CSCE 313-200
Introduction to Computer Systems
Spring 2025

Memory III

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Homework #4

- Why are lookup tables useful?
  - Allow verification of set membership in 1 cache access
- How to initialize?
  - E.g., need to set up LUT to verify that character belongs to set {+, -, =, /, *}

```
char LUT [256];
memset (LUT, false, 256);
const char special[] = “+-=/*”;
for (int i = 0; i < strlen(special); i++)
    LUT [special [i]] = true;
```

- When bool maps to 1 byte, can use it instead of char
  - Keep in mind though that BOOL is 4 bytes
- Make sure to test code on various input and buf size
  - Debugging: elimination of crashes/incorrect output
  - Testing: discovery of input configurations that expose previously unseen problems

Chapter 7: Roadmap

7.1 Requirements

7.2 Partitioning

7.3 Paging

7.4 Segmentation

7.5 Security

8.1 Hardware virtual memory

8.2 OS software

Memory Dumps

- Process crash is usually good news
  - Attach debugger, examine location of crash…
- Except when product has shipped to customers
  - Users do stuff with code that makes it crash
  - Developer is unable to replicate bug locally, what's next?
- Idea: catch faults with SEH (Structured Exception Handling)
  - Create a crash dump, send it to main server, then probably restart

Memory Dumps

- Instead of dumping entire RAM contents, Windows allows much smaller files called MiniDumps
  - Can be customized during exception handling to vary in size from a few KB to a few MB
- MiniDumps can be loaded into Visual Studio
  - Shows the exact location of crash, call stack, certain variables (even if crashed in release mode)
- Example:
  - Important application that must work 24/7, years in a row
  - When it crashes, saves internal data and dump, restarts
  - Debugging is done offline from a collection of minidumps
- See MiniDumpWriteDump on MSDN

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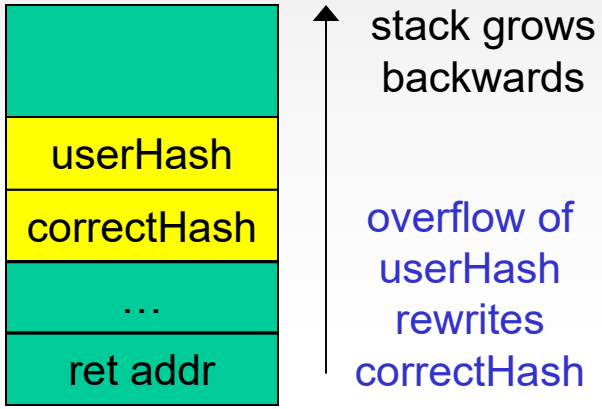
Buffer Overflow Attacks

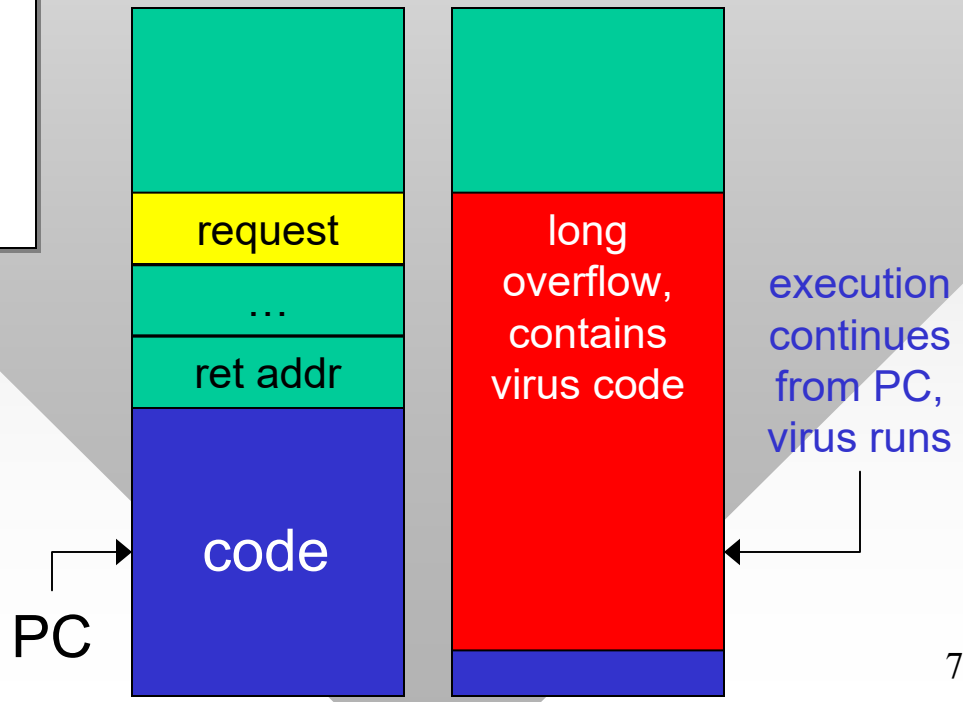
- Example 1:

```
int CheckPassword (HANDLE user) {
    char correctHash [16];
    char userHash [16];

    GetPassHash (user, correctHash);
    // remote desktop hashes password
    // and sends the hash to server
    Network.Read (userHash);
    if (!strcmp (correctHash, userHash))
          return MATCH;
    else
          return BOGUS;
}
```



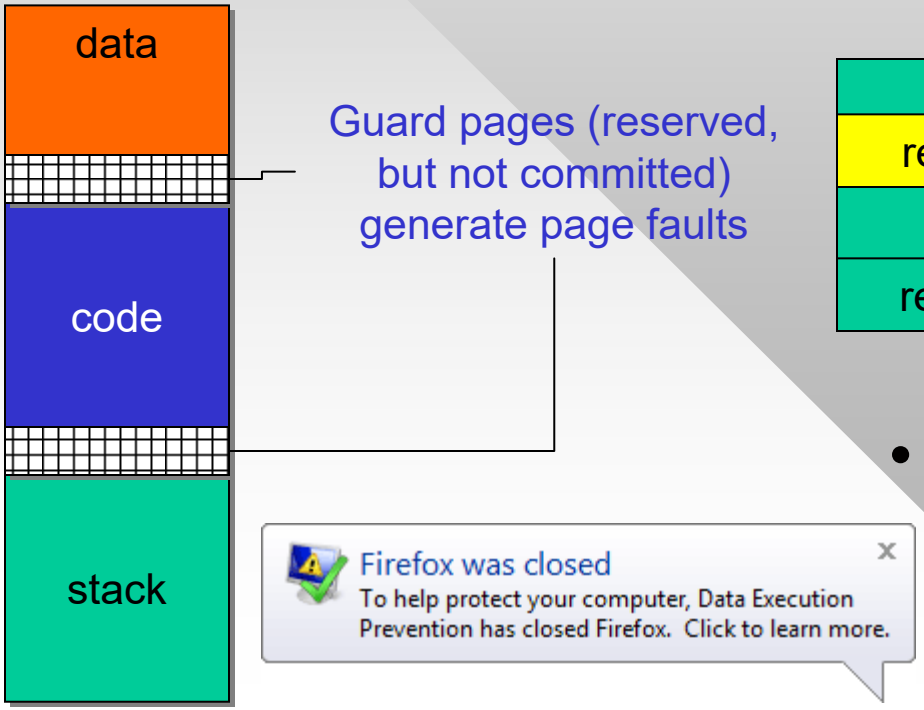
- Example 2:

```
void HandleServerRequest (void) {
    char request [256];

    Network.Read (request);
    ...
}
```



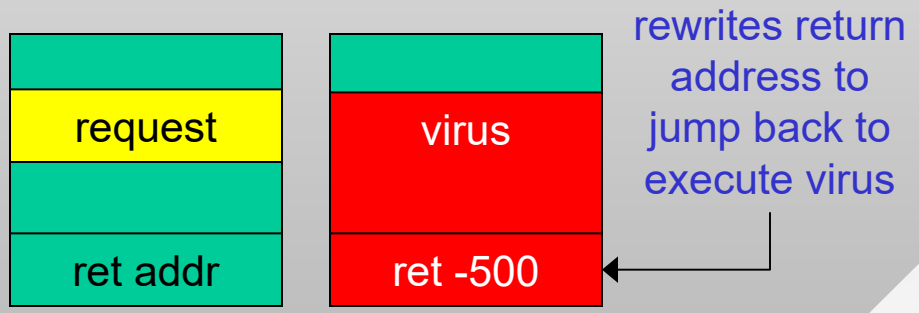
Buffer Overflow Attacks

- Modern OS usually puts a guard page between data, code, and stack



- Example 3:

```
void HandleServerRequest (void) {
    char request [256];

    Network.Read (request);
    ...
}
```



- Modern OS marks data and stack pages as non-executable (DEP)

Buffer Overflow Attacks

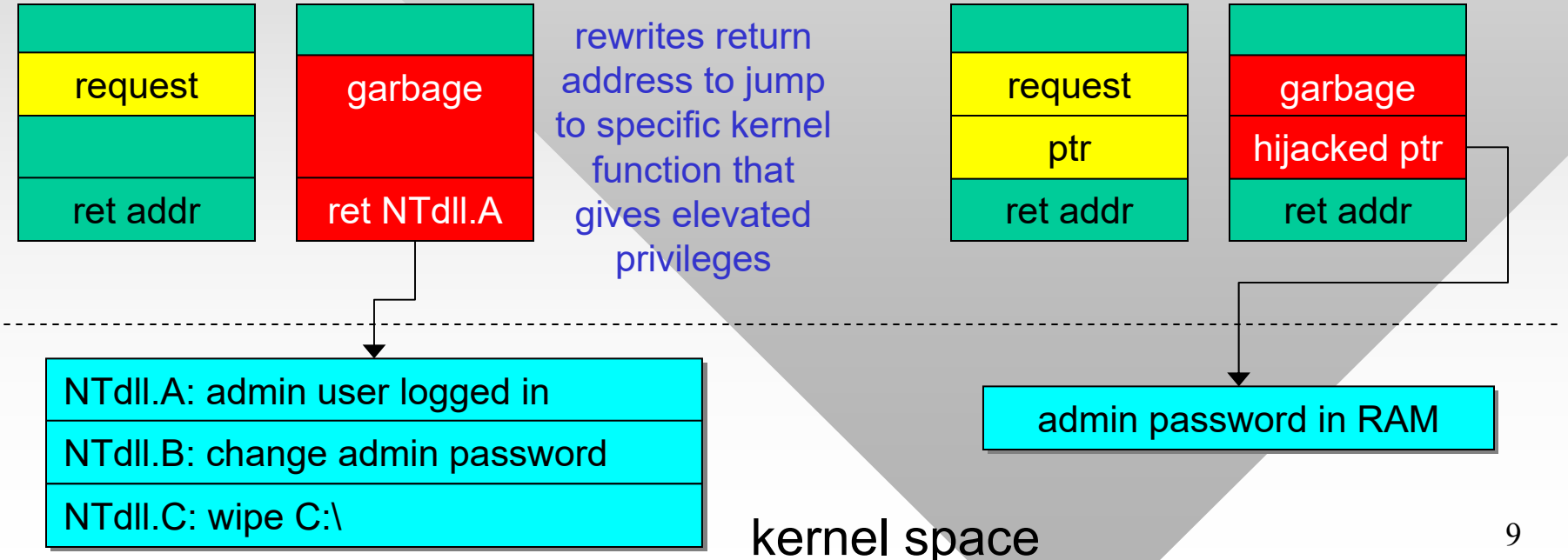
more in CSCE 465

- Example 4:

```
void HandleServerRequest (void) {
    char request [256];

    Network.Read (request);
    ...
}
```

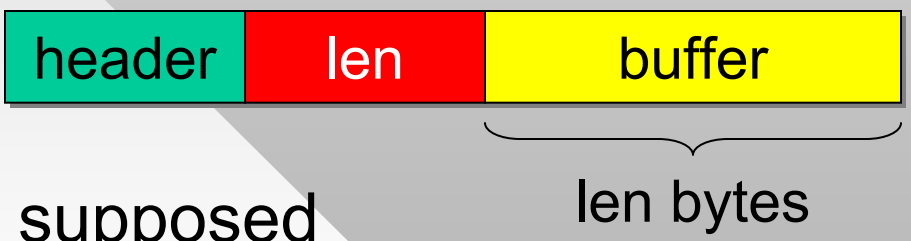
- Example 5:

```
void HandleServerRequest (void) {
    char *ptr = new char [50];
    char request [256];

    Network.Read (request);
    strcpy (ptr, "hello world");
}
```



Heartbleed Bug

- OpenSSL is a library that encrypts/decrypts traffic
  - Commonly used in HTTPS, SSH, secure IMAP/SMTP
- Heartbeat extension introduced in 2011
  - OpenSSL periodically sends a request that is echoed back to verify the connection is alive
- Request message format:



- Response is supposed to echo the buffer
  - Implementation →

```
size = Network.GetNextPacketSize();
char *packet = new char [size];
Network.Read (packet);
len = ExtractLenField (packet);
Network.Send (packet, len+sizeof(header)+sizeof(short));
```

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Managing Virtual Memory

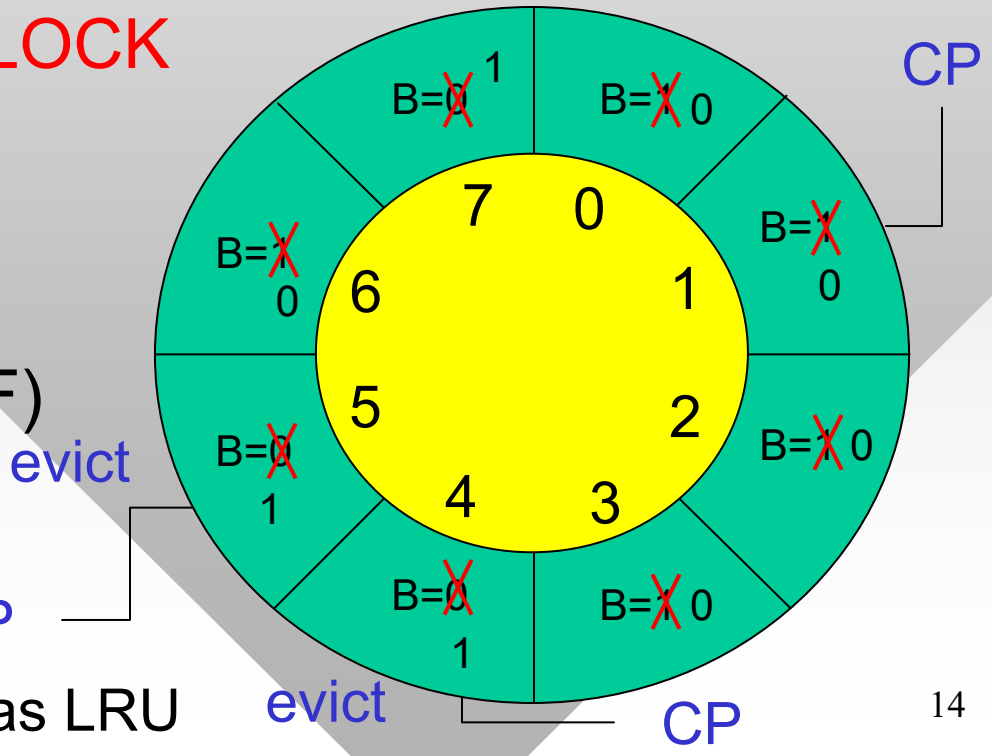
- The OS has to make two main decisions when managing virtual memory and swapping
  - Which page to bring back to RAM (fetch policy)
  - Which page to offload to disk (replacement policy)
- Similar concepts may be useful in user-mode programs (e.g., object caching, browser prefetch)
- Fetch policy
  - Demand paging: bring page only on access (Windows)
  - Prepaging: OS attempts to guess future demand, bring those pages in memory ahead of the request
- Replacement policy
  - FIFO: treats all pages as circular buffer, evicts the next one

Managing Virtual Memory

- Replacement policy (cont'd)
  - LRU: evicts the page that has not been used the longest
  - Optimal: evicts the page that won't be used the longest (only used in simulations for comparison purposes)
- How to implement LRU?
  - Can't tag each page with an access timestamp (updating timestamps would incur huge overhead)
  - Can't organize all pages into a linked list either (moving items to the front of the list on access is expensive)
- Idea: replace LRU with an approximation algorithm
  - Assume a set of pages 0, …, N-1 that the OS manages
  - Associate a bit B (e.g., in the TLB) with each page
  - CPU sets the bit to 1 upon each read/write access

Managing Virtual Memory

- Upon page fault that needs more space:
  - OS scans from current position CP in [0, N-1] forward
  - If next page has B = 1, flag is reset to 0 and scan continues
  - If next page has B = 0, OS stops and evicts that page
- This policy is called CLOCK
  - Next page evicted?
- Quality of algorithm measured by number of hard page faults (PF)
  - FIFO 2x worse than optimal in PF
  - CLOCK better than FIFO, but not as good as LRU



Managing Virtual Memory

- Should pages that were read be replaced at the same rate as those that have been written to?
  - Probably more expensive to evict a modified page
- Idea: set up an extra bit W for each page
  - CPU modifies them on access, CLOCK first evicts eligible pages with W = 0; if none left, then those with W = 1
- CLOCK is quicker than LRU even in user mode
- Examples where CLOCK might be useful:
  - Web crawler keeps a list of recently seen URLs
  - Search engine caches answers to popular queries
  - Homework #4: 50% of all hash table lookups refer to 1,270 words (20% to just 36 words), possible ways to speed up?