1. Problem Description

We are finally ready to multi-thread this program and achieve significantly faster download rates. Due to the high volume of outbound connections, your home ISP (e.g., Suddenlink, campus dorms) will probably block this traffic and/or take your Internet link down. Do not be alarmed, this condition is usually temporary, but it should remind you to run the experiments over VPN. The program may also generate high rates of DNS queries against your local server, which may be construed as malicious. In such cases, it is advisable to run your own version of BIND on localhost.

1.1. Code (25 points)

The command-line format remains the same as in Part 2, but allows more threads:

```bash
hw1.exe 3500 URL-input.txt
```

To achieve proper load-balancing, you need to create a shared queue of pending URLs, which will be drained by the crawling threads using an unbounded producer-consumer from CSCE 313. The general algorithm follows this outline:

```c
int _tmain(int argc, _TCHAR* argv[])
{
    // parse command line args
    // initialize shared data structures & parameters sent to threads
    // read file and populate shared queue
    // start stats thread
    // start N crawling threads
    // wait for N crawling threads to finish
    // signal stats thread to quit; wait for it to terminate
    // cleanup
}
```

The output should be printed by the stats thread every 2 seconds:

```
*** crawling 87.5 pps @ 12.3 Mbps
```

The first column is the elapsed time in seconds (to achieve 3-character alignment, use `%3d` in `printf`). The next column shows the number of active threads (i.e., those that are still running). As the program nears shutdown, you will see this number slowly decay towards zero. The remaining columns are labeled with a single letter whose meaning is given below:

- **Q**: current size of the pending queue
- **E**: number of extracted URLs from the queue
- **H**: number of URLs that have passed host uniqueness
- **D**: number of successful DNS lookups
I: number of URLs that have passed IP uniqueness
R: number of URLs that have passed robots checks
C: number of successfully crawled URLs (those with a valid HTTP code)
L: total links found

Note that proper alignment of columns is required. You will need six character positions for Q,
seven for E, six for (H, D), five for (I, R, C), and four for L. The second line of the example
prints the crawling speed in pages per second (pps) and the download rate in Mbps, computed
over the period since the last report. You will need to determine the number of pages/bytes
downloaded and the elapsed time between wakeups in the stats thread, then divide the two. For a
more accurate bandwidth usage, you should combine both robots and page bytes; however, the
crawling speed only refers to non-robot pages.

At the end, the following stats should be printed:

```
Extracted 1000004 URLs @ 9666/s
Looked up 139300 DNS names @ 1346/s
Downloaded 95460 robots @ 923/s
Crawled 59904 pages @ 579/s (1651.63 MB)
Parsed 3256521 links @ 31476/s
HTTP codes: 2xx = 47185, 3xx = 5826, 4xx = 6691, 5xx = 202, other = 0
```

1.2. Report (25 points)

The report should address the following questions based on the links in `URL-input-1M.txt`:

1. (5 pts) Briefly explain your code architecture and lessons learned. Using Part 3, show a
   complete trace with 1M input URLs.

2. (5 pts) Obtain the average number of links per HTML page that came back with a 2xx
code. Estimate the size of Google’s webgraph (in terms of edges and bytes it occupies on
disk) that contains 1T (trillion) crawled nodes and all of their out-links. Assume the graph
is stored using adjacency lists, where each URL is represented by a 64-bit hash.

3. (5 pts) Determine the average page size in bytes (across all HTTP codes). Estimate the
   bandwidth (in Gbps) needed for Bing to crawl 10B pages a day.

4. (5 pts) What is the probability that a link in the input file contains a unique host? What is
   the probability that a unique host has a valid DNS record? What percentage of contacted
   sites had a 4xx robots file?

5. (5 pts) How many of the crawled 2xx pages contain a hyperlink to our domain
tamu.edu? How many of them originate from outside of TAMU? Explain how you ob-
tained this information. Examples of suitable links:
   - irl.cs.tamu.edu/
   - afcerc.tamu.edu/index.html
   - tamu.edu/
   - www.cse.tamu.edu/people

   Examples of false-positives:
   - tamu.edu.cn/
1.3. Parser

The parser is not multi-threaded safe and thus should not be called from multiple threads. It maintains an internal buffer of produced links that gets overwritten in each call. One option is to enclose all parser-related functionality in a mutex; however, this prevents concurrent parsing of pages and hurts performance. For maximum speed, the best approach is to create a separate instance of the parser inside each thread. This prevents corruption of the shared buffer and avoids the need for synchronization. It is not advisable to create/delete the parser for each URL; instead, create it once when the thread starts and keep using it for all subsequent links.

1.4. Synchronization and Threads

It is a good idea to learn Windows threads and synchronization primitives by running and dissecting the sample project on the course website. As long as you remember the main concepts from CSCE 313, most of the APIs are pretty self-explanatory and have good coverage on MSDN. The main synchronization algorithm you will be using is called producer-consumer. In fact, our problem is slightly simpler and can be solved using the following:

```
Producer ()     // called by _tmain()
{
    // produce items into the queue
    for (i = 0; i < N; i++)
        Q.push (host [i]);
}
Consumer ()     // crawling thread
{
    while (true)
    {
        mutex.Lock ();
        if (Q.size() == 0)  // finished crawling?
        {
            mutex.Unlock ();
            break;
        }
        x = Q.front (); Q.pop ();
        mutex.Unlock ();
        // crawl x
    }
}
```

For mutexes, there is a user-mode pair of functions EnterCriticalSection and LeaveCriticalSection that operate on objects of type CRITICAL_SECTION. Note that you must call InitializeCriticalSection before using them. You can also use kernel mutexes created via CreateMutex, but they are much slower.

To update the stats, you can use a critical section, but it is often faster to directly use interlocked operations, each mapping to a single CPU instruction. You may find InterlockedIncrement and InterlockedAdd useful.

After emptying the input queue, most of the threads will quit successfully, but some will hang for an extra 20-30 seconds, which will be caused by connect() and select() hanging on timeout. There is no good way to reduce the shutdown delay unless you employ overlapped or non-
blocking sockets (i.e., using WSA_FLAG_OVERLAPPED in WSASocket or FIONBIO in ioctlsocket). These are not required, but can be explored for an additional level of control over your program.

Quit notification can be accomplished with a manual event. See CreateEvent and SetEvent. For example, the stats thread boils down to a simple loop waiting for this event:

```c
DWORD WINAPI StatsRun(LPVOID lpPara)
{
    Parameters *p = (Parameters*) lpPara;  // shared parameters
    while (WaitForSingleObject (p->eventQuit, 2000) == WAIT_TIMEOUT)
    {
        // print
    }
}
```

Note that the Parameters structure can accommodate other shared state:

```c
DWORD WINAPI CrawlerRun(LPVOID lpPara)
{
    Parameters *p = (Parameters*) lpPara;  // shared parameters
    while (true)
    {
        EnterCriticalSection (&p->cs);
        if (p->Q.size () == 0)
            ...
        LeaveCriticalSection (&p->cs);
    }
}
```

**1.5. Extra Credit (20 pts)**

To receive extra credit, you must be able to process HTTP 1.1 responses that are chunked. This will be checked using Part-I functionality of the homework (i.e., one command-line argument). Please specify in the report that your program can do HTTP 1.1 downloads. This will be checked with the final part of the homework.

Chunking is indicated by the “Transfer-Encoding” field in the response:

```
GET / HTTP/1.1
Host: tamu.edu
User-agent: myTAMUcrawler/1.0
Connection: close

HTTP/1.1 200 OK\r\nConnection: close\r\nDate: Thu, 1 Sep 2006 12:00:15\r\nServer: Apache/1.3.0\r\nContent-type: text/html\r
Transfer-Encoding: chunked\r
\r
2A0\r
<html><head><meta http-equiv="Content-Language" content="en-us">...
```

In these cases, the data following the header is split into blocks, each of which is preceded by a hex number that specifies its size. As there may be many such segments, the last one has size 0.

For all 2xx pages, print an extra line indicating the body length (i.e., page size without the HTTP header) before and after dechunking.
Note that dechunking in place is the preferred approach. This can be done using repeated memcpy operations within the buffer, i.e., shifting chunks up to eliminate the gaps. Also, if you plan to use string functions to find the transfer-encoding field, make sure to NULL-terminate the buffer. Otherwise, strstr may escape the buffer and cause a crash. Finally, since HTTP fields are case-insensitive, you should use StrStrI in your search.

### 1.6. Traces

The first example uses URL-input-100.txt and 10 threads (produced in 2015, which may differ from the results today):

<table>
<thead>
<tr>
<th>Opened URL-input-100.txt with size 6003</th>
</tr>
</thead>
<tbody>
<tr>
<td>[ 2] 10 Q 41 E 59 H 55 D 55 I 50 R 8 C 0 L 0K</td>
</tr>
<tr>
<td>*** crawling 0.0 pps @ 0.1 Mbps</td>
</tr>
<tr>
<td>[ 4] 10 Q 16 E 84 H 75 D 75 I 66 R 10 C 5 L 0K</td>
</tr>
<tr>
<td>*** crawling 2.5 pps @ 0.4 Mbps</td>
</tr>
<tr>
<td>[ 6] 4 Q 0 E 100 H 84 D 84 I 74 R 12 C 7 L 1K</td>
</tr>
<tr>
<td>*** crawling 1.0 pps @ 0.4 Mbps</td>
</tr>
<tr>
<td>Extracted 100 URLs @ 13/s</td>
</tr>
<tr>
<td>Looked up 84 DNS names @ 11/s</td>
</tr>
<tr>
<td>Downloaded 74 robots @ 9/s</td>
</tr>
<tr>
<td>Crawled 11 pages @ 1/s (0.23 MB)</td>
</tr>
<tr>
<td>Parsed 543 links @ 70/s</td>
</tr>
<tr>
<td>HTTP codes: 2xx = 7, 3xx = 4, 4xx = 0, 5xx = 0, other = 0</td>
</tr>
</tbody>
</table>

The next run was obtained using 5000 threads and 1M URLs:

<table>
<thead>
<tr>
<th>Opened URL-input-1M.txt with size 66152005</th>
</tr>
</thead>
<tbody>
<tr>
<td>[ 2] 5000 Q 950541 E 49462 H 6489 D 6448 I 5014 R 2207 C 5 L 0K</td>
</tr>
<tr>
<td>*** crawling 2.5 pps @ 4.2 Mbps</td>
</tr>
<tr>
<td>[ 4] 5000 Q 952781 E 67223 H 10456 D 10387 I 8008 R 4568 C 123 L 5K</td>
</tr>
<tr>
<td>*** crawling 58.6 pps @ 12.8 Mbps</td>
</tr>
<tr>
<td>*** crawling 1217.6 pps @ 207.8 Mbps</td>
</tr>
<tr>
<td>[ 8] 5000 Q 877451 E 122553 H 18130 D 18010 I 14598 R 8676 C 4386 L 215K</td>
</tr>
<tr>
<td>*** crawling 894.6 pps @ 223.3 Mbps</td>
</tr>
<tr>
<td>[10] 5000 Q 854240 E 145764 H 21680 D 21526 I 17691 R 10648 C 6522 L 343K</td>
</tr>
<tr>
<td>*** crawling 1060.1 pps @ 236.1 Mbps</td>
</tr>
<tr>
<td>[12] 5000 Q 809350 E 169074 H 25105 D 24924 I 20626 R 12641 C 8443 L 457K</td>
</tr>
<tr>
<td>*** crawling 952.8 pps @ 227.3 Mbps</td>
</tr>
<tr>
<td>[14] 5000 Q 803317 E 196686 H 28467 D 28240 I 23486 R 14580 C 10375 L 561K</td>
</tr>
<tr>
<td>*** crawling 958.3 pps @ 193.2 Mbps</td>
</tr>
<tr>
<td>[16] 5000 Q 778447 E 221557 H 32003 D 31728 I 26444 R 16463 C 12227 L 665K</td>
</tr>
</tbody>
</table>

5
*** crawling 918.0 pps @ 198.9 Mbps
[18] 5000 Q 245355 H 35107 I 29280 R 16386 C 14045 L 766K
*** crawling 300.6 pps @ 207.0 Mbps
...
[76] 5000 Q 44366 E 955638 H 133113 D 131807 I 92391 R 60734 C 55962 L 2998K
*** crawling 502.7 pps @ 93.7 Mbps
[78] 5000 Q 17924 E 982080 H 136261 D 134919 I 93926 R 61695 C 56975 L 3072K
*** crawling 500.5 pps @ 132.7 Mbps
[80] 3223 Q 0 E 1000004 H 137818 I 95413 R 62755 C 57872 L 3112K
*** crawling 445.1 pps @ 89.7 Mbps
[83] 2111 Q 0 E 1000004 H 137829 D 137888 I 95457 R 62855 C 58766 L 3152K
*** crawling 444.3 pps @ 76.8 Mbps
[85] 1185 Q 0 E 1000004 H 137891 I 95459 R 62864 C 59529 L 3193K
*** crawling 378.2 pps @ 76.7 Mbps
[87] 543 Q 0 E 1000004 H 137892 D 137892 I 95460 R 62867 C 59800 L 3246K
*** crawling 132.6 pps @ 89.6 Mbps
[89] 410 Q 0 E 1000004 H 137896 D 137892 I 95460 R 62867 C 59857 L 3252K
*** crawling 28.3 pps @ 17.2 Mbps
[91] 311 Q 0 E 1000004 H 137896 D 137892 I 95460 R 62868 C 59890 L 3255K
*** crawling 15.9 pps @ 6.5 Mbps
[93] 230 Q 0 E 1000004 H 139300 D 137892 I 95460 R 62868 C 59900 L 3256K
*** crawling 5.0 pps @ 8.7 Mbps
[95] 170 Q 0 E 1000004 H 139300 D 137892 I 95460 R 62868 C 59901 L 3256K
*** crawling 0.5 pps @ 2.9 Mbps
[97] 123 Q 0 E 1000004 H 139300 D 137892 I 95460 R 62868 C 59902 L 3256K
*** crawling 0.5 pps @ 0.3 Mbps
[99] 79 Q 0 E 1000004 H 139300 D 137892 I 95460 R 62868 C 59902 L 3256K
*** crawling 0.0 pps @ 0.3 Mbps
[101] 22 Q 0 E 1000004 H 139300 D 137892 I 95460 R 62868 C 59904 L 3257K
*** crawling 1.0 pps @ 1.0 Mbps
[103] 3 Q 0 E 1000004 H 139300 D 137892 I 95460 R 62868 C 59904 L 3257K
*** crawling 0.0 pps @ 0.0 Mbps

Extracted 1000004 URLs @ 9666/s
Looked up 139300 DNS names @ 1346/s
Hit 95460 robots @ 923/s
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HTTP codes: 2xx = 47185, 3xx = 5826, 4xx = 6691, 5xx = 202, other = 0
### 463/612 Homework 1 Grade Sheet (Part 3)

Name: ______________________________

<table>
<thead>
<tr>
<th>Function</th>
<th>Points</th>
<th>Breakdown</th>
<th>Item</th>
<th>Deduction</th>
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<tbody>
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<td>Printouts not every 2 seconds</td>
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</tr>
<tr>
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<td>Incorrect active threads</td>
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<td>Incorrect extracted URLs</td>
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<td></td>
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<td>1</td>
<td>Incorrect unique hosts</td>
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<td></td>
<td>1</td>
<td>Incorrect DNS lookups</td>
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<td>Incorrect attempted robots</td>
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<td>1</td>
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<td>Incorrect robots rate</td>
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<td>1</td>
<td>Incorrect HTTP breakdown</td>
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<tr>
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<td>1</td>
<td>&gt;&gt; 200 MB RAM w/500 threads</td>
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<td>Improper stats thread</td>
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<td>Other</td>
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<td>Missing files for compilation</td>
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<td>Report</td>
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<td>Lessons learned and trace</td>
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Additional deductions are possible for memory leaks and crashing.

Total points: ________________