Shell introduction

Historical basic shell is “`sh`”. Modern systems default to Bourne Again Shell (a pun) “`bash`”—more features and cursor editing.

I begin with less fancy `sh` for fundamental understanding, then sensible extra features in `bash` (e.g., arrays).

Docs in ‘`man sh`’, ‘`man bash`’, and Bash Ref. Manual. Hard to follow for beginners, but hopefully much better after these notes.

There are others, e.g., `zsh`, `fish`, `csh`, `tcsh`.

Homework and test/exam questions specify which shell to use. You may use other nicer shells otherwise.

Comments

A comment begins with ‘#’ and extends until end of line. Can be whole line or begin from middle of line.

```
# whole line comment
ls -l      # comment
```

echo: The Print Command

To print stuff to stdout:

```
echo xxx yyy zzz
```

By default has newline at the end. To omit:

```
echo -n xxx yyy zzz
```

echo: The Print Command

To print stuff to stdout:

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By default has newline at the end. To omit:

```
echo -n xxx yyy zzz
```

What if you want 4 spaces between xxx and yyy?

This won't work. (Exercise: Why?)

```
echo xxx    yyy zzz
```

Solutions:

```
echo xxx\ \ \ \ yyy zzz
echo 'xxx    yyy zzz'
echo "xxx    yyy zzz"
echo xxx'    'yyy zzz
```

etc.

Variables

Type is string.

Set value: `var=abc`
Tricky: No space around ‘=’

Read value: `$var` or `${var}`
(If uninit: get empty string.)

Why ‘`${var}`’ syntax provided:

```
v=xxx
v0=yyy
echo $v0            # yyy
echo ${v}0          # xxx0
```

Want your $ back?

What if you want the string “`$v`” itself, not the variable:

```
echo \$v
echo '$v'
echo '$'v
echo "\$v"
```

Want your $ back?

What if you want the string “`$v`” itself, not the variable:

```
echo \$v
echo '$v'
echo '$'v
echo "\$v"
```

Here is what `"$v"` does:

Suppose

```
v='Sale Receipt.pdf'
```

This is 2 arguments “Sale”, “Receipt.pdf”:

```
ls $v
```

i.e., shell reinterprets string under shell syntax.

This is 1 argument “Sale Receipt.pdf”:

```
ls "$v"
```

Good idea to always write like that.

Shell Scripts

Put your commands in a file, call it “myscript” say. You can run it with

```
sh myscript
```

More savvy users go one step further:

- Put as first line: `#!/bin/sh`
- Set executable flag on the file:
  `chmod u+x myscript`
- Run it with `./myscript`

Example: print-things

Command Line Arguments: Positional Parameters

If I run your script with arguments:

```
./myscript foo bar xyz
sh myscript foo bar xyz
```

- `$#` is 3, the number of arguments
- `$0` is name of script
- `$1` is foo
- `$2` is bar
- `$3` is xyz
- `$*` is foo bar xyz
  `"$*"` expands to one single word “foo bar xyz”
- `$@` is foo bar xyz
  `"$@"` expands to 3 words “foo”, “bar”, “xyz”

Demo: `print-3-args`

shift

Shift positional parameters. E.g., starting from the previous slide, one `shift` causes:

- `$#` is 2
- `$1` is bar
- `$2` is xyz
- `$*` is bar xyz
  `"$*"` expands to one single word “bar xyz”
- `$@` is “bar xyz”
  `"$@"` expands to 2 words “bar”, “xyz”

Demo: `print-args`

Empty-string argument and argument containing spaces:

```
sh print-args "" " " "hello world"
```

Command Grammar: “Simple” Commands

“simple command” = command name, arguments, optionally [file] redirection (next slide).

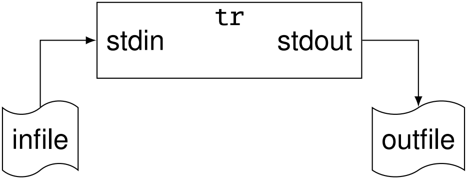
Example (without redirection): `tr -d 123`

Command name has 4 cases, not apparent from syntax:

- Shell built-in command, e.g., ‘`cd`’
- Shell function (user-defined).
- Shell alias (user-defined) (omitted, but dead simple).
- Program name, e.g., ‘`tr`’, ‘`./print-args`’

[File] Redirection

```
tr -d 123 < infile > outfile
tr -d 123 0< infile 1> outfile
```



'>' erases and overwrites. To append: '>>'

Redirect stderr:

```
command 2> file
```

Redirect both stdout and stderr to the same file:

```
command > file 2>&1
```

Command Substitution

Run a command, capture its stdout, insert output data in-place:

```
  $(command)
```

The data is split into words.

```
./print-args $(echo ’aaa bbb ccc’)
```

⇒ 3 arguments, spaces stripped.

If inside double-quotes, not splitted.

```
./print-args "$(echo ’ aaa bbb ccc ’)"
```

⇒ 1 argument, spaces preserved.
But tricky details for newlines, not shown.

More use cases:

```
echo "Time: $(date)"
x="$(date)"
```

Shell Grammar: Compound Commands Overview

Next slides explain constructs for compound commands.

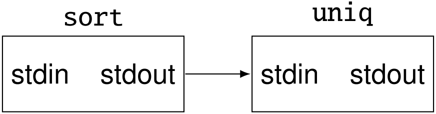
Operators from highest to lowest precedence:

description	operator
grouping	{} ()
redirection	< > >>
pipeline	|
not	!
and, or	&& ||
command list	; newline

Also if-then-else, loops.

Pipeline

E.g., `sort | uniq`



[Command] List—Sequential Composition

Multiple commands can be separated by newlines (especially in shell script files). Example:

```
cd B09
ls -l
cd ..
```

Or, a single line but separated by semicolons. Example:

```
cd B09 ; ls -l ; cd ..
```

Either way, known as “list” or “command list”, sequentially executed: wait for one to finish before running the next.

[Command] List—Sequential Composition

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```

Or, a single line but separated by semicolons. Example:

```
cd B09 ; ls -l ; cd ..
```

Either way, known as “list” or “command list”, sequentially executed: wait for one to finish before running the next.

One command but you want to split into multiple lines: Need to escape the newlines:

```
echo hello B09 \
     students
```

Exit Code, Success, Failure

Commands give an exit code when done.

In C, recall “`int main(...)`”, return value is exit code!
Demo: `ret.c`

Special shell variable `$?` is most recent command’s exit code.

Exit codes also convey success/true and failure/false.
0 for success/true
non-0 for failure/false, e.g.,

- Most commands declare failure if file not found.
- A string search program declares failure if string not found.

Beware: ‘`echo $?`’ is also a command! And it succeeds. Exercise: What does it print if you run it twice consecutively?

Logical AND, OR, NOT, true, false

```
mkdir foo && cp myfile foo
```

Sequential execution, but stop upon first “false”.

```
mkdir foo1 || mkdir foo2 || mkdir foo3
```

Sequential execution, but stop upon first “true”.

(So they are short-circuiting.)

```
! mkdir foo
```

Logical not: turn 0 to 1, non-0 to 0.

Operator precedence:
‘&&’, ‘||’ same precedence (tricky!)
both lower than ‘!’

`true`: Always true.
`false`: Always false.

Test Commands

A whole suite of shell builtin “[expression]” commands to do useful tests and give you exit codes for booleans.

File tests (more on man page, search for “[expression]”):

- `[ -e path ]`: exists
- `[ -f path ]`: exists and regular file
- `[ -d path ]`: exists and directory
- `[ -r path ]`: exists and readable
- `[ -w path ]`: exists and writable
- `[ -x path ]`: exists and executable
- `[ path1 -nt path2 ]`: both exist and path1 is newer
- `[ path1 -ot path2 ]`: both exist and path1 is older

Example: `[ -d lab02 ] || echo sadface`

Test Commands

String comparisons:

- `[ s1 = s2 ]`: string equality
  Also '`!=`', '`<`', '`>`' (need escaping/quoting)
- `[ -n string ]`: string not empty
- `[ -z string ]`: string empty

Recall `$v` vs `"$v"`. You want:

```
[ "$v" = xxx ]
[ -n "$v" ]
[ -z "$v" ]
```

Number comparisons (parsing strings to numbers):

- `[ n1 -eq n2 ]`: integer equality
  Also '`-ne`', '`-gt`', '`-ge`', '`-lt`', '`-le`'

Test Commands

Logical connectives, by example:

- `[ ! -e path ]`: not
- `[ "$x" -eq 5 -a "$y" -eq 6 ]`: and
- `[ "$x" -eq 5 -o "$y" -eq 6 ]`: or

`-a` higher precedence than `-o`

Parentheses also supported, but need escaping or quoting.

```
[ -d dir1 -a ’(’ -d dir2 -o -d dir3 ’)’ ]
```

Test Commands

Why need quoting (or backslahses) and spaces in

```
[ ! '(' "$x" '>' "$y" ')' ]
```

and why these are misinterpreted

```
[!'('"$x"'>'"$y"')']
[ ! ( "$x" > "$y" ) ]
```

- Command name is `[`
- Expression represented as arguments.
  One argument per operand/operator, separately.
- Last argument must be `]`
- Grammar clashes with shell grammar. Need quoting to tell shell “not for you; pass-thru to the command”.

Grouping 1/2

When operator precedence doesn't work for you, write

```
{ list ; }
```

for explicit grouping. (Recall "[command] list".)

Example:

```
{ grep foo file1 ; ls ; } > file2
```

Again, may use newline instead of ;

Easy to miss: This looks right but is wrong, tricky!

```
{ grep foo file1 ; ls } > file2
```

Missing one last newline or ; before }

Grouping 2/2: Subshell

`( )` also does grouping, plus one more thing.

```
( list ; )
```

Difference from `{}` by example:

```
{ x=hello ; cd / ; }
```

Effects retained afterwards. Faster.

```
( x=hello ; cd / ; )
```

Effects lost afterwards. Slower, in fact new shell process.
Hence known as “run in subshell”.

Operators Summary And Precedence

From highest to lowest precedence:

description	operator
grouping	{} ()
redirection	< > >>
pipeline	|
not	!
and, or	&& ||
command list	; newline

Conditional Branching

Demo: `if-demo`

```
if list1 ; then
    list2
elif list3 ; then
    list4
else
   list5
fi
```

Easy to miss:

- before “`then`”, need `;` or newline
- “`elif`”, not “`else if`”

Exercise: “`else if`” is not wrong, but what is annoying about it?

While-Loop

Demo: `while-demo`, `print-args`

```
while list1 ; do
    list2
done
```

```
while list1 ; do list2 ; done
```

May use ‘`break`’ and ‘`continue`’.

Easy to miss: before “do”, need `;` or newline.
These look right but are wrong:

```
while list1 do
    list2
done
```

```
while list1 ; do list2 done
```

Test Commands in if/while

```
if [ $x = $y ] ; then
  ...
fi

while [ $x = $y ] ; do
  ...
done
```

Easy to miss: Still need `;` or newline, even though `]` ends the condition. `]` is the last argument of the test command.

Arithmetic

Arithmetic is delegated to the `expr` program.

But most symbols need escaping/quoting, lest clash with shell syntax.

Example: `expr '(' 1 + 2 ')' '*' 10`

Outputs answer to stdout. Usually you add command substitution to store answer in variable or give to another command.

```
x=5
x=$(expr $x + 1)
echo "$(expr $x + 1)"
```

See link for all features. `expr --help` and `man expr` have quick reminders.

For-loop

Demo: for-demo

```
for var in word1 word2 ... ; do
    list
done
```

Use `$var` to read the variable.

May use ‘`break`’ and ‘`continue`’.

Easy to miss: Need `;` or newline before `do` to mark end of words.
Lest computer thinks your `do` is one of the words, like above.

for i=0 to 3

Integer range is delegated to the `seq` program.

`seq 0 3` outputs 0 to 3 to stdout.

Use command substitution to capture, give to for-loop.

```
for i in $(seq 0 3) ; do ... ; done
```

Demo: `for-demo`

See `seq --help` or `man seq` for variations.

Patterns (to match filenames)

- ‘*’ matches any string (but doesn’t cross directory boundaries)
  Example: `ls a2/*.py`
  All python files in directory a2
- ‘?’ matches one character
- ‘`[ace]`’ matches “a” or “c” or “e”
- ‘`[0-9]`’ matches a digit
- ‘`[!0-9]`’ matches a non-digit

Important: Shell expands pattern to multiple pathnames before handing to command. `ls` never saw “a2/*.py”; it saw “a2/foo.py”, “a2/bar.py”, etc.

Important: If no match, the pattern stays as itself.

Good for for-loops too:

```
for i in *.py ; do echo $i ; done
```

Case

Pattern matching but on the string you want.

```
case "$var" in
    *.py)
        rm "$var"
        ;;
    *.c | *.sh | myscript)
        echo w00t "$var"
        ;;
    *)
        echo meh "$var"
esac
```

Small Example Script (Pg 1/2)

```
#!/bin/sh
dryrun=
verbose=
while [ $# -gt 0 ]; do
    case "$1" in
        -n)
            dryrun=y
            ;;
        -v)
            verbose=y
            ;;
        *)
            break
    esac
    shift
done
```

Small Example Script (Pg 2/2)

```
for f in "$@" ; do
  case "$f" in
    *.py)
      [ -n "$verbose" ] && echo "deleting $f"
      [ -z "$dryrun" ] && rm "$f"
      ;;
    *)
      [ -n "$verbose" ] && echo "not deleting $f"
  esac
done
```

Code file: `smallscript`

Small Example Script: Explanation

Go through arguments (meant to be filenames), delete those that are Python files.

But if there are ‘`-n`’ and/or ‘`-v`’ at the beginning:
`-n` means dry-run—don’t actually delete
`-v` means verbose—say what is happening to each filename

Page 1 detects ‘`-n`’ and ‘`-v`’.

After that, `$@` is left with the filenames.

Page 2 can use a for-loop over `$@` to process each filename.

Functions

Example function definition:

```
myfunction() {
  echo "$1"
  echo "$@"
}
```

Example function call:

```
myfunction foo bar xyz
```

Inside a function, positional parameters become function arguments.

May return from function early, or specify exit code, with ‘`return`’ or e.g., ‘`return 1`’.

(Default exit code is from the last executed command.)

Exit

Command ‘`exit`’ terminates the whole shell script and the shell process.

Not required if your script just runs from start to finish normally.

But handy for:

Early termination (even inside loops, functions, etc.)

Controlling exit code, e.g., ‘`exit 1`’.

(Default exit code is whatever the last executed command gives.)

getopts: General Option Processing

Shell built-in `getopts` helps pick out those `-n`, `-v` options.

Suppose I want to support these options:

- `-M` followed by a string
- `-n`
- `-v`

and after options, arbitrarily many filenames.

I also need to choose a variable name. I choose `myflag`.

Then I use one of these (they're equivalent):

```
getopts M:nv myflag
getopts vM:n myflag
getopts nvM: myflag
```

getopts Sample Run 1

If user runs my script (code: `tinyscript`) with

```
./tinyscript -n -v -Mfoo -v -M bar abc def -n xyz
```

then when I call `getopts M:nv myflag` the *i*th time:

i	`$myflag`	`$OPTARG`	`$OPTIND`	exit code
1	n	(empty)	2	0
2	v	(empty)	3	0
3	M	foo	4	0
4	v	(empty)	5	0
5	M	bar	7	0
6	?	bar	7	1

Note that `$7` is abc, 1st non-option argument (filename for me). I can do `shift 6` to get rid of options.

`getopts` does not pick out options after seeing 1st non-option argument.

getopts Sample Run 2

If user adds `--` to explicitly mark end of options:

```
./tinyscript -n -v -Mfoo -v -M bar -- abc def -n xyz
```

then when I call `getopts M:nv myflag` the *i*th time:

i	`$myflag`	`$OPTARG`	`$OPTIND`	exit code
1	n	(empty)	2	0
2	v	(empty)	3	0
3	M	foo	4	0
4	v	(empty)	5	0
5	M	bar	7	0
6	?	bar	8	1

Note that `$8` is abc, 1st non-option argument (filename for me). I can do `shift 7` to get rid of options.

`getopts` honours using `--` to mean end of options.

getopts Sample Run 3

If user gives unsupported option, e.g., `-k`:

```
./tinyscript -n -v -Mfoo -k -M bar abc def -n xyz
```

then when I call `getopts M:nv myflag` the *i*th time:

i	`$myflag`	`$OPTARG`	`$OPTIND`	exit code
1	n	(empty)	2	0
2	v	(empty)	3	0
3	M	foo	4	0
4	?	(empty)	5	0
	and “Illegal option -k” to stderr			
5	M	bar	7	0
6	?	bar	7	1

Small Example Script But getopts

Code: toyscript

```
while getopts M:nv myflag ; do
  case "$myflag" in
    n)
      dryrun=y
      ;;
    v)
      verbose=y
      ;;
    M)
      msg="$OPTARG"
      ;;
  esac
done

shift $(expr $OPTIND - 1)

for f in "$@" ; do ...
```

Escaping And Quoting

Recall special-meaning characters in shell syntax:
< * $ # (& | ; space newline (and more)

Use escaping or quoting to get the character itself.

Example: print “<*; #” (2 spaces in between):

```
echo \<\*\;\ \ \#
echo '<*;  #'
echo "<*;  #"
```

Note: So ‘\’ is also special! Use ‘\\’ for backslash itself.

Example: store that string in a variable:

```
v='<*;  #'
```

Example: Many use cases of [and expr:

```
[ "$v" '<' "$w" ]
expr '(' 1 + 2 ')' '*' 10
```

Variables in Double Quotes

Common mistake when checking whether `$v` is non-empty:

```
[ -n $v ]
```

No!

- If `$v` is empty, shell sees `[ -n ]`, which makes no sense.
- If `$v` is purely spaces, shell still sees `[ -n ]`
- If `$v` is “x y”, shell sees `[ -n x y ]`, which makes no sense.

Solution: `[ -n "$v" ]`

Exercise: Older generation used

```
[ x != x$v ]
```

When does it work? When does it break?

More Fun with echo

Why do I need 4*n* backslashes to get `echo` to print *n* backslashes?

```
$ echo \\\\\\\\\\\\
\\\
```

(BTW: Odd number ⇒ last backslash escapes newline, shell thinks I am splitting my command into two lines.)

If I use quoting, I still need 2*n* backslashes:

```
$ echo ’\\\\\\’
\\\
```

More Fun with echo

Use C to verify how many backslashes actually seen by command.

```
$ ./print-args-c \\\\\\\\\\\\
argc = 2
argv[0] = "./print-args-c"
argv[1] = "\\\\\\"
```

No surprise, shell said it would translate 2 backslashes to 1.

```
$ ./print-args-c '\\\\\\'
argc = 2
argv[0] = "./print-args-c"
argv[1] = "\\\\\\"
```

No surprise, quoting works.

Code: `print-args-c.c`

Oh so `echo` adds its own translation…

More Fun with echo

sh man page: echo also interprets backslash:

`\n`	newline
`\t`	tab
`\\`	1 backslash

etc.

More Fun with echo

`sh` man page: `echo` also interprets backslash:

`\n`	newline
`\t`	tab
`\\`	1 backslash

etc.

Moral of the story:

What you see is never what you get.

It’s telephone games all the way down.

It’s lasagna all the way down.

Unless you prefer desserts, in which case:
It’s baklava all the way down.

Dot command: Execute stuff in current shell

This reads commands from cmds.sh, executes them in current shell:

```
. ./cmds.sh
```

The command name is a single dot "`.`"

Contrast: `sh cmds.sh` runs in newly spawned shell process.

Use case: If cmds.sh defines functions, set variables, or uses `cd`, then

- `. ./cmds.sh` does them in current shell.
- `sh cmds.sh` does them in new shell process, which then quits, much ado about nothing.
  `./cmds.sh` ditto.

Demo: `dot-demo`

Here Document

To feed multi-line hardcoded text into stdin of a command:

```
cat << EOF
Hello I’m Albert.
You can use variables too
E.g., \$x=$x
EOF
```

The first time I said “EOF”, shell takes note. Second time, shell knows I’m marking the end.

“EOF” is not a keyword, you may choose another word, just don’t clash with your actual text!

Code file: here-doc

Here Document: One More Thing

If you declare your end-marker in quotes:

```
cat << 'EOF'
Hello I'm Albert.
Now $x is $x
EOF

cat << "EOF"
Hello I'm Albert.
And $x is still $x
EOF
```

then `$` is no longer special.

Code file: `here-doc`

Environment Variables

Every process (shell or otherwise) has a collection of “environment variables”, as part of process state.

Names are strings, values are strings too. Convention: Names in all caps, e.g., PATH, HOME, TZ, LC_ALL (these are standard Unix ones), CLASSPATH (specific to Java).

Initialized by copying from launcher (done by kernel): If *p* launches *q*, *q* gets a copy of *p*’s. But independently changeable otherwise.

Program ‘`printenv`’ prints the environment variables you currently have. It works because at startup it gets a copy of yours! Now it just has to print what *it* has.

Environment Variables in Shell

Shell *downplays* difference between shell variables and environment variables. Only convention: shell variable names are in lowercase.

Both read by same syntax: `$x`, `$LC_ALL`

Both changeable by same syntax:

```
x=C
LC_ALL=C
```

Both erasable by same ‘`unset`’ command.

How to mark a variable as environment variable:

```
  export MYENVVAR=foo
```

or two commands:

```
  MYENVVAR=foo
  export MYENVVAR
```

Environment Variables in Shell

To run a program but give it different environment variables (existing or new) without changing your own:

```
LC_ALL=C MYNEWENV=foo printenv
```

This is why the following two commands mean different things:

```
x='foo bar'
x=foo bar
```

Some Standard Environment Variables

HOME: Home directory.

TZ: User timezone preference. (Can be absent.)

PATH: Colon-separated list of directories. Searched when you launch a program, if program name does not contain any slash.

Example: Assume
`PATH=/usr/local/cms/jdk1.8.0_31/bin:/usr/bin:/bin`

`javac Foo.java`
found in `/usr/local/cms/jdk1.8.0_31/bin`

`printenv`
found in `/usr/bin`

`sh`
found in `/bin`

Bash Feature: Local Variables in Functions

Basic shell has global variables only.
Bash supports local variables in functions. Use `local`

```
myfunc() {
  local x y=hello  # x,y local, y inited
  x=hi
  echo "$x" "$y"
}
```

Demo: `bash-local-demo`

But dynamic scoping, not lexical scoping. See demo.

Bash Feature: Arithmetic

Bash has builtin arithmetic so you don't need `$(expr ...)`.

```
shift $(($OPTIND - 1))
```

even

```
shift $((OPTIND - 1))
```

bash Feature: Arrays

```
crew=(kermit piggy fozzie)  # set
crew[3]='sam eagle'         # set by index
echo "${crew[1]}"           # get by index
crew+=(gonzo 'dr pepper')   # append
echo ${#crew[@]}            # number of elements
for c in "${crew[@]}"; do   # all elements, like $@
  ...
done
# no prepend feature, but you can always do:
crew=(scooter "${crew[@]}")
```

Demo: `bash-array-demo`

Bash Feature: Associative Arrays

Key-value dictionary. “Array” but string indexes.

```
declare -A mark
mark=([denise]=4 [bob]=9)            # set
mark[charles]=3                      # set one
mark+=([bob]=7 [alice]=5)            # set more
for k in "${!mark[@]}"; do           # all keys
  echo "$k has ${mark[$k]} marks"    # lookup
done
```

`declare -A` required, lest bash assumes integer-indexed array.

Demo: `bash-array-demo`

Bash Feature: Process Substitution

Pipelining (`cmd1 | cmd2`) connects processes but limitation: only 1 input src, only 1 output dst ⇒ chaining only

Bash's process substitution generalizes to multiple srcs and dsts.

Example (2 input srcs): `sort <(cmd1) <(cmd2)`

Behaviour: Two input files to `sort`: stdout of `cmd1`, stdout of `cmd2`.

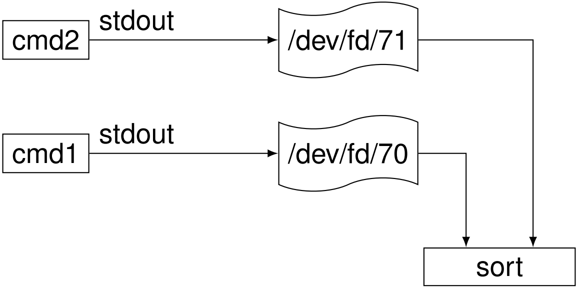
Oversimplified theory:

- Bash spawns `cmd1`, redirects stdout to fresh fake file, say /dev/fd/70. (Kernel helps.)
- Ditto for `cmd2`, say /dev/fd/71.
- Bash spawns `sort /dev/fd/70 /dev/fd/71`.

Demo: `bash-procsub-demo`

Process Substition Example Picture

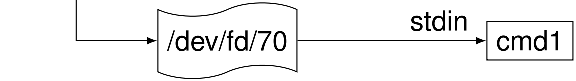
```
sort <(cmd1) <(cmd2)
```



Process Substition Example Picture

Example (1 output dst): `foo >(cmd1)`

Behaviour: If `foo` outputs to given filename, that goes to stdin of `cmd1`.


foo
/dev/fd/70
stdin
cmd1