Waiting for a Child Process Exit

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

pid_t waitpid(pid_t pid, int *status, int ops);
```

Waits until the process **`pid`** exits and sets **`*status`**

Use **`WEXITSTATUS(status)`** to get the value that **`main`** returned or passed to **`exit`**

Using `waitpid`

```c
#include "csapp.h"

int main() {
  pid_t pid = Fork();
  if (pid == 0) {
    printf("HC: hello from child\n");
    exit(17);
  } else {
    int child_status;
    printf("HP: hello from parent\n");
    Waitpid(pid, &child_status, 0);
    printf("CT: child result %d\n",
           WEXITSTATUS(child_status));
  }
  printf("Bye\n");
  return 0;
}
```

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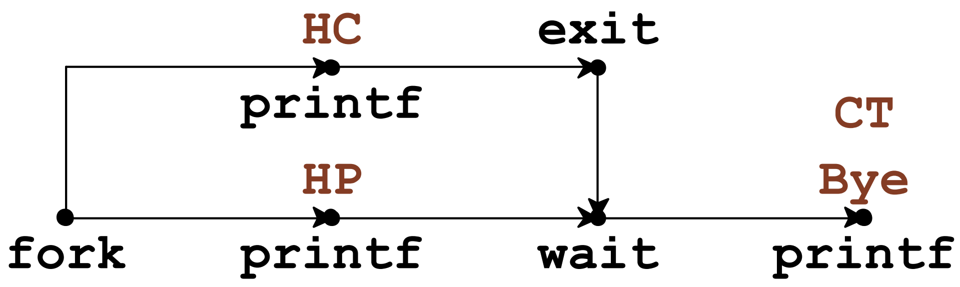

Child Process that Continues

Without using **`waitpid`**, a child process can continue after its parent exits:

```
#include "csapp.h"

int main() {
  pid_t pid = Fork();
  if (pid == 0) {
    Sleep(10);
    printf("Child done\n");
  } else
    printf("Parent of %d done\n", pid);
  return 0;
}
```

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Process IDs Get Recycled

```
#include "csapp.h"
#define SHOW_EACH_N 1000

int main() {
  int count = 0;
  while (1) {
    pid_t pid = Fork();
    if (pid == 0)
      return count / SHOW_EACH_N;
    else {
      int child_status;
      Waitpid(pid, &child_status, 0);
      if ((count % SHOW_EACH_N) == 0) {
        printf("child %d; pid %d; result %d\n",
               count, pid, WEXITSTATUS(child_status));
      }
      count++;
    }
  }
}
```

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Zombie Processes

Q: If a process ID can be recycled, how do you know that **`waitpid`** waits for the intended process?

A: **`waitpid`** must ***reap*** a process before its ID can be recycled

```
pid_t init_pid = Fork();
if (init_pid == 0) {
  return 0;
}
....
if (pid == init_pid)
  printf("recycled!\n");
```
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A process that has exited but not yet been reaped is a ***zombie*** or ***defunct*** process

The `init` Process

If a parent doesn’t wait for a child, the child process is adopted by **`init`**, which is process **`1`**

```
#include "csapp.h"

int main() {
  pid_t pid = Fork();
  if (pid == 0) {
    printf("Child of %d started\n", getppid());
    Sleep(2);
    printf("Child of %d done\n", getppid());
  } else {
    Sleep(1);
    printf("Parent of %d done\n", pid);
  }
  return 0;
}
```

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Child likely (not guaranteed) to print **`1`** as parent when done

Waiting for Multiple Processes

Use **−1** in place of a process ID to wait on all children

```
#include "csapp.h"
#define N 10

int main() {
  pid_t pid[N];
  int i, child_status;

  for (i = 0; i < N; i++) {
    if ((pid[i] = fork()) == 0) {
      /* Child */
      Sleep(i % 3);
      printf("Done %d\n", getpid());
      exit(i);
    }
  }

  for (i = 0; i < N; i++) {
     pid_t wpid = Waitpid(-1, &child_status, 0);
     if (WIFEXITED(child_status))
       printf("Saw %d done with %d\n", wpid, WEXITSTATUS(child_status));
    else
       printf("Child %d terminated abnormally\n", wpid);
  }
}
```

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Alternate Wait Function

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

pid_t wait(int *status);
```

Short for `waitpid(-1, status, 0)`

Running Programs

```
#include <unistd.h>

int execve(char *prog, char **argv, char **env);
```

Replaces current process state with executable **`prog`**

- Discards current code, stack, and heap
- Preserves process ID

Gives new program **`argv`**

`NULL`-terminated, and

`argv[0]` matches **`prog`** by convention

Sets its environment variables to **`env`**

... normally **`environ`**

Running Programs

dee.c

```
#include "csapp.h"

char *dum_argv[] = { "dum", NULL };

int main(int argc, char **argv) {
  printf("Dee, pid = %d\n", getpid());
  Execve("dum", dum_argv, environ);
  printf("Never happens!\n");
  return 0;
}
```

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dum.c

```
#include "csapp.h"

int main(int argc, char **argv) {
  printf("Dum, pid = %d\n", getpid());
  return 0;
}
```

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Example: Running a Program as a New Process

ls.c

```
#include "csapp.h"

char *ls_argv[] = { "/bin/ls", "-lt", "/usr/include", NULL };

int main(int argc, char **argv) {
  int status;

  printf("Listing /usr/include...\n");

  if (Fork() == 0)
    Execve(ls_argv[0], ls_argv, environ);

  (void)Wait(&status);
  printf("Done listing.\n");

  return 0;
}
```

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