Windows Vista Heap Management Enhancements

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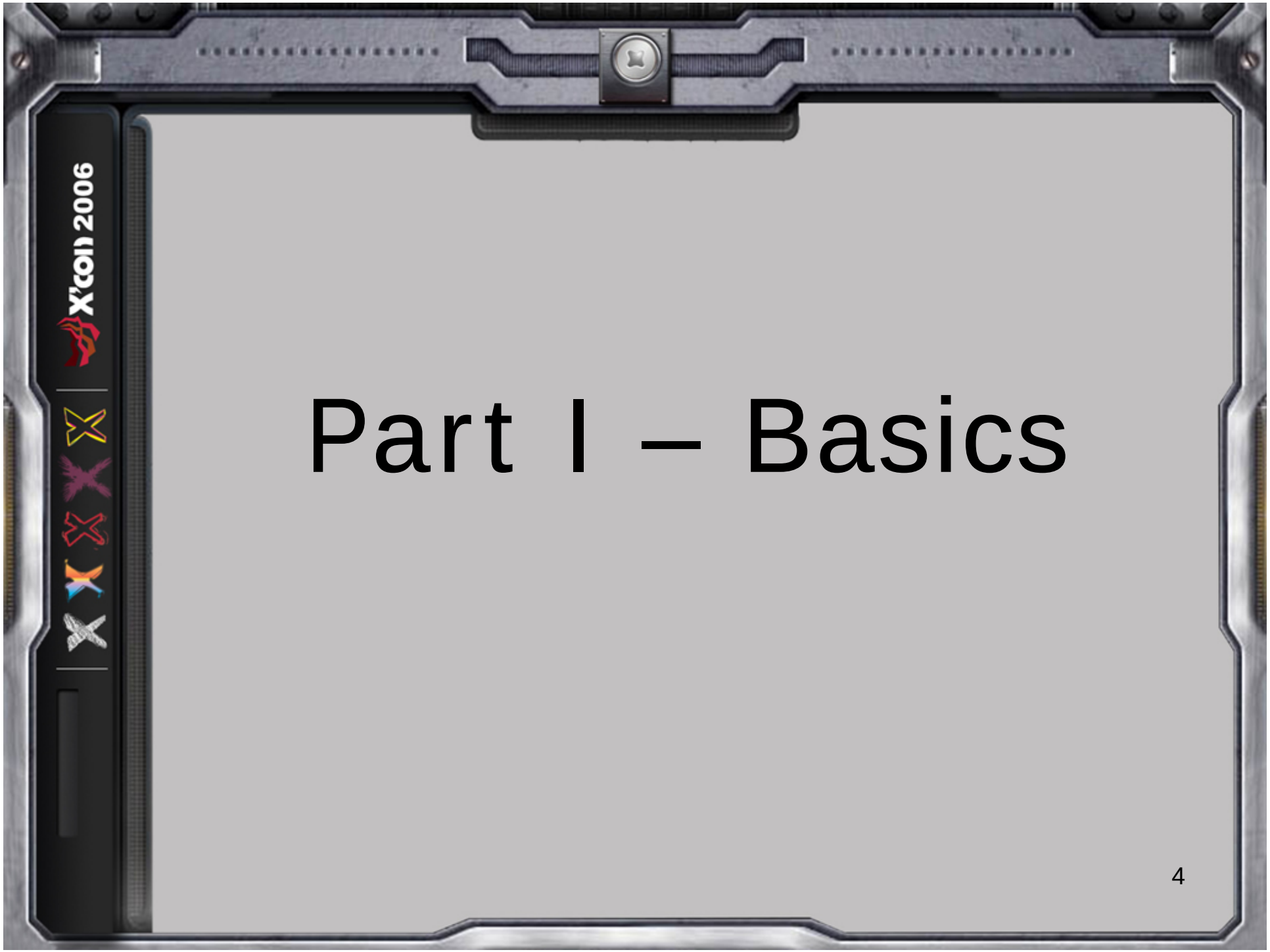
Agenda

- Windows NT Heap Management basics and evolution
- Windows Vista heap – major milestone
  - Development principles and guidelines
  - Security features
  - Performance features
- Q & A

Introduction

- Security – industry-wide concern
- TwC driving multiple security initiatives
- The NT Heap
  - Strategic point in defense
  - Improved to respond to industry trends in usage



Part I – Basics

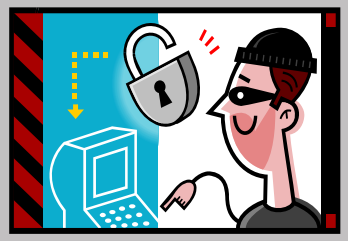
Heap Evolution

Basics	Performance	Opt-in SMP Scalability Heap Mitigations	Enhanced security Performance Quality tool
NT 4	NT 4 / SP4 Windows 2000	XP / SP2 Windows 2003	Windows Vista

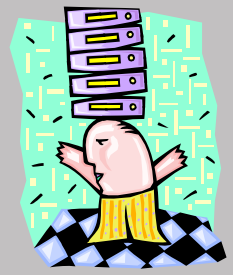
Time

Industry

Workload

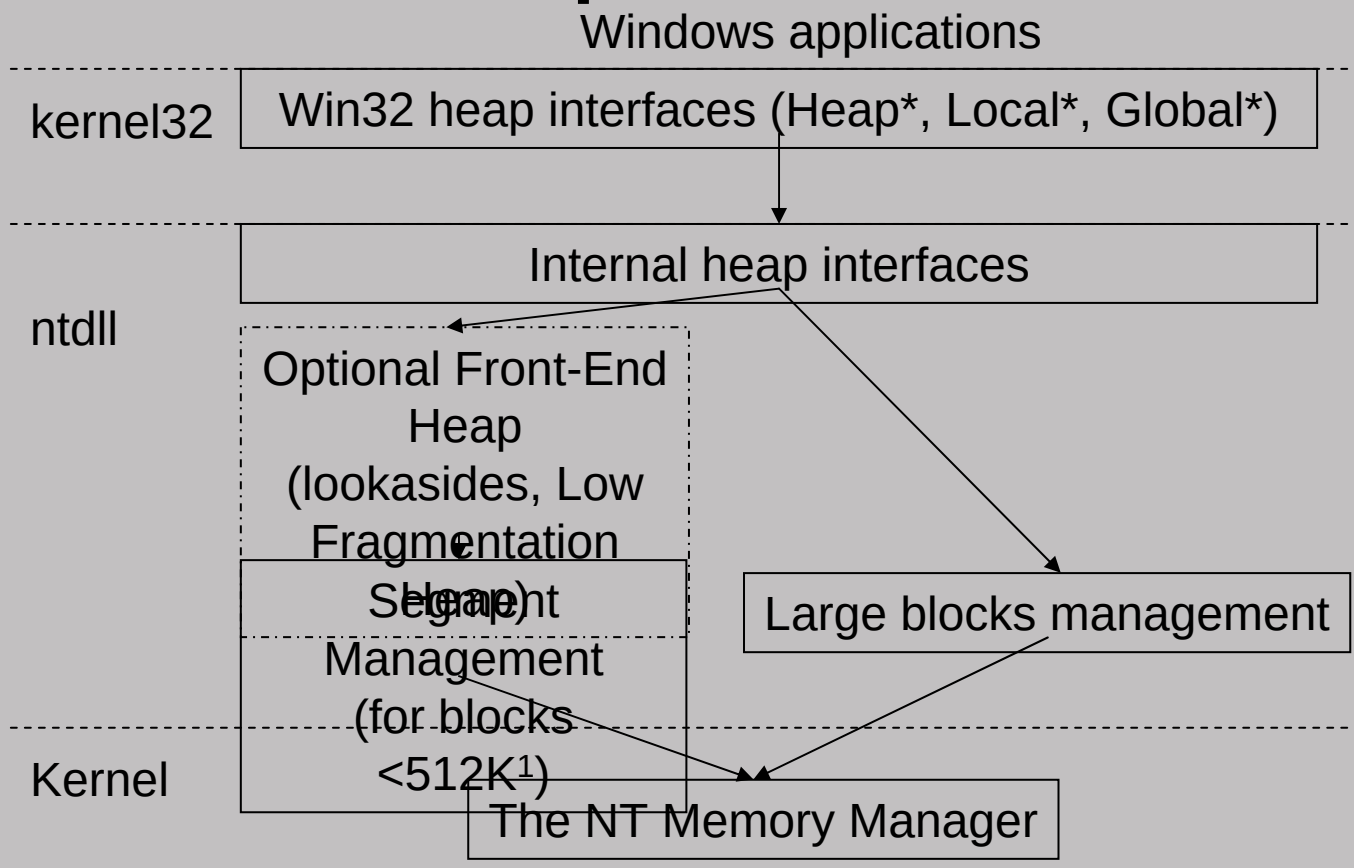


Exploitation



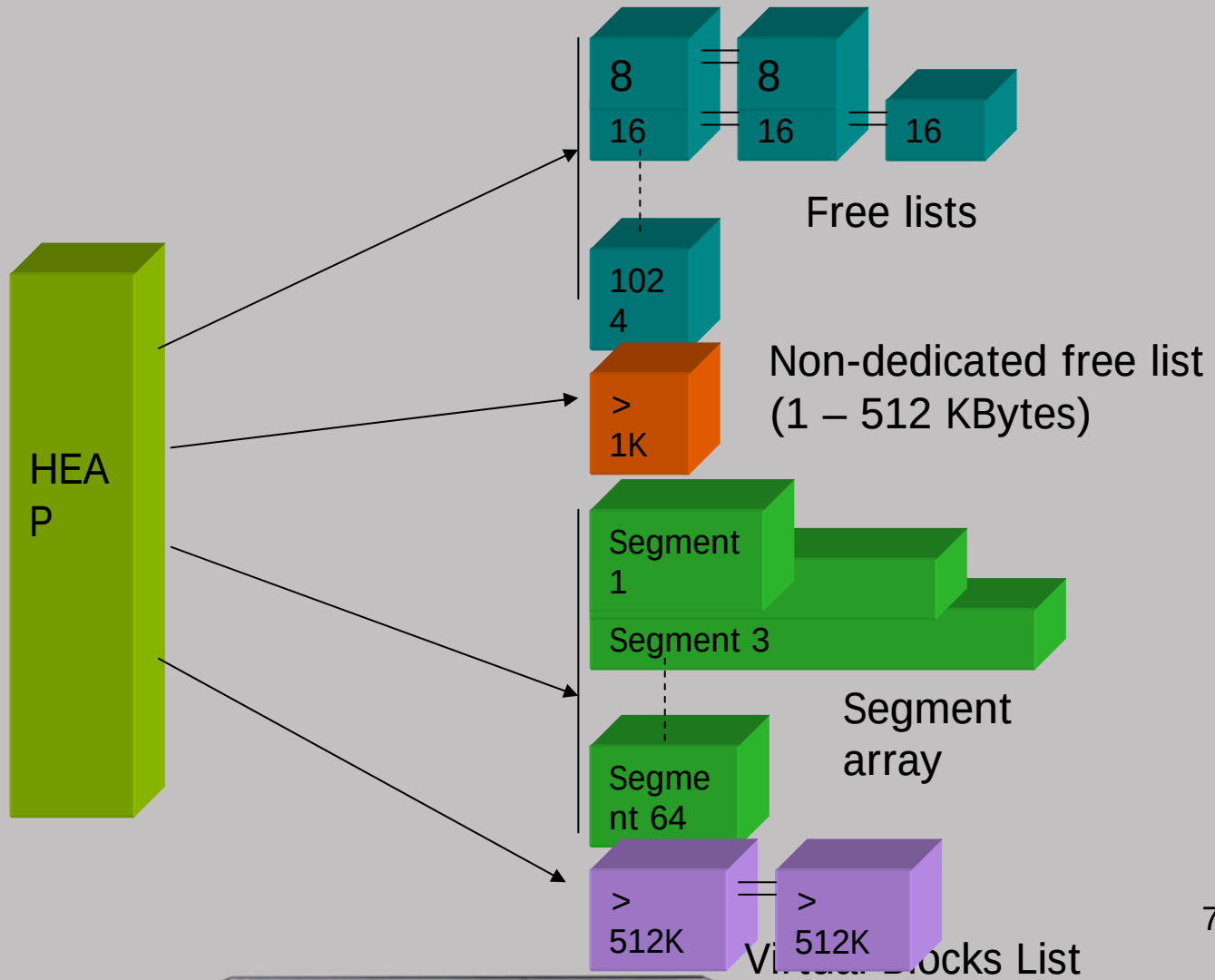
Parallelism

NT Heap Overview

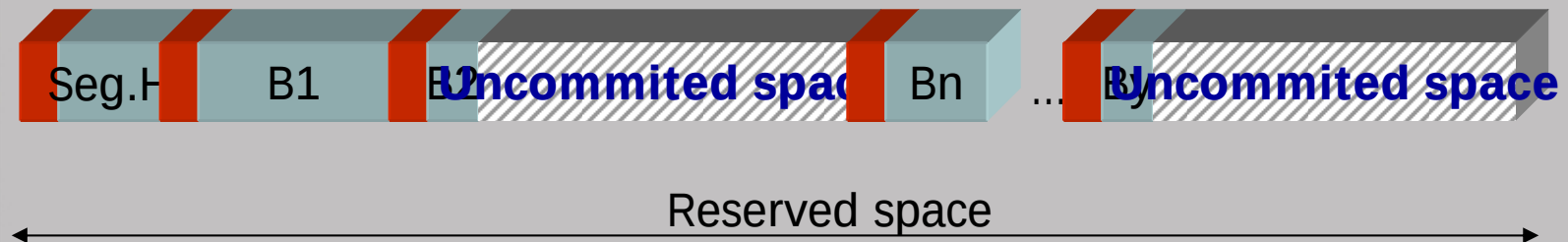


[1] On 32 bit platforms

The NT Heap Core Management



Heap Segments



Block Entry in prior Windows NT Versions

F-Link B-Link

```
0:018> dc 04392f80
04392f80  00040002 00000001 0442da60
00240e68
```

Previous block size

Size

segment

unused bytes

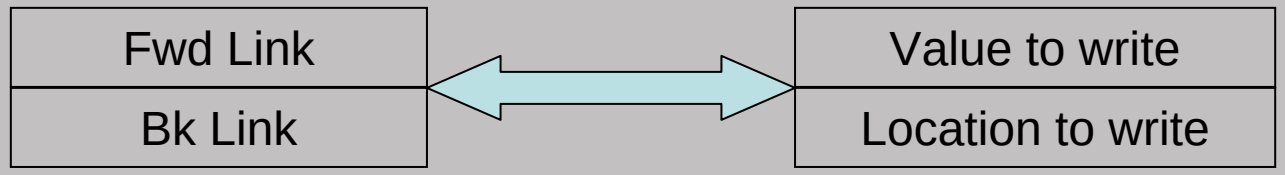
flags

tag

Role of Link Entry in Early Exploits

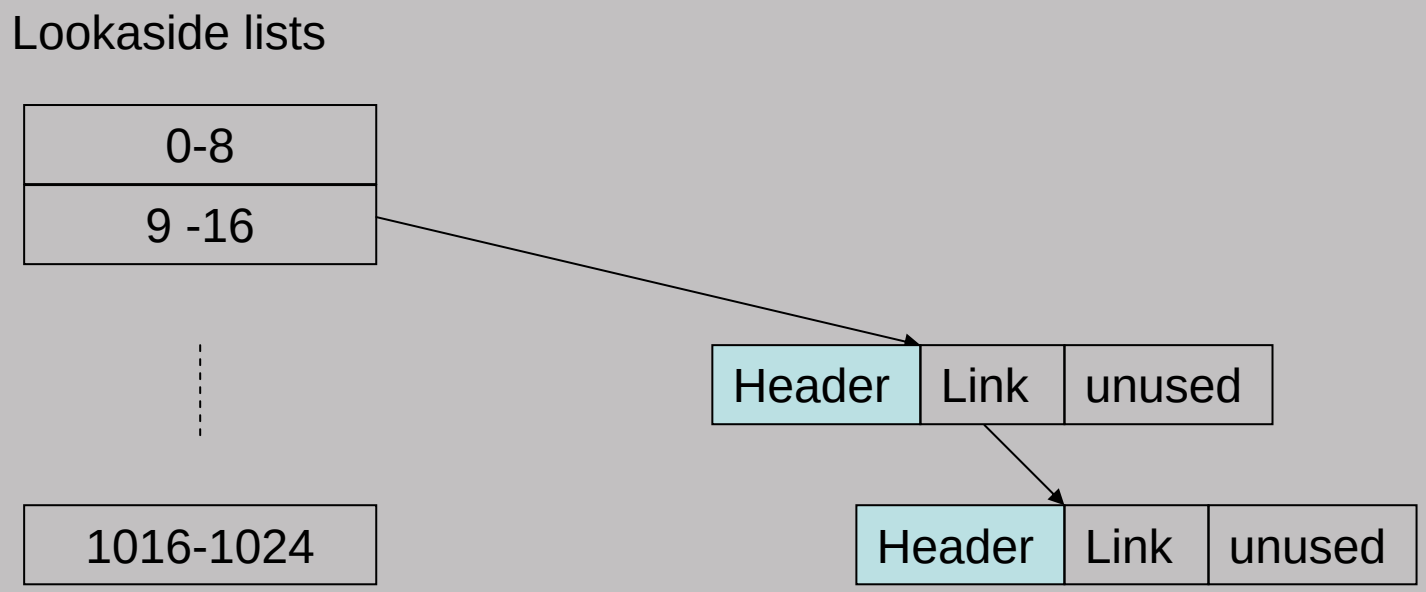
- Arbitrary pointer write

```
mov eax, DWORD PTR [ecx]
mov ecx, DWORD PTR [ecx+4]
mov DWORD PTR [ecx], eax
mov DWORD PTR [eax+4], ecx
```

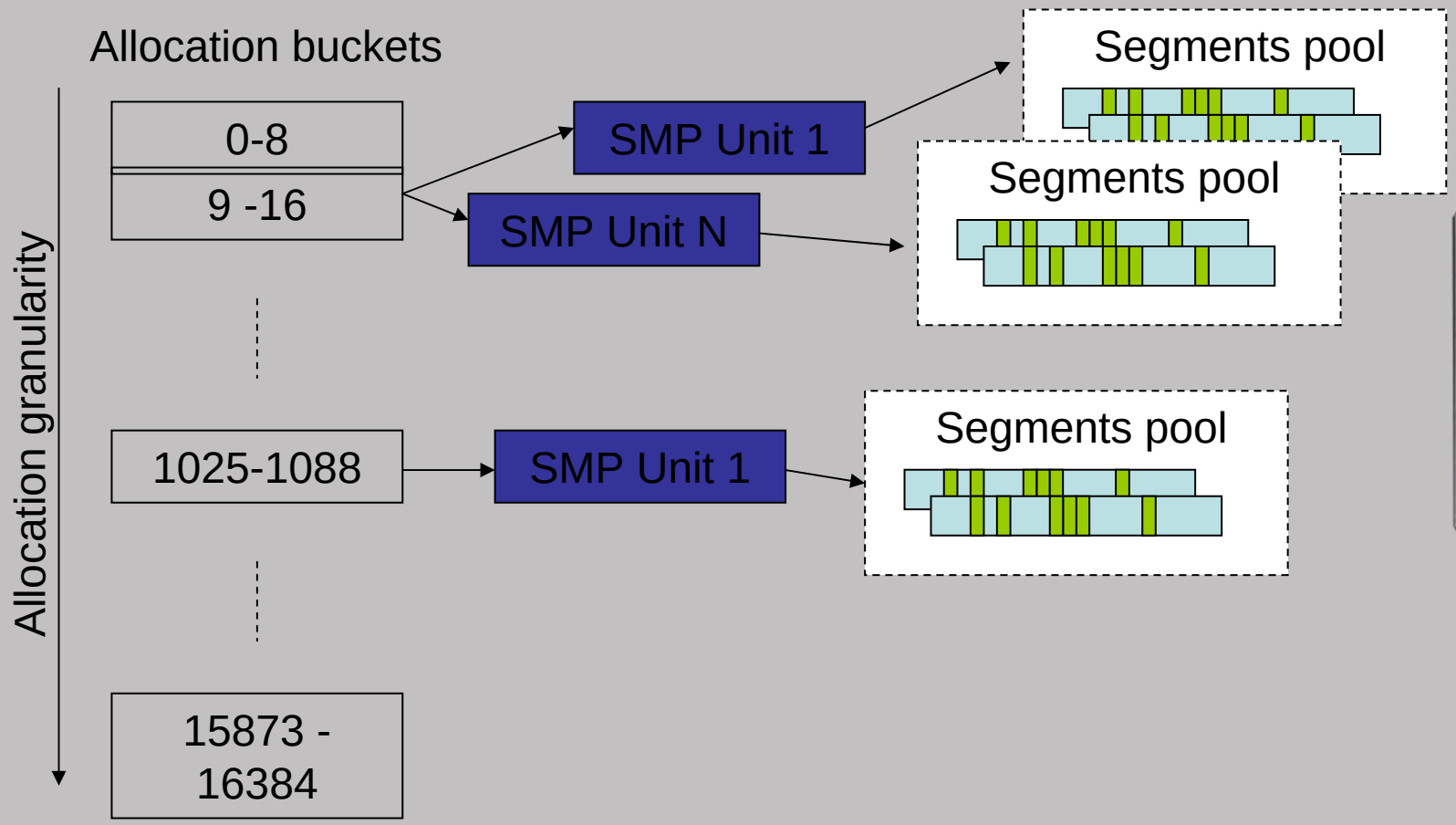


Lookaside Lists

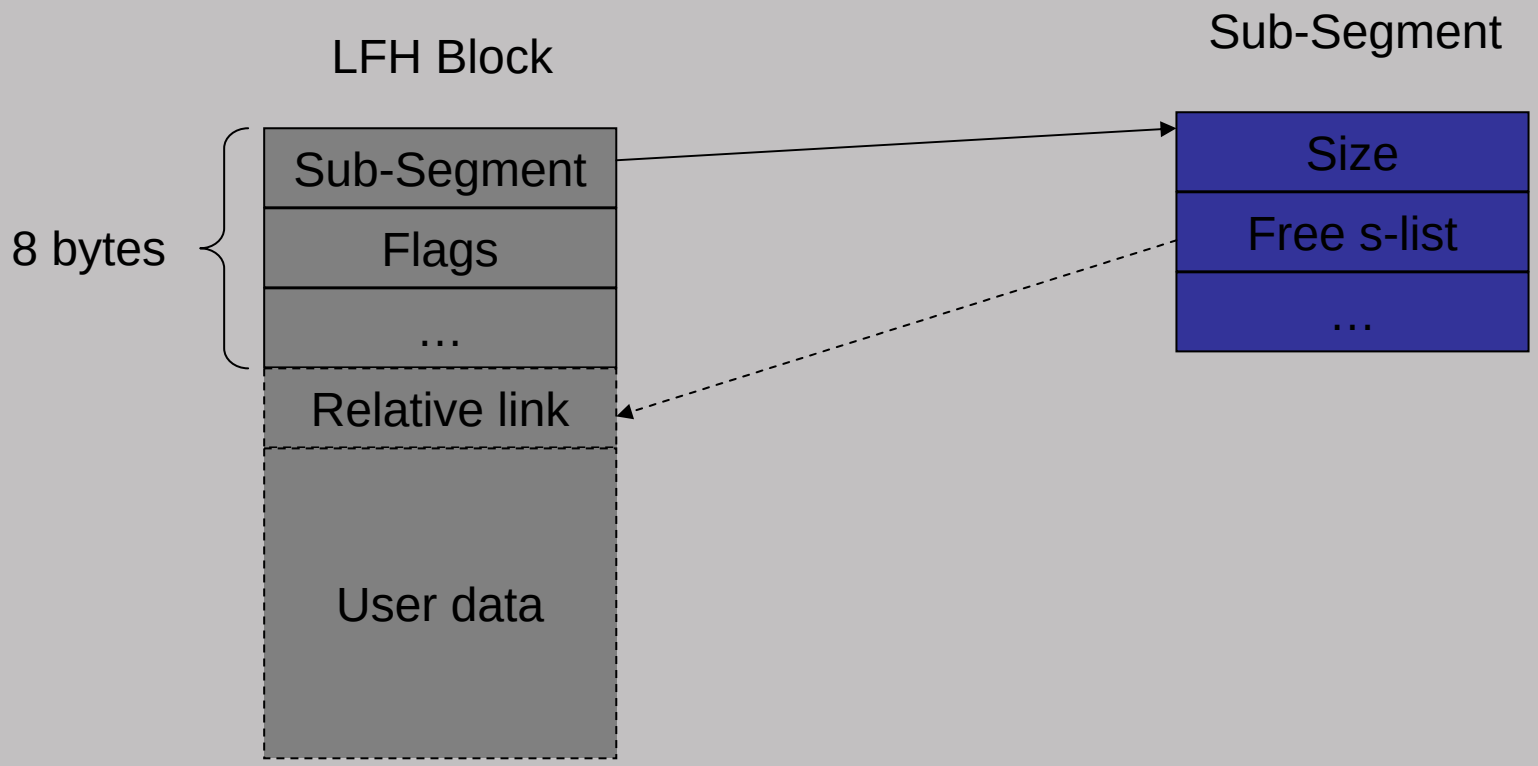
- Non-blocking single-linked lists



The Low Fragmentation Heap Architecture



Low Fragmentation Heap Block Entry



Early Heap Mitigations

- Safe List Removal

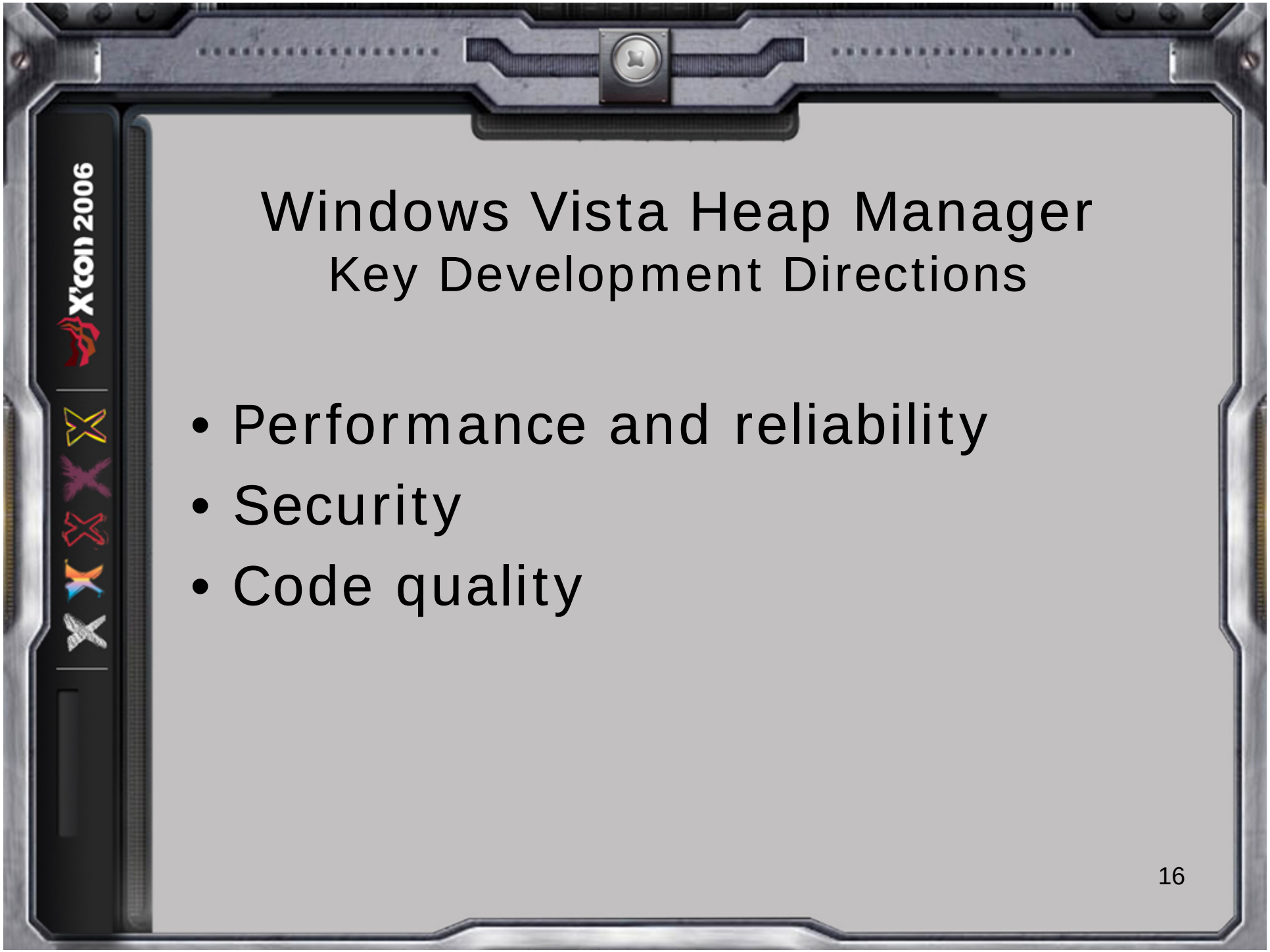
  Entry->FwdLink->BkLink == Entry->BkLink->FwdLink == Entry

- 8-bit cookie tested on free
- LFH block entry encoding

  F (random number,Block address, heap)

Change in Landscape

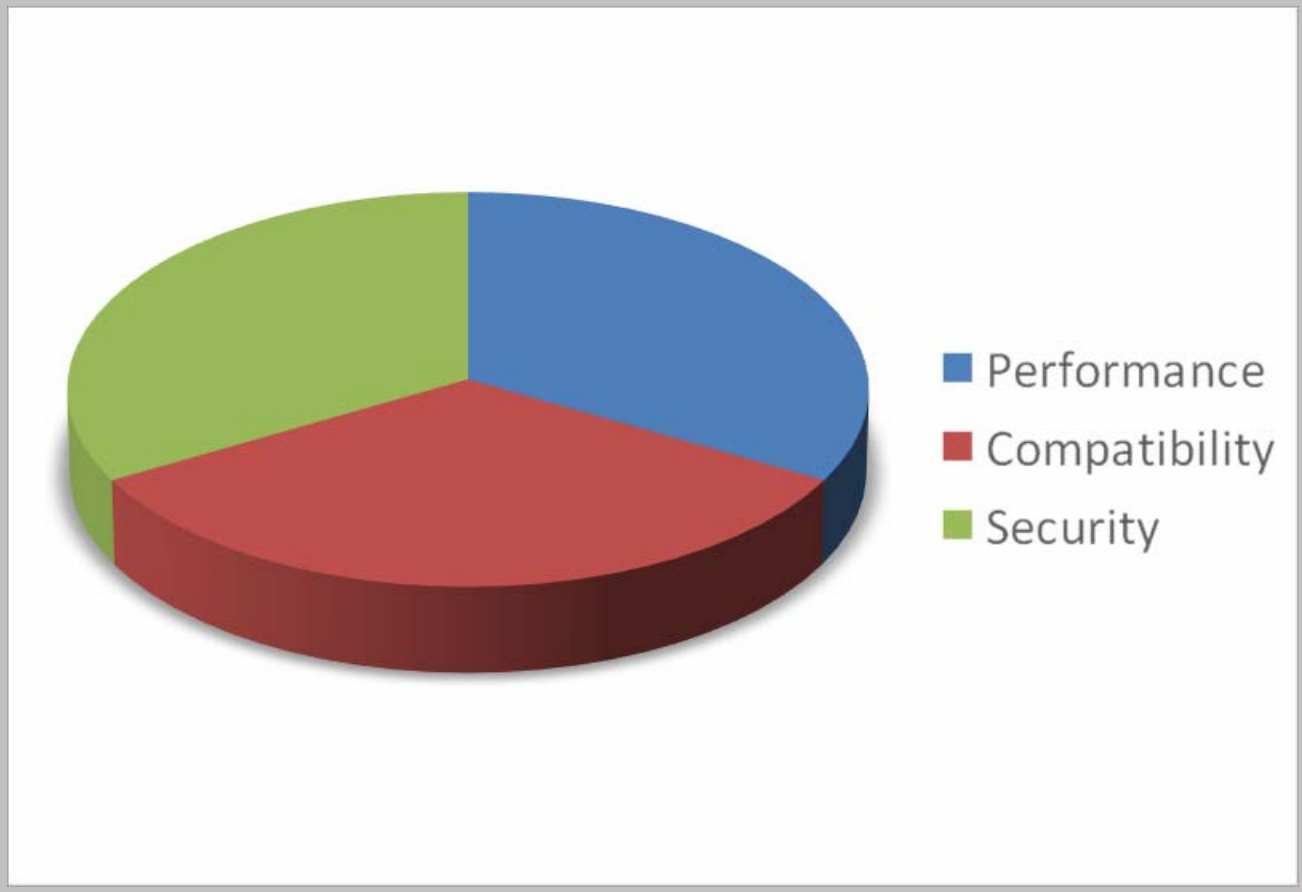
- New exploiting methods surfaced
- Change in usage outlook
  - Memory usage
  - Increase availability of SMP
  - Increase relevance of 64 bit computing
- Code quality – higher demand in industry



Windows Vista Heap Manager
Key Development Directions

- Performance and reliability
- Security
- Code quality

Windows NT Heap Requirements



Security

- Correctness – like:
  - Guarantees requested sizes
  - Lifetime of allocations
  - Clearing content when requested
    etc.
- Defense line in heap based exploits:
  - Attempts to mitigate the effect of an attack
  - Makes difficult hiding heap-based exploits

Performance

- Scale from small devices to large servers
- Optimized for varied usage patterns
- Follow the industry trend
  - Memory usage
  - Increase in SMP availability
  - H/W architecture advances

Compatibility

- Applications may rely on things like:
  - Realloc returning same pointer
  - Read/write after releasing a block
  - Double free
  - Overruns over unused structures etc.
- Heap changes may have unintended effects, such as:
  - Crashes, leaks or broken functionality in poorly written applications
  - Severe performance regressions

Part II - Windows Vista Heap

Windows Vista Heap Security Features

- Block metadata randomization
- Integrity check on block entry
- Algorithm variation in response to usage pattern
- Random rebasing
- Function pointer randomization
- Abrupt application termination on error

Block Metadata Randomization

- A part of the header is XORd with a random value
- Low performance impact
- Should make guessing the right value impractical
- Flexible and contained algorithm and implementation
- Agile in updates

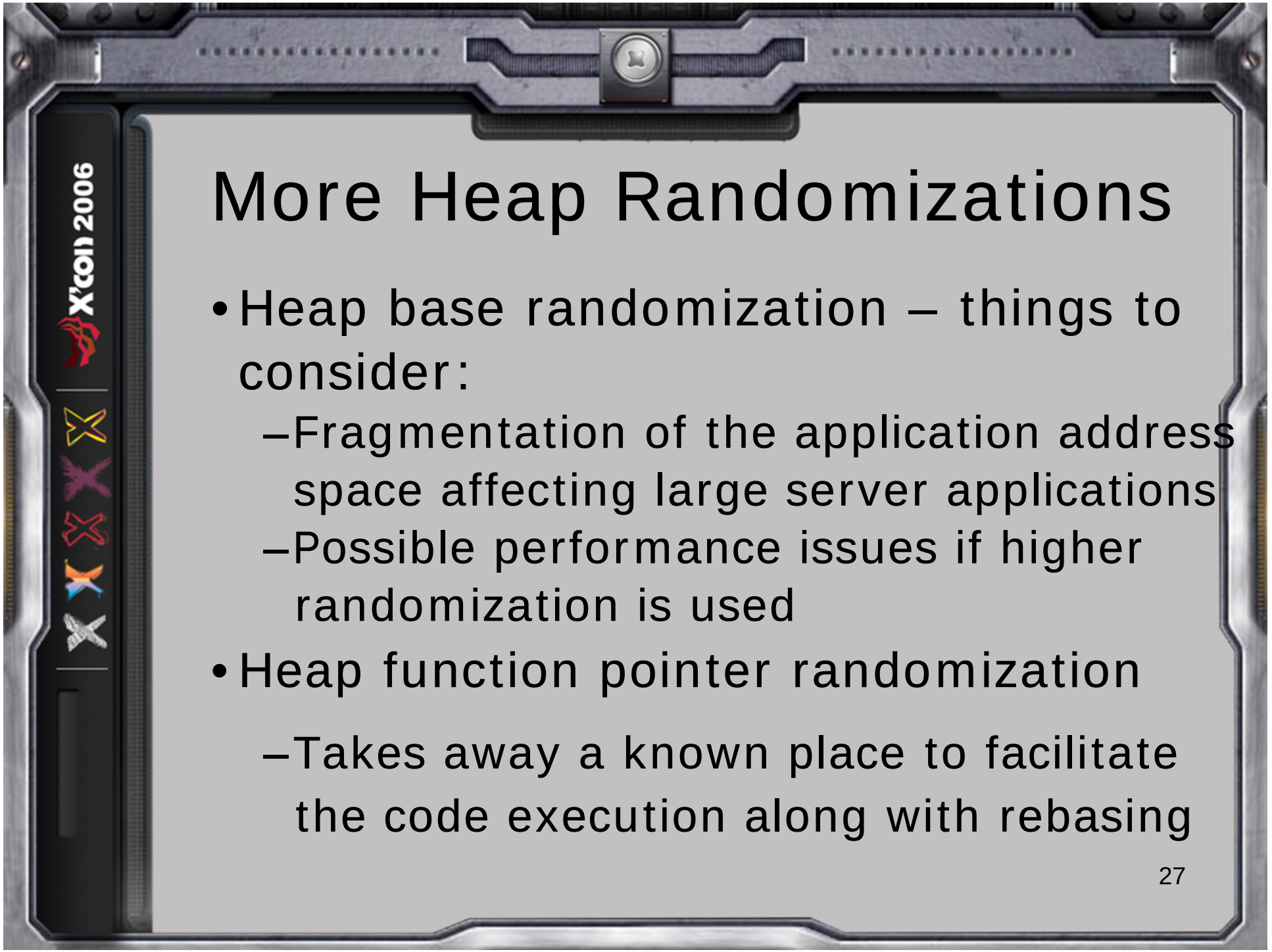
Entry Integrity Check

- Previous 8-bit cookie has been repurposed to validate a larger part of the header
- Value may be randomized along with the other fields
- Validated during internal operations too

Demo – Heap Header Layout

Runtime Algorithm Variation

- Automatic tuning
  - Shift to LFH allocations at arbitrary points on runtime
  - Triggers on various patterns
  - Involves also de-commit / commit policies



More Heap Randomizations

- Heap base randomization – things to consider:
  - Fragmentation of the application address space affecting large server applications
  - Possible performance issues if higher randomization is used
- Heap function pointer randomization
  - Takes away a known place to facilitate the code execution along with rebasing

Demo

Abrupt Termination on Error

- Any data inconsistency or invalid heap function usage detected may trigger it
- The scope is process-wide (any heap in the process has the same behavior)
- The process is terminated via Windows Error Reporting
- Detailed info is available in the dump file
- No function provided to disable it
- On by default for 64 bit platforms & apps

Termination on Errors (cont.)

- Programmatic opt-In method

(new **HeapEnableTerminationOnCorruption** class defined)

```
BOOL HeapSetInformation(
    HANDLE HeapHandle,
    HEAP_INFORMATION_CLASS HeapInformationClass,
    PVOID HeapInformation,
    SIZE_T HeapInformationLength);
```

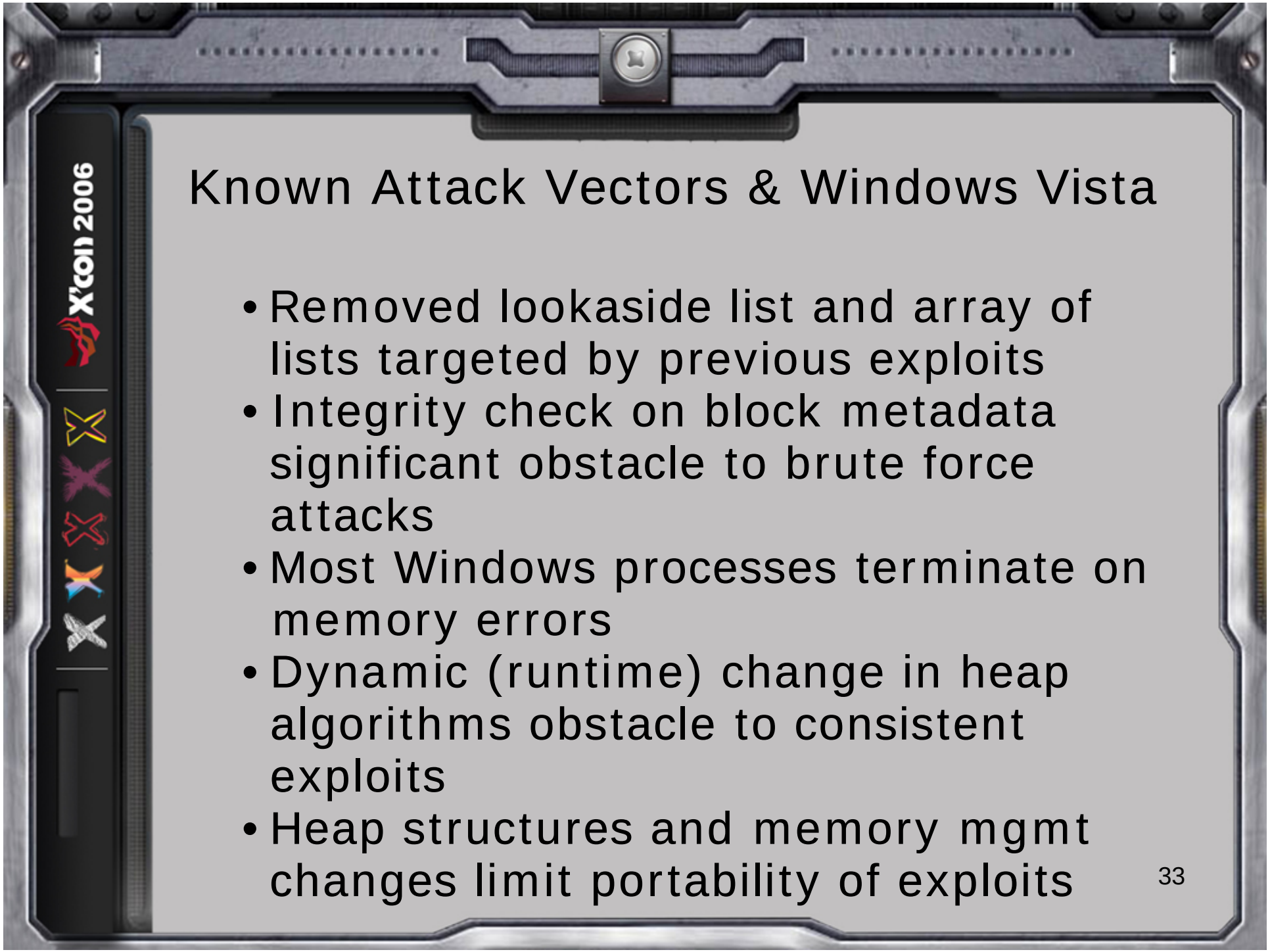
- Large number of components with Windows Vista are opted in
- The information is available in a debugger extension

Demo

NT Heap Manager – Improves Code Quality

Benefits to app developers

- Early error detection
- Improved debugging aid to reduce cost of investigating corruptions
- Reduced tolerance to misusage
- Windows Vista apps will be more resilient to future heap changes



Known Attack Vectors & Windows Vista

- Removed lookaside list and array of lists targeted by previous exploits
- Integrity check on block metadata significant obstacle to brute force attacks
- Most Windows processes terminate on memory errors
- Dynamic (runtime) change in heap algorithms obstacle to consistent exploits
- Heap structures and memory mgmt changes limit portability of exploits

Security enhancements are a journey

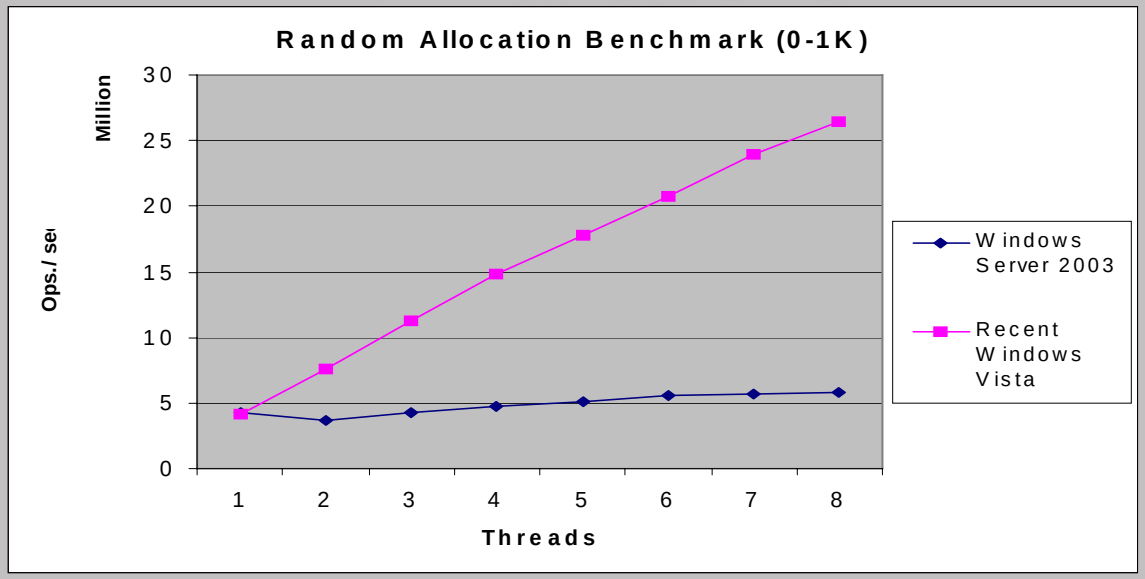
- Mitigations are not substitute for good development practices
- Windows Vista is just a milestone in continual heap improvements

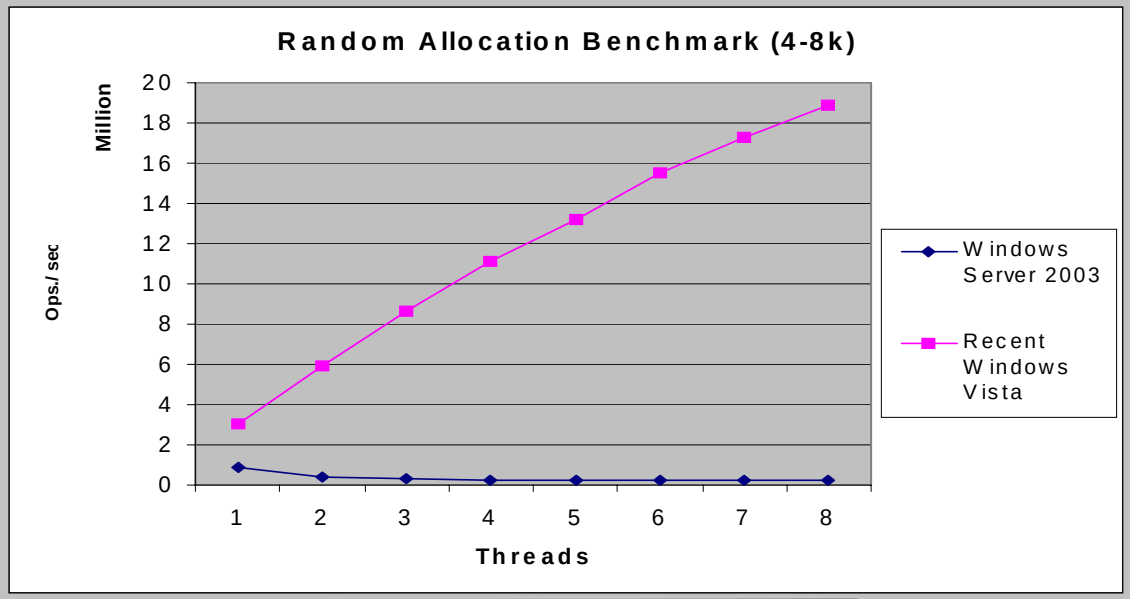
Windows Vista Heap Perf & Reliability

- Improved scenarios by default for:
  - SMP scalability
  - External fragmentation
  - Large heaps
- Improved reference locality on 64 bit platforms
- Reduced Virtual Address exhaustion
- Increased resilience to patterns involving long-term allocations

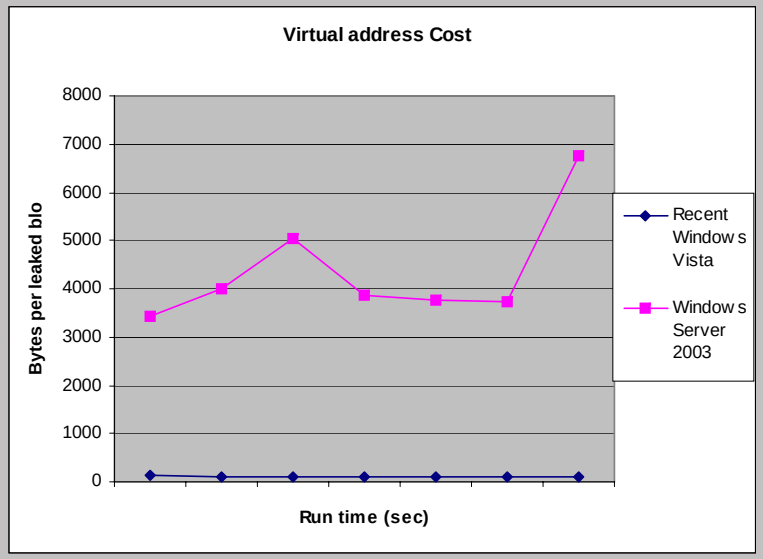
Key Performance Enhancements

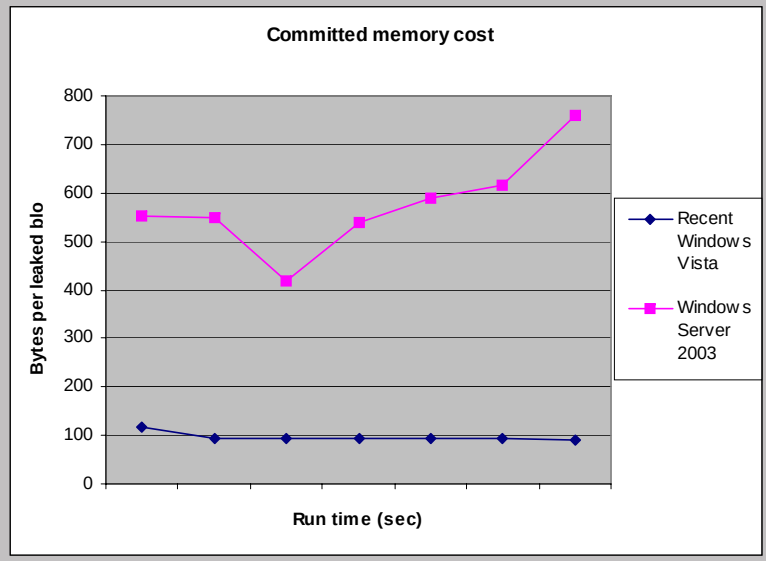
- Automatic tuning
- Lower granularity of control policies to switch to the Low Fragmentation Heap
- Use of lazy initialization
- Redesigned segment management
- Improved internal lookup algorithms
- Addressed fragmentation in problematic scenarios
- Lower overhead on 64 bit


Random Allocation Benchmark (0-1K)
Million
Ops./ sec
30
25
20
15
10
5
0
1
2
3
4
5
6
7
8
Threads
Windows Server 2003
Recent Windows Vista

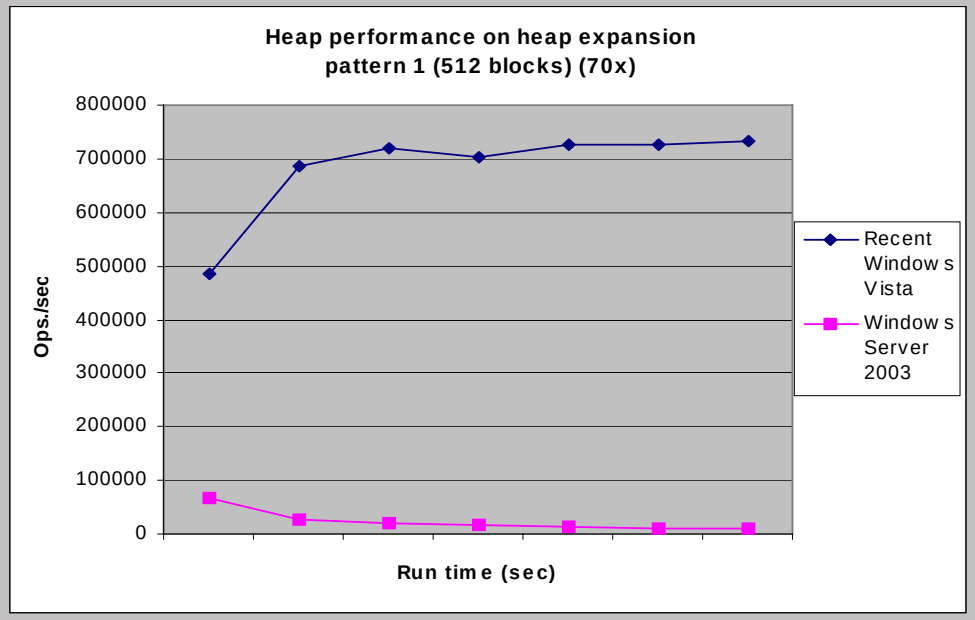

Random Allocation Benchmark (4-8k)
Million
Ops./ sec
20
18
16
14
12
10
8
6
4
2
0
1
2
3
4
5
6
7
8
Threads
Windows Server 2003
Recent Windows Vista

Fragmentation Test (512 blocks / 80 bytes)



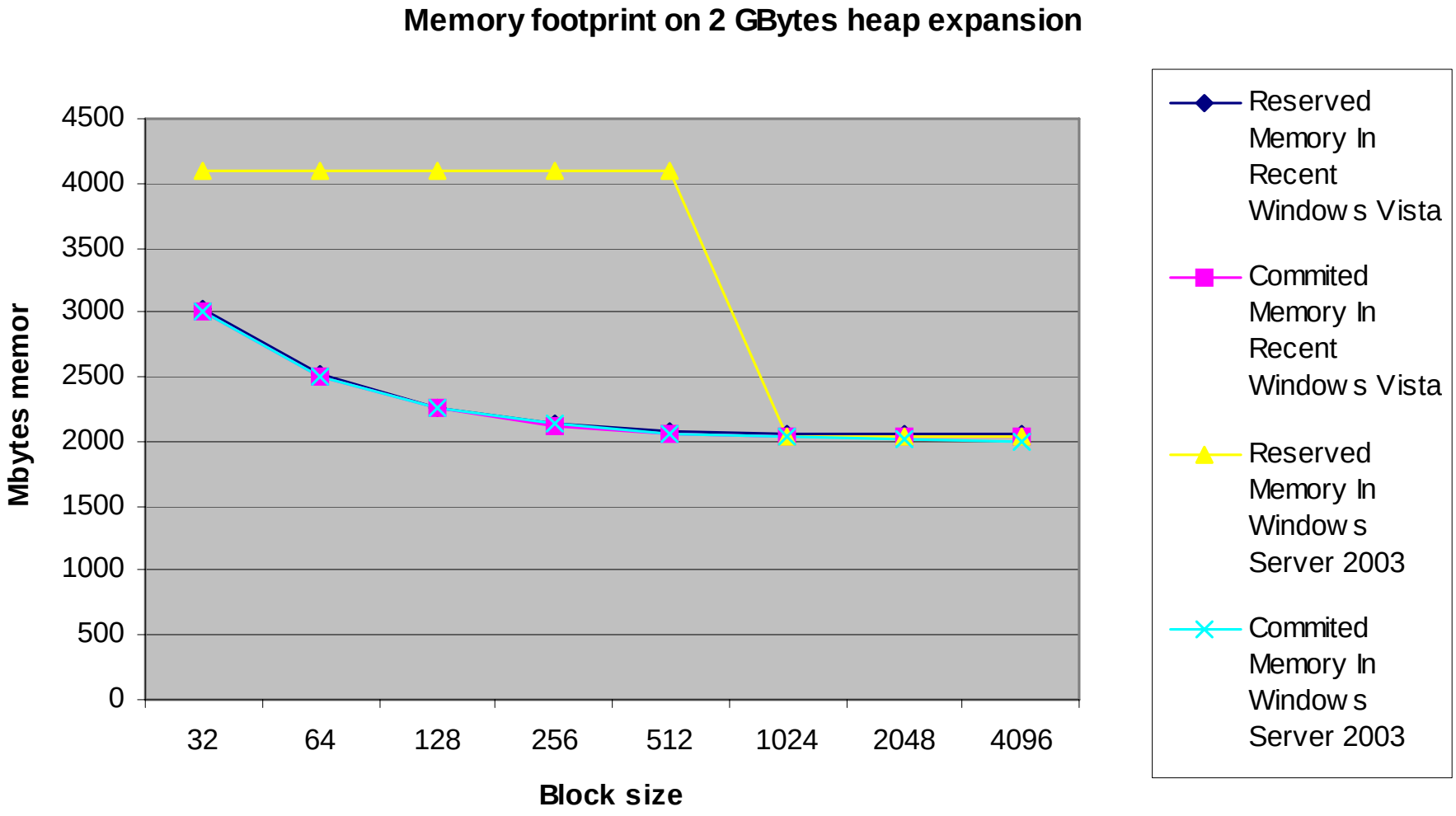


Fragmentation Test (512 blocks / 80 bytes)



Fragmentation Scenario II

Pattern	Ops/sec (Recent Windows Vista)	Ops/sec (Windows Server 2003 SP 1)	Improvement x
256	2576004	388	6639
512	927709	151	6144
1024	403774	51	7917
2048	194180	25	7767
4096	82534	12	6878


Memory footprint on 2 GBytes heap expansion
Mbytes memor
4500
4000
3500
3000
2500
2000
1500
1000
500
0
32
64
128
256
512
1024
2048
4096
Block size
Reserved Memory In Recent Windows Vista
Commited Memory In Recent Windows Vista
Reserved Memory In Windows Server 2003
Commited Memory In Windows Server 2003

Summary

- Attacks get more sophisticated …
- But so does the heap management – and not only for security
- We laid the foundation for increased agility in heap improvements with reduced compatibility risks
- Improved scenarios for SMP and large memory usage
- Designed to enhance the code quality for applications
- We are not yet done … we are looking forward for further enhancements as needed
- Come see me with your ideas!

Resources

- Feedback on Heap:
  heapext@microsoft.com
- Debugging tools:
  http://www.microsoft.com/whdc/devtools/debugging/debugstart.mspx
- Application Verifier:
  http://www.microsoft.com/downloads/details.aspx?FamilyID=bd02c19c-1250-433c-8c1b-2619bd93b3a2&DisplayLang=en

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