CSCE 313-201
Introduction to Computer Systems
Fall 2019

Operating Systems

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Chapter 2: Book Overview

- Lectures skip chapter 1
  - Mostly 312 background with some examples

- Our goal in chapter 2
  - Understand the motivation for building an OS
  - Introduce basic terminology and history
  - Glance over the main concepts studied later
Chapter 2: Motivation

• Early computers (1940-1950s) did not have an OS

• Programs (called jobs) were loaded manually from punch cards
  – Errors were indicated by lights
  – Printer output signaled successful completion

• Three main problems:
  – Scheduling inefficiency
  – Setup delays
  – Hardware awareness
Chapter 2: Motivation

• Scheduling inefficiencies
  - Sign-up sheet to reserve computer time
  - Wasted resources if job finishes quicker than reserved time
  - Forced termination and repeated visits if taking too long

• Setup delays
  - Loading compiler, source code, libraries, input data, and linking involved mounting tapes and/or card decks
  - If an error occurred, the user had to restart the process
  - Considerable time dedicated to setting up the program to run

• Hardware awareness
  - Programmer had to write directly into device registers in every program, keep track of hardware changes
  - Time wasted on largely irrelevant code development
Chapter 2: Roadmap

2.1 OS objectives and functions
2.2 Evolution of the OS
2.3 Major achievements
2.4 Other developments
2.5 Virtual Machines
2.6 Multi-core considerations
2.7 MS Windows
2.6 Traditional UNIX
2.7 Modern UNIX
2.8 Linux
**Evolution of the OS**

- Manual job control in the 1940s was known as **serial processing**
- Extreme inefficiency and inconvenience prompted automation of the process and development of an OS
- Main functions
  - Controls the execution of application programs
  - Provides an interface to hardware
Simple Batch System (1955)

- Early computers were extremely expensive
  - Was important to maximize processor utilization
- With an OS present, user no longer had direct access to CPU or devices
  - Instead, submitted jobs into a FIFO queue that was read and executed by a monitor
- When programs were done, they returned control to the monitor

**OS = monitor**

- **Device drivers**
- **Job sequencing**
- **JCL interpreter**

**User program area**

**Job Control Language (JCL)**
- Directives how to run the job (e.g., compiler, input data, job owner)
Simple Batch System

Hardware features

- **Memory protection**
  - Jobs with access violations (e.g., trying to wipe out the monitor) were aborted

- **Timer**
  - Prevented jobs from monopolizing system or infinitely looping
  - Each job had a fixed deadline by which it had to finish

- **Privileged instructions**
  - Execution allowed only by the monitor
  - Prevented jobs from crashing the system or reading unauthorized data (e.g., the next job)
  - Monitor controlled all I/O

- **Interrupts**
  - Were not needed as all I/O was synchronous
Multi-Programmed Batch System (1959)

- Even in batched systems, the CPU was often idle
  - Automatic job sequencing helped reduce the delay between the jobs, but not within them
  - Reason: I/O devices are slow compared to processor
- **Example**: a job spends 15 ms reading a record from the file, then processes it for 1 ms, and finally writes one record to another file (also 15 ms)
  - What is the CPU utilization?

| CPU | I/O wait | CPU | I/O wait | CPU |

- This is often called **uni-programming**
Multi-Programmed Batch System

- **Idea**: when one job needs to wait for I/O, the monitor can switch the CPU to another job
  - Various scheduling algorithms are possible
  - Example below uses strict priority scheduling from A to C

<table>
<thead>
<tr>
<th></th>
<th>CPU</th>
<th>I/O wait</th>
<th>CPU</th>
<th>I/O wait</th>
<th>CPU</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>wait</td>
<td>CPU</td>
<td>I/O wait</td>
<td>CPU</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>wait</td>
<td>CPU</td>
<td>wait</td>
<td>CPU</td>
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</tr>
</tbody>
</table>

- Interrupts are now needed for monitor to regain control
- This is called **multi-programming** (or **multi-tasking**) and is now the central theme of modern OSes
Example

- At time 0, three jobs are submitted to a monitor in a system with 250 MB of RAM
  - CPU in table means % of time task is not blocked on I/O
  - Assume jobs never conflict on the same I/O device

- Uni-programming

<table>
<thead>
<tr>
<th></th>
<th>Job 1</th>
<th>Job 2</th>
<th>Job 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPU</td>
<td>70%</td>
<td>10%</td>
<td>10%</td>
</tr>
<tr>
<td>Duration</td>
<td>5 min</td>
<td>15 min</td>
<td>10 min</td>
</tr>
<tr>
<td>RAM</td>
<td>50 MB</td>
<td>100 MB</td>
<td>75 MB</td>
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</table>

- Multi-programming

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<td>10%</td>
</tr>
<tr>
<td>RAM</td>
<td>20%</td>
<td>40%</td>
<td>30%</td>
</tr>
</tbody>
</table>
**Example**

- **Task 1**: completion time of last job in uni-programming?
- **Task 2**: what is the average CPU and RAM utilization?
  - Metric computed over the entire interval
- **Uni-programming**
  - CPU: \( \frac{(70\% \times 5 + 10\% \times 15 + 10\% \times 10)}{30} = 20\% \)
  - RAM: \( \frac{(20\% \times 5 + 40\% \times 15 + 30\% \times 10)}{30} = 33.3\% \)
- **Task 3**: what is the **throughput** of the system?
  - Number of jobs finished per time unit (e.g., 1 hour)
- **Task 4**: what is the **mean response time**?
  - Average delay from job submission to its completion
  - Uniprocessing: \( \frac{(5 + 20 + 30)}{3} = 18.333 \text{ min} \)

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Time Sharing System (1961)

- Batch mode favors long CPU-bound jobs
  - Response time for other tasks may be minutes or hours
- Maximizing CPU utilization does not suit interactive jobs
  - E.g., a text editor cannot wait 3 hours for its turn
- Under time-sharing, CPU is periodically provided to all jobs not waiting for I/O
  - Goal: minimize response delay
- Time divided into slices
  - E.g., 200 ms in early systems, 1-10 ms in modern OSes
- The kernel rotates through all jobs scheduling them to run on the CPU
- Max delay before getting on the CPU
  - Slice * (number of competing jobs – 1)
Time Sharing System

• Comparison

  multi-programmed batch mode

  Time Sharing

  A
  B
  C

  CPU
  wait
  wait

  1 hour

  20 ms to process keyboard

  60 ms

• Response time of C with 10-ms slices?

• First time-sharing OS
  – *Compatible Time-Sharing System* (CTSS), MIT 1961

• Modern OSes derived from these early concepts
Real-Time System

• In regular OSes, job switching delays are random and depend on the immediate backlog of CPU-bound tasks and their priority
  - Under worst-case scenarios, a job may not receive its turn for many slices
• This presents certain problems in mission-critical applications
  - E.g., car traction control, helicopter missile-guidance system
• Real-time OS (RTOS) provides guarantees on scheduling and interrupt delays
  - Examples include Windows CE, RTLinux, VxWorks
OS Growth

- OSes are complex pieces of software
  - MIT’s CTSS (1961-3): 32,000 machine words
  - IBM’s OS/360 (1964): 1M CPU instructions
  - Multics (1978): 20M CPU instructions
- Later, software was measured in source lines of code (SLOC)
  - Estimates from Wikipedia:

<table>
<thead>
<tr>
<th>Year</th>
<th>OS</th>
<th>SLOC</th>
</tr>
</thead>
<tbody>
<tr>
<td>93</td>
<td>NT 3.1</td>
<td>4M</td>
</tr>
<tr>
<td>94</td>
<td>NT 3.5</td>
<td>7M</td>
</tr>
<tr>
<td>96</td>
<td>NT 4.0</td>
<td>11M</td>
</tr>
<tr>
<td>00</td>
<td>2000</td>
<td>29M</td>
</tr>
<tr>
<td>01</td>
<td>XP</td>
<td>45M</td>
</tr>
<tr>
<td>03</td>
<td>Server 2003</td>
<td>50M</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Year</th>
<th>OS</th>
<th>SLOC</th>
</tr>
</thead>
<tbody>
<tr>
<td>91</td>
<td>Linux kernel</td>
<td>10K</td>
</tr>
<tr>
<td>94</td>
<td>Linux 1.0.0</td>
<td>176K</td>
</tr>
<tr>
<td>12</td>
<td>Linux 3.3 kernel</td>
<td>15M</td>
</tr>
<tr>
<td>05</td>
<td>MacOS 10.4</td>
<td>86M</td>
</tr>
<tr>
<td>07</td>
<td>Debian 4.0</td>
<td>283M</td>
</tr>
<tr>
<td>09</td>
<td>Debian 5.0</td>
<td>324M</td>
</tr>
</tbody>
</table>
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Major Achievements

- Impossible to deal with OS complexity without certain systematic ways of managing resources, jobs, and users
- Major advances in the development of operating systems (layout of the book):
  - Processes and threads (ch. 3-4)
  - IPC (inter-process communication) and synchronization mechanisms (ch. 5-6)
  - File systems (ch. 11-12)
  - Memory (RAM) management (ch. 7-8)
  - Scheduling and resource allocation (ch. 9-10)
  - Information protection and security (ch. 14-15)

covered in this class
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Homework #1

- When running A*
  - Incorrect # of nodes if weight is integer in $q = L + \frac{w}{(d+1)}$
- Basic BFS and DFS
  - Order of traversal on this graph?

Adjacency list
A: E, D, B
B: A, G
C: E, D, F
D: A, C
E: A, C
F: C, G
G: B, F

$q = L + (\text{float})w / (d+1)$
Homework #1

• Refresh the concept of search
  - Assume an undirected graph \( G = (V,E) \)
  - Start node \( s \in V \)

• Maintain two structures
  - Unexplored set \( U \)
  - Discovered set \( D \)

• Approach #1:

```java
U.add (s)
while ( U.notEmpty () )
  x = U.removeNextNode () // node to explore
  if ( D.find(x) == true ) // if already explored, ignore
    continue
  N = G.getNeighbors (x) // N is a set of nodes
  if ( N.size() == 0 ) break // exit?
  for each y in N
    U.add (y)
```

Any problems?
• This code fails to actually insert anything into D
• Correct version:

```java
U.add (s)
while ( U.notEmpty () )
    x = U.removeNextNode ()
    if ( D.find(x) == true ) // if already explored, ignore
        continue
    D.add (x)
    N = G.getNeighbors (x)
    if ( N.size() == 0 ) break // exit?
    for each y in N
        U.add (y)
```

Any drawbacks?

• Requires huge storage as each node may be pushed into U as many times as there are links to it
  - Not advisable in practice
Homework #1

• Approach #2 inserts a single copy of each node in U:

```c
U.add (s); D.add (s);    // s = source node
while ( U.notEmpty () )
    x = U.removeNextNode ()
    N = G.getNeighbors (x)
    if ( N.size() == 0 ) break    // exit?
    for each y in N
        if ( D.find (y) == false ) // has been pushed in U?
            U.add (y)
            D.add (y)
```

Always use this version!

• For most types of non-trivial exploration, approach #2 is far superior to #1

• What if D has a function that combines find/add?
  - Can directly use STL set’s insert() function
Homework #1

• When you find the exit, how far is it from s?
• Idea: make U keep track of tuples (nodeID, distance)

```
U.add(s, 0); D.add(s);
while (U.notEmpty())
    t = U.removeNextTuple(); // t is a tuple
    N = G.getNeighbors(t.ID)
    if (N.size() == 0)
        printf("Found at distance %d\n", t.distance)
        break
    for each y in N
        if (D.find(y) == false) // new node?
            U.add(y, t.distance + 1)
            D.add(y)
```

• Note that U.add() also needs light intensity for bFS/A*
  – See the handout for details
Homework #1

- Reusing the search algorithm
  - Create a base class

```cpp
class Ubase {
    virtual void Add (uint64 ID, int distance, float intensity) = 0;
    virtual UnexploredRoom RemoveNextTuple (void) = 0;
    ...
}
```

- Inherit four classes

```cpp
class Ubreadth : public Ubase {
    // implement a queue here
}
class Udepth : public Ubase {
    // implement a stack here
}
...
```

- Create base pointer to a specific class, then send it to search()

```cpp
Ubase *ptr;
if (searchType == BFS)
    ptr = new Ubreadth;
else if ...
    Search (ptr);
```

```cpp
Search (Ubase *U)
{
    while (U->size() > 0)
        ...
}
```