Processes

Processes and concurrency

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Program

- ***Algorithm:*** a logical procedure that in a finite number of steps solves a problem
- ***Program:*** formal expression of an algorithm by means of a programming language
  - Static entity
  - Sequence of code lines

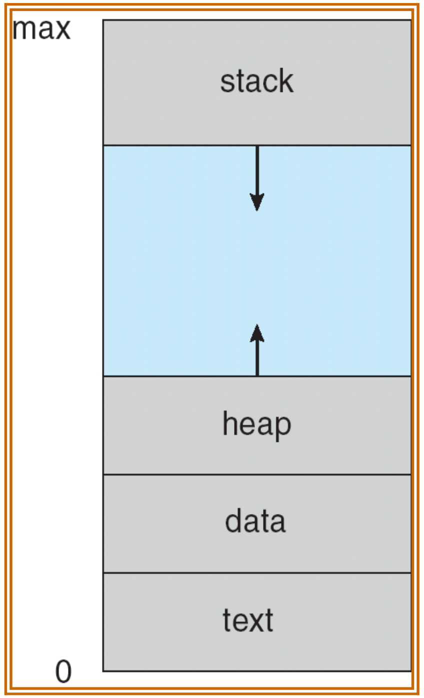
Process

- ***Process:*** a **sequence** of operations performed by a program in execution on a given set of input data.
- The temporal behavior of a process can be analyzed through its **trace**
  - Program in execution
  - Dynamic entity

Program counter	Stack pointer	Register A	Register B	Variable X	Variable Y
0	0x1234	0	0	0	0
4	0x1234	-10	0	0	0
8	0x1234	-10	0	-10	0

Process

- Text area (source code)
- Data area (global variables)
- Stack (function parameters and local variables)
- Heap (dynamic variables allocated during the process execution)
- Registers (Program counter, stack pointer, etc.)

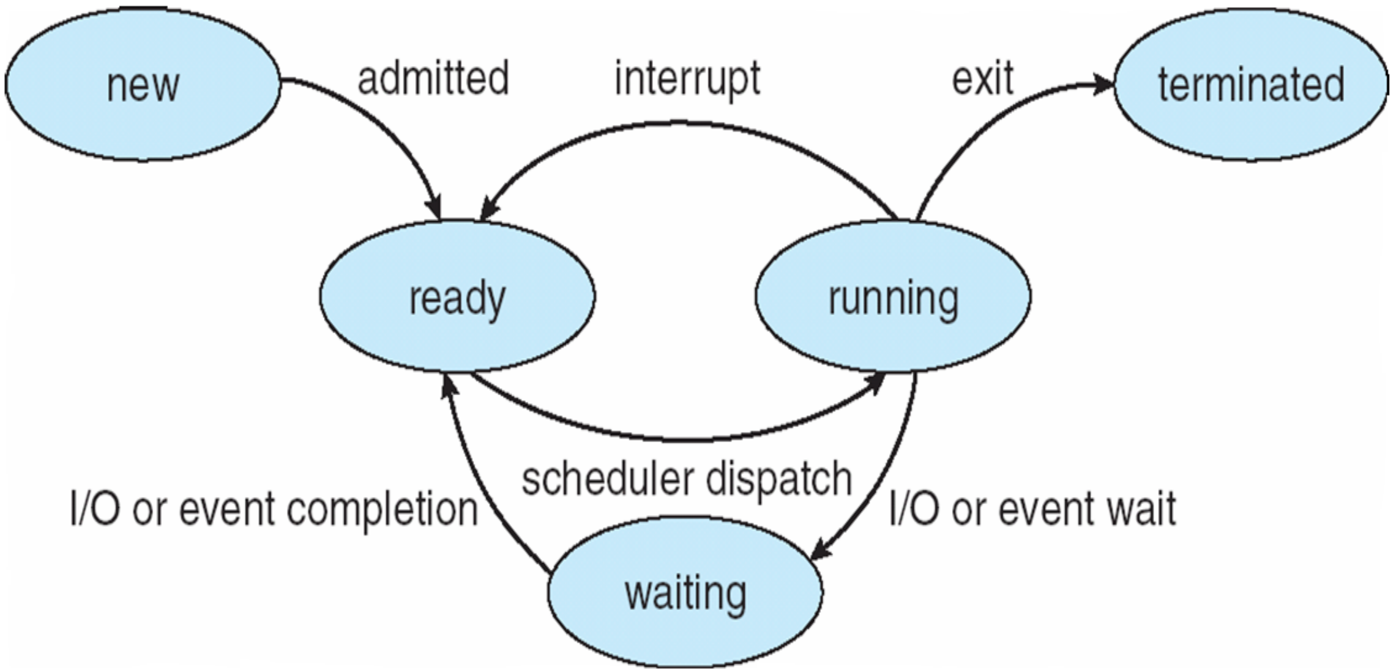


Process state

- During its execution a process change its state
  - **New**: process is created and submitted to the OS
  - **Running**: a CPU is allocated to the process
  - **Ready**: logically ready to run, waiting that a CPU is available
  - **Waiting**: for an event or for a resource
  - **Terminated**: releases the resource it is using

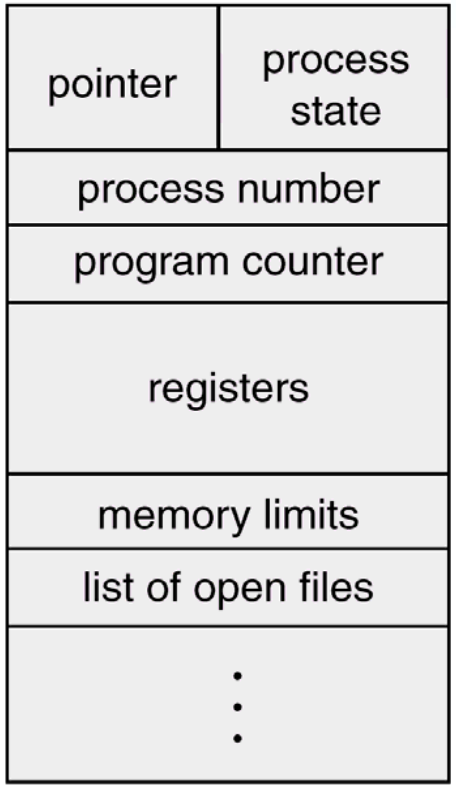
State diagram

- The possible state evolution of a process is described by a state diagram



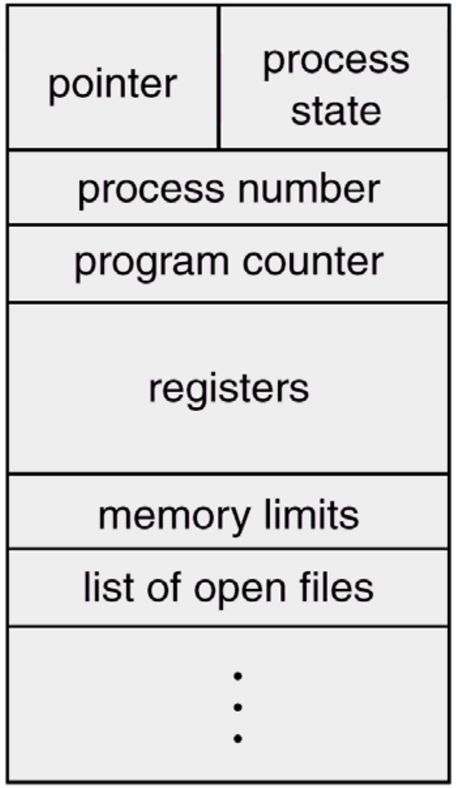
Process Control Block (PCB)

- The kernel stores for each process a set of data, e.g.,
  - The process state
    - New, Ready, Running, Waiting, Terminated
  - Copy of the CPU registers
    - Their number and type is hardware-dependent
  - The program counter
    - Address of the next instruction to be executed



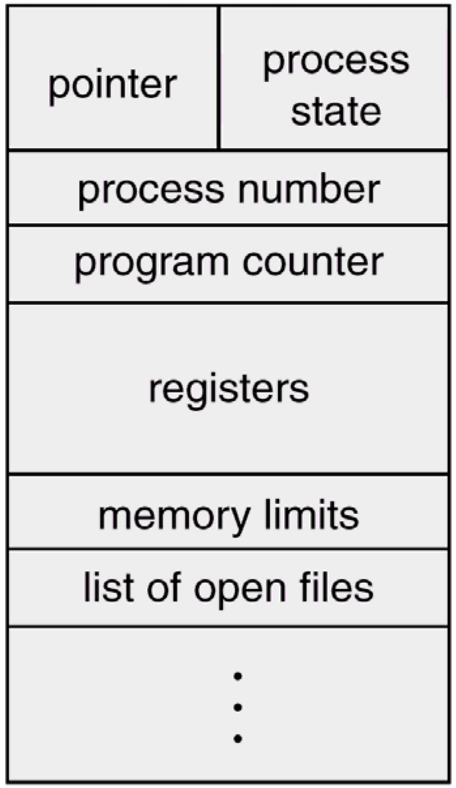
Process Control Block (PCB)

- Data useful for CPU scheduling
  - Priority, pointers to queues, etc.
- Data useful for memory management
  - Segment and paging registers, segment and page tables, etc.
- File table
  - open files
- Signal table
  - signal handlers
- Etc.



Process Control Block (PCB)

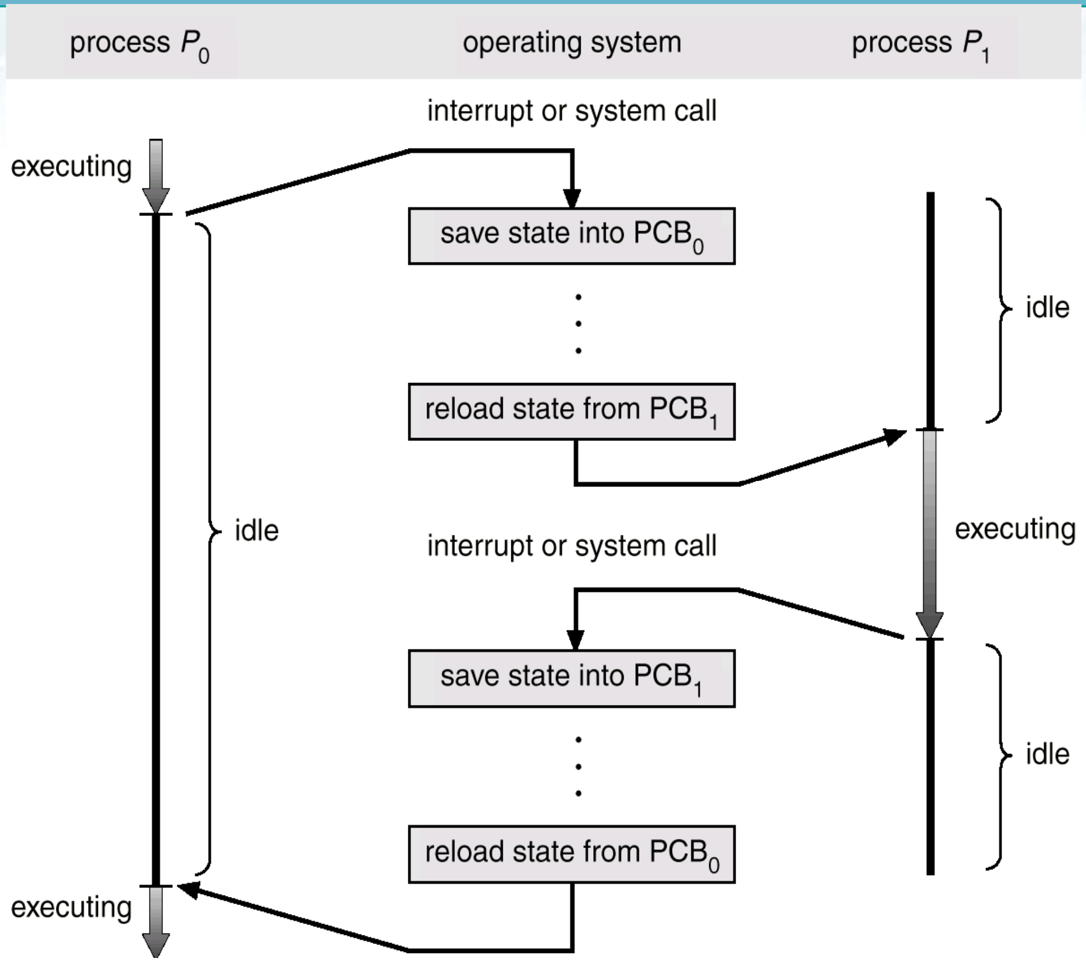
- Various administration data
  - CPU usage, limits, etc.
- I/O status information
  - I/O device list, etc.



Context switching

- When the CPU is assigned to another process, the kernel
  - Save the state of the running process
  - Load the state previously saved for the new process
- The time devoted to this **context switching** is overhead, i.e., time not directly useful for any process
- The amount of time for context switching is hardware-dependent

Context switching



Process scheduling

- Multiprogramming aims at maximizing the CPU usage by processes
- Processes can be classified as
  - I/O-bound
    - Spend more time for I/0 than for computation
    - Require short CPU service times
  - CPU-bound
    - Spend more time for computation than for I/0
    - Require long CPU service times

Process scheduling

- The kernel manages the sharing of the CPU among processes by means of a **scheduler**
  - A scheduler selects the next process to run, among the ready ones, according to a strategy that tries to maximize the CPU usage and to satisfy the response time for users

Process scheduling

- Different types of schedulers
  - Short-term scheduler
    - Selects the next process to run (context-switching)
    - Run frequently
    - Rescheduling performed every 1 to 10 milliseconds
    - Must be extremely fast

Process scheduling

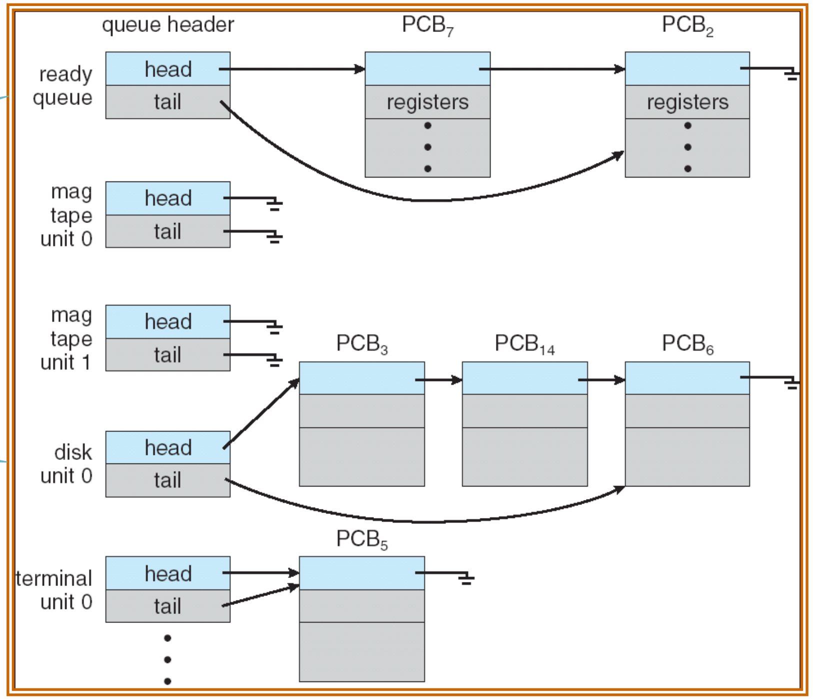
- Long-term scheduler
  - Run less frequently
  - Rescheduling time in the order of seconds/minutes
  - Selects which process image can be loaded in main memory (swapper)
  - Controls multiprogramming to avoid trashing
    - Too many processes that conflicts for the use of limited resources

Process scheduling

- A scheduler manages **process queues**

Ready process queue

I/O waiting process queue

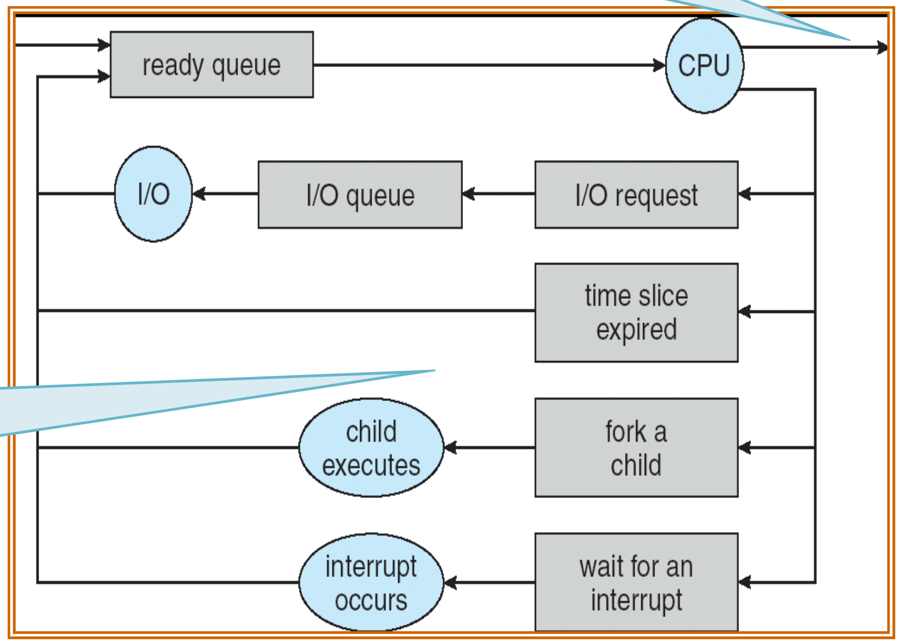


Queuing diagram

- The queuing diagram shows the possible process transitions from one queue to another one

Process initially goes on the ready queue

Process terminates



A running process releases the CPU and goes on the ready state due to (I/O completion, interrput, fork, etc.)

Concurrency

- **Parallel computing** is a type of computation in which many tasks are carried out simultaneously.
  - Large problems can often be divided into smaller ones, which can then be solved at the same time
- Concurrency
  - Has been used since long time
  - Large development in the last years due to upper limits on the CPU frequency, and power consumption

Concurrency

Dissipated power

$$P = C \cdot V^2 \cdot F$$

Capacity (switch)

Voltage

Frequency

- Due to the limits of frequency scaling
  - Parallel computing is now one of the main programming paradigms
  - Concurrent programming has introduced new challenges and pitfalls (bugs)

Concurrency

- Parallel computation levels
  - Bit-level
    - Word length determines the efficiency of an instruction (e.g., 8 bit versus 16 bit adder)
  - Instruction-level
    - Use of multi-stage pipelines for the execution of an instruction flow (e.g., fetch, decode, execute)
  - Task-level
    - Different computations are executed in parallel (e.g., sorting and matrix product)

Speed-up

- Concurrency aims at increasing the usage of the CPUs
  - Only multi-processor or multi-core systems allow obtaining real concurrency.
- Different levels of concurrency
  - Computer-cluster
  - Multi-processor
  - Multi-core

Speed-up

- **In theory** concurrency should allow linear speed-up
  - Doubling the number of computation units, the execution time should be halved
- This behavior is obtained
  - Rarely
    - If a process is intrinsically sequential, augmenting the processing units does not change its execution time.
  - For a limited number of processors/cores
    - The speed-up curve grows linearly initially, but then goes towards an horizontal asymptote

Speed-up

- Amdahl law [1967]
  - Small program segments intrinsically sequential limit the total speed-up that can be obtained

$$\lim_{P\to\infty} \frac{1}{\frac{1-\alpha}{P}+\alpha} = \frac{1}{\alpha}$$

#Processors

% sequential run-time

α = 10% = 0.1
→
10x speed-up max

Speed-up

- Amdahl law [1967]
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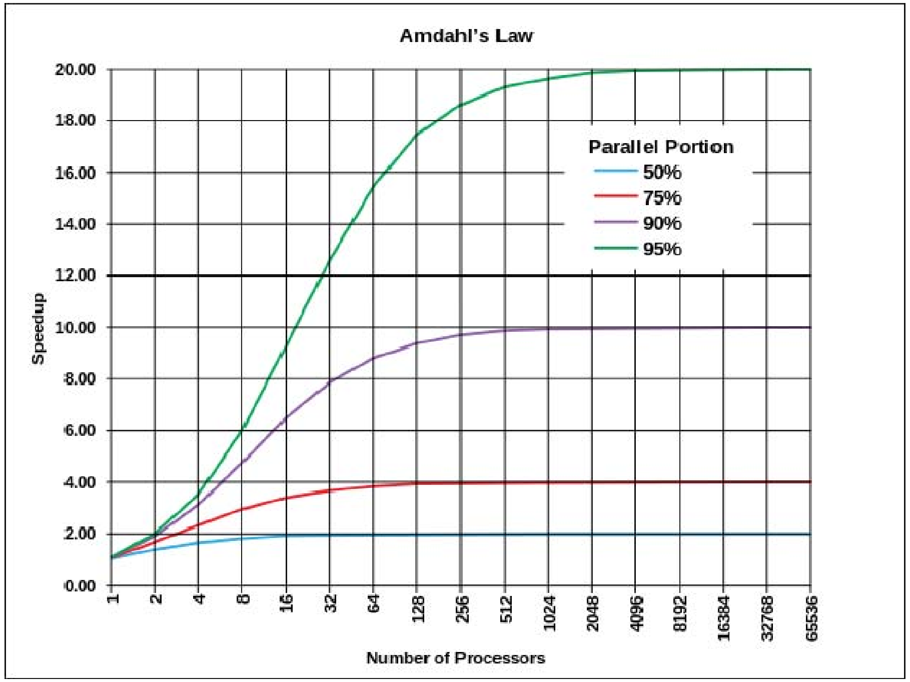
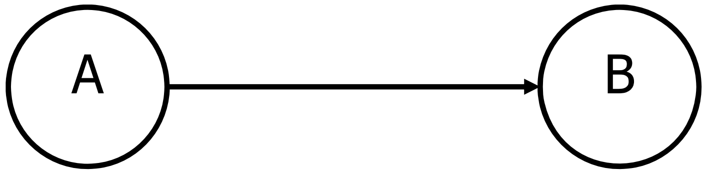


Parallel implementation

- An algorithm can be parallelized only respecting all its dependencies
  - Precedence constraints among operations (i.e., instructions, instruction blocks, processes)
  - A program cannot be executed faster than its slower sequence of operations (**critical path**)
- Precedence constraints can be represented by means of **precedence graphs**
  - Relation with Control Flow Graph an Process generation trees

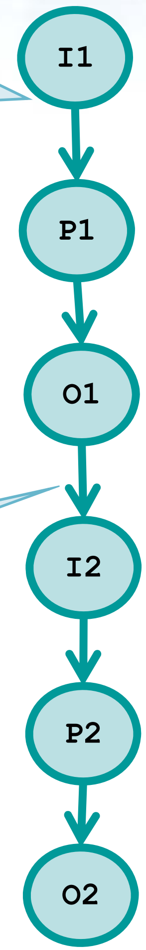
Precedence graphs

- A precedence graph is an acyclic direct graph with
  - Nodes corresponding to instructions, instruction blocks, processes
  - Arcs represent precedence conditions
    - An arc from node A to node B means that B can be executed only when A is completed



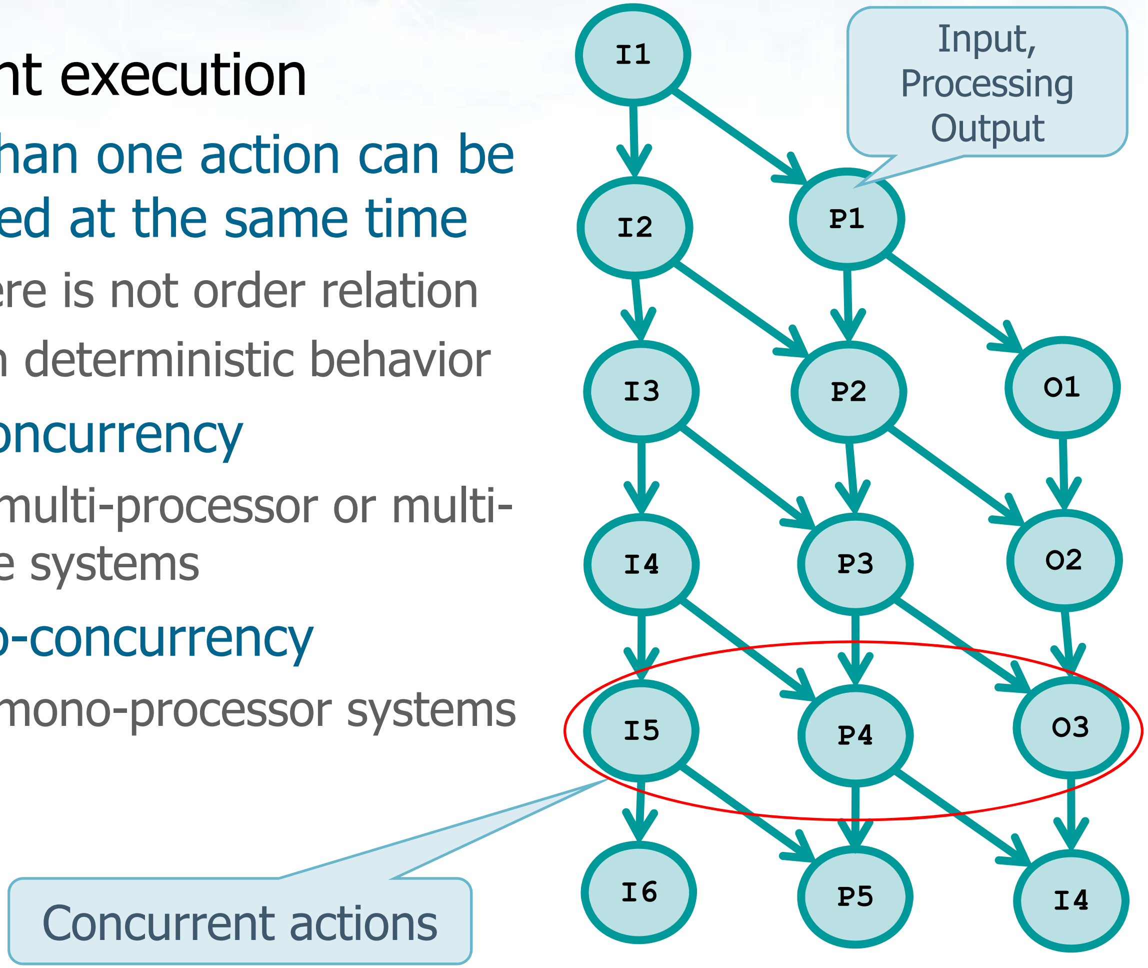
Sequential and concurrent processes

- Sequential execution
  - Actions are executed one **after** the other
    - A new action begins only after the termination of the previous one
  - Deterministic behavior
    - Given the same input, the output produced is always the same, it does not depend on
      - The time of execution
      - The speed of execution
      - The number of active processes on the same system

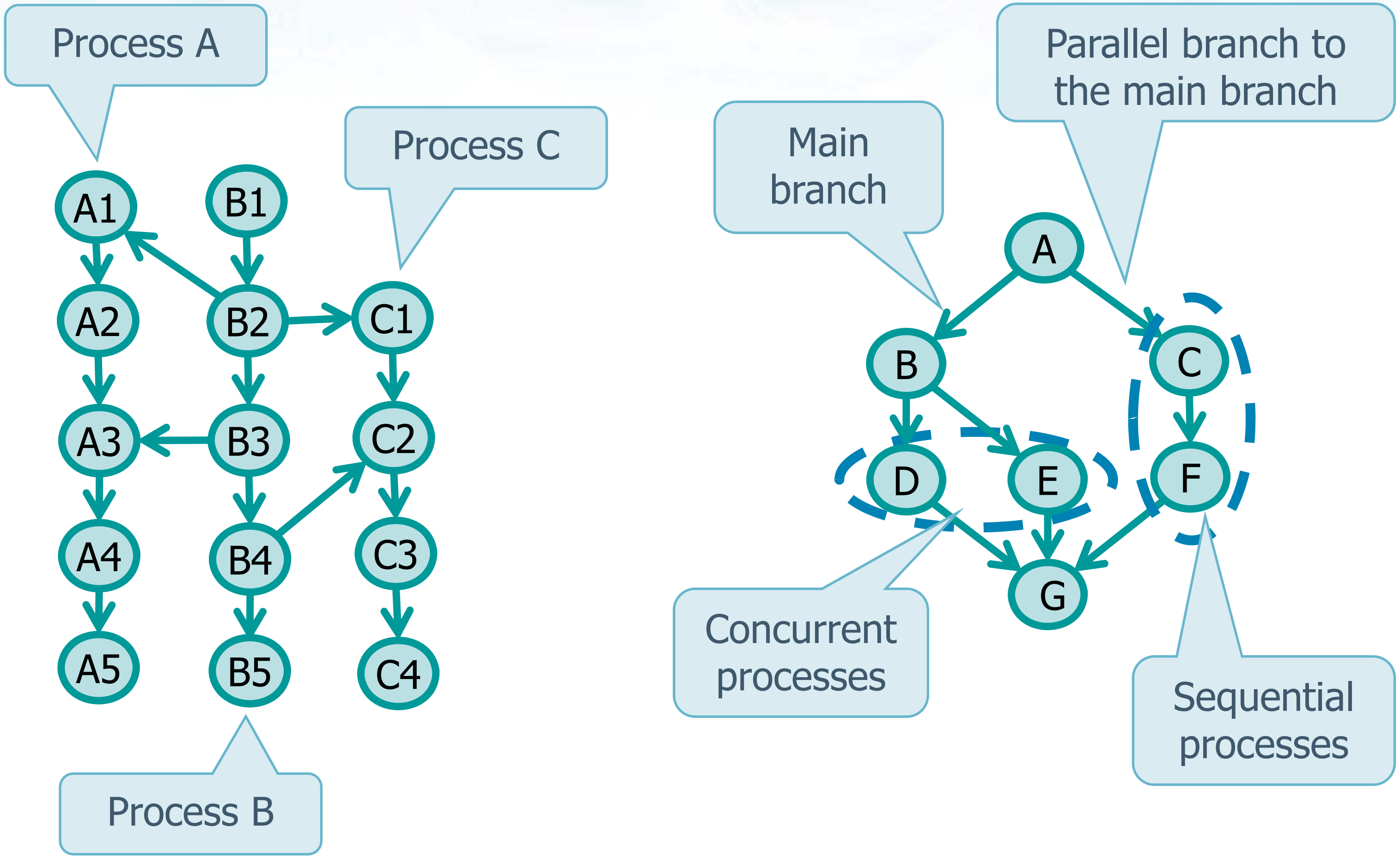


Sequential and concurrent processes

- Concurrent execution
  - More than one action can be executed at the same time
    - There is not order relation
    - Non deterministic behavior
  - Real concurrency
    - on multi-processor or multi-core systems
  - Pseudo-concurrency
    - on mono-processor systems



Precedence graphs



Conditions for concurrency

- When two processes can be executed in concurrency?
- Given a process **P**, let's define
  - R (P)
    - Read set of P: the set of variables read by P
  - W (P)
    - Write set of P: the set of variables modified by P

Conditions for concurrency

- Bernstein conditions [1966]
  - Two processes Pi and Pj can be executed in concurrency iff
    - $R(P_i) \cap W(P_j) = 0$
    - $W(P_i) \cap R(P_j) = 0$
    - $W(P_i) \cap W(P_j) = 0$
  - Otherwise time-dependent errors, or the programmer must impose regions of **Mutual Exclusion** among processes

Example

```
S1. a = x + y
S2. b = z + 1
S3. c = a - b
S4. w = c + 1
```

- The sequential flow of instructions
  - S1→S2→S3→S4

can be optimized because

  - instruction 3 must be executed after 1 and 2
  - instruction 4 must be executed after 3
  - but, instructions 1 and 2 can be executed in parallel

Example

```
S1. a = x + y
S2. b = z + 1
S3. c = a - b
S4. w = c + 1
```

```
R(S1)={x, y}, W(S1)={a}
R(S2)={z},    W(S2)={b}
R(S3)={a, b}, W(S3)={c}
R(S4)={c},    W(S4)={w}
```

```
R (S1) ∩ W (S2) = 0
R (S2) ∩ W (S1) = 0
W (S1) ∩ W (S2) = 0
...
```