Processes and Threads

Learning Outcomes

- An understanding of fundamental concepts of processes and threads

Major Requirements of an Operating System

- Interleave the execution of several processes to maximize processor utilization while providing reasonable response time
- Allocate resources to processes
- Support interprocess communication and user creation of processes

Processes and Threads

- Processes:
  - Also called a task or job
  - Execution of an individual program
  - "Owner" of resources allocated for program execution
  - Encompasses one or more threads
- Threads:
  - Unit of execution
  - Can be traced
    - list the sequence of instructions that execute
  - Belongs to a process
    - Executes within it.

Execution snapshot of three single-threaded processes (No Virtual Memory)

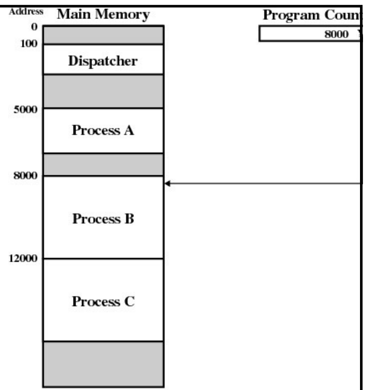


Figure 3.1 Snapshot of Example Execution (Figure
at Instruction Cycle 13

Logical Execution Trace

5000	8000	12000
5001	8001	12001
5002	8002	12002
5003	8003	12003
5004		12004
5005		12005
5006		12006
5007		12007
5008		12008
5009		12009
5010		12010
5011		12011
(a) Trace of Process A	(b) Trace of Process B	(c) Trace of Process C

5000 = Starting address of program of Process A
8000 = Starting address of program of Process B
12000 = Starting address of program of Process C

Figure 3.2 Traces of Processes of Figure 3.1

Combined Traces

(Actual CPU Instructions)

What are the shaded sections?

1	5000
2	5001
3	5002
4	5003
5	5004
6	5005
---------------------Time out	
7	100
8	101
9	102
10	103
11	104
12	105
13	8000
14	8001
15	8002
16	8003
-------------------I/O request	
17	100
18	101
19	102
20	103
21	104
22	105
23	12000
24	12001
25	12002
26	12003

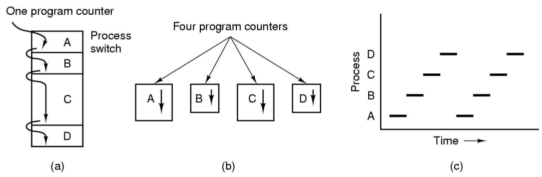
27	12004
28	12005
---------------------Time out	
29	100
30	101
31	102
32	103
33	104
34	105
35	5006
36	5007
37	5008
38	5009
39	5010
40	5011
---------------------Time out	
41	100
42	101
43	102
44	103
45	104
46	105
47	12006
48	12007
49	12008
50	12009
51	12010
52	12011
---------------------Time out	

100 = Starting address of dispatcher program

shaded areas indicate execution of dispatcher process;
first and third columns count instruction cycles;
second and fourth columns show address of instruction being executed

Figure 3.3 Combined Trace of Processes of Figure 3.1

Summary: The Process Model



- Multiprogramming of four programs
- Conceptual model of 4 independent, sequential processes (with a single thread each)
- Only one program active at any instant

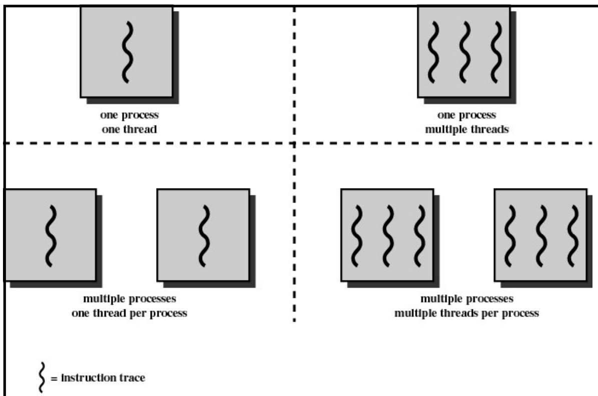


Figure 4.1 Threads and Processes [ANDE97]

Process and thread models of selected OSes

- Single process, single thread
  - MSDOS
- Single process, multiple threads
  - OS/161 as distributed
- Multiple processes, single thread
  - Traditional unix
- Multiple processes, multiple threads
  - Modern Unix (Linux, Solaris), Windows

Note: Literature (incl. Textbooks) often do not cleanly distinguish between processes and threads (for historical reasons)

Process Creation

Principal events that cause process creation

1. System initialization
   - Foreground processes (interactive programs)
   - Background processes
     - Email server, web server, print server, etc.
     - Called a *daemon* (unix) or *service* (Windows)
2. Execution of a process creation system call by a running process
   - New login shell for an incoming telnet/ssh connection
3. User request to create a new process
4. Initiation of a batch job

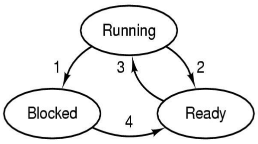
Note: Technically, all these cases use the same system mechanism to create new processes.

Process Termination

Conditions which terminate processes

1. Normal exit (voluntary)
2. Error exit (voluntary)
3. Fatal error (involuntary)
4. Killed by another process (involuntary)

Process/Thread States



1. Process blocks for input
2. Scheduler picks another process
3. Scheduler picks this process
4. Input becomes available

- Possible process/thread states
  - running
  - blocked
  - ready
- Transitions between states shown

Some Transition Causing Events

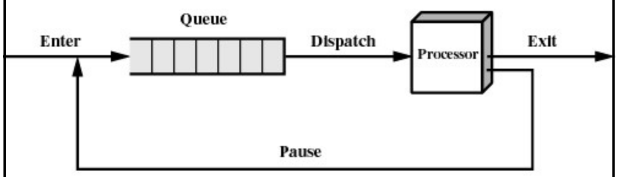
Running → Ready
- Voluntary `Yield()`
- End of timeslice

Running → Blocked
- Waiting for input
  - File, network,
- Waiting for a timer (alarm signal)
- Waiting for a resource to become available

Scheduler

- Sometimes also called the *dispatcher*
  - The literature is also a little inconsistent on with terminology.
- Has to choose a *Ready* process to run
  - How?
  - It is inefficient to search through all processes

The Ready Queue

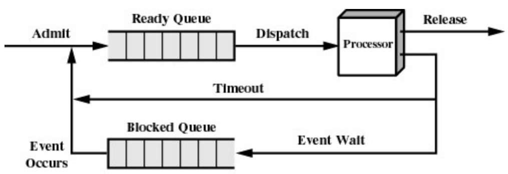


(b) Queuing diagram

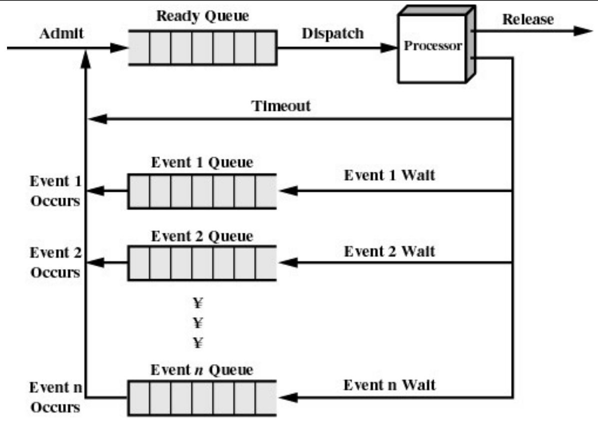
What about blocked processes?

- When an *unblocking* event occurs, we also wish to avoid scanning all processes to select one to make *Ready*

Using Two Queues



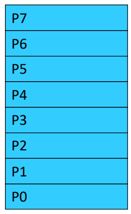
(a) Single blocked queue



(b) Multiple blocked queues

Implementation of Processes

- A processes' information is stored in a *process control block* (PCB)
- The PCBs form a *process table*
  - Sometimes the kernel stack for each process is in the PCB
  - Sometimes some process info is on the kernel stack
    - E.g. registers in the *trapframe* in OS/161
  - Reality is much more complex (hashing, chaining, allocation bitmaps,…)

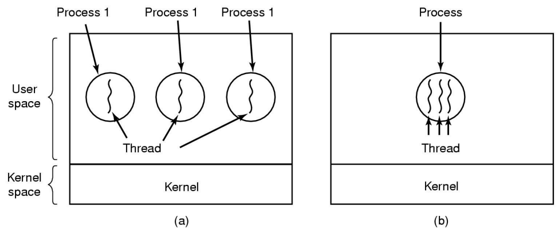


Implementation of Processes

Process management	Memory management	File management
Registers Program counter Program status word Stack pointer Process state Priority Scheduling parameters Process ID Parent process Process group Signals Time when process started CPU time used Children's CPU time Time of next alarm	Pointer to text segment Pointer to data segment Pointer to stack segment	Root directory Working directory File descriptors User ID Group ID

Example fields of a process table entry

Threads
The Thread Model



(a) Three processes each with one thread
(b) One process with three threads

The Thread Model – Separating execution from the environment.

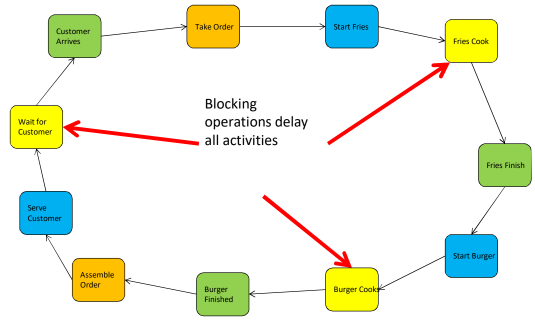
Per process items	Per thread items
Address space Global variables Open files Child processes Pending alarms Signals and signal handlers Accounting information	Program counter Registers Stack State

- Items shared by all threads in a process
- Items private to each thread

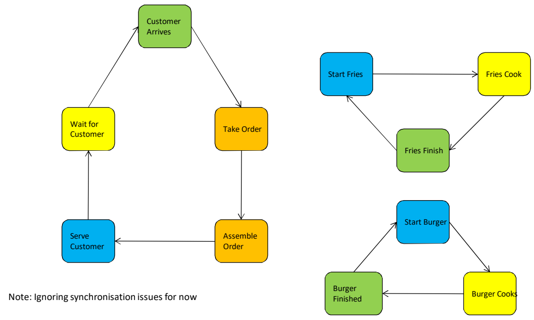
Threads Analogy

The Hamburger Restaurant

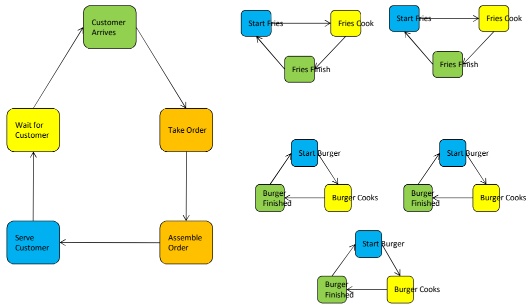
Single-Threaded Restaurant



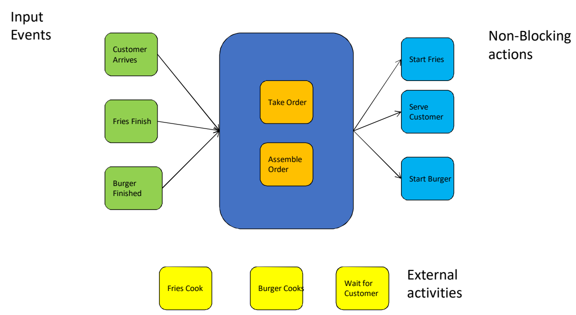
Multithreaded Restaurant



Multithreaded Restaurant with more worker threads

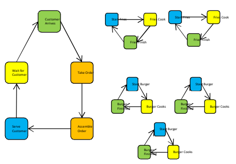


Finite-State Machine Model
(Event-based model)



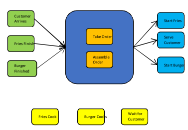
Observation: Computation State

Thread Model



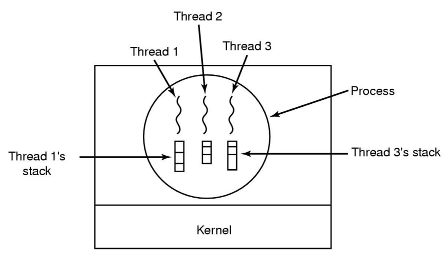
- State implicitly stored on the stack.

Finite State (Event) Model



- State explicitly managed by program

The Thread Model

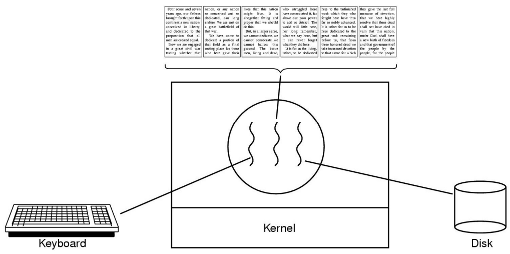


Each thread has its own stack

Thread Model

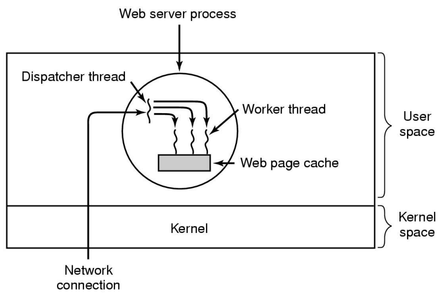
- Local variables are per thread
  - Allocated on the stack
- Global variables are shared between all threads
  - Allocated in data section
  - Concurrency control is an issue
- Dynamically allocated memory (malloc) can be global or local
  - Program defined (the pointer can be global or local)

Thread Usage



A word processor with three threads

Thread Usage



A multithreaded Web server

Thread Usage

```
while (TRUE) {
  get_next_request(&buf);
  handoff_work(&buf);
}
```
(a)

```
while (TRUE) {
  wait_for_work(&buf)
  look_for_page_in_cache(&buf, &page);
  if (page_not_in_cache(&page)
     read_page_from_disk(&buf, &page);
  return_page(&page);
}
```
(b)

- Rough outline of code for previous slide
  - (a) Dispatcher thread
  - (b) Worker thread – can overlap disk I/O with execution of other threads

Thread Usage

Model	**Characteristics**
Threads	Parallelism, blocking system calls
Single-threaded process	No parallelism, blocking system calls
Finite-state machine	Parallelism, nonblocking system calls, interrupts

Three ways to construct a server

Summarising "Why Threads?"

- Simpler to program than a state machine
- Less resources are associated with them than a complete process
  - Cheaper to create and destroy
  - Shares resources (especially memory) between them
- Performance: Threads waiting for I/O can be overlapped with computing threads
  - Note if all threads are *compute bound*, then there is no performance improvement (on a uniprocessor)
- Threads can take advantage of the parallelism available on machines with more than one CPU (multiprocessor)