A Guide to using MOOS-V10 Communications

Paul Newman, University of Oxford

4th February 2013

....ten years on

Contents

1 Headlines - What's New?

MOOS Version 10 is a major new release of MOOS. It comes just over 10 years after MOOS was first written and it incorporates many changes that improve its performance and answer to requests made by the user community. This document sets out the features, changes and their implications on users of the communications API of MOOS.

Functional Headlines

- **Low latency** Asynchronous communications are now supported via an upgraded `MOOSDB` and a new kind of communications client object `MOOSAsyncCommClient.` This allows data to be pushed to clients by the `MOOSDB` rather than clients having to fetch messages which match their subscriptions when the call into the `MOOSDB.` This affords a drastically decreased latency between data being published and clients receiving it. Latencies are routinely sub-millisecond now.
- **Multithreaded design** The `MOOSDB` now offers improved resilience when working with clients which reside at the end of a high latency or low bandwidth link. Each client is now furnished with its own thread within the DB which allows each client to take as long as it needs to complete and `read` or `write` without holding up the interactions of other clients. This behaviour can be disabled from the command line in which case the behaviour of the DB reverts to pre V10 behaviour.
- **Wildcard subscriptions** The `MOOS` communications API now supports wildcard subscriptions whereby clients can subscribe to variable which match variable name patterns and also source name patterns. For example a client could register for "*:*" meaning all variables from all sources or "J*:*K" meaning any variable beginning with "J" from a process ending in "K"
- **Configurable behaviour** in the way CMOOSApp handles mail. You can have mail handled pretty much as soon as it comes in. If you are using the low level comms object `MOOSAsyncCommClient` you can have a call back handled the instant mail arrives.
- **Standard Command Line Switches** All MOOS applications can with a trivial code change be configured to handle and interpret standard command line parameters. Additionally, a tool is provided to ease parsing command line options. CMOOSApp has new hooks to support and encourage the writing of user help and example configurations which can be printed to stdio.
- **A new build system** is provided which via CMake make linking against MOOS (and the right version) easy.
- **New testing** command line programs which can easily be used to test MOOS communications
- **Live diagnostics** from the MOOSDB are avaiable over udp

Structural Headlines

- **Fission into smaller, neater delineated code trees:** The communication layer, utility applications (like `pLogger`), and graphical tools all now live in separate projects. For example, it is now possible to download only the communications layer and work just with that.
- **A single core library:** There is now just one core library `libMOOS` which is an amalgamation of what was previously `MOOSGenLib` and `MOOSLib`
- **A rationalised header file structure:** The header structure for commonly used files has changed to reflect this (but a backwards compatibility mode is provided so users can in the first instance carry on as if this is not the case)

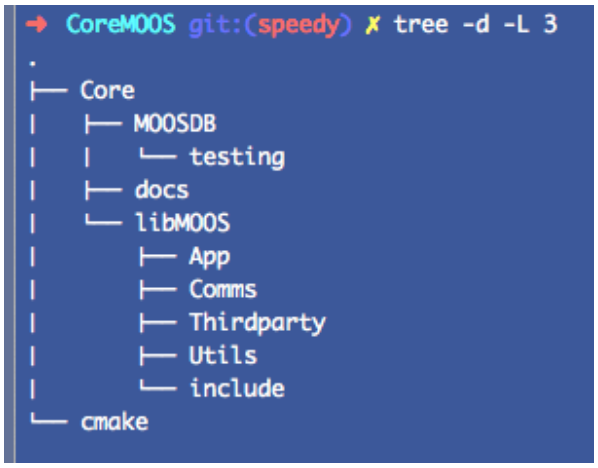


Figure 1: Top-level directory structure for MOOS V10

2 Structural Changes

2.1 Separate Projects

Pre version 10, the MOOS project was an ugly mash-up of source code which covered a strange span of functionality. This belied its Maritime roots- it included things like `iINS` and pNav -appications which had clear heritage in marine autonomy and also the domain independent communications tools. In V10 these have been teased apart. There is now a standalone `core-moos` library which only contains communication and domain neutral basic utilities. This project is the sole focus of this document.

2.2 Library Structure and Header Files

The classes that implement the communications and application management (for example `CMOOSApp`) now reside in a single library called `libMOOS`. There is no `MOOSGenLib` anymore - the classes and function that lived in that lump of code now reside in `libMOOS` and the headers can be found in a subdirectory called `Utils` within `core-moos`. There are in fact four key subdirectories in `libMOOS`. In figure 1you can see the basic structure of the V10 code base.

App contains the classes like CMOOSApp and CMOOSInstrument

Comms contains everything to do with IPC communications

Utils contains everything that used to be in MOOSGenLib (with some nice additions)

Thirdparty contains small pots of thirdparty code which is being leveraged in V10 (all licenses included)

include contains some high level include directories that make using libMOOS easy (and backwards compatible)

You might be wondering where all the header files that used to be in `MOOSGenLib` have gone. They are now in `"MOOS/libMOOS/Utils/*.h"`.

> **Tip:** If you were previously including `"MOOSGenLibGlobalHelper.h"` then you now need to include "`MOOS/libMOOS/Utils/MOOSUtilityFunctions.h`" instead (or use the compatibility mode described in Section 3.2

3 Developing with V10

3.1 Ethos

3.1.1 No code change required

A lot of effort has been taken to make the users transition to MOOS V10 painless. Indeed the goal was to make it possible to upgrade to V10 without having to change any source code. The only thing a user does need to do is link against the new library and this is made easy with the revamped `CMake` build system. Of course good citizens would probably be uncomfortable with living a legacy interface and in time will want to upgrade. However the point is you can get started with MOOS-V10 for zero overhead.

3.1.2 Backward Compatibility (Mixed Systems)

No assumption is made the all components of a MOOS system will be upgraded. It is entirely possible to use a holy relic pre-V10 clients or and old trusted MOOSDB with new or rebuilt software which has linked against V10. The motivation here is to start using V10 you don't need to rebuild everything. You could for example simply run the new MOOSDB and you will still get improved performance. If you circumstances dictate, you can even run the new `MOOSDB` in safe mode in which it reverts to running the pre-V10 source code.

3.2 Building V10

3.2.1 The quickest way

We shall begin where we should and check out a version of MOOS-V10 from a git repos. We will follow good practice and do an out of place build - the source code will go in "src" and we will build in "build". We will also, after fetching the source switch to the "devel" branch because here we are living on the edge [1].

```
pmn@mac:~$ mkdir core-moos-v10
pmn@mac:~$ cd core-moos-v10
pmn@mac:~$ git clone git@github.com:themoos/core-moos.git src
pmn@mac:~$ cd src
pmn@mac:~$ git checkout devel
pmn@mac:~$ cd ..
pmn@mac:~$ mkdir build
pmn@mac:~$ ccmake ../src
```

At this point you should, after hitting 'c' a couple of times be presented with a CMake screen that looks like that shown in Figure 2 (note some of the entries are platform dependent so don't worry if what you see is not identical to this). If you simply want to link your existing code against MOOS V10 without needing to worry about the new header file structure then you will need to turn on `ENABLE_V10_COMPATIBILITY`. This switch adds an additional set of include path to those exported by the project, which have the same structure as those present in previous (now legacy) versions of MOOS. If you "include" one of these files they actually simply redirect to include header files residing in the new structure. This is not a happy long term policy - you should think if possible about updating your code - but there is much to be said for not *having* to change your code simply to use V10.

[1] if you want to know what branches are available type `git branch`

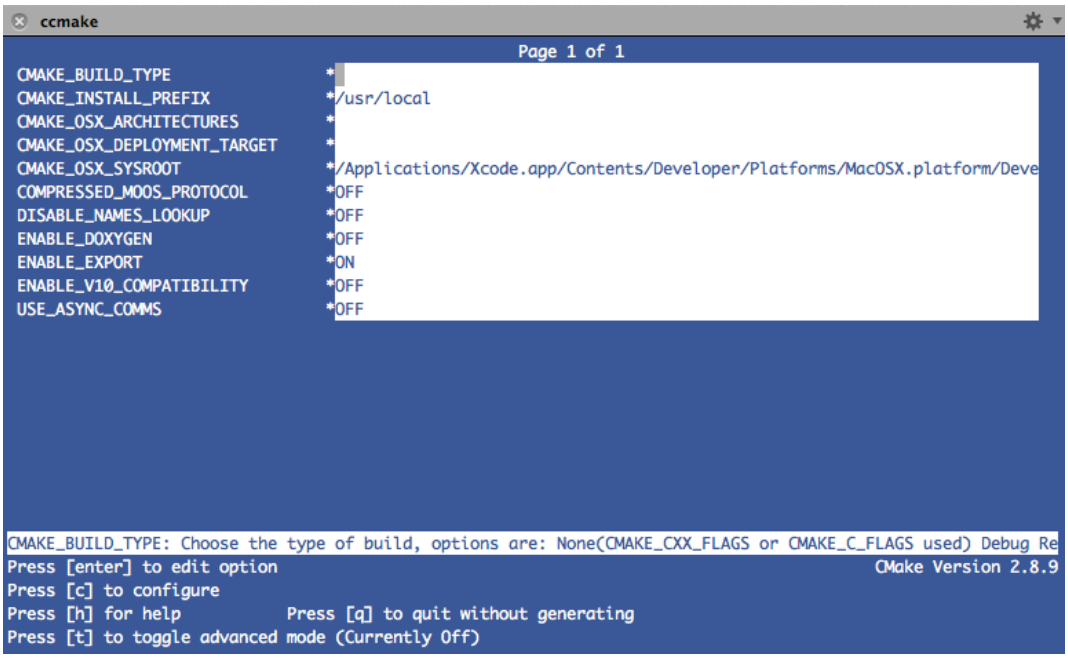


Figure 2: The default build screen for MOOS V10. Note that by default USE_ASYNC_COMMS is off. If you want really fast communications you should enable this.

> **Tip:** Turn on `ENABLE_V10_COMPATIBILITY` to make V10 appear to have the header structure of earlier versions. This allows you to use V10 without needing to change any of your source code

You are are now in a position to build the MOOS. So press 'c' until 'g' appears, then press 'g' and you are good to go. Then at the terminal prompt type 'make' to build the project. Two directories should have been created **bin** and **lib.** In lib you will see `libMOOS.a` and in `bin` you will find the newly created `MOOSDB`. If you run up the MOOSDB (by typing ./MOOSDB you should see output similar to that in Figure 3. You should be able to use this `MOOSDB` to manage all communications with any existing MOOS applications you have lying around - you should not have to upgrade them. Again, at the risk of labouring a point, MOOS-V10 is backwardly compatible in many senses. You are probably wondering if just running this new DB by itself buys you anything. The answer is yes, it does. Each client now has its own thread so if you have dodgey comms between one client and the `MOOSDB` this ne'er-do-well client will not interfere with other client DB interactions - it won't be able to hold them up\[2].

> **Tip:** you can use the V10 `MOOSDB` with old MOOS applications - you don't *have* to recompile them. V10 is backwards compatible.

3.2.2 Changing `#include` directives:

If you are prepared to invest 30 minutes in committing to the new MOOS V10 project structure then this section tells you what to do. If you are as yet unsure if you want to upgrade, then don't bother

[2]this was a big annoyance in earlier versions. There were occasions in which a dodgey wireless connection between a client and a DB causes all other clients connections to suffer. Misery

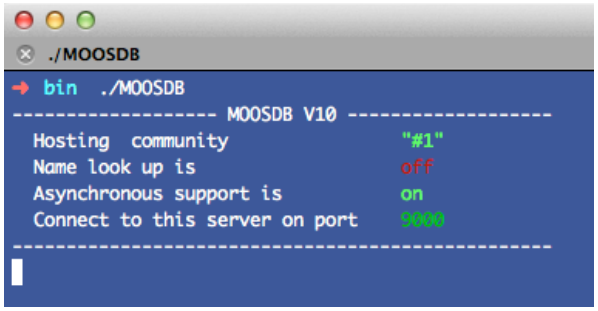


Figure 3: running the new MOOSDB

simply use the `ENABLE_V10_COMPATIBILITY` option in CMake - this allows you to simply revert to old versions of MOOS without lifting a finger.

The actions needed to upgrade are pretty simple. Where previously you had something like `#include "MOOSLIB/MOOSCommClient.h"` you now use `#include "MOOS/libMOOS/Comms/MOOSCommClient.h"`. The following table will help you figure out how to include an particular header.

Header	include prefix
MOOSAsyncCommClient.h MOOSMsg.h XPCEndian.h XPCTcpSocket.h MOOSCommClient.h MOOSSkewFilter.h XPCException.h XPCUdpSocket.h MOOSCommObject.h MOOSVariable.h XPCGetHostInfo.h MOOSCommPkt.h ServerAudit.h XPCGetProtocol.h MOOSCommServer.h ThreadedCommServer.h XPCSocket.h	#include "MOOS/libMOOS/Comms/---.h"
ConsoleColours.h MOOSMemoryMapped.h MOOSTimeJournal.h IPV4Address.h MOOSNTSerialPort.h MOOSUtilityFunctions.h InterpBuffer.h MOOSPlaybackStatus.h MOOSUtils.h KeyboardCapture.h MOOSSafeList.h NTSerial.h MOOSAssert.h MOOSSafeList.h~ ProcessConfigReader.h MOOSException.h MOOSScopedLock.h SafeList.h MOOSFileReader.h MOOSSerialPort.h TMaxPair.h MOOSLinuxSerialPort.h MOOSThread.h TMinPair.h MOOSLock.h MOOSThreadedTimeJournal.h ThreadPrint.h	#include "MOOS/libMOOS/Utils/---.h"
MOOSApp.h MOOSInstrument.h	#include "MOOS/libMOOS/App/---.h"
MOOSLib.h	#include "MOOS/libMOOS/MOOSLib.h"

3.3 Importing and Building Against MOOS-V10

So now you have built the new MOOS. Next questions is "how do you link against it". If you use `CMake` then this is trivial you just need to insert the line `find_package(MOOS 10)` in your `CMakeList.txt` script. This goes and finds the latest build you made of MOOS V10 (and only V10) and collects the correct include paths, library names and library paths and puts them in the following `CMake` variables:

`MOOS_INCLUDE_DIRS` This contains the list of include directories you need to include to find `MOOS V10` header files.

`MOOS_DEPEND_INCLUDE_DIRS` This contains the list of include directories which MOOS needs to find teh headers it depends on (should be empty)

`MOOS_LIBRARIES` This contains the precise library name (absolute path) for `libMOOS`

`MOOS_DEPEND_LIBRARIES` This contains the absolute paths for the libraries MOOS depends on (should be empty)

These variables can be used to import all you need to know about MOOS into an external project. You can see how to do this in some the example `CMakeLists.txt` file given below. Here we make an executable called `example_moos` , explicitly search for MOOS-V10, set up include paths, set up an executable and finally indicate how to link.

```
#this builds some code using MOOS
set(EXECNAME example_moos)

#find MOOS version 10 be explicit about version 10 so we don't
#find another old version
find_package(MOOS 10)

#what source files are needed to make this exectutable?
set(SRCS  example_moos.cpp)

#where should one look to find headers?
include_directories( ${MOOS_INCLUDE_DIRS} ${MOOS_DEPEND_INCLUDE_DIRS})

#state we wish to make a computer program
add_executable(${EXECNAME} ${SRCS} )

#and state what libraries said program needs to link against
target_link_libraries(${EXECNAME} ${MOOS_LIBRARIES} ${MOOS_DEPEND_LIBRARIES})
```

3.3.1 How is MOOS found?

You have probably noticed that you do not need to install MOOS V10 for `find_package(MOOS V10)` to work. CMake simply appears to automagically find the latest build directory. It is worth understanding how this is done. CMake provides support for `find_package` by writing at build time to a file in ~/.cmake/modules. In this case because we are talking about `MOOS` there is a file in ~/.cmake/modules/MOOS (who's name is a whole load of crazy letters) inside of which is the location to a file called `MOOSConfig.cmake`. This file is created in the build directory when MOOS is configured. The find_package directive imports `MOOSConfig.cmake` (and from there `UseMOOS.cmake`) and this tells the importing CMake instance how to use MOOS.

3.3.2 Trouble Shooting

All the above should go smoothly but there have been instances reported in which things go wrong - this is always due to previous installations of MOOS and old configuration files hanging around. Executing the following steps should help if you get into trouble

- clean down the `MOOS-V10` project (why not remove the whole build directory?)
- remove all contents of `~/.cmake/modules/MOOS`
- remove any old copies of MOOSConfig.cmake you may have hanging around in you build tree. Note that once upon a time, long ago there was a `MOOSConfig.cmake` file checked into the source tree of MOOS-IvP. This can cause all kinds of trouble.....
- If header files are not being found by you project:

– if your code previously worked with older versions of MOOS did you change your source code to reflect the new locations of headers? Or, if you really don't want to change you code, did you enable `V10_COMPATIBILITY` when you built MOOS-V10?

4 Leveraging V10

This section will explain how programmers and users of MOOS can leverage some of the important and hopefully helpful new functionality in MOOS V10.

4.1 Asynchronous Comms

This section explains new functionality offered in the V10 communications classes which allow for very low latency communications between components. This new facility allows one clients write of data to instigate a read on all other clients who have previously expressed interest in that data. This then is a departure from the model of a client having to call in to the DB, deliver its post and while "on the line", pick up and mail the DB has waiting for it. Of course we must stress that the user has to opt in for this new functionality - there is no imperative to run new code. To enable Asynchronous Comms in clients derived from `CMOOSApp` you need to enable `USE_ASYNC_COMMS` in a configure time in CMake..

This flag makes the `m_Comms` member of `CMOOSApp` an `MOOS::MOOSAsyncCommsClient` rather than a `CMOOSCommClient`. Note that you can have this flag turned off and still use a `MOOS::MOOSAsyncCommsClient` object and the `MOOSDB` will service that object's interactions appropriately.

> **Tip:** To enable fast asynchronous comms in MOOSApps you have to turn `USE_ASYNC_COMMS` to `ON` when configuring MOOS using CMake.

4.1.1 Low Latency Communications via `MOOSAsyncCommClient`

The key class is `MOOS::MOOSAsyncCommClient` which is a derivate of the tried and test `CMOOSCommClient`. Its interface is identical to `CMOOSCommClient` and so the user should notice no progammatical difference in using this client.[3]

When a `MOOS::MOOSAsyncCommClient` connects to a V10 `MOOSDB` it instigates some quite different behaviour. Firstly the DB spawns two additional threads -one to handle reading from the client and one to handle writing to the client. These threads are not synchronised - they operate independently pulling and pushing data from work queues from within the DB itself. The client itself also has distinct read and write threads - when a user posts some data it is added to a work queue on which the read thread is waiting. The read thread pushes this data to the DB and simply waits for another chunk of work to appear on the queue. Similarly the clients read thread sits in a blocking read on the socket linking it to the DB. When data arrives it is placed into the clients "mailbox" and optionally a user callback is invoked. Importantly, this architecture of each client having a read and write thread at the client and `MOOSDB` ends, allows for data to be pushed to clients at any time. Take for example the case of 50 clients all having subscribed for variable **''X''**. When the 51st client publishes "**X**" this data can be instantly placed on the outgoing queue of all 50 interested clients within th3 `MOOSDB`. Because the read threads on the clients are in a blocking read they two an respond immediately leading to some very responsive behaviour. Note also that if one of those clients has a dodgey communications link to the DB this has not effect on the other 49 clients. This then is in stark contrast to the pre V10 releases of MOOS. In section 5some performance metrics are given which highlight the difference in behaviour between V10 and previous incantations of the MOOS communications API.

[3] Indeed many users have little direct interaction with the communications object preferring instead to operate withing the comfort of classes derived from CMOOSApp which wraps the low level communications API.

4.1.2 Supporting Iterate Modes in MOOSApp

If MOOS is compiled with USE_ASYNC_COMMS then the m_Comms member of CMOOSApp becomes a MOOSAsyncCommClient and so all communications will be using this new faster functionality. CMOOSApp is designed to provide an easy to use framework in which to write applications which leverage the MOOS communications API. The ability for MOOSAsyncCommClients to have data pushed to them and invoke an asynchronous callback affords the opportunity to augment the behaviour of CMOOSApp to provide application developed with greater flexibility and develop apps which respond quickly to communication events.

MOOS V10 offers three new configuration modes which are described in the table below. The mode in which the application operates can be set either in the applications configuration block (e.g by having a line like IterateMode = 2 or programmatically by calling SetIterateMode(REGULAR_ITERATE_AND_COMMS_DRIVEN_MAIL). These modes are supported by an additional configuration parameter called MaxAppTick who's function is described in the table. This new parameter can be set in the configuration file MaxAppTick=100 or passed as second parameter in CMOOSApp::SetAppFreq(AppTick,MaxAppTick).

	REGULAR_ITERATE_AND_MAIL
Summary	This mode is the default just as in pre-V10 releases Iterate() and OnNewMail() are called regularly and if mail is available, in lock step.
Configuration Block	IterateMode=0
OnNewMail	called at most every 1/AppTick seconds. If mail has arrived OnNewMail() will be called just before Iterate()
Iterate	called every 1/AppTick seconds. So if AppTick=10 Iterate() will be called at 10Hz.
Role of AppTick	sets the speed of Iterate() in calls per second
Role of MaxAppTick	not used
Role of CommsTick	not used as communications are asynchronous

	COMMS_DRIVEN_ITERATE_AND_MAIL
Summary	The rate at which Iterate is called is coupled to the reception of mail. As soon as mail becomes available OnNewMail is called and is then followed by Iterate(). If no mail arrives for 1/AppTick seconds then iterate is called by itself. When mail is arriving Iterate() and OnNewMail() are synchronous - if OnNewMail() is called it will always be followed by a called to Iterate()
Configuration Block	IterateMode=1
OnNewMail	Called at up to MaxAppTick times per second. So if MaxAppTick=100 OnNewMail() will be called in response to the reception of new mail at up to 100Hz.
Iterate	called at least AppTick times per second (if no mail) and up to MaxAppTick times per second
Role of AppTick	sets a lower bound on the frequency at which Iterate() is called. So if AppTick = 10 then Iterate will be called at at least 10Hz
Role of MaxAppTick	sets an upper limit on the rate at which Iterate (and OnNewMail) can me called. If MaxAppTick=0 both the speed is unlimited.
Role of CommsTick	not used as communications are asynchronous

	REGULAR_ITERATE_AND_COMMS_DRIVEN_MAIL
Summary	Iterate is called regularly and `OnNewMail` is called when new mail arrives. Iterate will not always be called after `OnNewMail` unless it is scheduled to do so. In this way `OnNewMail` and `Iterate` are decoupled.
Configuration Block	IterateMode=2
OnNewMail	Called as soon as mail is delivered at up to `MaxAppTick` times per second.
Iterate	called every AppTick times per second
Role of AppTick	sets the speed of `Iterate()` in calls per second as in REGULAR_ITERATE_AND_MAIL
Role of MaxAppTick	limits the rate at which OnNewMail is called. If `MaxAppTick`=0 both the speed is unlimited. With a slight abuse of notation in this mode `MaxAppTick` does not control `Iterate()` speed at all - it simply limits the rate at which new mail can be responded to
Role of CommsTick	not used as communications are asynchronous

4.2 Wildcard Subscriptions

MOOS-V10 extends the way in which clients can subscribe for data by allowing "wildcard subscriptions". A client can register its interest in variable whose name and source matches a simple regex pattern. Currently only patterns containing * and ? wildcards are supported with their usual meanings so ? means any single character and * means any number of characters. An example will make this whole thing clear and we will be using the new `CMOOSApp::Register( sVarPattern, sAppPattern,dfInterval)` interface.

```
bool MyApp::OnConnectToServer()
{
    //register for all variables ending with "image"
    //from any process with an name beginning with "camera_"
    Register("*image","camera_*, 0.0);

    //register for every single variable coming from a process
    //called "system_control"
    Register("*","sytem_control",0.0);

    //register for any variable beginning with "error_" and
    //produced by a process with a nine letter name beginning
    //with "process_0" but please, only tell us at most twice
    //a second
    Register("error_*","process_0?", 2.0);
    return true;
}
```

The logic which supports this new functionality is implemented at the MOOSB and turns our to be a pretty useful and compact way to define some fine granularity on what MOOSApp (or indeed CommsClient because that is the fundamental communications object) receives. Of course it can also be used to achieve blunderbuss subscriptions by subscribing to all variables from a given process - `Register(''*'',ProcessName)` - or even all variables from all processes - `Register(''*'',''*'')` the ultimate wildcard.

4.3 Common Command Line Interface

MOOSApp now supports a whole set of command line options which, by making a very small change to your code will make all your programs which use MOOSApp respond in the same way [4]. The upgrade is effected by invoking a new version of CMOOSApp::Run which takes argc and argv as parameters:

```
bool Run(const std::string &  sName,const std::string & sMissionFile, int argc↩
    , char * argv[]);
bool Run( const std::string &,int argc, char * argv[]);
```

This in turn populates a member variable within CMOOSApp called m_CommandLineParser which is used internally to parse the following command line variables and flags.

```
variables:
--moos_app_name=<string>     : name of application
--moos_name=<string>         : name with which to register with MOOSDB
--moos_file=<string>         : name of configuration file
--moos_host=<string>         : address of machine hosting MOOSDB
--moos_port=<number>         : port on which DB is listening
--moos_app_tick=<number>     : frequency of application (if relevant)
--moos_max_app_tick=<number>: max frequency of application (if relevant)
--moos_comms_tick=<number>   : frequency of comms (if relevant)
--moos_iterate_Mode=<0,1,2>  : set app iterate mode
--moos_time_warp=<number>    : set moos time warp

flags:
--moos_iterate_no_comms      : enable iterate without comms
--moos_filter_command        : enable command message filtering
--moos_no_sort_mail          : do not sort mail by time
--moos_no_comms              : do not start communications
--moos_quiet                 : do not print banner information
--moos_quit_on_iterate_fail  : quit if iterate fails
help:
--moos_print_example         : print an example configuration block
--moos_print_interface       : describe the interface (subscriptions/pubs)
--moos_print_version         : print the version of moos in play
--moos_help                  : print help on moos switches
--help                       : print help on moos messages and custom help
```

Tip: To enable common command line parsing call
CMOOSApp::Run(moos_name,mission_file,argc,argv)
or a variant when you start a MOOSApp

4.3.1 New Command Line Related Functions to Overload

MOOS-V10 adds new virtual functions to CMOOSApp which can be overloaded to process additional command line parameters if argc, and argv have been passed to your CMOOSApp derived class.

- OnProcessCommandLine() is called so you can do additional command line parsing

[4] sadly this does require a code change as there is no other way to get command line parameters in CMOOSApp..

- `OnPrintExampleAndExit()` is called when `--moos_print_example` is present on the command line. The intent is you use this function to print out an example configuration file block.
- `OnPrintInterfaceAndExit()` is called when `--moos_print_interface` is present on the command line. The intent is you use this function to print out details of the processes subscriptions and publications.
- `OnPrintHelpAndExit()` is called when `--moos_help` or `--help` is present on the command line. The intent here is that you print out help for additional command line parameters inside this function.

4.4 MOOSDB Interface Improvements

4.4.1 Command Line

Its pretty dull to only be able to configure processes from a script. `MOOSDB` now supports a better command line interface which allows you to set the port it is serving on and various other configurations. All accessed via `./MOOSDB --help`

```
>>pmn@mac  ./MOOSDB --help
MOOSDB command line help:
--moos_file=<string>                    specify mission file name
--moos_port=<positive_integer>          specify server port number
--moos_timewarp= <positive_float>       specify time warp
--moos_community=<string>               specify community name
--moos_timeout=<positive_float>         specify client timeout

--response=<string-list>                specifiy client response times <name:↩
   response_ms,... >
-s (--single_threaded)                  run as a single thread
-d (--dns)                              run with dns lookup
--webserver_port=<positive_integer>     run webserver on given port
-h    (--help)                          print help and exit
```

4.4.2 Configuring Client Response Times

The MOOSDB has some inbuilt security controls that are designed to prevent a rogue, ill mannered client to hog resources. It seems improper that a random client joining a community can decide to send 10 million messages persecond and because of that reduce the performance of other clients. On the other hand it seems inappropriate to disallow all clients for all time very rapid performance simply because of a percieved risk. The solution offered in MOOS-V10 is that the MOOSDB by default offers premiums service to all comers [5] - in other words every client will be serviced as soon as possible and all clients will be have data pushed to them as soon as possible. However the launcher of the `MOOSDB` may choose to restrict response times for clients- this has the effect of having each transaction with the DB contain more indvidual messages and prevents rogue clients being disruptive. Even introducing a repsonse time of 10ms can have a marked increase in performance for a very heavily loaded system. It is also possible to control which clients should be throttled and which should not.

```
pmn@mac:~$ ./MOOSDB --response=*:20
pmn@mac:~$ ./MOOSDB --response=VisualOdometry:10
```

[5] if they are using the AsyncComms

```
pmn@mac:~$ ./MOOSDB --response=Camera??:10,VisualOdometry:10,*:20
```

In the above, the first example sets all clients to have a minimum reposnse time of 20ms. The second example expicitly sets a client called `VisualOdometry` to have a 10ms response while all others have the default of 0ms (instant response). The final example has any client whos name begins with "Camera" followed by two characters set to 10ms and `VisualOdometry` at 10ms and every other client at 20ms.

4.4.3 Live Network Audit

Sometimes its nice to quickly get a summary of the network performance of the MOOSDB and the clients it supports. The MOOS V10 DB supports a very lightweight way to see how things are going. When the DB starts you'll see it print out something like `"network performance data published on localhost:9090 listen with "nc -u -lk 9090" "`. So if you follow this advice and in a terminal start `netcat (which is the "nc" command)` listening on port 9090 it will receive UDP packets which contain performance data. Here is an example output - don't be put off by the fact that the client names are actually numbers in this case - that just happens to be the naming scheme this community was running. The network summary packet is sent once a second and contains valid statistics for that last second.

```
client name    pkts in   pkts out   msgs in   msgs out    B/s in   B/s out
          0         20         17        20         20      1207      1227
          1         19         19        19         19      1216      2177
      total         39         36        39         39      2423      3404
```

4.5 Backwards Compatibility

MOOS V10 was designed to offer complete backwards compatibility between all versions of MOOS. You should be able to run legacy code with modern clients and old DB's alike. You should be able to run heterogenous communities with any combination of pre V10 and V10 applications. The table below shows the options available for different combinations.

Client	MOODB	OK	Async. Comms	Synch. Comms	Multithreading DB	Single Threaded DB
Pre10	Pre10	✔	✗	✔	✗	✔
Pre10	V10	✔	✗	✔	✔	✔
V10	Pre V10	✔	✗	✔	✗	✔
V10	V10	✔	✔	✔	✔	✔

4.5.1 Retreating back to the known

It is also possible to force the MOOSDB to behave (ie run almost exactly the same code) as previous versions did. So if you are using the V10 code base but want to return to the good old days the recipe is:

1. Run MOOSDB with the single threaded switch `./MOOSDB -s`
2. Make sure you compile V10 with USE_ASYNC_COMMS=OFF and ENABLE_V10_COMPATIBILITY=ON

5 Bench Marks and Testing Tools

5.1 Testing with umm

Sometimes its attractive to be able to simply to fire up a program from the command line that subscribes to an publishes messages of your choosing - just to test the MOOS Communications facilities and explore performance. There is a tool called `umm` [6] which is designed to achieve just this and it also allows you to simulate applications crashing or operating with high latency networks. It is entirely configurable from the command line and has the following options (in addition to the standard MOOS ones described in Section 4.3 which you use to set MOOS parameters to something other than their default value).

```
Publication and Subscription  settings:
-s=<string>  : list of subscriptions as var_name@period
-w=<string>  : list of wildcard subscriptions as var_pattern:app_patter@period
-p=<string>  : list of publications as var_name[:optional_binary_size]@period
--latency    : show latency (time between posting and receiving)
--verbose    : verbose output
--bandwidth  : show badnwidth statistics

Network failure simulation:
--simulate_network_failure=<numeric>
            : enable simulation of network/app failure
--network_failure_prob=<numeric>
            : probability of each DB interaction having network failure [0.1]
--network_failure_time=<numeric>
            : duration of network failure [3s]
--application_failure_prob=<numeric>
            : probability of application failing during DB-communication [0]
```

Some examples are probably useful at this point. So if we wanted to send the variable `X` at 20Hz we would type:

```
./umm -p=X@20
```

and in this case X would be a numeric (MOOS_DOUBLE) variable. Imagine now we wanted to try sending binary data. We would be compelled to write:

```
./umm -p=X@20,Y:10000@15
```

and this would write Y as 10K of binary data a 15 Hz. We can also subscribe to data

```
./umm -p=X@20,Y:10000@15 -s=Z@8,X@0 --verbose
```

which subscribes for every issue of X (which we are publishing ourself!) and also Z at to 8 Hz. Note that $0Hz$ is overloaded to mean subscribe to everything. The verbose flag simply adds some printing so you can check progress. You can of course also access the wildcard subscription service offered by MOOS 10. This is done via the `-w` switch. For example

```
./umm -p=X@20,Y:10000@15 -s=Z@8,X@0 --verbose -w='*:ProcA@0'
```

[6] if you forget this name you may end up saying "umm..." as you recall you are looking to "**u** **m**onitor **m**oos"

does all the above and subscribes to all messages from a process called `ProcA`. Note the use of the single quotation to stop the shell interpreting the wilcard '*'. Of course you can build complicated filters this way

```
./umm --verbose --bandwidth -w='*:ProcA@1,battery_*:monitor_?'
```

which subscribes to everything from ProcA at 1Hz and every issue of any variable which begins with "battery_" from any process which whose name begins with "monitor_" and ends with any single character. This example also prints out these messages and also bandwidth statistics. You can also use the network failure simulation switches to test MOOS's ability to deal with errant clients.

Tip: you can use `umm` to watch all MOOS traffic try `./umm -w='*:*@0' --verbose` to see everything or `./umm -w='*:ProcA@1'` to see everything from `ProcA` at 1Hz.

5.2 Profiling with `async_test`

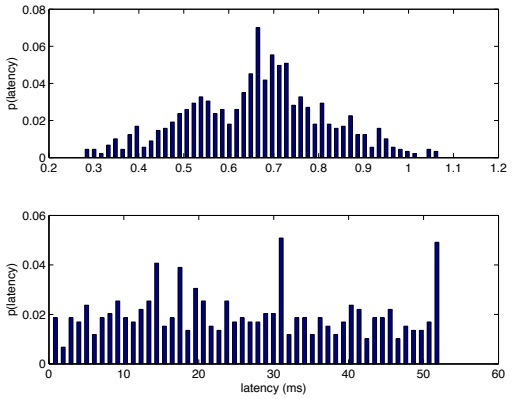
It is useful to have some statistical sense of performance. Its nice, when you have built V10 to have some sense of latencies and throughputs. In the directory build directory `bin` you will find an executable called `async_test` which can be used to do some benchmarking. The program `async_test` instantiates a configurable number $2N$ of Comms Clients N of which are AsyncCommsClients and the other N of which are pre-V10 clients. Client C_j is asynchronous if j is even. All clients register with the `MOOSDB` under the numerical name `j (so "1","2" etc)` Client C_0 is Asynchronous and is charged with regularly posting a variable "`X`" or configurable size to the MOOSDB. All clients including C_0 subscribe to `X`. The time in milliseconds betweenC_0 sending and client C_j receiving the data is logged to file `asynctest.log` as a plain text matrix :

$$\begin{array}{ccccc} 0 & \tau_1^0 & \tau_2^0 & \tau_3^0 & \cdots \\ 1 & \tau_1^1 & \tau_1^1 & \tau_1^1 & \cdots \\ 2 & \tau_1^0 & \tau_1^0 & \tau_1^0 & \cdots \\ \vdots & \vdots & \vdots & \vdots & \ddots \end{array}$$

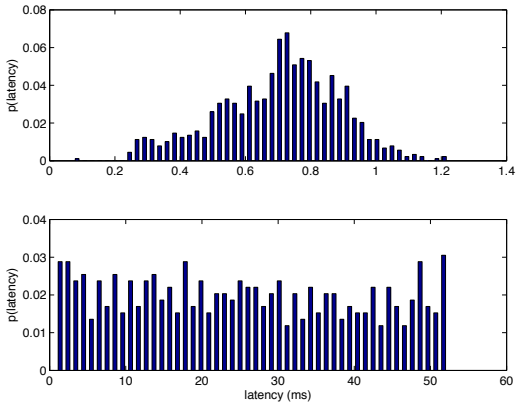
where ${}^j\tau_i$ is the i^{th} latency for client C_j and each row begins with j . The test can be run for a configurable number of seconds after which histograms of performance for each kind of client can be produced. The options for `uDBAsyncTest` are below.

```
V10 performance and compatibility testing
  -p              : test period in seconds (20 seconds default)
  -m              : send test data every m milliseconds (default 100 ms)
  -c              : number of clients to instantiate (default 40)
  -s              : size of data to send default (default 1024 bytes)

Example Usage:  test for 15 seconds with 20 clients and sending 100K every 50 ↩
    ms

    ./async_test  -p=15 -c=20 -m=50 -s=100000
```

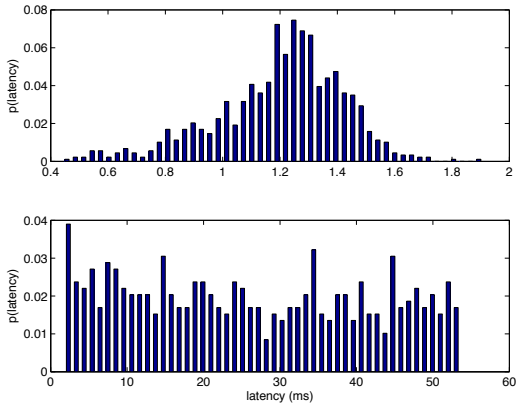
The figures on the following pages give the probability distributions over message latencies under different conditions (specified in caption). For example Figure 4 was generated with



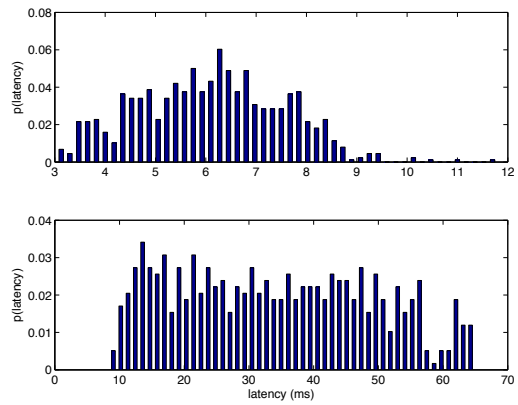
(a) Sending and receiving 1KB messages.



(b) Sending and receiving 10KB messages.



(c) Sending and receiving 100KB messages.

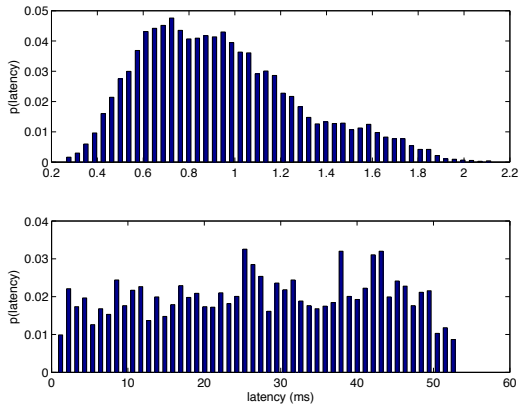


(d) Sending and receiving 1MB messages

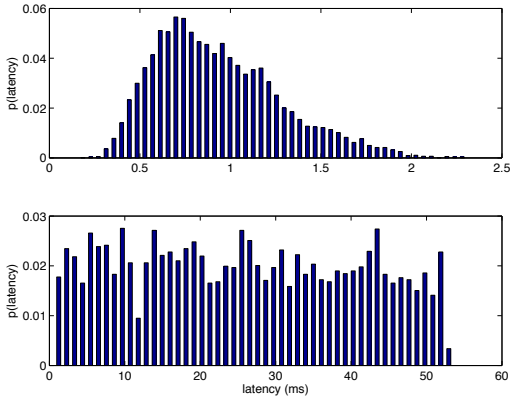
Figure 4: Histograms of latencies between sending and receiving 1KB,10KB, 100KB and 1MB messages. Messages are sent to 5 clients at 20Hz. Top figures are for asynchronous clients lower figures are for pre V10 clients with a comms-tick set 20Hz. All cases are using the `V10 MOOSDB`. As an example of total throughput take the example of sending 100KB messages to 5 clients 20 times a second so 100K*5*20=10MB/s.

```
./async_test -p=20 -c=5 -m=50 -s=1000
./async_test -p=20 -c=5 -m=50 -s=10000
./async_test -p=20 -c=5 -m=50 -s=10000
./async_test -p=20 -c=5 -m=50 -s=1000000
```

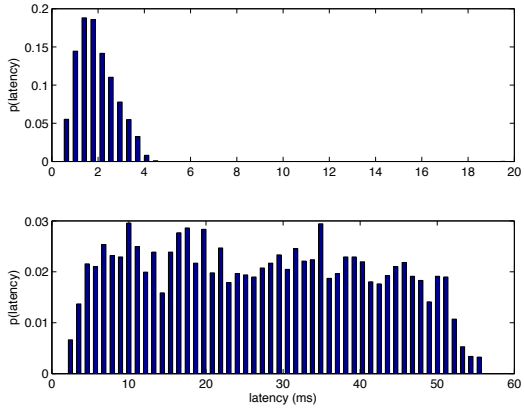
Which fires 1K,10K 100K and 1MB messages at 20Hz (every 50ms) to the DB which are immediately routed to 5 clients. This sort of testing not only gives a sense of latencies but also a sense of the total through-put of the system. For the results given here the `MOOSDB` was on the same machine as ./async_test which means we are testing logic speed not network speed. The results are gathered on a 2.2GHz Intel Core i7 Mac book Pro running OS X 10.8 and all code was built in Debug (so these results are conservative). Its pretty clear that V10 clients offer between one and two orders of magnitude improvement in performance in terms of latency.



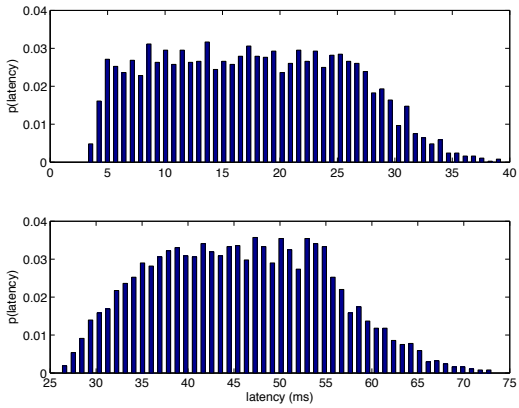
(a) Sending and receiving 1KB messages.



(b) Sending and receiving 10KB messages.



(c) Sending and receiving 100KB messages.



(d) Sending and receiving 1MB messages at 10Hz

Figure 5: Histograms of latencies between sending and receiving 1KB,10KB, 100KB and 1MB messages. Messages are sent to 50 clients at 20Hz unless otherwise stated. Top figures are for asynchronous clients lower figures are for pre V10 clients with a comms-tick to 20Hz. All cases are suing the `V10 MOOSDB`. As an example of total through put take the example of sending 100KB messages to 50 clients 20 times a second so 100K*50*20=100MB/s.

6 Example Codes

6.1 The simplest example using `MOOSAsyncCommClient`

The simplest (in terms of its proximity to the core communication classes) example of using MOOS-V10 communications is given in figure **??**. Here a MOOS::MOOSAsyncCommClient is instantiated in its rawest form. It is configured with a Mail and OnConnect callback and set free with a call to Run. Note that in the Connect callback it registers for the data that is being posted once a second in the main() forever loop. Many MOOS users will be used to using CMOOSApp which manages the interaction with the Comms Client Objects however it is instructive to look at the most fundamental example. The CMakeLists.txt file for this example is also given below.

Listing 1: A simple example using MOOSAsyncCommClient

```
/*
 * A simple example showing how to use a comms client
 */
#include "MOOS/libMOOS/Comms/MOOSAsyncCommClient.h"
#include "MOOS/libMOOS/Utils/CommandLineParser.h"

bool OnConnect(void * pParam){
    CMOOSCommClient* pC =  reinterpret_cast<CMOOSCommClient*> (pParam);
    pC->Register("X",0.0);
    return true;
}

bool OnMail(void *pParam){
    CMOOSCommClient* pC = reinterpret_cast<CMOOSCommClient*>(pParam);

    MOOSMSG_LIST M; //get the mail
    pC->Fetch(M);

    MOOSMSG_LIST::iterator q; //process it
    for(q=M.begin();q!=M.end();q++){
        q->Trace();
    }
    return true;
}

int main(int argc, char * argv[]){

    //understand the command line
    MOOS::CommandLineParser P(argc,argv);

    std::string db_host="localhost";
    P.GetVariable("--moos_host",db_host);

    int db_port=9000;
    P.GetVariable("--moos_port",db_port);

    std::string my_name ="exampleA";
    P.GetVariable("--moos_name",my_name);

    //configure the comms
    MOOS::MOOSAsyncCommClient Comms;
    Comms.SetOnMailCallBack(OnMail,&Comms);
```

```
    Comms.SetOnConnectCallBack(OnConnect,&Comms);

    //start the comms running
    Comms.Run(db_host,db_port,my_name);

    //for ever loop sending data
    std::vector<unsigned char> X(100);
    for(;;){
        MOOSPause(1000);
        Comms.Notify("X",X);
    }
    return 0;
}
```

Listing 2: CMakeLists.txt to the simple example above

```
CMAKE_MINIMUM_REQUIRED(VERSION 2.8)

if(COMMAND cmake_policy)
   cmake_policy(SET CMP0003 NEW)
endif(COMMAND cmake_policy)


#this builds an example program
set(EXECNAME comms_example)

find_package(MOOS 10)

#what files are needed?
SET(SRCS CommsExample.cpp)

include_directories(  ${MOOS_INCLUDE_DIRS} ${MOOS_DEPEND_INCLUDE_DIRS})
add_executable(${EXECNAME} ${SRCS} )
target_link_libraries(${EXECNAME} ${MOOS_LIBRARIES} ${MOOS_DEPEND_LIBRARIES})
```

6.2 The Simplest Example using CMOOSApp

We can of course achieve the same thing by subclassing CMOOSApp. The code listing below shows how.

Listing 3: A simple example using MOOSAsyncCommClient

```
/*
 * simple MOOSApp example
 */

#include "MOOS/libMOOS/App/MOOSApp.h"

class ExampleApp : public CMOOSApp
{
    bool OnNewMail(MOOSMSG_LIST & Mail)
    {
```

```
        //process it
        MOOSMSG_LIST::iterator q;
        for(q=Mail.begin();q!=Mail.end();q++){
            //q->Trace();
        }
        return true;
    }
    bool OnConnectToServer()
    {
        return Register("X",0.0);
    }
    bool Iterate()
    {
        std::vector<unsigned char> X(100);
        Notify("X",X);
        return true;
    }
};

int main(int argc, char * argv[])
{
    //here we do some command line parsing...
    MOOS::CommandLineParser P(argc,argv);
    //mission file could be first free parameter
    std::string mission_file = P.GetFreeParameter(0, "Mission.moos");

    //app name can be the  second free parameter
    std::string app_name = P.GetFreeParameter(1, "ExampleApp");

    ExampleApp App;

    App.Run(app_name,mission_file,argc,argv);

    return 0;
}
```

6.3 Sharing Video Rate Data

Here is a simple example code for sharing video data using the package OpenCV [7]. The program can be started in one of two ways - once as a server which opens a camera and starts streaming images and as a client which displays them in a window. Note this is not an elegant program - it fixes the images size and does a fairly ugly bit of memory management. It is presented here as a quick and dirty exposition of using MOOS to send data at a moderate rate - its not an example of good use of OpenCV.

- Start a MOOSDB
- To start a server in a terminal window from the command line whilst in the directory containing the binary type :
  - `./camera_example -s --moos_name SERVER`

[7] so you will need OpenCV installed on your machine. The CMakeLists.txt file should find this installation and handle everything for you but if you are using mac ports you may need to specify the location of OpenCV in the ccmake gui as Cmake does not look in /opt by default.

- To start a client from a similar terminal to that above type :
  - `./camera_example --moos_name A`
- To start another client, you guess it, open another terminal and try
  - `./camera_example --moos_name B`

If you do the above you should see you camera output appearing in two windows with very little lag.

Listing 4: Example code to build a camera sharing example

```
#include "opencv2/opencv.hpp"
#include "MOOS/libMOOS/App/MOOSApp.h"

class CameraApp : public CMOOSApp
{
public:
    bool Iterate()
    {
        if(server_){
            vc_>>capture_frame_;
            cv::cvtColor(capture_frame_, bw_image_, CV_BGR2GRAY);
            cv::resize(bw_image_, image_, image_.size(), 0, 0, cv::↩
                INTER_NEAREST);
            Notify("Image",(void*)image_.data,image_.size().area(),↩
                MOOSLocalTime());
        }
        else{
            cv::imshow("display", image_);
            cv::waitKey(10);
        }
        return true;
    }
    bool OnStartUp()
    {
        SetAppFreq(20,400);
        SetIterateMode(COMMS_DRIVEN_ITERATE_AND_MAIL);

        image_ = cv::Mat(378,512,CV_8UC1);

        if(server_){
            if(!vc_.open(0))
                return false;
        }
        else{
            cv::namedWindow("display",1);
        }

        return true;
    }
    void OnPrintHelpAndExit()
    {
        PrintDefaultCommandLineSwitches();
        std::cout<<"\napplication specific help:\n";
        std::cout<<"  -s              : be a video server grabs and sends images↩
             (no window)\n";
```

```
        exit(0);
    }
    void OnPrintExampleAndExit()
    {
        std::cout<<" ./video_share -s    \n";
        std::cout<<" and on another terminal..\n";
        std::cout<<" ./video_share       \n";
        exit(0);
    }

    bool OnProcessCommandLine()
    {
        server_=m_CommandLineParser.GetFlag("-s");

        return true;
    }
    bool OnNewMail(MOOSMSG_LIST & mail)
    {
        MOOSMSG_LIST::iterator q;
        for(q = mail.begin();q!=mail.end();q++){
            if(q->IsName("Image")){
                std::cerr<<"bytes: "<<q->GetBinaryDataSize()<<" latency "<<
                        std::setprecision(3)<<(MOOSLocalTime()-q->GetTime())*1↩
                            e3<<" ms\r";

                memcpy(image_.data,q->GetBinaryData(),
                        q->GetBinaryDataSize());
            }
        }
        return true;
    }
    bool OnConnectToServer()
    {
        if(!server_)
            Register("Image",0.0);
        return true;
    }
protected:
    cv::VideoCapture vc_;
    cv::Mat capture_frame_,bw_image_,image_;
    bool server_;


};
int main(int argc, char* argv[])
{
    //here we do some command line parsing...
    MOOS::CommandLineParser P(argc,argv);
    //mission file could be first free parameter
    std::string mission_file = P.GetFreeParameter(0, "Mission.moos");
    //app name can be the  second free parameter
    std::string app_name = P.GetFreeParameter(1, "CameraTest");

    CameraApp App;
    App.Run(app_name,mission_file,argc,argv);
```

```
    return 0;
}
```

Listing 5: CMakeLists.txt to build the camera sharing example above

```
#this builds an example program
project(camera_example)
if(COMMAND cmake_policy)
       cmake_policy(SET CMP0003 NEW)
endif(COMMAND cmake_policy)

cmake_minimum_required(VERSION 2.8)

#find MOOS version 10 or later
find_package(MOOS 10)

find_package( OpenCV )

set(EXECNAME video_share)

#what files are needed?
set(SRCS CameraExample.cpp)

#what include directives?
include_directories(  ${MOOS_INCLUDE_DIRS} ${MOOS_DEPEND_INCLUDE_DIRS} ${↩
    OpenCV_INCLUDE_DIRS})

#make a program!
add_executable(${EXECNAME} ${SRCS} )

#and link thus...
target_link_libraries(${EXECNAME} ${MOOS_LIBRARIES} ${MOOS_DEPEND_LIBRARIES} $↩
    {OpenCV_LIBS})
```

There are several things to note about this example which are worth spotting:

1. The way in which MOOS-V10 can handle command line argument parsing for you using the `OnParseCommandLine()` virtual function in `CMOOSApp`. Also note that the switches like `--moos_name` are handled automatically for you. If this is a surprise read section 4.3.

2. The way in which in this example `SetIterateMode` is used to make the application respond quickly to the reception of mail.