YARP and iCub code tutorials

Software installation

- http://wiki.icub.org/wiki/ICub_Software_Installation
- Linux: installation from sources

Code available on github

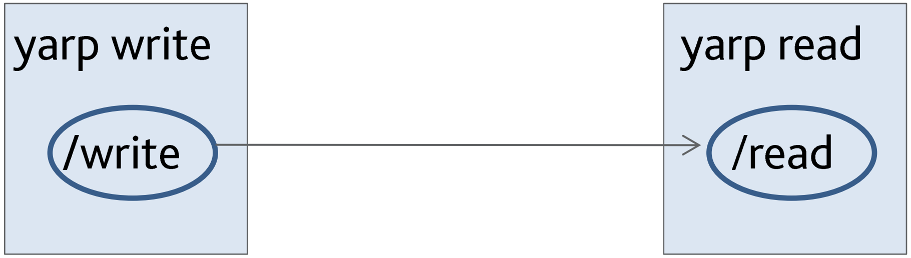
- https://github.com/lornat75/Teaching
- Type:

```
git clone git@github.com:lornat75/Teaching.git
```

Yarp from command line

A (very) simple example: read data to/from a port

[on terminal 1] yarpserver
[on terminal 2] yarp read /read
[on terminal 3] yarp write /write /read



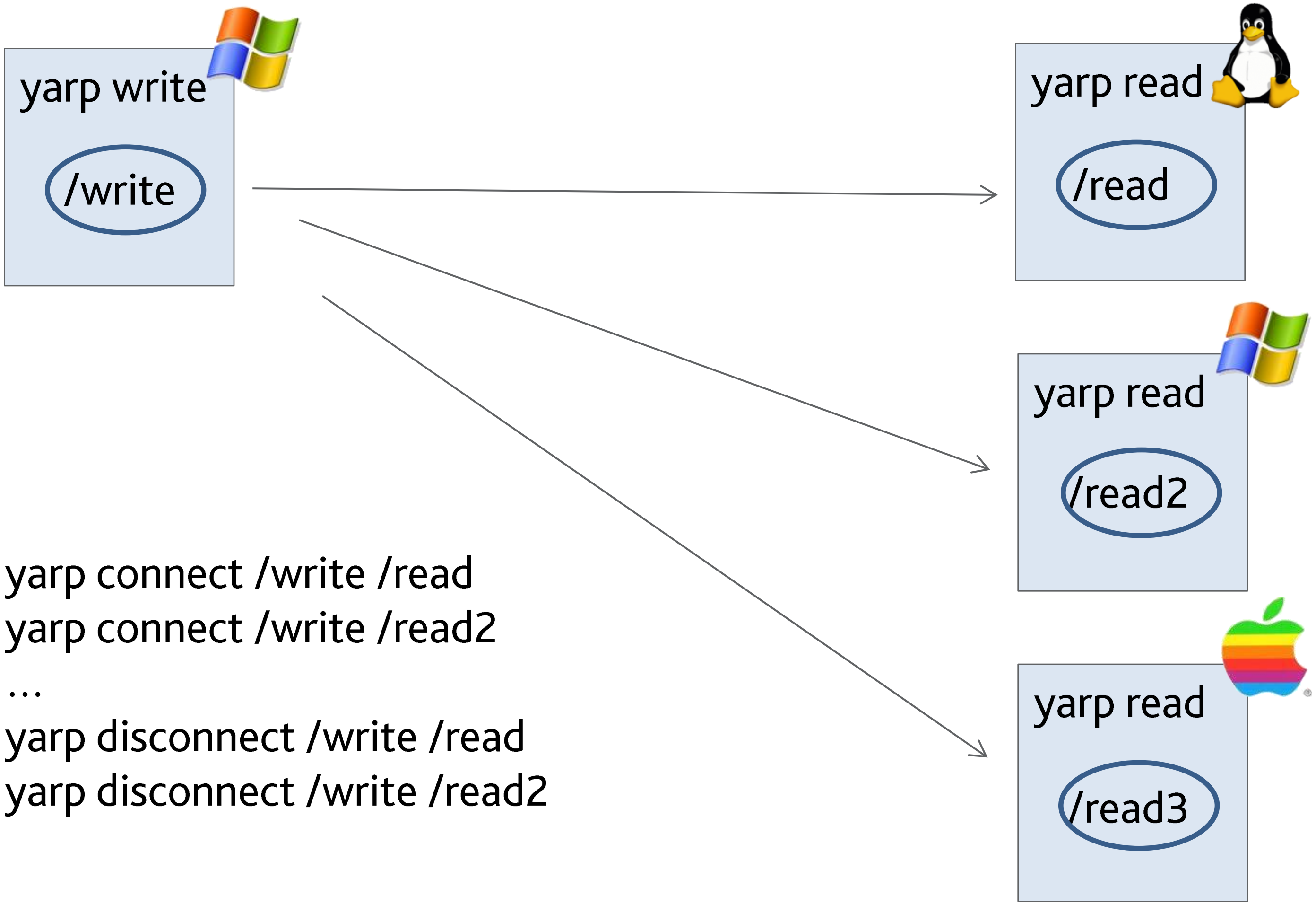
```
$ yarp write /write /read
Port /write listening at tcp://127.0.0.1:10012
yarp: Sending output from /write to /read using tcp
Added output connection from "/write" to "/read"
hello yarp
1 2 3
```

```
$ yarp read /read
Port /read listening at tcp://127.0.0.1:10002
yarp: Receiving input from /write to /read using tcp
hello yarp
1 2 3
```

```
yarp name list
yarp name query /read
yarp name register PORT CARRIER IP NUMBER
yarp name unregister PORT
```

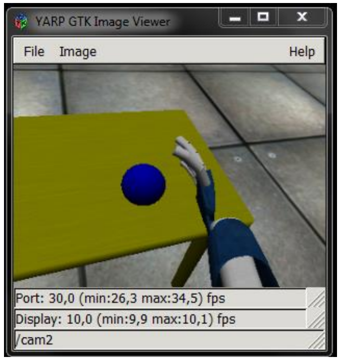
how the network grows

It is easy to add, for example, another reader…
Processes can run on different machines, with different OS

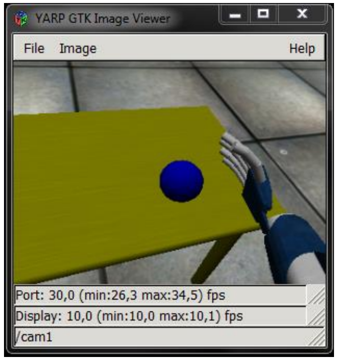


```
yarp connect /write /read
yarp connect /write /read2
…
yarp disconnect /write /read
yarp disconnect /write /read2
```

yarpview



```
Port: 30,0 (min:26,3 max:34,5) fps
Display: 10,0 (min:9,9 max:10,1) fps
/cam2
```



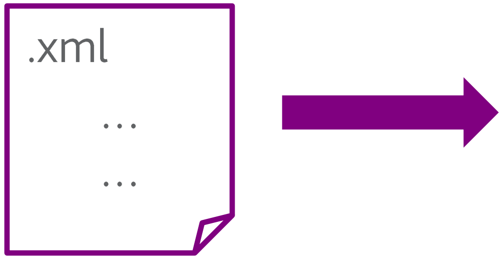
```
Port: 30,0 (min:26,3 max:34,5) fps
Display: 10,0 (min:10,0 max:10,1) fps
/cam1
```

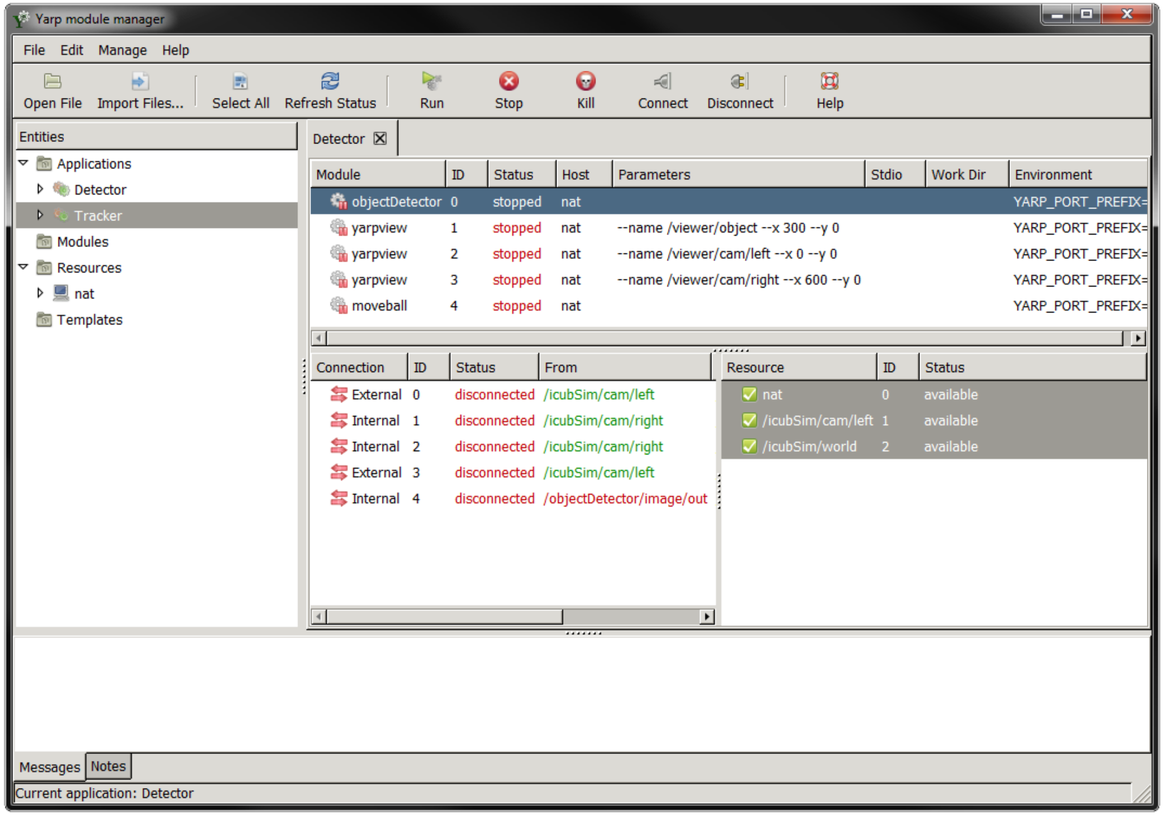
```
yarpdev –-device test_grabber  --name /cam/right
yarpdev –-device test_grabber –name /cam/left
yarpview –name /view1
yarpview –name /view2

yarp connect /cam/right /view1
yarp connect /cam/left /view2
```

Automation

The YARP Manager

- The yarp manager is a graphic interface to monitor processes
- It allows to start/stopping/monitor, redirect i/o
- In addition it automates establishing connections between modules



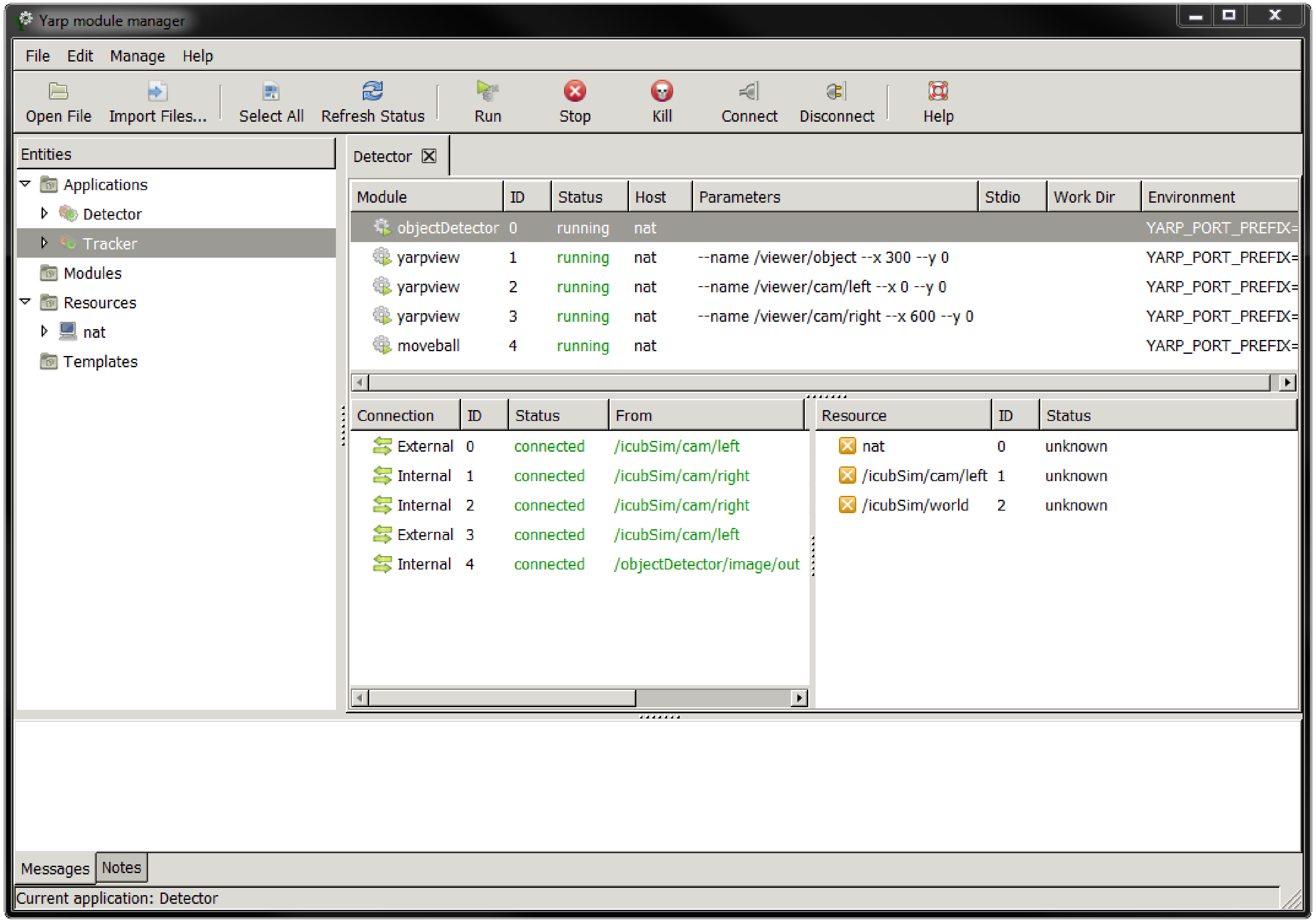


Module	ID	Status	Host	Parameters	Stdio	Work Dir	Environment
objectDetector	0	stopped	nat				YARP_PORT_PREFIX=
yarpview	1	stopped	nat	--name /viewer/object --x 300 --y 0			YARP_PORT_PREFIX=
yarpview	2	stopped	nat	--name /viewer/cam/left --x 0 --y 0			YARP_PORT_PREFIX=
yarpview	3	stopped	nat	--name /viewer/cam/right --x 600 --y 0			YARP_PORT_PREFIX=
moveball	4	stopped	nat				YARP_PORT_PREFIX=

Connection	ID	Status	From
External	0	disconnected	/icubSim/cam/left
Internal	1	disconnected	/icubSim/cam/right
Internal	2	disconnected	/icubSim/cam/right
External	3	disconnected	/icubSim/cam/left
Internal	4	disconnected	/objectDetector/image/out

Resource	ID	Status
✓ nat	0	available
✓ /icubSim/cam/left	1	available
✓ /icubSim/world	2	available

Current application: Detector



Module	ID	Status	Host	Parameters	Stdio	Work Dir	Environment
objectDetector	0	running	nat				YARP_PORT_PREFIX=
yarpview	1	running	nat	--name /viewer/object --x 300 --y 0			YARP_PORT_PREFIX=
yarpview	2	running	nat	--name /viewer/cam/left --x 0 --y 0			YARP_PORT_PREFIX=
yarpview	3	running	nat	--name /viewer/cam/right --x 600 --y 0			YARP_PORT_PREFIX=
moveball	4	running	nat				YARP_PORT_PREFIX=

Connection	ID	Status	From
External	0	connected	/icubSim/cam/left
Internal	1	connected	/icubSim/cam/right
Internal	2	connected	/icubSim/cam/right
External	3	connected	/icubSim/cam/left
Internal	4	connected	/objectDetector/image/out

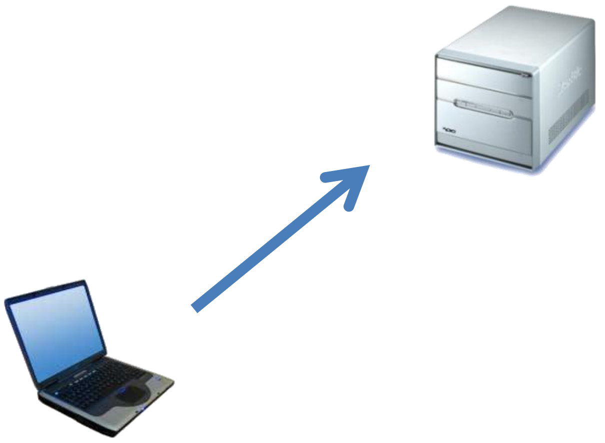
Resource	ID	Status
nat	0	unknown
/icubSim/cam/left	1	unknown
/icubSim/world	2	unknown

Current application: Detector

gyarpmanager documentation

- http://wiki.icub.org/yarpdoc/yarpmanager.html run a server, which will wait for commands on /node1

Starting a server
$node1: yarprun –server /node1

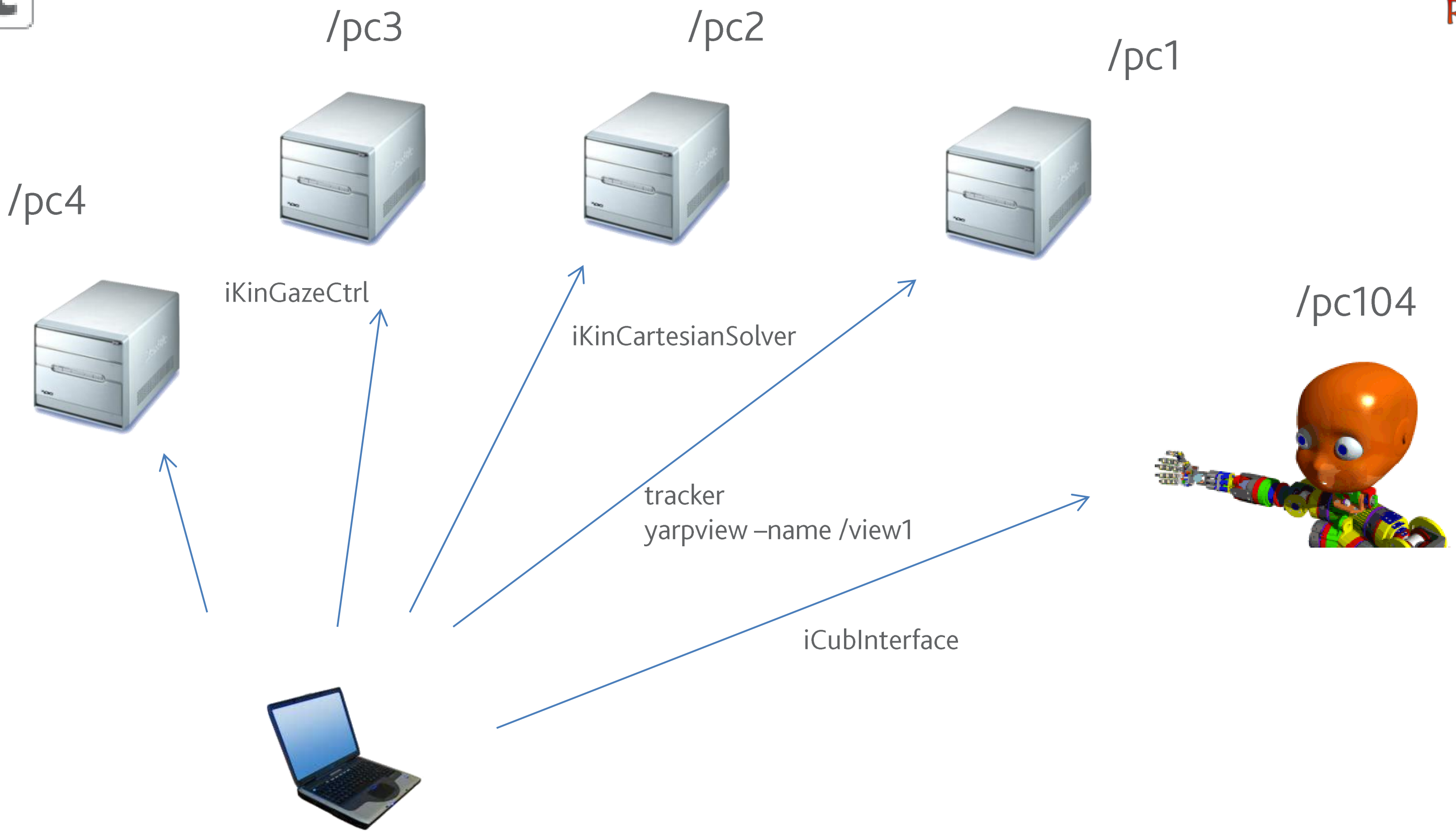


/node1

localhost

- The manager has two ways to execute processes: locally (localhost) or through yarprun
- yarprun is a server that waits for commands on a port
- start/termination/kill monitor lifecycle

http://wiki.icub.org/yarpdoc/db/dd7/yarprun.html



/pc3

/pc2

/pc1

/pc4

iKinGazeCtrl

/pc104

iKinCartesianSolver

tracker
yarpview –name /view1

iCubInterface

Syntax

```
<application>
     <name>Name of the application</name> //this can be anything, just a symbolic name

    <dependencies>
      <port>/port1 </port>
      <port>/port2 </port>
    </dependencies>

     <module>
      <name>mymodule1 </name>
      <parameters>--threshold 1 --name /myName</parameters>
      <node>localhost</node>
    </module>

    <module>
      <name>mymodule2</name>
      ...
    </module>

    <connection>
      <from>/port1</from>
      <to>/otherport</to>
      <protocol>udp</protocol>
    </connection>

    <connection>
      …
    </connection>

</application>
```

```
<application>
    <name>Name of the application</name> //this can be anything, just a symbolic name

    <module>
      <name>yarpdev</name>
      <parameters>--device test_grabber --name /cam/right</parameters>
      <node>localhost</node>
    </module>

    <module>
      <name>yarpview</name>
      <parameters>--name /view/right</parameters>
      <node>localhost</node>
    </module>

    <connection>
      <from>/cam/right</from>
      <to>/view/right</to>
      <protocol>udp</protocol>
    </connection>

</application>
```

or any other node in the network:
/node1, /node2 etc..
E.g. on the iCub: icub14, icub15, icub-b11…

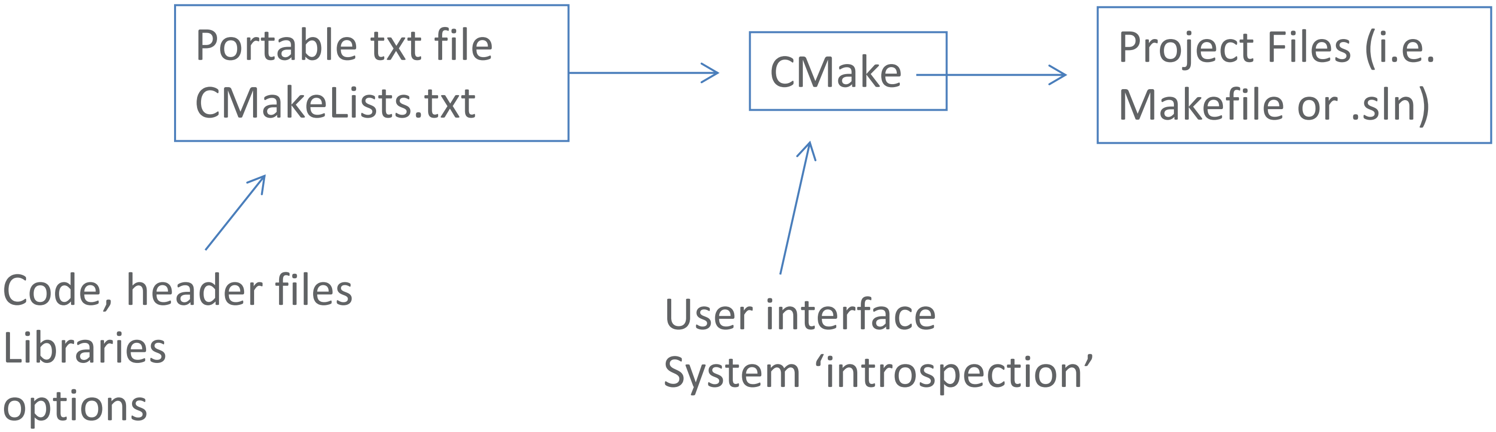
Other tags

```
<dependencies>
    <port>/icub/cam/left</port>
    <port>/icub/cam/right</port>
</dependencies>

<module>
    ...
    <workdir>C:/mydir</workdir>
    <stdio>node3</stdio>
</module>
```

CMake Basics

Introduction

- Open source build manager
- Specify build parameters in a simple portable text format



Portable txt file
CMakeLists.txt

CMake

Project Files (i.e.
Makefile or .sln)

Code, header files
Libraries
options

User interface
System ‘introspection’

Problems solved by CMake

- Write and maintain project files for multiple platforms
- Optional components?
- Build on more than a single machine: different OS have different libraries, same OS can be installed differently → automatically search for programs libraries header files
- Build directory tree different from source tree
- Handle dependencies
- Static versus Dynamic libraries
- …

Basics

- Commands (case insensitive)
- Variables (case sensitive)

```
command(a b c)
set(FOO a b c)

command(${FOO})
command(“${FOO}”)
```

Consider:

```
set(PATH_TO_MY_FILE C:\program files\myfile)
command(${PATH_TO_MY_FILE})

command(“${PATH_TO_MY_FILE}”)
```

Hello World with CMake

```
cmake_minimum_required(VERSION 2.8)

project(hello)

include_directories(${CMAKE_CURRENT_SOURCE_DIR})

message(STATUS "--> Hello from CMake")

if (WIN32)
        message("--> Running on windows")
else()
                message("--> Assuming running on Linux")
endif()

if (NOT EXISTS "${CMAKE_CURRENT_SOURCE_DIR}/hello.cpp")
    message(FATAL_ERROR "File hello.cpp not found!")
endif()

add_executable(hello hello.cpp)
```

How to run CMake

- Source versus build directories
- From command line:
  - mkdir build
  - cd build
  - cmake ../ or ccmake ../
- From gui:
  - mkdir build
  - cmake-gui
  - Set source and build directories
- Hit “c” until you get “g”

When build = source dir: in source build
When build != source dir: out of source build

Cache

- Some variables are determined only once and cached on disk; CMake will not touch them, only the user can
- E.g. user options or result of system introspection, info that are expensive to determine (compiler to use, system libraries, etc..)
- To do a fresh restart, clean the cache
  - From the gui
  - Remove CMakeCache.txt

Commands on targets

- add_executable(name file1.cpp file2.cpp header1.h header2.h)
- target_link_libraries(name libname)
- add_library(name file1.cpp file2.cpp header1.h)
- include_directories(dir1 dir2)
- add_definitions(-DFOO -DBAR)

Example:

```
#if _ENABLE_DEBUG_
  printf(“Value of variable v is %d”, v);
#endif

option(ENABLE_DEBUG "Enable debugging messages"
       FALSE)

if (ENABLE_DEBUG)
     message(STATUS "Debugging messages are enabled")
     add_definitions(-D_ENABLE_DEBUG_)
endif()
```

Installation

- In some builds include an installation step
- You can add installation rules using CMake

```
install(TARGETS myExe RUNTIME DESTINATION  <dir>)

install(FILES files DESTINATION <dir>)
```

<dir> can be:

- Absolute path
- Relative path, in this case it will be CMAKE_INSTALL_PREFIX\<dir>
- The user can customize CMAKE_INSTALL_PREFIX

Hello World with CMake (2)

```
…
add_executable(hello hello.cpp)
install(TARGETS hello
    RUNTIME DESTINATION
    ${CMAKE_CURRENT_SOURCE_DIR}/../bin)
```

Finding libraries

- The problem
- You want to compile an executable that links libraries from another package, e.g. YARP
- Naïve way:

```
cmake_minimum_required(VERSION 2.8)

project(hello)

include_directories(“C:\Program files\yarp\include”)

add_executable(hello hello.cpp)

target_link_libraries(hello “C:\Program files\yarp\lib\libYARP_OS.lib”)
```

Finding libraries

- The problem
- You want to compile an executable that links libraries from another package, e.g. YARP
- Naïve way:

```
cmake_minimum_required(VERSION 2.8)

project(hello)

include_directories(“C:\Program files\yarp\include”)

add_executable(hello hello.cpp)

target_link_libraries(hello “C:\Program files\yarp\lib\libYARP_OS.lib”)
```

Os dependent (.a in Linux)

Installation dependent

Finding libraries…

- CMake has a few commands that can be used to find directories, executables and libraries inside a computer

```
find_file(<var> name dir1 dir2)
find_library(<var> name dir1 dir2)
find_path(<var> name dir1 dir2)
```

- However there is a better interface…

find_package()

- A package should provide you:
  - Paths to libraries
  - Paths to header files
  - Linker flags (if any)

find_package(<PACKAGE> [VERSION])
This function attempts to locate the package called <PACKAGE> and will return a set of variables:

<PACKAGE>_FOUND
<PACKAGE>_INCLUDE_DIRS
<PACKAGE>_LIBRARIES
<PACKAGE>_VERSION
<PACKAGE>_VERSION_MAJOR
<PACKAGE>_VERSION_MINOR

Example:

```
find_package(YARP)
```

```
YARP_FOUND
YARP_INCLUDE_DIRS
YARP_LIBRARIES
```

- How does find_package() work?
  - Looks for system directories

    C:\Program files\<package>

    /usr/<package>

    /usr/local/<package>

    …
  - Look for environment variables, very popular <PACKAGE>_DIR
- CMake does not enforce a particular set of variables each package set different variables
- Other examples:

  <PACKAGE>_INCLUDE_DIR

  <PACKAGE>_LIBS

  etc..

Hello YARP

```
cmake_minimum_required(VERSION 2.8)

project(myproject)

find_package(YARP)

include_directories(${YARP_INCLUDE_DIRS})

add_executable(hello hello.cpp)
target_link_libraries(hello ${YARP_LIBRARIES})

add_executable(hello2 hello.cpp)
target_link_libraries(hello2 ${YARP_LIBRARIES})
```

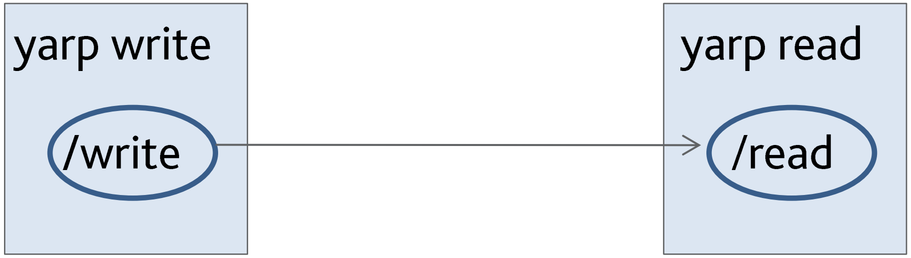
Hello yarp

```
#include <stdio.h>
#include <yarp/os/Time.h>

int main()
{
    printf("Starting the application\n");
    int times=10;

    while(times--)
    {
        printf("Hello iCub\n");
        yarp::os::Time::delay(0.5);        //wait 0.5 seconds
    }
    printf("Goodbye!\n");
}
```

Ports

A (very) simple example: read data to/from a port

[on terminal 1] yarpserver
[on terminal 2] yarp read /read
[on terminal 3] yarp write /write /read



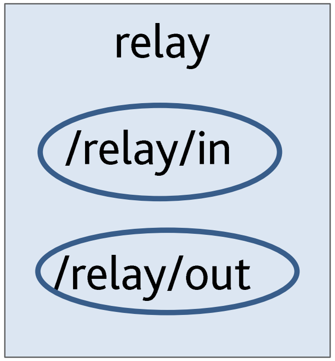
```
$ yarp write /write /read
Port /write listening at tcp://127.0.0.1:10012
yarp: Sending output from /write to /read using tcp
Added output connection from "/write" to "/read"
hello yarp
1 2 3
```

```
$ yarp read /read
Port /read listening at tcp://127.0.0.1:10002
yarp: Receiving input from /write to /read using tcp
hello yarp
1 2 3
```

How do we get this?

Let’s now to write a simple “relay” executable which takes whatever comes from a port and forwards it to another one.

```
int main(int argc, char *argv) {
    Network yarp;
    Port inPort;
    inPort.open("/relay/in");

    Port outPort;
    outPort.open("/relay/out");


    while (true) {
        cout << "waiting for input" << endl;
        Bottle input,output;
        inPort.read(input);
        output=input;
        cout << "writing " << output.toString().c_str() << endl;
        outPort.write(output);
    }
    return 0;
}
```

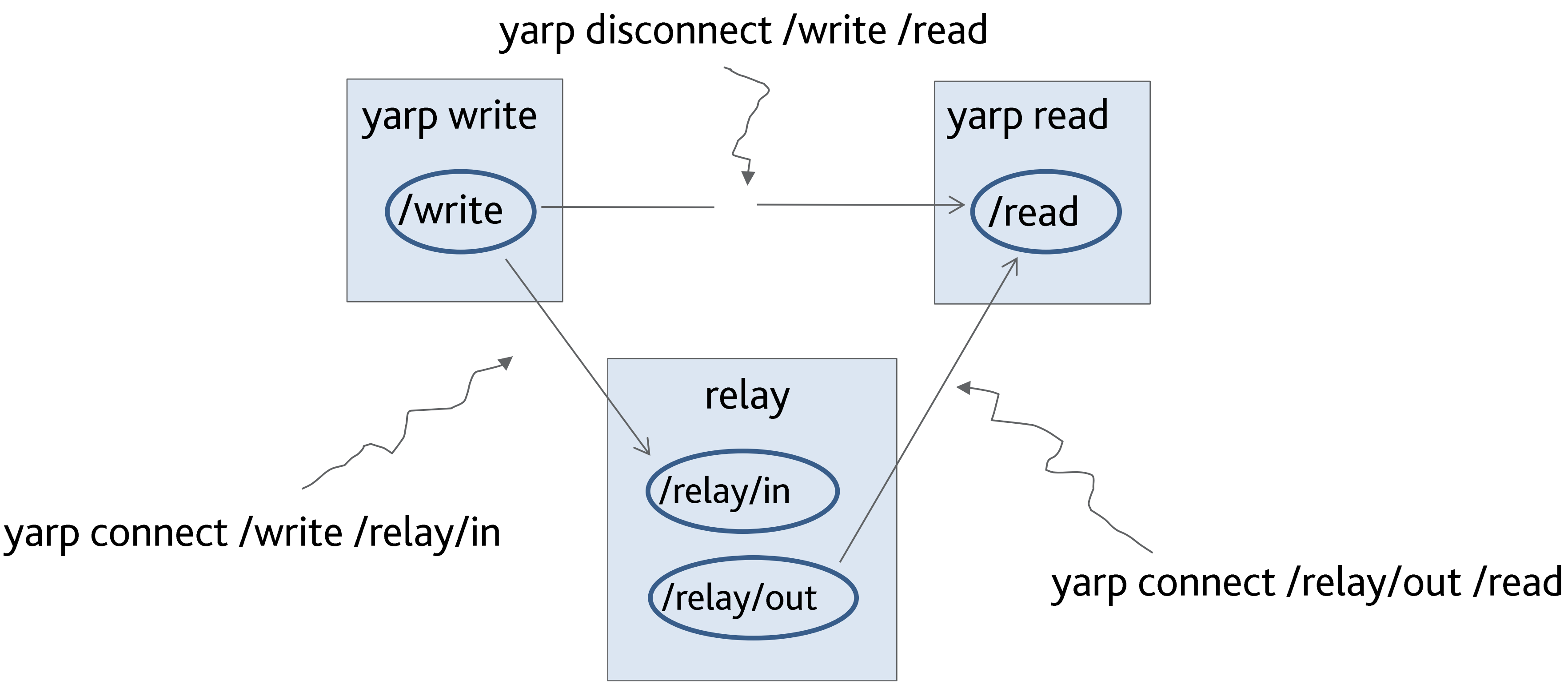


relay

/relay/in

/relay/out

Connect the new module to our network



yarp disconnect /write /read

yarp write

/write

yarp read

/read

relay

/relay/in

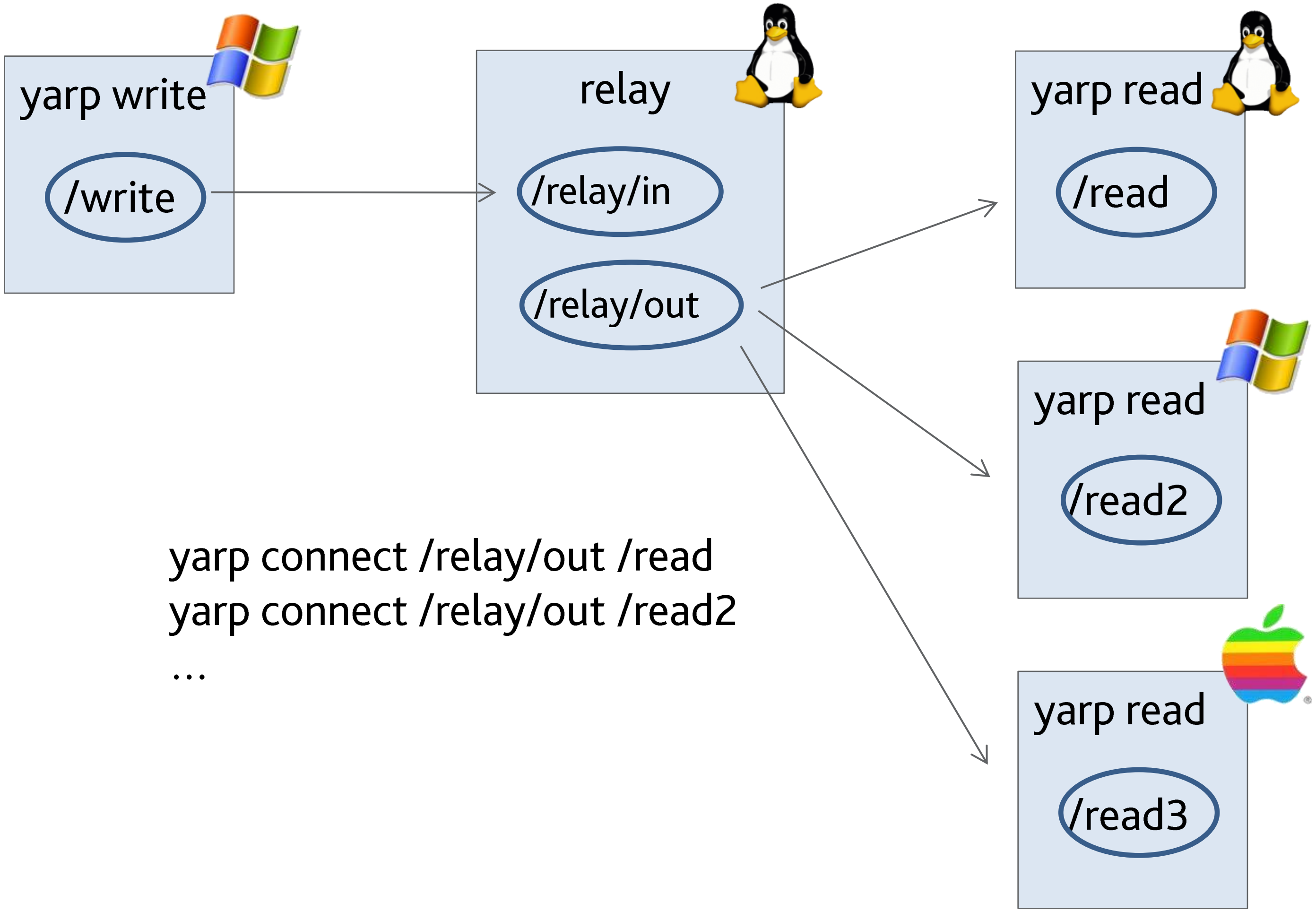
/relay/out

yarp connect /write /relay/in

yarp connect /relay/out /read

how the network grows

It is easy to add, for example, another reader…
Processes can run on different machines, with different OS



```
yarp connect /relay/out /read
yarp connect /relay/out /read2
…
```

BufferedPort

- In the previous example timing between ports is coupled:
  - The reader waits until data arrives to the port
  - The writer waits until data is transmitted
- Buffered ports allow decoupling time:
  - non blocking read
  - non blocking write
- May loose messages

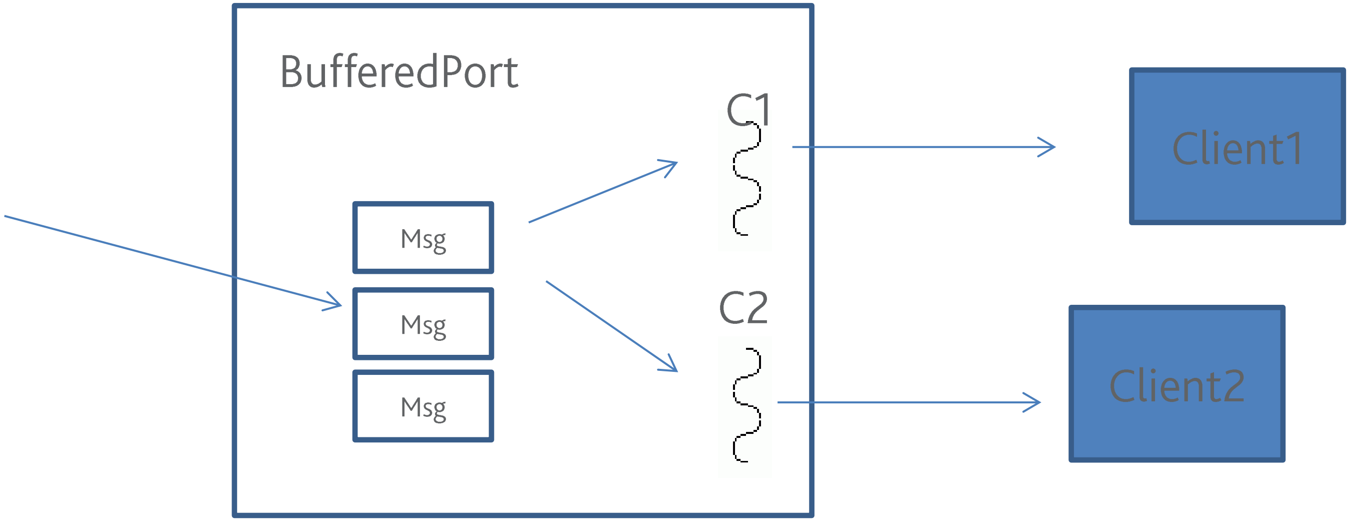
- Read:

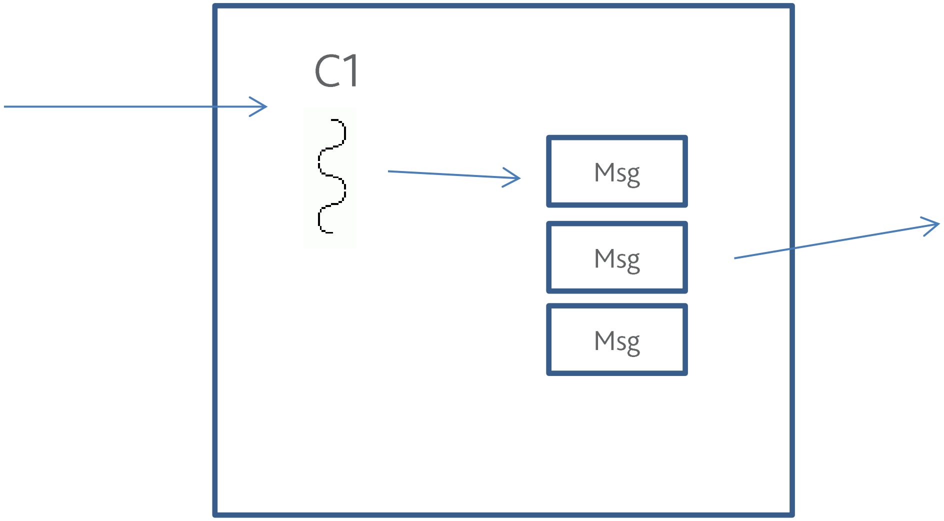
```
BufferedPort<Bottle> p;         // Create a port.
p.open("/in");                  // Give it a name on the network.
while (true) {
    Bottle *b = p.read();       // Read/wait for until data arrives. ...
    // Do something with data in *b
 }
```

- Write:

```
BufferedPort<Bottle> p;         // Create a port.
p.open("/out");                 // Give it a name on the network.
while (true) {
    Bottle& b = p.prepare();    // Get a place to store things. ...
    // Generate data.
    p.write();                  // Send the data.
}
```

```
Msg  m =port.prepare();
//fill m
Port.write()
```





```
Msg *m=port.read();
//read from m

Delay(100000)
```

- Polling: when you do not want to wait for input data:

```
BufferedPort<Bottle> p;
...
Bottle *b = p.read(false);
if (b!=NULL) {
  // data received in *b
}
```

Getting callbacks

- Callbacks: useful if you want to be notified when data arrives
- Easy to do with BufferedPorts

```
class DataPort : public BufferedPort<Bottle> {
    virtual void onRead(Bottle& b) {
        // process data in b
    }
};
...
DataPort p;
p.useCallback();  // input should go to onRead() callback
p.open("/in");
```

Things are a bit more complicated with normal ports

```
class DataProcessor : public PortReader {
    virtual bool read(ConnectionReader& connection) {
        Bottle b;
        bool ok = b.read(connection);
        if (!ok) return false;
        // process data in b
        return true;
    }
};

Port p;
p.open(..)
DataProcessor processor;
...
p.setReader(processor);  // no need to call p.read() on port any more.
```

Replies in a callback

```
class DataProcessor : public PortReader {
   virtual bool read(ConnectionReader& connection) {
      Bottle in, out;
      bool ok = in.read(connection);
      if (!ok) return false;
      ...     // process data "in", prepare "out"
      ConnectionWriter *returnToSender = connection.getWriter();
      if (returnToSender!=NULL) {
        out.write(*returnToSender);
      }
      return true;
   }
};
DataProcessor processor;
...
p.setReader(processor);  // no need to call p.read() on port any more.
```

Bidirectional communication: Getting replies

Client side

```
RpcClient p;                // Create a port.
p.open("/out");      // Give it a name on the network.
while (true) {
  Bottle in,out;     // Make places to store things.
  ...                // prepare command "out".
  p.write(out,in);   // send command, wait for reply.
  ...                 // process response "in".
}
```

Server side

```
RpcServer p;                        // Create a port.
p.open("/in");          // Give it a name on the network.
Bottle in, out;         // Make places to store things.
while (true) {
  p.read(in,true);      // Read and warn that we'll be replying.
  ...                   // Do something with data, prepare reply
  p.reply(out);         // send reply.

}
```

YARP modules: RFModule

The RFModule class

- You create a new module by deriving a new class from RFModule

```
class MyModule:public RFModule
{
public:
      bool configure(ResourceFinder &rf)
      { //module configuration }
      bool close()
      { //code executed at shutdown }
};
```

get parameters form RF and configure the module, return true on success, false otherwise

perform cleanup, close ports, delete memory

```
MyModule module;
ResourceFinder rf;
//configure resource finder

module.runModule(rf);     //if configure returns true block here until the module closes
```

- What does a module do?
- Nothing, really…

- What does a module do?
- Nothing, really…
- Wait for termination signal (message or ctrl-c)
- Can be configured to receive messages from a port/keyboard
- Can perform periodic activities
- It is a container for active objects (threads)

Attach callbacks

```
class MyModule::RFModule
{
    Port handlerPort;
     …
    bool configure(ResourceFinder &rf)
    {
     // use rf to configure your module

     handlerPort.open("/myModule");
     attach(handlerPort);
      …
    }
…
}
```

- Now add a respond message to catch data from terminal or/and the handler port

```
// Message handler. Just echo all received messages.
bool respond(const Bottle& command, Bottle& reply)
{
    cout<<"Got something, echo is on"<<endl;
    if (command.get(0).asString()=="quit")
      return false;
    else
      reply=command;
    return true;
 }
```

Periodic Activities

- In MyModule overload:

define period in seconds

```
double getPeriod()
 { return 1; }

bool updateModule()
{
        // place here code that will be
        // executed every "getPeriod" seconds
        return true;
}
```

this function will be executed until termination

- You can interrupt blocking reads on ports in the interrupt method:

```
bool interruptModule()
 {
      port1.interrupt();
      port2.interrupt();
      …
      return true;
   }
```

Threads

```
#include <yarp/os/Thread.h>

Class yarp::os::Thread
{
public:
        virtual bool start();
        virtual bool stop();

        virtual bool threadInit();
        virtual bool threadRelease();
        virtual void run();

        bool isStopping();

};
```

yarp::os::Thread is the class that provides thread support in YARP

```
#include <yarp/os/Thread.h>

Class MyThread: public Thread
{
public
        void run()
        {
                while(!isStopping)
                //thread body
        }
};

MyThread thread;
thread.start();
…
thread.stop();
```

You can implement your own thread by deriving a class from Thread

Override threadInit() and threadRelease() to peform initialization and cleanup:

```
Class MyThread: public Thread
{
public
        bool threadInit()
        {
                //perform init tasks, memory allocation…
                //return true if successful false otherwise
        }
        bool threadRelease()
        {
                //cleanup memory, release resources…
        }
        void run() {..}
}
```

```
#include <yarp/os/RateThread.h>

Class yarp::os::RateThread
{
public:
        RateThread(int period); //periodicity, ms
        virtual bool start();
        virtual bool stop();

        virtual bool threadInit();
        virtual bool threadRelease();
        virtual void run();

};
```

Very often you want a thread to perform periodic activities (e.g. control loop)

RateThread supports periodic threads

```
#include <yarp/os/RateThread.h>

Class MyRateThread: public RateThread
{
public:
        MyRateThread(int p=50): RateThread(p){}

        void run()
        {
                …
        }
};



MyRateThread rthread;
rthread.start();
…
rthread.stop();
```

Getting images

- YARP defines an image class
- ImageOf<…> is a template class that provides:
  - basic methods for image manipulation
  - support for remotization (i.e. images can travel across Ports/the network)
- data format is opencv compatible
- See: YARP image class online documentation

- Images from cameras are streamed from two ports:
  - /icub/cam/right
  - /icub/cam/left
- Easily read:

```
BufferedPort<ImageOf<PixelRgb> > imagePort;
imagePort.open("/imageProc/image/in");
ImageOf<PixelRgb> *image = imagePort.read(); //read an image:
```

```
BufferedPort<ImageOf<PixelRgb> > imagePort;

imagePort.open("/imageProc/image/in");

//read an image:
ImageOf<PixelRgb> *image = imagePort.read();

//do something with the image, for example cycle through all pixels
int ct=0
for (int x=0; x<image->width(); x++) {
        for (int y=0; y<image->height(); y++) {
          PixelRgb& pixel = image->pixel(x,y);
          // very simple test for blueishness
          // make sure blue level exceeds red and green by a certain factor
          if (pixel.b>pixel.r*1.2+10 && pixel.b>pixel.g*1.2+10) {
                 xMean += x;
                 yMean += y;
                 ct++;
          }
    }
}

if (ct>0) {
    xMean /= ct;
    yMean /= ct;
}

printf("Best guess at blue target: %g %g\n", xMean, yMean);
```

- Complete tutorial shows a program example that control the gaze of the robot to fixate a blue ball:
  - http://wiki.icub.org/iCub/dox/html/icub_basic_image_processing.html