalDataIndex);

RtlpSubSegmentInitialize(LFH,
       NewSubSegment,
       UserBlock,
       RtlpBucketBlockSizes[HeapBucket->SizeIndex],
       UserDataAllocSize,HeapBucket);

_HEAP_LOCAL_SEGMENT_INFO *HeapLocalSegmentInfo =
       HeapLocalData->SegmentInfo[HeapBucket->SizeIndex];

_HEAP_SUBSEGMENT *SubSeg = HeapLocalSegmentInfo->ActiveSubsegment;
```

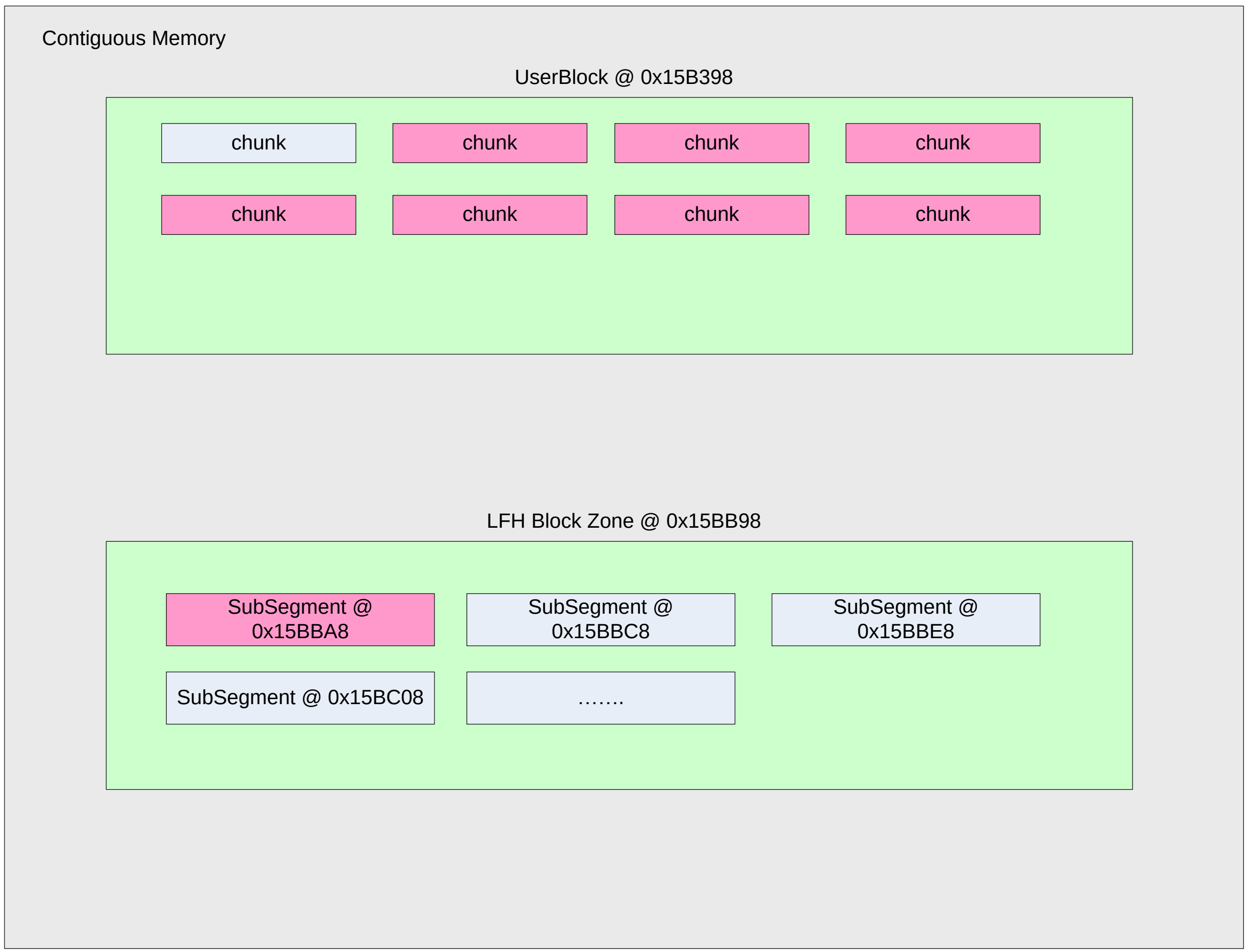
Tactics : Exploitation : SubSegment Overwrite: Part II

This provides a memory layout where the **UserBlock** data resides **before** the **_LFH_BLOCK_ZONE** structures (which hold pointers for SubSegment initialization).



Tactics : Exploitation : SubSegment Overwrite: Part III

An overflow past the end of the UserBlock will result in the overwriting of SubSegment information. The item of most concern is the pointer to the **UserBlocks** structure inside the SubSegment. If this value can be overwritten, then a subsequent allocation will result in a write-n to a user-supplied address.



Tactics : Exploitation : SubSegment Overwrite: Part IV

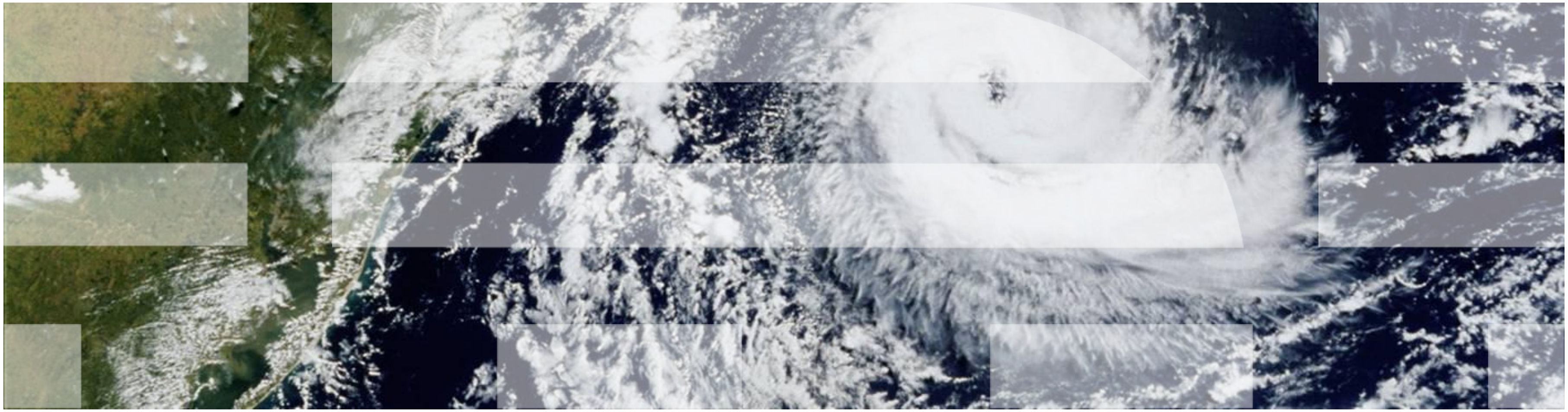
```
if(!Depth ||
       !UserBlocks ||
       SubSeg->LocalInfo != HeapLocalSegmentInfo)
{
       break;
}
```

Issues

1. The **UserBlock** that can be overflowed MUST reside before the space allocated for the _HEAP_SUBSEGMENT. This is not trivial, due to most applications not having a deterministic **BlockZone->Limit**. You won't know how many pointers are left.
2. **SubSeg->LocalInfo != HeapLocalSegmentInfo**. The address of the _HEAP_LOCAL_SEGMENT_INFO structure for a specific Bucket is required. The easiest way to determine this value would be a leak of the _LFH_HEAP pointer. (There are probably other ways as well)
3. A guard page could mitigate the effects of an overflow into an adjacent SubSegment.

Conclusion

“I know that most of the audience will be fast asleep by now.”



Conclusion

- Data structures have become far more complex
- Dedicated FreeLists / Lookaside List are dead
  - Replaced with new FreeList structure and LFH
- Many security mechanisms added since Win XP SP2
- Meta data corruption now leveraged to overwrite application data
- Heap normalization more important than ever
- Much more work to be done…

What's next?

- Developing reliable exploits specifically for Win7
- Abusing Un-encoded header information
- Look at Virtual / Debug allocation/free routines
- Caching mechanisms
- Continuing to come up with heap manipulation techniques
- Figuring out information leaks (heap addresses)
- HeapCON ?

Greetz

Thanks to all the Busticati for their help!

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Demo

“Fin.”