CS 455: Introduction To Distributed Systems [Networking & Threads]

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Frequently asked questions from the previous class survey

- IP: Why doesn't IPv6 use checksums? Fragmentation of IPv6 packets?
  - Why have checksum in IPv4 when UDP does it anyways …
  - In IPv4: Why set the Do Not Fragment flag?
- UDP over TCP: when? Is it faster than TCP?
- Can multiple threads listen for connections/data on the same port?
- How do you enforce packet/message sizes?
- Is the TCP buffer shared across multiple connections?
  - Is the size of the buffer/sliding window/etc. per machine?
- If one TCP fragment has several extension headers, would all the fragments have the extension headers? It depends … e.g. Routing Headers

Topics covered in this lecture

- Wrap up of networking
- Threads
  - Creation and Management
  - Lifecycle

Transmission Control Protocol (TCP)

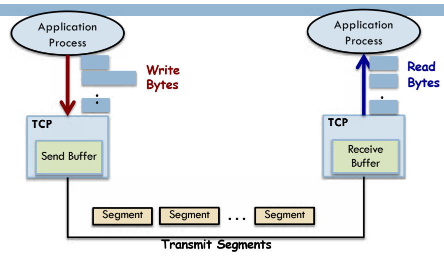
TCP Segments & how they come about

- TCP
  - Accepts data from a data stream
  - Breaks it up into chunks
  - Adds a TCP header … creating a **TCP segment**
- Segment is then *encapsulated* in a IP datagram
- TCP packet is a term that you will often hear
  - Segment is more precise, packets are generally datagrams, frames are at the link layer

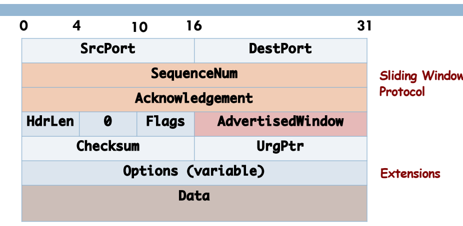
Maximum Segment Size (MSS)

- To avoid fragmentation in the IP layer, a host must specify the MSS as equal to the largest IP datagram that the host can handle **minus** (the IP and TCP header sizes)
- The **minimum** requirements (in bytes) at the hosts are as follows
  - IPv4: 576 – 20 – 20 = 536
  - IPv6: 1280 – 40 – 20 = 1220
- Each direction of the data flow can use a different MSS

How TCP manages a byte stream



TCP Header Format



SourceAddr and **DestinationAddr** from IP

Relationship between `SequenceNum`, `Acknowledgement` and `AdvertisedWindow`

Each byte of data has a sequence number
SequenceNum contains sequence number for first byte of data in segment

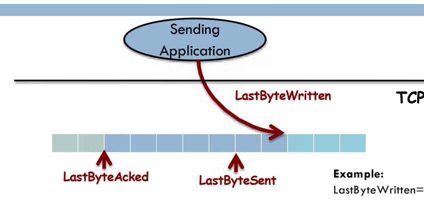
TCP Sliding Window [1/2]

- Guarantees **reliable** delivery of data
- Data is delivered in **order**
- Enforces **flow control** between the sender and receiver

TCP Sliding Window [2/2]

- Sender has a **limit** on unacknowledged data
  - Limited to no more than **`AdvertisedWindow`** bytes of unacknowledged data
- Receiver **selects `AdvertisedWindow`**
  - Based on memory set aside for connection's buffer space

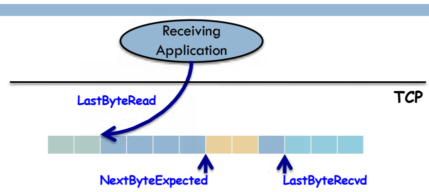
TCP Send Buffer



LastByteAcked ≤ LastByteSent
LastByteSent ≤ LastByteWritten

Example:
LastByteWritten= 3000
LastByteSent=2800
LastByteAcked:= 2400
How many unacknowledged bytes?
(3000-2400)= 600

TCP Receive Buffer



LastByteRead ≤ NextByteExpected

NextByteExpected ≤ LastByteRecvd + 1

Flow Control: Buffers are of finite size `MaxSendBuffer` and `MaxRcvBuffer`

- Receiver **throttles** sender
  - Advertises a window
  - No bigger than what it can buffer

LastByteRcvd – LastByteRead ≤ MaxRcvBuffer

AdvertisedWindow =
MaxRcvBuffer − $\underbrace{\textbf{(} \text{ (NextByteExpected -1)} - \text{LastByteRead)} \textbf{)}}_{\text{Space Utilized in the receiver's buffer}}$

The advertised window may potentially shrink

- If the process is reading data as fast as it arrives?
  - The advertised window *stays open*
    - i.e. `AdvertisedWindow = MaxRcvBuffer`
- If the receiving process falls behind?
  - Advertised window becomes *smaller* with every segment that arrives
  - Until it becomes 0

Flow Control: Buffers are of finite size MaxSendBuffer and MaxRcvBuffer

- On the sender size, TCP **adheres** to the advertised window from the receiver

LastByteSent – LastByteAcked ≤ AdvertisedWindow

EffectiveWindow =
AdvertisedWindow – **(**LastByteSent – LastByteAcked**)**

EffectiveWindow should be > 0 before source can send more data

Issues with TCP

Protecting against wraparound: 32-bit sequence space

- TCP assumes each segment has a max lifetime
  - **Maximum segment lifetime** (MSL)
  - Currently this is 120 seconds
- Sequence number used on a connection might wrap-around
  - Within the MSL

Time until 32-bit sequence number wraps around

Bandwidth	Time until wraparound
T1 (1.5 Mbps)	6.4 hours
Ethernet (10 Mbps)	57 minutes
T3 (45 Mbps)	13 minutes
FDDI (100 mbps)	6 minutes
STS-3 (155 Mbps)	4 minutes
STS-12 (622 Mbps)	55 seconds
STS-24 (1.2 Gbps)	28 seconds

STS : Synchronous Transport Signal
FDDI: Fiber Distributed Data Interface

Keeping the pipe full

- **`AdvertisedWindow`** field (16-bits) must be big enough
  - To allow sender to keep the pipe full
  - 16 bit allows us a max window size of 64 KB (2^{16})
- If receiver has unlimited buffer space?
  - **`AdvertisedWindow`** dictated by Delay x Bandwidth product

Required Window Size for 100 ms delay

Bandwidth	Delay x Bandwidth Product
T1 (1.5 Mbps)	18 KB
Ethernet (10 Mbps)	122 KB
T3 (45 Mbps)	549 KB
FDDI (100 mbps)	1.2 MB
STS-3 (155 Mbps)	1.8 MB
STS-12 (622 Mbps)	7.4 MB
STS-24 (1.2 Gbps)	14.8 MB

STS : Synchronous Transport Signal
FDDI: Fiber Distributed Data Interface

TCP extensions: Use 32-bit timestamp to extend sequence number space

- **Distinguish** between different incarnations of the same sequence number
- Timestamp not treated as part of sequence number
  - For ordering etc.
  - Just protects against wraparound

TCP Extension: Allow TCP to advertise larger window

- Fill larger Delay x Bandwidth pipes
- Include option defining **scaling** factor
- Option allows TCP endpoints to agree that **`AdvertisedWindow`** counts **larger chunks**

A caveat regarding Options

- You cannot solve all problems with Options
- TCP Header has room for only **44 bytes of options**
  - `HdrLen` is 4 bits long, so header length cannot exceed 16 x 32-bit = 64 bytes
  - Adding a TCP option that extends the space available for options?

THREADS

What are threads?

- Miniprocesses or lightweight processes
- Why would anyone want to have a *kind of process* **within** a process?

The main reason for using threads

- In many applications *multiple activities* are going on at once
  - Some of these may block from time to time
- Decompose application into multiple sequential threads
  - Running **concurrently**

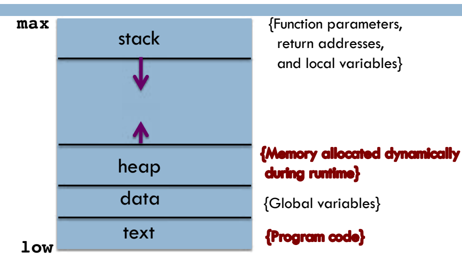
Isn't this precisely the argument for processes?

- Yes, *but* there is a new dimension …
- Threads have the ability to **share the address space** (and all of its data) among themselves
- For several applications
  - Processes (with their *separate* address spaces) don't work

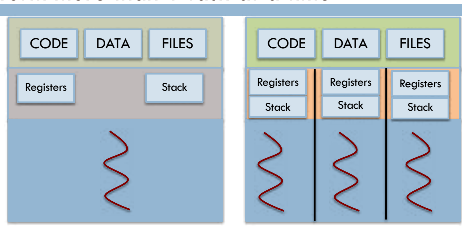
Contrasting items unique & shared across threads

Per process items {Shared by threads with a process}	Per thread items {Items unique to a thread}
Address space	**Program Counter**
Global variables	**Registers**
Open files	**Stack**
Child Processes	**State**
Pending alarms	
Signals and signal handlers	
Accounting Information	

A process in memory



A process with multiple threads of control can perform more than 1 task at a time



Traditional Heavy weight process **Process with multiple threads**

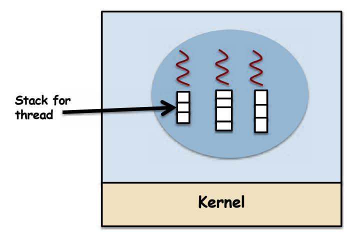
Why each thread needs its own stack (1)

- Stack contains one **frame** for each procedure *called but not returned from*
- Frame contains
  - Local variables
  - Procedure's return address

Why each thread needs its own stack (2)

- Procedure **X** calls procedure **Y**, **Y** then calls **Z**
  - When **Z** *is executing*?
    - Frames for **X**, **Y** and **Z** will be on the stack
- Each thread calls *different* procedures
  - So has a *different execution* history

Each thread has its own stack



Almost impossible to write programs in Java without threads

- We use multiple threads without even realizing it

Blocking I/O: Reading data from a socket

- Program blocks *until data is available* to satisfy the `read()` method
- Problems:
  - Data may not be available
  - Data may be delayed (*in transit*)
  - The other endpoint sends data sporadically
- If program **block**s when it tries to read from socket?
  - Unable to do anything else *until data is actually available*

Three techniques to handle such such situations

- **I/O multiplexing**
  - Take all input sources and use system call, `select()`, to notify data availability on any of them
- **Polling**
  - Test if data is available from a particular source
    - System call such as `poll()` is used
    - In JDK 1.4, `available()` on the `FilterInputStream`
- **Signals**
  - File descriptor representing signal is set
  - *Asynchronous* signal delivered to program when data is available
  - Java does not support this

Writing to a socket may also block

- If there is a **backlog** getting data onto the network
  - Does not happen in fast LAN settings
  - But if it's over the Internet? Possible.
- So, often handling TCP connections requires both a sender and receiver thread

Writing programs that do I/O in Java?

- Use multiple threads
  - Handle traditional, blocking I/O
- Use the NIO library
- Or both

We are trained to think linearly

- Often don't see *concurrent paths* our programs may take
- No reason why processes that we conventionally think of as single-threaded should remain so

Thread Creation & Management

Computing the factorial of a number

```
public class Factorial {

   public static void main(String[] args)  {
      int n = Integer.parseInt(args[0]);

      int factorial = 1;
      while (n>1) {
        factorial *=n;
         n--;
      }
      System.out.println(factorial);
   }
}
```

Behind the scenes …

- Instructions are executed as machine-level assembly instructions
  - Each logical step requires many machine instructions to execute
- Applications are executed as a series of instructions
  - The *execution path* of these instructions?
    - **Thread**

Every program has at least one thread

- Thread executes the body of the application
  - In Java, this is called the **main thread**
    - Begins executing statements starting with the first statement of the `main()` method
- In Java every program has more than 1 thread
  - E.g. threads that do *garbage collection*, *compile bytecodes* into machine-level instructions, etc.
  - Programs are highly threaded
    - You may add additional application threads to this

Let's add another task to our program

- Say, computing the square-root of a number
- What if we wrote these as separate threads?
  - JVM has two distinct lists of instructions to execute
- Threads can be thought of *as tasks that we execute at roughly the same time*
- But in that case, why not just write multiple applications?

Threads that run within the same application process

- **Share the memory space** of the process
  - Information sharing is seamless
- Two diverse applications within the same machine may not communicate so well
  - For e.g. mail client and music application

In a multi-process environment data is separated by default

- This is fine for **dissimilar programs**
- Not OK for certain types of programs; e.g. a network server sends stock quotes to clients
  - Discrete task: Sending quote to client
    - Could be done in a separate thread
  - Data sent to the clients is the same
    - *No point having a separate server for each client* and …
    - *Replicating data* held by the network server

Threads and sharing

- Threads within a process can access and share any object on the **heap**
  - Each thread has space for its own local variables (stack)
- A thread is a discrete task that operates on data **shared** with other threads

The contents of this slide-set are based on the following references

- *Computer Networks: A Systems Approach. Larry Peterson and Bruce Davie. 4th edition. Morgan Kaufmann. ISBN: 978-0-12-370548-8.* Chapters [4, 5]
- *https://en.wikipedia.org/wiki/Maximum_segment_size*
- *Java Threads. Scott Oaks and Henry Wong. . 3rd Edition. O'Reilly Press. ISBN: 0-596-00782-5/978-0-596-00782-9.* [Chapters 1, 2]
- *Andrew S Tanenbaum. Modern Operating Systems. 3rd Edition, 2007. Prentice Hall. ISBN: 0136006639/978-0136006633. [Chapter 2]*