🚀 Architecture & Deployment

2025-2026 v0.1.0 on branch main Rev: 03b1cdace14bb0b0720e24be862097b3792214ea

Unix Processes

Learn about processes in Unix operating systems, as well as how to manage them and make them communicate.

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You will need

- A Unix CLI
- An Ubuntu server to connect to

Recommended reading

- Command Line Introduction
- Secure Shell (SSH)

What is a process?

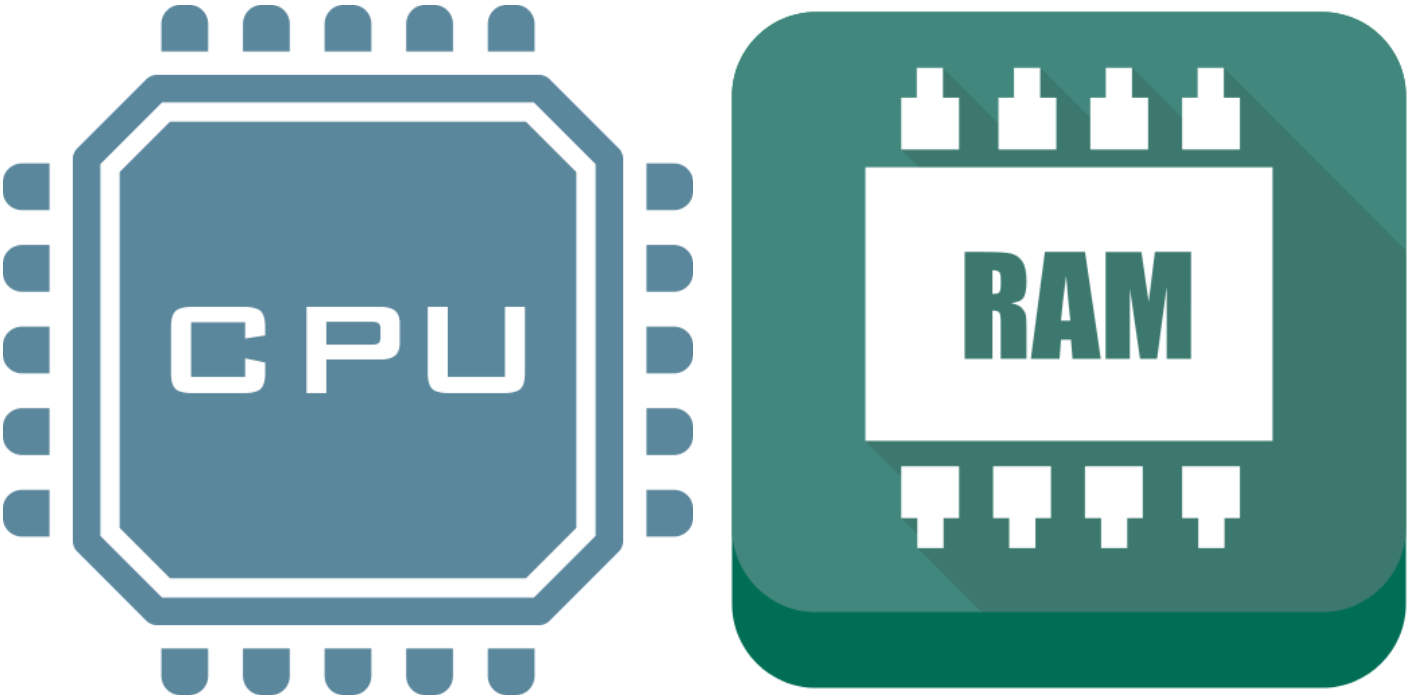
A process is an **instance of a computer program that is being executed**.

This is a C **program**. A program is a passive collection of **instructions stored on disk**:

```
 #include <stdio.h>

int main()
{
   printf("Hello, World!");
   return 0;
}
```

A **process** is the actual **execution of a program** that has been loaded into memory:



Every time you run an executable file or an application, **a process is created**. Simple programs only need one process. More complex applications may launch other child processes for greater performance. For example, most modern browsers will run at least one child process per tab.

Unix processes

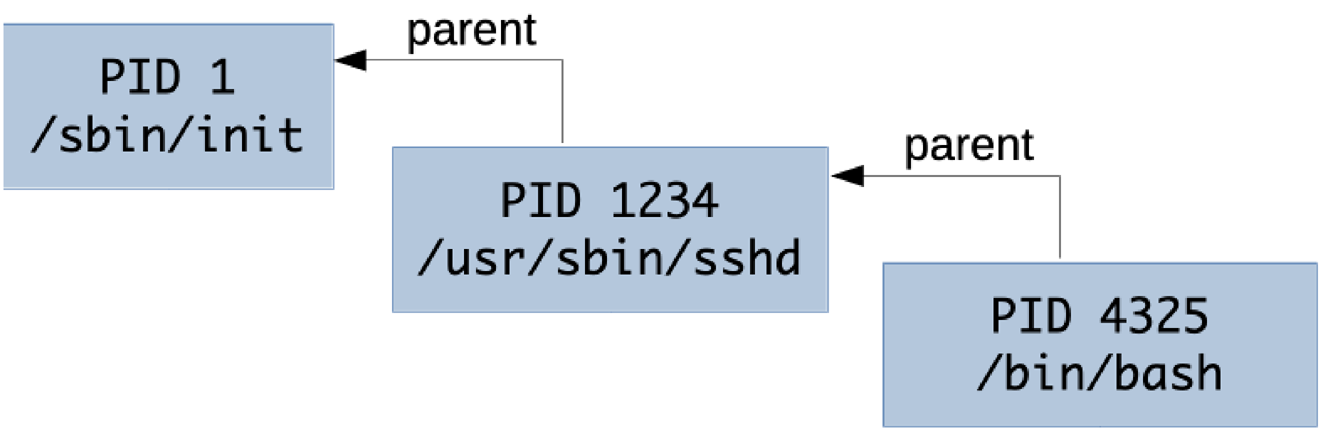
Processes work differently depending on the operating system. We will focus on processes in Unix systems, which have the following features:

Feature	Description
Process ID (PID)	A number uniquely identifying a process at a given time
Exit status	A number given when a process exits, indicating whether it was successful
Signals	Notifications sent to a process, a form of inter-process communication (IPC)
Standard streams	Preconnected input and output communication channels between a process and its environment
Pipelines	A way to chain processes in sequence by their standard streams, a form of inter-process communication (IPC)

> 📚 **More information**
>
> These features have been standardized for Unix systems as the Portable Operating System Interface (POSIX).

Process ID

Let's talk about how running processes are identified.



What is a process identifier?

Any process that is created in a Unix system is assigned an **identifier (or PID)**. Each new process gets the next available PID. This ID can be used to reference the process, for example to terminate it with the `kill` command (more about that later).

PIDs are sometimes reused as processes die and are created again, but **at any given time, a PID uniquely identifies a specific process**.

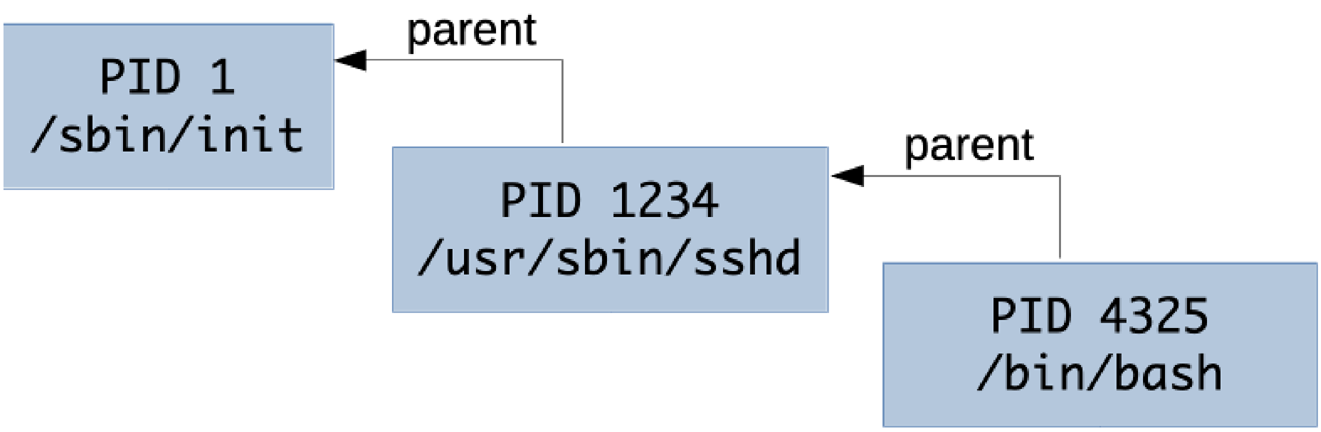
> 📚 **More information**
>
> By default, the maximum PID on Linux systems is 32,768 on 32-bit systems, and 4,194,304 (~4 million) on 64-bit systems.

Parent processes

The process with PID 0 is the **system process**, also originally known as the **swapper** or **scheduler**. This is the most low-level process managed directly by the kernel.

One of the first thing it does is run the init process, which naturally gets PID 1 (the next available PID). The init process is responsible for initializing the system. Most other processes are either launched by the init process directly, or by one of its children.

All processes retain a reference to the **parent process** that launched it. The ID of the parent process is commonly called **PPID (parent process ID)**.



The `ps` command

The `ps` (**p**rocess **s**tatus) command displays currently-running processes:

```
$> ps
  PID TTY          TIME CMD
14926 pts/0    00:00:00 bash
14939 pts/0    00:00:00 ps
```

> 💎 **Tip**
>
> By default, it only lists your user's processes that have a controlling terminal (`TTY`).

You can obtain more information with the `-f` (**f**ull format) option:

```
$> ps -f
UID        PID  PPID  C STIME TTY          TIME CMD
jde      15237 15158  1 17:48 pts/0    00:00:00 -bash
jde      15251 15237  0 17:48 pts/0    00:00:00 ps -f
```

> 💎 **Tip**
>
> We are mostly interested in the **P**rocess **ID** (`PID`), the **p**arent **P**rocess **ID** (`PPID`) and of course the **c**o**m**man**d** (`CMD`) that is being run. But the others also provide useful information.

Listing all processes

Of course, there are more than 2 processes running on your computer. Add the `-e` (**e**very) option to see all running processes. The list will be much longer. This is an abbreviated example:

```
$> ps -ef
UID        PID  PPID  C STIME TTY          TIME CMD
root         1     0  0 09:38 ?        00:00:30 /sbin/init
root         2     0  0 09:38 ?        00:00:30 [kthread]
...
root       402     1  0 09:39 ?        00:00:00 /lib/systemd/systemd-journald
syslog     912     1  0 09:39 ?        00:00:00 /usr/sbin/rsyslogd -n
root      1006     1  0 09:39 ?        00:00:00 /usr/sbin/cron -f
...
root      1700     1  0 Sep11 ?        00:00:00 /usr/sbin/sshd -D
jde       3350  1700  0 17:52 ?        00:00:00 sshd: jde@pts/0
jde       3378  3350  0 15:32 pts/0    00:00:00 -bash
jde       3567  3378  0 15:51 pts/0    00:00:00 ps -ef
```

> 💎 **Tip**

> Note that the command you just ran, `ps -ef`, is in the process list (at the bottom in this example). This is because it was running while it was listing the other processes.

Process tree

On some Linux distributions like Ubuntu, the `ps` command also accepts a `--forest` option which visually shows the relationship between processes and their parent:

```
$> ps -ef --forest
UID        PID  PPID  C STIME TTY          TIME CMD
...
root      1700     1  0 Sep11 ?        00:00:00 /usr/sbin/sshd -D
jde       3350  1700  0 17:52 ?        00:00:00  \_ sshd: jde@pts/0
jde       3378  3350  0 17:52 pts/0    00:00:00      \_ -bash
jde       3567  3378  0 17:54 pts/0    00:00:00          \_ ps -ef --forest
```

You can clearly see that:

- Process 1700, the SSH server (the `d` in `sshd` is for daemon), was launched by the init process (PID 1) and is run by `root`.
- Process 3350 was launched by the SSH server when you connected. It is your SSH session and manages your terminal device, named `pts/0` here.
- Process 3378 is a Bash login shell that was launched when you connected (as configured in `/etc/passwd`) and is attached to terminal `pts/0`.
- Process 3567 is the `ps` command you launched from the shell.

Running more processes

Let's run some other processes and see if we can list them.

Open a new terminal on your local machine and connect to the same server.

If you go back to the first terminal and run the `ps` command again, you should see both virtual terminal processes corresponding to your two terminals, as well as the two bash shells running within them:

```
$> ps -ef --forest
...
root      1700     1  0 Sep11 ?        00:00:00 /usr/sbin/sshd -D
jde       3350  1700  0 17:52 ?        00:00:00  \_ sshd: jde@pts/0
jde       3378  3350  0 17:52 pts/0    00:00:00  |   \_ -bash
jde       3801  3378  0 18:22 pts/0    00:00:00  |       \_ ps -ef --forest
jde       3789  1700  0 18:21 ?        00:00:00  \_ sshd: jde@pts/1
jde       3791  3789  0 18:21 pts/1    00:00:00      \_ -bash
```

Sleeping process

Run a [`sleep` command]() in the second terminal:

```
$> sleep 1000
```

It launches a process that does nothing for 1000 seconds, but keeps running.

It will block your terminal during that time, so go back to the other terminal and run the following `ps` command, with an additional `-u jde` option to filter only processes belonging to your **u**ser:

```
$> ps -f -u jde --forest
UID        PID  PPID  C STIME TTY          TIME CMD
...
jde       3350  1700  0 17:52 ?        00:00:00 sshd: jde@pts/0
jde       3378  3350  0 17:52 pts/0    00:00:00  \_ -bash
jde       3823  3378  0 18:24 pts/0    00:00:00      \_ ps -f -u jde --forest
jde       3789  1700  0 18:21 ?        00:00:00 sshd: jde@pts/1
jde       3791  3789  0 18:21 pts/1    00:00:00  \_ -bash
jde       3812  3791  0 18:23 pts/1    00:00:00      \_ sleep 1000
```

You can indeed see the running process started with the `sleep` command. You can stop it with `Ctrl-C` (in the terminal when it's running) when you're done.

Other monitoring commands

Here are other ways to inspect processes and have more information on their resource consumption:

- The [`htop` command](#) (a better version of the older [`top` command](#), meaning **t**able **o**f **p**rocesses, named after its creator, **H**isham's **top**), shows processes along with CPU and memory consumption. It's an interactive command you can exit with `q` (**q**uit).
- The [`free` command](#) is not directly related to processes, but it helps you know how much memory is remaining on your system.

```
$> free -m
              total        used        free      shared  buff/cache   available
Mem:            985          90         534           0         359         751
Swap:             0           0           0
```

> 📚 **More information**
>
> The `-m` option of the `free` command displays memory size in [mebibytes](#), a more human-readable quantity, instead of bytes.

Welcome to the future

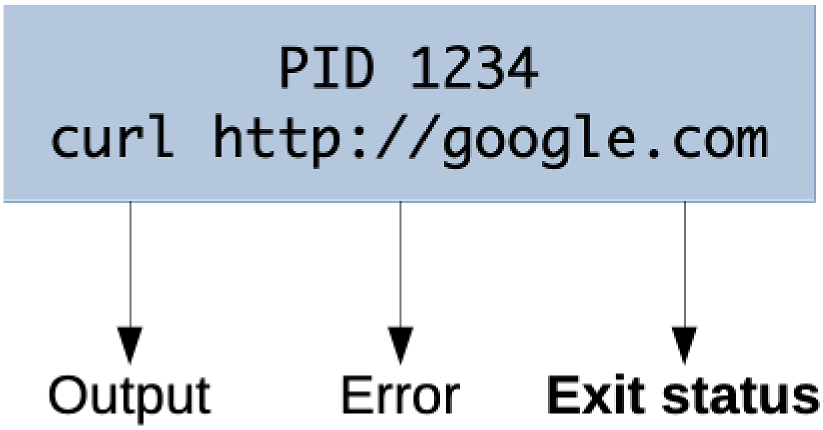
Some of the previously-mentioned commands may be older than you, although they are regularly updated. But new command line tools are also being developed today:

- The [`procs` command](#) is a modern interactive alternative to the `ps` command for listing processes, written in [Rust](#), a modern systems programming language.

- The `btm` command is a modern alternative to `htop` and `top` with more features, also written in Rust.

Exit status

How children indicate success to their parent.



What is an exit status?

The **exit status** of a process is a small number (typically from 0 to 255) passed from a child process to its parent process when it has finished executing.

It is meant to allow the child process to indicate how or why it exited.

It's common practice for the exit status of Unix/Linux programs to be **0 to indicate success**, and **greater than 0 to indicate an error** (it is sometimes also called an *error level*).

Retrieving the exit status in a shell

In a typical shell like Bash, you can retrieve the exit status of last executed command from the special variable `$?`:

```
$> ls /
...

$> echo $?
0

$> ls file-that-does-not-exist
ls: cannot access 'file-that-does-not-exist': No such file or directory

$> echo $?
2
```

Retrieving the exit status in code

Exit codes are not a feature that is limited to command line use. When running a program from an application, you can also obtain the exit status.

For example:

- By using the `&$return_var` reference when calling PHP's `exec` function
- By calling the `Process#exitValue()` method after calling `Runtime#exec(String command)` in Java
- By listening to the `close` event when calling Node.js's `spawn` function

Meaning of exit statuses

The meaning of exit statuses is unique to the program you are running. For example, the manual of the `ls` command documents the following values:

```
Exit status:
  0      if OK,
```

```
    if minor problems (e.g., cannot access subdirectory),
    if serious trouble (e.g., cannot access command-line argument).
```

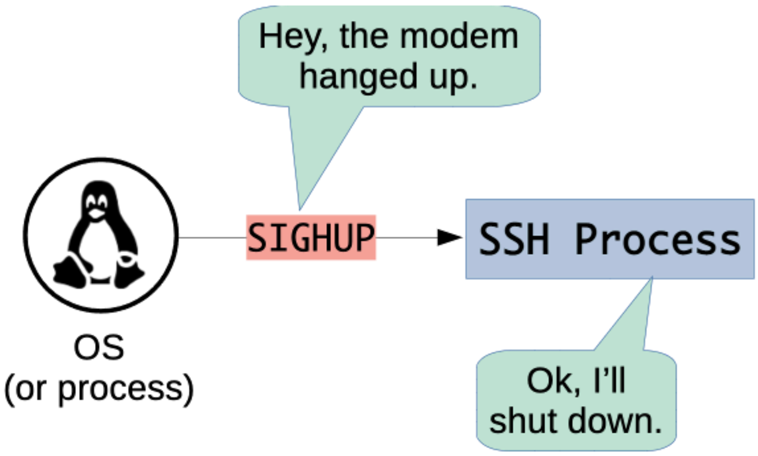
But this will be different for other programs or applications.

The only thing you can rely on for the majority of programs is that **0 is good, anything else is probably bad**.

Signals

What is a signal?

A signal is an asynchronous **notification sent to a process** to notify it that an event has occurred. Signals are sent by other processes or by the system (i.e. the kernel).



If the process has registered a **signal handler** for that specific signal, it is executed. Otherwise the **default signal handler** is executed.

Common Unix signals

A signal is defined by the `SIG` prefix followed by a mnemonic name for the signal. Some signals also have a standard number assigned to them. Here are some of the most commonly encountered Unix signals:

Signal	Number	Default handler	Description
`SIGHUP`	1	Terminate	Hangup (i.e. connection lost)
`SIGINT`	2	Terminate	Interrupt signal (sent when you use `Ctrl-C`)
`SIGTERM`	15	Terminate	Termination signal (default signal sent by the `kill` command)
`SIGQUIT`	3	Terminate (with core dump)	Termination signal
`SIGKILL`	9	Terminate	Kill (cannot be caught or ignored)
`SIGUSR1`	-	Terminate	User-defined signal 1
`SIGUSR2`	-	Terminate	User-defined signal 2
`SIGWINCH`	-	Ignore	Terminal window size changed

> 💎 **Tip**
>
> You can **l**ist available signals on your system by running `kill -l`. Here's a more complete list: POSIX signals.

The terminal interrupt signal (`SIGINT`)

When you type `Ctrl-C` in your terminal to terminate a running process, you are actually using Unix signals.

The shortcut is interpreted by your shell, which then sends a **terminal interrupt signal**, or **`SIGINT`**, to the running process.

Most processes handle that signal by terminating (altough some don't respond to it, like some interactive helps, e.g. `man ls`).

The `kill` command

The `kill` command **sends a signal to a process**.

Since the default signal handler for most signals is to terminate the process, it often has that effect, hence the name "kill".

Its syntax is:

```
kill [-<SIGNAL>] <PID>
kill [-s <SIGNAL>] <PID>
```

Command	Effect
`kill 10000`	Send the **default `SIGTERM` signal** to process with PID `10000`
`kill -s HUP 10000`	Send the `SIGHUP` signal to that same process
`kill -HUP 10000`	Equivalent to the previous command
`kill -1 10000`	Equivalent to the previous command (1 is the official POSIX number for `SIGHUP`)

Trapping signals

This command will run a badly behaved script which traps and ignores all signals sent to it:

```
$> curl -s -L https://git.io/JitFQ|sh -s
Hi, I'm running with PID 10000
Try and kill me!
```

Since it ignores the `SIGINT` signal among others, you will not be able to stop it with `Ctrl-C`.

Open another terminal and try to kill the process by referring to its PID (which is `10000` in this example but will be different on your machine):

```
$> kill 10000
$> kill -s HUP 10000
$> kill -s QUIT 10000
$> kill -s USR1 10000
```

The script will simply log that it is ignoring your signal and continue executing.

The `KILL` signal

There is one signal that cannot be ignored: **the `KILL` signal**.

Although a process can detect the signal and attempt to perform additional operations, **the OS will permanently kill the process** shortly after it is received, and the process can do nothing to prevent it.

Send a `KILL` signal to the process with the same PID as before:

```
$> kill -s KILL 10000
```

The script will finally have the decency to die.

Unix signals in the real world

Many widely-used programs react to Unix signals, for example:

- Nginx
- PostgreSQL
- OpenSSH

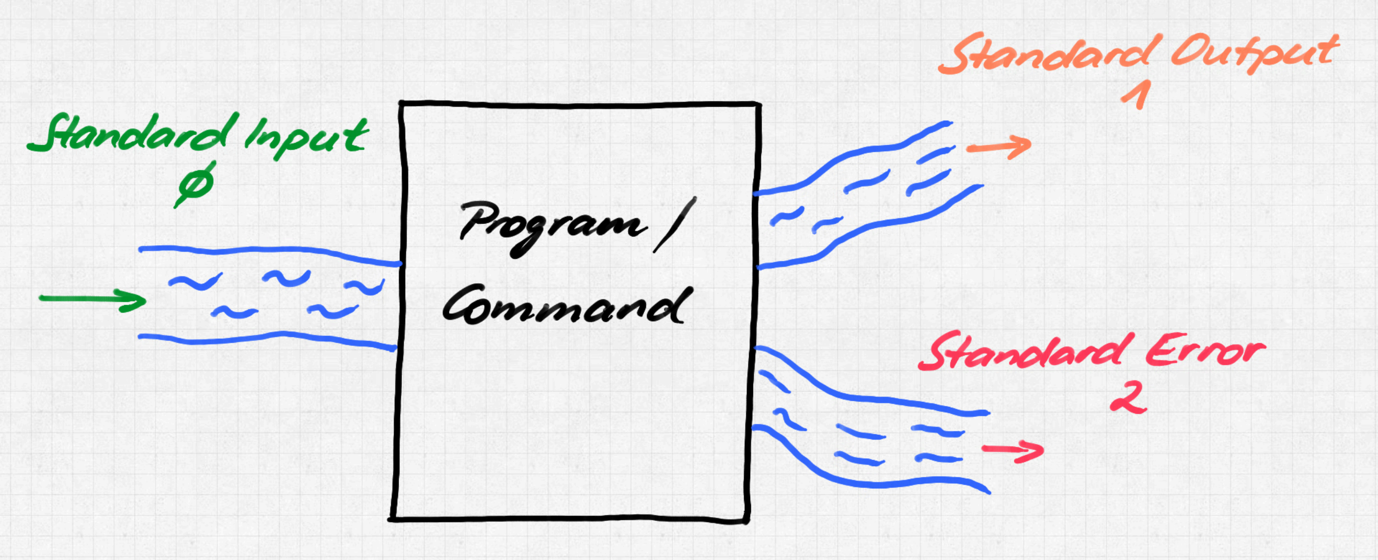
A common example is the `SIGHUP` signal. Originally it was meant to indicate that the modem hanged up.

That’s not relevant to programs not directly connected to a terminal, but some programs repurposed it for another use.

Many background services like Nginx and PostgreSQL will reload their configuration (without shutting down) when receiving that signal. Many other tools follow this convention.

Standard streams

Standard streams are preconnected input and output communication channels between a process and its environment.



The good old days

In **pre-Unix** (before 1970) systems, programs had to **explicitly connect to input and output devices**. This was done differently for each device (e.g. magnetic tape drive, disk drive, printer, etc) and operating system. For example, IBM mainframes used a Job Control Language (JCL) to establish connections between programs and devices.

Unix file copy

`cp a.txt b.txt`

JCL copy instructions for OS/360

```
//IS198CPY JOB (IS198T30500),'COPY JOB',CLASS=L,MSGCLASS=X
//COPY01   EXEC PGM=IEBGENER
//SYSPRINT DD SYSOUT=*
//SYSUT1   DD DSN=a.txt,DISP=SHR
//SYSUT2   DD DSN=b.txt,
//            DISP=(NEW,CATLG,DELETE),
//            SPACE=(CYL,(40,5),RLSE),
//            DCB=(LRECL=115,BLKSIZE=1150)
//SYSIN  DD DUMMY
```

Unix streams

Unix introduced **abstract devices** and the concept of a **data stream**: an ordered sequence of data bytes which can be read until the **e**nd **o**f **f**ile (EOF).

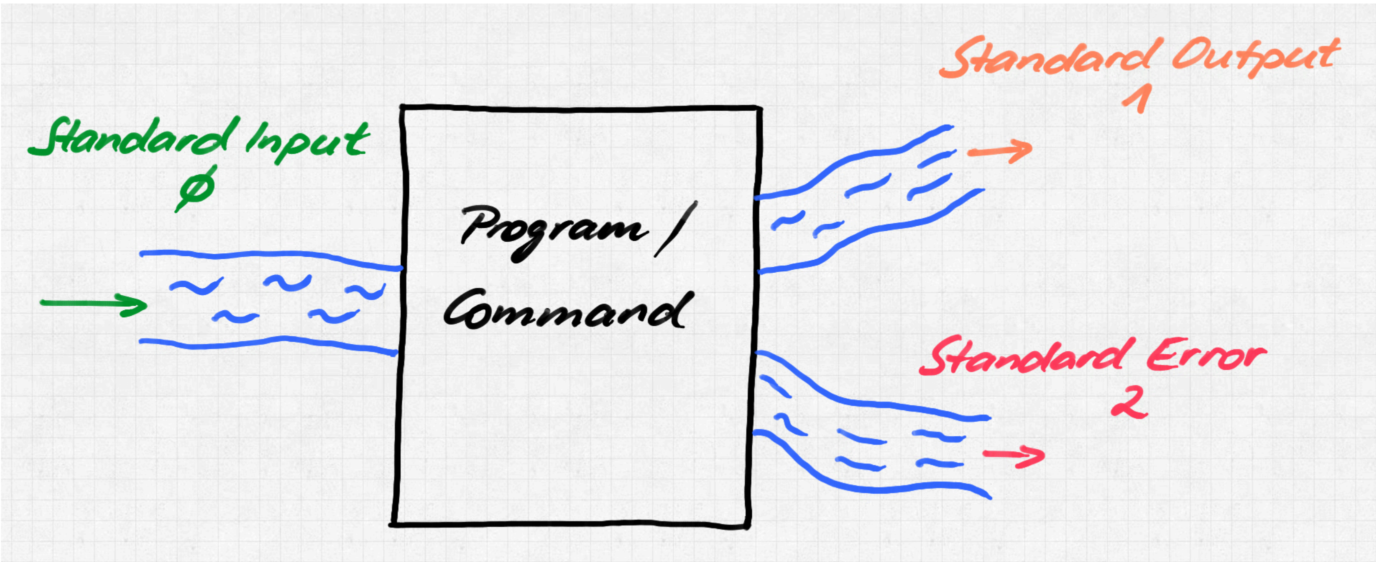
A program may also write bytes as desired and need not declare how many there will be or how to group them. The data going through a stream may be **text** (with any encoding) **or binary data**.

This was groundbreaking at the time because a program no longer had to know or care what kind of device it is communicating with, as had been the case until then.

stdin, stdout & stderr

Any new Unix process is **automatically connected** to the following streams by default:

Stream	Shorthand	Description
Stand**a**rd **in**put	`stdin`	Stream **data** (often text) **going into a program**
Stand**a**rd **out**put	`stdout`	Stream where a program writes its **output data**
Stand**a**rd **err**or	`stderr`	Another output stream programs can use to output **error messages or diagnostics** (separate from standard output, allowing output and errors to be distinguished, solving the semipredicate problem)

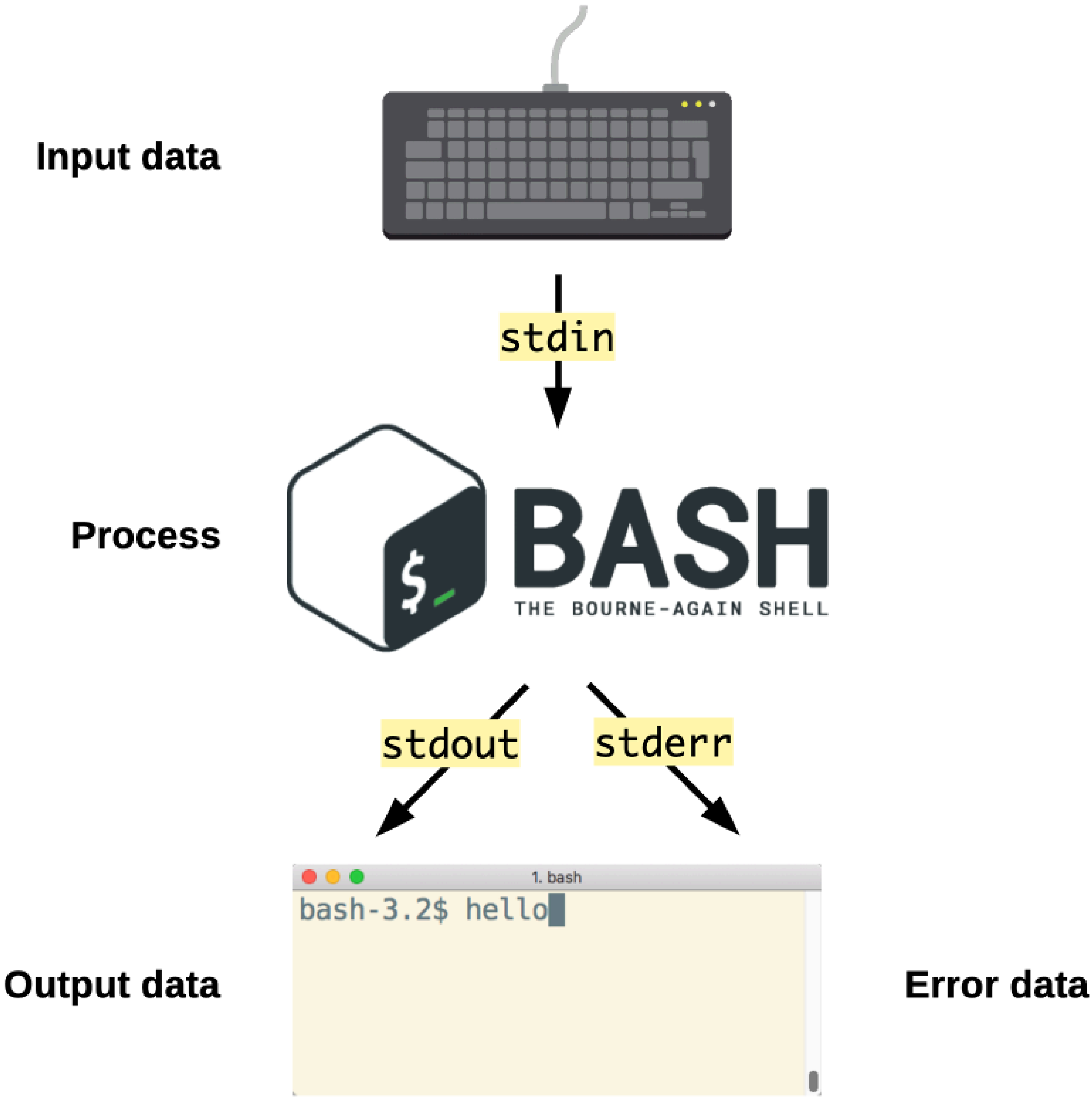


Streams, the keyboard, and the terminal

Another Unix breakthrough was to **automatically associate**:

- The **input stream** with your **terminal keyboard**;
- The **output and error streams** with your **terminal display**.

This is done by default unless a program chooses to do otherwise.



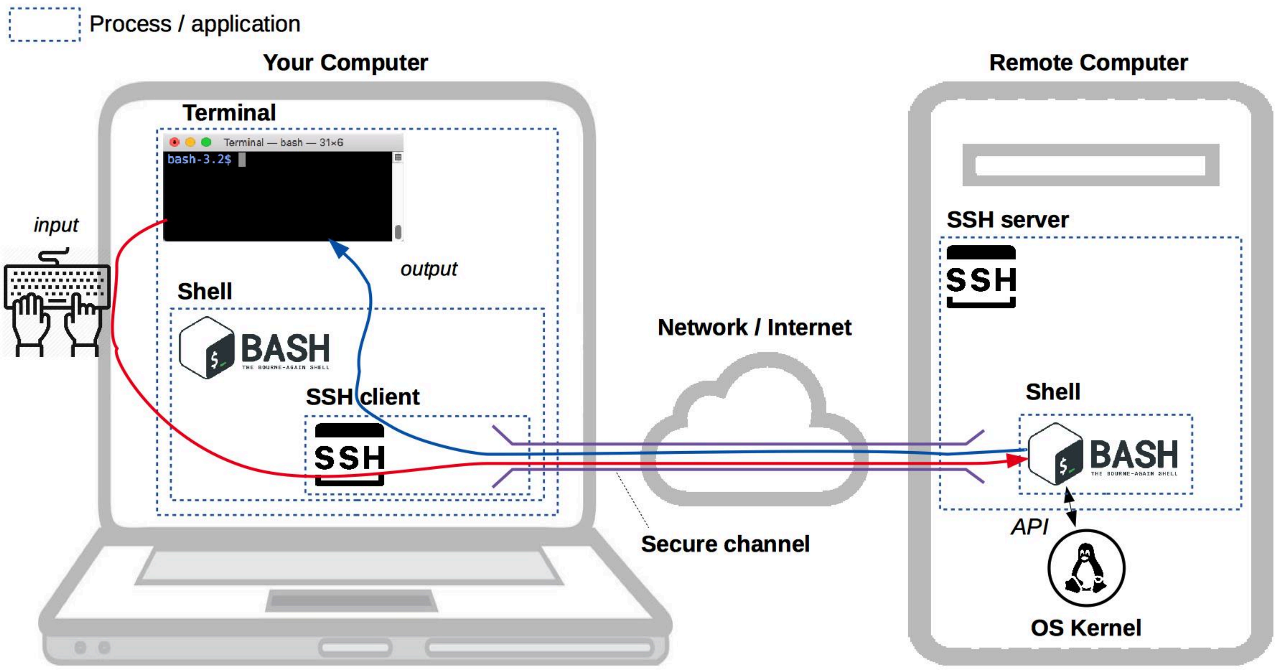
For example, when your favorite shell, e.g. [Bash](), is running, it automatically receives keyboard input, and its output data and errors are automatically displayed in the terminal.

Stream inheritance

A child will **automatically inherit the standard streams of its parent process** (unless redirected, more on that later).

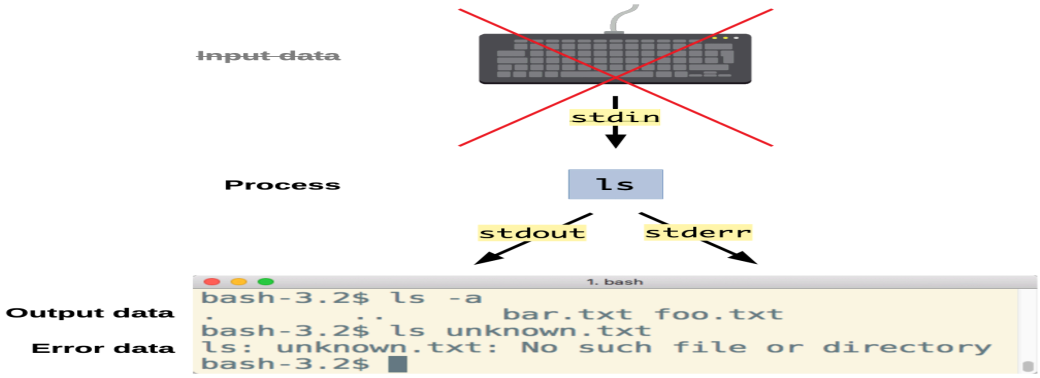
For example, when you run an `ls` command, you do not have to specify that the resulting list of files should be displayed in the terminal. The standard output of the parent process, in this case your shell (e.g. Bash) is inherited by the `ls` process.

Similarly, when you run the `ssh` command to communicate with another machine, you do not have to explicitly connect your keyboard input to this new process. As the SSH client is a child process of the shell, it inherits the same standard input.



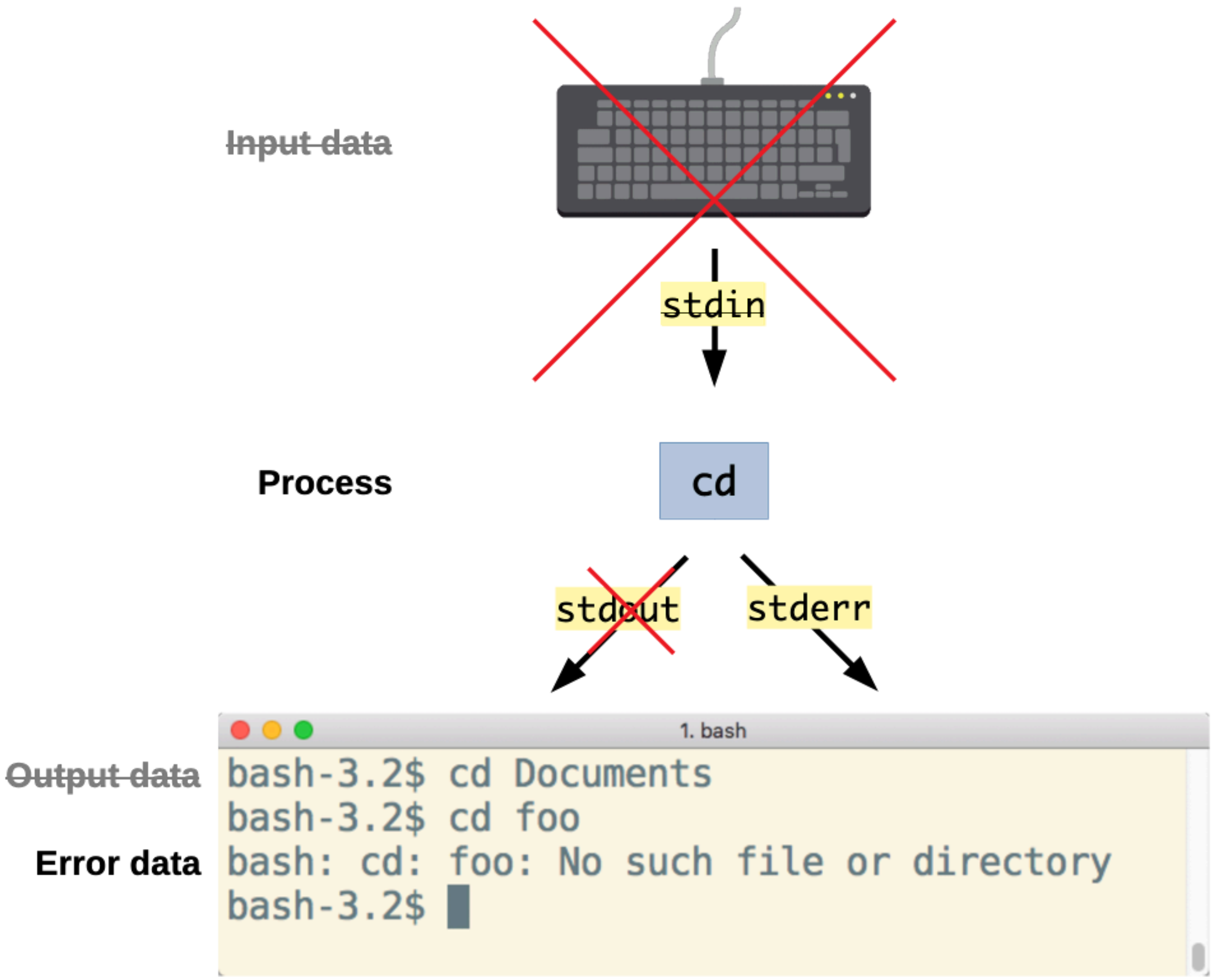
Optional input stream

A process is not obligated to use its input or output streams. For example, **the `ls` command** produces output (or an error) but **takes no input** (it has arguments, but that does not come from the input data stream).



Optional output stream

The `cd` command takes no input and **produces no output** either, although it can produce an error.



Stream redirection

The standard streams can be **redirected**.

Redirection means capturing output from a file or command, and sending it as input to another file or command.

Any Unix process has a number of file descriptors. They are an abstract indicator used to access a file or other input/output resource such as a pipe (we'll talk about these later) or socket.

The first three file descriptors correspond to the standard streams by default:

File descriptor	Stream
`0`	**St**an**d**ard **in**put (`stdin`)
`1`	**St**an**d**ard **out**put (`stdout`)
`2`	**St**an**d**ard **err**or (`stderr`)

Redirect standard output stream

The `>` shell operator **redirects an output stream**.

For example, the following line runs the `ls` command, but instead of displaying the result in the terminal, the **standard output stream (file descriptor `1`) is redirected** to the file `data.txt`:

```
$> ls -a 1> data.txt

$> ls
data.txt

$> cat data.txt
```

```
.
..
file1
directory1
...
```

How to use standard output redirection

You can do the same with any command that produces output:

```
$> echo Hello 1> data.txt

$> cat data.txt
Hello
```

Note that the `>` operator **overwrites the file**. Use `>>` instead to **append to the end of the file**:

```
$> echo World 1>> data.txt

$> cat data.txt
Hello
World
```

If you specify no file descriptor, **standard output is redirected by default**:

```
$> echo Hello > data.txt
$> echo Again >> data.txt
$> cat data.txt
Hello
Again
```

Redirect standard error stream

Note that error messages are not redirected using the redirect operator (`>`) like in the previous example. Errors are still displayed in the terminal and the file remains empty:

```
$> ls unknown-file > error.txt
ls: unknown-file: No such file or directory

$> cat error.txt
```

This is because **most commands send errors to the standard error stream (file descriptor `2`)** instead of the standard output stream.

If you want to redirect the error message to a file, you must **redirect the standard error stream instead**:

```
$> ls unknown-file 2> error.txt

$> cat error.txt
ls: unknown-file: No such file or directory
```

Both standard output and error streams

Some commands will **send data to both output streams** (standard output and standard error). As we've seen, both are displayed in the terminal by default.

For example, the `curl` (**C**lient **URL**) command is used to make HTTP requests. By default, it only outputs the HTTP response body to the standard output stream, but with the `-v` (**v**erbose) option it also prints diagnostics information to the standard error stream:

```
$> curl -L -v https://git.io/fAp8D
  % Total    % Received % Xferd  Average Speed   Time    Time     Time  Current
```

```
                                 Dload  Upload   Total   Spent    Left  Speed
  0     0    0     0    0     0      0      0 --:--:-- --:--:-- --:--:--     0
 TCP_NODELAY set
 Connected to git.io (54.152.127.232) port 443 (#0)
...
Hello World
...
```

Here, `Hello World` is the output data, while the rest of the output is the diagnostics information on the standard error stream.

Redirect standard output stream (curl)

This example demonstrates how the **standard output and error streams** can be **redirected separately**.

The following version redirects standard output to the file `curl-output.txt`:

```
$> curl -L -v https://git.io/fAp8D > curl-output.txt
  % Total    % Received % Xferd  Average Speed   Time    Time     Time  Current
                                 Dload  Upload   Total   Spent    Left  Speed
  0     0    0     0    0     0      0      0 --:--:-- --:--:-- --:--:--     0
 TCP_NODELAY set
 Connected to git.io (54.152.127.232) port 443 (#0)
...

$> cat curl-output.txt
Hello World
```

As you can see, the `Hello World` output data is no longer displayed since it has been redirected to the file, but the diagnostics information printed on the standard error stream is still displayed.

Redirect standard error stream (curl)

The following version redirects standard error to the file `curl-error.txt`:

```
$> curl -L -v https://git.io/fAp8D 2> curl-error.txt
Hello World

$> cat curl-error.txt
  % Total    % Received % Xferd  Average Speed   Time    Time     Time  Current
                                 Dload  Upload   Total   Spent    Left  Speed
  0     0    0     0    0     0      0      0 --:--:-- --:--:-- --:--:--     0
 TCP_NODELAY set
 Connected to git.io (54.152.127.232) port 443 (#0)
...
```

This time, the `Hello World` output data is displayed in the terminal as with the initial command, but the diagnostics information has been redirected to the file.

Redirect both standard output and error streams (curl)

You can **perform both redirections at once** in one command:

```
$> curl -L -v https://git.io/fAp8D > curl-output.txt 2> curl-error.txt

$> cat curl-error.txt
  % Total    % Received % Xferd  Average Speed   Time    Time     Time  Current
                                 Dload  Upload   Total   Spent    Left  Speed
  0     0    0     0    0     0      0      0 --:--:-- --:--:-- --:--:--     0
 TCP_NODELAY set
 Connected to git.io (54.152.127.232) port 443 (#0)
...

$> cat curl-output.txt
Hello World
```

Combine standard output and error streams (curl)

In some situations, you might want to **redirect all of a command's output** (both the standard output stream and error stream) to the same file.

You can do that with the `&>` operator:

```
$> curl -L -v https://git.io/fAp8D &> curl-result.txt

$> cat curl-result.txt
  % Total    % Received % Xferd  Average Speed   Time    Time     Time  Current
                                 Dload  Upload   Total   Spent    Left  Speed
  0     0    0     0    0     0      0      0 --:--:-- --:--:-- --:--:--     0
 TCP_NODELAY set
 Connected to git.io (54.152.127.232) port 443 (#0)
...
Hello World
...
```

> 💎 **Tip**
>
> `&> file.txt` is equivalent to using both `1> file.txt` and `2> file.txt`.

Discard an output stream

Sometimes you might not be interested in one of the output streams.

For example, let's say you want to display the diagnostics information from a `curl` command to identify a network issue, but you **don't care about the standard output**. You don't want to have to delete a useless file either.

The `/dev/null` device

The file `/dev/null` is available on all Unix systems and is a **null device** (sometimes also called a *black hole*). It's a Unix device file that you can write anything to, but that will discard all received data.

It never contains anything:

```
$> cat /dev/null
```

Even after you write to it:

```
$> echo Hello World > /dev/null

$> cat /dev/null
```

Redirect a stream to the null device

When you don't care about an output stream, you can simply **redirect it to the null device**:

```
$> curl -L -v https://git.io/fAp8D > /dev/null
  % Total    % Received % Xferd  Average Speed   Time    Time     Time  Current
                                 Dload  Upload   Total   Spent    Left  Speed
  0     0    0     0    0     0      0      0 --:--:-- --:--:-- --:--:--     0
 TCP_NODELAY set
 Connected to git.io (54.152.127.232) port 443 (#0)
...
```

In this example, the standard output stream is redirected to the null device, and therefore discarded, while the standard error stream is displayed normally.

Other redirections to the null device

You can also redirect the standard error stream to the null device:

```
$> curl -L -v https://git.io/fAp8D 2> /dev/null
Hello World
```

Or you can redirect both output streams. In this case, all output, diagnostics information and error messages will be discarded:

```
$> curl -L -v https://git.io/fAp8D &> /dev/null
```

> **Note**
>
> Please send complaints to `/dev/null`.

Redirect one output stream to another

You can also redirect one output stream into another output stream.

For example, the `echo` command prints its data to the standard output stream by default:

```
$> echo Hello World
Hello World

$> echo Hello World > /dev/null

$> echo Hello World 2> /dev/null
Hello World
```

The `i>&j` operator redirects file descriptor `i` to file descriptor `j`.

This `echo` command has its data redirected to the standard error stream:

```
$> echo Hello World 1>&2
Hello World

$> echo Hello World > /dev/null 1>&2
Hello World
```

```
$> echo Hello World 2> /dev/null 1>&2
```

> 💎 **Tip**
>
> This can be useful if you're writing a shell script and want to print error messages to the standard error stream.

Redirect standard input stream

Just as a command's output can be redirected to a file, its **input can be redirected from a file**.

Let's create a file for this example:

```
$> echo foo > bar.txt
```

The `gzip` command **reads data from its standard input stream**, and with the `--stdout` option outputs the result to its standard output stream:

```
gzip --stdout < bar.txt > bar.txt.gz
```

> 📚 **More information**
>
> The above command combines two redirections to compress the contents of the `bar.txt` file and save the result into `bar.txt.gz`.

Here documents

The `<<` operator also performs **standard input stream redirection** but is a bit different. It's called a **here document** and can be used to send multiline input to a command or script, preserving line breaks and other whitespace. For example, you could use it to send a list of names or a set of commands to be executed to a script.

Typing the following `cat` command starts a here document delimited by the string `EOF`:

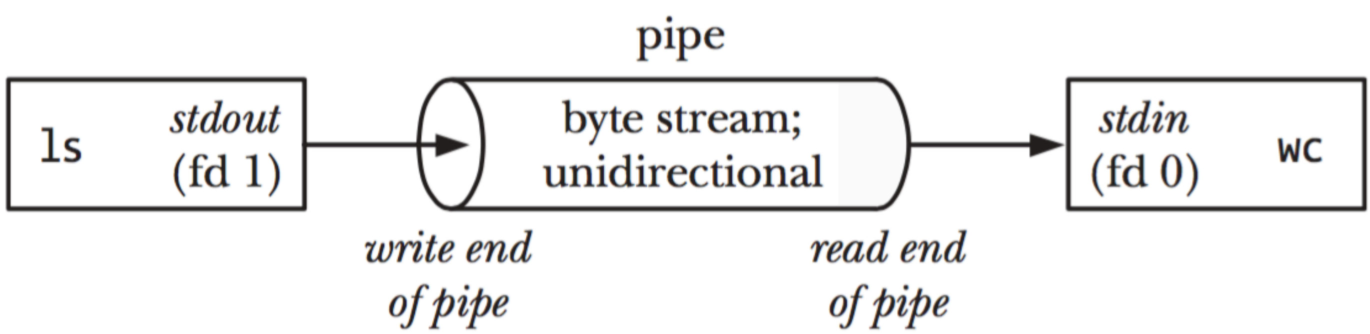
```
$> cat << EOF
heredoc> Hello
heredoc> World
heredoc> EOF
Hello
World
```

> 💎 **Tip**
>
> After you type the first line, you won't get a prompt back. The here document remains open and you can type more text. Typing `EOF` again and pressing `Enter` closes the document.

As you can see, the text you typed is printed by `cat`, with line breaks preserved.

Pipelines

The **Unix philosophy**: the power of a system comes more from the relationships among programs than from the programs themselves.



What is a pipeline?

Remember that all Unix systems standardize the following:

- All processes have a standard input stream.
- All processes have a standard output stream.
- Data streams transport text or binary data.

Therefore, the **standard output stream** of process A can be **connected to the standard input stream** of another process B.

Processes can be **chained into a pipeline, each process transforming data and passing it to the next process**.

Imagine a production chain, where the parts (data) go from one person (process) to the next until the final product is assembled.

A simple pipeline

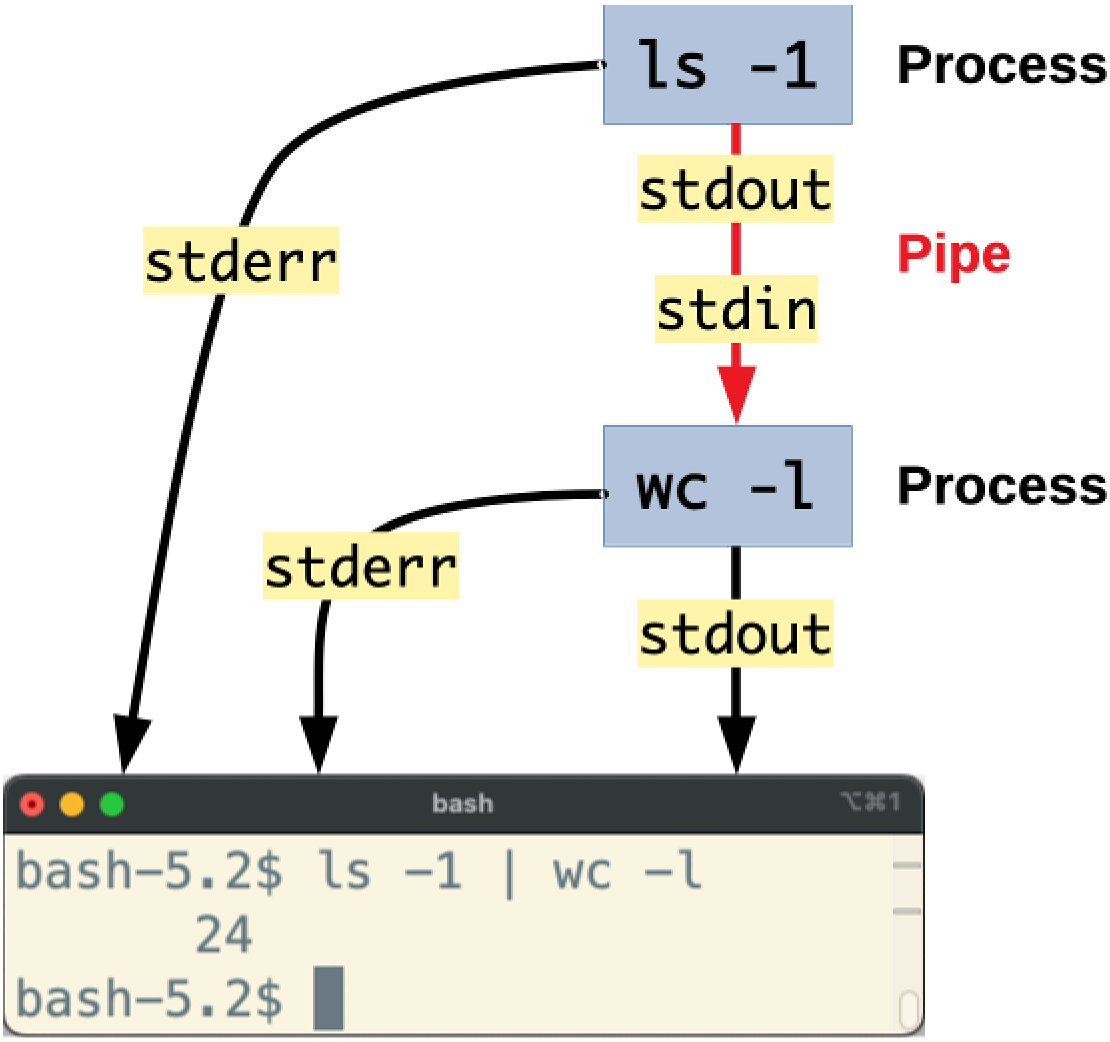
The `|` operator (a vertical pipe) is used to connect two processes together. Let's use two commands, one that prints text as output and one that reads text as input:

- The `ls` (**l**i**s**t) command produces a list of files, one by line with the `-1` option.
- The `wc` (**w**ord **c**ount) command can count words, **l**ines (with the `-l` option), characters or bytes in its input.

You can pipe them together like this:

```
$> ls -1 | wc -l
```

This **redirects (pipes) the output of the `ls` command into the input of the `wc` command**, which will tell us how many files there are in the listed directory.



The Unix philosophy

Pipelines are one of the core features of Unix systems.

Because **Unix programs** can be easily chained together, they **tend to be simpler and smaller**. Complex tasks can be achieved by chaining many small programs together.

This is, in a few words, the Unix philosophy:

- Write programs that **do one thing and do it well**
- Write programs to **work together**
- Write programs to **handle text streams**, because that is a universal interface

> 💎 **Tip**
>
> Although many programs handle text streams, others also handle binary streams. For example, the ImageMagick library can process images and the FFmpeg library can process videos.

A more complex pipeline

This command pipeline combines five different commands, processing the text data at each step and passing it along to the next command to arrive at the final result. **Each of these commands only knows how to do one job**:

```
$> find . -type f | \
   sed 's/.*\///' | \
   egrep ".+\.[^\.]+$" | \
   sed 's/.*\.//' | \
   sort | \
   uniq -c

  147 jpg
10925 js
 2158 json
   15 less
```

```
  45 map
1515 md
```

The final result is a list of file extensions and the number of files with that extension.

- `find` is used to recursively list all files in the current directory.
- `sed` (**s**tream **ed**itor) is used to obtain the files' basenames.
- `egrep` (**e**xtended **g**lobal **r**egular **e**xpression search and **p**rint) is used to filter out names that do not have an extension.
- `sed` is used again to transform basenames into just their extension.
- `sort` is used to sort the resulting list alphabetically.
- `uniq` is used to group identical adjacent lines and count them.

References

- The Linux Process Journey - PID 0 (swapper) - Shlomi Boutnaru
- The Linux Process Journey - PID 1 (init) - Shlomi Boutnaru
- The Linux Process Journey - PID 2 (kthreadd) - Shlomi Boutnaru
- SIGINT And Other Termination Signals in Linux
- What is the main purpose of the swapper process in Unix? - superuser
- I/O Redirection (The Linux Documentation Project)
- Here Documents (The Linux Documentation Project)
- Unix/Linux - Shell Input/Output Redirections
- Signals - Unix fundamentals 201 - Ops School Curriculum

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