Lecture 7: Escaping. Quotes. Handling processes and jobs.

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1. Escaping: `\`

Some characters in **Bash** have a special meaning. As an elementary example:

```
echo $var
```

would reference the content of variable named `var` since the variable is preceded with the special character `$`, but `$` itself would not appear in the printout. To see also the special character `$` in the printout, we need to *escape* (or kill) its special meaning with the backslash character `\`.

The escaping mechanism in **Bash** is illustrated in the following example:

```
var=44
echo $var
echo \$var
```

The above code snippet produces the following output:

```
44
$var
```

It is possible in the same way to escape the special meaning of any other special character, and in any other context (not necessarily only in their printout as demonstrated here). If there are multiple special characters in the input expression, they can be escaped one-by-one with backslash `\`.

As another example, we consider the double quotes `"..."`, which also have a special meaning in **Bash** (clarified in the next section!) and are not printed by default:

```
echo "Hi "there""
Hi there # no quotes in the printout
```

However, we can escape the special meaning of two inner-most quotes, and they will show up in the printout:

```
echo "Hi \"there\""
Hi "there"
```

Finally, we can also escape the special meaning of two outer-most quotes:

```
echo \"Hi \"there\"\"
"Hi "there""
```

As another example, we compare:

```
echo "Today is: $(date)"
Sat Jun  6 19:24:20 CEST 2020
```

with

```
echo "Today is: \$(date)"
Today is: $(date)
```

In the second example nothing happened, because the command substitution operator was escaped.

We have already seen that in **Bash** the command input is terminated either with semicolon `;` or with the new line. Frequently, the command input needs to span over a few lines in the terminal, and in order to handle such a case, we need to escape the end of the line, i.e. we need to kill the special meaning of a new line. To achieve that, it suffices to place backslash `\` at the very end of the line:

```
echo "Welcome \
to \
the \
lecture PH8124."
```

This produces the one-line output:

```
Welcome to the lecture PH8124.
```

When used to escape the new line, backslash `\` must be the very last character on that line. The frequent mistake occurs when `\` is followed by an empty character, because then it will merely escape the special meaning of an empty character, and not the special meaning of a new line.

Alternatively, we can escape the meaning of special characters with strong (single) quotes `'...'`, which is the topic of the next section.

2. Quotes: `'...'` and `"..."`

Strong (single) quotes

In complex expressions, containing a huge number of special characters, it becomes quickly impractical to escape the special meaning of each character separately with `\`. Instead, they can be escaped all in one go by embedding the whole expression within strong (single) quotes `'...'`. This is the primary use case of strong quotes, and their meaning can be literally understood with the following phrase: *what you see is what you get*.

For instance:

```
Var1=44
Var2=440
echo '$Var1   $Var2'
```

The printout is literally:

```
$Var1   $Var2
```

Neither variable was referenced, because the special meaning of both `$`'s was killed with strong quotes, and the exact number of empty characters was also preserved in the printout.

Strong quotes are used frequently to pass the file or directory whose name contains empty characters:

```
ls 'crazy name'
```

Without strong quotes, the command **ls** would interpret 'crazy' and 'name' separately, as two different arguments.

To illustrate the importance of strong quotes, consider the following example:

```
echo 100 > 10 # WRONG!!
```

We wanted to print a literal inequality, `100 > 10`, on the screen but the above code snippet didn't produce any printout on the screen. Instead, something completely different has happened: **echo** printed only `100` but that was redirected immediately into the file named `10`. We can circumvent this problem with:

```
echo '100 > 10'
100 > 10
```

Single quotes may not occur between single quotes, even when preceded by a backslash.

As the last remark, strong quotes appear in a rarely used context, which is here outlined just for completeness sake. Some characters cannot be represented with the literal syntax, instead, we need to use *backslash-escaped characters* for them. The best examples are new line and tab space, which are represented with '\n' and '\t', respectively. However, neither **Bash** nor a lot of **Linux** commands by default interpret such backslash-escaped characters. For instance:

```
echo "Hi\nthere"
```

prints literally:

```
Hi\nthere
```

We need to instruct **echo** to interpret backslash-escaped characters by supplying a flag '-e':

```
echo -e "Hi\nthere"
```

The printout it now:

```
Hi
there
```

Similarly:

```
echo -e "Hi\tthere"
```

prints the tab space:

```
Hi      there
```

and so on.

In general, we can force **Bash** to interpret directly the backslash-escaped characters by using the following generic syntax**:**

```
$'whatever'
```

With this syntax, we do not rely any longer on the details of command implementation, and whether there exists some option, like '-e' for **echo**, which will instruct the command to interpret backslash-escaped characters. For instance:

```
echo $'Hi\nthere'
```

will print:

```
Hi
there
```

Now **Bash** has interpreted the special meaning of '\n' character, not the **echo** command.

Example: Prompt the user with the following multi-line question in **read** command:

```
Dear User,
do you want to continue [Y/n]?
```

The problem here is that the command **read**, unlike **echo**, does not have a specialized flag to interpret the backslash-escaped characters. Therefore, the simplest solution is to use `$` in combination with single quotes:

```
read -p $'Dear User,\ndo you want to continue [Y/n]? ' Answer
```

In the next section, we clarify the meaning of weak (double) quotes `"..."`.

Weak (double) quotes

Unlike the strong quotes, the weak (double) quotes `"..."` preserve the special meaning of some special characters, while the special meaning of all others is stripped off. Just like within strong quotes, within double quotes the empty character does not retain its special meaning, i.e. it is not any longer the default field separator. The exact number of empty characters is preserved within weak quotes:

```
echo "a b    c"
echo  a b    c
```

The output is:

```
a b    c
a b c
```

We can now compare the effect of two types of quotes in the following example:

```
var1=44
var2=440
```

- no quotes:

  ```
  echo $var1   $var2
  44 440
  ```

- strong quotes:

  ```
  echo '$var1   $var2'
  $var1   $var2
  ```

- weak quotes:

  ```
  echo "$var1   $var2"
  44   440
  ```

In each case, we got a different result. Within double quotes, the content of variables is referenced with the special character `$` , and the exact number of empty characters is preserved.

The special meaning of the following special characters or constructs are preserved within weak quotes `"..."`:

- `$` : referencing content of variable
- `$( ... )` : command substitution operator
- `$(( ... ))` : arithmetic expression evaluation
- `\` : backslash preserves its special meaning within double quotes only in some cases, for instance, when it is followed by `$`, `"`, `\`, or newline.

Nested double quotes are allowed as long as the inner ones are escaped with `\` . For instance,

```
echo "\"test\""
```

prints

```
"test"
```

as expected. On the other hand, single quotes have no special meaning within double quotes:

```
var=44
echo "'$var'"
```

prints

```
'44'
```

To memorize the rules easier, to leading order only the **Bash** constructs which begin with `$` or `\` keep their special meanings within double quotes.

3. Handling processes and jobs

In **Linux** world, an executable stored on disk is called a *program*. Loosely speaking, the program loaded into the computer's memory and running is called a *process*. On the other hand, *job* is more specifically a process that is started by a shell. A group of processes launched from a shell can be also considered as a job. Therefore, a job is a shell-only concept, while a process is a more general, system-wide, concept. There are specific **Bash** and **Linux** commands which keep track only of jobs launched from the current shell, but there are also commands which keep track of all processes running on the computer. Therefore, it is important to understand the difference between processes and jobs, and in which context which commands for their handling need to be used.

Jobs launched from the shell can be divided into two important groups: *foreground* and *background* jobs. Foreground jobs are jobs that have control over the terminal, i.e. while they are running nothing else can be done in the current terminal session by the user. The control over the terminal is regained only when the foreground job has finished its execution. Background jobs are jobs that do not have control over the terminal during their execution. They are typically started on multicore machines, when the parallelization of jobs makes perfect sense and reduces a lot the overall execution time. While jobs launched from the current terminal session are running in the background, in that terminal session we have full control over the terminal and can do whatever we want.

By default, any job which is started from the terminal is executed in the foreground. If we want to submit a job execution to the background, we need to end the command line input with the special character `&` . For testing purposes, in this section we use the dummy command **sleep**, which runs a perfectly valid process even though it does nothing besides blocking the execution of subsequent commands for the specified time interval. Whatever is demonstrated in this section for the **sleep** command applies also to any other command, we use **sleep** command merely because of its simplicity. In addition, a word command is used in this section in the broader sense, and it encapsulates also functions, scripts, code blocks, etc.

To illustrate the difference between foreground and background job execution, we first execute a job in the foreground:

```
sleep 10s
```

With this syntax, the command **sleep** runs in the foreground and therefore it takes over the control over the terminal during its execution. What happens now is that for 10s nothing else can be done in the terminal, until the command **sleep** terminates. If we would have started some other command in the foreground, in the very same spirit during the execution of that command, we could not do anything in the terminal, until that command terminates.

With the slightly modified syntax, we can execute a job in the background:

```
sleep 10s &
```

By using the special character `&` at the end of the command input, we have sent the execution of command **sleep** in the background. The main difference to the previous case is that now we can continue immediately to execute another command in the terminal, while the command **sleep** is running in parallel in the background.

When in some **Bash** code a command is started in the background with `&` at the end of command input, that command essentially starts off another process in parallel (that processes *forks off* from the current shell). Note, however, that the *stdout* stream of the forked process is still attached to the shell from which the job was sent to the background, which means that any output of that job will still appear in your terminal, even if the job is running in the background. This sometimes leads to surprising printout in the terminal, if the *stdout* stream of background job was not redirected somewhere else (e.g. to some file or to `/dev/null`).

It is also perfectly feasible to launch in the same command input multiple processes in separate background sessions:

```
sleep 10s & sleep 20s & sleep 30s &
```

With the above syntax, we have three instances of **sleep** command running in parallel in the background. Analogously, we can start off any other three commands to run in parallel in the background.

Next, we will see how a process can be handled programmatically either via its *Process ID (PID)* or its *Job Number*.

Process IDs and Job Numbers

Linux gives to each process the unique number, called *Process ID (PID)*, when the process was created. On the other hand, **Bash** gives to each job also the number, called *Job Number*, when some process was started in the current shell. Therefore, each process has a unique system-wide PID, while job numbers are unique only within the current terminal. Each terminal keeps track of its own job numbers. The PID of the running process is the same in all terminals. In general, we can handle programmatically in any terminal a running process via its PID, and in the specific terminal both with its PID and with a job number corresponding only to that specific terminal.

The difference between PID and job number is illustrated with the following code snippet:

```
sleep 10m &
[1] 15
```

In the above example, the number `15` is a system-wide PID, given by **Linux** to the command **sleep 10m** executed in the background. This information is accessible in any terminal on the computer, i.e. `15` is the unique identifier for the command **sleep 10m** across the whole computer. If multiple users are using the same computer, PID is unique for all processes of all

users, which is an essential feature for multitasking.

On the other hand, `[1]` is the job number given by **Bash** (not by the operating system!), to the command **sleep 10m** sent to the background. This information is visible only to the terminal in which this command was executed. In particular, `[1]` in this example indicates that this is the first job sent to the background in the current terminal session, and which is still running. If we have another open terminal, in that terminal `[1]` indicates a completely different job. When job execution of all jobs running in the background terminates, the job counter is reset, and `[1]` can be given later to some other job sent to the background, in the same terminal.

The two most frequently used commands to handle running jobs and processes programmatically are **jobs** and **top**. In order to get the list of running jobs which were submitted only from the current terminal, we can use:

```
jobs -l
```

The output of this command might look for instance:

```
[1]+    15 Running                 sleep 10m &
```

The above output literally means that in the current terminal session there is one job, which:

- was started with the command input **sleep 10m &**
- at the moment is in the state 'Running'
- its job number is `[1]`
- its PID is `15`

Other possible job states include 'Done', 'Terminated', 'Hangup', 'Stopped', 'Aborted', 'Quit', 'Interrupt', etc., and some of them are discussed in detail later.

If we execute another command, for instance:

```
sleep 20m &
jobs -l
```

we now see that both commands are running in parallel in the background (remember, we use **sleep** for its simplicity of usage, but what is explained here applies to any other command):

```
[1]-    15 Running                 sleep 10m &
[2]+    17 Running                 sleep 20m &
```

In the above output, symbol `+` next to the job number indicates the most recent job sent to the background in the current terminal, while symbol `-` indicates the one before the most recent job sent to the background. Only these two jobs get the special treatment and notation in the output of **jobs** command.

We now demonstrate how the running job or process can be terminated programmatically. To terminate the particular job, we need to use the **Bash** built-in command **kill**, either by specifying job number or PID as an argument. The syntax is a bit different, to kill a job by job number we use:

```
kill %2
```

and to kill a job via PID we use:

```
kill 17
```

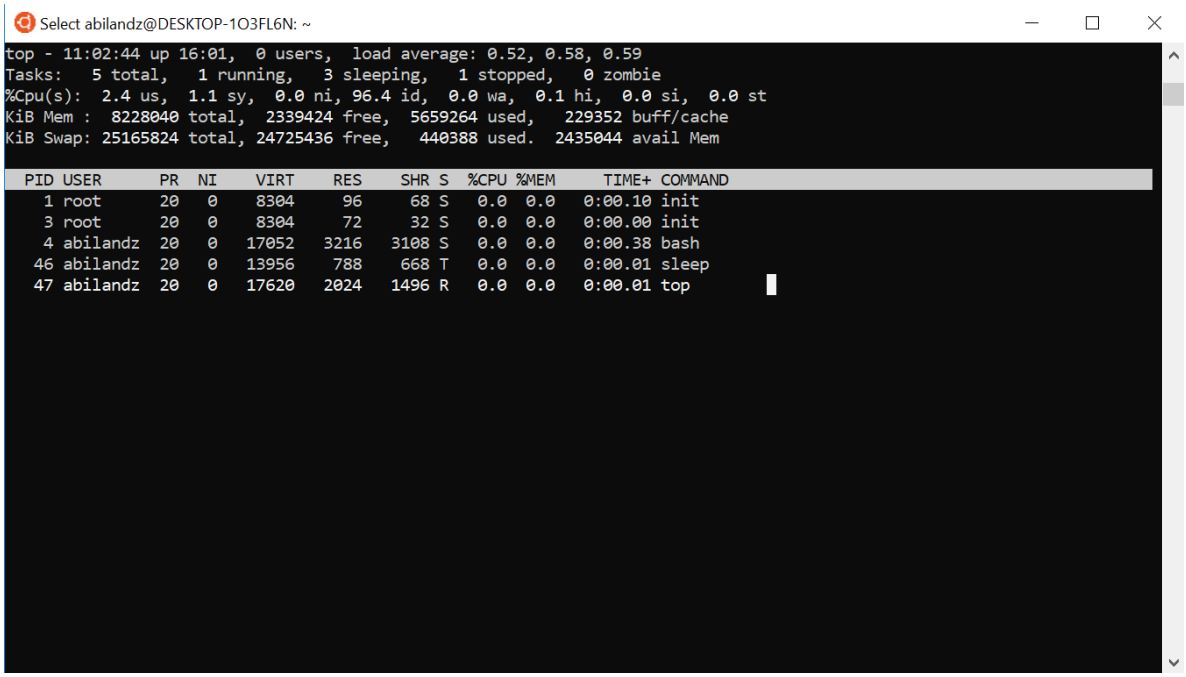
Note the usage of percentage symbol `%` in the first case---without it, **Bash** would attempt to kill the process with system-wide PID 2. Only after the percentage symbol `%` is used, **Bash** will interpret the following number as the job number, which is specific and known only to the current terminal. Note also that only the second version can be used from any terminal, as the PID of any job or process is the same in all terminals. Later we will see that the command **kill**, despite its terse name, can do much more than mere termination of running jobs.

We have seen already how we can get the list of all background jobs started from the current terminal with **jobs -l** command. With the more general command named **top** we can get the list of all running processes on the computer, from all users, running both in foreground and background.

After executing in the terminal:

```
top
```

the output could look like this:



The command **top** continuously updates the terminal display with the summary of the current status of system resources followed by the list of most CPU-intensive processes (default ordering). The first column contains the PID of each running process, followed by the user name, priority of the process, 'nice' value of the process, memory and CPU consumption, total running time, etc. In order to parse the output of **top** programmatically, or to redirect it to some file, we need to run command **top** in the batch (text) mode via:

```
top -b
```

We can dump the output of **top** command to some external file with the following syntax:

```
top -b > topOutput.log
```

We can also pipe that output so some other command, for instance:

```
top -b | grep ${USER}
```

The above code snippet filters out only the information relevant for your own processes.

The command **top** can be run from any terminal on the computer, and its printout to a large extent will be the same in each terminal. On the other hand, the output of the command **jobs** will be completely different from one terminal to another.

Closely related to **top** command is **ps** command (see the corresponding 'man' pages), which gives only the current snapshot of currently active processes, while **top** is being continuously updated and can be used interactively.

In the case you are interested only in the PID of the running process, there is also a command **pidof**, which takes as an argument only the process name:

```
sleep 10s &
[1] 433
pidof sleep
433
```

This command becomes very handy if there are multiple instances of the same command running in parallel, and we need to get PIDs of all of them. For instance:

```
sleep 10s & sleep 20s & sleep 30s &
[1] 587
[2] 588
[3] 589
```

We now have 3 instances of the same command **sleep** running in parallel. We can get the list of all PIDs corresponding to different instances of the same command with:

```
pidof sleep
587 588 589
```

There is also a related command **pkill**, which can terminate on the spot all running instances of the same command, just by its name. For the above example, we can terminate all 3 instances of the command **sleep** running in parallel as follows:

```
pkill sleep
[1]   Done                    sleep 10s
[2]   Done                    sleep 20s
[3]-  Done                    sleep 30s
```

To conclude this section, we remark that one very important process is always listed in the output of **top** command and is called **init**. The process **init** is the grandfather of all processes on the system because all other processes run under it. Every process can be traced back to **init**, and it always has a PID of 1.

Moving job execution from background to foreground, and vice versa

We have already seen how the job execution can be sent to the background by appending the special character `&` to the command input. The similar functionality can be achieved with the **Bash** built-in command **bg**, only the syntax and typical use cases are slightly different. Typically, the command **bg** is used after the job was started in the foreground, but then for one reason or another, we need to regain control over the terminal in order to do something else. The trivial solution is to terminate the running job, and then restart it later from scratch. But there is a more elegant and efficient solution, which amounts to the following two generic steps:

1. Suspend the foreground job with `Ctrl+Z`
2. Resume (not restart!) the suspended job in the background with **bg** command

This is best illustrated with the concrete example. Imagine that we have started in the foreground the following command (we stress it out again that the following discussion applies to any other command, **sleep** is used only because of its simplicity!):

```
sleep 10m
```

Now the terminal is blocked for 10 minutes because the command **sleep** is running in the foreground. We can, however, suspend the execution of the command **sleep** by pressing `Ctrl+Z` and regain control of the terminal. After we have regained the control over the terminal, we can start executing other commands. In the meanwhile, the suspended command doesn't do anything:

```
jobs -l
[2]+    15 Stopped                 sleep 10m
```

After pressing `Ctrl+Z` the job was not killed or terminated, it was suspended. The job remains in exactly the same state as it was at the time of the suspension. The suspended job does literally nothing, it is on hold until its execution is resumed. From the user's perspective, the execution of this job appears to be paused. In the output of command **jobs -l** the state description 'Stopped' is a bit misleading, and 'Paused' or even 'Frozen' would be a much better word to describe the state of the job after we suspended it with `Ctrl+Z`. The suspended job will no longer use any CPU, but it will, however, still claim the same amount of RAM. This last fact implies that we can re-start it anytime later and it will continue where it stopped.

To restart the suspended job in the background, we can use the following generic syntax:

```
bg %jobNumber
```

To re-start in the background the above **sleep** command, whose job number is `2`, we need to use:

```
bg %2
```

There is an alternative syntax, which is more limited in scope but sometimes can be nevertheless handier---to restart the suspended job in the background we can also use:

```
bg %commandName
```

If we have only one instance of a given command running and suspended, it suffices to specify only the name of that command to restart it in the background, i.e. it is not needed to specify all options and arguments. However, if we have multiple instances of the same command running with different options and arguments, the whole composite command input needs to be enclosed within strong quotes, for instance:

```
bg %'sleep 10m'
```

If we have multiple instances of the same command running with exactly the same options and arguments, clearly the 2nd version becomes ambiguous. However, we can in that case still use the first syntax and restart the suspended job in the background via its job number, which is always unique.

After restarting the suspended job in the background, we see the following:

```
jobs -l
[2]+    15 Running                 sleep 10m &
```

This is precisely what we wanted to achieve: We have suspended with `Ctrl+Z` the job running in the foreground which was blocking the terminal input, and then restarted its execution in the background with the command **bg %jobNumber**. While that job is now running in parallel in the background, we can do our thing in the terminal again. As the last remark, we stress out that the command **bg** can accept as an argument the job number, but not its PID.

A closely related command is the **Bash** built-in command **fg**. This command moves the jobs running in the background to the foreground. Before discussing its syntax, we first stress out the following important fact: It is impossible solely by using **Bash** built-in features to bring to the foreground a process running in the background in the current shell instance if it was not started in the background from the current shell instance. Basically, this means that you cannot in the current terminal take over a process that was started in a different terminal. To achieve that level of flexibility, there are specialized programs available that allow us to move other programs around from one shell instance to another, for instance **screen**.

After using command **fg**, the background job is continuing to run in the foreground and is, therefore, taking over the control over the terminal. Generically, the syntax of **fg** command is:

```
fg %jobNumber
```

or the alternative version

```
fg %commandName
```

The explanation for both versions of the syntax is the same as for the **bg** command outlined previously, and we do not repeat it here.

We illustrate the usage of **fg** command with the following simple example. First, we launch the command **sleep** (or any other command) in the background:

```
sleep 30m &
```

The relevant line in the output of **jobs -l** command might look like:

```
[5]   5194 Running                 sleep 30m &
```

If we want to bring to the foreground the execution of this background job, we need to use either:

```
fg %5
```

or

```
fg %'sleep 30m'
```

If used without arguments, both **bg** and **fg** commands act on the most recent job.

We finalize this section by mentioning that **Bash** provides the two special variables relevant in this context:

- `$$` : this variable holds the PID of the currently running process
- `$!` : this is the PID of the last job sent to the background

For instance, we can programmatically close the current terminal session by using:

```
kill -9 $$
```

The above line can be placed at the end of the script, if after the script execution we do not need that terminal session any longer. The meaning of option `-9` to command **kill** will be clarified a bit later.

The second special variable, `$!`, has a very neat use case in combination with the **Bash** built-in command **wait**. Quite frequently, we can release the execution burden on the current script by sending part of the execution to the separate processes to run in parallel in the background. We can hold the execution of the main script, and continue only when the last job sent to the background has terminated, with the following syntax:

```
wait $!
```

However, it can happen that the last job sent to the background has terminated before than some other jobs sent to the background earlier. This problem is fixed with the even simpler syntax:

```
wait
```

With the above syntax, the execution of the main script will wait until all jobs running in the background are terminated. This feature is extremely neat on multicore machines: Whenever your script is facing some CPU intensive task, that task can be split across multiple processes, and then each process can be sent independently to the background:

```
commandInput1 &
commandInput2 &
...
wait
```

With the above syntax, while processes **commandInput1**, **commandInput2**, ..., are all running in parallel in the background, the main script waits with further execution. Only when all background processes have terminated, the main script will proceed with further execution.

The classical example when the above functionality can be used is the case when we need to process large datasets. The starting large dataset can be split into subsamples, and then each subsample can be analyzed in parallel, schematically:

```
commandName subsample1 &
commandName subsample2 &
...
wait
```

The main script waits all jobs running in parallel in the background to terminate, and then merely collects the output result of each job, and combines them to obtain the final, large statistic result. Clearly, this feature can considerably speed up the script execution on multicore machines, and all this can be achieved programmatically.

Sending signals to the running processes

We have already seen that we can suspend the running job by hitting `Ctrl+Z`, and that we can terminate the running job by executing the command input **kill -9 processPID** in the terminal. Conceptually, there is no much of a difference in what is happening in these two cases, and these two examples are just a small subset of *signals* that we can send to the process. In this section we cover in detail from the user's perspective how the signals can be sent programmatically to the running processes, and modify their running conditions on the fly. In the next section, we will cover this topic from the developer's side, i.e. we will discuss the code implementation which is needed to enable the process to receive and handle the signals while running.

Loosely speaking, a signal is a message that a user sends programmatically to the running process. One running process can also send a signal to another running process. A signal is typically sent when some abnormal event takes place or when we want another process to do something per explicit request. As we already saw, two processes can communicate with pipes `|`. Signals are another way for running processes to communicate with each other.

All available signals have:

- numbers (starting from 1)
- names

To get the list of all signals on your system by name and number, we can execute:

```
kill -l
```

The output could look like:

```
 1) SIGHUP       2) SIGINT       3) SIGQUIT      4) SIGILL       5) SIGTRAP
 6) SIGABRT      7) SIGBUS       8) SIGFPE       9) SIGKILL     10) SIGUSR1
11) SIGSEGV     12) SIGUSR2     13) SIGPIPE     14) SIGALRM     15) SIGTERM
16) SIGSTKFLT   17) SIGCHLD     18) SIGCONT     19) SIGSTOP     20) SIGTSTP
21) SIGTTIN     22) SIGTTOU     23) SIGURG      24) SIGXCPU     25) SIGXFSZ
26) SIGVTALRM   27) SIGPROF     28) SIGWINCH    29) SIGIO       30) SIGPWR
31) SIGSYS      34) SIGRTMIN    35) SIGRTMIN+1  36) SIGRTMIN+2  37) SIGRTMIN+3
38) SIGRTMIN+4  39) SIGRTMIN+5  40) SIGRTMIN+6  41) SIGRTMIN+7  42) SIGRTMIN+8
43) SIGRTMIN+9  44) SIGRTMIN+10 45) SIGRTMIN+11 46) SIGRTMIN+12 47) SIGRTMIN+13
48) SIGRTMIN+14 49) SIGRTMIN+15 50) SIGRTMAX-14 51) SIGRTMAX-13 52) SIGRTMAX-12
53) SIGRTMAX-11 54) SIGRTMAX-10 55) SIGRTMAX-9  56) SIGRTMAX-8  57) SIGRTMAX-7
58) SIGRTMAX-6  59) SIGRTMAX-5  60) SIGRTMAX-4  61) SIGRTMAX-3  62) SIGRTMAX-2
63) SIGRTMAX-1  64) SIGRTMAX
```

When we are executing in the terminal:

```
kill -9 somePID
```

we are essentially sending the signal number `9`, i.e. the signal with the name `SIGKILL`, to the running process whose PID is `somePID` . For instance, if we start a process in the background:

```
sleep 10m &
[1] 9485
```

we can terminate it either with

```
kill -9 9485
```

or with

```
kill -SIGKILL 9485
```

In both cases, we get the same result:

```
jobs -l
[1]+  9485 Killed                  sleep 10m
```

For the most frequently used signals, there are also the case-insensitive shortcut versions, e.g.:

```
kill -KILL 9485
kill -kill 9485
```

From the table above, we see there are 64 different signals we can send to the running process. Note, however, that some signals are typically used only by the operating system, to tell the process that something went wrong (e.g. division by zero was encountered). As another remark, we indicate that it is somewhat more portable to use signal by its name instead of by its number across different platforms: It is unlikely that the name of the signal like `KILL` will be interpreted in any other way, however number `9` can be.

After we have illustrated the simple use case of **Bash** built-in command **kill**, let us now elaborate on it more in detail. The command **kill** is used to send signals to the already running job, or to any new job. If used without arguments, it will send the default signal to the running process. That default signal is `TERM` ('terminate', number 15), which usually has the same effect as the signal `INT` ('interrupt', number 2). Whenever we execute the following command in a shell:

```
kill somePID
```

we are essentially sending the signal `TERM` ('terminate') to the running process:

```
kill -TERM somePID
```

On the other hand, when we hit `Ctrl+Z` to suspend a running process, we are essentially using a shortcut for the following command input

```
kill -TSTP somePID
```

The signal `TSTP` ('suspend') has a signal number `20`, so pressing `Ctrl+Z` is also equivalent to the following:

```
kill -20 somePID
```

When we hit `Ctrl+C` to interrupt the running process, we are using a shortcut for sending the `INT` signal. Pressing `Ctrl+C` is therefore completely equivalent to:

```
kill -INT somePID
```

or a shorter version (see the above table):

```
kill -2 somePID
```

Yet another way to terminate a running process is to send the `QUIT` signal (number 3):

```
kill -QUIT somePID
```

This case typically produces the message 'core dumped', for instance:

```
sleep 20m &
[2] 11126
kill -QUIT 11126
jobs -l
[2]- 11126 Quit                  (core dumped) sleep 20m
```

The message `Quit (core dumped)` indicates that there is a file called 'core' which contains the image of the process to which you sent a signal. The name 'core' is a very old-fashioned name for computer's memory, and 'core dumps' are generated when the process receives certain signals (such as `QUIT`, `SEGV`, etc.), which the **Linux** kernel sends to the process when it accesses memory outside its address space.

Although it sounds trivial, it makes actually a big difference with which signal we kill the job. Recommended ordering of signals used to terminate the job is the following:

1. **kill** : the default signal is `TERM` (similar to `INT`). If we kill the process this way, we still give a chance to the process to clean up (for instance, to delete all temporary files it was using while running) before terminating. May or may not terminate the running job.
2. **kill -QUIT** : this dumps the process' memory image in the file named 'core', which can be used for debugging. May or may not terminate the running job.
3. **kill -KILL** : 'last-ditch', we use this as the very last resort. If we send this signal to the process, the process is killed by the operating system now and unconditionally. The process cannot clean up. The signal `KILL` always succeeds and terminates the running process, whatever are the consequences. If even this signal has failed, that means that the operating system has failed.

We remark that sending signals to the running job is not only about terminating its execution. For instance, we can resume programmatically the suspended job by sending it the signal `CONT` (number 18). That is illustrated with the following sequence:

```
sleep 44m &
[1] 12254
jobs -l
[1]+ 12254 Running                 sleep 44m &
kill -TSTP 12254
jobs -l
[1]+  Stopped                 sleep 44m
kill -CONT 12254
[1]+ 12254 Running                 sleep 44m &
```

In the next section we will see how we can further customize the signal catching.

At the end of this section, we stress out that, since the command **kill** can accept PID as an argument which is system-wide available, we can send signals to the jobs running in one terminal, by executing **kill** command with the specified signal in another terminal. In practice, if the running process has crashed and frozen the current terminal, we can still try to recover it by using its PID and sending to it signals with **kill** command from another terminal.

Catching signals in your own code

We have already seen how we can send the signal to the process, taking for granted that the implementation of that process has the relevant lines in the source code which can handle that particular signal. In this section, we clarify what is happening behind the scene when a process receives a signal.

We introduce and discuss first the commands which are used to handle programmatically the signal input. This can be achieved by using the **Bash** built-in command **trap**. In general, programs can be set up to trap specific signals, and interpret them in their own way. The command **trap** is used mostly for bullet-proofing, i.e. ensuring that your program behaves well under abnormal circumstances. The generic syntax of **trap** command is:

```
trap someCommand signal1 signal2 ...
```

The above generic syntax is interpreted as follows: When any of the signals `signal1`, `signal2`, `...`, is received, the following sequence follows:

1. pause the program execution and execute command **someCommand**
2. resume the program execution

After the execution of **someCommand** has terminated, the program execution resumes just after the command that was interrupted. In this context, **someCommand** can be also a script or a function. The signals `signal1`, `signal2`, `...`, can be specified either by signal name or by signal number.

The usage of **trap** is best illustrated with examples. We use the script named `trapExample.sh` with the following content:

```
#!/bin/bash

trap "echo Hi there!; echo How is life?" USR1
trap "pwd; ls" USR2

while :; do
 date
 sleep 10s
done

return 0
```

This script does nothing except that every 10 seconds prints the time stamp via **date** command. It is not possible to catch via **trap** the arbitrary user-defined signal, we have to use the standard 64 signals enlisted with **kill -l** (or **trap -l**). The closest we can get it to use `USR1` and `USR2` signals (numbers 10 and 12) as the standard supported signals reserved for the user's custom input.

We send this script to execute in the background via:

```
source trapExample.sh &
[1] 87
```

Every 10 seconds on the screen we get the timestamp printed, and in this simple example, that's the proof that our script is running. Now, while the script is running in the background, we start to communicate with our script by sending the signals to it:

```
kill -USR1 %1
```

The script pauses its execution, and responds to the signal `USR1` to produce the following output:

```
Hi there!
How is life?
```

Our signal was literally trapped by **trap** command, and whatever we have defined to correspond to the signal `USR1`, it will be executed. After that signal is processed, the script resumes normal execution, and we see every 10 seconds again on the screen the timestamp printed.

After sending the signal `ÙSR2`:

```
kill -USR2 %1
```

the script execution is paused again, this time two commands **pwd** and **ls** are executed, and the script resumes execution.

After sending these two signals, the script is still running in the background:

```
jobs -l
[1]+  87 Running                 source trapExample.sh &
```

Therefore, by using the **trap** command we can programmatically and on-the-fly modify the behaviour of the running program, without terminating its execution, changing something in the code, and restarting from scratch. Just like we have implemented traps for signals `USR1` and `USR2`, we can implement our own version of traps for the more standard signals like `ÌNT`, `TERM`, etc.

We conclude this section with a few additional remarks. The traps can be reset, by using the following generic syntax:

```
trap - someSignal
```

Signals sent to your script can be ignored by using the following syntax:

```
trap "" someSignal
```

For instance, if we want to prevent `Ctrl+C` (which is a shortcut for **kill -INT**) to terminate the script execution, at the beginning of the script we need to add:

```
trap "" INT
```

With the above implementation, whenever signal `INT` is received, the script will literally do nothing about it.

The only signal which cannot be trapped, and therefore in particular which cannot be ignored, is `KILL`. That explains why **kill -KILL** or **kill -9** will always and unconditionally terminate your running program.