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:

```
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 main(int argc, char *argv[])
{
    // parse command line args
    // initialize Crawler class (shared data structures & parameters)
    // 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 for which a full HTTP response was obtained)
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 summary should be printed (see the traces in Section 1.6 for the details on how each of these numbers is produced from earlier printouts):

```
Extracted 1000004 URLs @ 9666/s
Looked up 139300 DNS names @ 1346/s
Attempted 95460 site 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) Across all pages that came back with a 2xx code, calculate the average number of HTML links (i.e., out-neighbors) found by the parser. Estimate the size of Google’s webgraph (in terms of edges and bytes it occupies on disk) assuming they crawl 1T (trillion) pages. A webgraph here would store each crawled node \( x \) and its out-neighbors \( (y_1, y_2, \ldots) \) using adjacency lists, where URLs are represented by 64-bit hashes.

3. (5 pts) Determine the average page size in bytes (across all HTTP codes). Estimate the bandwidth (in Gbps) needed for Google 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 obtained 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.org/
- www.x.com/tamu.edu/

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:

```cpp
void Crawler::ReadFile (...)  // called by main()
{
    // produce all items into the queue before the crawl begins
    for (i = 0; i < N; i++)
        Q.push (host [i]);
}
void Crawler::Run (...)  // crawling thread, N instances running
{
    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()` waiting 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
void Crawler::StatsRun(...) {
    while (WaitForSingleObject (eventQuit, 2000) == WAIT_TIMEOUT)
    {
        // print
    }
}
```

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-1 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
Connection: close
Date: Thu, 1 Sep 2006 12:00:15
Server: Apache/1.3.0
Content-type: text/html
Transfer-Encoding: chunked

2A0
<html><head><meta http-equiv="Content-Language" content="en-us">...
0
```

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 2xx pages, print an extra line indicating the body length (i.e., page size without the HTTP header) before and after dechunking. For example:

```
URL: http://www.cygwin.com
    Parsing URL... host www.cygwin.com, port 80, request /
    Doing DNS... done in 2 ms, found 8.43.85.97
    * Connecting on page... done in 42 ms
    Loading... done in 48 ms with 7045 bytes
    Verifying header... status code 200
    Dechunking... body size was 6639, now 6601
    + Parsing page... done in 0 ms with 35 links
----------------------------------------
HTTP/1.1 200 OK
```
To find additional URLs to test, run your crawler with HTTP/1.1 on the 1M input file to detect which of the servers provide chunking. Some of the URLs this produced in prior semesters:

http://www.google.com
http://ace.mu.nu/archives/246080.php
http://almajdtv.tv/
http://alkalineearth.com/
http://www.gnu.org
http://www.wikidot.com
http://www.cygwin.com
http://www.openoffice.org
http://www.wikidot.com
http://www.gov.cn

We also have an apache server at s2.irl.cs.tamu.edu:8080, which will chunk responses if they are compressed. To achieve this for testing purposes, send an extra header field “Accept-Encoding: gzip” in the request. There is a range of files (IRL1–IRL10) that cover 1 MB to 512 MB. The response is binary, so no links will be found.
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 sometimes treated by servers as case-insensitive, you might as well use StrStrI in your search.

1.6. Traces

The results below, collected in 2015, will likely differ from those observed today since a lot of the websites have either gone to secure http or completely disappeared. If you would like a more up-to-date trace, you can post a question on Piazza and we’ll do a fresh run.

The first example uses URL-input-100.txt and 10 threads:

<table>
<thead>
<tr>
<th>Threads</th>
<th>Q</th>
<th>E</th>
<th>H</th>
<th>D</th>
<th>I</th>
<th>R</th>
<th>C</th>
<th>L</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>10</td>
<td>41 E</td>
<td>59 H</td>
<td>55 D</td>
<td>55 I</td>
<td>50 R</td>
<td>8 C</td>
<td>0 L</td>
<td>0 K</td>
</tr>
<tr>
<td></td>
<td>*** crawling 0.0 pps @ 0.1 Mbps</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>10</td>
<td>16 E</td>
<td>84 H</td>
<td>75 D</td>
<td>75 I</td>
<td>66 R</td>
<td>10 C</td>
<td>5 L</td>
<td>0 K</td>
</tr>
<tr>
<td></td>
<td>*** crawling 2.5 pps @ 0.4 Mbps</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>4</td>
<td>0 E</td>
<td>10 H</td>
<td>84 D</td>
<td>84 I</td>
<td>74 R</td>
<td>12 C</td>
<td>7 L</td>
<td>1 K</td>
</tr>
<tr>
<td></td>
<td>*** crawling 1.0 pps @ 0.4 Mbps</td>
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</tr>
</tbody>
</table>

Extracted 100 URLs @ 13/s
Looked up 84 DNS names @ 11/s
Attempted 74 site robots @ 9/s
Crawled 11 pages @ 1/s (0.23 MB)
Parsed 543 links @ 70/s
HTTP codes: 2xx = 7, 3xx = 4, 4xx = 0, 5xx = 0, other = 0

The next run was obtained using 5000 threads and URL-input-1M.txt:

<table>
<thead>
<tr>
<th>Threads</th>
<th>Q</th>
<th>E</th>
<th>H</th>
<th>D</th>
<th>I</th>
<th>R</th>
<th>C</th>
<th>L</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>5000 Q</td>
<td>950541 E</td>
<td>49462 H</td>
<td>6489 D</td>
<td>6448 I</td>
<td>5014 R</td>
<td>2207 C</td>
<td>5 L</td>
<td>0 K</td>
</tr>
<tr>
<td></td>
<td>*** crawling 2.5 pps @ 4.2 Mbps</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>5000 Q</td>
<td>932781 E</td>
<td>67223 H</td>
<td>10456 D</td>
<td>10387 I</td>
<td>8008 R</td>
<td>4568 C</td>
<td>123 L</td>
<td>5K</td>
</tr>
<tr>
<td></td>
<td>*** crawling 58.6 pps @ 12.0 Mbps</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>5000 Q</td>
<td>902274 E</td>
<td>97728 H</td>
<td>14567 D</td>
<td>14467 I</td>
<td>11532 R</td>
<td>6556 C</td>
<td>2578 L</td>
<td>99K</td>
</tr>
<tr>
<td></td>
<td>*** crawling 1217.6 pps @ 207.8 Mbps</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>5000 Q</td>
<td>877451 E</td>
<td>122553 H</td>
<td>18130 D</td>
<td>18010 I</td>
<td>14598 R</td>
<td>8676 C</td>
<td>4386 L</td>
<td>215K</td>
</tr>
<tr>
<td></td>
<td>*** crawling 894.6 pps @ 223.3 Mbps</td>
<td></td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>10</td>
<td>5000 Q</td>
<td>854240 E</td>
<td>145764 H</td>
<td>21680 D</td>
<td>21526 I</td>
<td>17691 R</td>
<td>10648 C</td>
<td>6522 L</td>
<td>343K</td>
</tr>
<tr>
<td></td>
<td>*** crawling 1060.1 pps @ 236.1 Mbps</td>
<td></td>
<td></td>
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<tr>
<td>12</td>
<td>5000 Q</td>
<td>830930 E</td>
<td>169074 H</td>
<td>25105 D</td>
<td>24924 I</td>
<td>20626 R</td>
<td>12641 C</td>
<td>8443 L</td>
<td>457K</td>
</tr>
<tr>
<td></td>
<td>*** crawling 952.8 pps @ 227.3 Mbps</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>5000 Q</td>
<td>803317 E</td>
<td>196686 H</td>
<td>28467 D</td>
<td>28240 I</td>
<td>23486 R</td>
<td>14580 C</td>
<td>10375 L</td>
<td>561K</td>
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<tr>
<td></td>
<td>*** crawling 958.3 pps @ 193.2 Mbps</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>5000 Q</td>
<td>778447 E</td>
<td>221557 H</td>
<td>32003 D</td>
<td>31728 I</td>
<td>26444 R</td>
<td>16463 C</td>
<td>12227 L</td>
<td>665K</td>
</tr>
<tr>
<td></td>
<td>*** crawling 918.0 pps @ 198.9 Mbps</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>18</td>
<td>5000 Q</td>
<td>754649 E</td>
<td>245355 H</td>
<td>35431 D</td>
<td>35107 I</td>
<td>29280 R</td>
<td>18386 C</td>
<td>14045 L</td>
<td>766K</td>
</tr>
<tr>
<td></td>
<td>*** crawling 900.6 pps @ 207.0 Mbps</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
For additional testing, there is a newer file on the course website (i.e., URL-input-1M-2019.txt) that contains hosts that were alive in 2019. It takes longer to run, but provides a higher fraction of successful downloads.
### 463/612 Homework 1 Grade Sheet (Part 3)

Name: ______________________________

<table>
<thead>
<tr>
<th>Function</th>
<th>Points</th>
<th>Break down</th>
<th>Item</th>
<th>Deduction</th>
</tr>
</thead>
<tbody>
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<td>Printouts not every 2 seconds</td>
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<td>Incorrect active threads</td>
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<td>Incorrect Q</td>
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<td>Incorrect E</td>
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<td>1</td>
<td>Incorrect H</td>
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<td>1</td>
<td>Incorrect D</td>
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<td>Incorrect R</td>
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<td>Incorrect C</td>
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<td>1</td>
<td>Incorrect L</td>
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<td>Incorrect pps</td>
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<td></td>
<td>1</td>
<td>Incorrect Mbps</td>
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<td>Summary</td>
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<td>1</td>
<td>Incorrect URL processing rate</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>Incorrect DNS rate</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>Incorrect robots rate</td>
<td></td>
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<tr>
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<td></td>
<td>1</td>
<td>Incorrect crawled rate/totals</td>
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<tr>
<td></td>
<td></td>
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<td>Incorrect parser speed</td>
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<tr>
<td></td>
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<td>Incorrect HTTP breakdown</td>
<td></td>
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<tr>
<td>Code</td>
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<td>&lt;&lt; 20 Mbps w/500 threads</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>&gt;&gt; 200 MB RAM w/500 threads</td>
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<td>2</td>
<td>Deadlocks on exit</td>
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<td>Issues with the file reader</td>
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<tr>
<td></td>
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<td>Improper stats thread</td>
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<tr>
<td>Other</td>
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<td>Missing files for compilation</td>
<td></td>
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<tr>
<td>Report</td>
<td>25</td>
<td>5</td>
<td>Lessons learned and trace</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>5</td>
<td>Google graph-size analysis</td>
<td></td>
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<td></td>
<td>5</td>
<td>Yahoo bandwidth analysis</td>
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<td></td>
<td>5</td>
<td>Probability analysis</td>
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<tr>
<td></td>
<td></td>
<td>5</td>
<td>In-degree of tamu.edu</td>
<td></td>
</tr>
</tbody>
</table>

Additional deductions are possible for memory leaks and crashing.

Total points: ________________