



Sistemas de Operação / Fundamentos de Sistemas Operativos

Processes in Unix/Linux

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Outline

- ① Program vs. Process
- ② Process creation
- ③ The `fork` system call
- ④ A `fork` illustration program
- ⑤ Launching a program: the `fork` and `exec` system calls
- ⑥ Execution of a C/C++ program
- ⑦ Address space of a Unix program

Process

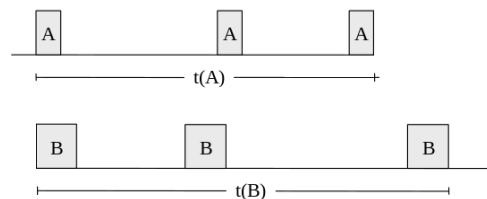
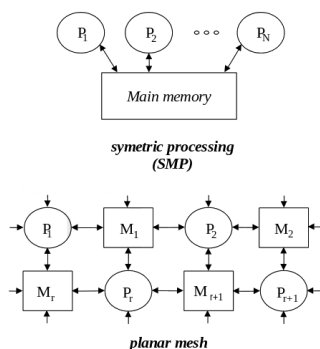
Program vs. process

- **Program** – set of instructions describing how a task is performed by a computer
 - In order for the task to be actually performed, the corresponding program has to be executed
- **Process** – an entity that represents a computer program being executed
 - it represents an activity of some kind
 - it is characterized by:
 - **addressing space** – code and data (actual values of the different variables) of the associated program
 - input and output data (data that are being transferred from input devices and to output devices)
 - process specific variables (PID, PPID, ...)
 - actual values of the processor internal registers
 - state of execution
- Different processes can be running the same program
- In general, there are more processes than processors – **multiprogramming**

Multiprocessing vs. Multiprogramming

Multiprocessing

- **Parallelism** – ability of a computational system to simultaneously run two or more programs
 - more than one processor is required (one for each simultaneous execution)
- The operating systems of such computational systems supports **multiprocessing**

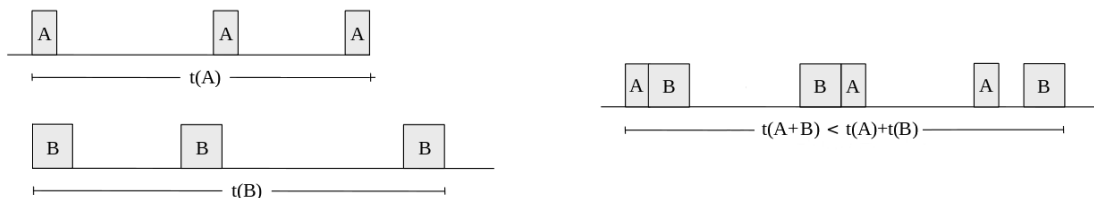


- Programs A and B are executing parallelly in at least two-processors computational system

Multiprocessing vs. Multiprogramming

Multiprogramming

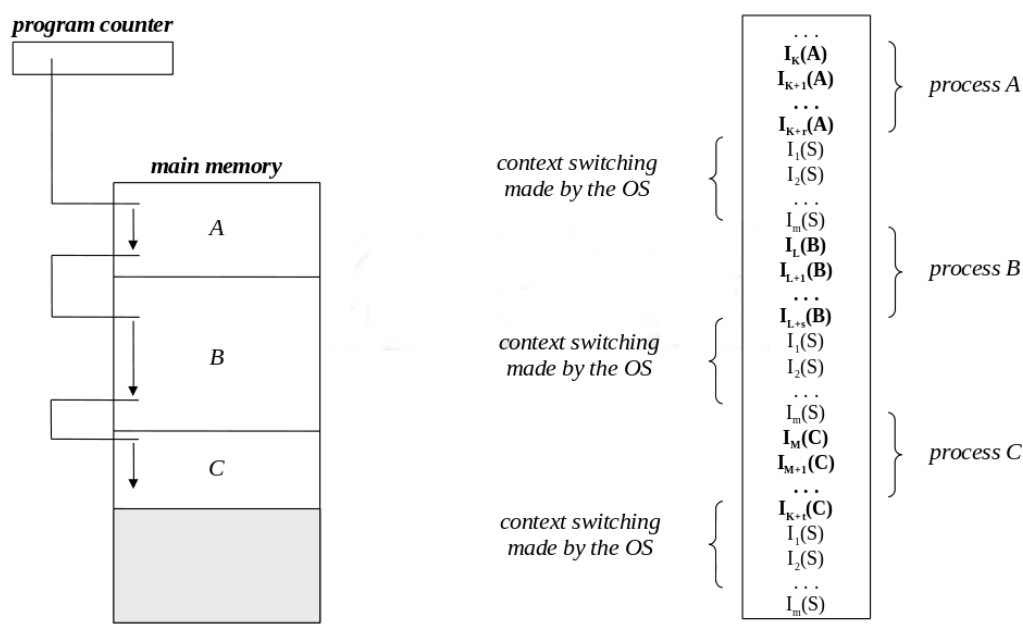
- **Concurrency** – illusion created by a computational system of apparently being able to simultaneously run more programs than the number of existing processors
- The existing processor(s) must be assigned to the different programs in a time multiplexed way
- The operating systems of such computational systems supports **multiprogramming**



- Programs A and B are executing concurrently in a single processor computational system

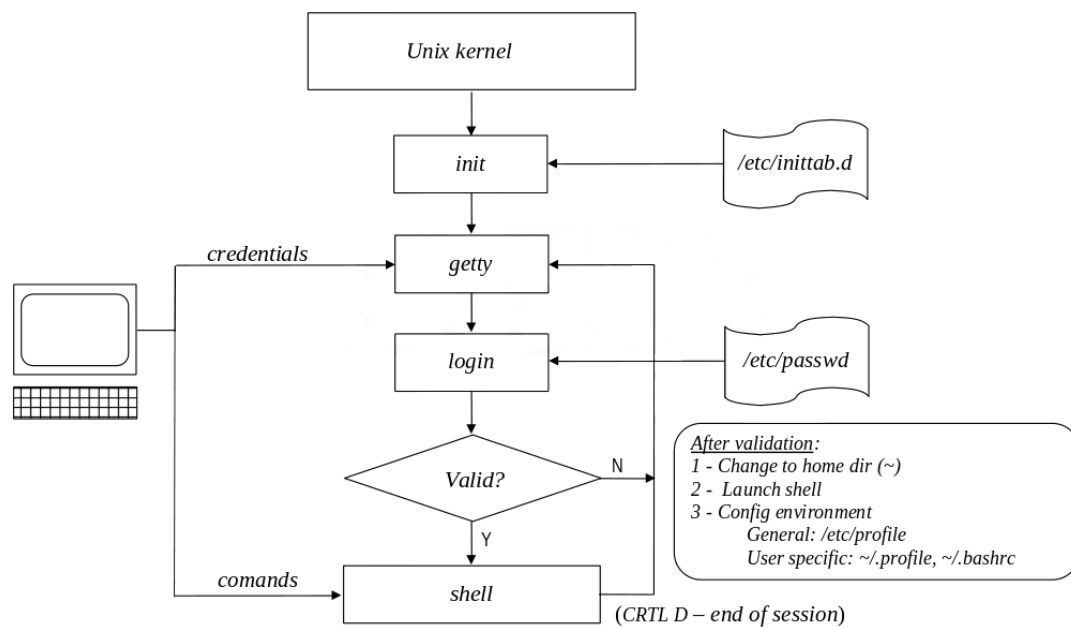
Process

Execution in a multiprogrammed environment



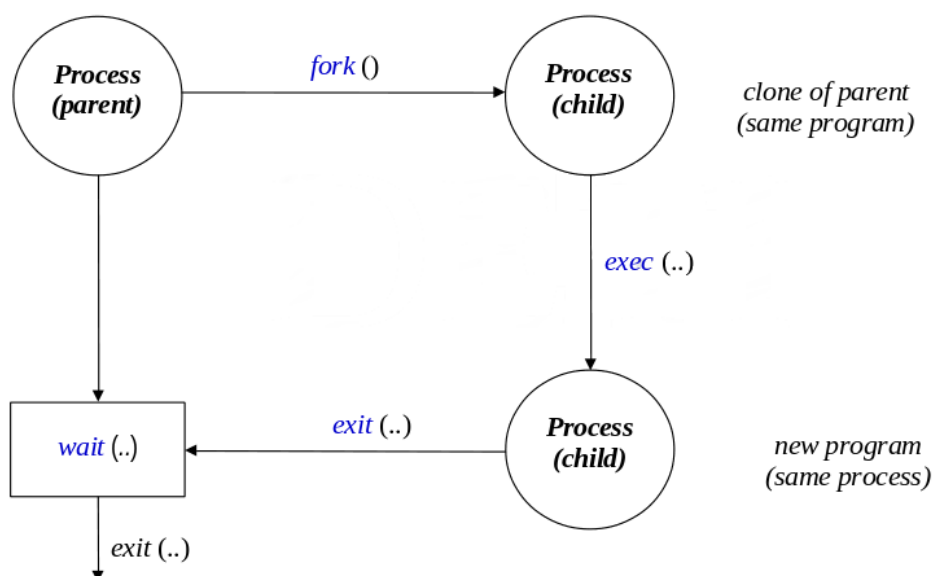
Processes in Unix

Traditional login



Processes in Unix

Creation by cloning



Processes in Unix

Process creation: `fork0`

```
#include <stdio.h>
#include <stdlib.h>
#include <sys/types.h>
#include <unistd.h>

int main(void)
{
    printf("Hello , World!\n");
    fork();
    printf("Hello , World! Again\n");
    return EXIT_SUCCESS;
}
```

- The `fork` clones the executing process, creating a replica of it
- The address spaces of the two processes are equal
 - actually, just after the fork, they are the same
 - typically, a `copy on write` approach is followed
- The states of execution are the same
 - including the value of the program counter

Processes in Unix

Process creation: `fork1`

```
#include <stdio.h>
#include <stdlib.h>
#include <sys/types.h>
#include <unistd.h>

int main(void)
{
    printf("Before the fork:\n");
    printf("  PID = %d, PPID = %d.\n",
        getpid(), getppid());

    fork();

    printf("After the fork:\n");
    printf("  PID = %d, PPID = %d.\n",
        "  Am I the parent or the child?"
        "  How can I know it?\n",
        getpid(), getppid());

    return EXIT_SUCCESS;
}
```

- The `fork` clones the executing process, creating a replica of it
- The address spaces of the two processes are equal
 - actually, just after the fork, they are the same
 - typically, a `copy on write` approach is followed
- The states of execution are the same
 - including the value of the program counter
- Some process variables are different (PID, PPID, ...)
- What can we do with this?

Processes in Unix

Process creation: `fork2` and `fork3`

```
#include <stdio.h>
#include <stdlib.h>
#include <sys/types.h>
#include <unistd.h>

int main(void)
{
    printf("Before the fork:\n");
    printf("  PID = %d, PPID = %d.\n",
        getpid(), getppid());

    int ret = fork();

    printf("After the fork:\n");
    printf("  PID = %d, PPID = %d.\n",
        getpid(), getppid());
    printf("  ret = %d\n", ret);

    return EXIT_SUCCESS;
}
```

- The value returned by the fork is different in parent and child processes
 - in the parent, it is the PID of the child
 - in the child, it is always 0

Processes in Unix

Process creation: `fork2` and `fork3`

```
#include <stdio.h>
#include <stdlib.h>
#include <sys/types.h>
#include <unistd.h>

int main(void)
{
    printf("Before the fork:\n");
    printf("  PID = %d, PPID = %d.\n",
        getpid(), getppid());

    int ret = fork();

    if (ret == 0)
    {
        printf("I'm the child:\n");
        printf("  PID = %d, PPID = %d\n",
            getpid(), getppid());
    }
    else
    {
        printf("I'm the parent:\n");
        printf("  PID = %d, PPID = %d\n",
            getpid(), getppid());
    }

    return EXIT_SUCCESS;
}
```

- The value returned by the fork is different in parent and child processes
 - in the parent, it is the PID of the child
 - in the child, it is always 0
- This return value can be used as a boolean variable
 - so we can distinguish the code running on child and parent
- Still, what can we do with it?

Processes in Unix

Process creation: `fork3`

```
#include <stdio.h>
#include <stdlib.h>
#include <sys/types.h>
#include <unistd.h>

int main(void)
{
    printf("Before the fork:\n");
    printf("  PID = %d, PPID = %d.\n",
        getpid(), getppid());

    int ret = fork();

    if (ret == 0)
    {
        printf("I'm the child:\n");
        printf("  PID = %d, PPID = %d\n",
            getpid(), getppid());
    }
    else
    {
        printf("I'm the parent:\n");
        printf("  PID = %d, PPID = %d\n",
            getpid(), getppid());
    }

    return EXIT_SUCCESS;
}
```

- In general, used alone, the `fork` is of little interest
- In general, we want to run a different program in the child
 - `exec` system call
 - there are different versions of `exec`
- Sometimes, we want the parent to wait for the conclusion of the program running in the child
 - `wait` system call
- *In this code, we are assuming the `fork` doesn't fail*
 - in case of an error, it returns `-1`

Processes in Unix

`fork` illustration program

- What are the possible outputs of the execution of this program?

```
int main(int argc, char *argv[])
{
    uint32_t t = 1000;

    printf("1"); fflush(stdout);
    int pid = fork();
    switch (pid)
    {
        case 0:
            bwDelay(t);
            printf("2"); fflush(stdout);
            bwDelay(t);
            printf("3"); fflush(stdout);
            break;
        default:
            bwDelay(t);
            printf("4"); fflush(stdout);
            bwDelay(t);
            printf("5"); fflush(stdout);
            wait(NULL);
            printf("\n");
    }
    return EXIT_SUCCESS;
}
```

Processes in Unix

fork illustration program

parent process

```
int main(int argc, char *argv[])
{
    uint32_t t = 1000;

    printf("1"); fflush(stdout);
    int pid = fork();
    switch (pid)
    {
        case 0:
            bwDelay(t);
            printf("2"); fflush(stdout);
            bwDelay(t);
            printf("3"); fflush(stdout);
            break;
        default:
            bwDelay(t);
            printf("4"); fflush(stdout);
            bwDelay(t);
            printf("5"); fflush(stdout);
            wait(NULL);
            printf("\n");
    }
    return EXIT.SUCCESS;
}
```

- At the beginning, there is only the parent process

Processes in Unix

fork illustration program

parent process

```
int main(int argc, char *argv[])
{
    uint32_t t = 1000;
    printf("1"); fflush(stdout);
    int pid = fork();
    switch (pid)
    {
        case 0:
            bwDelay(t);
            printf("2"); fflush(stdout);
            bwDelay(t);
            printf("3"); fflush(stdout);
            break;
        default:
            bwDelay(t);
            printf("4"); fflush(stdout);
            bwDelay(t);
            printf("5"); fflush(stdout);
            wait(NULL);
            printf("\n");
    }
    return EXIT.SUCCESS;
}
```

- So, the first `printf` only occurs in the parent

Processes in Unix

fork illustration program

parent process

```
int main(int argc, char *argv[])
{
    uint32_t t = 1000;
    printf("1"); fflush(stdout);
    int pid = fork();
    switch (pid)
    {
        case 0:
            bwDelay(t);
            printf("2"); fflush(stdout);
            bwDelay(t);
            printf("3"); fflush(stdout);
            break;
        default:
            bwDelay(t);
            printf("4"); fflush(stdout);
            bwDelay(t);
            printf("5"); fflush(stdout);
            wait(NULL);
            printf("\n");
    }
    return EXIT.SUCCESS;
}
```

- When the `fork` starts, still only the parent process exists

Processes in Unix

fork illustration program

parent process

```
int main(int argc, char *argv[])
{
    uint32_t t = 1000;
    printf("1"); fflush(stdout);
    int pid = fork();
    switch (pid)
    {
        case 0:
            bwDelay(t);
            printf("2"); fflush(stdout);
            bwDelay(t);
            printf("3"); fflush(stdout);
            break;
        default:
            bwDelay(t);
            printf("4"); fflush(stdout);
            bwDelay(t);
            printf("5"); fflush(stdout);
            wait(NULL);
            printf("\n");
    }
    return EXIT.SUCCESS;
}
```

child process

```
int main(int argc, char *argv[])
{
    uint32_t t = 1000;
    printf("1"); fflush(stdout);
    int pid = fork();
    switch (pid)
    {
        case 0:
            bwDelay(t);
            printf("2"); fflush(stdout);
            bwDelay(t);
            printf("3"); fflush(stdout);
            break;
        default:
            bwDelay(t);
            printf("4"); fflush(stdout);
            bwDelay(t);
            printf("5"); fflush(stdout);
            wait(NULL);
            printf("\n");
    }
    return EXIT.SUCCESS;
}
```

- But when it ends, the child exists, so there is a return value on both parent and child

Processes in Unix

fork illustration program

parent process

```
int main(int argc, char *argv[])
{
    uint32_t t = 1000;

    printf("1"); fflush(stdout);
    int pid = fork();
    switch (pid)
    {
        case 0:
            bwDelay(t);
            printf("2"); fflush(stdout);
            bwDelay(t);
            printf("3"); fflush(stdout);
            break;
        default:
            bwDelay(t);
            printf("4"); fflush(stdout);
            bwDelay(t);
            printf("5"); fflush(stdout);
            wait(NULL);
            printf("\n");
    }
    return EXIT_SUCCESS;
}
```

child process

```
int main(int argc, char *argv[])
{
    uint32_t t = 1000;

    printf("1"); fflush(stdout);
    int pid = fork();
    switch (pid)
    {
        case 0:
            bwDelay(t);
            printf("2"); fflush(stdout);
            bwDelay(t);
            printf("3"); fflush(stdout);
            break;
        default:
            bwDelay(t);
            printf("4"); fflush(stdout);
            bwDelay(t);
            printf("5"); fflush(stdout);
            wait(NULL);
            printf("\n");
    }
    return EXIT_SUCCESS;
}
```

- The value of `pid` is 0 in child and different from 0 in parent

Processes in Unix

fork illustration program

parent process

```
int main(int argc, char *argv[])
{
    uint32_t t = 1000;

    printf("1"); fflush(stdout);
    int pid = fork();
    switch (pid)
    {
        case 0:
            bwDelay(t);
            printf("2"); fflush(stdout);
            bwDelay(t);
            printf("3"); fflush(stdout);
            break;
        default:
            bwDelay(t);
            printf("4"); fflush(stdout);
            bwDelay(t);
            printf("5"); fflush(stdout);
            wait(NULL);
            printf("\n");
    }
    return EXIT_SUCCESS;
}
```

child process

```
int main(int argc, char *argv[])
{
    uint32_t t = 1000;

    printf("1"); fflush(stdout);
    int pid = fork();
    switch (pid)
    {
        case 0:
            bwDelay(t);
            printf("2"); fflush(stdout);
            bwDelay(t);
            printf("3"); fflush(stdout);
            break;
        default:
            bwDelay(t);
            printf("4"); fflush(stdout);
            bwDelay(t);
            printf("5"); fflush(stdout);
            wait(NULL);
            printf("\n");
    }
    return EXIT_SUCCESS;
}
```

- So, parent and child follow different directions

Processes in Unix

fork illustration program

parent process

```
int main(int argc, char *argv[])
{
    uint32_t t = 1000;

    printf("1"); fflush(stdout);
    int pid = fork();
    switch (pid)
    {
        case 0:
            bwDelay(t);
            printf("2"); fflush(stdout);
            bwDelay(t);
            printf("3"); fflush(stdout);
            break;
        default:
            bwDelay(t);
            printf("4"); fflush(stdout);
            bwDelay(t);
            printf("5"); fflush(stdout);
            wait(NULL);
            printf("\n");
    }
    return EXIT_SUCCESS;
}
```

child process

```
int main(int argc, char *argv[])
{
    uint32_t t = 1000;

    printf("1"); fflush(stdout);
    int pid = fork();
    switch (pid)
    {
        case 0:
            bwDelay(t);
            printf("2"); fflush(stdout);
            bwDelay(t);
            printf("3"); fflush(stdout);
            break;
        default:
            bwDelay(t);
            printf("4"); fflush(stdout);
            bwDelay(t);
            printf("5"); fflush(stdout);
            wait(NULL);
            printf("\n");
    }
    return EXIT_SUCCESS;
}
```

- Parent and child are concurrent and the delay may influence multiprogramming

Processes in Unix

fork illustration program

parent process

```
int main(int argc, char *argv[])
{
    uint32_t t = 1000;

    printf("1"); fflush(stdout);
    int pid = fork();
    switch (pid)
    {
        case 0:
            bwDelay(t);
            printf("2"); fflush(stdout);
            bwDelay(t);
            printf("3"); fflush(stdout);
            break;
        default:
            bwDelay(t);
            printf("4"); fflush(stdout);
            bwDelay(t);
            printf("5"); fflush(stdout);
            wait(NULL);
            printf("\n");
    }
    return EXIT_SUCCESS;
}
```

child process

```
int main(int argc, char *argv[])
{
    uint32_t t = 1000;

    printf("1"); fflush(stdout);
    int pid = fork();
    switch (pid)
    {
        case 0:
            bwDelay(t);
            printf("2"); fflush(stdout);
            bwDelay(t);
            printf("3"); fflush(stdout);
            break;
        default:
            bwDelay(t);
            printf("4"); fflush(stdout);
            bwDelay(t);
            printf("5"); fflush(stdout);
            wait(NULL);
            printf("\n");
    }
    return EXIT_SUCCESS;
}
```

- So, no way to know who prints first

Processes in Unix

fork illustration program

parent process

```
int main(int argc, char *argv[])
{
    uint32_t t = 1000;

    printf("1"); fflush(stdout);
    int pid = fork();
    switch (pid)
    {
        case 0:
            bwDelay(t);
            printf("2"); fflush(stdout);
            bwDelay(t);
            printf("3"); fflush(stdout);
            break;
        default:
            bwDelay(t);
            printf("4"); fflush(stdout);
            bwDelay(t);
            printf("5"); fflush(stdout);
            wait(NULL);
            printf("\n");
    }
    return EXIT_SUCCESS;
}
```

child process

```
int main(int argc, char *argv[])
{
    uint32_t t = 1000;

    printf("1"); fflush(stdout);
    int pid = fork();
    switch (pid)
    {
        case 0:
            bwDelay(t);
            printf("2"); fflush(stdout);
            bwDelay(t);
            printf("3"); fflush(stdout);
            break;
        default:
            bwDelay(t);
            printf("4"); fflush(stdout);
            bwDelay(t);
            printf("5"); fflush(stdout);
            wait(NULL);
            printf("\n");
    }
    return EXIT_SUCCESS;
}
```

- The 5 is always after the 4; the 3 is always after the 2

Process in Unix

Launching a program: fork + exec

```
#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>
#include <sys/types.h>
#include <sys/wait.h>

int main(int argc, char *argv[])
{
    /* check arguments */
    if (argc != 2)
    {
        fprintf(stderr, "launch <<cmd>>\n");
        exit(EXIT_FAILURE);
    }
    char *aplic = argv[1];

    printf("=====\n");

    /* clone phase */
    int pid;
    if ((pid = fork()) < 0)
    {
        perror("Fail cloning process");
        exit(EXIT_FAILURE);
    }
}
```

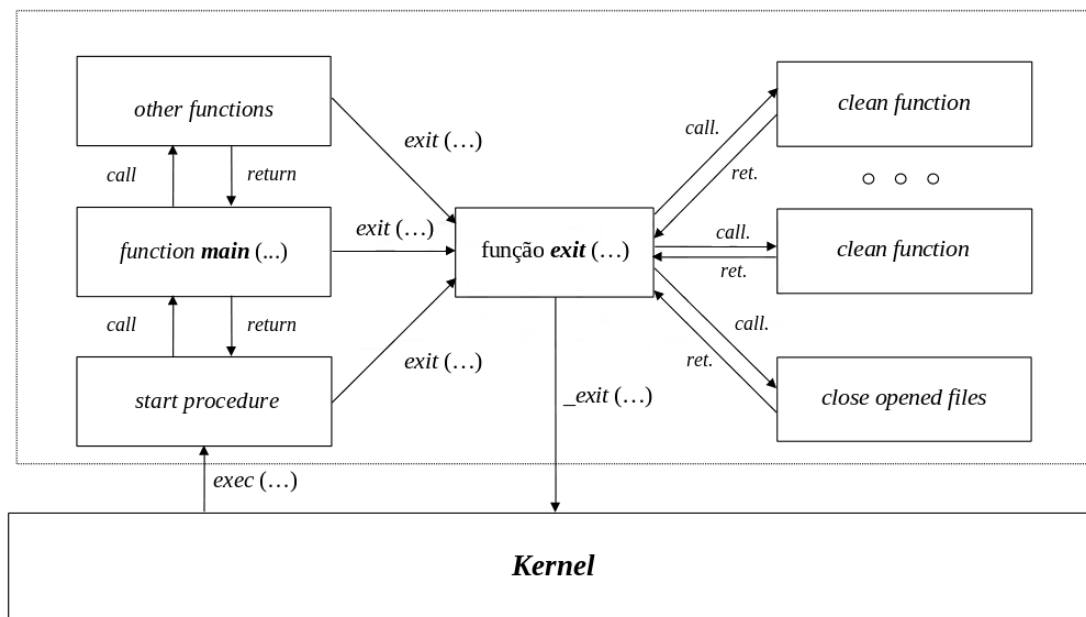
```
/* exec and wait phases */
if (pid != 0) // only runs in parent process
{
    int status;
    while (wait(&status) == -1);
    printf("=====\n");
    printf("Process %d (child of %d)"
           " ends with status %d\n",
           pid, getpid(), WEXITSTATUS(status));
}
else // this only runs in the child process
{
    execl(aplic, aplic, NULL);
    perror("Fail launching program");
    exit(EXIT_FAILURE);
}

exit(EXIT_SUCCESS); // or return EXIT_SUCCESS
}
```

- Launching a program is done using the `fork` and the `exec` on the child side

Processes in Unix

Execution of a C/C++ program



Processes in Unix

Executing a C/C++ program: atexit

```
#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>
#include <assert.h>

/* cleaning functions */
static void atexit_1(void)
{
    printf("atexit 1\n");
}

static void atexit_2(void)
{
    printf("atexit 2\n");
}

/* main programa */
int main(void)
{
    /* registering at exit functions */
    assert(atexit(atexit_1) == 0);
    assert(atexit(atexit_2) == 0);

    /* normal work */
    printf("hello world 1!\n");

    for (int i = 0; i < 5; i++) sleep(1);

    return EXIT_SUCCESS;
}
```

- The **atexit** function allows to register a function to be called at the program's normal termination
- They are called in reverse order relative to their register
- *What happens if the termination is forced?*

Processes in Unix

Command line arguments and environment variables

```
#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>

int main(int argc, char *argv[], char *env[])
{
    /* printing command line arguments */
    printf("Command line arguments:\n");
    for (int i = 0; argv[i] != NULL; i++)
    {
        printf(" %s\n", argv[i]);
    }

    /* printing all environment variables */
    printf("\nEnvironment variables:\n");
    for (int i = 0; env[i] != NULL; i++)
    {
        printf(" %s\n", env[i]);
    }

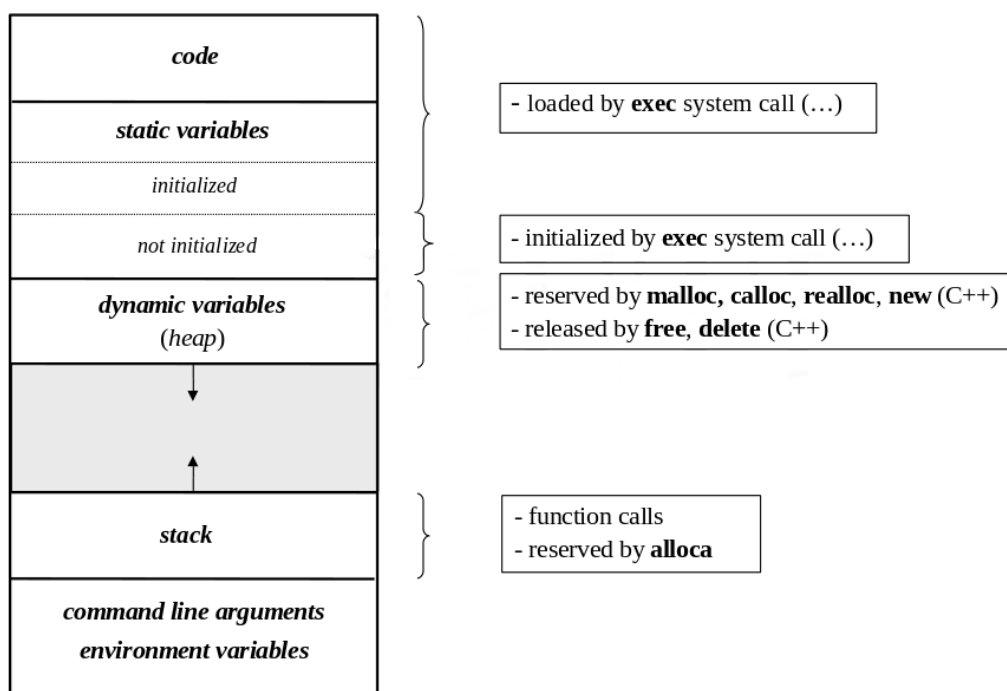
    /* printing a specific environment variable */
    printf("\nEnvironment variable:\n");
    printf(" env[\"HOME\"] = \"%s\"\n", getenv("HOME"));
    printf(" env[\"zzz\"] = \"%s\"\n", getenv("zzz"));

    return EXIT_SUCCESS;
}
```

- **argv** is an array of strings
- **argv[0]** is the program reference
- **env** is an array of strings, each representing a variable, in the form **name-value** pair
- **getenv** returns the value of a variable name

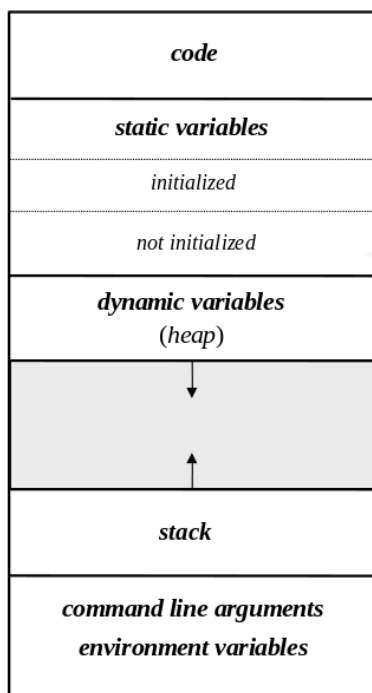
Processes in Unix

Address space of a Unix process



Processes in Unix

Address space of a Unix process (2)

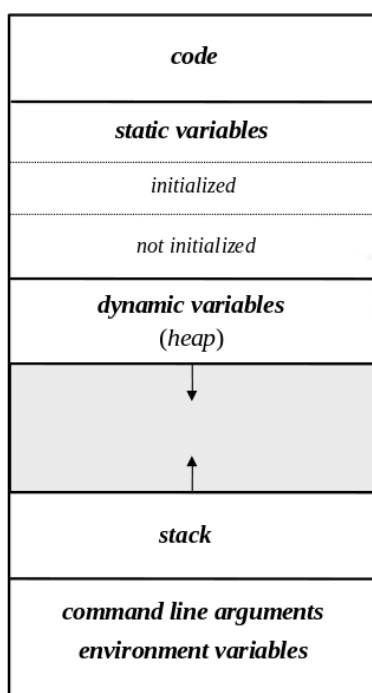


```
int n1 = 1;
static int n2 = 2;
int n3;
static int n4;
int n5;
static int n6 = 6;

int main(int argc, char *argv[], char *env[])
{
    extern char** environ;
    static int n7;
    static int n8 = 8;
    int *p9 = (int*) malloc(sizeof(int));
    int *p10 = new int;
    int *p11 = (int*) alloca(sizeof(int));
    int n12;
    int n13 = 13;
    int n14;
    printf("\ngetenv(n0): %p\n", getenv("n0"));
    printf("\nargv: %p\nenviron: %p\nenv: %p\nmain: %p\n",
        argv, environ, env, main);
    printf("\n&argc: %p\n&argv: %p\n&env: %p\n",
        &argc, &argv, &env);
    printf("&n1: %p\n&n2: %p\n&n3: %p\n&n4: %p\n&n5: %p\n"
        "&n6: %p\n&n7: %p\n&n8: %p\n&n9: %p\n&n10: %p\n"
        "&p11: %p\n&n12: %p\n&n13: %p\n&n14: %p\n",
        &n1, &n2, &n3, &n4, &n5, &n6, &n7, &n8,
        p9, p10, p11, &n12, &n13, &n14);
}
```

Processes in Unix

Address space of a Unix process (3)



```
#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>
#include <wait.h>

int n01 = 1;

int main(int argc, char *argv[], char *env[])
{
    int pid = fork();
    if (pid != 0)
    {
        fprintf(stderr, "%5d: n01 = %5d (%p)\n",
            pid, n01, &n01);
        wait(NULL);
        fprintf(stderr, "%5d: n01 = %5d (%p)\n",
            pid, n01, &n01);
    }
    else
    {
        fprintf(stderr, "%5d: n01 = %5d (%p)\n",
            pid, n01, &n01);
        n01 = 1111;
        fprintf(stderr, "%5d: n01 = %5d (%p)\n",
            pid, n01, &n01);
    }
    return 0;
}
```