Processes - Linux

Stefano Quer – Pietro Laface
Dipartimento di Automatica e Informatica
Politecnico di Torino

Processes

- Several processes are started at bootstrap
  - Automatic
    - Daemon Processes eg admin
    - E-mail applications
    - Various control activities, virus scan and others
    - …
  - On user request
    - Line printer management
    - WEB server
    - …

Started at bootstrap, terminated at shut-down. Execute support activities.

Processes

- Process identity and process control
  - ID & system calls: **`pid`, `getpid`, `getppid`**, etc.

- Process creation
  - The creating process is called the **parent process**, the process created is called the **child process**
  - It is possible to create a **process tree**.
  - System calls: **`fork`, `exec`, `system`**, etc.

- Process synchronization and termination
  - System calls: **`wait`, `waitpid`, `exit`**.

Process identifier

- Every process has a unique identifier
  - PID o Process Identifier
- The PID is a non negative integer
  - Although a PID is unique, UNIX reuses the numbers of terminated processes.
  - PID can be used by concurrent processes for creating unique objects, or temporary filenames
    - For example :

```
sprintf(filename, “file-%d”, getpid());
```

creates a different process-dependent filename

Process identification

- The first process, PID=0, is a system process
  - The **swapper**, which is responsible for memory management and process scheduling
- The second process, PID=1, is **init** a daemon executed at user level, but with super-user privileges
  - Becomes the parent of each orphan process, i.e., of a child of a parent process already terminated

Process identification

```
#include <unistd.h>

pid_t getpid();    // Process ID
pid_t getppid();   // Parent Process ID
```

- Other identifiers related to a process

```
uid_t getuid();    // Get the real user ID
gid_t geteuid();   // Get the effective ID
```

superuser at exec time

- **getppid** returns the identifier of the parent process

```
pid_t getppid();   // Parent Process ID
```

Process creation

- System call `fork()` creates a new **child** process
  - The child is a copy of the parent excluding the Process ID (**PID**) returned by **`fork`**
    - The parent process receives the child PID
      - A process may have more than one child that can identify on the basis of its PID
    - The child process receives the value 0
      - It can identify its parent by means of the system call **`getppid`**
  - **`fork`** is issued once in the parent process, but returns in two different processes, and returns different values to the parent, and to the child.

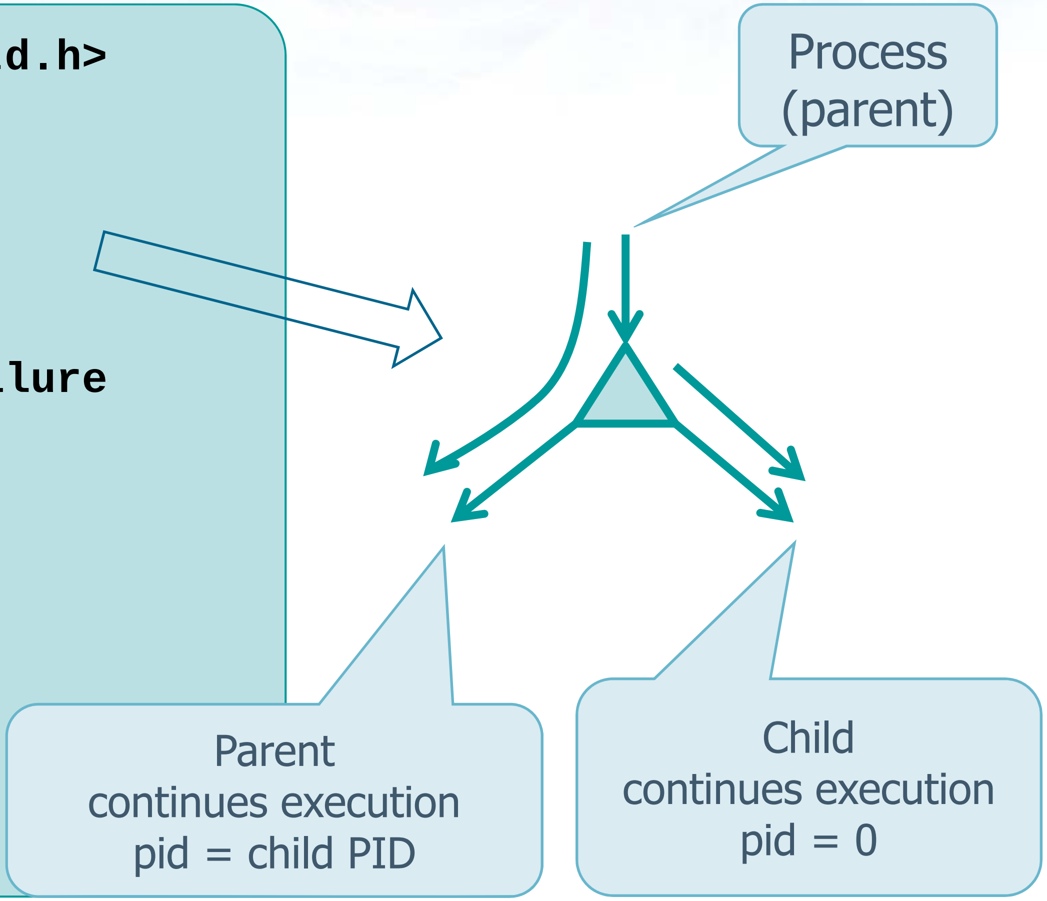
Process creation

```
#include <unistd.h>

pid_t fork (void);
```

- Returned values
  - If **`fork`** returns without error
    - Child PID in the parent process
    - Zero in the child process
  - **`Fork`** returns -1 in case of error
    - Normally because a limit on the number of allowed process has been reached

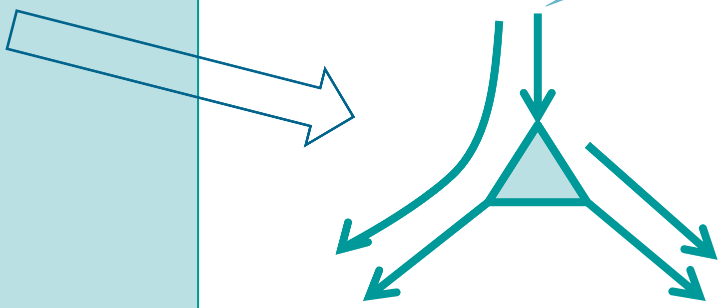
Process creation

```
#include <unistd.h>
...
pid_t pid;
...
pid = fork();
switch (pid) {
  case -1:
    // Fork failure
    ...
    exit (1);
  case 0:
    // Child
    ...
  default:
    // Parent
    ...
}
...
```

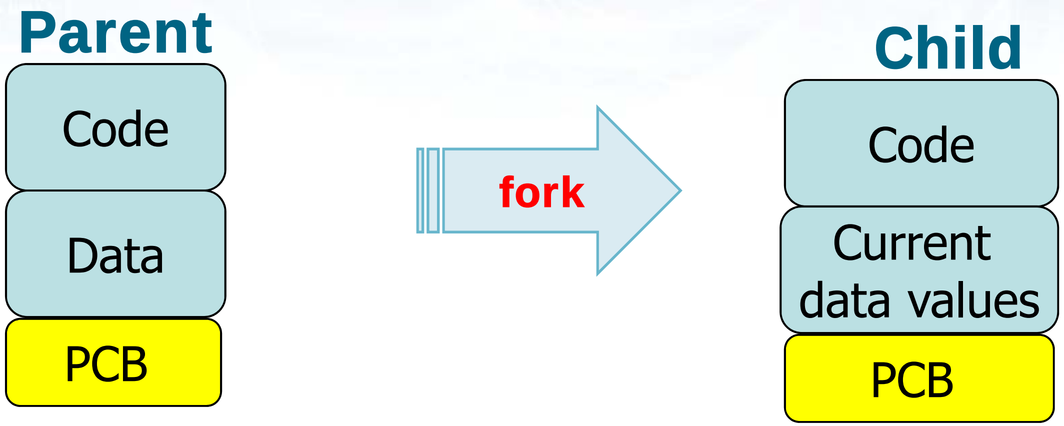


Process creation

```
#include <unistd.h>
...
pid_t pid;
...
pid = fork();
if (pid>0) {
  // Parent
  ...
  } else {
  // Child
  ...
  }
...
}
...
```



Address space



- Parent and child share their code, but they have a different PCB

cp the stack pointer

- They also share the **value of the data at the time of fork.**
- Parent and child may then change the data values independently

Example

- Write a concurrent C program that allows
  - Creating a child process
  - Terminating the parent process before the child process, or viceversa
- Output in both cases the Process Identifier of the terminating process and the Process Identifier of its parent.
  - Who is the parent's parent? bash
  - Who is the child's parent if the parent terminates before the child?

pid 1

Example

```
tC = atoi (argv[1]);
tF = atoi (argv[2]);
```

```
#include <unistd.h>
...
printf ("Main  :                        ");
printf ("PID=%d; My parent PID=%d\n",
  getpid(), getppid());
...
pid = fork();
if (pid == 0){
  sleep (tC);
  printf ("Child : PIDreturned=%d    ", pid);
  printf ("PID=%d; My parent PID=%d\n",
    getpid(), getppid());
} else {
  sleep (tF);
  printf (“Parent: PIDreturned=%d ", pid);
  printf ("PID=%d; My parent PID=%d\n",
    getpid(), getppid());
}
```

Child

Parent

Example

```
> ps
  PID TTY          TIME CMD
 2088 pts/10   00:00:00 bash
 2760 pts/10   00:00:00 ps
```

Shell status
(**ps**: prints process status)

Child waits 2 secs
Parent waits 5 secs

```
> ./u04s01e03-fork 2 5
Main   :                PID=2813; My parent PID=2088
Child  : PIDreturned=0    PID=2814; My parent PID=2813
Parent: PIDreturned=2814 PID=2813; My parent PID=2088
```

zombie

Notice increasing PID values

Child waits 5 secs
parent waits 2 secs

```
> ./u04s01e03-fork 5 2
Main   :                PID=2815; My parent PID=2088
Parent: PIDreturned=2816 PID=2815; My parent PID=2088
> Child : PIDreturned=0    PID=2816; My parent PID=1
```

opha

init process PID

Exercise

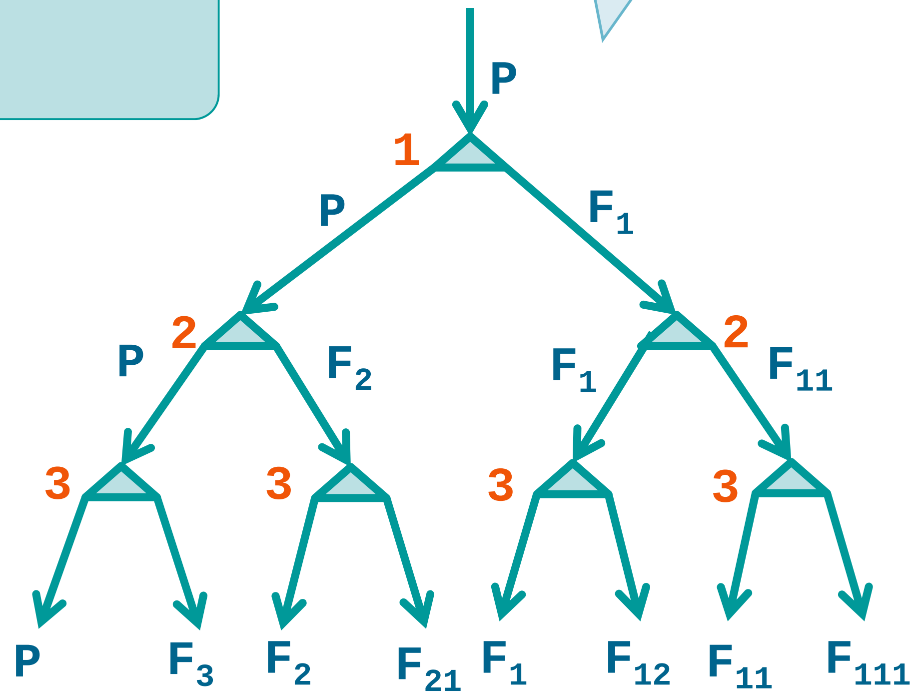
- Given the following program, draw its
  - Control Flow Graph, CFG
  - Process generation graph

```
int main () {
  /* fork a child process */
  fork();

  /* fork another child process */
  fork();

  /* fork a last one */
  fork();
}
```

Solution

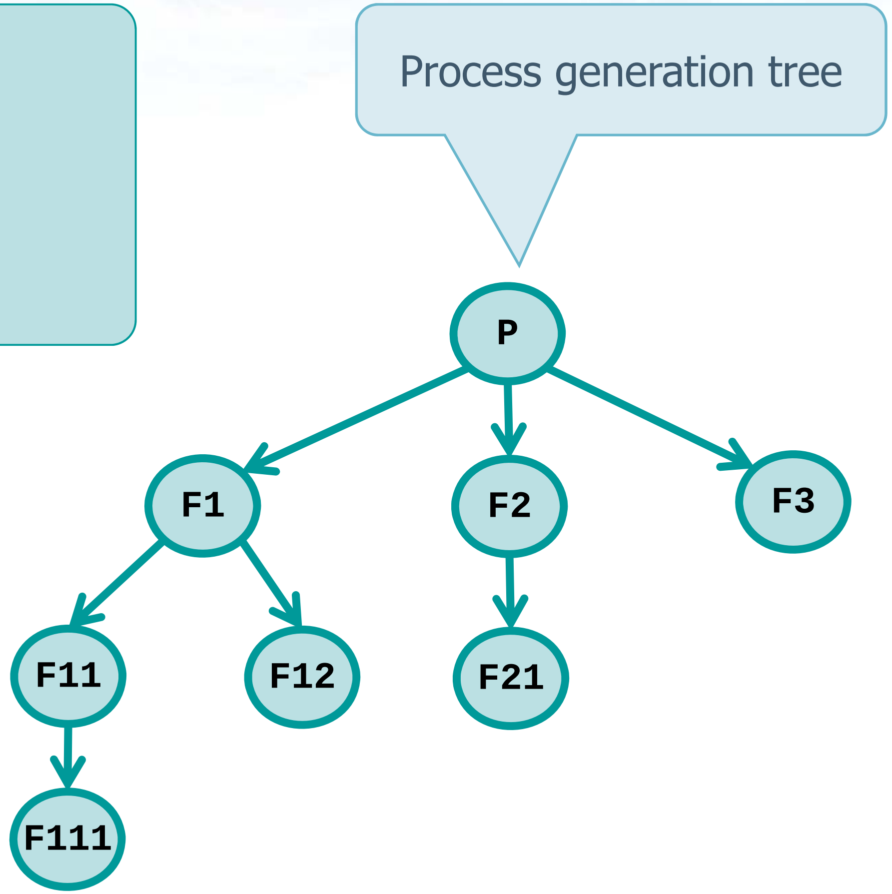
```
int main () {
  fork ();  // 1
  fork ();  // 2
  fork ();  // 3
}
```

Control Flow Graph (CFG)



Solution

```
int main () {
  fork ();  // 1
  fork ();  // 2
  fork ();  // 3
}
```



Exercise

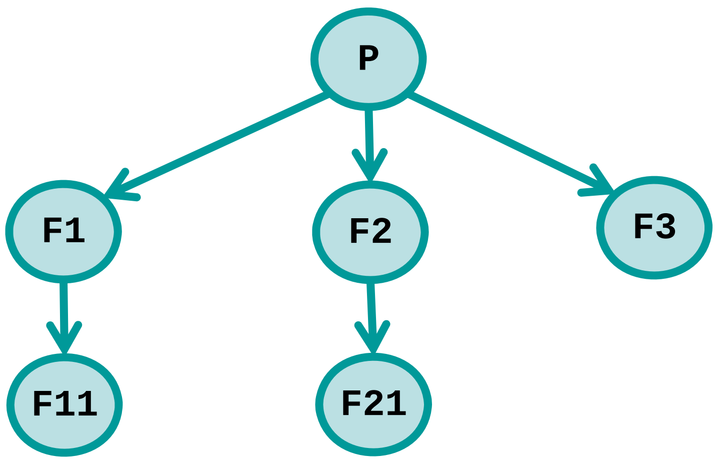
- Given the following program, draw its
  - Control Flow Graph, CFG
  - Process generation graph

```
pid = fork ();  /* call #1 */

if (pid != 0)
  fork ();      /* call #2 */

fork ();        /* call #3 */
```

Solution

```
pid = fork ();  // 1
if (pid != 0)
   fork ();     // 2
fork ();        // 3
```

Process generation tree



Control Flow Graph (CFG)

...

Exercise

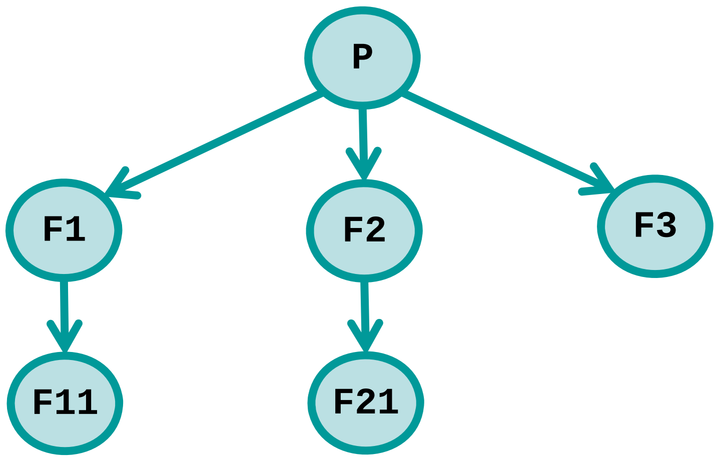
- Given the following program, draw its
  - Control Flow Graph, CFG
  - Process generation graph

```
pid = fork() /* call #1 */

fork();      /* call #2 */

if (pid != 0)
  fork();    /* call #3 */
```

Solution

```
pid = fork()    // 1
fork();   // 2
if (pid != 0)
  fork();       // 3
```

Process generation tree



Control Flow Graph (CFG)

...

Exercise

- Given the following program, draw its
  - Control Flow Graph, CFG
  - Process generation graph

```
#include <stdio.h>

int main () {
  int i:
  for (i=0; i<2; i++) {
    printf("i: %d \n", i);
    if (fork())    /* call #1 */
      fork();    /* call #2 */
  }
}
```

LAB

Solution

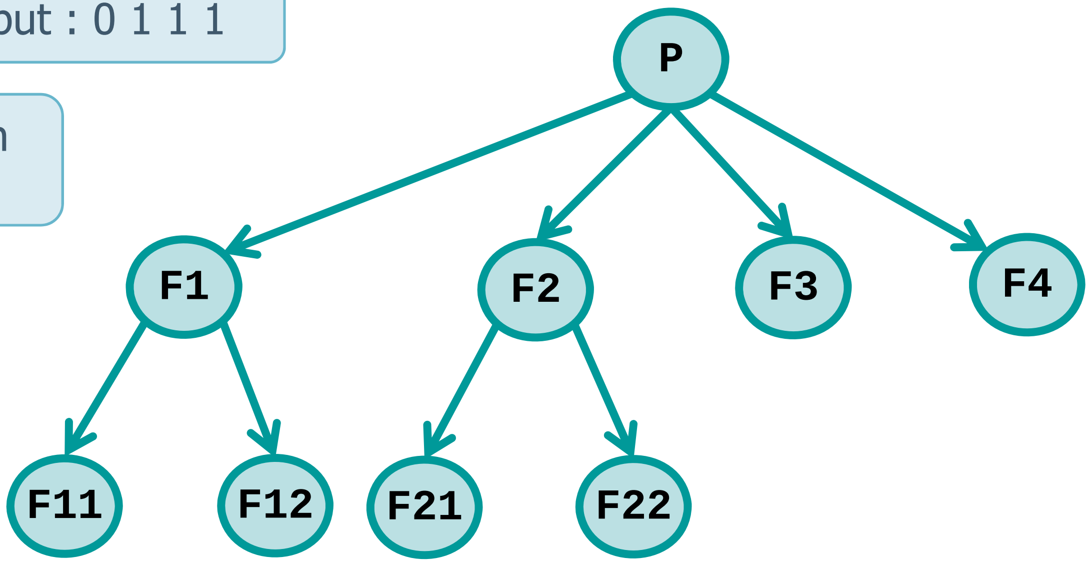
```
for (i=0; i<2; i++) {
  printf("i: %d \n", i);
  if (fork()) // 1
    fork();  // 2
}
```

Possible output : 0 1 1 1

Control Flow Graph (CFG)

...

Process generation tree



Exercise

- Write a concurrent program that, given **n** as its argument, generates **n** children processes
- Each child process outputs its PID and terminates

Solution 1

```
int i, n;

scanf (“%d”, &n);
for (i=0; i<n; i++) {
  fork();
  printf (“Proc %d (PID=%d)\n",
    i, getpid());
}

exit (0);
```

Erroneous solution 1

```
int i, n;

scanf ("%d", &n);
for (i=0; i<n; i++) {
  fork();
  printf ("Proc %d (PID=%d)\n",
    i, getpid());
}

exit (0);
```

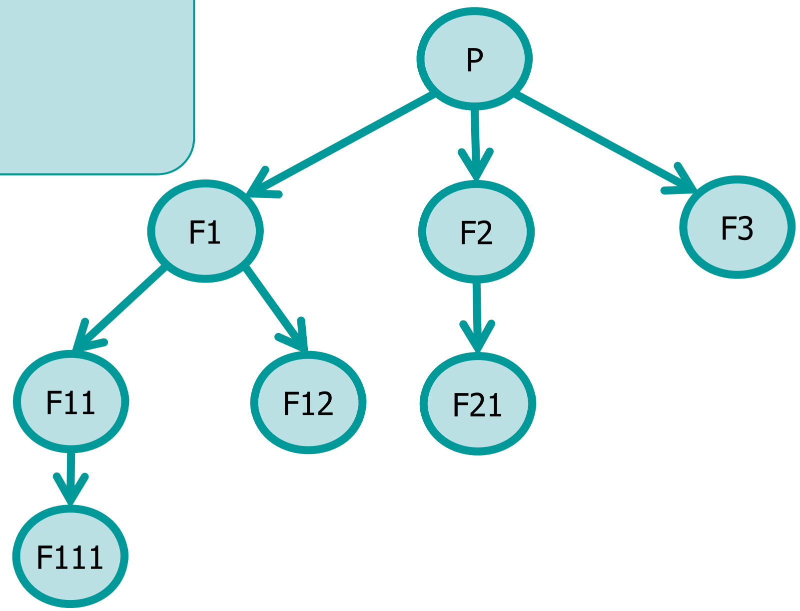
Possible output with n=3

```
Proc 0 (PID=3188)
Proc 1 (PID=3188)
Proc 2 (PID=3188)
Proc 2 (PID=3191)
Proc 1 (PID=3190)
Proc 2 (PID=3190)
Proc 0 (PID=3189)
Proc 1 (PID=3189)
Proc 2 (PID=3189)
Proc 2 (PID=3192)
Proc 2 (PID=3194)
Proc 1 (PID=3193)
Proc 2 (PID=3193)
Proc 2 (PID=3195)
```

Erroneous solution 2

```
int i, n;

scanf (“%d”, &n);
for (i=0; i<n; i++) {
  if (fork() > 0);
    printf (“Proc %d (PID=%d)\n",
                 i, getpid());
}

exit (0);
```

Process tree with n=3



Generates 7 children processes

子进程进入下一个for

Solution 3

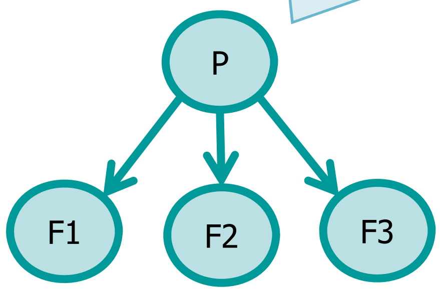
```
int i, n;
…
scanf (“%d”, &n);
printf (“Start PID=%d\n",
  getpid());
for(i=0; i<n; i++) {
  if (fork() == 0) {
    printf (“Proc %d (PID=%d)\n",
      i, getpid());
    break;
  }
}
printf ("End PID=%d (PPID=%d)\n",
   getpid(), getppid());

exit(0);
```

Solution 3

```
int i, n;
…
scanf ("%d", &n);
printf ("Start PID=%d\n",
  getpid());
for(i=0; i<K; i++) {
  if (fork() == 0) {
    printf ("Proc %d (PID=%d)\n",
      i, getpid());
    break;
  }
}
printf ("End PID=%d (PPID=%d)\n",
   getpid(), getppid());

exit(0);
```

```
> ps
PID TTY          TIME CMD
088 pts/10    00:00:00 bash

> ./u04s01e06-fork
Star PID=3225
End PID=3225 (PPID=2088)
Proc 2 (PID=3228)
End PID=3228 (PPID=1314)
Proc 1 (PID=3227)
End PID=3227 (PPID=1314)
Proc 0 (PID=3226)
End PID=3226 (PPID=1314)
```

Process tree with n=3



把子进程break掉

公用一个父进程

Resources

- The child process is a new entry in the Process Table
- The process **resources** can be
  - Completely shared among parent and children processes
    - Same address space
  - Partially shared
    - Address spaces partially overlapped
  - Non shared
    - Separate address spaces

Resources

- In UNIX/Linux parent and child **share**
  - The source code
  - UID, GID, etc.
  - The open file descriptors (File Description Table)
    - In particular, **`stdin`**, **`stdout`**, and **`stderr`**
      - Concurrent I/O operation implies producing interlaced I/O
  - The root and the working directory
  - System resources and their utilization limits
  - Signal Table
  - Etc.

Resources

- In UNIX/Linux parent and child have **different**
  - return fork value
  - PID
    - The parent keeps its PID
    - The child gets a new PID
  - Data, heap and stack space
    - The **initial value** of the variables is inherited, but the spaces are completely separated
    - **copy-on-write** technique is used by the OS
      - New memory is allocated only when one of the processes changes the content of a variable

Example

```
char c, str[10];

c = 'X';
if (fork()) {
  // parent (!=0)
  c = 'F';
  strcpy (str, “parent");
  sleep (5);
} else {
  // child (==0)
  strcpy (str, "child");
}

fprintf(stdout, "PID=%d; PPID=%d; c=%c; str=%s\n",
  getpid(), getppid(), c, str);
```

子进程在fork时copy char str【】

Output

```
PID=2777; PPID=2776; c=X; str=child
PID=2776; PPID=2446; c=F; str=parent
```

char str 都被分离

Process termination

- Five standard methods for process termination
  - **`return`** from main main return 0;because bash 0 means true
  - **`exit`** system call for termination in function
  - **`_exit`** or **`_Exit`**
    - Synonyms defined in ISO C or POSIX
    - Similar effects of **`exit`**, but different management of stdio flushing etc.
  - **`return`** from main of the last process thread
  - **`pthread_exit`** from the last process thread

Process termination

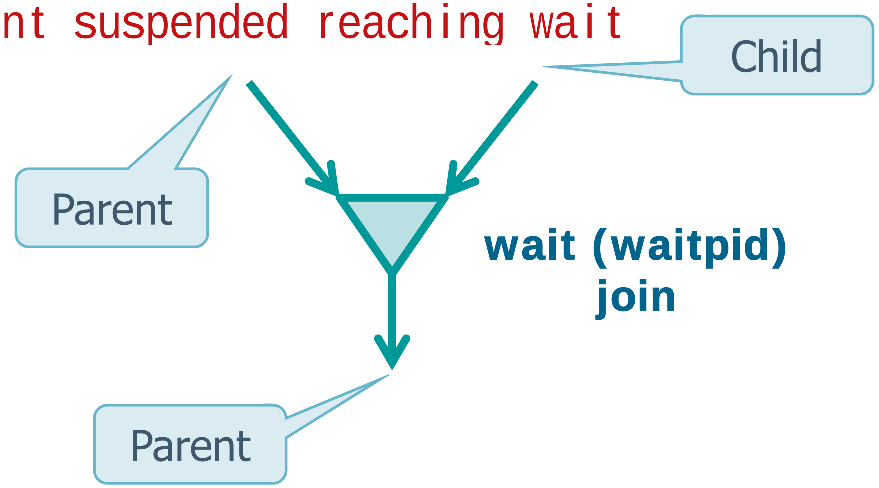
- Three not-normal method for process termination
  - If a termination signal, or a signal not caught is received
  - **`abort`**
    - Generates the signal **`SIGABORT`**
  - If the last thread of a process is cancelled

System call wait () and waitpid ()

- When a process terminates (normally or not) one of its child is terminated
  - The kernel sends a signal (**SIGCHLD**) to its parent
  - For the parent this is an asynchronous event
  - The parent process may
    - Manage the child termination (and/or the signal)
    - Ignore the event (default)

System call wait () and waitpid ()

- A parent process can manage child termination
  - By means of system calls
    - **wait** parent suspended reaching wait
    - **waitpid**



  - Using a signal handler for signal **SIGCHLD**
    - This approach will be introduced in the section devoted to signals

System call wait ()

```
#include <sys/wait.h>

pid_t wait (int *statLoc);  int *status
```

- Blocks the calling process if all its children are running (none is already terminated)
  - wait will return as soon as one of its children terminates
- Returns an error if the calling process has not children.

System call wait ()

```
#include <sys/wait.h>

pid_t wait (int *statLoc);
```

the exit status of a child

wait 返回的另一个参数，子进程的状态信息

wait(0)

- Returns the **exit status** of a child
  - If a child process terminates, and the parent process does not call wait, the child exit status remains pending in the kernel Process Control Block

System call wait ()

```
#include <sys/wait.h>

pid_t wait (int *statLoc);
```

- The **statLoc** parameter
  - Is an integer pointer
    - If not NULL collects the exit value of the child
  - The status information are
    - Implementation dependent
    - Recovered using macros in **<sys/wait.h>** (**WIFEXITED**, **WIFSIGNALED**, etc.)

Exit status of the child process

System call wait ()

```
#include <sys/wait.h>

pid_t wait (int *statLoc);
```

- Returns
  - The PID of a terminated child

Example

```
...
pid_t pid, childPid;
int statVal;
...
pid = fork();
switch (pid) {
  case -1:
    printf (“Fork failed\n”); exit(1);
  case 0:
    // Child
    sleep (10);
  default:
    // Parent
    sleep (05);
}
...
```

Example

```
...
if (pid != 0) {
  // Padre
  childPid = wait (&statVal);    blocking for 5 sec
  printf("Child terminated: PID = %d\n", childPid);
  if (WIFEXITED(statVal))                           child 正常返回1
    // WIFEXITED: True if correctly terminated
    // WEXITSTATUS: Takes the 8 returned LSBs (exit)
    printf ("Exit value: %d\n",
      WEXITSTATUS (statVal));           child 的exit值换算
    else
      printf ("Abnormal termination\n");
  }
  exit(code);
}
...
```

Zombie processes

- A child process terminated, whose parent is running, but has not et executed **wait** is in the **zombie** state
  - The data segment of the process remains in the process table because the parent could need the child exit status

    rubbish
  - The child entry is removed only when the parent executes **wait**
    - Many zombie processes may remain in the system if one or more parents do not execute their wait system call.

Zombie processes

- It the parent process terminates (without executing **wait**, and the child is still running, the latter is inherited by **init** the process (PID=1).

  The child does not become **zombie** because the system knows that no one is waiting for its exit status.

System call waitpid ( )

- If a parent needs to wait a specific child it is better to use **waitpid**, which
  - suspends execution of the calling process until a child, specified by *pid* argument, has changed state. By default, **waitpid**() waits only for terminated children.

System call waitpid ( )

```
#include <sys/wait.h>

pid_t waitpid (
  pid_t pid,
  int *statLoc,
  int options);
```

- The parameter **pid** allows waiting for
  - Any child (waitpid==wait) (pid = -1)
  - The child whose PID=pid if >0 (pid > 0) typically
  - Any child whose GID is equal to that of the calling process (pid = 0)
  - Any child whose GID=abs(pid) (pid < -1)

System call waitpid ( )

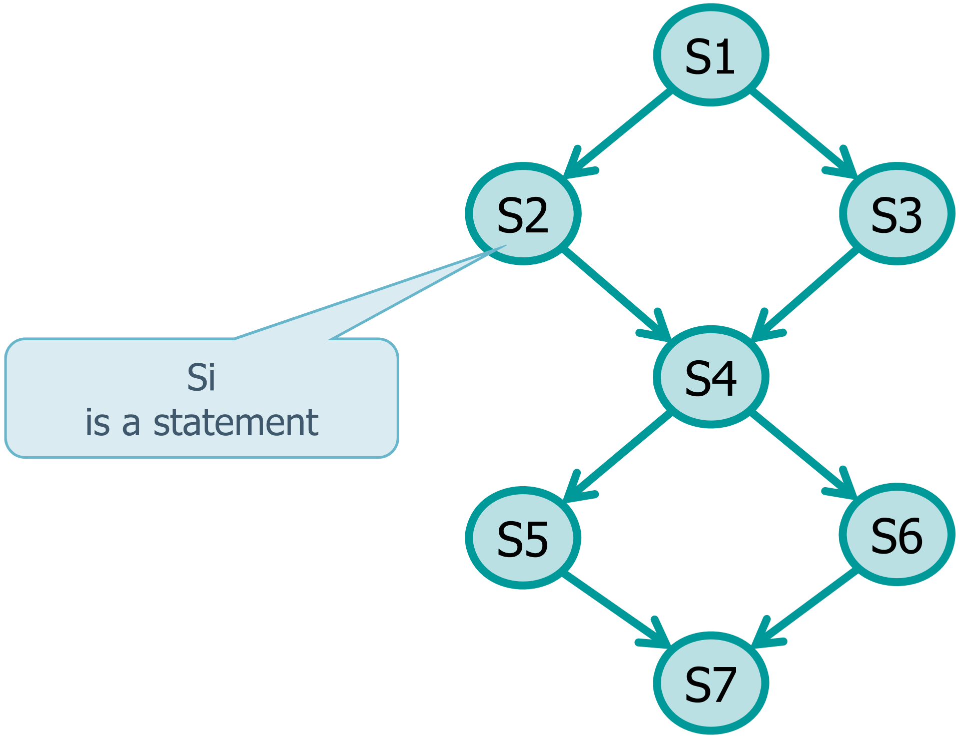
```
#include <sys/wait.h>

pid_t waitpid (
  pid_t pid,
  int *statLoc,
  int options);
```

- The **options** parameter allow additional controls
  - Default is 0, or is a bitwise OR of constants
    - **WNOHANG**, if the child specified by PID is running, the caller does not bock (not blocking version of **wait**)
    - **WCONTINUED**, etc.

Exercise

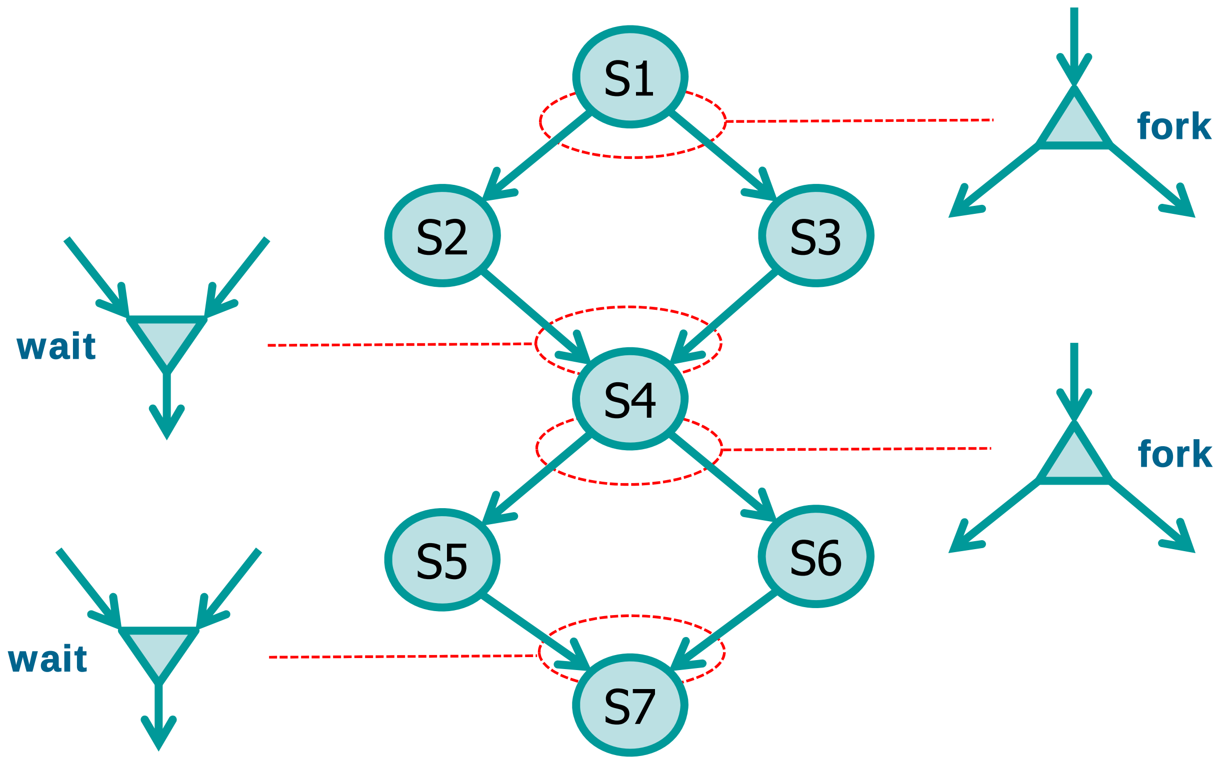
procedence graph

- Implement this Control Flow Graph (CFG) by means of the system calls **fork** and **wait**



Exercise

❖ Implement this Control Flow Graph (CFG) by means of the system calls **fork** and **wait**



Solution

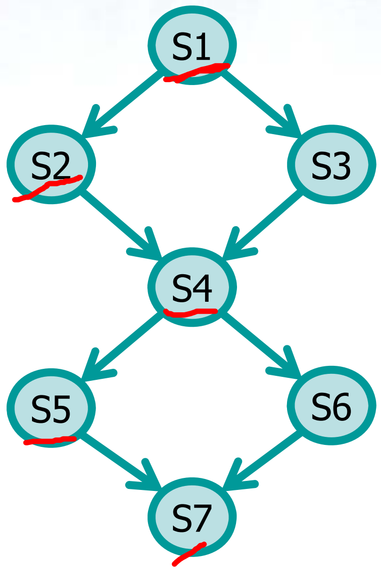
```
int main() {
  pid_t pid;
  printf ("S1\n");
  pid = fork();
  if (pid == 0) {
    //sleep (2);
    printf ("S3\n");
    exit (0);
  } else {
    //sleep (2);
    printf ("S2\n");
    wait ((int *) 0);
  }
```

Debug ...

Child

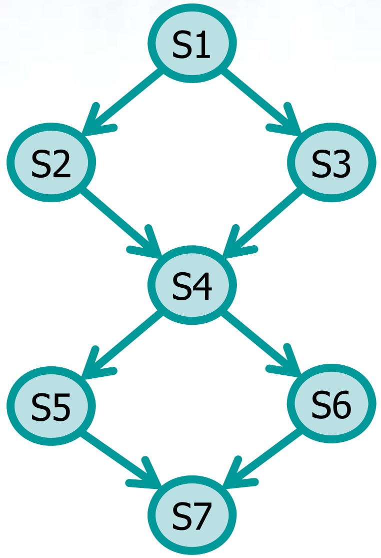
Parent

Termination state ignored



Solution

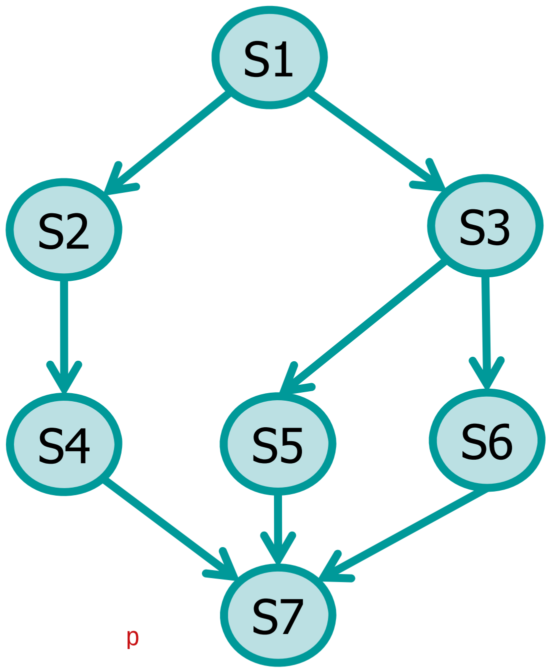
```
  printf ("S4\n");
  pid = fork();
  if (pid == 0) {
    //sleep (2);
    printf ("S6\n");
    exit (0);
  } else {
    //sleep (2);
    printf ("S5\n");
    wait ((int *) 0);
  }
  printf ("S7\n");
  return (0);
}
```



Exercise

- Implement this Control Flow Graph (CFG) by means of the system calls **fork** and **wait**

p

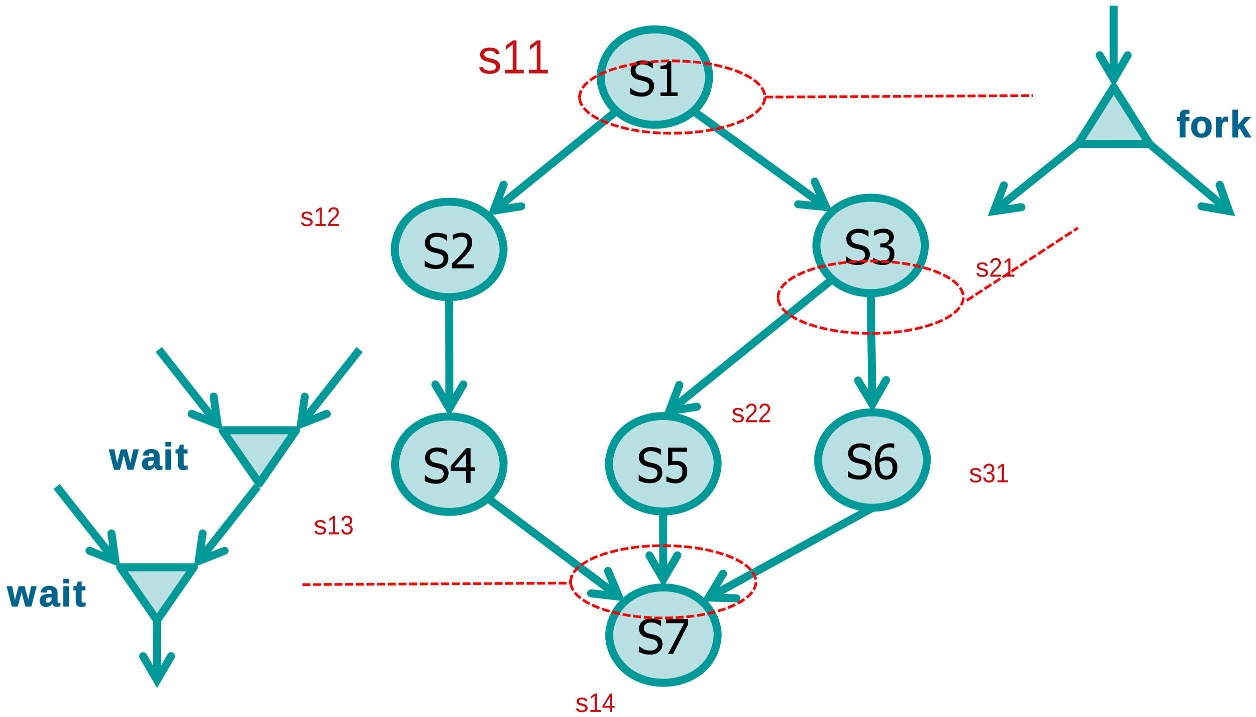


p

p

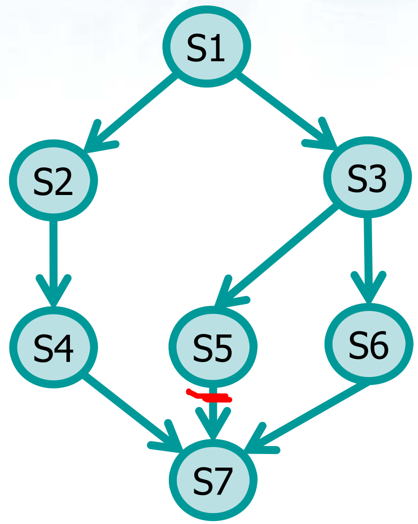
Exercise

- Implement this Control Flow Graph (CFG) by means of the system calls **fork** and **wait**



Solution

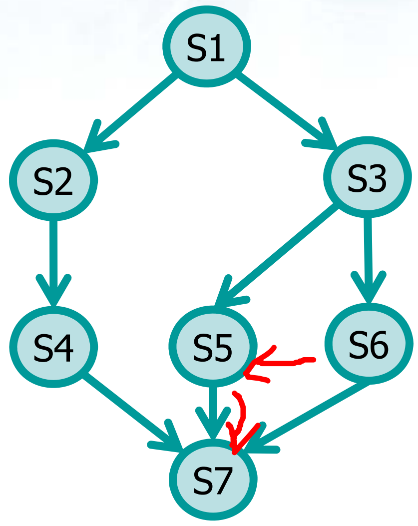
```
int main () {
  pid_t pid;
  printf (“S1\n“);
  if ( (pid = fork())==-1 )
    err_sys( "can't fork" );
  if ( pid == 0 ){
    P356();
  } else {
    printf ("S2\n");
    printf ("S4\n");
    while (wait((int *)0)!= pid);
    printf ("S7\n");
    exit (0);
  }
  return (1);
}
```



wait until recieved

Solution

```
P356() {
  pid_t pid;
  printf ("S3\n");
  if ( ( pid = fork() ) == -1 )
    err_sys( "can't fork" );
  if (pid > 0 ){
    printf ("S5\n");
    while (wait((int *)0)!=pid );
  } else {
    printf ("S6\n”);
    exit (0);
  }
  exit (0);
}
```



Exercise

- Write a program that
  - Takes as argument an integer value **n**
  - Allocates dynamically an integer vector of dimension **n**
  - Fills the vector with values reads from the terminal
  - Displays the vector content, from the last to the first element, using **n-1** processes, each displaying a single element of the vector

  - Hint
    - Synchronize the processes by means of **wait** system calls

Solution

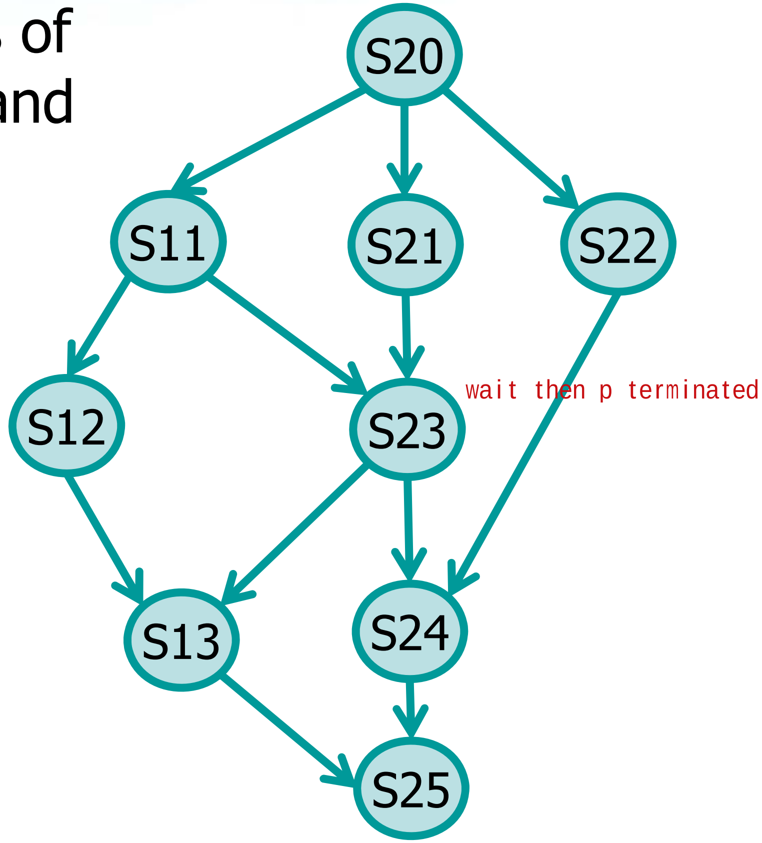
```
int main(int argc, char *argv[]) {
  int i, n, *vet;
  int retValue;
  pid_t pid;
  n = atoi (argv[1]);
  vet = (int *) malloc (n * sizeof (int));
  if (vet==NULL) {
    fprintf (stderr, "Allocation Error.\n");
    exit (1);
  }
  fprintf (stdout, "Input:\n");
  for (i=0; i<n; i++) {
    fprintf (stdout, "vet[%d]:", i);
    scanf ("%d", &vet[i]);
  }
```

Solution

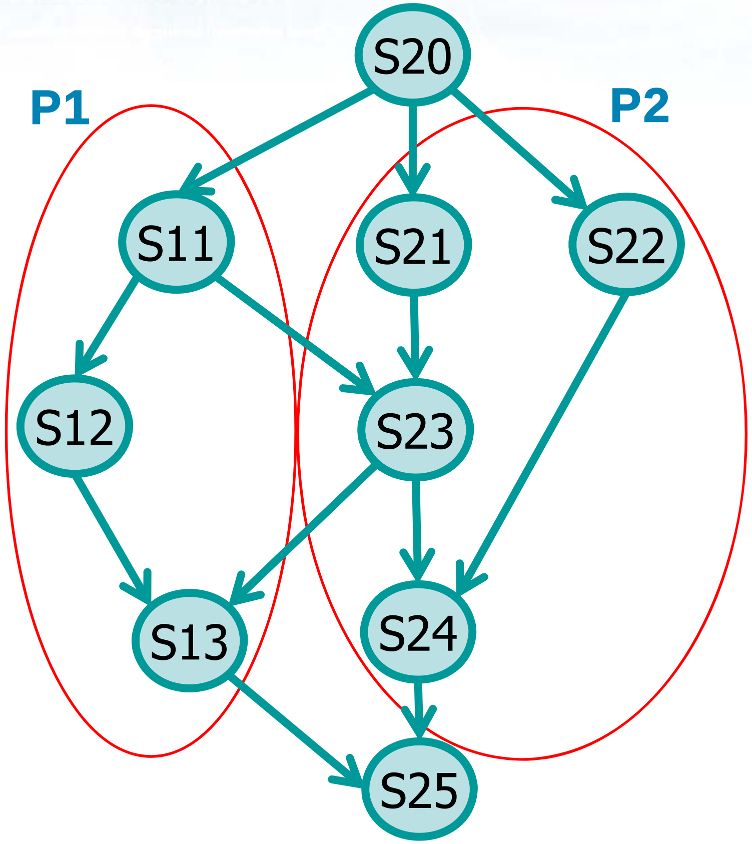
```
  fprintf (stdout, "Output:\n");
  for (i=0; i<n-1; i++) {
    pid = fork();
    if (pid>0) {
      pid = wait (&retValue);
      break;
    }
    fprintf (stdout, "Run PID=%d\n", getpid());
  }

  fprintf (stdout, "vet[%d]:%d - ", i, vet[i]);
  fprintf (stdout, "End PID=%d\n", getpid());

  exit (0);
}
```

Exercise

- Implement this Control Flow Graph (CFG) by means of the system calls **fork** and **wait**

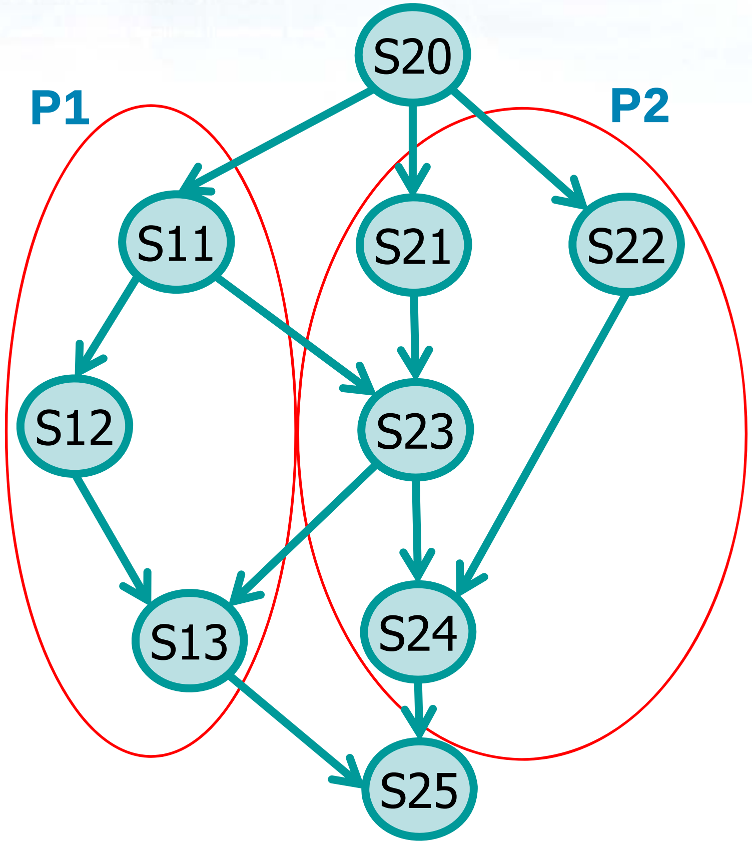


Solution



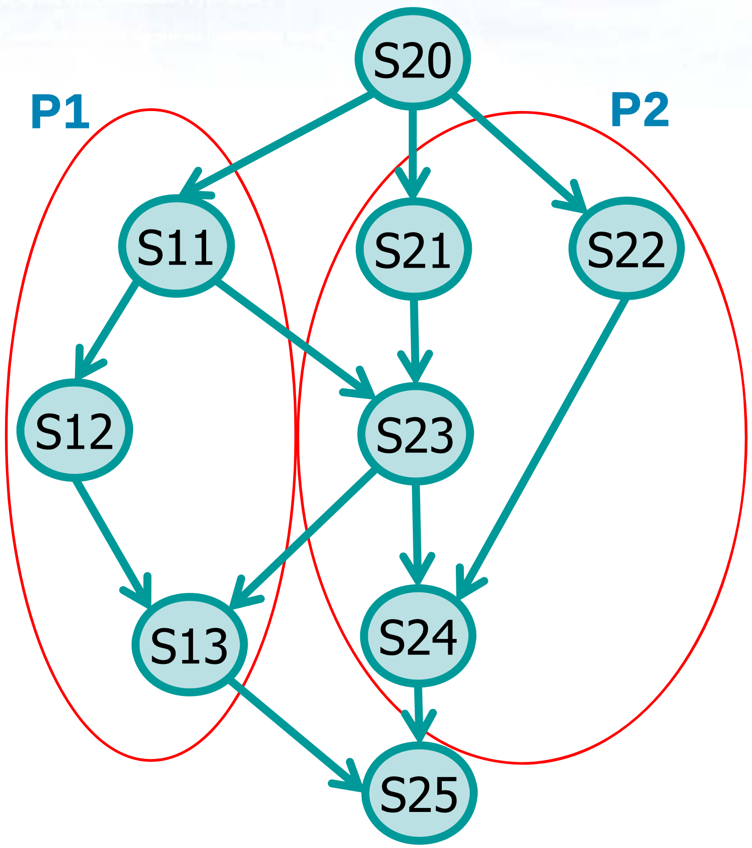

```
main () {
  S20 ();
  pid = fork ();
  if (pid>0) {
    P1 ();
    wait ((int *)0);
  } else {
    P2 ();
  }
  S25 ();
  return;
}
```

Solution




```
P1() {
  S11 ();
  pid = fork ();
  if (pid>0) {
    S12 ();
    wait((int *)0);
  } else {
    ??? To P2 ???;
    exit(0);
  }
  S13 ();
}
```

Solution

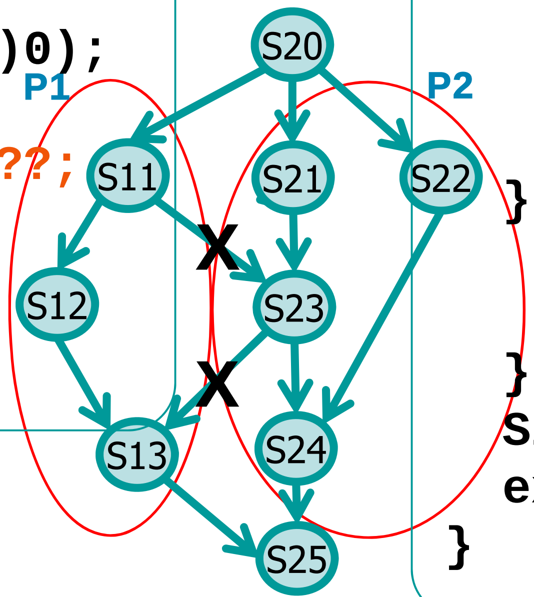



```
P2() {
  pid = fork ();
  if (pid>0) {
    S21 ();
    ??? From S1 ???;
    S23 ();
    wait((int *)0);
  } else {
    S22 ();
    exit(0);
  }
  S24 ();
  exit (0);
}
```

Solution

Unfeasible graph

```
P1() {
  S11 ();
  pid = fork ();
  if (pid>0) {
    S12 ();
    wait((int *)0);
  } else {
    ??? To P2 ???;
    exit(0);
  }
  S13 ();
}
```




```
P2() {
  pid = fork ();
  if (pid>0) {
    S21 ();
    ??? From S1 ???;
    S23 ();
    wait((int *)0);
  } else {
    S22 ();
    exit(0);
  }
  S24 ();
  exit (0);
}
```