Advanced C and System Programming

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D-Bus

D-Bus

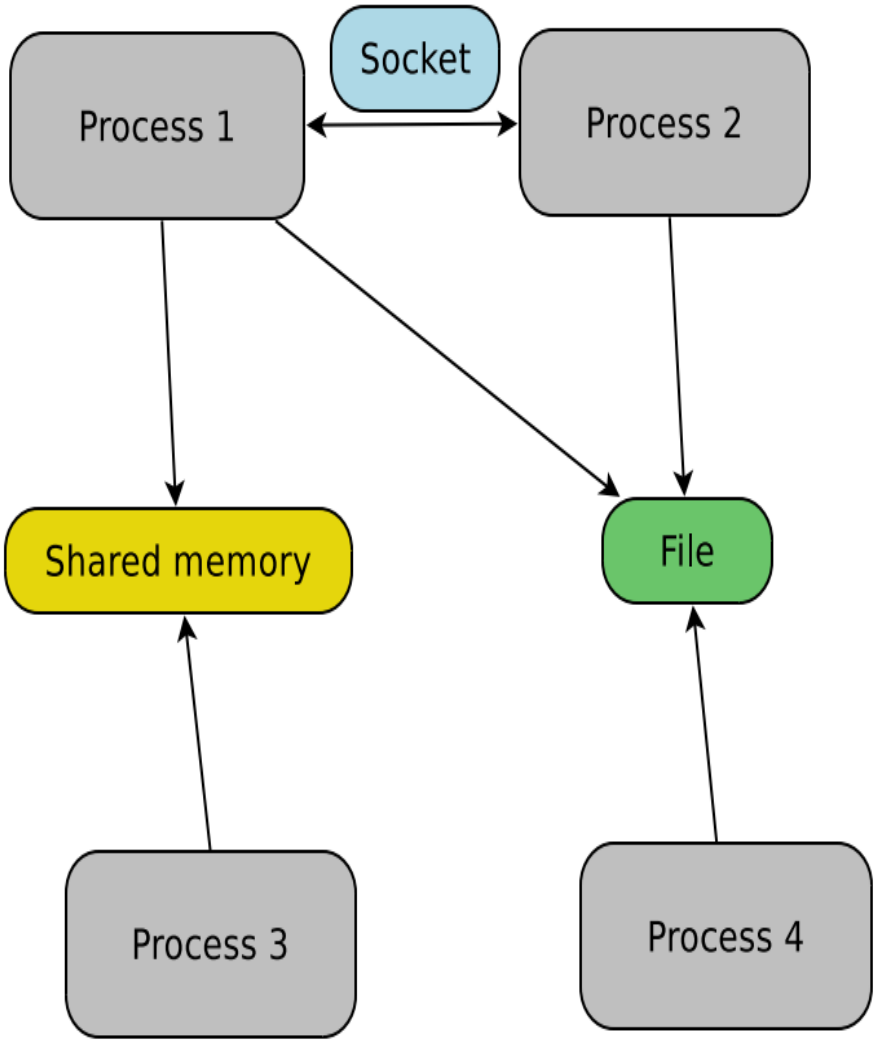
- Created in 2002
- Is part of the *freedesktop.org* project
- Maintained by RedHat and the community
- Is an Inter-process communication mechanism
- Initiated to standardize services of Linux desktop environments

freedesktop.org

redhat.

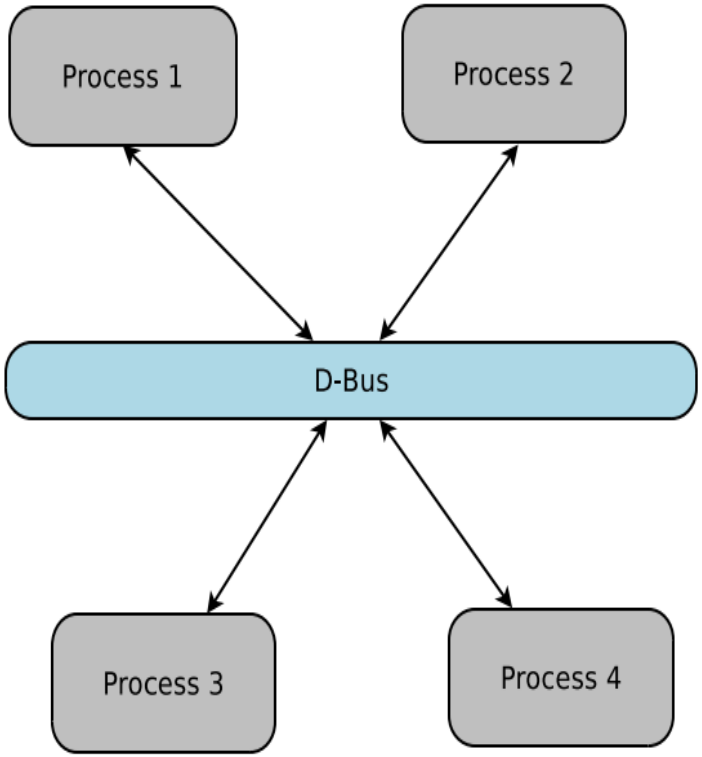
D-Bus

- Mechanisms allowing processes to communicate with each other
  - **Shared memory**: read/write into a defined memory location
  - **Memory-mapped file**: same as `shared memory` but uses a file
  - **Pipe**: two-way data stream (standard input / output)
  - **Named pipe**: same as `pipe` but uses a file (FIFO)
  - **Socket**: communication even on distant machines
  - and others



D-Bus

- Uses the socket mechanism
- Provides software bus abstraction
- Way simpler than most alternatives



D-Bus

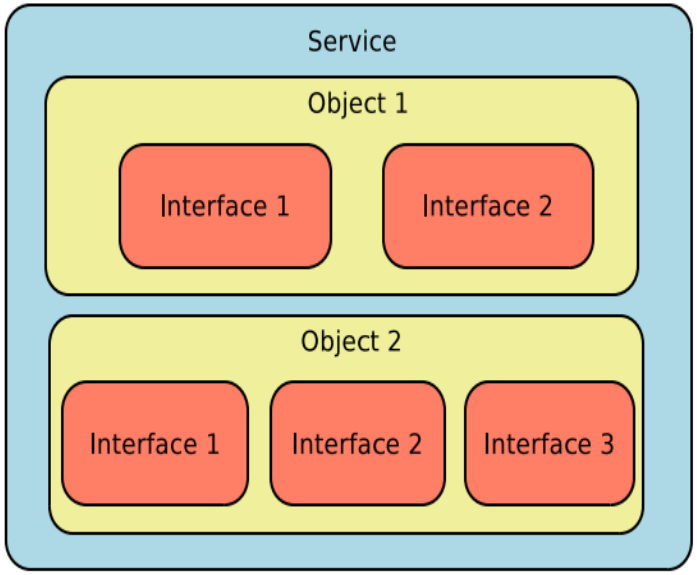
- D-Bus includes:
  - `libdbus`: a low-level library
  - `dbus-daemon`: a daemon based on libdbus. Handles and controls data transfers between DBus peers
  - two types of busses: a `system` and a `session` one. Each bus instance is managed by a `dbus-daemon`
  - a security mechanism using `policy` files

D-Bus

- System bus
  - On desktop, a single bus for all users
  - Dedicated to system services
  - Is about low-level events such as connection to a network, USB devices, etc
  - On embedded Linux systems, this bus is often the only D-Bus type
- Session bus
  - One instance per user session
  - Provides desktop services to user applications
  - Linked to the X session

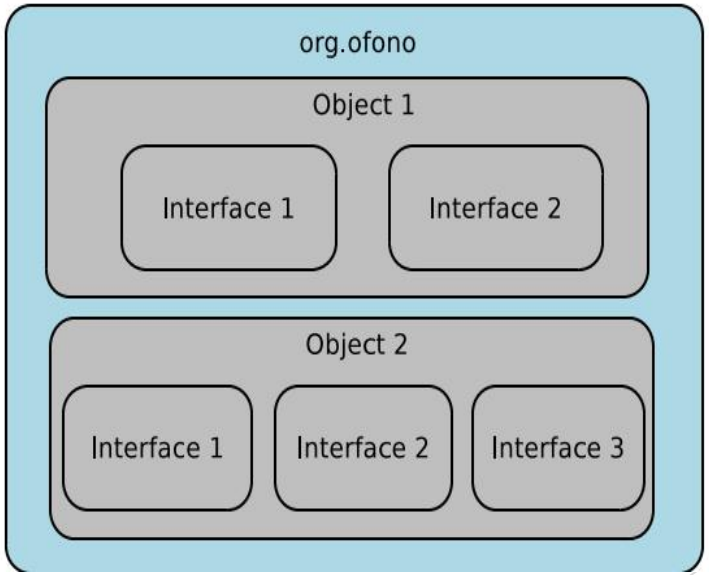
D-Bus

- D-Bus is working with different elements:
  - Services
  - Objects
  - Interfaces
  - Clients: applications using a D-Bus service
- One D-Bus *service* contains *object(s)* which implements *interface(s)*



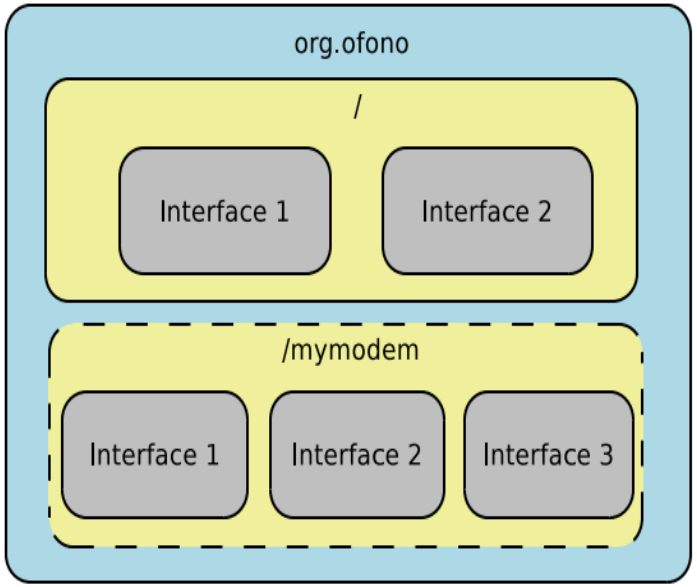
D-Bus Service

- An application can expose its services to all D-Bus users by registering to a bus instance
- A `service` is a collection of `objects` providing a specific set of features
- When an application opens a connection to a bus instance, it is assigned a unique name (ie `:1.40`)
- Can request a more human-readable service name: the **well-known name** (ie `org.ofono`) See the freedesktop.org specification



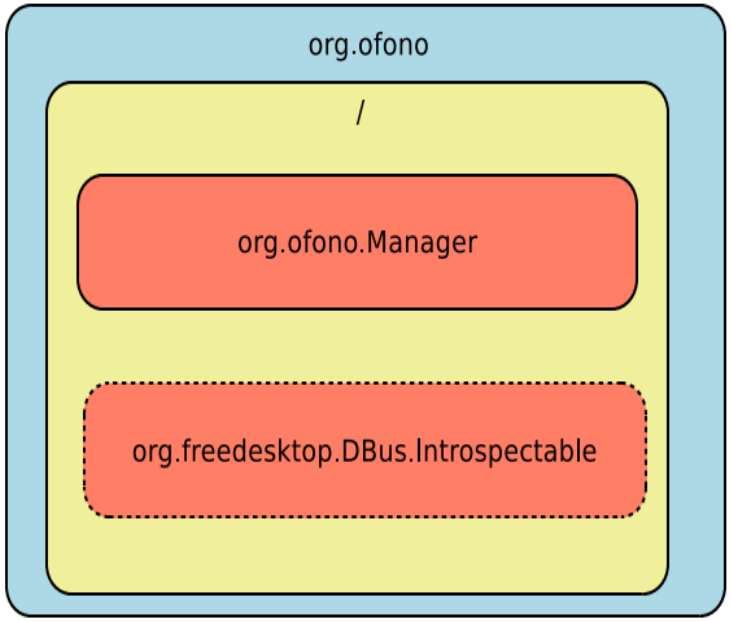
D-Bus Objects

- Are attached to one service
- Can be dynamically created or removed
- Are uniquely identified by an **object path** (ie / or `/net/connman/technology/cellular`)
- Implement one or several interfaces



D-Bus Interfaces

- Can be compared to a "namespace" in Java
- Has a unique name ressembling Java interface names, using dots (ie `org.ofono.Manager`)
- Contains *members*: properties, methods and signals



D-Bus Interfaces

- D-Bus defines a few standard interfaces
- They all belong to the namespace "org.freedesktop.DBus" :
  - **org.freedesktop.DBus.Introspectable** : Provides an introspection mechanism. Exposes information about the object (interfaces, methods and signals it implements)
  - **org.freedesktop.DBus.Peer** : Provides methods to know if a connection is alive (ping)
  - **org.freedesktop.DBus.Properties** : Provides methods and signals to handle properties
  - **org.freedesktop.DBus.ObjectManager** : Provides an helpful API to handle sub-tree objects
- Interfaces expose properties, methods and signals

D-Bus Properties

- Directly accessible fields
- Can be read / written
- Can be of different types defined by the D-Bus specification :
  - basic types: bytes, boolean, integer, double, ...
  - string-like types : string, object path (must be valid) and signature
  - container-types: structure, array, variant (complex types) and dictionnary entry (hash)
- Very convenient standard interface : `org.freedesktop.DBus.Properties`
- Types are represented by characters

byte	y	string	s	variant	v
boolean	b	object-path	o	array of int32	ai
int32	i	array	a	array of an array of int32	aai
uint32	u	struct	()	array of a struct with 2 int32 fields	a(ii)
double	d	dict	{}	dict of string and int32	{si}

D-Bus Methods

- allow remote procedure calls from one process to another
- Can be passed one or several parameters
- Can return values/objects
- Look like any method you could know from other languages

```
org.freedesktop.DBus.Properties :
  Get (String interface_name, String property_name) => Variant value
  GetAll (String interface_name) => Dict of {String, Variant} props
  Set (String interface_name, String property_name, Variant value)
```

D-Bus Signals

- Messages / notifications
- Unidirectionnal
- Sent to every clients that are listening to it
- Can contain parameters
- A client will subscribe to signals to get notifications

```
org.freedesktop.DBus.Properties :
   PropertiesChanged (String, Dict of {String, Variant}, Array of String)
```

D-Bus Policy

- Adds a security mechanism
- Represented by XML files
- Handled by each `dbus-daemon` (under `/etc/dbus-1/session.d` and `/etc/dbus-1/system.d`)
- Allows the administrator to control which user can talk to which interface, which user can send message to which interface, and so on
- If you are not able to talk with a D-Bus service or get an `org.freedesktop.DBus.Error.AccessDenied` error, check this file!
- `org.freedesktop.PolicyKit1` has been created to handle all security accesses

D-Bus

- In this example, "toto" can :
  - own the interface `org.ofono`
  - send messages to the owner of the given service
  - call `GetContexts` from interface `org.ofono.ConnectionManager`

```
<!DOCTYPE busconfig PUBLIC
 ``-//freedesktop//DTD D-BUS Bus Configuration 1.0//EN''
 ``http://www.freedesktop.org/standards/dbus/1.0/busconfig.dtd''>
 <busconfig>
    <policy user="toto">
        <allow own="org.ofono"/>
        <allow send_destination="org.ofono"/>
        <allow send_interface="org.ofono.ConnectionManager" send_member="GetContexts"/>
    </policy>
</busconfig>
```

- Can `allow` or `deny`

D-Bus

- Libdbus
  - This is the low-level library used by the dbus-daemon.
  - As the homepage of the project says: *"If you use this low-level API directly, you're signing up for some pain"*.
  - Recommended to use it only for small programs and you do not want to add many dependencies
- GDbus
  - Is part of GLib (GIO)
  - Provides a very comfortable API
- QtDbus
  - Is a Qt module
  - Is useful if you already have Qt on your system
  - Contains many classes to handle/interact such as `QDBusInterface`

D-Bus

- Bindings exist for other languages: dbus-python, dbus-java, ...
- All the bindings allow to:
  - Interact with existing D-Bus services
  - Create your own D-Bus services, objects, interfaces, and so on!
  - but... D-Bus is not a high performance IPC
  - Should be used only for **control** and not data
  - For example, you can use it to activate an audio pipeline but not to send the audio stream

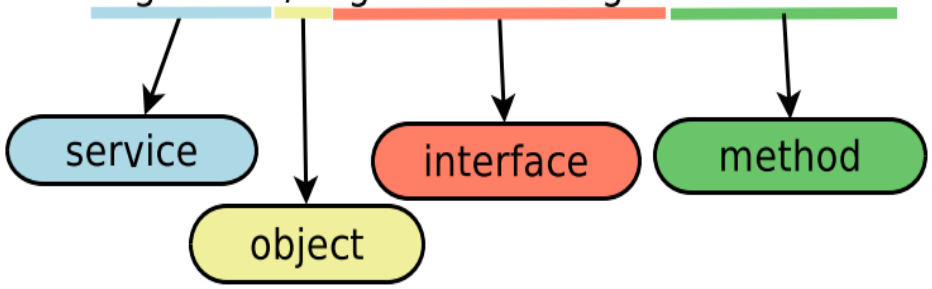
D-Bus

- Will present every tool with a demo
- dbus-send: Command-line interface (cli) to call method of interfaces (and get/set properties)
- dbus-monitor: Cli to subscribe and monitor signals
- gdbus: A GLib implementation of a more complete tool than dbus-send/monitor
- d-feet: A GUI application to handle all D-Bus services
- and others...

D-Bus

- Can chose the session or system bus (`--session` or `--system`)
- Here is an example:

```
dbus-send --system --print-reply --dest=org.ofono / org.ofono.Manager.GetModems
```



D-Bus

- Get properties:

```
dbus-send --system --print-reply --dest=net.connman / net.connman.Clock.GetProperties
```

- Set property:

```
dbus-send --system --print-reply --dest=net.connman \
          / net.connman.Clock.SetProperty \
          string:TimeUpdates variant:string:manual
```

- Using standard interfaces:

```
dbus-send --system --print-reply --dest=net.connman \
          / org.freedesktop.DBus.Introspectable.Introspect

dbus-send --system --print-reply --dest=fi.w1.wpa_supplicant1 \
          /fi/w1/wpa_supplicant1 org.freedesktop.DBus.Properties.Get \
          string:fi.w1.wpa_supplicant1 string:Interfaces
```

D-Bus

- Can monitor all traffic (including methods and signals if enabled in policy):

```
dbus-monitor
```

- Or filter messages based on the interface:

```
dbus-monitor --system type=signal interface=net.connman.Clock
```

D-Bus

- Also provides a command line interface
- Is more featureful than `dbus-send` because it handles "dict entry"
- Has a different interface: must add a "command" such as "call" or "monitor"

```
gdbus call --system --dest net.connman \
      --object-path / --method net.connman.Clock.GetProperties
gdbus call --system --dest net.connman --object-path / \
      --method net.connman.Clock.SetProperty 'TimeUpdates' "<'manual'>"
gdbus monitor --system --dest net.connman
```

- Can even emit signals

```
gdbus emit --session --object-path / --signal \\
       net.connman.Clock.PropertyChanged ``['TimeUpdates', ``\<'auto'\>'']''
```

D-Bus

- KDE: A desktop environment based on Qt
- Gnome: A desktop environment based on gtk
- Systemd: An init system
- Bluez: A project adding Bluetooth support under Linux
- Pidgin: An instant messaging client
- Network-manager: A daemon to manage network interfaces
- Modem-manager: A daemon to provide an API to dial with modems - works with Network-Manager
- Connman: Same as Network-Manager but works with Ofono for modem
- Ofono: A daemon that exposing features provided by telephony devices such as modem

Serial programming using Rapberry pi

Memory management

3.2 Variable Partitioning

With fixed partitions we have to deal with the problem of determining the number and sizes of partitions to minimize internal and external fragmentation.

If we use variable partitioning instead, then partition sizes may vary dynamically.

In the variable partitioning method, we keep a table (linked list) indicating used/free areas in memory.

3.2 Variable Partitioning

Initially, the whole memory is free and it is considered as one large block.

When a new process arrives, the OS searches for a block of free memory large enough for that process.

We keep the rest available (free) for the future processes.

If a block becomes free, then the OS tries to merge it with its neighbors if they are also free.

3.2 Variable Partitioning

There are three algorithms for searching the list of free blocks for a specific amount of memory.

- First Fit
- Best Fit
- Worst Fit

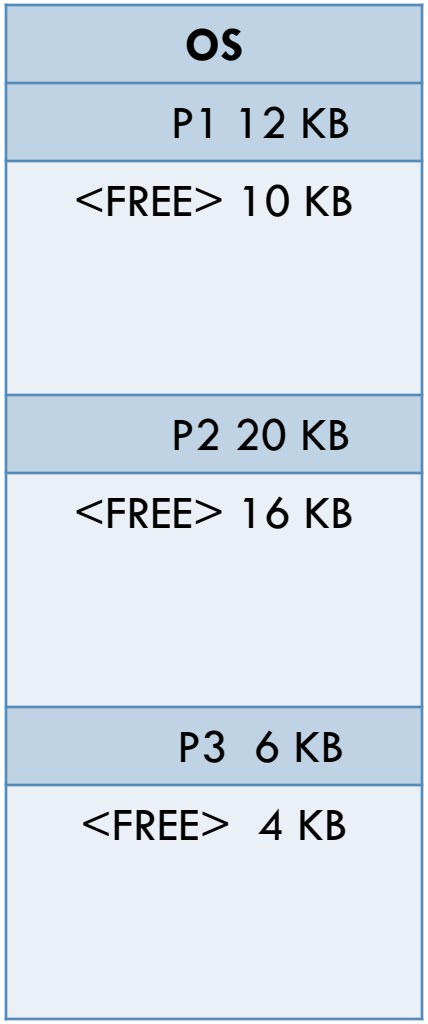
first fit

- First Fit : Allocate the first free block that is large enough for the new process.

- This is a fast algorithm.

first fit

Initial memory mapping



first fit

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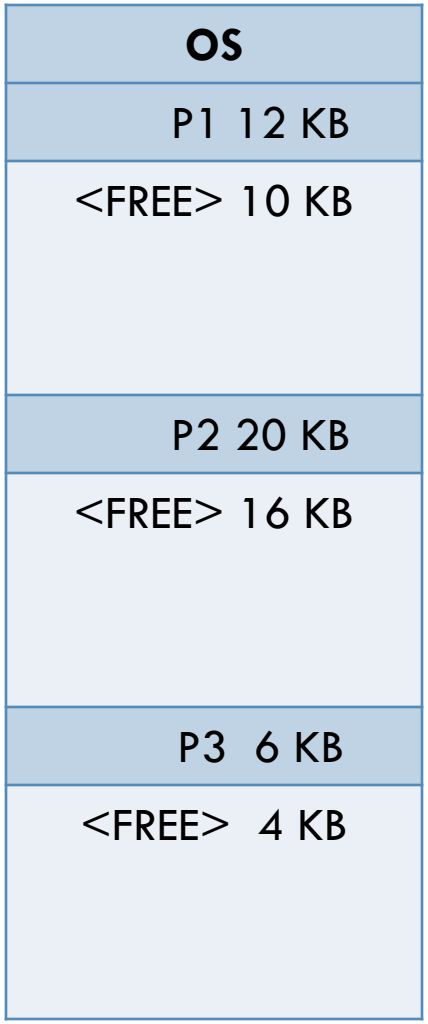
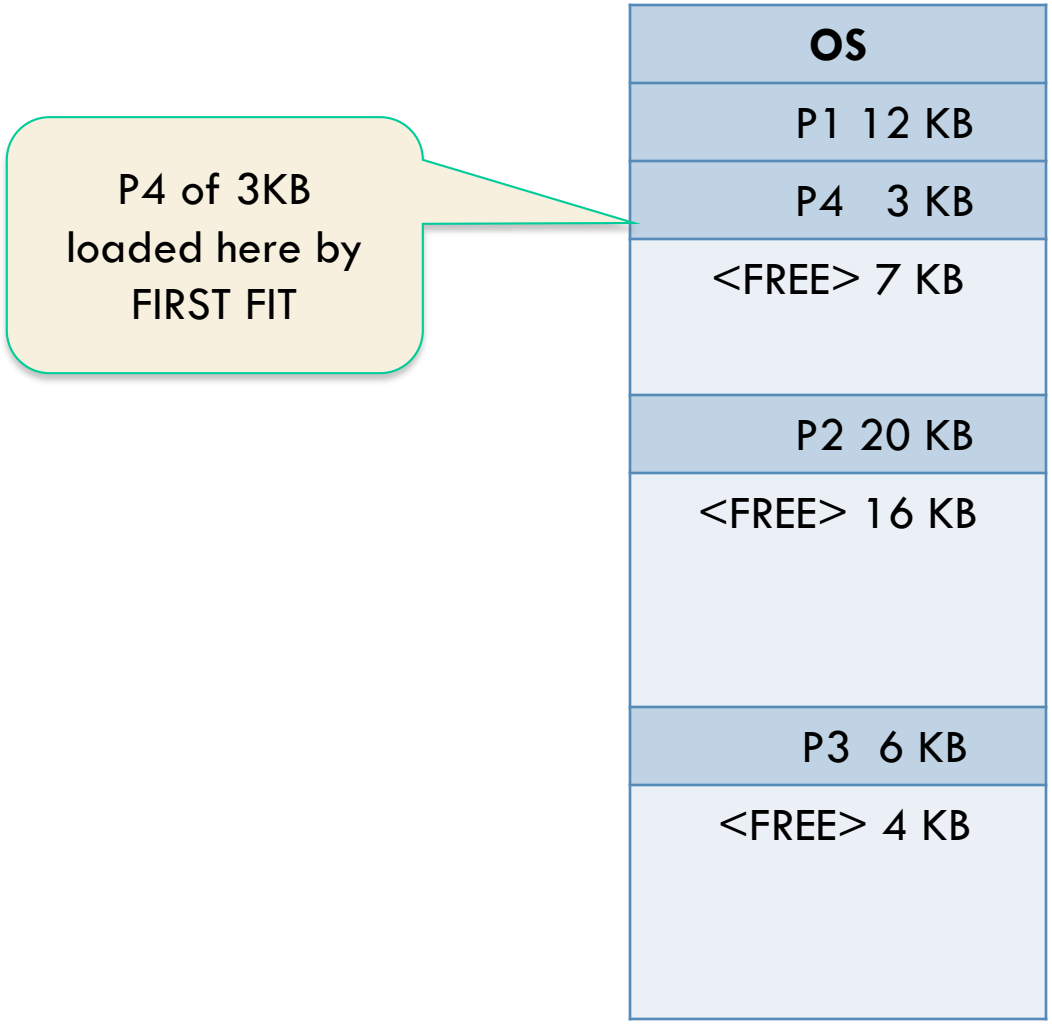
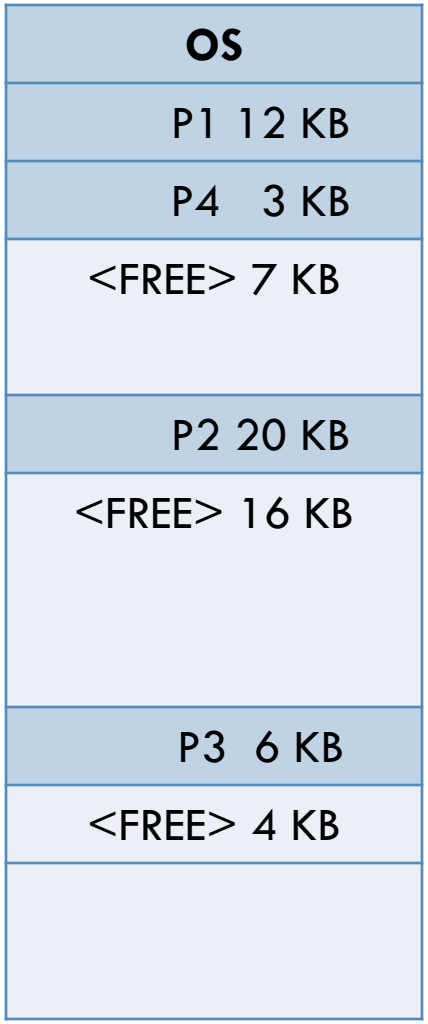


first fit


P4 of 3KB loaded here by FIRST FIT
OS
P1 12 KB
P4 3 KB
<FREE> 7 KB
P2 20 KB
<FREE> 16 KB
P3 6 KB
<FREE> 4 KB

first fit

P5 of 15KB arrives



first fit

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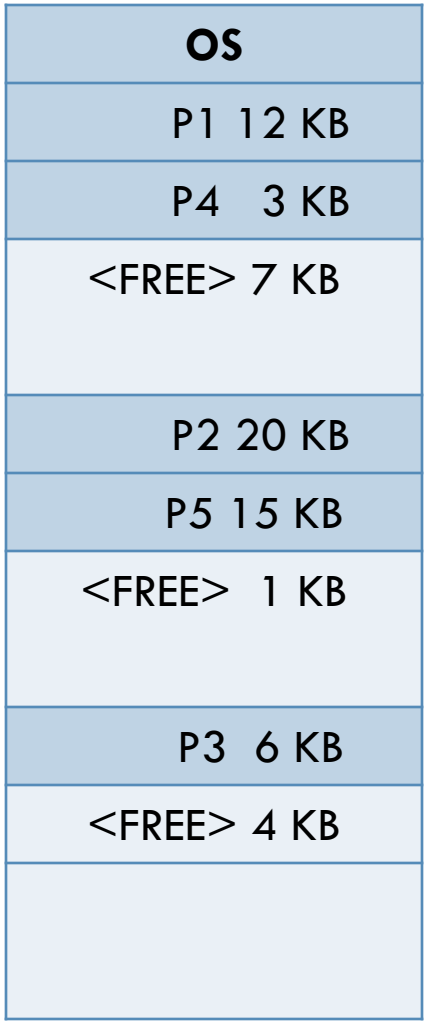
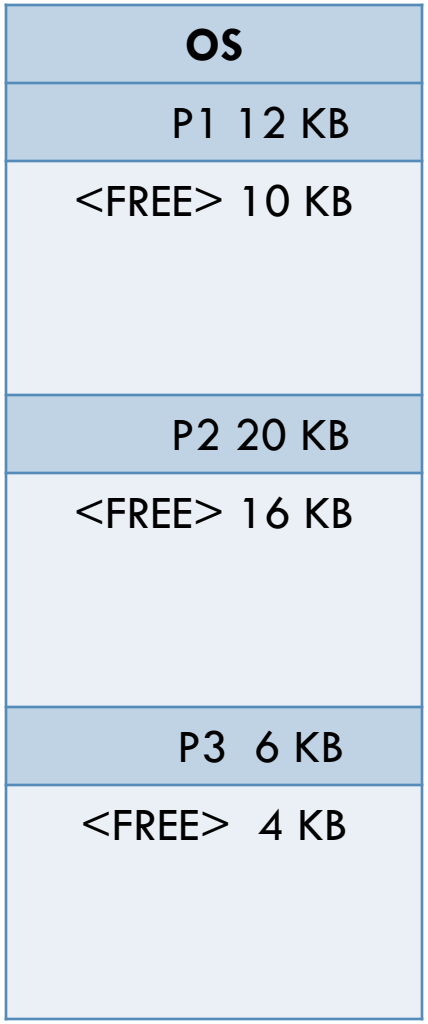


Best fit

- Best Fit : Allocate the smallest block among those that are large enough for the new process.
- In this method, the OS has to search the entire list, or it can keep it sorted and stop when it hits an entry which has a size larger than the size of new process.
- This algorithm produces the smallest left over block.
- However, it requires more time for searching all the list or sorting it
- If sorting is used, merging the area released when a process terminates to neighboring free blocks, becomes complicated.

best fit

Initial memory mapping



best fit

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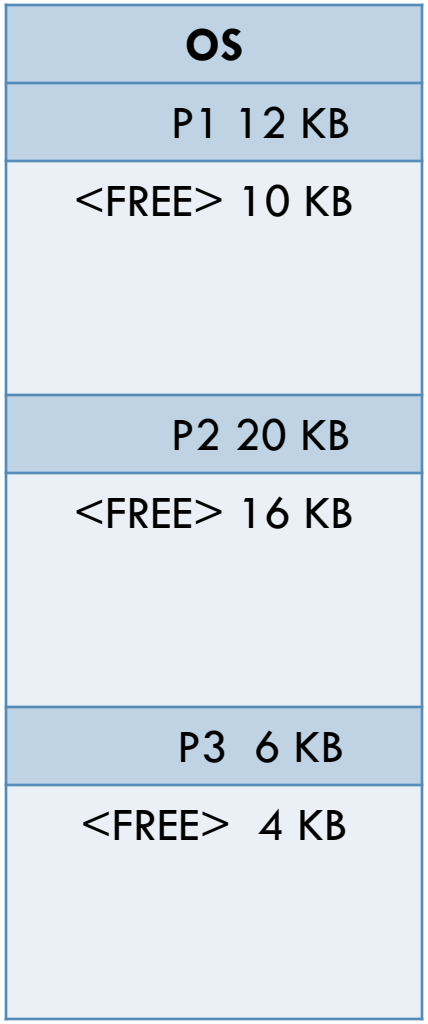

best fit

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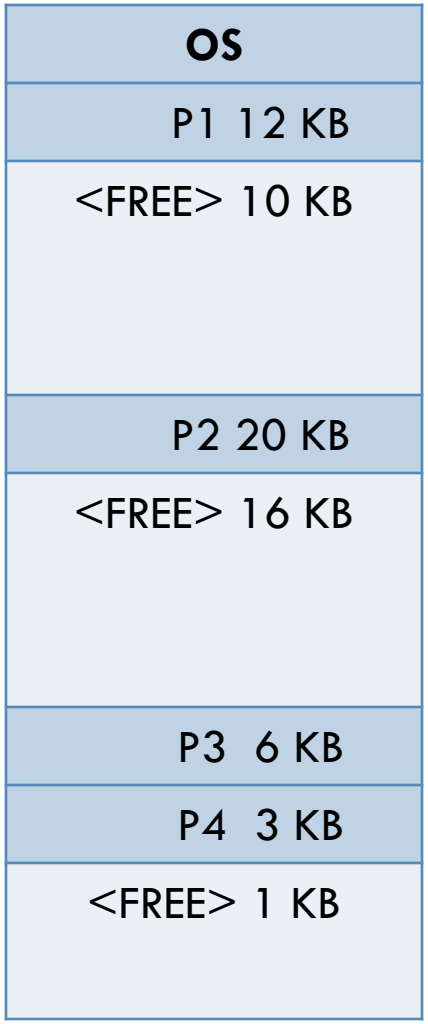

best fit

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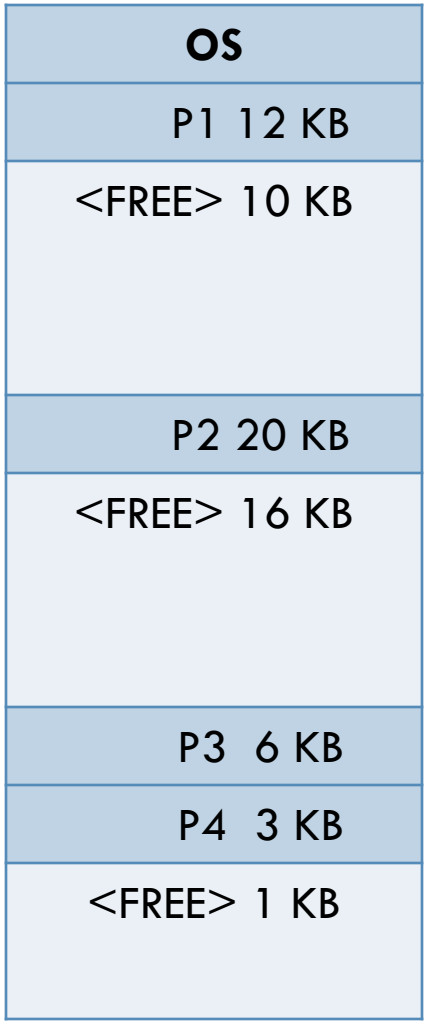

best fit

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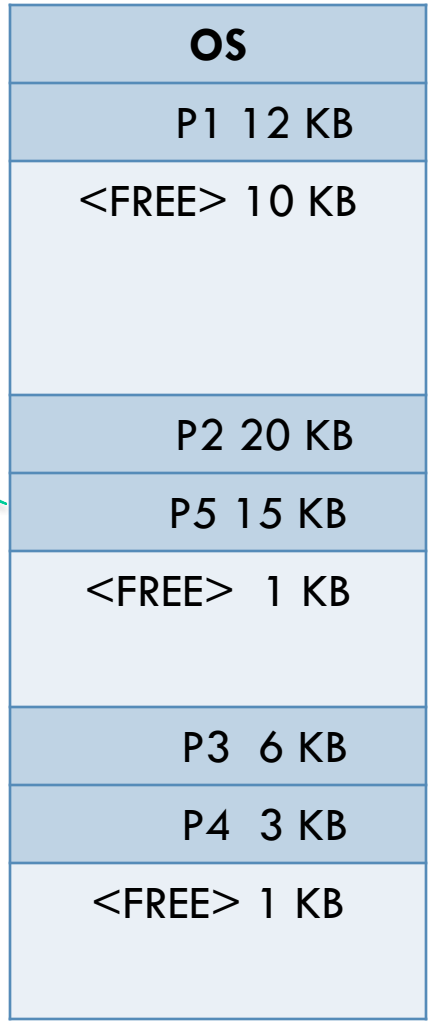
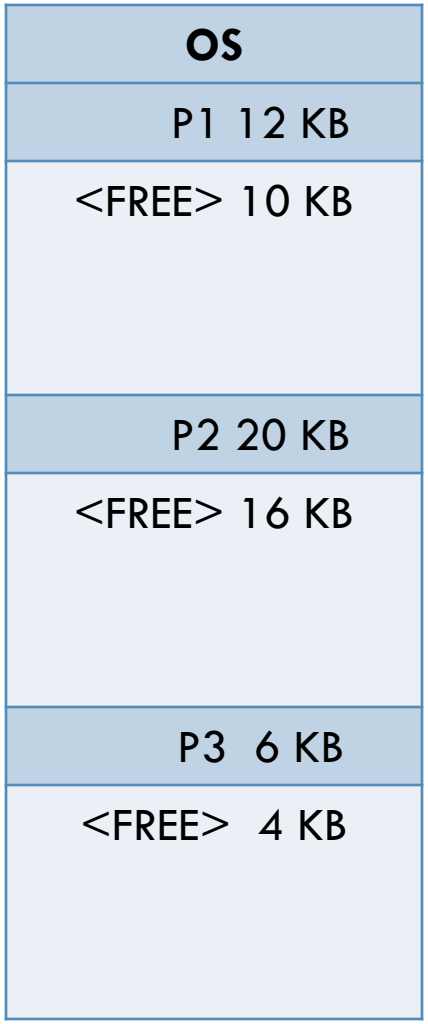


worst fit

- Worst Fit : Allocate the largest block among those that are large enough for the new process.
- Again a search of the entire list or sorting it is needed.
- This algorithm produces the largest over block.

worst fit

Initial memory mapping



worst fit

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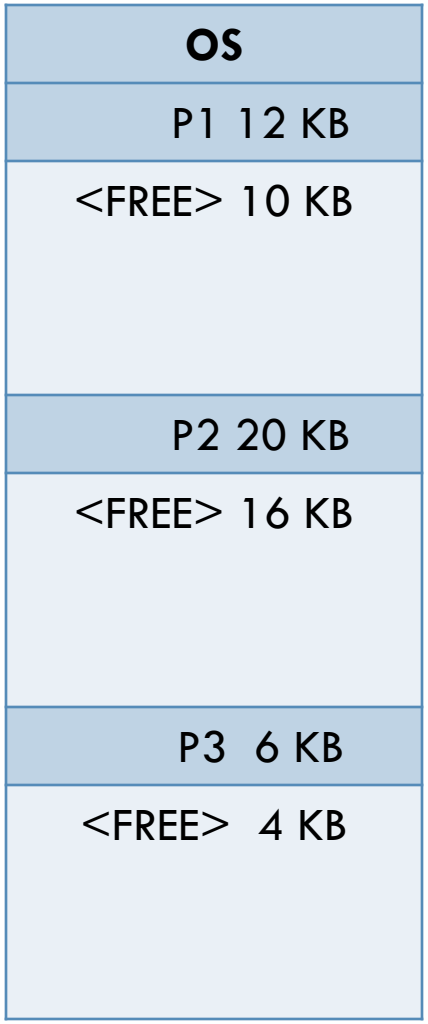

worst fit

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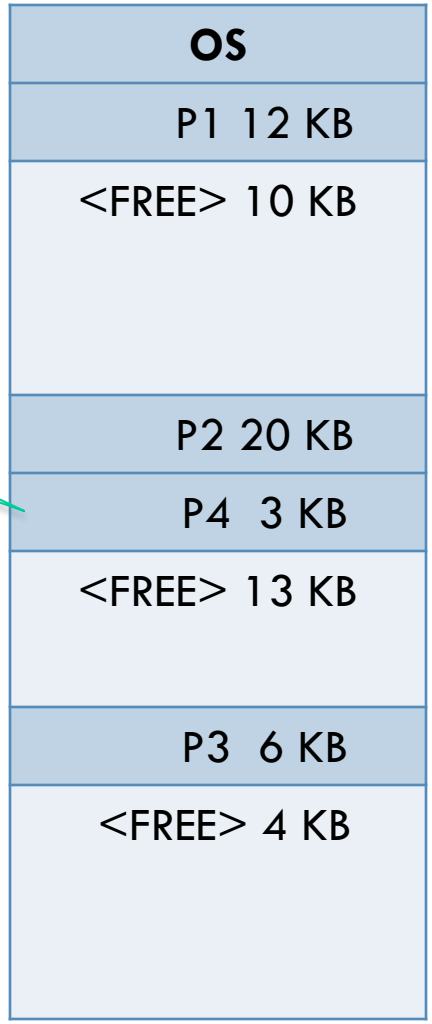
WORST FIT



worst fit

No place to load
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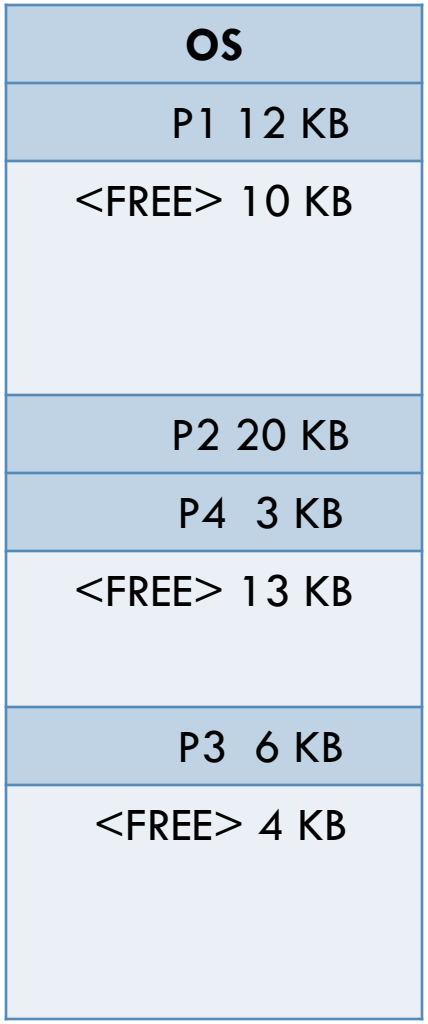
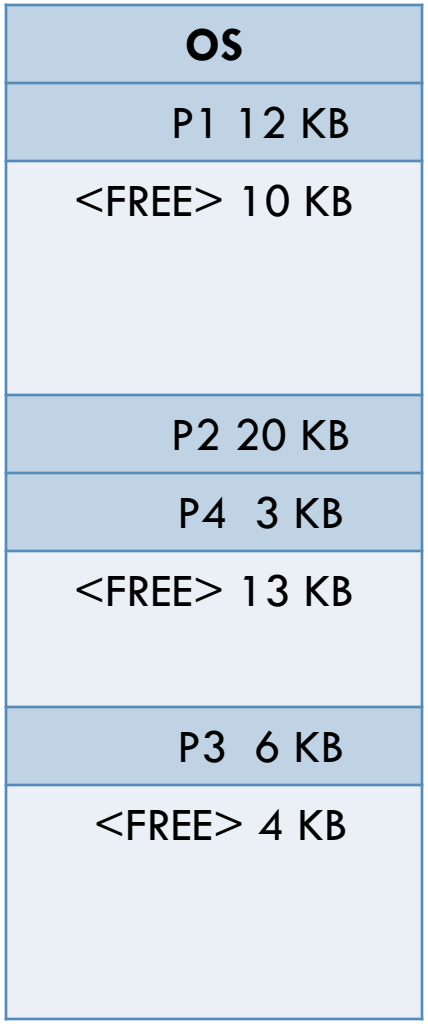


worst fit

No place to load P5 of 15K

Compaction is needed !!



compaction

Compaction is a method to overcome the external fragmentation problem.

All free blocks are brought together as one large block of free space.

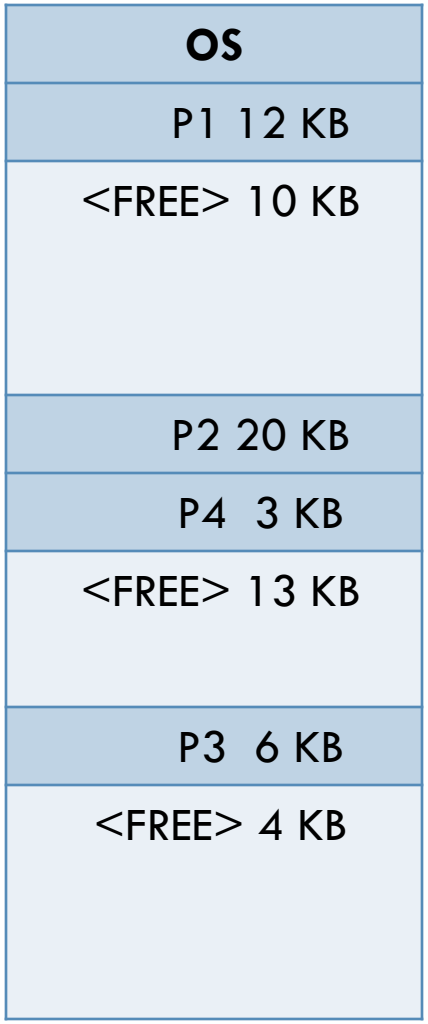
Compaction requires dynamic relocation.

Certainly, compaction has a cost and selection of an optimal compaction strategy is difficult.

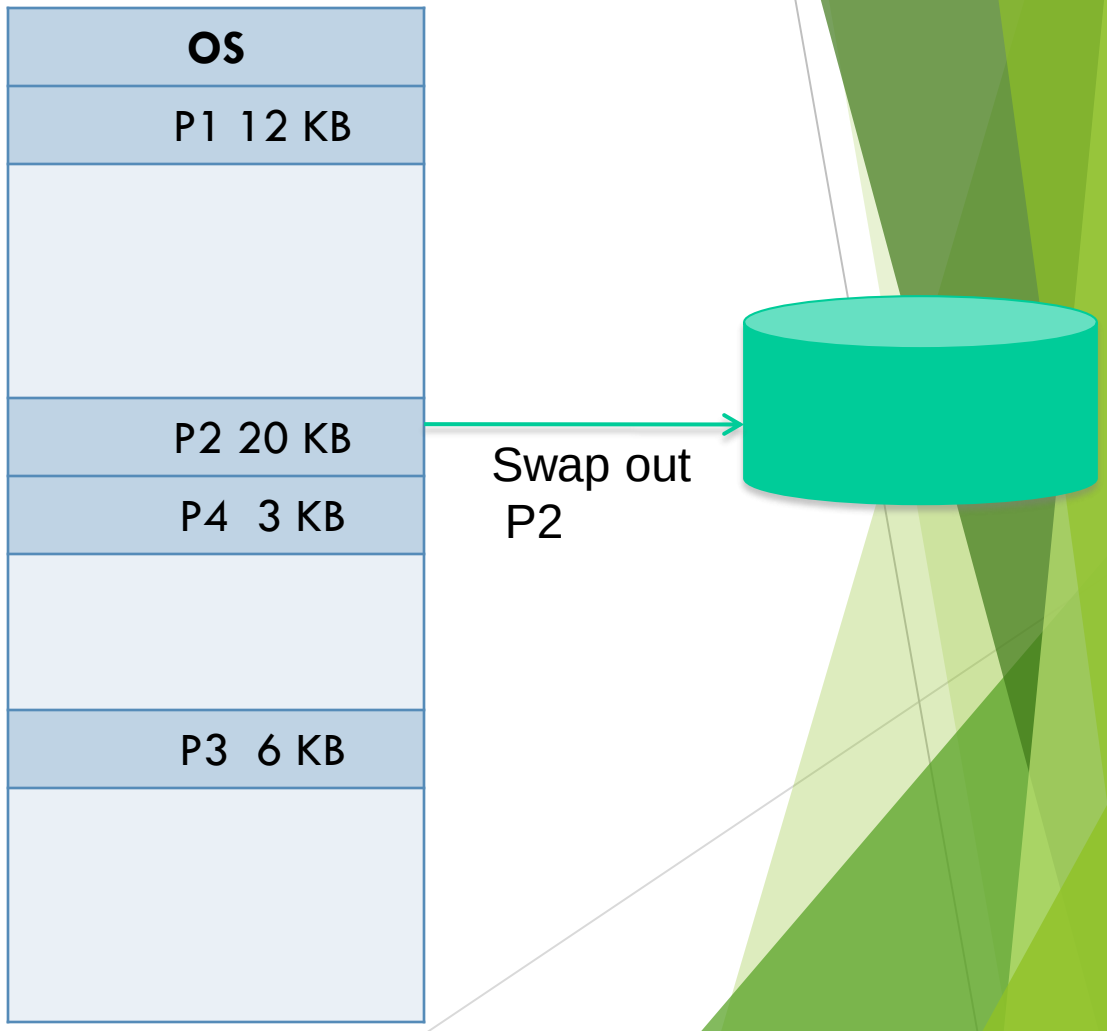
One method for compaction is swapping out those processes that are to be moved within the memory, and swapping them into different memory locations

compaction

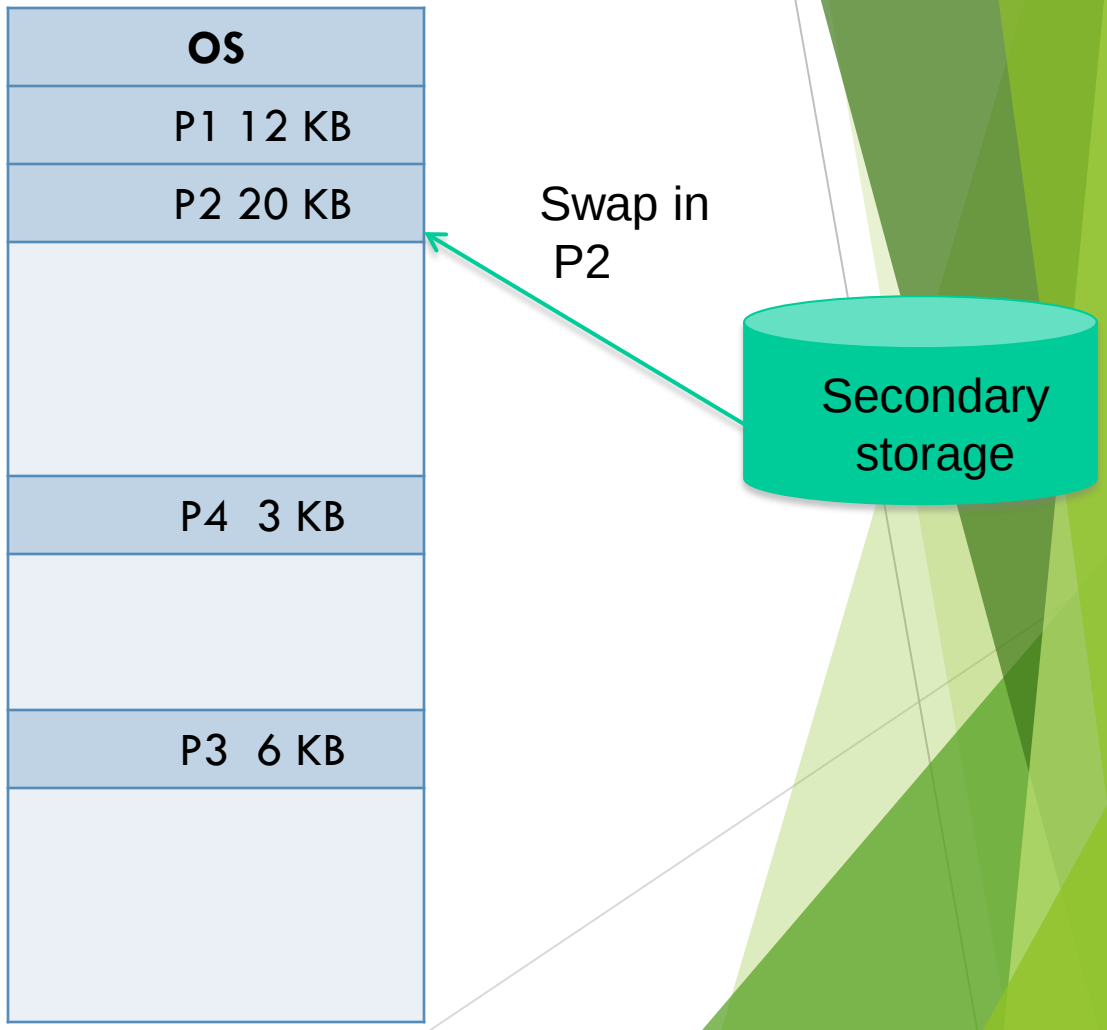
Memory mapping before compaction



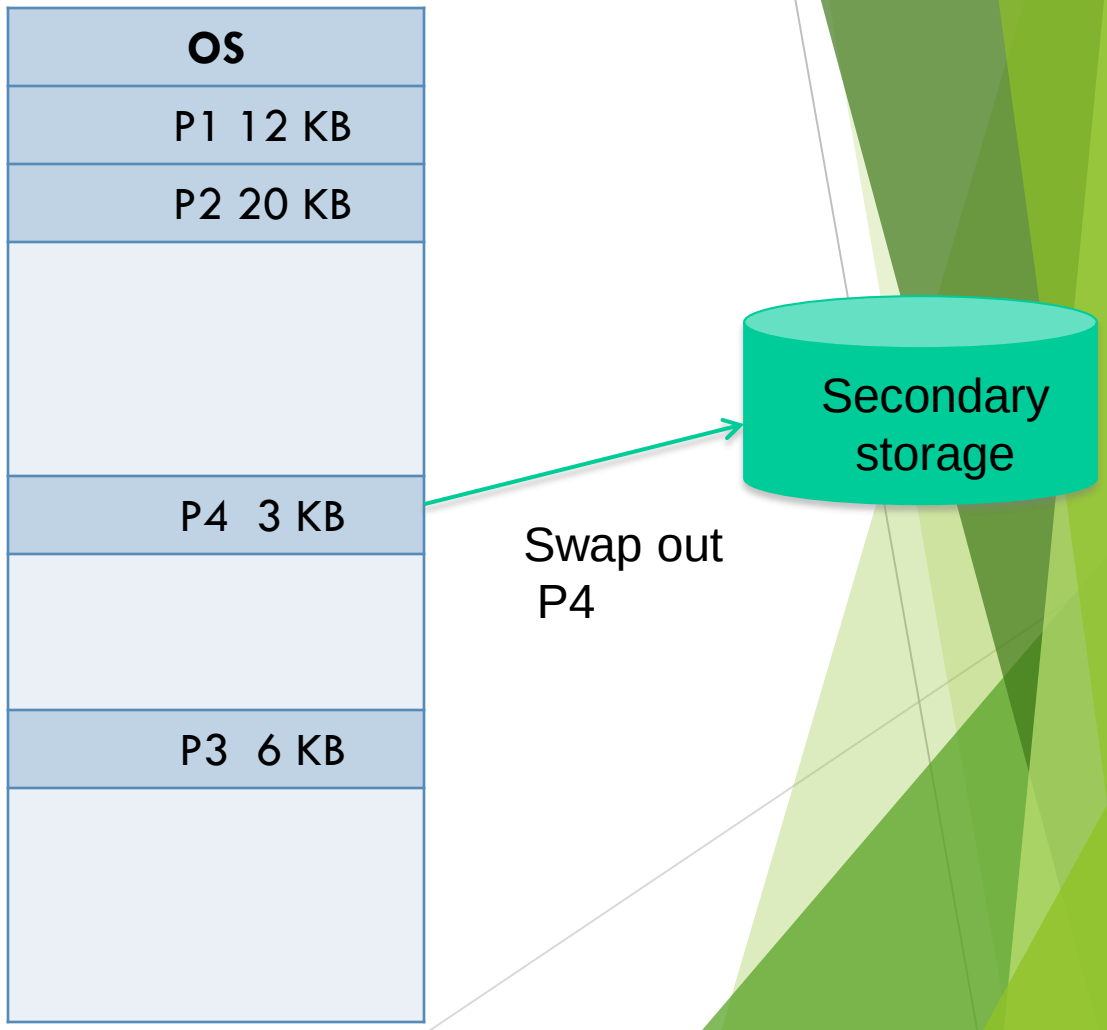
compaction



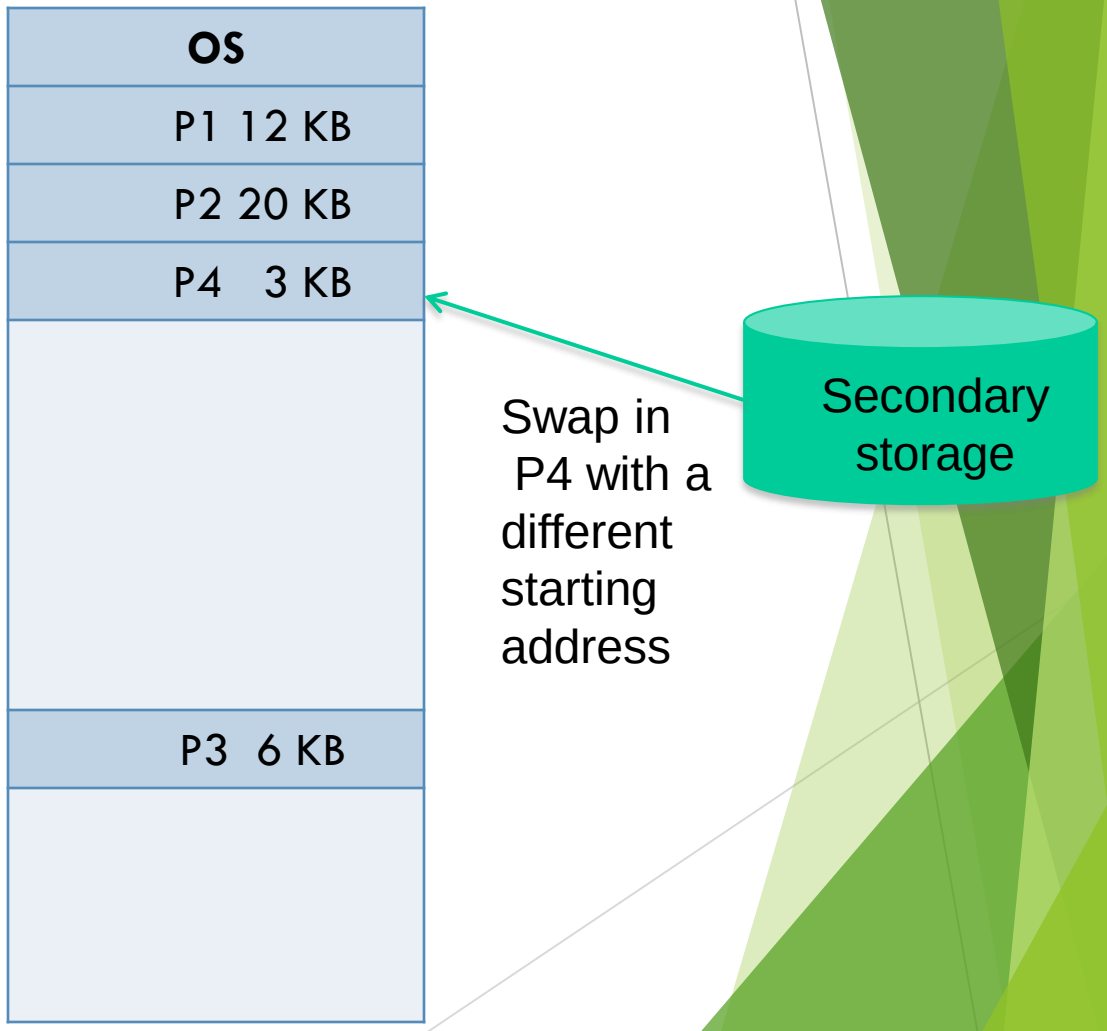
compaction



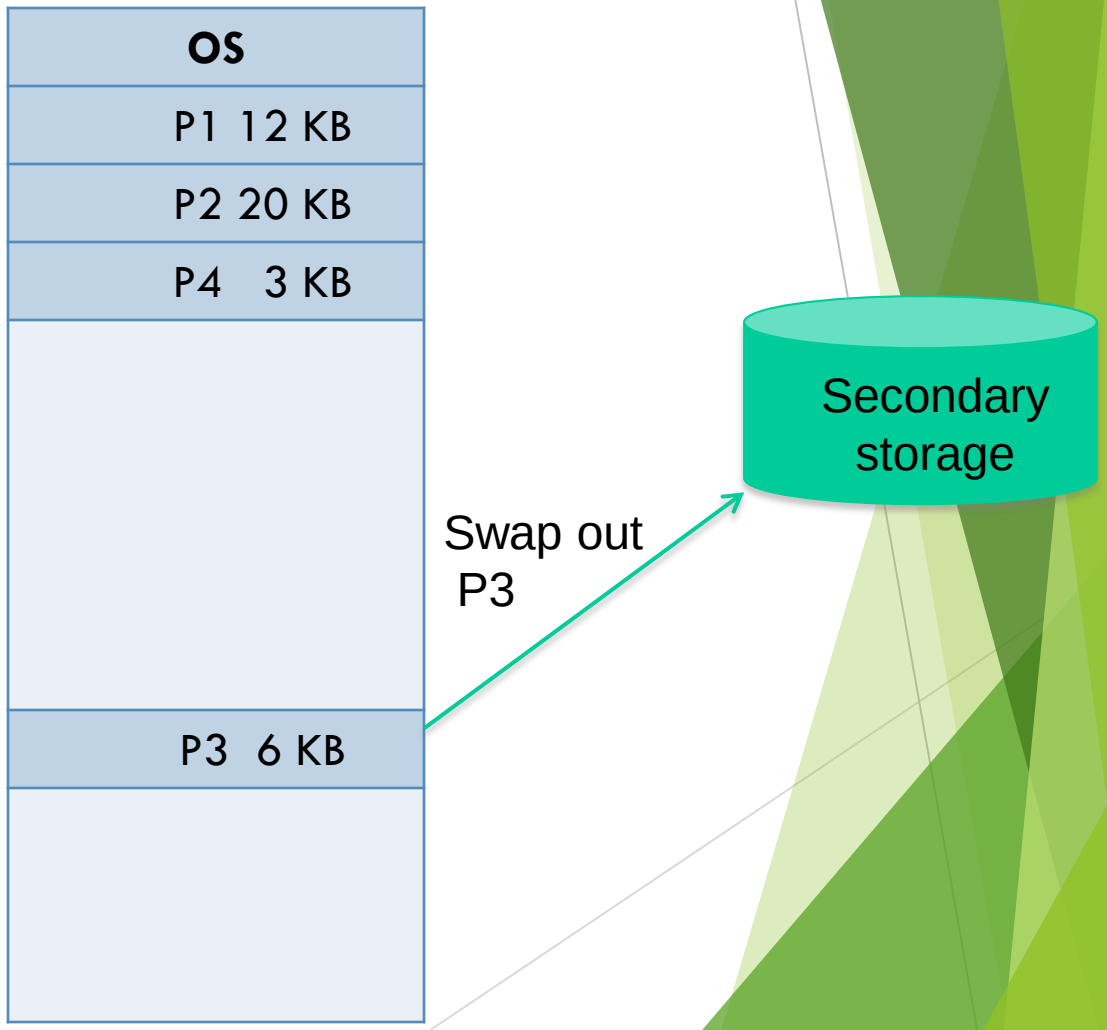
compaction



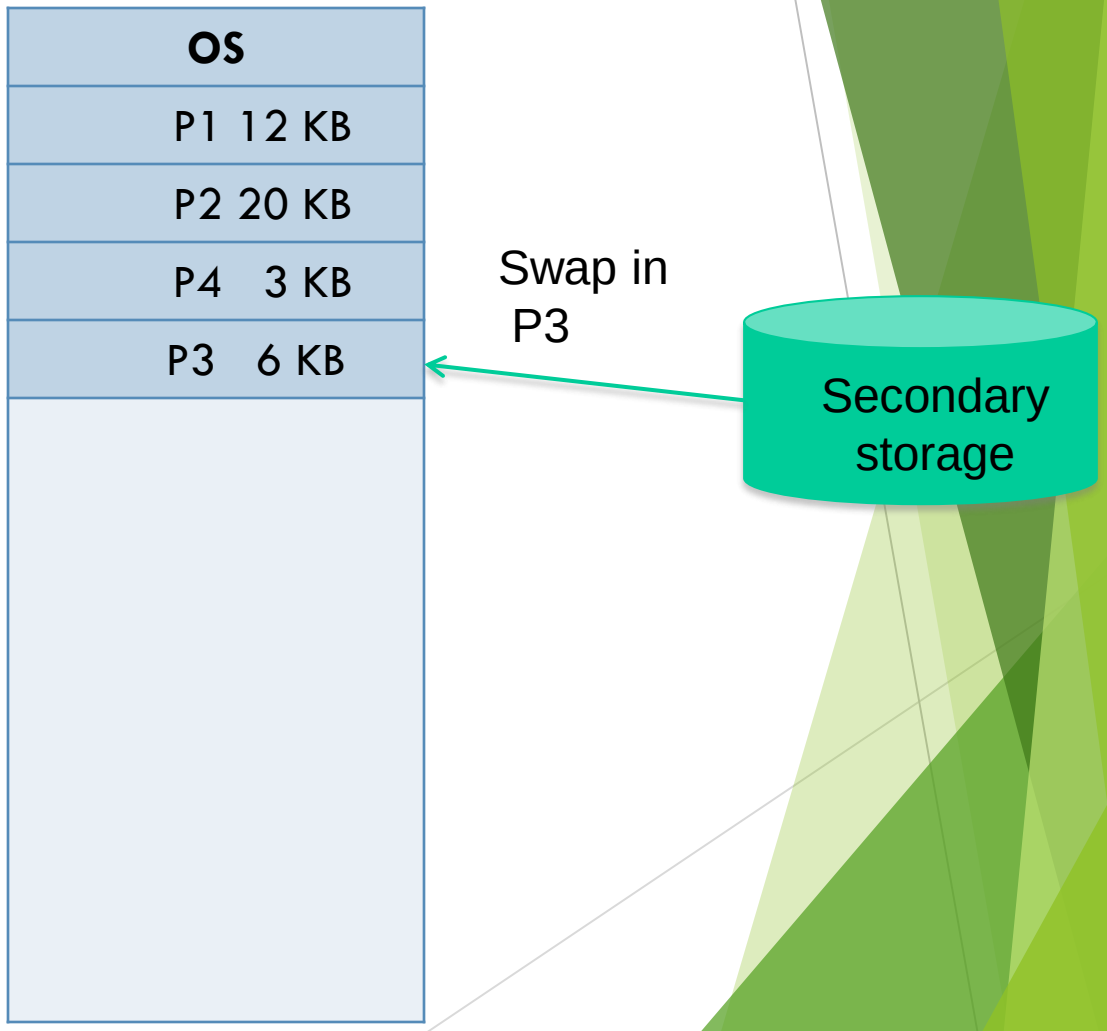
compaction


OS
P1 12 KB
P2 20 KB
P4 3 KB
P3 6 KB
Swap in P4 with a different starting address
Secondary storage

compaction

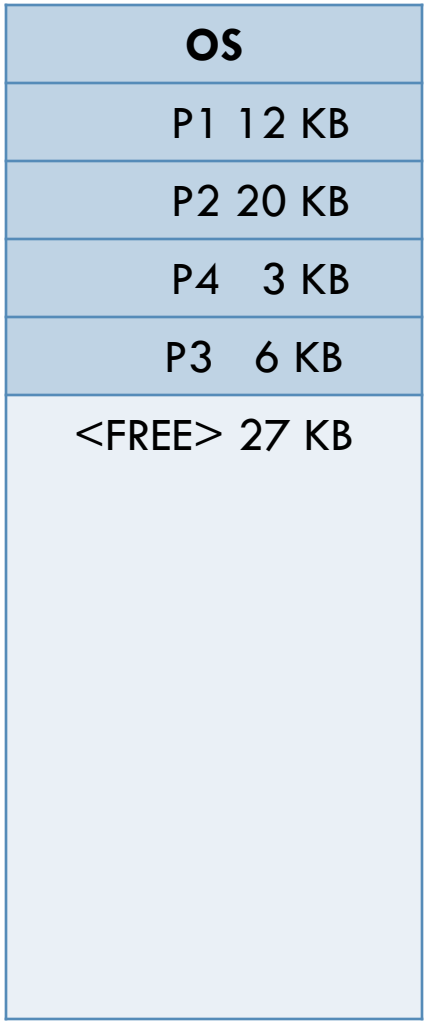


compaction



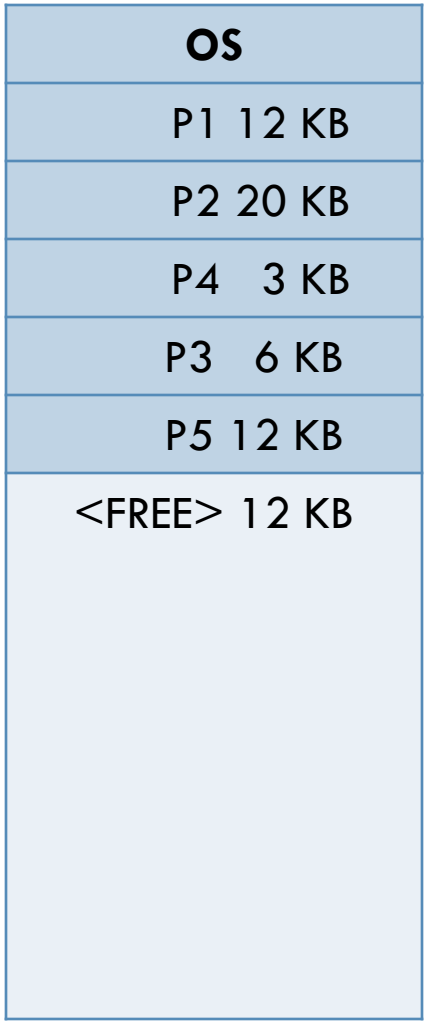
compaction

Memory mapping after compaction



Now P5 of 15KB can be loaded here

compaction



P5 of 15KB is loaded

Memory Allocation Functions

malloc

Allocates requested number of bytes and returns a pointer to the first byte of the allocated space

calloc

Allocates space for an array of elements, initializes them to zero and then returns a pointer to the memory.

free

Frees previously allocated space.

realloc

Modifies the size of previously allocated space.

We will only do malloc and free

Allocating a Block of Memory

A block of memory can be allocated using the function malloc

Reserves a block of memory of specified size and returns a pointer of type void

The return pointer can be type-casted to any pointer type

General format:

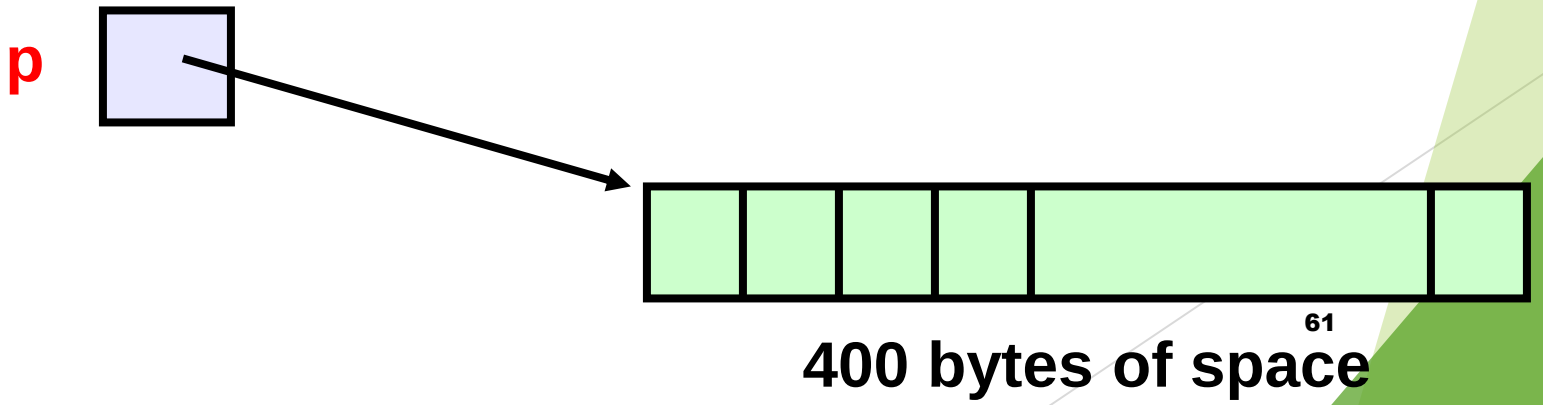
```
type *p;
p =  (type *) malloc (byte_size);
```

Example

```
p = (int *) malloc(100 * sizeof(int));
```

A memory space equivalent to 100 times the size of an int bytes is reserved

The address of the first byte of the allocated memory is assigned to the pointer p of type int



Contd.

```
cptr = (char *) malloc (20);
```

Allocates 20 bytes of space for the pointer cptr of type char

```
sptr = (struct stud *) malloc(10*sizeof(struct stud));
```

Allocates space for a structure array of 10 elements. sptr points to a structure element of type struct stud

Always use sizeof operator to find number of bytes for a data type, as it can vary from machine to machine

Points to Note

malloc always allocates a block of contiguous bytes

The allocation can fail if sufficient contiguous memory space is not available

If it fails, malloc returns NULL

```
if  ((p = (int *) malloc(100 * sizeof(int))) == NULL)
  {
      printf ("\n Memory cannot be allocated");
      exit();
   }
```

Releasing the Allocated Space: free

An allocated block can be returned to the system for future use by using the free function

General syntax:

```
free (ptr);
```

where ptr is a pointer to a memory block which has been previously created using malloc

Note that no size needs to be mentioned for the allocated block, the system remembers it for each pointer returned

Implementation of malloc and free

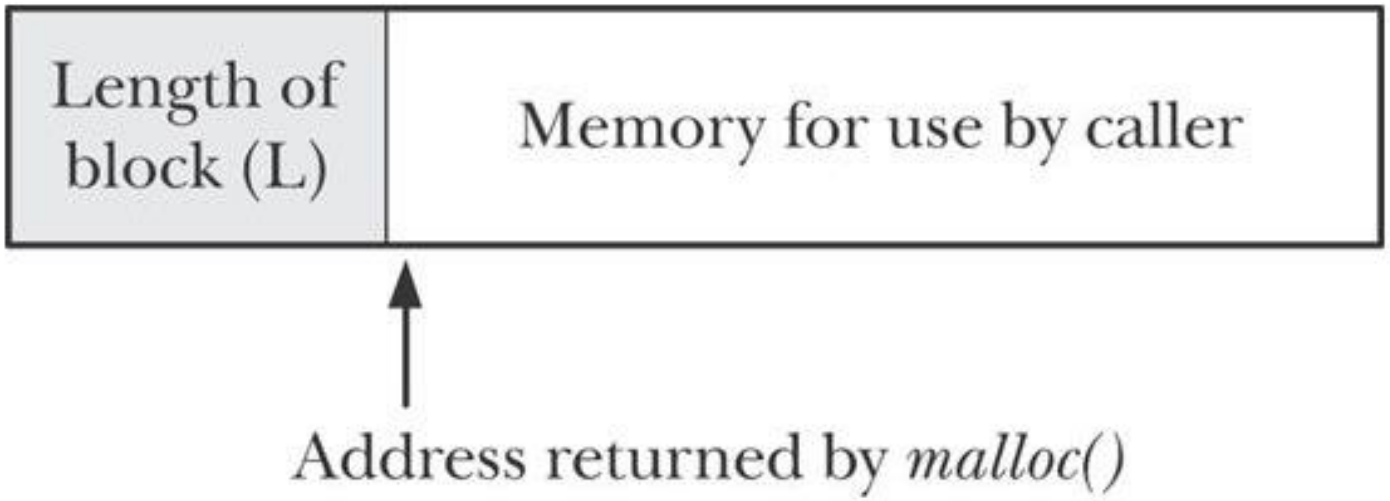


Figure 7-1. Memory block returned by malloc()

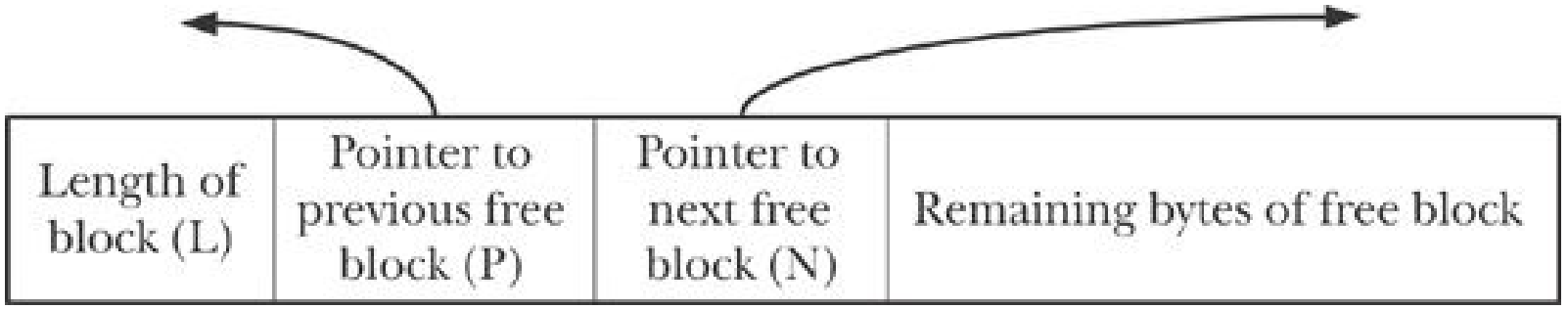


Figure 7-2. A block on the free list

Fig 7.3

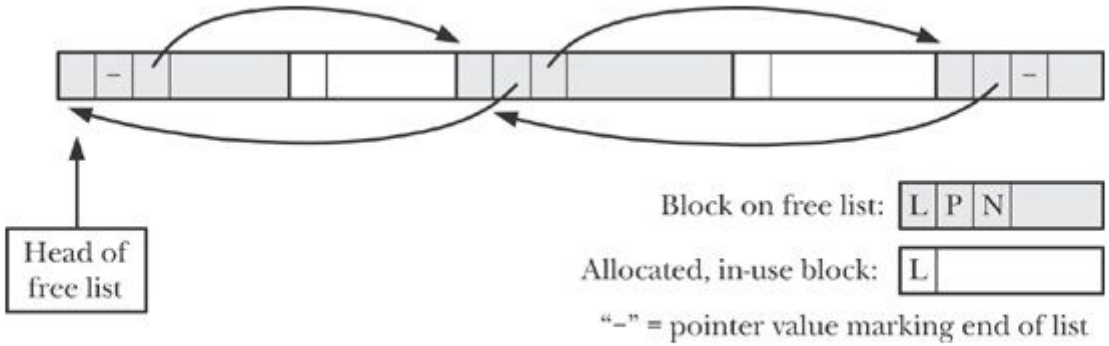


Figure 7-3. Heap containing allocated blocks and a free list

Checking for memory leaks?

NAME -- brk, sbrk - change data segment size

SYNOPSIS

```
#include <unistd.h>

int brk(void *addr);

void *sbrk(intptr_t increment);

brk(), sbrk(): _BSD_SOURCE || _SVID_SOURCE || _XOPEN_SOURCE >= 500
```

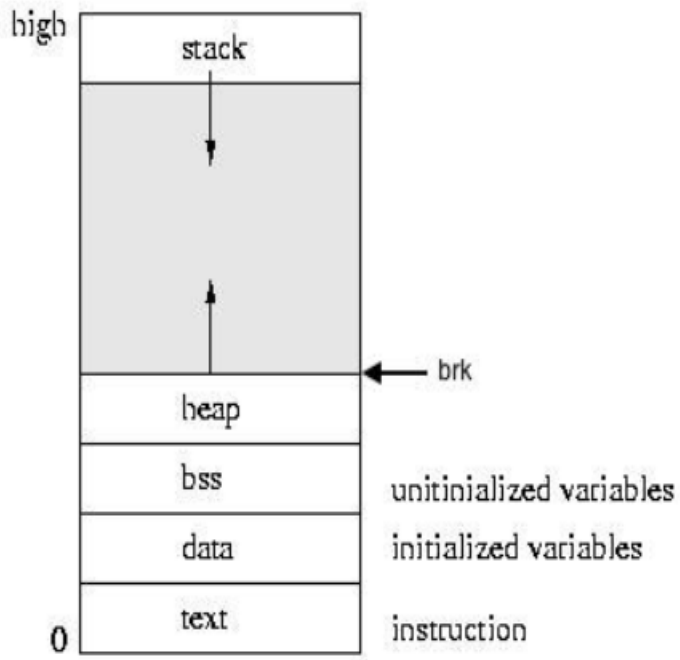
DESCRIPTION - brk() and sbrk() change the location of the program break, which defines the end of the process's data segment. Increasing the program break has the effect of allocating memory to the process; decreasing the break deallocates memory.

brk() sets the end of the data segment to the value specified by addr,

when that value is reasonable, the system has enough memory, and the process does not exceed its maximum data size (see setrlimit(2)).

sbrk() increments the program's data space by increment bytes.

Text section: The part that contains the binary instructions to be executed by the processor.
Data section: Contains non-zero initialized static data.
BSS (Block Started by Symbol) : Contains zero-initialized static data. Static data uninitialized in program is initialized 0 and goes here.
Heap: Contains the dynamically allocated data.
Stack: Contains your automatic variables, function arguments, copy of base pointer etc.



As you can see in the image, the stack and the heap grow in the opposite directions.
Sometimes the data, bss and heap sections are collectively referred to as the "*data segment*",
the end of which is demarcated by a pointer named program break or **brk**.
That is, *brk* points to the end of the heap.

Now if we want to allocate more memory in the heap, we need to request the system to increment brk. Similarly, to release memory we need to request the system to decrement *brk*.

malloc_usable_size - obtain size of block of memory allocated from heap

Synopsis

#include <malloc.h>

size_t malloc_usable_size (void *_ptr_);

Description

The **malloc_usable_size**() function returns the number of usable bytes in the block pointed to by *ptr*, a pointer to a block of memory allocated by ***malloc***(*3*) or a related function.

Return Value

malloc_usable_size() returns the number of usable bytes in the block of allocated memory pointed to by *ptr*. If *ptr* is NULL, 0 is returned.

NAME top

malloc_stats - print memory allocation statistics

SYNOPSIS top

```
#include <malloc.h>

void malloc_stats(void);
```

DESCRIPTION top

The **malloc_stats**() function prints (on standard error) statistics about memory allocated by malloc(3) and related functions. For each arena (allocation area), this function prints the total amount of memory allocated and the total number of bytes consumed by in-use allocations. (These two values correspond to the *arena* and *uordblks* fields retrieved by mallinfo(3).) In addition, the function prints the sum of these two statistics for all arenas, and the maximum number of blocks and bytes that were ever simultaneously allocated using mmap(2).

__malloc_hook, __malloc_initialize_hook, __memalign_hook, __free_hook, __realloc_hook, __after_morecore_hook - malloc debugging variables

Synopsis

```
#include <malloc.h>
void *(*__malloc_hook)(size_t size, const void *caller);
void *(*__realloc_hook)(void *ptr, size_t size", const void *" caller );

void *(*__memalign_hook)(size_t alignment, size_t size,
         const void *caller);
void (*__free_hook)(void *ptr, const void *caller);
void (*__malloc_initialize_hook)(void);
void (*__after_morecore_hook)(void);
```

Description

The GNU C library lets you modify the behavior of ***malloc***(3), ***realloc***(3), and ***free***(3) by specifying appropriate hook functions. You can use these hooks to help you debug programs that use dynamic memory allocation, for example.

The variable **__malloc_initialize_hook** points at a function that is called once when the malloc implementation is initialized. This is a weak variable, so it can be overridden in the application with a definition like the following:

```
void (*__malloc_initialize_hook)(void) = my_init_hook;
```

Now the function *my_init_hook*() can do the initialization of all hooks.

alloca - allocate memory that is automatically freed

Synopsis

#include <alloca.h>

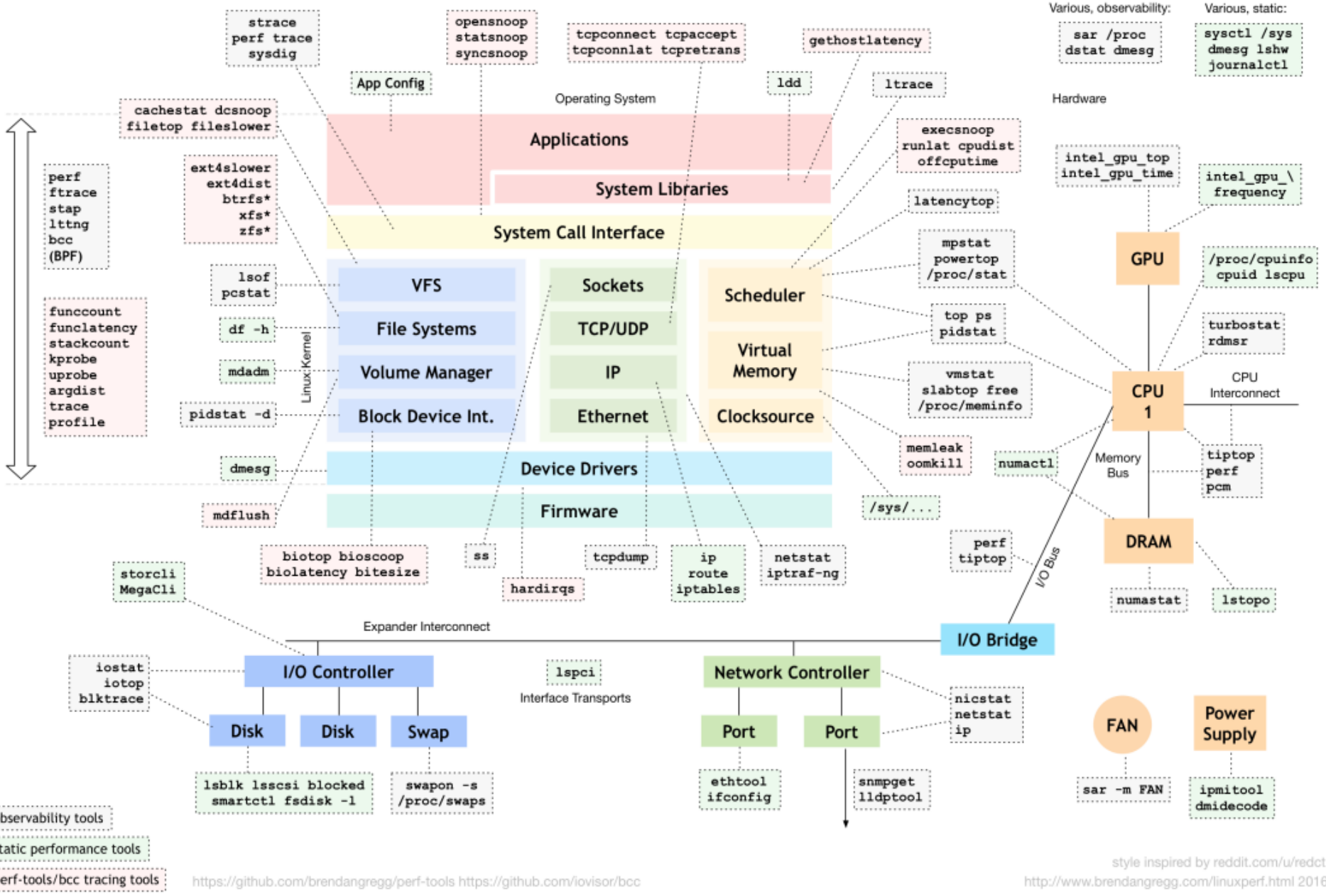
void *alloca(size_t *size***);**

Description

The **alloca**() function allocates *size* bytes of space in the stack frame of the caller. This temporary space is automatically freed when the function that called **alloca**() returns to its caller.

Linux Application Debugging

Linux Performance Tools



Syslog

Syslog is a known standard for message logging. Most times, the system that does the logging and the software that gets to generate them tend to interfere during processes. But syslog helps separate the software generating the logs from the system that stores the logs, thereby making the process of logging less complicated and stressful.

- **Syslog Daemon**: It is a daemon that listens for logs and writes them to a specific location. The location(s) is defined in the configuration file for the daemon. rsyslog is the Syslog daemon shipped with most of the distros.

- **Syslog Message Format**: It refers to the syntax of Syslog messages. The syntax is usually defined by a standard (for eg RFC5424).

Syslog

- **Syslog Protocol**: It refers to the protocol used for remote logging. Modern Syslog daemons can use TCP and TLS in addition to UDP which is the legacy protocol for remote logging.

Syslog

Benefits of syslog

- Helps analyze the root cause for any trouble or problem caused
- Reduce overall downtime helping to troubleshoot issues faster with all the logs
- Improves incident management by active detection of issues
- Self-determination of incidents along with auto resolution
- Simplified architecture with different level of severity like error,info,warning etc

Syslog

Display syslogs with the ls command

Listing the contents of /var/log for an Ubuntu 20.04 machine using the ls command:

$ sudo ls /var/log

```
test@test-VirtualBox:~$ sudo ls /var/log
[sudo] password for test:
alternatives.log       auth.log.3.gz  dmesg           journal            syslog.5.gz
alternatives.log.1     auth.log.4.gz  dmesg.0         kern.log           syslog.6.gz
alternatives.log.2.gz  boot.log       dmesg.1.gz      kern.log.1         syslog.7.gz
apport.log             boot.log.1     dmesg.2.gz      kern.log.2.gz      ubuntu-advantage.log
apport.log.1           boot.log.2     dmesg.3.gz      kern.log.3.gz      ubuntu-advantage.log.1
apport.log.2.gz        boot.log.3     dmesg.4.gz      kern.log.4.gz      ubuntu-advantage.log.2.gz
apport.log.3.gz        boot.log.4     dpkg.log        lastlog            unattended-upgrades
apport.log.4.gz        boot.log.5     dpkg.log.1      openvpn            vboxadd-install.log
apport.log.5.gz        boot.log.6     dpkg.log.2.gz   private            vboxadd-setup.log
apport.log.6.gz        boot.log.7     faillog         speech-dispatcher  vboxadd-setup.log.1
apport.log.7.gz        bootstrap.log  fontconfig.log  syslog             vboxadd-setup.log.2
apt                    btmp           gdm3            syslog.1           vboxadd-setup.log.3
auth.log               btmp.1         gpu-manager.log syslog.2.gz        vboxadd-setup.log.4
auth.log.1             cups           hp              syslog.3.gz        vboxadd-uninstall.log
auth.log.2.gz          dist-upgrade   installer       syslog.4.gz        wtmp
test@test-VirtualBox:~$
```

Syslog

View system logs in Linux using the tail command

Using the tail command you can view the last few logs. Adding the -f option lets you watch them in real time.

$ sudo tail -f /var/log/syslog

Similarly, the tail command can be used to view kernel logs (kern.log), boot logs (boot.log), etc .

Syslog

Syslog Configuration

The rules for which logs go where are defined in the Syslog daemon's configuration file.

$ sudo vi /etc/rsyslog.conf

$ sudo vi /etc/rsyslog.d/50-default.conf

```
#  Default rules for rsyslog.
#
#                       For more information see rsyslog.conf(5) and /etc/rsyslog.conf

#
# First some standard log files.  Log by facility.
#
auth,authpriv.*                 /var/log/auth.log
*.*;auth,authpriv.none          -/var/log/syslog
#cron.*                         /var/log/cron.log
#daemon.*                       -/var/log/daemon.log
kern.*                          -/var/log/kern.log
#lpr.*                          -/var/log/lpr.log
mail.*                          -/var/log/mail.log
#user.*                         -/var/log/user.log
local1.*                        -/var/log/test41.log
```

Strace

strace is a powerful command line tool for debugging and trouble shooting programs in Unix-like operating systems such as Linux. It captures and records all system calls made by a process and the signals received by the process.

Trace Linux Command System Calls

You can simply run a command with strace like this, here we are tracing of all system calls made by the free command.

 # strace free

Strace

Trace Linux Process PID

If a process is already running, you can trace it by simply passing its PID as follows; this will fill your screen with continues output that shows system calls being made by the process, to end it, press [Ctrl + C]

 # sudo strace -p 3569

Get Summary of Linux Process

Using the -c flag, you can generate a report of total time, calls, and errors for each system call, as follows.

 # strace –c free

Strace

Print Instruction Pointer During System Call

The -i option displays the instruction pointer at the time of each system call made by the program.

 # sudo strace -i free

Show Time of Day For Each Trace Output Line

You can also print the time of day for each line in the trace out

put, by passing the -t flag.

 # sudo strace –t free

Strace

Print Command Time Spent in System Calls

To shows the time difference between the starting and the end of each system call made by a program, use the -T option.

 # sudo strace –T free

Trace Only Specific System Calls

In the command below, trace=write is known as a qualifying expression, where trace is a qualifier (others include signal, abbrev, verbose, raw, read, or write). Here, write is the value of the qualifier.

Strace

The following command actually shows the system calls to print df output on standard output.

 # sudo strace –e trace=write free

 # sudo strace -e trace=open,close free

 # sudo strace -e trace=open,close,read,write free

 # sudo strace -e trace=all free

Strace

Trace System Calls Based on a Certain Condition

Let’s look at how to trace system calls relating to a given class of events. This command can be used to trace all system calls involving process management.

 # sudo strace -e trace=process free

Strace

Trace System Calls Based on a Certain Condition

Let’s look at how to trace system calls relating to a given class of events. This command can be used to trace all system calls involving process management.

 # sudo strace -e trace=process free

Next, to trace all system calls that take a filename as an argument, run this command.

$ sudo strace -q -e trace=file free

Strace

To trace all system calls involving memory mapping, type.

$ sudo strace -q -e trace=memory free

You can trace all network and signals related system calls.

$ sudo strace -e trace=network free

$ sudo strace -e trace=signal free

Strace

Redirect Trace Output to File

To write the trace messages sent to standard error to a file, use the -o option. This means that only the command output is printed on the screen as shown below.

$ sudo strace -o df_debug.txt free

strace a program and threads

To trace both program and it threads using option -f

 # strace -f ./program

Strace

strace a program and print strings

This will print the first 80 characters of every string.

 # strace -s 80 -f ./program

ftrace

Ftrace is a tracing framework for the Linux kernel. It was added to the kernel back in 2008 and has evolved a lot since then.

Ftrace stands for function tracer and basically lets you watch and record the execution flow of kernel functions. It was created by Steven Rostedt, derived from two other tools called latency tracer from Ingo Molnar and Steven’s logdev utility.

ftrace

With ftrace you can really see what the kernel is doing. You can trace function calls and learn a lot about how the kernel works. You can find out which kernel functions are called when you run a user space application. You can profile functions, measure execution time and find out bottlenecks and performance issues. You can identify hangs in kernel space. You can measure the time it takes to run a real-time task and find out latency issues. You can measure stack usage in kernel space and find out possible stack overflows. You can really do a lot of things to monitor and find bugs in the kernel!

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ftrace

And this is the filesystem interface provided by ftrace:

```
# ls /sys/kernel/tracing/
README                          set_ftrace_filter
available_events                set_ftrace_notrace
available_filter_functions      set_ftrace_pid
available_tracers               set_graph_function
buffer_size_kb                  set_graph_notrace
buffer_total_size_kb            snapshot
current_tracer                  stack_max_size
dyn_ftrace_total_info           stack_trace
enabled_functions               stack_trace_filter
events                          timestamp_mode
free_buffer                     trace
function_profile_enabled        trace_clock
hwlat_detector                  trace_marker
instances                       trace_marker_raw
max_graph_depth                 trace_options
options                         trace_pipe
per_cpu                         trace_stat
printk_formats                  tracing_cpumask
saved_cmdlines                  tracing_max_latency
saved_cmdlines_size             tracing_on
saved_tgids                     tracing_thresh
set_event                       uprobe_events
set_event_pid                   uprobe_profile
```

ftrace

We can print the list of available tracers:

```
# cat available_tracers
hwlat   blk      function_graph   wakeup_dl   wakeup_rt
wakeup  irqsoff  function         nop
```

There are function tracers (*function*, *function_graph*), latency tracers (*wakeup_dl*, *wakeup_rt*, *irqsoff*, *wakeup*, *hwlat*), I/O tracers (*blk*) and many more!

To enable a tracer, we just have to write its name to *current_tracer*:

```
# echo function > current_tracer
```

ftrace

And we can read the trace buffer with the *trace* or *trace_pipe* file:

```
# cat trace
# tracer: function
#
#                              _-----=> irqs-off
#                             / _----=> need-resched
#                            | / _---=> hardirq/softirq
#                            || / _--=> preempt-depth
#                            ||| /     delay
#           TASK-PID   CPU#  ||||    TIMESTAMP  FUNCTION
#              | |       |   ||||       |         |
          <idle>-0     [001] d...    23.695208: _raw_spin_lock_irqsave <-hrtimer_next_event_wi...
          <idle>-0     [001] d...    23.695209: __hrtimer_next_event_base <-hrtimer_next_event...
          <idle>-0     [001] d...    23.695210: __next_base <-__hrtimer_next_event_base
          <idle>-0     [001] d...    23.695211: __hrtimer_next_event_base <-hrtimer_next_event...
          <idle>-0     [001] d...    23.695212: __next_base <-__hrtimer_next_event_base
          <idle>-0     [001] d...    23.695213: __next_base <-__hrtimer_next_event_base
          <idle>-0     [001] d...    23.695214: _raw_spin_unlock_irqrestore <-hrtimer_next_eve...
          <idle>-0     [001] d...    23.695215: get_iowait_load <-menu_select
          <idle>-0     [001] d...    23.695217: tick_nohz_tick_stopped <-menu_select
          <idle>-0     [001] d...    23.695218: tick_nohz_idle_stop_tick <-do_idle
          <idle>-0     [001] d...    23.695219: rcu_idle_enter <-do_idle
          <idle>-0     [001] d...    23.695220: call_cpuidle <-do_idle
          <idle>-0     [001] d...    23.695221: cpuidle_enter <-call_cpuidle
```

ftrace

The function graph tracer is an alternative function tracer that traces not only the function entry but also the return of the function, allowing you to create a call graph of the function flow and output the trace data in a C-like style with information about the duration of each function.

```
# echo function_graph > current_tracer

# cat trace
# tracer: function_graph
#
# CPU  DURATION                  FUNCTION CALLS
# |     |   |                     |   |   |   |
 0)   1.000 us    |                } /* idle_cpu */
 0)               |                tick_nohz_irq_exit() {
 0)               |                  ktime_get() {
 0)   1.000 us    |                    clocksource_mmio_readl_up();
 0)   7.666 us    |                  }
 0) + 14.000 us   |                }
 0)               |                rcu_irq_exit() {
 0)   1.334 us    |                  rcu_nmi_exit();
 0)   7.667 us    |                }
 0) ! 556.000 us  |              } /* irq_exit */
 0) # 1187.667 us |            } /* __handle_domain_irq */
 0) # 1194.333 us |          } /* gic_handle_irq */
 0)   <========== |
 0) # 8197.333 us |        } /* cpuidle_enter_state */
 0) # 8205.334 us |      } /* cpuidle_enter */
[...]
```

Trace-cmd

trace-cmd is a user-space command-line tool for ftrace created by Steven Rostedt.

It is a front-end to the tracefs filesystem and can be used to configure ftrace, read the trace buffer and save the data to a file (*trace.dat* by default) for further analysis.

```
# trace-cmd

trace-cmd version 2.6.1

usage:
  trace-cmd [COMMAND] ...

  commands:
     record - record a trace into a trace.dat file
     start - start tracing without recording into a file
     extract - extract a trace from the kernel
     stop - stop the kernel from recording trace data
     restart - restart the kernel trace data recording
     show - show the contents of the kernel tracing buffer
     reset - disable all kernel tracing and clear the trace buffers
     report - read out the trace stored in a trace.dat file
     stream - Start tracing and read the output directly
     profile - Start profiling and read the output directly
     hist - show a historgram of the trace.dat information
     stat - show the status of the running tracing (ftrace) system
     split - parse a trace.dat file into smaller file(s)
     options - list the plugin options available for trace-cmd report
     listen - listen on a network socket for trace clients
     list - list the available events, plugins or options
     restore - restore a crashed record
     snapshot - take snapshot of running trace
```

Trace-cmd

For example, the command below will start a function tracing:

```
# trace-cmd start -p function
```

And the command below will trace GPIO events:

```
# trace-cmd start -e gpio
```

We can also trace a specific process and record the tracing data to a file:

```
# trace-cmd record -p function -F ls /
  plugin 'function'
CPU0 data recorded at offset=0x30d000
    737280 bytes in size
CPU1 data recorded at offset=0x3c1000
    0 bytes in size

# ls trace.dat
trace.dat
```

Trace-cmd

We can show the tracing data with the *report* command:

```
# trace-cmd report
CPU 1 is empty
cpus=2
             ls-175   [000]    43.359618: function:             mutex_unlock <-- rb_simple_write
             ls-175   [000]    43.359624: function:             __fsnotify_parent <-- vfs_write
             ls-175   [000]    43.359625: function:             fsnotify <-- vfs_write
             ls-175   [000]    43.359627: function:             __sb_end_write <-- vfs_write
```

Or we can open it with **KernelShark**.

KernelShark

KernelShark is a graphical tool that works as a frontend to the *trace.dat* file generated by the *trace-cmd* tool.

Address Sanitizer

AddressSanitizer (ASan) is an instrumentation tool created by Google security researchers to identify memory access problems in C and C++ programs.

When the source code of a C/C++ application is compiled with AddressSanitizer enabled, the program will be instrumented at runtime to identify and report memory access errors.

Address Sanitizer

Memory access errors and AddressSanitizer

C and C++ are very insecure and error-prone languages. And one of the main sources of problems is memory access errors.

Different kind of bugs in the source code could trigger a memory access error, including:

- **Buffer overflow or buffer overrun** occurs when a program overruns a buffer's boundary and overwrites adjacent memory locations.
- **Stack overflow** is when a program crosses the boundary of function's stack.

Address Sanitizer

- **Heap overflow** is when a program overruns a buffer allocated in the heap.
- **Memory leak** is when a program allocates memory but does not deallocate.
- **Use after free (dangling pointer)** is when a program uses memory regions already deallocated.
- **Uninitialized variable** is when a program reads a memory location before it is initialized.

All these errors are due to programming bugs. They could prevent the application from executing, cause invalid results or expose a vulnerability that could be exploited by a malicious actor. They are usually very hard to reproduce, debug and fix.

Address Sanitizer

- **Heap overflow** is when a program overruns a buffer allocated in the heap.
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Address Sanitizer

-fsanitize=address

Thread Sanitizer

ThreadSanitizer is a tool that detects data races. It consists of a compiler instrumentation module and a run-time library. Typical slowdown introduced by ThreadSanitizer is about 5x-15x. Typical memory overhead introduced by ThreadSanitizer is about 5x-10x.

-fsanitize=thread

Valgrind

Valgrind is a multipurpose code profiling and memory debugging tool for Linux when on the x86 and, as of version 3, AMD64, architectures. It allows you to run your program in Valgrind's own environment that monitors memory usage such as calls to malloc and free (or new and delete in C++). If you use uninitialized memory, write off the end of an array, or forget to free a pointer, Valgrind can detect it. Since these are particularly common problems, this tutorial will focus mainly on using Valgrind to find these types of simple memory problems, though Valgrind is a tool that can do a lot more.

Valgrind

 # valgrind --tool=memcheck --leak-check=yes --show-reachable=yes --num-callers=20 ./test

Valgrind

Connecting GDB to a valgrind GDB Server

 # valgrind --tool=memcheck --leak-check=yes --show-reachable=yes --num-callers=20 --vgdb=yes --vgdb-error=0 ./val5

 # gdb ./val5

(gdb) target remote | vgdb

Valgrind

Cachegrind

Cachegrind simulates how your program interacts with a machine's cache hierarchy and (optionally) branch predictor. It simulates a machine with independent first-level instruction and data caches (I1 and D1), backed by a unified second-level cache (L2). This exactly matches the configuration of many modern machines.

 # valgrind --tool=cachegrind prog

Valgrind

Manually specifies the I1/D1/L2 cache configuration, where size and line_size are measured in bytes. The three items must be comma-separated, but with no spaces, eg:

valgrind --tool=cachegrind --I1=65536,2,64

You can specify one, two or three of the I1/D1/L2 caches. Any level not manually specified will be simulated using the configuration found in the normal way (via the CPUID instruction for automagic cache configuration, or failing that, via defaults).

Valgrind

Cache-simulation specific options are:

--I1=<size>,<associativity>,<line size>

Specify the size, associativity and line size of the level 1 instruction cache.

--D1=<size>,<associativity>,<line size>

Specify the size, associativity and line size of the level 1 data cache.

--L2=<size>,<associativity>,<line size>

Specify the size, associativity and line size of the level 2 cache

Valgrind

Callgrind

valgrind Callgrind is a program that can profile your code and report on its resources usage. It is another tool provided by Valgrind, which also helps detect memory issues.

 # valgrind --tool=callgrind program-to-run program-arguments

 # callgrind_annotate --auto=yes callgrind.out.pid

Valgrind

helgrind

Helgrind is a Valgrind tool for detecting synchronisation errors in C, C++ and Fortran programs that use the POSIX pthreads threading primitives.

The main abstractions in POSIX pthreads are: a set of threads sharing a common address space, thread creation, thread joining, thread exit, mutexes (locks), condition variables (inter-thread event notifications), reader-writer locks, spinlocks, semaphores and barriers.

Valgrind

helgrind

Helgrind can detect three classes of errors, which are discussed in detail in the next three sections:

- Misuses of the POSIX pthreads API.
- Potential deadlocks arising from lock ordering problems.
- Data races -- accessing memory without adequate locking or synchronisation.

 # valgrind --tool=helgrind program_name

Valgrind

massif

Massif is a heap profiler. It measures how much heap memory your program uses. This includes both the useful space, and the extra bytes allocated for book-keeping and alignment purposes. It can also measure the size of your program's stack(s), although it does not do so by default.

Valgrind

massif

Heap profiling can help you reduce the amount of memory your program uses. On modern machines with virtual memory, this provides the following benefits:

- It can speed up your program -- a smaller program will interact better with your machine's caches and avoid paging.

- If your program uses lots of memory, it will reduce the chance that it exhausts your machine's swap space.

 # valgrind --tool=massif prog

 # ms_print massif.out.pid

gdb (GNU Debugger)

Debuggers are programs which allow you to execute your program in a controlled manner, so you can look inside your program to find a bug.

gdb is a reasonably sophisticated text based debugger. It can let you:

Start your program, specifying anything that might affect its behavior.

Make your program stop on specified conditions.

Examine what has happened, when your program has stopped.

Change things in your program, so you can experiment with correcting the effects of one bug and go on to learn about another.

SYNOPSIS

gdb [prog] [core|procID]

gdb

GDB is invoked with the shell command gdb.

Once started,it reads commands from the terminal until you tell it to exit with the GDB command quit.

The most usual way to start GDB is with one argument or two, specifying an executable program as the argument:

 # gdb program

You can also start with both an executable program and a core file specified:

 # gdb program core

You can, instead, specify a process ID as a second argument, if you want to debug a running process:

 # gdb program 1234

would attach GDB to process 1234

Compiling with the -g Option

To use gdb best, compile your program with:

gcc –g –c my_math.c

gcc –g –c sample.c

gcc –o sample my_math.o sample.o

or:

gcc –o sample -g my_math.c sample.c

That is, you should make sure that –g option is used to generate the .o files.

This option tells the compiler to insert more information about data types, etc., so the debugger gets a better understanding of it.

Common Commands for gdb

Here are some of the most frequently needed GDB commands:

b(reak) [file:]function	Set a breakpoint at function (in file).
r(un) [arglist]	Start program (with arglist, if specified).
bt or where	Backtrace: display the program stack; especially useful to find where your program crashed or dumped core.
print expr	Display the value of an expression.
c	Continue running your program (after stopping, e.g. at a breakpoint).
n(ext)	Execute next program line (after stopping); step over any function calls in the line.

Common Commands for gdb

s(tep) Execute next program line (after stopping); step into any function calls in the line.

help [name] Show information about GDB command name, or general information about using GDB.

q(uit) Exit from GDB.

l(ist) print the source code

Gdb pass comma line arguments

 # gdb --args executablename arg1 arg2 arg3

Or

$ gdb executablename

(gdb) r arg1 arg2 arg3

Debugging fork

set follow-fork-mode mode

Set the debugger response to a program call of fork or vfork. A call to fork or vfork creates a new process. The mode argument can be:

parent

The original process is debugged after a fork. The child process runs unimpeded. This is the default.

child

The new process is debugged after a fork. The parent process runs unimpeded.

Debugging fork

set detach-on-fork mode

Tells gdb whether to detach one of the processes after a fork, or retain debugger control over them both.

on

The child process (or parent process, depending on the value of follow-fork-mode) will be detached and allowed to run independently. This is the default.

off

Both processes will be held under the control of GDB. One process (child or parent, depending on the value of follow-fork-mode) is debugged as usual, while the other is held suspended.

Debugging fork

(gdb) info inferior

(gdb) inferior

Debugging exec

set follow-exec-mode mode

Set debugger response to a program call of exec. An exec call replaces the program image of a process.

follow-exec-mode can be:

new

GDB creates a new inferior and rebinds the process to this new inferior. The program the process was running before the exec call can be restarted afterwards by restarting the original inferior.

Debugging exec

same

GDB keeps the process bound to the same inferior. The new executable image replaces the previous executable loaded in the inferior. Restarting the inferior after the exec call, with e.g., the run command, restarts the executable the process was running after the exec call. This is the default mode.

Thread debugging

(gdb) info thread

(gdb) thread

Core dump debugging

(gdb) info thread

(gdb) thread

Variable manipulation

(gdb) print variable

(gdb) print func::variable

print variable in different format

x

Regard the bits of the value as an integer, and print the integer in hexadecimal.

d

Print as integer in signed decimal.

u

Print as integer in unsigned decimal.

Variable manipulation

o

Print as integer in octal.

t

Print as integer in binary. The letter `t' stands for "two". (1)

a

Print as an address, both absolute in hexadecimal and as an offset from the nearest preceding symbol. You can use this format used to discover where (in what function) an unknown address is located:

(gdb) p/a 0x54320

$3 = 0x54320 <_initialize_vx+396>

Variable manipulation

c

Regard as an integer and print it as a character constant.

f

Regard the bits of the value as a floating point number and print using typical floating point syntax.

Variable manipulation

(gdb) set variable=90

(gdb) print &a

Type **info variables** to list "All global and static variable names".

Type **info locals** to list "Local variables of current stack frame" (names and values), including static variables in that function.

Type **info args** to list "Arguments of the current stack frame" (names and values).

Conditional break point

(gdb) condition <breakpoint> <condition>

Example:

(gdb) break 28

(gdb) condition 2 i>5

- **watch**: gdb will break when a *write* occurs
- **rwatch**: gdb will break wnen a *read* occurs
- **awatch**: gdb will break in *both cases*

Ptrace

ptrace is a system call found in Unix and several Unix-like operating systems. By using ptrace (the name is an abbreviation of "process trace") one process can control another, enabling the controller to inspect and manipulate the internal state of its target. ptrace is used by debuggers and other code-analysis tools, mostly as aids to software development.

Ptrace

ptrace is used by debuggers (such as gdb and dbx), by tracing tools like strace and ltrace, and by code coverage tools. ptrace is also used by specialized programs to patch running programs, to avoid unfixed bugs or to overcome security features. It can further be used as a sandbox and as a run-time environment simulator (like emulating root access for non-root software).

Ptrace

By attaching to another process using the ptrace call, a tool has extensive control over the operation of its target. This includes manipulation of its file descriptors, memory, and registers. It can single-step through the target's code, can observe and intercept system calls and their results, and can manipulate the target's signal handlers and both receive and send signals on its behalf. The ability to write into the target's memory allows not only its data store to be changed, but also the application's own code segment, allowing the controller to install breakpoints and patch the running code of the target.

Ptrace

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Introduction to Bash Shell

What is Shell?

The shell is a command interpreter.

It is the layer between the operating system kernel and the user.

Some Special characters used in shell scripts

#:Comments

~:home directory

Invoking the script

The first line must be “#!/bin/bash”.

- setup the shell path

chmod u+x scriptname (gives only the script owner execute permission)

./scripname

Some Internal Commands and Builtins

getopts:

parses command line arguments passed to the script.

exit:

- Unconditionally terminates a script

set:

- changes the value of internal script variables.

read:

- **Reads" the value of a variable from stdin**
- **also "read" its variable value from a file redirected to stdin**

Some Internal Commands and Builtins (cont.)

grep:

grep pattern file

- search the files file, etc. for occurrences of *pattern*

expr:

- evaluates the arguments according to the operation given

y=`expr $y + 1` (same as **y=$(($y+1))**

I/O Redirection

>: Redirect stdout to a file, Creates the file if not present, otherwise overwrites it

< : Accept input from a file.

>>: Creates the file if not present, otherwise appends to it.

<<:

Forces the input to a command to be the shell's input, which until there is a line that contains only *label*.

cat >> mshfile << .

if

```
 if [ condition ] then
    command1
 elif   # Same as else if
then
    command1
else
    default-command
 fi
```

case

```
x=5
 case $x in
   0) echo "Value of x is 0."
      ;
   5) echo "Value of x is 5."
      ;
   9) echo "Value of x is 9."
      ;
   *) echo "Unrecognized value."
esac
 done
```

Loops

```
for [arg] in [list];
    do
    command
    done
while [condition];
    do
       command...
    done
```

Loops (cont.)

break, continue

- **break** command terminates the loop
- **continue** causes a jump to the next iteration of the loop

Introduction to Variables

$: variable substitution

- If **variable1** is the name of a variable, then **$variable1** is a reference to its *value*.

Pattern Matching

${variable#pattern}

${variable##pattern}

${variable%pattern}

${variable%%pattern}

Examples of Pattern Matching

```
x=/home/cam/book/long.file.name
echo ${x#/*/}
echo ${x##/*/}
echo ${x%.*}
echo ${x%%.*}
```

cam/book/long.file.name

long.file.name

/home/cam/book/long.file

/home/cam/book/long

Aliases

avoiding typing a long command sequence

Ex: alias lm="ls -l | more"

Array

Declare:

declare -a array_name

To dereference (find the contents of) an array variable, use *curly bracket* notation, that is, **${ array[xx]}**

refers to *all* the elements of the array

${array_name[@]}* or *${array_name[*]}

get a count of the number of elements in an array

${#array_name[@]}* or *${#array_name[*]}

Functions

Type

function function-name {
command...
}

function-name () {
command...
}

Local variables in function:

Declare: local var_name

functions may have arguments

function-name $arg1 $arg2

Positional Parameters

$1, $2, $3 …..

$0 is the name of the script.

The variable $# holds the number of positional parameter.

Positional Parameters in Functions

$1, $2, $3….

Not from $0

The *read* Statement

Use to get input (data from user) from keyboard and store (data) to variable.

Syntax:

```
read variable1, variable2,...variableN
```

Example: Write a shell script to

- first ask user, name
- then waits to enter name from the user via keyboard.
- Then user enters name from keyboard (after giving name you have to press ENTER key)
- entered name through keyboard is stored (assigned) to variable fname.
- Solution is in the next slide

Example (*read* Statement)

$ vi sayH

```
#
#Script to read your name from key-board
#
echo "Your first name please:"
read fname
echo "Hello $fname, Lets be friend!"
```

Run it as follows:

```
$ chmod 755 sayH
$ ./sayH
```

Your first name please: ***vivek***

Hello vivek, Lets be friend!

Wild Cards

Wild card /Shorthand	Meaning	Examples	
*	Matches any string or group of characters.	**$ ls ***	will show all files
		$ ls a*	will show all files whose first name is starting with letter 'a'
		$ ls *.c	will show all files having extension .c
		$ ls ut*.c	will show all files having extension .c but file name must begin with 'ut'.
?	Matches any single character.	**$ ls ?**	will show all files whose names are 1 character long
		$ ls fo?	will show all files whose names are 3 character long and file name begin with fo
[...]	Matches any one of the enclosed characters	**$ ls [abc]***	will show all files beginning with letters a,b,c

More commands on one command line

Syntax:

`command1;command2`

To run two command in one command line.

Examples:

$ *`date;who`*

Will print today's date followed by users who are currently login.

Note that You can't use

$ *`date who`*

for same purpose, you must put semicolon in between the ***`date`*** and ***`who`*** command.

Command Line Arguments

1. Telling the command/utility
   - which option to use.
2. Informing the utility/command
   - which file or group of files to process

Let's take ***rm*** command,

is used to remove file,

which of the file?

how to tail this to ***rm*** command

rm command does not ask the name of the file

So what we do is to write command as follows:

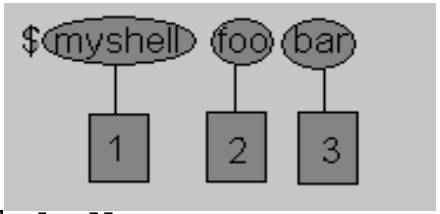
$ *rm* {file-name}

rm : is the command

file-name :file to remove

Arguments - Specification

$ myshell foo bar



1. Shell Script name i.e. **myshell**
2. First command line argument passed to **myshell** i.e. ***foo***
3. Second command line argument passed to **myshell** i.e. **bar**

In shell if we wish to refer this command line argument we refer above as follows

```
1    myshell it is $0
2    foo it is $1
3    bar it is $2
```

•Here **$#** (built in shell variable) will be 2 (Since ***foo*** and **bar** only two Arguments),

•Please note at a time such 9 arguments can be used from $1..$9,

•You can also refer all of them by using $* (which expand to `$1,$2...$9`).

•Note that $1..$9 i.e command line arguments to shell script is know as "*positional parameters*".

Arguments - Example

```
$ vi demo
   #!/bin/sh
   #
   # Script that demos, command line args
   #
   echo "Total number of command line argument are $#"
   echo "$0 is script name"
   echo "$1 is first argument"
   echo "$2 is second argument"
   echo "All of them are :- $* or $@"
```

- Run it as follows
- Set execute permission as follows:

```
$ chmod 755 demo
```

- Run it & test it as follows:

```
$ ./demo Hello World
```

- If test successful, copy script to your own bin directory (Install script for private use)

```
$ cp demo ~/bin
```

- Check whether it is working or not (?)

```
$ demo
$ demo Hello World
```

Redirection of Input/Output

In Linux (and in other OSs also)

it's possible to send output to file

or to read input from a file

For e.g.

$ ***ls*** command gives output to screen;

to send output to file of ls command give command

ls > filename

It means put output of ***ls*** command to filename.

redirection symbols: '>'

There are three main redirection symbols: **>,>>,<**

(1) **>** Redirector Symbol

Syntax:

Linux-command > filename

To output Linux-commands result to file.

Note that if the file already exist,

it will be overwritten

else a new file will be created.

For e.g.

To send output of ***ls*** command give

$ *ls* > myfiles

if '**myfiles**' exist in your current directory

it will be overwritten without any warning.

redirection symbols: '>>'

(2) **>>** Redirector Symbol

Syntax:

```
Linux-command >> filename
```

To output Linux-commands result

to the END of the file.

if file exist:

it will be opened

new information/data will be written to the **END** of the file,

without losing previous information/data,

if file does not exist, a new file is created.

For e.g.

To send output of date command

to already exist file give command

```
$ date >> myfiles
```

redirection symbols: ‘<’

(3) < Redirector Symbol

Syntax:

`Linux-command < filename`

To provide input to Linux-command

from the file instead of standart input (key-board).

For e.g. To take input for cat command give

`$ cat < myfiles`

Pipes

A pipe is a way

to connect the output of one program

to the input of another program

without any temporary file.

Definition

"*A pipe is nothing but a temporary storage place*

where the output of one command

is stored and then passed

as the input for second command.

Pipes are used

to run more than two commands

Multiple commands

from same command line."

Pipe - Examples

Command using Pipes	Meaning or Use of Pipes
`$ ls | more`	Output of **ls** command is given as input to the command **more** So output is printed one screen full page at a time.
`$ who | sort`	Output of **who** command is given as input to sort command So it will print sorted list of users
`$ who | sort > user_list`	Same as above except output of sort is send to (redirected) the file named user_list
`$ who | wc -l`	**who** command provides the input of **wc** command So it will count the users logged in.
`$ ls -l | wc -l`	**ls** command provides the input of **wc** command So it will count files in current directory.
`$ who | grep raju`	Output of **who** command is given as input to **grep** command So it will print if particular user is logged in. Otherwise nothing is printed

Filter

Accepting the input

from the standard input

and producing the result

on the standard output

is know as a filter.

A filter

performs some kind of process on the input

and provides output.

Filter: Examples

Suppose you have a file

called 'hotel.txt'

with 100 lines data,

you would like to print the content

only between the line numbers 20 and 30

and then store this result to the file 'hlist'

The appropriate command:

```
$ tail +20 < hotel.txt | head -n30 >hlist
```

Here ***head*** command is filter:

takes its input from ***tail*** command

tail command starts selecting

from line number 20 of given file

i.e. hotel.txt

and passes this lines as input to the ***head***,

whose output is redirected

to the 'hlist' file.

Filter: Examples

Consider one more following example

```
$ sort < sname | uniq > u_sname
```

Here ***uniq*** is filter

takes its input from ***sort*** command

and redirects to "u_sname" file.

Processing in Background

Use ampersand (&)

at the end of command

To start the execution in background

and enable the user to continue his/her processing

during the execution of the command

without interrupting

```
$ ls / -R | wc -l
```

This command will take lot of time

to search all files on your system.

So you can run such commands

in Background or simultaneously

by adding the ampersand (&):

```
$ ls / -R | wc -l&
```

Commands Related With Processes

For this purpose	Use this Command	Examples
To see currently running process	**ps**	$ **ps**
To stop any process by PID i.e. to kill process	**kill** {PID}	$ **kill** 1012
To stop processes by name i.e. to kill process	**killall** {Proc-name}	$ **killall** httpd
To get information about all running process	**ps** -ag	$ **ps** -ag
To stop all process except your shell	**kill** 0	$ **kill** 0
For background processing (With &, use to put particular command and program in background)	linux-command &	$ **ls** / -R | **wc** -l &
To display the owner of the processes along with the processes	**ps** aux	$ **ps** aux
To see if a particular process is running or not. For this purpose you have to use ps command in combination with the grep command	**ps** ax | **grep** {Proc-name}	For e.g. you want to see whether Apache web server process is running or not then give command **$ *ps* ax | *grep* httpd**
To see currently running processes and other information like memory and CPU usage with real time updates.	**top**	$ **top** Note that to exit from top command press q.
To display a tree of processes	**pstree**	$ **pstree**

if condition

if condition

used for making decisions in shell script,

If the condition is true

then command1 is executed.

Syntax:

```
if condition then command1 if condition is
   true or if exit status of condition is 0
   (zero) ... ... fi
```

condition

is defined as:

"*Condition is nothing but comparison between two values.*"

For compression

you can use test

or [expr] statements

or even exist status

if condition - Examples

```
$ cat > showfile
   #!/bin/sh
   #
   #Script to print file
   #
   if cat $1
   then
   echo -e "\n\nFile $1, found and successfully echoed"
   fi
```

Run above script as:

```
   $ chmod 755 showfile
   $./showfile foo
```

Shell script name is: **showfile** (**$0**)

The argument is **foo** (**$1**).

Then shell compare it as follows:

if cat $1 :is expanded to ***if cat foo***.

Example: Detailed explanation

if ***cat*** command finds foo file

and if its successfully shown on screen,

it means our ***cat*** command

is successful and

its exist status is 0 (indicates success),

So our if condition is also true

the statement **`echo -e "\n\nFile $1, found and successfully echoed"`**

is proceed by shell.

if cat command is not successful

then it returns non-zero value

indicates some sort of failure

the statement ***echo*** **`-e`** `"\n\nFile $1, found and successfully echoed"`

is skipped by our shell.

test command or [expr]

test command or **[expr]**

is used to see if an expression is true,

and if it is true it return zero(0),

otherwise returns nonzero for false.

Syntax:

test `expression` or **[** `expression` **]**

test command - Example

determine whether given argument number is positive.

```
$ cat > ispostive
   #!/bin/sh
   #
   # Script to see whether argument is positive
   #
   if test $1 -gt 0
   then
   echo "$1 number is positive"
   fi
```

Run it as follows

```
   $ chmod 755 ispostive
```

```
$ ispostive 5
```

5 number is positive

```
$ispostive -45
```

Nothing is printed

Mathematical Operators

Mathematical Operator in Shell Script	Meaning	Normal Arithmetical/ Mathematical Statements	But in Shell	
			For test statement with if command	For [expr] statement with if command
-eq	is equal to	5 == 6	if test 5 -eq 6	if [5 -eq 6]
-ne	is not equal to	5 != 6	if test 5 -ne 6	if [5 -ne 6]
-lt	is less than	5 < 6	if test 5 -lt 6	if [5 -lt 6]
-le	is less than or equal to	5 <= 6	if test 5 -le 6	if [5 -le 6]
-gt	is greater than	5 > 6	if test 5 -gt 6	if [5 -gt 6]
-ge	is greater than or equal to	5 >= 6	if test 5 -ge 6	if [5 -ge 6]

String Operators

Operator	Meaning
string1 = string2	string1 is equal to string2
string1 != string2	string1 is NOT equal to string2
string1	string1 is NOT NULL or not defined
-n string1	string1 is NOT NULL and does exist
-z string1	string1 is NULL and does exist

File and Directory Operators

Test	Meaning
-s file	Non empty file
-f file	File exists or is a normal file and not a directory
-d dir	Directory exists and not a file
-w file	file is a writeable file
-r file	file is a read-only file
-x file	file is executable

Logical Operators

Operator	Meaning
! expression	Logical NOT
expression1 -a expression2	Logical AND
expression1 -o expression2	Logical OR

if...else...fi

If given condition is true

then command1 is executed

otherwise command2 is executed.

Syntax:

```
if condition
then
 condition is zero (true - 0)
 execute all commands up to else statement
else
 if condition is not true then
 execute all commands up to fi
fi
```

if...else…fi -Example

```
$ vi isnump_n
#!/bin/sh
#
# Script to see whether argument is
positive or negative
#
if [ $# -eq 0 ]
then
   echo "$0 : You must give/supply one
   integers"
   exit 1
fi
if test $1 -gt 0
then
   echo "$1 number is positive"
   else echo "$1 number is negative"
fi
```

Try it as follows:

$ chmod 755 isnump_n

$ isnump_n 5

5 number is positive

$ isnump_n -45

-45 number is negative

$ isnump_n

./ispos_n : You must give/supply one integers

$ isnump_n 0

0 number is negative

Loops in Shell Scripts

Bash supports:

for loop

while loop

Note that in each and every loop,

(a) First, the variable used in loop condition

- must be initialized,
- then execution of the loop begins.

(b) A test (condition) is made

at the beginning of each iteration.

(c) The body of loop ends

with a statement modifies

the value of the test (condition) variable.

for Loop

Syntax:

```
for { variable name } in { list }
do
   execute one for each item in the list
   until the list is not finished
   (And repeat all statements between do and done)
done
```

for Loop: Example

Example:

```
$ cat > testfor
for i in 1 2 3 4 5
do

        echo "Welcome $i times"

done
```

- The for loop first creates i variable
  - and assigned a number to i from the list of numbers 1 to 5,
- The shell executes echo statement for each assignment of i.
- This process will continue until all the items in the list were not finished,
- because of this it will repeat 5 echo statements.

Run it above script as follows:

```
$ chmod +x testfor
$ ./testfor
```

for loop - Example

- ```
  $ vi chessboard
  for (( i = 1; i <= 9; i++ )) ### Outer for loop ###
  do
     for (( j = 1 ; j <= 9; j++ )) ### Inner for loop ###
     do
          tot=`expr $i + $j`
          tmp=`expr $tot % 2`
          if [ $tmp -eq 0 ]; then
              echo -e -n "\033[47m "
          else
              echo -e -n "\033[40m "
          fi
    done
   echo -e -n "\033[40m" #### set back background colour to
  black
   echo "" #### print the new line ###
  done
  ```
  ```

while Loop

Syntax:

```
while [ condition ]
do
   command1
   command2
   ..
   ....
done
```

```
while [ $i -le 10 ]
do
  echo "$n * $i = `expr $i \* $n`"
  i=`expr $i + 1`
done
```